Architecture Manual

CLIPS Version 5.1

January 6th 1992

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Preface

The History of CLIPS

The origins of the C Language Integrated Production System (CLIPS) date back to 1984 at NASA's Johnson Space Center. At this time, the Artificial Intelligence Section (now the Software Technology Branch) had developed over a dozen prototype expert systems applications using state-of-the-art hardware and software. However, despite extensive demonstrations of the potential of expert systems, few of these applications were put into regular use. This failure to provide expert systems technology within NASA's operational computing constraints could largely be traced to the use of LISP as the base language for nearly all expert system software tools at that time. In particular, three problems hindered the use of LISP based expert system tools within NASA: the low availability of LISP on a wide variety of conventional computers, the high cost of state-of-the-art LISP tools and hardware, and the poor integration of LISP with other languages (making embedded applications difficult).

The Artificial Intelligence Section felt that the use of a conventional language, such as C, would eliminate most of these problems, and initially looked to the expert system tool vendors to provide an expert system tool written using a conventional language. Although a number of tool vendors started converting their tools to run in C, the cost of each tool was still very high, most were restricted to a small variety of computers, and the projected availability times were discouraging. To meet all of its needs in a timely and cost effective manner, it became evident that the Artificial Intelligence Section would have to develop its own C based expert system tool.

The prototype version of CLIPS was developed in the spring of 1985 in a little over two months. Particular attention was given to making the tool compatible with expert systems under development at that time by the Artificial Intelligence Section. Thus, the syntax of CLIPS was made to very closely resemble the syntax of a subset of the ART expert system tool developed by Inference Corporation. Although originally modelled from ART, CLIPS was developed entirely without assistance from Inference or access to the ART source code.

The original intent of the prototype was to gain useful insight and knowledge about the construction of expert system tools and to lay the groundwork for the construction of a fully usable tool. The CLIPS prototype had numerous shortcomings, however, it demonstrated the feasibility of the project concept. After additional development, it became apparent that sufficient enhancements to the prototype would produce a low cost expert system tool that would be ideal for the purposes of training. Another year of development and internal use went into CLIPS improving its portability, performance, and functionality. A reference manual and user's guide were written during this time.

The first release of CLIPS to groups outside of NASA, version 3.0, occurred in the summer of 1986.

Further enhancements transformed CLIPS from a training tool into a tool useful for the development and delivery of expert systems as well. Versions 4.0 and 4.1 of CLIPS, released respectively in the summer and fall of 1987, featured greatly improved performance, external language integration, and delivery capabilities. Version 4.2 of CLIPS, released in the summer of 1988, was a complete rewrite of CLIPS for code modularity. Also included with this release were an architecture manual providing a detailed description of the CLIPS software architecture and a utility program for aiding in the verification and validation of rule-based programs. Version 4.3 of CLIPS, released in the summer of 1989, added still more functionality.

Originally, the primary representation methodology in CLIPS was a forward chaining rule language based on the Rete algorithm (hence the Production System part of the CLIPS acronym). Version 5.0 of CLIPS, released in the spring of 1991, introduced two new programming paradigms: procedural programming (as found in languages such as C and Ada) and object-oriented programming (as found in languages such as the Common Lisp Object System and Smalltalk). The object-oriented programming language provided within CLIPS is called the CLIPS Object-Oriented Language (COOL).

Because of its portability, extensibility, capabilities, and low-cost, CLIPS has received widespread acceptance throughout the government, industry, and academia. The development of CLIPS has helped to improve the ability to deliver expert system technology throughout the public and private sectors for a wide range of applications and diverse computing environments. CLIPS is being used by over 3,300 users throughout the public and private community including: all NASA sites and branches of the military, numerous federal bureaus, government contractors, 170 universities, and many companies. CLIPS is available at a nominal cost through COSMIC, the NASA software distribution center (for more on COSMIC, see appendix E of the *Basic Programming Guide*).

CLIPS Version 5.1

Version 5.1 of CLIPS is primarily a software maintenance upgrade required to support the newly developed and/or enhanced X Window, MS-DOS, and Macintosh interfaces. For a detailed listing of differences between versions 4.3, 5.0, and 5.1 of CLIPS, refer to appendix D of the *Basic Programming Guide*.

CLIPS Documentation

Three documents are provided with CLIPS.

- The *CLIPS Reference Manual* which is split into the following parts:
    - *Volume I - The Basic Programming Guide*, which provides the definitive description of CLIPS syntax and examples of usage.
    - *Volume II - The Advanced Programming Guide*, which provides detailed discussions of the more sophisticated features in CLIPS and is intended for people with extensive programming experience who are using CLIPS for advanced applications.
    - *Volume III - The Utilities and Interfaces Guide*, which provides information on machine-specific interfaces and CLIPS utility programs.
- The *CLIPS User's Guide* which provides an introduction to CLIPS and is intended for people with little or no expert system experience.
    - *Volume I - Rules*, which provides an introduction to rule-based programming using CLIPS.
    - *Volume II - Objects*, which provides an introduction to object-oriented programming using COOL.
- The *CLIPS Architecture Manual* which provides a detailed description of the CLIPS software architecture. This manual describes each module of CLIPS in terms of functionality and purpose. It is intended for people with extensive programming experience who are interested in modifying CLIPS or who want to gain a deeper understanding of how CLIPS works.

Acknowledgements

As with any large project, CLIPS is the result of the efforts of numerous people. The primary contributors have been: Robert Savely, head of the STB, who conceived the project and provided overall direction and support; Frank Lopez, who wrote the original prototype version of CLIPS; Gary Riley, who rewrote the prototype and is responsible for most of the kernel code; Chris Culbert, who managed the project, wrote the original *CLIPS Reference Manual*, and designed the original version of CRSV; Dr. Joseph Giarratano of the University of Houston-Clear Lake, who wrote the *CLIPS User's Guide*; Brian Donnell, who designed and developed the CLIPS Object Oriented Language (COOL); and Bebe Ly, who is responsible for maintenance and enhancements to CRSV.

Many other individuals contributed to the design, development, review, and general support of CLIPS, including: Jack Aldridge, Paul Baffes, Ann Baker, Stephen Baudendistel, Les Berke, Tom Blinn, Marlon Boarnet, Dan Bochsler, Bob Brown, Barry Cameron, Tim Cleghorn, Major Paul Condit, Major Steve Cross, Andy Cunningham, Dan Danley, Kirt Fields, Kevin Greiner, Ervin Grice, Sharon Hecht, Patti Herrick, Mark Hoffman, Gordon Johnson, Phillip Johnston, Sam Juliano, Ed Lineberry, Bowen Loftin, Linda Martin, Daniel McCoy, Terry McGregor, Becky McGuire, Scott Meadows, C. J. Melebeck, Paul Mitchell, Steve Mueller, Cynthia Rathjen, Reza Razavipour, Marsha Renals, Monica Rua, Gregg Swietek, Eric Taylor, James Villarreal, Lui Wang, Jim Wescott, Charlie Wheeler, and Wes White.

Introduction

This manual provides an architecture description for version 5.0 of CLIPS. Each module of the CLIPS program is described in terms of its functionality and purpose. In addition, significant variables and functions (both local and global to the modules) are described. All functions relating to a given module are not necessarily listed. In other cases, some function names may not directly correspond to their counterpart in the CLIPS source code. This manual is intended partly as a set of instructions for building CLIPS from scratch and partly as a roadmap to the 'C' implementation of CLIPS.

Function and variable names will be shown in boldface when they are referred to in a sentence. Other words which may cause confusion when used in a sentence will also be shown in boldface. For example, the word **and** can refer either to the function **and** or to the conditional element **and**.

This manual is written with the assumption that the reader has a basic understanding of the Rete Match Algorithm. A good source for information on the Rete Match Algorithm is Charles Forgy's Ph.D. Dissertation, “On the Efficient Implementation of Production Systems.” It can be obtained from

University Microfilms International
300 N. Zeeb Road
Ann Arbor, MI 48106
(313) 761-4700

Another source for information is Charles Forgy's article “Rete: A Fast Algorithm for the Many Pattern/Many Object Pattern Match Problem.” This can be found in *Artificial Intelligence* 19, pp. 17-37, 1982.

Document Overview

The modules described in this document are listed in order beginning with the lower-level modules and ending with the higher-level modules. The higher-level modules generally require the lower-level modules to operate.

The first four modules (System Dependent, Memory, Symbol Manager, and Router) provide basic support for very low-level CLIPS operations. The System Dependent Module (sysdep.c) implements system-dependent features such as timing functions. The Memory Module (memory.c) is used to efficiently allocate and maintain memory requests. The Symbol Manager Module (symbol.c) is used to avoid storage duplication for multiple occurrences of symbols, floats, and integers. It also assures that storage is not used for symbols, floats, and integers that are no longer in use. The Router Module (router.c) handles input/output (I/O) requests and allows these requests to be redirected to different I/O handlers. This redirection capability allows sophisticated interfaces to be built on top of the CLIPS kernel without making changes to the code.

The next eight modules (Scanner, Expression, Special Forms, Parser Utility, Evaluation, Command Line, Construct Manager, and Utility) provide the basic functionality necessary for expression evaluation, construct support, and the CLIPS command line interface. The Scanner Module (scanner.c) reads tokens from an input source. The Expression Module (expressn.c) builds expressions from tokens returned by the Scanner Module. The Special Forms Module (spclform.c) is used for parsing functions that do not conform with the standard syntax for function expressions (such as the **assert** function). The Parser Utility Module (parsutil.c) contains some utility functions useful for parsing both functions and constructs. The Evaluation Module (evaluatn.c) can evaluate expressions generated by the Expression Module. The Command Line Module (commline.c) provides the necessary functionality for a command line interface. It also is capable of determining when an expression has been formed from a series of input characters before it calls the Expression Module to build an expression. It then calls the Evaluation Module to evaluate the expression. The Construct Manager Module (constrct.c) provides the necessary support for registering constructs so that they are recognized by the CLIPS parser. It calls the appropriate routines needed by each construct for loading and parsing, resetting, and clearing. The Utility Module (utility.c) provides a number of general purpose routines for printing values, detecting errors, handling garbage collection, and registering items for use with the **watch** command.

The Fact Manager Module (factmngr.c) is used to maintain the fact-list and provide support for the creation of multifield values (by functions such as **mv-append**). The Fact Commands Module (factcom.c) implements the top level interface for commands such as **assert** and **facts**.

The Deffacts Module (deffacts.c) provides the capability needed to implement the deffacts construct. The Defglobal Module (defglobl.c) provides the capability needed to implement the defglobal construct.

The next six modules (Defrule Parser, Reorder, Variable Manager, Analysis, Generate, and Build) are used to build the appropriate data structures for the defrule construct. The Defrule Parser Module (ruleprsr.c) is used to parse the left-hand side (LHS) of a rule, yielding an intermediate data structure. The Reorder Module (reorder.c) transforms the LHS of a single rule containing **and** and **or** conditional elements nested throughout the intermediate LHS data structure into an intermediate data structure which contains at most a single **or** conditional element at the beginning of the intermediate data structure. The Variable Manager Module (variable.c) checks the patterns on the LHS of a rule for semantic errors involving variables. It also maintains information about the location and usage of variables in the patterns of a rule. The Analysis Module (analysis.c) works closely with the Variable Manager Module to generate expressions for the rule that will be used in the join and pattern networks. The Generate Module (generate.c) is used to generate the expressions requested by the Analysis Module. The Build Module (build.c) is used to integrate the new rule and its expressions into the join and pattern network.

The next six modules (Drive, Engine, Match, Retract, Rete Utility, and Logical Dependencies) form the core of the CLIPS inference engine. The Drive Module (drive.c) is used to update the join network when a fact has been added. The Engine Module (engine.c) maintains the agenda and handles execution of the RHS of rules. The Match Module (match.c) determines which patterns in the pattern network have been matched when a fact has been added. The Retract Module (retract.c) is used to update the join network when a fact is removed. The Rete Utility Module (reteutil.c) provides useful utility functions used by other modules for maintaining the join network. The Logical Dependencies Module (lgcldpnd.c) is used to maintain the links between the join network and facts to support the **logical** conditional element.

The Defrule Manager Module (defrule.c) coordinates the activities of all modules used for maintaining the defrule construct. The Defrule Deployment Module (drulebin.c) provides the functionality needed to use the defrule construct with the

bsave, **bload**, and **constructs-to-c** commands. The Defrule Commands Module (rulecom.c) implements the top level interface for defrule commands.

The Deftemplate Command Module (deftmcom.c) is used for maintaining deftemplates, providing type and value checking for deftemplate slots, providing the top level interface for deftemplate commands, and providing the functionality needed to use the deftemplate construct with the **bsave**, **bload**, and **constructs-to-c** commands. The Deftemplate Function Module (deftmfun.c) is used for parsing **assert**, **modify**, and **duplicate** commands which use deftemplate formats. The Deftemplate Parser Module (deftmpsr.c) is used to parse the deftemplate construct. The Deftemplate LHS Module (deftmlhs.c) is used to parse deftemplate patterns found on the LHS of a rule.

The Binary Save Module (bsave.c) provides the functionality needed for the **bsave** command, the Binary Load Module (bload.c) provides the functionality needed for the **bload** command, and the Construct Compiler Module (constrct.c) provides the functionality needed for the **constructs-to-c** command.

The next nine modules (Primary Functions, Predicate Functions, I/O Functions, Secondary Functions, Multifield Functions, String Functions, Math Functions, Text Processing Functions, and File Commands) provide functions and commands for a variety of tasks. The Primary Functions Module (sysprime.c) provides a set of environment commands and procedural functions.The Predicate Functions Module (syspred.c) provides a number of predicates and simple mathematical functions commonly used in CLIPS. The I/O Functions Module (sysio.c) provides a number of functions convenient for performing I/O. The Secondary Functions Module (syssecnd.c) provides a set of useful functions that perform a wide variety of useful tasks. The Multifield Functions Module (multivar.c) provides a set of useful functions for use with multifield values. The String Functions Module (strings.c) provides a set of useful functions for manipulating strings. The Math Functions Module (math.c) provides a set of useful math functions beyond the basic math functions provided by the Predicate Functions Module. The Text Processing Module (textpro.c) provides a set of useful functions for building and accessing a hierarchical lookup system for multiple external files. The File Commands Module (filecom.c) provides a set of useful interface commands that performs certain file operations not associated with standard file I/O operations.

The Deffunction Module (deffnctn.c) provides the capability to define new user-defined functions directly in CLIPS.

The next four modules implement overloaded functions which can be defined directly in CLIPS: Generic Function Commands, Generic Function Functions, Generic Function Construct Compiler Interface and Generic Function Binary Load/Save Interface. Generic functions can do different things depending on the number and type of arguments they receive. The Generic Function Commands Module (genrccom.c) contains most of the parsing routines necessary for generic functions and their methods. The Generic Function Functions Module (genrcfun.c) determines the precedence between different methods of a generic function, provides the generic dispatch when a generic function is actually called and contains various other maintenance routines for generic functions and their methods. The Generic Function Construct Compiler Interface (genrccmp.c) and the Generic Function Binary Load/Save Interface Modules provide the interfaces for generic functions to the **constructs-to-c** and **bload**/**bsave** commands.

The next ten modules give all the functionality of the CLIPS Object-Oriented Language (COOL): Class Commands, Class Functions, Instance Commands, Instance Functions, Message-Handler Commands, Message-Handler Functions, Instance-Set Queries, Definstances, Object Construct Compiler Interface and Object Binary Load/Save Interface. The Class Commands Module (classcom.c) furnishes the parsing and general interface routines for the defclass construct. The Class Functions Module (classfun.c) handles all the internal manipulations of classes, including the construction of class precedence lists from multiple inheritance. The Instance Commands Module (inscom.c) provides the parsing and general interface functions for instances of user-defined classes. The Instance Functions Module (insfun.c) deals with the internal details of creating, accessing and deleting instances. The Message-Handler Commands Module (msgcom.c) contains the parsing and general interface routines for the procedural attachments to classes. The Message-Handler Functions Module (msgfun.c) implements the message dispatch when a message is actually sent to an object and maintains the internal details of the defmessage-handler construct. The Instance-Set Queries Module (insquery.c) provides the routines for a useful query system which can determine and perform actions on sets of instances of user-defined classes that satisfy user-defined criteria. The Definstances Module (defins.c) provides the capability needed to implement the definstances construct. The Object Construct Compiler Interface (objcmp.c) and the Object Binary Load/Save Interface (objbin.c) Modules provide the interfaces for COOL to the **constructs-to-c** and **bload**/**bsave** commands.

The Main Module (main.c) contains the CLIPS startup function and should be the only file modified to add extensions or to embed CLIPS under normal circumstances.

Portability Notes

There are a number of coding practices in the CLIPS code that in general have proven to be portable among a wide variety of machines, but that are not guaranteed to be portable for all ANSI C compilers. In particular, the conversion of integers to pointers (and conversion back again expecting the original integer) is used quite extensively to implement the **bload**/**bsave** commands. Strict ANSI C conformance does not guarantee the portability of converting non-zero integers to pointers. Such a conversion may involve a representation change which would cause a subsequent conversion back to an integer to yield a value other than the original starting integer. Some machines may also generate access violations when attempting to store integers into pointer values when the integers represent invalid addresses. Also, similar to typecasting integers to pointers, typecasting a pointer type into another pointer type and expecting to be able to retrieve the original pointer is also not always ANSI C conformant (depending upon the pointer types). The code may be changed to be more portable in the next release. Compromises to functionality and efficiency will be considered when making these determinations.

System Dependent Module

The System Dependent Module (sysdep.c) maintains a set of functions that contains system and/or machine dependent features (such as timing functions) and initialization routines. The generic setting for CLIPS will compile the functions in this module to forms which should run on any system or machine.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

CatchControlC

PURPOSE: A function which provides for interrupt handling. Used to break execution when ctrl-C is pressed.

C IMPLEMENTATION: Handled on most machines by using the **signal** function.

genexit

PURPOSE: Generic exit routine.

ARGUMENTS: Exit number. The number -1 indicates a normal exit from CLIPS. The number 1 indicates CLIPS was unable to obtain necessary memory; the number 2 indicates an arbitrary limit has been exceeded; and the numbers 3 through 6 indicate that an internal CLIPS error has occurred.

genrand

PURPOSE: Generic random number generator function.

RETURNS: A randomly generated number (or zero if no random number facility is available).

C IMPLEMENTATION: Handled on most machines by using the **rand** function.

genseed

PURPOSE: Generic function for seeding the random number generator.

ARGUMENTS: An integer “seed” value.

C IMPLEMENTATION: Handled on most machines by using the **srand** function.

gensystem

PURPOSE: A generic function which access to Operating System (OS) commands.

ARGUMENTS: A string which is a command to be executed by the OS.

gentime

PURPOSE: A generic function for providing time information.

RETURNS: Current time as a floating-point number.

InitializeCLIPS

PURPOSE: Performs initialization of CLIPS.

OTHER NOTES: Initialization differs between standard and run-time configurations.

InitializeNonportableFeatures

PURPOSE: Performs machine-dependent initialization for features such as interrupt handling.

RerouteStdin

PURPOSE: Forces CLIPS to read input from a file when the -f option is used when CLIPS is first started.

SystemFunctionDefinitions

PURPOSE: Sets up the definitions of CLIPS system defined functions.

Memory Module

Allocation of memory occurs constantly during loading, browsing, and execution of CLIPS programs. Memory allocation/deallocation is provided through two levels of indirection. The first level of indirection provides separation from the system-level allocation/deallocation functions. Functions **genalloc** and **genfree** (defined in the Machine Dependent Module) provide the first level of indirection. Another level of indirection is needed to allow for efficient memory usage. This second level of indirection provides efficiency by taking advantage of the fact that data structures of the same size are constantly being requested and freed by CLIPS. If memory is constantly being requested from the system, freed to the system, and then immediately rerequested from the system, a great deal of inefficiency can occur. If memory requested and then freed by CLIPS is maintained by internal CLIPS memory management routines, much of the overhead of constantly requesting, freeing, and rerequesting memory can be avoided.

The Memory Module also contains routines which perform block memory management. These routines provide another level of indirection for memory management if desired. Block memory management routines request large blocks of memory from the system and split these large blocks to provide memory for smaller requests. On certain machines, this can provide increased efficiency if the system-level memory management routines are not very efficient at handling small blocks of memory.

CLIPS memory management of free memory blocks utilizes an array of pointers to memory blocks (the **MemoryTable**). The array index refers to the memory size being stored in that location. Requests for memory of sizes greater than the size of the **MemoryTable** are requested from the system. A request with this range would retrieve the block of memory pointed to by the array (if one exists). Returned memory would be added to the linked list of memory already stored in the array. The first four bytes of all memory would be used as a pointer to the next block of memory (hence, the 4-byte memory restriction for requests). Requests of less than four bytes are automatically converted to 4-byte requests.

Functions defined in this module should be used by external functions that wish to utilize memory in conjunction with the CLIPS kernel. The use of functions **genalloc** and **genfree** should be avoided in external functions.

GLOBAL VARIABLES

MemoryTable

PURPOSE:	A table containing free memory of various sizes.
C IMPLEMENTATION:	Currently implemented as an array of pointers to various sizes of memory. For example, array location 7 would have a pointer to the first free block of memory of size 7. Each memory block uses its first four bytes as a pointer to the next free block of memory; therefore, memory blocks of less than size 4 cannot be stored in the memory table.

TempMemoryPtr

PURPOSE: Provides a global temporary pointer for use with deallocation macros.

TempSize

PURPOSE: Provides a global temporary integer for use with allocation of variable size structure macros.

INTERNAL VARIABLES

BlockInfoSize

PURPOSE: Amount of space needed to store information pertaining to a block of memory. Only defined when block memory management is in use.

BlockMemoryInitialized

PURPOSE: Boolean variable indicating whether block memory management has been initialized. Only defined when block memory management is in use.

ChunkInfoSize

PURPOSE: Amount of space needed to store information pertaining to a chunk of memory that has been allocated for use. Only defined when block memory management is in use.

ConserveMemory

PURPOSE: Boolean flag which indicates whether or not memory should be conserved. If TRUE, then pretty print representations of constructs are not stored.

MemoryAmount

PURPOSE: Contains amount of memory allocated by CLIPS. Does not include overhead associated with maintaining the memory.

MemoryCalls

PURPOSE: Contains total number of outstanding memory requests.

OutOfMemoryFunction

PURPOSE: A pointer to a function which is to be called when CLIPS cannot satisfy a memory request. This function either exits CLIPS or attempts to free the requested amount of memory.

TopMemoryBlock

PURPOSE: Pointer to the top block allocated by the block memory manager. Only defined when block memory management is in use.

GLOBAL FUNCTIONS

ActualPoolSize

PURPOSE: Indicates how much memory CLIPS has available in its free pool. On IBM PC DOS machines, the overhead associated with allocation is also included.

RETURNS: The number of bytes in the CLIPS free pool of memory (plus overhead on IBM PC DOS machines).

CopyMemory

PURPOSE: Copies data structures from a source to a destination.

ARGUMENTS: The type of structures being copied, the number of structures to copy, a pointer to the destination memory, and a pointer to the source memory.

C IMPLEMENTATION: Implemented as a macro. Calls the function **genmemcpy** to copy the memory.

DefaultOutOfMemoryFunction

PURPOSE: The default function which is called when CLIPS runs out of memory. Prints an “Out of memory” message.

ARGUMENTS: The size of the memory block which could not be allocated (this argument is unused).

RETURNS: A non-zero value indicating that the memory request cannot be satisfied and that CLIPS should be exited.

genalloc

PURPOSE: Generic memory allocation function which provides a level of indirection.

ARGUMENTS: Size of memory requested.

RETURNS: A memory block of the appropriate size.

OTHER NOTES: **genalloc** uses either **malloc** or **RequestChunk** depending upon whether block memory allocation is being performed. If **genalloc** cannot get the requested memory, it will release all free memory used by CLIPS to the system. It will then try to allocate the memory again, returning whether it succeeds or fails. Note that this function is not called by the CLIPS kernel with the exception of the Memory Module, which provides another level of memory allocation indirection.

genfree

PURPOSE: Generic memory release function which provides a level of indirection.

ARGUMENTS: A block of memory and the memory size.

OTHER NOTES: **genfree** uses either **free** or **ReturnChunk** depending upon whether block memory allocation is being performed. Note that this function is not called by the CLIPS kernel with the exception of the Memory Module, which provides another level of memory deallocation indirection.

genlongalloc

PURPOSE: Generic memory allocation function which provides a level of indirection.

ARGUMENTS: Size of memory requested as a long integer.

RETURNS: A memory block of the appropriate size.

C IMPLEMENTATION: If the size of an integer is the same as the size of a long integer or if the long integer can be truncated to an integer, then **genalloc** is used to satisfy the request. In addition, special code is included to handle long integer memory requests for the Macintosh and IBM PC computers. If the request cannot be satisfied because the long integer value cannot be truncated to an integer, then CLIPS is exited.

genlongfree

PURPOSE: Generic memory release function which provides a level of indirection.

ARGUMENTS: A block of memory and the memory size as a long integer.

genmemcpy

PURPOSE: Generic memory copy function which provides a level of indirection.

ARGUMENTS: A pointer to a block of memory to be copied, a pointer to a block of memory to store the copied memory, and the amount of memory to be copied.

RETURNS: No meaningful value.

genrealloc

PURPOSE: Generic memory reallocation function which provides a level of indirection.

ARGUMENTS: A block of memory, the size of the memory block, and the new desired size of the memory block.

RETURNS: A memory block of the new size with the contents of the original memory block.

OTHER NOTES: Current implementation is not very sophisticated. The new block is allocated using **genalloc**, the content of the old block is copied to the new block, and then the old block is freed using **genfree**.

GetConserveMemory

PURPOSE: Returns the current value of the **ConserveMemory** flag.

RETURNS: A boolean value.

get_struct

PURPOSE: Allocates memory needed for a structure.

ARGUMENTS: A structure name.

C IMPLEMENTATION: Implemented as a macro. Uses the global variable **TempMemoryPtr** to provide a temporary pointer.

get_var_struct

PURPOSE: Allocates memory needed for a structure of varying size.

ARGUMENTS: A structure name and the size of the variable length portion of the structure.

C IMPLEMENTATION: Implemented as a macro. Uses the global variable **TempMemoryPtr** to provide a temporary pointer.

gm1

PURPOSE: Allocates a block of memory from the CLIPS maintained pool of free memory. Initializes the contents of the memory to zero.

ARGUMENTS: Size of memory required.

C IMPLEMENTATION: Searches **MemoryTable** for free memory of the appropriate size. Calls **genalloc** if it cannot find memory of the appropriate size.

gm2

PURPOSE: Allocates a block of memory from the CLIPS maintained pool of free memory. Does not initialize the contents of the memory.

ARGUMENTS: Size of memory required.

C IMPLEMENTATION: Searches **MemoryTable** for free memory of the appropriate size. Calls **genalloc** if it cannot find memory of the appropriate size.

gm3

PURPOSE: Allocates a block of memory from the CLIPS maintained pool of free memory. Does not initialize the contents of the memory.

ARGUMENTS: Size of memory required (a long integer).

C IMPLEMENTATION: Searches **MemoryTable** for free memory of the appropriate size. Calls **genlongalloc** if it cannot find memory of the appropriate size.

MemoryRequests

PURPOSE: Returns number of memory requests currently outstanding.

RETURNS: Number of memory requests currently outstanding.

OTHER NOTES: Uses variables incremented and decremented by **genalloc** and **genfree**.

MemoryUsed

PURPOSE: Returns amount of memory currently allocated by CLIPS.

RETURNS: Amount of memory currently used by CLIPS.

OTHER NOTES: Uses variables incremented and decremented by **genalloc** and **genfree**. May not include overhead memory.

PoolSize

PURPOSE: Indicates how much memory CLIPS has available in its free pool.

RETURNS: The number of bytes in the CLIPS free pool of memory.

ReleaseMemory

PURPOSE: Releases a specified amount of free memory maintained by CLIPS back to the system.

ARGUMENTS: A number which indicates when to stop. If the number is -1, all memory will be released. Otherwise, the function will stop when the amount of memory released has exceeded the number. Another argument specifies whether a message is to be printed when CLIPS releases memory.

RequestChunk

PURPOSE: Allocates memory by returning a chunk of memory from a larger block of memory.

ARGUMENTS: Size of memory needed.

C IMPLEMENTATION: Implemented using several functions.

ReturnChunk

PURPOSE: Frees memory allocated using **RequestChunk**.

ARGUMENTS: A pointer to the memory and size of the memory.

C IMPLEMENTATION: Implemented using several functions.

rm

PURPOSE: Returns a block of memory to the CLIPS maintained pool of free memory.

ARGUMENTS: A pointer to a block of memory and a size argument.

C IMPLEMENTATION: Adds memory to the appropriate location in the **MemoryTable**. The first four bytes of the memory block are modified to point to the next block of free memory of the same size.

rm3

PURPOSE: Returns a block of memory to the CLIPS maintained pool of free memory.

ARGUMENTS: A pointer to a block of memory and a size argument.

C IMPLEMENTATION: Adds memory to the appropriate location in the **MemoryTable**. The first four bytes of the memory block are modified to point to the next block of free memory of the same size. Calls **genlongfree** to return the memory if it can not be placed in the **MemoryTable**.

rtn_struct

PURPOSE: Returns memory needed for a structure to the CLIPS maintained pool of free memory.

ARGUMENTS: A structure name and a pointer to the structure.

C IMPLEMENTATION: Implemented as a macro. Uses the global variable **TempMemoryPtr** for temporary storage.

rtn_var_struct

PURPOSE: Returns memory needed for a structure of varying size to the CLIPS maintained pool of free memory.

ARGUMENTS: A structure name, the size of the variable length portion of the structure, and a pointer to the structure.

C IMPLEMENTATION: Implemented as a macro. Uses the global variables **TempMemoryPtr** and **TempSize** for temporary storage.

SetConserveMemory

PURPOSE: Sets the current value of the **ConserveMemory** flag.

ARGUMENTS: A boolean value (the new value of the flag).

RETURNS: A boolean value (the old value of the flag).

SetOutOfMemoryFunction

PURPOSE: Allows the function which is called when CLIPS runs out of memory to be changed.

ARGUMENTS: A pointer to a function which returns an integer and has a single integer argument. The argument to the function is the size of the memory request that could not be satisfied. The return value of the function should be zero if CLIPS should attempt to allocate the memory again or non-zero if CLIPS should not attempt to allocate the memory again (and exit).

RETURNS: A pointer to the previous out of memory function.

UpdateMemoryRequests

PURPOSE: Allows the number of memory requests to CLIPS to be updated.

ARGUMENTS: A signed integer value to be added to the number of memory requests currently outstanding.

RETURNS: Updated number of memory requests currently outstanding.

UpdateMemoryUsed

PURPOSE: Allows the amount of memory used by CLIPS to be updated.

ARGUMENTS: A signed integer value to be added to the amount of memory currently used by CLIPS.

RETURNS: Updated amount of memory currently used by CLIPS.

INTERNAL FUNCTIONS

AllocateBlock

PURPOSE: Adds a new block of memory to the list of memory blocks.

ARGUMENTS: Size of new block and a pointer to the last block of memory being managed by the memory manager.

AllocateChunk

PURPOSE:	Allocates a chunk of memory for use. Called by **RequestChunk** when it finds a memory chunk of the appropriate size.
ARGUMENTS:	A pointer to the memory block information record, a pointer to the memory chunk information record, and the size of memory requested.
RETURNS:	Nothing. Updates information records for future memory management.

InitializeBlockMemory

PURPOSE:	Initializes block memory management and allocates the first block.
ARGUMENTS:	Size of the initial block.

Symbol Manager Module

Symbolic data in the form of words and strings must be handled efficiently both in terms of speed and storage management. CLIPS storage management of symbols requires that multiple copies of a symbol be stored in the same location. To accomplish this goal, CLIPS uses a **SymbolTable** to store all occurrences of symbols. For example, the fact (data red green red) would require three entries in the **SymbolTable**: one each for the symbols data, red, and green. The **SymbolTable** also must keep track of symbols that are no longer in use and remove them. To accomplish this, each symbol is given a count to indicate the number of references to the symbol. In the above example (assuming no other previous entries in the **SymbolTable**), symbols data and green would each have a count of 1 while symbol red would have a count of 2. If at any time a symbol has a count of 0, it is no longer necessary to maintain the symbol and it may be removed.

Symbols not expected to remain in the **SymbolTable** are labeled as ephemeral. All symbols initially added to the **SymbolTable** are marked as ephemeral. These symbols have a count of 0 but are not yet removed. The set of all ephemeral symbols is maintained in a list. At certain times, the **EphemeralSymbolList** is traversed to remove unneeded symbols from the **SymbolTable**. Ephemeral symbols that still have a count of 0 are removed from the symbol table, while ephemeral symbols that have a count greater than 0 are left in the **SymbolTable** and their ephemeral status is lost. As an example, consider the following top-level command:

```
CLIPS> (str-cat "red" "blue")
"redblue"
CLIPS>
```

Four symbols are created during execution of this command. The symbols **str-cat**, **red**, and **blue** are added to the **SymbolTable** when the command is parsed, and the symbol **redblue** is added during the execution of the **str-cat** command. Each of these symbols is labeled as ephemeral. After execution of this command, none of the symbols is needed and all can be removed from the **SymbolTable**. Now consider the following command:

```
CLIPS> (assert (data =(str-cat "red" "blue")))
CLIPS>
```

Six symbols are created during execution of this command. The symbols **assert**, **data**, **str-cat**, **red**, and **blue** are added to the **SymbolTable** when the command is parsed, and the symbol **redblue** is added during the evaluation of the **str-cat** function. This command asserts the fact (data redblue) which contains the symbols **data** and **redblue**. The locations in the **SymbolTable** of these two symbols will have their count incremented by one to reflect that another non-ephemeral reference to the symbol is being made. After execution of this command, the symbols **assert**, **str-cat**, **red**, and **blue** could be removed from the **SymbolTable**, whereas the symbols **data** and **redblue** would have to remain.

As stated previously, all symbols are initially marked as ephemeral. This ensures that temporary symbols created during the parsing of commands and the evaluation of functions are easily removed. A symbol can have its count incremented in a variety of ways including the use of a symbol as part of a construct (such as a defrule, deffacts, or defclass) or the use of a symbol as part of a fact or an instance. As a corollary, the count of a symbol is decremented whenever the corresponding item which refers to that symbol is removed (such as deleting a construct or retracting a fact). The **EphemeralSymbolList** is periodically checked for symbols that can be removed from the **SymbolTable**. These periodic checks occur at various times including after the execution of a rule, deffunction, generic function, message-handler, or top-level command.

Because symbols can be created at different evaluation depths (see the Evaluation Module), it is also necessary to store the evaluation depth at which the symbol was created. Ephemeral symbols are not deleted unless they have a count of zero and the ephemeral symbol is being removed at an evaluation depth less than the depth at which the symbol was created.

In addition to symbols, floating point and integer values are also stored in tables. Floating point values are stored in the **FloatTable** and integer values are stored in the **IntegerTable**. The operation of these tables is virtually identical to the **SymbolTable** (with the primary exception being that they are used to store floats and integers rather than strings). The **SymbolTable** is used to store the values for the CLIPS data types **symbol**, **string**, and **instance name** (i.e. red, "red", and [red] all have the same location in the **SymbolTable**). The **IntegerTable** is only used for storing the CLIPS data type **integer** and the **FloatTable** is only used for storing the CLIPS data type **float**. Note that since each symbol, float, or integer data value is represented by a unique pointer value into a table, comparisons of values can be accomplished by comparing these pointer values (although types must also be compared to distinguish between **symbols**, **strings**, and **instance names**).

Symbols can also be linked to other symbols via a *relatedSymbol* field. In CLIPS 5.1, this field is used only in COOL to conveniently determine the slot name symbol from a slot-accessor message. For example, the **get-temperature** slot-accessor symbol would be linked to the slot name symbol **temperature**.

GLOBAL VARIABLES

CLIPSFalseSymbol

PURPOSE: A pointer, useful for comparison, to the symbol table entry of the **FalseSymbol** generated using the **AddSymbol** function.

CLIPSTrueSymbol

PURPOSE: A pointer, useful for comparison, to the symbol table entry of the **TrueSymbol** generated using the **AddSymbol** function.

INTERNAL VARIABLES

EphemeralFloatList

PURPOSE: A list of pointers to ephemeral floats currently in the **FloatTable**.

C IMPLEMENTATION: Implemented as a linked list.

EphemeralIntegerList

PURPOSE: A list of pointers to ephemeral integers currently in the **IntegerTable**.

C IMPLEMENTATION: Implemented as a linked list.

EphemeralSymbolList

PURPOSE: A list of pointers to ephemeral symbols currently in the **SymbolTable**.

C IMPLEMENTATION: Implemented as a linked list.

FalseSymbol

PURPOSE: The character string that CLIPS uses for the boolean value FALSE. The value of this string is “FALSE", however, it could be changed to another value such as “WRONG".

FloatTable

PURPOSE: Stores all floats used by CLIPS.

C IMPLEMENTATION: Implemented as an array. Each entry corresponds to a list of float table entries. Collisions are resolved by adding the float entry to list of entries.

IntegerTable

PURPOSE: Stores all integers used by CLIPS.

C IMPLEMENTATION: Implemented as an array. Each entry corresponds to a list of integer table entries. Collisions are resolved by adding the integer entry to list of entries.

SymbolTable

PURPOSE: Stores all symbols used by CLIPS.

C IMPLEMENTATION: Implemented as an array. Each entry corresponds to a list of symbol table entries. Collisions are resolved by adding the symbol entry to list of entries.

TrueSymbol

PURPOSE: The character string that CLIPS uses for the boolean value TRUE. The value of this string is “TRUE", however, it could be changed to another value such as “RIGHT".

GLOBAL FUNCTIONS

AddDouble

PURPOSE: Adds a double precision floating-pointer number to the **FloatTable**.

ARGUMENTS: A double precision floating point number that is to be added to the **FloatTable**.

RETURNS: The address of the float entry structure for the given number in the **FloatTable**.

AddLong

PURPOSE: Adds a long integer to the **IntegerTable**.

ARGUMENTS: A long integer that is to be added to the **IntegerTable**.

RETURNS: The address of the integer entry structure for the given integer in the **IntegerTable**.

AddSymbol

PURPOSE: Adds a symbol to the **SymbolTable**.

ARGUMENTS: A string that is to be added to the **SymbolTable**.

RETURNS: The address of the symbol entry structure for the given string in the **SymbolTable**.

DecrementFloatCount

PURPOSE: Decrements the count value for a **FloatTable** entry. Adds the float to the **EphemeralFloatList** if the count becomes zero.

ARGUMENTS: A **FloatTable** entry.

DecrementIntegerCount

PURPOSE: Decrements the count value for an **IntegerTable** entry. Adds the integer to the **EphemeralIntegerList** if the count becomes zero.

ARGUMENTS: An **IntegerTable** entry.

DecrementSymbolCount

PURPOSE: Decrements the count value for a **SymbolTable** entry. Adds the symbol to the **EphemeralSymbolList** if the count becomes zero.

ARGUMENTS: A **SymbolTable** entry.

FindSymbol

PURPOSE: Determines if a symbol is already in the **SymbolTable**.

ARGUMENTS: A string that is to be searched for in the **SymbolTable**.

RETURNS: If the string is contained in the **SymbolTable**, the address of the symbol entry structure for the given string in the **SymbolTable** is returned, otherwise NULL is returned.

FindSymbolMatches

PURPOSE: Finds all symbols in the **SymbolTable** which begin with a specified symbol. This function is used to implement the command completion feature found in some of the CLIPS machine specific interfaces.

ARGUMENTS: A pointer to a string and a pointer to an integer.

RETURNS: Returns a pointer to a list of symbols which begin with the specified sequence of characters. The number of matches is stored in the integer passed as an argument.

GetFloatTable

PURPOSE: Returns a pointer to the **FloatTable**.

RETURNS: A pointer to the **FloatTable**.

OTHER NOTES: Normally used by the construct compiler and binary save to gain access to the **FloatTable**.

GetIntegerTable

PURPOSE: Returns a pointer to the **IntegerTable**.

RETURNS: A pointer to the **IntegerTable**.

OTHER NOTES: Normally used by the construct compiler and binary save to gain access to the **IntegerTable**.

GetNextSymbolMatch

PURPOSE: Finds the next symbol in the **SymbolTable** which begins with a specified symbol. This function is used to implement the command completion feature found in some of the CLIPS machine specific interfaces.

ARGUMENTS: A pointer to a string, the number of characters to use in performing the comparison of strings, and the previous symbol in the symbol table which was checked.

RETURNS: Returns a pointer to the next **SymbolTable** entry which begins with the specified sequence of characters.

GetSymbolTable

PURPOSE: Returns a pointer to the **SymbolTable**.

RETURNS: A pointer to the **SymbolTable**.

OTHER NOTES: Normally used by the construct compiler and binary save to gain access to the **SymbolTable**.

HashFloat

PURPOSE: Computes a hash value for a float.

ARGUMENTS: A float and maximum value for the hash value.

RETURNS: An integer hash value which is less than the maximum value.

C IMPLEMENTATION: The float number is converted to a long integer through the use of a union structure to yield a hash value. This value is then divided by the maximum value and the remainder is returned.

HashInteger

PURPOSE: Computes a hash value for an integer.

ARGUMENTS: An integer and maximum value for the hash value.

RETURNS: An integer hash value which is less than the maximum value.

C IMPLEMENTATION: The integer value is used as the hash value. This value is then divided by the maximum value and the remainder is returned.

HashSymbol

PURPOSE: Computes a hash value for a symbol.

ARGUMENTS: A string and maximum value for the hash value.

RETURNS: An integer hash value which is less than the maximum value.

C IMPLEMENTATION: The characters of the string are grouped together to form long integers which are then added together to yield a hash value. This value is then divided by the maximum value and the remainder is returned.

IncrementFloatCount

PURPOSE: Increments the count value for a **FloatTable** entry.

ARGUMENTS: A **FloatTable** entry.

IncrementIntegerCount

PURPOSE: Increments the count value for an **IntegerTable** entry.

ARGUMENTS: An **IntegerTable** entry.

IncrementSymbolCount

PURPOSE: Increments the count value for a **SymbolTable** entry.

ARGUMENTS: A **SymbolTable** entry.

InitializeAtomTables

PURPOSE: Initializes the **SymbolTable**, **IntegerTable**, and **FloatTable**. It also initializes the **CLIPSTrueSymbol** and **CLIPSFalseSymbol**.

RefreshBooleanSymbols

PURPOSE: Resets the values of the **CLIPSTrueSymbol** and the **CLIPSFalseSymbol**.

OTHER NOTES: Normally called during initialization of a run-time module generated using the constructs-to-c function.

RemoveEphemeralAtoms

PURPOSE: Causes the removal of all ephemeral symbols, integers, and floats, that still have a count value of zero, from their respective storage tables. This function performs this action by calling the functions **RemoveEphemeralSymbols**, **RemoveEphemeralIntegers**, and **RemoveEphemeralFloats**.

ReturnSymbolMatches

PURPOSE: Returns a set of symbol matches.

ARGUMENTS: A pointer to a list of symbol matches found using the **FindSymbolMatches** function.

SetFloatTable

PURPOSE: Sets the value of the **FloatTable**.

ARGUMENTS: A pointer to a **FloatTable**.

OTHER NOTES: Normally used by a run-time module generated using the constructs-to-c function to install the **FloatTable**.

SetIntegerTable

PURPOSE: Sets value of the **IntegerTable**.

ARGUMENTS: A pointer to a **IntegerTable**.

OTHER NOTES: Normally used by a run-time module generated using the constructs-to-c function to install the **IntegerTable**.

SetSymbolTable

PURPOSE: Sets value of the **SymbolTable**.

ARGUMENTS: A pointer to a **SymbolTable**.

OTHER NOTES: Normally used by a run-time module generated using the constructs-to-c function to install the **SymbolTable**.

INTERNAL FUNCTIONS

AddEphemeralFloat

PURPOSE: Adds a float to the **EphemeralFloatList**.

ARGUMENTS: A **FloatTable** entry.

OTHER NOTES: Typically called when a float is added to the **FloatTable** or when a float's count value reaches zero.

AddEphemeralInteger

PURPOSE: Adds an integer to the **EphemeralIntegerList**.

ARGUMENTS: An **IntegerTable** entry.

OTHER NOTES: Typically called when an integer is added to the **IntegerTable** or when an integer's count value reaches zero.

AddEphemeralSymbol

PURPOSE: Adds a symbol to the **EphemeralSymbolList**.

ARGUMENTS: A **SymbolTable** entry.

OTHER NOTES: Typically called when a symbol is added to the **SymbolTable** or when a symbol's count value reaches zero.

RemoveEphemeralFloats

PURPOSE: Removes all ephemeral floats from the **FloatTable** that still have a count value of zero and were created at a evaluation depth greater than the current evaluation depth. Uses the **EphemeralFloatList** to determine which floats to check. Floats that have a count greater than zero are removed from the **EphemeralFloatList**.

RemoveEphemeralIntegers

PURPOSE: Removes all ephemeral integers from the **IntegerTable** that still have a count value of zero and were created at a evaluation depth greater than the current evaluation depth.

Uses the **Ephemeral IntegerList** to determine which integers to check. Integers that have a count greater than zero are removed from the **EphemeralIntegerList**.

RemoveEphemeralSymbols

PURPOSE: Removes all ephemeral symbols from the **SymbolTable** that still have a count value of zero and were created at a evaluation depth greater than the current evaluation depth. Uses the **EphemeralSymbolList** to determine which symbols to check. Symbols that have a count greater than zero are removed from the **EphemeralSymbolList**.

RemoveFloat

PURPOSE: Removes a float from the **FloatTable**.

ARGUMENTS: A **FloatTable** entry.

RemoveInteger

PURPOSE: Removes an integer from the **IntegerTable**.

ARGUMENTS: An **IntegerTable** entry.

RemoveSymbol

PURPOSE: Removes a symbol from the **SymbolTable**.

ARGUMENTS: A **SymbolTable** entry.

Router Module

The Router Module (router.c) provides a level of indirection between low-level I/O implementations and high-level requests for I/O. All high-level requests for I/O are directed to logical names. The logical names are then associated with specific I/O implementations. Changing the CLIPS interface using this technique is now made very easy. To change the interface from a command line interface to a windowed interface only requires reassociating the appropriate logical names with I/O implementations for windows. High-level requests do not need to be changed. More details of the I/O Router mechanism can be found in Section 7 of the *Advanced Programming Guide*.

GLOBAL VARIABLES

CLIPSInputCount

PURPOSE:	Integer used to keep track of the number of characters currently entered while CLIPS is accepting input. Used by some of the machine specific interfaces to prevent backing over output (such as the CLIPS prompt) when input is being deleted.

WCLIPS

PURPOSE:	Global variable which can be used to refer to the **wclips** logical name.

WDIALOG

PURPOSE:	Global variable which can be used to refer to the **wdialog** logical name.

WDISPLAY

PURPOSE:	Global variable which can be used to refer to the **wdisplay** logical name.

WERROR

PURPOSE:	Global variable which can be used to refer to the **werror** logical name.

WTRACE

PURPOSE:	Global variable which can be used to refer to the **wtrace** logical name.

INTERNAL VARIABLES

Abort

PURPOSE: Boolean flag which indicates if the **ExitCLIPS** call should be aborted without exiting CLIPS.

FastLoadFilePtr

PURPOSE: Variable which indicates whether I/O router system is to be bypassed and input performed directly from a file.

C IMPLEMENTATION: If **FastLoadFilePtr** is NULL, regular I/O router procedure is used. If **FastLoadFilePtr** is not NULL, it is the file pointer to which I/O should be performed.

FastSaveFilePtr

PURPOSE: Variable which indicates whether I/O router system is to be bypassed and output performed directly to a file.

C IMPLEMENTATION: If **FastSaveFilePtr** is NULL, regular I/O router procedure is used. If **FastSaveFilePtr** is not NULL, it is the file pointer to which I/O should be performed.

ListOfFileRouters

PURPOSE: List of all defined file routers. File routers provide a mechanism for reading and writing to files. File routers are created using the open command.

ListOfRouters

PURPOSE: List of all defined I/O routers.

C IMPLEMENTATION: Router structure has information on router name, priority, boolean active flag, query function, print function, exit function, get character function, unget character function, and a pointer to the next router. The routers are linked in order of priority.

ListOfStringRouters

PURPOSE: List of all defined string routers. String routers provide a mechanism for reading input from a string or writing output to a string.

GLOBAL FUNCTIONS

AbortExit

PURPOSE: Sets the value of the **Abort** flag to TRUE.

ActivateRouter

PURPOSE: Activates a specified router.

ARGUMENTS: Name of router.

AddRouter

PURPOSE: Adds an I/O router to the **ListOfRouters**. The router is placed before routers with a lower priority and after routers with a higher priority.

ARGUMENTS: Router name, priority, boolean active flag, query function, print function, exit function, get character function, unget character function.

OTHER NOTES: Routers are active when created.

CloseAllFiles

PURPOSE: Closes all opened files.

CloseFile

PURPOSE: Closes a file.

ARGUMENTS: The logical name associated with the file when opened with **OpenFile**.

CloseStringDestination

PURPOSE: Closes a string output destination.

ARGUMENTS: Name of string router used when created with **OpenStringDestination**.

CloseStringSource

PURPOSE: Closes a string input source.

ARGUMENTS: Name of string router used when created with **OpenStringSource**.

DeactivateRouter

PURPOSE: Deactivates a specified router.

ARGUMENTS: Name of router.

DeleteRouter

PURPOSE: Removes an I/O router from the **ListOfRouters**.

ARGUMENTS: Name of I/O router.

RETURNS: Boolean value. TRUE if the router was successfully deleted, otherwise FALSE.

ExitCLIPS

PURPOSE: High-level CLIPS exit routine. Calls all router exit functions before calling genexit function.

ARGUMENTS: Exit number.

FindFile

PURPOSE: Determines if a file which the specified logical name has been opened.

ARGUMENTS: A logical name.

RETURNS: Boolean value. TRUE if a file with the specified logical name has been opened, otherwise FALSE.

FindFptr

PURPOSE: Returns a pointer to an opened file.

ARGUMENTS: A logical name.

RETURNS: Boolean value. A pointer to the specified file, if found, otherwise NULL.

GetcCLIPS

PURPOSE: High-level request function to get a character.

ARGUMENTS: Logical name from which character is requested.

RETURNS: A character.

OTHER NOTES: Routine must check for **FastLoadFilePtr** and **FastSaveFilePtr**.

GetFastLoad

PURPOSE: Returns the value of the variable **FastLoadFilePtr**.

GetFastSave

PURPOSE: Returns the value of the variable **FastSaveFilePtr**.

InitializeDefaultRouters

PURPOSE: Initializes the standard I/O routers used by CLIPS (file and string).

OpenFile

PURPOSE: Opens a file for input or output by creating a file router.

ARGUMENTS: The name of the file, the mode in which the file is to be opened (read, write, etc.), and the logical name to be associated with the file.

OpenStringDestination

PURPOSE: Allows a string to be used as an output destination by creating a string router.

ARGUMENTS: Name to be associated with the string router, the string to which output is sent, and the maximum number of characters that can be sent to the string.

RETURNS: Boolean value. TRUE if the string router was successfully created, otherwise FALSE.

OpenStringSource

PURPOSE: Allows a string to be used as a source of input by creating a string router.

ARGUMENTS: Name to be associated with the string router, the string from which input is read, and the starting location within the string.

RETURNS: Boolean value. TRUE if the string router was successfully created, otherwise FALSE.

OpenTextSource

PURPOSE: Allows a string to be used as a source of input by creating a string router. Since this function allows the maximum number of characters which can be read from the string to be specified, it is useful for reading from strings which are not NULL terminated and for reading from a substring of a string.

ARGUMENTS: Name to be associated with the string router, the string from which input is read, the starting location within the string, and the maximum number of characters which can be read from the string.

RETURNS: Boolean value. TRUE if the string router was successfully created, otherwise FALSE.

PrintCLIPS

PURPOSE: High-level request function to print a string.

ARGUMENTS: A string to print and the logical name to which the string is to be printed.

OTHER NOTES: Routine must check for **FastLoadFilePointer** and **FastSaveFilePointer**.

QueryRouters

PURPOSE: Determines if any router recognizes a logical name.

ARGUMENTS: Logical name.

RETURNS: Boolean value. TRUE if the logical name is recognized by any router, otherwise FALSE.

SetFastLoad

PURPOSE: Sets value of the variable **FastLoadFilePtr**.

ARGUMENTS: Value to which **FastLoadFilePtr** is to be set.

SetFastSave

PURPOSE: Sets value of the variable **FastSaveFilePtr**.

ARGUMENTS: Value to which **FastSaveFilePtr** is to be set.

UngetcCLIPS

PURPOSE: High-level request function to unget a character.

ARGUMENTS: Logical name to which character is ungotten and the character to unget.

OTHER NOTES: Routine must check for **FastLoadFilePtr** and **FastSaveFilePtr**.

UnrecognizedRouterMessage

PURPOSE: A generic error message which can be printed when a logical name is not recognized by any routers.

ARGUMENTS: The logical name which was unrecognized.

INTERNAL FUNCTIONS

CreateReadStringSource

PURPOSE: Drive routine for creating a string router for a string input source.

ARGUMENTS: Name to be associated with the string router, the string from which input is read, the starting location within the string, and the maximum number of characters which can be read from the string.

RETURNS: Boolean value. TRUE if the string router was successfully created, otherwise FALSE.

File Router Functions

PURPOSE: Set of functions needed to handle file routers. Note that this is not a single function but actually a series of functions.

QueryRouter

PURPOSE: Determines if a specific router recognizes a logical name.

ARGUMENTS: Logical name and an I/O router.

RETURNS: Boolean value. TRUE if the logical name is recognized by the router, otherwise FALSE.

String Router Functions

PURPOSE: Set of functions needed to handle string routers. Note that this is not a single function but actually a series of functions.

Scanner Module

The Scanner Module (scanner.c) “scans” input sources for tokens recognizable by CLIPS. The scanner receives input from logical names as described in the Router Module. The scanner returns token information in a data structure with several fields. One field indicates the type of token. For example, the token 783 would have type INTEGER, the token **(** would have type LEFT_PARENTHESIS, and the token **"cat"** would have type STRING. Another field in the token structure supplies the data value for tokens which have a data value. In the example above, "cat" would have a data value of "cat" (which would be a pointer to the symbol entry for "cat" in the **SymbolTable**). Note that the symbol cat would have the same data value as the string "cat". In addition, tokens also have a printed representation. The token ?x, for example, would have token type VARIABLE, data type "x", and printed representation "?x".

CLIPS produces a formatted representation for every parsed command or construct. Since this formatting process is closely linked with the scanner, the routines for creating this “pretty print” representation are included in the Scanner Module and directly called by the scanner routines. Every token that is read using the Scanner Module is placed in the **PrettyPrintBuffer** unless the buffer has been disabled. The buffer is normally disabled during execution of a knowledge base (it is not normally desirable to format input read from a file).

GLOBAL VARIABLES

IgnoreCompletionErrors

PURPOSE: Boolean flag which indicates whether an error should be signalled when a string is being scanned and an end-of-file is encountered.

INTERNAL VARIABLES

GlobalMax

PURPOSE: The maximum number of characters which can be stored in **GlobalString**.

GlobalPos

PURPOSE: The current number of characters stored in **GlobalString**.

GlobalString

PURPOSE: Buffer to store string data values for tokens.

IndentationDepth

PURPOSE: Used by the pretty print functions to determine how many spaces to indent when an indentation command is given.

PPBufferMax

PURPOSE: The maximum number of characters which can be stored in **PrettyPrintBuffer**.

PPBufferPos

PURPOSE: The current number of characters stored in **PrettyPrintBuffer**.

PrettyPrintBuffer

PURPOSE: Buffer to maintain a “pretty” representation of the current command or rule being parsed. Also requires several variables to keep track of current position in buffer.

PPBackupOnce

PURPOSE: The position to which to backup in the **PrettyPrintBuffer** the first time that **PPBackup** is called.

PPBackupTwice

PURPOSE: The position to which to backup in the **PrettyPrintBuffer** the second time that **PPBackup** is called.

PPBufferStatus

PURPOSE: Boolean flag which indicates whether parsed tokens should be stored in the **PrettyPrintBuffer**.

GLOBAL FUNCTIONS

CopyPPBuffer

PURPOSE: Makes a copy of the **PrettyPrintBuffer**.

RETURNS: A string copy of the **PrettyPrintBuffer**.

CopyToken

PURPOSE: Copies values of one token to another token.

ARGUMENTS: Source token and target token.

RETURNS: Nothing. Values of the target token will be set to values of the source token.

DecrementIndentDepth

PURPOSE: Decrements **IndentationDepth** for pretty printing.

ARGUMENTS: Value by which **IndentationDepth** is to be decremented.

DestroyPPBuffer

PURPOSE: Resets the state of the **PrettyPrintBuffer** to contain nothing and returns the string associated with the pretty print representation to the pool of free memory.

FlushPPBuffer

PURPOSE: Resets state of the **PrettyPrintBuffer** to contain nothing.

GetPPBuffer

PURPOSE: Returns a pointer to the **PrettyPrintBuffer**.

RETURNS: A pointer to the **PrettyPrintBuffer**.

GetPPBufferStatus

PURPOSE: Returns the value of the **PPBufferStatus** flag.

RETURNS: Boolean value.

GetToken

PURPOSE: Reads next token from the input stream.

ARGUMENTS: Logical name from which input is read and a pointer to a token structure in which to store the scanned token.

RETURNS: Nothing. The pointer to the token data structure passed as an argument is set to contain the type of token (e.g., symbol, string, integer, etc.), the data value for the token (i.e., a symbol table location if it is a symbol or string, an integer table location if it is an integer), and the pretty print representation.

IncrementIndentDepth

PURPOSE: Increments **IndentationDepth** for pretty printing.

ARGUMENTS: Value by which **IndentationDepth** is to be incremented.

PPBackup

PURPOSE: Backs up past last appended string to the **PrettyPrintBuffer**.

OTHER NOTES: Should only have to be capable of backing up over last two appended strings.

PPCRAndIndent

PURPOSE: Prints a carriage return (CR) followed by a number of spaces equal to the **IndentationDepth** of the **PrettyPrintBuffer**.

SavePPBuffer

PURPOSE: Appends a string to the end of the **PrettyPrintBuffer**.

ARGUMENTS: String to append to buffer.

SetIndentDepth

PURPOSE: Sets **IndentationDepth** for pretty printing.

ARGUMENTS: Value to which **IndentationDepth** is to be set.

SetPPBufferStatus

PURPOSE: Sets **PPBufferStatus** on or off.

ARGUMENTS: Boolean value. TRUE if **PrettyPrintBuffer** is to be turned on; FALSE if **PrettyPrintBuffer** is to be turned off.

OTHER NOTES: **PPBufferStatus** should be on during rule or command parse and off during rule execution.

StringPrintForm

PURPOSE: Generates printed representation of a string. Replaces **/** with **//** and **"** with **/"**.

ARGUMENTS: A string.

RETURNS: Printed representation of the string.

INTERNAL FUNCTIONS

AppendStrings

PURPOSE: Appends two strings together.

ARGUMENTS: Two pointers to strings.

RETURNS: A pointer to a string created by appending the two strings passed as arguments. The string is added to the **SymbolTable** so it is not necessary to deallocate the string returned.

ScanNumber

PURPOSE: Parses a number.

ARGUMENTS: Logical name from which input is read and a token data structure to store the parsed value.

RETURNS: The parsed data value in the token structure passed as an argument. The type of the token will either be an integer (in which cause the value in the token will be an **IntegerTable** entry), a float (in which cause the value in the token will be a **FloatTable** entry), or a symbol otherwise (in which cause the value in the token will be an **SymbolTable** entry). The pretty print representation of the data value will also be stored in the token.

OTHER NOTES: See the *Basic Programming Guide* for a detailed explanation of the integer and float data types. Note that any data value that first appears to be a number, but does not satisfy the requirements of a number is treated as a symbol (e.g. 37-A).

ScanString

PURPOSE: Parses a string.

ARGUMENTS: Logical name from which input is read.

RETURNS: **SymbolTable** entry for the string.

OTHER NOTES: See the *Basic Programming Guide* for a detailed explanation of the string data type.

ScanSymbol

PURPOSE: Parses a symbol.

ARGUMENTS: Logical name from which input is read, the number of characters in the symbol that have already been placed in the **StringBuffer**, and integer value for storing the symbol's type (since a symbol may actually be an instance name).

RETURNS: **SymbolTable** entry for the symbol.

OTHER NOTES: See the *Basic Programming Guide* for a detailed explanation of the symbol data type.

Expression Module

The standard format used by CLIPS for expressions is very similar to a LISP format. In general, expressions follow the format

```
(function-name arg1 arg2 ... argn)
```

where each argument may be an expression, a typeable primitive data type (symbol, string, integer, float, or instance name, but not external address or instance), or a variable (either local or global). The function name refers either to a system or user defined function, a deffunction, or a generic function. All of the following would be valid CLIPS expressions:

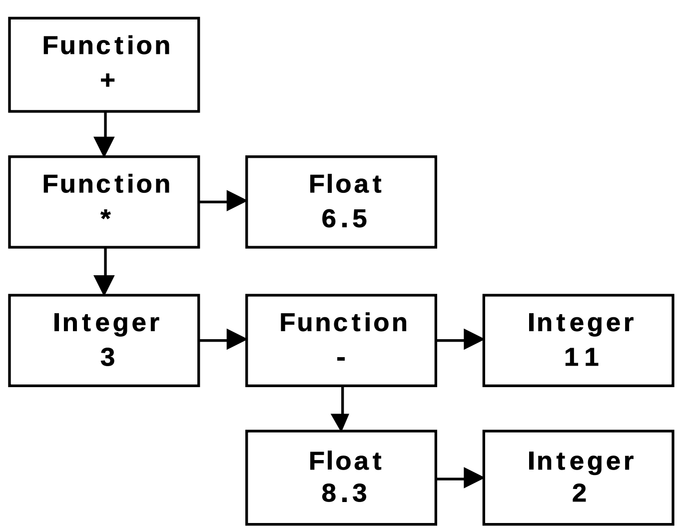
```
(facts)
(+ (* 3 (- ?x 3)) 6)
(str-cat "red" "blue")
```

The Expression Module (expressn.c) contains routines which parse expressions into a format which, in most cases, is suitable for evaluation by the Evaluation Module (evaluatn.c). It also checks that the first symbol found in a function call is a function name. The parsing of constructs (such as defrule and deffacts) is handled by the Constructs Module (constrct.c). In addition, the parsing of certain CLIPS expressions which do not conform to the standard expression format are handled by the Special Forms Module (spclform.c).

The data structure used to store each component of an expression consists of a type field (such as SYMBOL or INTEGER), a value field (such as a pointer to a **SymbolTable** entry), a pointer to an argument list (for functions), and a pointer to the next argument in the argument list. For example, the following expression

```
(+ (* 3 (- 8.3 2) 11) 6.5)
```

would be represented as shown following (with down pointing arrows representing the argument list pointers and right pointing arrows representing the next argument pointer).



GLOBAL VARIABLES

None.

INTERNAL VARIABLES

FunctionHashTable

PURPOSE: Stores all of the system and user defined functions registered with CLIPS by calling the function **DefineFunction**. The functions entries are hashed in this table so that any specified function can be retrieved quickly.

C IMPLEMENTATION: Implemented as an array. Each entry corresponds to a list of function entry. Collisions are resolved by adding the function entry to the list of entries.

ListOfFunctions

PURPOSE: Contains a linked list of all system and user defined functions registered with CLIPS by calling the function **DefineFunction**.

GLOBAL FUNCTIONS

AddFunctionParser

PURPOSE: Associates a specialized expression parsing function with the function entry for a function which was defined using **DefineFunction**. When this function is parsed, the specialized parsing function will be called to parse the arguments of the function. Only user and system defined functions can have specialized parsing routines. Generic functions and deffunctions can not have specialized parsing routines.

ARGUMENTS: Name of function for which the parsing function is to be applied, and a pointer to the parsing function.

AddHashFunction

PURPOSE: Adds a function entry to the **FunctionHashTable**.

ARGUMENTS: A function entry.

ArgumentParse

PURPOSE: Parses an argument within a function call expression.

ARGUMENTS: Logical name from which input is read, and a pointer to an integer in which an error code is returned.

RETURNS: A pointer to an expression representing the next argument in the function call. Note that this value may be null, indicating that no further arguments exist. The error status is passed back through the pointer to an integer passed as a parameter.

CollectArguments

PURPOSE: Parses and groups together all of the arguments for a function call expression by repeatedly calling **ArgumentParse**.

ARGUMENTS: Logical name from which input is read a pointer to the function call expression to which the arguments are to be attached.

RETURNS: The pointer to the function call expression with its arguments attached. If an error occurs, the function call expression is returned to the pool of free memory and NULL is returned.

ConstantExpression

PURPOSE: Identifies expressions that are constants.

ARGUMENTS: An expression.

RETURNS: Returns TRUE if the expression is a constant (symbol, string, integer, float, instance, or instance name), otherwise FALSE is returned.

CopyExpression

PURPOSE: Copies an expression.

ARGUMENTS: Expression to be copied.

RETURNS: A copy of the expression.

CountArguments

PURPOSE: Returns the number of arguments associated with an expression (i.e. how many arguments a function call has).

ARGUMENTS: An expression.

RETURNS: Returns an integer value representing the number of arguments found.

ExpressionContainsVariables

PURPOSE: Determines if an expression contains any variables.

ARGUMENTS: An expression and a boolean flag indicating whether global variables should be considered as variables.

RETURNS: Returns TRUE if the expression contains any variables, otherwise FALSE is returned.

ExpressionDeinstall

PURPOSE: Decrements count values for generic functions, deffunctions, and constant values (such as symbols) for all such occurrences found in an expression.

ARGUMENTS: An expression.

ExpressionInstall

PURPOSE: Increments count values for generic functions, deffunctions, and constant values (such as symbols) for all such occurrences found in an expression.

ARGUMENTS: An expression.

ExpressionSize

PURPOSE: Returns the total number of nodes contained in an expression.

ARGUMENTS: An expression (packed or unpacked).

RETURNS: Returns an integer value representing the total number of nodes in the expression.

Function0Parse

PURPOSE: Parses a function call. Assumes that none of the functions has been parsed yet.

ARGUMENTS: Logical name from which input is read.

RETURNS: A pointer to an expression. Returns null if an error occurs.

Function1Parse

PURPOSE: Parses a function call. Assumes that the opening left parenthesis of the function has already been parsed.

ARGUMENTS: Logical name from which input is read.

RETURNS: A pointer to an expression. Returns null if an error occurs.

Function2Parse

PURPOSE: Parses a function call. This routine is able to distinguish between system and user defined functions, deffunctions, and generic functions. If the routine has a specialized parsing routine, then that routine will be called by this routine in place of the default argument parsing routine. This routine assumes that the opening left parenthesis and the name of the function have already been parsed.

ARGUMENTS: Logical name from which input is read and name of the function to be parsed.

RETURNS: A pointer to an expression. Returns null if an error occurs.

FindFunction

PURPOSE: Determines if a function has been defined using the function **DefineFunction**.

ARGUMENTS: A function name.

RETURNS: A pointer to the function entry if it exists, otherwise NULL.

GetFunctionList

PURPOSE: Returns the **ListOfFunctions**.

IdenticalExpression

PURPOSE: Determines if two expressions are identical.

ARGUMENTS: Two expressions.

RETURNS: Returns TRUE if the expressions are identical, otherwise FALSE is returned.

InstallFunctionList

PURPOSE: Sets the **ListOfFunctions** and adds all the function entries to the **FunctionHashTable**.

ARGUMENTS: A linked list of function entries.

OTHER NOTES: Normally used by a run-time module generated using the constructs-to-c function to install the list of functions used by the module.

ListToPacked

PURPOSE: Copies a list of expressions to an array.

ARGUMENTS: A pointer to the expression list to be copied, a pointer to the array to which the expression is to be copied, and an integer index indicating the starting point in the array at which the copying should begin.

RETURNS: The last array index into which the expression was copied.

PackExpression

PURPOSE: Copies an expression (created using multiple memory requests) into an array (created using a single memory request) while maintaining all appropriate links in the expression. A packed expression requires less total memory because it reduces the overhead required for multiple memory allocations.

ARGUMENTS: The expression to be packed.

RETURNS: A copy of the expression packed into an array.

ParseAtomOrExpression

PURPOSE: Parses an expression which may be a function call, atomic value (string, symbol, etc.), or variable (local or global).

ARGUMENTS: Logical name from which input is read.

RETURNS: A pointer to an expression. Returns NULL if an error occurs.

ParseConstantArguments

PURPOSE: Creates an argument list from a series of constants found in a string.

ARGUMENTS: A string and a pointer to an integer.

RETURNS: A pointer to an expression. The integer passed as a parameter is set to TRUE if an error occurs.

PrintExpression

PURPOSE: Prints an expression.

ARGUMENTS: An expression and the logical name to which output is to be sent.

RemoveFunctionParser

PURPOSE: Removes a specialized expression parsing function (if it exists) from the function entry for a function.

ARGUMENTS: Name of function whose parsing function is to be removed.

ReturnExpression

PURPOSE: Returns an expression to the memory manager.

ARGUMENTS: An expression.

OTHER NOTES: If expression was installed using **InstallExpression** it should be deinstalled using **DeinstallExpression** before this function is called.

ReturnPackedExpression

PURPOSE: Returns a packed expression created using **PackExpression** to the memory manager.

ARGUMENTS: A packed expression.

OTHER NOTES: If expression was installed using **InstallExpression** it should be deinstalled using **DeinstallExpression** before this function is called.

SetFunctionList

PURPOSE: Sets the **ListOfFunctions**.

ARGUMENTS: A linked list of function entries.

INTERNAL FUNCTIONS

InitializeFunctionHashTable

PURPOSE: Initializes the **FunctionHashTable**.

Special Forms Module

Some CLIPS expressions do not conform to the standard expression format. An example of this type of expression is the assert:

```
(assert (data 35))
```

The subexpression found within the assert (data 35) is not a function call to be evaluated but, rather, a piece of data for the assert function. Special parsing is required to allow this format for the assert function. Many other functions such as if, while, bind, and retract either transform the expression in some special way or perform additional syntax checking on the expression format. These functions all require special parsing.

Specialized parsing functions are responsible for constructing an appropriate expression representation, as well as for making the appropriate calls to the pretty print routines to format the expression correctly for output.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

ListOfParsedBindNames

PURPOSE: Contains the list of variables encountered by parsing the bind function.

GLOBAL FUNCTIONS

ClearParsedBindNames

PURPOSE: Clears the **ListOfParsedBindNames** returning all structures to the pool of free memory.

GetParsedBindNames

PURPOSE: Returns the **ListOfParsedBindNames**.

InitializeSpecialForms

PURPOSE: Initializes specialized parsing functions for assert, bind, if, while, and retract. Also initializes several parsing functions for some math and predicate functions which provide additional error checking for the arguments of these functions.

ParsedBindNamesEmpty

PURPOSE: Indicates if any bind names have been parsed.

RETURNS: Returns TRUE if the **ListOfParsedBindNames** is NULL, otherwise FALSE.

SearchParsedBindNames

PURPOSE: Searches the **ListOfParsedBindNames** for a particular variable name.

ARGUMENTS: A variable name.

RETURNS: Returns TRUE if the variable was found, otherwise FALSE.

SetParsedBindNames

PURPOSE: Sets the value of the **ListOfParsedBindNames**.

ARGUMENTS: A new list of parsed bind names.

INTERNAL FUNCTIONS

AssertParse

PURPOSE: Handles special parsing of assert expression.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the assert function (or NULL if an error occurs).

AddBindName

PURPOSE: Adds a variable name to the **ListOfParsedBindNames**.

ARGUMENTS: Name of the variable.

BindParse

PURPOSE: Handles special parsing of bind expression.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the bind function (or NULL if an error occurs).

CheckArgListParse

PURPOSE: Handles parsing for functions which require a specified number of arguments of either numeric or non-numeric values.

ARGUMENTS: Logical name from which input is read, a pointer to the expression function call, an integer representing the restriction on the arguments (EXACTLY, AT_LEAST, NO_MORE_THAN, etc.), the number of arguments to which the restriction applies, and a boolean value indicating whether the arguments must be numeric.

RETURNS: Expression representing the parsed function (or NULL if an error occurs).

IfParse

PURPOSE: Handles special parsing of if expression.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the if function (or NULL if an error occurs).

MultiArgNumericParse

PURPOSE: Handles parsing for functions which require at least two numeric arguments. Currently used by the following functions: **+**, *****, **-**, **/**, **<=**, **>=**, **<**, **>**, **=**, **<>**, **min**, and **max**.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the parsed function (or NULL if an error occurs).

MultiArgParse

PURPOSE: Handles parsing for functions which require at least two arguments. Currently used by the following functions: **and** and **or**.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the parsed function (or NULL if an error occurs).

NotParse

PURPOSE: Handles parsing for functions which require exactly one argument. Currently used by the **not** function.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the parsed function (or NULL if an error occurs).

RetractParse

PURPOSE: Handles special parsing of retract expression.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the retract function (or NULL if an error occurs).

WhileParse

PURPOSE: Handles special parsing of while expression.

ARGUMENTS: Logical name from which input is read, and a pointer to the expression function call.

RETURNS: Expression representing the while function (or NULL if an error occurs).

Parser Utility Module

The Parser Utility Module (parsutil.c) provides a number of function which perform various parsing tasks.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

BuildRHSAssert

PURPOSE:	Parses one or more RHS pattern and creates an **assert** command from the patterns.
ARGUMENTS:	A pointer to an **assert** function call expression (which will be converted to a **progn** if more than one pattern is to be asserted), logical name from which input is read, a boolean flag indicating if opening right parenthesis of the first RHS pattern has already been parsed, and a pointer to a boolean flag which indicates if a parsing error occurred.
RETURNS:	A pointer to an expression (NULL if an error was encountered). The parsing error flag is always set to either TRUE or FALSE by this routine.

CompactActions

PURPOSE:	Converts a **progn** function call expression to a simpler format if it contains less than two arguments. A **progn** with no arguments if converted to an expression containing the symbol FALSE. A **progn** with a single argument is converted to an expression containing the single argument.
ARGUMENTS:	A pointer to an expression.
RETURNS:	A pointer to an expression.

GetAssertArgument

PURPOSE:	Parses a single argument for use within an assert command (e.g. a single symbol or variable).

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to a boolean flag which indicates whether a multifield value was parsed, a pointer to a boolean flag which indicates if a parsing error occurred, the type of token which indicates that no more assert arguments are available (e.g. a right parenthesis), a boolean flag indicating if only constants are allowed to be parsed, and a boolean flag indicating whether an error message should be printed by the calling function when an error is detected by this function.

RETURNS: A pointer to an expression. The multifield flag and error flag are set to TRUE if a multifield or error is encountered while parsing. The print error message flag is always set to either TRUE or FALSE by this routine.

GetConstructNameAndComment

PURPOSE: Parses the name and comment fields of a construct. If the construct is being redefined, then the current definition of the construct is deleted. If compilations are being watched then this function will print out an informational message, otherwise a single character is printed to indicate a new construct is being defined.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, the name of the construct type being parsed (e.g. defrule), a pointer to a function which will delete the construct in case the parsed construct is being redefined, the character symbol which is printed to indicate a construct is being defined (e.g. '*' for defrule), and a boolean flag indicating if a carriage return should be printed after the long informational message when compilations are being watched.

RETURNS: The name of the construct being parsed.

GetRHSPattern

PURPOSE: Parses the type of pattern typically encountered on the RHS of a rule for functions such as **assert** and **modify**, but can also be found in constructs such as **deffacts**. A RHS pattern consists of a left parenthesis, followed by one or more primitive data types or variables, followed by a right parenthesis. The fields in the RHS pattern may also be specified using a deftemplate format.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to a

	boolean flag which indicates whether a multifield value was parsed, a pointer to a boolean flag which indicates if a parsing error occurred, a boolean flag indicating if only constants are allowed to be parsed, a boolean flag indicating if opening right parenthesis of the RHS pattern has already been parsed, and the type of token which indicates the end of the RHS pattern (e.g. a right parenthesis).
RETURNS:	A pointer to an expression. The multifield flag and error flag are set to TRUE if a multifield or error is encountered while parsing.
OTHER NOTES:	Primarily uses the function **GetAssertArgument** to parse an ordered fact and the function **ParseAssertTemplate** to parse a deftemplate fact.

GroupActions

PURPOSE:	Parses a series of actions and groups them together in a **progn** command.
ARGUMENTS:	Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a boolean flag indicating if first token of the group of actions has already been parsed, and the string representation of the type of token which indicates the end of the group of actions (in addition to a right parenthesis).
RETURNS:	A pointer to an expression (NULL if an error was encountered).

ReadUntilClosingParen

PURPOSE:	Scans tokens until a matching closing right parenthesis is found. This function assumes that an opening left parenthesis has already been parsed before the function was called and verifies that each left parenthesis encountered has a matching right parenthesis.
ARGUMENTS:	Logical name from which input is read and a pointer to a token structure in which scanned tokens are placed.
RETURNS:	Boolean value. TRUE if the closing right parenthesis was found, otherwise FALSE.

INTERNAL FUNCTIONS

None.

Evaluation Module

The Evaluation Module (evaluatn.c) provides a set of functions for evaluating expressions. In addition, functions for defining functions and accessing the argument values of expressions are provided.

In versions of CLIPS previous to version 5.0, garbage collection was simplified by that fact that it could be performed on rule firing boundaries. Symbols and other data structures created by the evaluation of expressions could be checked at the end of each rule firing to determine if they could be garbage collected. Version 5.0 of CLIPS, however, introduced object-oriented and procedural programming paradigms. It is now possible to have a CLIPS program which contains no rules at all. Thus, it is no longer sufficient to perform garbage collection only on rule boundaries. Garbage collection of symbols and other ephemeral data structures can now occur at the completion of each rule, deffunction, generic function, or message-handler that is executed.

Because rule firings, function calls, and message passing can be nested many levels deep, it is necessary to associate an "evaluation depth" with each ephemeral data structure that is created. This evaluation depth indicates the levels of unnesting that must occur before a particular data structure can be garbage collected. For example, if function *foo* calls function *bar* which in turn calls function *yak*, then data structures created through the evaluation of expressions in function *foo* would have an evaluation depth of 1. Similarly, expression evaluation results in function *bar* would have an evaluation depth of 2 and results from function *yak* would have an evaluation depth of 3. Ephemeral data structures created at a depth of 3 could be garbage collected upon return to either function *foo* or *bar*. Similarly, data structures created at a depth of 2 could be garbage collected upon return to function *foo* and the data structures created by *foo* could be garbage collected once *foo* was exited.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

BindList

PURPOSE: A linked list of the local variables that are dynamically allocated by the **bind** command for a given evaluation depth. Any routine which increments the **CurrentEvaluationDepth** value must store the old value of the **BindList** and restore this value when the **CurrentEvaluationDepth** is decremented.

CurrentEvaluationDepth

PURPOSE: The current "depth" of evaluation. This value is used for the purposes of garbage collection. At the beginning of the execution of each rule, deffunction, generic function, or message-handler, this value is incremented by one. At the completion of the execution of each rule, deffunction, generic function, or message-handler, this value is decremented by one. Note that the execution of a system or user-defined function does not affect this value.

EvaluationError

PURPOSE: Boolean flag which indicates if an error has occurred while evaluating an expression.

HaltExecution

PURPOSE: Boolean flag which indicates if execution (rules, certain functions such as while, deffunctions, etc.) should be halted.

CurrentExpression

PURPOSE: As expressions are evaluated, maintains list of arguments for each expression evaluation.

GLOBAL FUNCTIONS

Argument Access Functions

PURPOSE: A series of functions which allows access to the arguments of an expression. Some access functions are implemented as macros. The following are access functions implemented as functions: **RtnArgCount**, **ArgCountCheck**, **ArgTypeCheck**, **RtnLong**, **RtnUnknown**, **RtnLexeme**, **RtnDouble**, and **ArgRangeCheck**. See the *Advanced Programming Guide* for further details.

CLIPSFunctionCall

PURPOSE: Allows functions external to CLIPS to execute function calls. See the *Advanced Programming Guide* for further details.

DefineFunction

PURPOSE: Defines a function to be accessible to CLIPS.

ARGUMENTS: Function access name, pointer to the function, type of return value, and actual function name.

EvaluateExpression

PURPOSE: Evaluates an expression.

ARGUMENTS: An expression to evaluate, and a pointer to a data structure in which to return a value.

RETURNS: The current value of **EvaluationError**. The return value of the expression is stored in the data structure.

GetBoundVariable

PURPOSE: Searches the **BindList** for a specified variable.

ARGUMENTS: The name of the variable and a pointer to a DATA_OBJECT structure in which to store variable, if found.

RETURNS: A boolean value. TRUE if the variable was found, otherwise FALSE.

GetEvaluationError

PURPOSE: Returns the **EvaluationError** flag.

GetHaltExecution

PURPOSE: Returns the **HaltExecution** flag.

PrintDataObject

PURPOSE: Prints a DATA_OBJECT structure to the specified logical name.

ARGUMENTS: A pointer to a DATA_OBJECT structure and a logical name.

PropagateReturnValue

PURPOSE: Decrements the associated depth for a value stored in a DATA_OBJECT structure. In effect, the values returned by certain evaluations (such as a deffunction call) are passed up to the previous depth of evaluation. The return value's depth is decremented so that it will not be garbage collected along with other items that are no longer needed from the evaluation that generated the return value.

ARGUMENTS: A pointer to a DATA_OBJECT structure.

ReturnValues

PURPOSE: Returns a linked list of DATA_OBJECT structures to the pool of free memory.

ARGUMENTS: A pointer to the head DATA_OBJECT structure in a list.

Return Value Access Functions

PURPOSE: A series of functions which allows access to the return value data structures. Most of these access functions are implemented as macros. See the *Advanced Programming Guide* for further details.

SetEvaluationError

PURPOSE: Sets the **EvaluationError** flag.

ARGUMENTS: A boolean value (the new value of the flag). If the value of the flag is TRUE, then the **HaltExecution** flag is also set to TRUE.

SetHaltExecution

PURPOSE: Sets the **HaltExecution** flag.

ARGUMENTS: A boolean value (the new value of the flag).

SetMultifieldErrorValue

PURPOSE: Creates a multifield value of length zero for error returns.

ARGUMENTS: A pointer to a DATA_OBJECT structure in which the error value is to be stored.

ValueDeinstall

PURPOSE: Decrements the appropriate count (in use) values for a DATA_OBJECT structure.

ARGUMENTS: A pointer to a DATA_OBJECT structure.

ValueInstall

PURPOSE: Increments the appropriate count (in use) values for a DATA_OBJECT structure.

ARGUMENTS: A pointer to a DATA_OBJECT structure.

INTERNAL FUNCTIONS

NonexistantError

PURPOSE: Prints the error message for a nonexistant argument.

ARGUMENTS: The name of the access function which couldn't find the argument, the name of the function which called the access function, and the index position of the argument requested.

WrongTypeError

PURPOSE: Prints the error message for the wrong type of argument.

ARGUMENTS: The name of the access function which couldn't find the argument, the name of the function which called the access function, and the name of the type expected.

Command Line Module

The Command Line Module (commline.c) contains the basic functions for setting up a simple command line processor for CLIPS commands.

Command line routines are oriented for building interfaces that use an event-driven philosophy. These interfaces have windows, menus, and/or command entry windows. In an event-driven interface, keyboard input is just one of several possible events. If a key is pressed, it is placed in an input buffer. The input buffer will not be processed until a complete command has been entered. In CLIPS, commands are delimited by a set of matching parentheses. In addition, commands may also be variables or constants. During entry to the input buffer, other events such as menu selections can also be processed because CLIPS has not yet begun to process the input command.

The basic input buffer to CLIPS should be used for accepting keyboard entry. File entry should be permitted to lock out other events. In effect, menu commands cannot be accessed during the loading of a file. The file loading operation represents a complete event by itself whereas a single keyboard character entry is a single event.

The basic command loop for CLIPS works as follows:

```
procedure CommandLoop
   print the CLIPS prompt
   do forever
      call EventFunction
      if a complete command is in the input buffer then
         perform the command
         clear the input buffer
         print the CLIPS prompt
      end if
   end do
end procedure
```

Notice that the loop calls the **EventFunction** procedure repeatedly. The command is executed only when the **CompleteCommand** function indicates that a complete command is waiting in the input buffer. A typical **EventFunction** procedure for a non-windowed interface would be

```
procedure GenericEventFunction
   get a character from the keyboard
   stuff the character into the input buffer
end procedure
```

The only event possible is to grab a character which is then stuffed into an input buffer. If a command has been completed, the CompleteCommand function returns a non-zero value. Simple modifications to this basic function allow for the easy operation of a windowed interface as shown following.

```
procedure WindowEventFunction
   get the next event
   if the event is a key press then
      stuff the character into the input buffer
   else if the event is a menu selection
      execute the menu selection
   else if the event is a window operation
      execute the window operation
   end if
end procedure
```

In this function, a routine is used to get the next event. Depending upon the exact nature of the event, different actions are taken. This type of setup will allow the user to begin entering a command, browse the data base using menu options, and then finish entering the command.

GLOBAL VARIABLES

EvaluatingTopLevelCommand

PURPOSE: Boolean flag which indicates whether a top-level command is currently being executed.

INTERNAL VARIABLES

CommandString

PURPOSE: Input buffer for the command string being formed.

EventFunction

PURPOSE: A pointer to the function to be called to process the next event.

MaximumCharacters

PURPOSE: Current maximum length of the **CommandString**.

MemoryStatusFunction

PURPOSE: A pointer to a function which is periodically called during the command loop to allow the interface to update a display which indicates the amount of memory used by CLIPS.

ParsingTopLevelCommand

PURPOSE: Boolean flag which indicates whether a top-level command is currently being parsed.

VersionString

PURPOSE: The character string that is printed when CLIPS first starts indicating the CLIPS version number and date of creation.

GLOBAL FUNCTIONS

AppendCommandString

PURPOSE: Appends a value to the contents of the **CommandString**.

ARGUMENTS: A string.

CommandLoop

PURPOSE: Endless loop which waits for user commands and then executes them. The command loop will bypass the **EventFunction** if there is an active batch file.

CompleteCommand

PURPOSE: Determines whether a string forms a complete command. A complete command is either a constant, a variable, or a function call which is followed (at some pointer) by a carriage return. Once a complete command is found (not including the parenthesis), extraneous parenthesis and other tokens are ignored.

ARGUMENTS: A string.

RETURNS: Integer value. 1 if the string forms a complete command without errors, 0 if the string forms an incomplete command without errors, and -1 if the string has errors (e.g., the command begins with a right parenthesis).

OTHER NOTES: Implemented as several functions.

ExpandCommandString

PURPOSE: Appends a character to the **CommandString**.

ARGUMENTS: Character to be appended. This routine properly handles the backspace character by removing a character from the **CommandString**.

FlushCommandString

PURPOSE: Empties the contents of the **CommandString**.

GetCommandString

PURPOSE: Returns a pointer to the contents of the **CommandString**.

RETURNS: Current **CommandString**.

PrintPrompt

PURPOSE: Prints the CLIPS command prompt.

RouteCommand

PURPOSE: Processes a completed command.

ARGUMENTS: A command string.

RETURNS: Boolean value. TRUE if the command was successfully executed, otherwise FALSE.

OTHER NOTES: Creates a string router with its command string argument and then calls the appropriate parsing and execution functions to process the command.

SetCommandString

PURPOSE: Sets the contents of the **CommandString** to a specific value.

ARGUMENTS: A string.

OTHER NOTES: Flushes current contents of the **CommandString**.

SetEventFunction

PURPOSE: Replaces the current value of **EventFunction**.

ARGUMENTS: A pointer to the new event-handling function.

RETURNS: A pointer to the old event-handling function.

SetMemoryStatusFunction

PURPOSE: Replaces the current value of **MemoryStatusFunction**.

ARGUMENTS: A pointer to the new memory status function.

TopLevelCommand

PURPOSE: Indicates whether a top-level command is being parsed.

RETURNS: Returns the value of **ParsingTopLevelCommand**.

INTERNAL FUNCTIONS

DefaultGetNextEvent

PURPOSE: Default event-handling function. Handles only keyboard events by first calling **GetcCLIPS** to get a character and then calling **ExpandCommandString** to add the character to the **CommandString**.

DoComment

PURPOSE: Skips over a comment contained within a string until a line feed or carriage return is encountered.

ARGUMENTS: A pointer to a string and an integer representing the position of the character in the string currently being scanned.

RETURNS: An integer. The character position in the string where the comment terminates.

DoString

PURPOSE: Skips over a string contained within a string until the closing quotation mark is encountered.

ARGUMENTS: A pointer to a string, an integer representing the position of the character in the string currently being scanned, and a pointer to an integer flag which indicates if the closing quotation mark was actually encountered.

RETURNS: An integer. The character position in the string where the string terminates. If the string is terminated by a quotation mark then the integer flag passed as an argument is set to TRUE, otherwise the flag is set to FALSE.

DoWhiteSpace

PURPOSE: Skips over white space consisting of spaces, tabs, and form feeds that is contained within a string.

ARGUMENTS: A pointer to a string and an integer representing the position of the character in the string currently being scanned.

RETURNS: An integer. The character position in the string where the white space terminates.

Construct Manager Module

Several defining **constructs** appear in CLIPS: **defrule**, **deffacts**, **deftemplate**, **defglobal**, **deffunction**, **defclass**, **definstances**, **defmessage-handler**, **defgeneric**, and **defmethod**. The Construct Manager Module (constrct.c) handles a variety of operations generic to these constructs.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

BeforeClearFunction

PURPOSE: Contains a pointer to a function which is to be called before the clear command is executed (if this variables is not NULL). If the function returns FALSE, the clear command is not performed.

BeforeResetFunction

PURPOSE: Contains a pointer to a function which is to be called before the reset command is executed (if this variables is not NULL). If the function returns FALSE, the reset command is not performed.

Executing

PURPOSE: Boolean flag. If TRUE, indicates that a construct is being executed.

ListOfClearFunctions

PURPOSE: Contains a list of functions to be called whenever a clear command is issued.

ListOfConstructs

PURPOSE: Contains the list of constructs recognized by CLIPS along with pointers to the functions which parse each construct.

ListOfResetFunctions

PURPOSE: Contains a list of functions to be called when a reset is performed.

ListOfSaveFunctions

PURPOSE: Contains list of functions to be called whenever a save command is issued.

PrintWhileLoading

PURPOSE: Boolean flag. If on, then loading information will be printed during the loading of constructs. If off, then no loading information is printed. The top-level **load** command enables this flag (and either single characters or a more lengthy message will be printed for each construct depending upon the value of **WatchCompilations**). The embedded **LoadConstructs** function does not set this flag and thus by default messages will not be printed when this routine is called.

WatchCompilations

PURPOSE: Boolean flag. If on, indicates that the progress of construct definitions should be displayed.

GLOBAL FUNCTIONS

AddClearFunction

PURPOSE: Adds a function to the **ListOfClearFunctions**.

ARGUMENTS: A name to be associated with the function, a pointer to the function, and the priority of the clear item.

AddConstruct

PURPOSE: Adds a construct and its associated parsing function to the **ListOfConstructs**.

ARGUMENTS: Name of construct for which the parsing function is to be applied, and a pointer to the parsing function.

AddResetFunction

PURPOSE: Adds a function to **ListOfResetFunctions**.

ARGUMENTS: A name to be associated with the function, a pointer to the function, and the priority of the reset item.

AddSaveFunction

PURPOSE: Adds a function to the **ListOfSaveFunctions**.

ARGUMENTS: A name to be associated with the function and a pointer to the function.

CallClearFunctions

PURPOSE: Calls all clear functions in the **ListOfClearFunctions**.

ClearCLIPS

PURPOSE: Clears the CLIPS environment. See the *Basic Programming Guide* for details on the effects of a clear.

OTHER NOTES: Calls the **BeforeClearFunction**, then each function in the **ListOfClearFunctions** in order of descending priority.

ExecutingConstruct

PURPOSE: Returns the value of **Executing**.

GetCompilationsWatch

PURPOSE: Returns the value of **WatchCompilations**.

GetPrintWhileLoading

PURPOSE: Returns the value of **PrintWhileLoading**.

InitializeConstructs

PURPOSE: Initializes the Construct Manager.

InitializeIgnoredConstructs

PURPOSE: Initializes some parsing routines for skipping over CRSV constructs not handled by CLIPS such as defrelation and defexternal.

LoadConstructs

PURPOSE: Loads a set of constructs into the current CLIPS environment from a file.

ARGUMENTS: A file name.

OTHER NOTES: Converts file name to a logical name and calls function **LoadConstructsFromLogicalName**.

LoadConstructsFromLogicalName

PURPOSE: Loads a set of constructs into the current CLIPS environment from a specified logical name.

ARGUMENTS: A logical name.

OTHER NOTES: Calls function **ParseConstruct** to read in each construct.

ParseIgnoredConstruct

PURPOSE: Parsing routine for skipping over constructs recognized, but not handled by CLIPS (such as CRSV constructs).

ARGUMENTS: Logical name from which input is read.

ParseConstruct

PURPOSE: Parses a construct.

ARGUMENTS: Name of construct to be parsed, and a logical name from which input is to be read.

RETURNS: An integer. -1 if the construct name has no parsing function, 0 if the construct was parsed successfully, and 1 if the construct was parsed unsuccessfully.

OTHER NOTES: Construct parsing functions should return a value of 0 if the construct is parsed successfully and a value of 1 if the construct is not parsed successfully.

RemoveClearFunction

PURPOSE: Removes a function from the **ListOfClearFunctions**.

ARGUMENTS: Name associated with the function.

RemoveConstruct

PURPOSE: Removes a construct and its associated parsing function from the **ListOfConstructs**.

ARGUMENTS: Name of construct to be removed.

RemoveResetFunction

PURPOSE: Removes a function from the **ListOfResetFunctions**.

ARGUMENTS: Name associated with reset function.

RemoveSaveFunction

PURPOSE: Removes a function from the **ListOfSaveFunctions**.

ARGUMENTS: Name associated with function.

ResetCLIPS

PURPOSE: Resets the CLIPS environment. See the *Basic Programming Guide* for details on the effects of a reset.

OTHER NOTES: Calls the **BeforeResetFunction**, then each function in the **ListOfResetFunctions** in order of descending priority.

SaveConstructs

PURPOSE: Saves the constructs currently in the CLIPS environment to a file. This function is the primary routine called by the **save** command.

ARGUMENTS: The name of the file to which constructs should be saved.

OTHER NOTES: Opens the specified file then calls each function in the **ListOfSaveFunctions**.

SetBeforeClearFunction

PURPOSE: Sets the value of **BeforeClearFunction**.

ARGUMENTS: A pointer to a function.

SetBeforeResetFunction

PURPOSE: Sets the value of **BeforeResetFunction**.

ARGUMENTS: A pointer to a function.

SetCompilationsWatch

PURPOSE: Sets the value of **WatchCompilations**.

ARGUMENTS: A boolean value (TRUE or FALSE).

SetExecutingConstruct

PURPOSE: Sets the value of **Executing**.

ARGUMENTS: A boolean value (TRUE or FALSE).

SetPrintWhileLoading

PURPOSE: Sets the value of **PrintWhileLoading**.

ARGUMENTS: A boolean value (TRUE or FALSE).

ValidConstruct

PURPOSE: Determines whether a construct is in the **ListOfConstructs**.

ARGUMENTS: Name of the construct.

RETURNS: Boolean value. TRUE if the construct has a parsing function; otherwise FALSE.

INTERNAL FUNCTIONS

ErrorAlignment

PURPOSE: Positions the parser at a token which indicates the beginning of a valid construct. If called as the result of an error in a construct, this routine skips over tokens until it finds the beginning of a new construct. If an error hasn't occurred, then this routine checks to see that the parser is currently at the beginning of a new construct (a left parenthesis followed by a constructs name).

ARGUMENTS: Logical name from which input was being read when an error was detected, a boolean value indicating whether an error has occurred, and a pointer to a data structure in which parsed tokens can be stored.

Utility Module

The Utility Module (utility.c) contains a number of generally useful functions including functions for printing primitive data types, constructing string representations of primitive data types, appending characters and strings to other strings, checking argument types, printing generic error and informational messages, adding and manipulating items that can be watched using the **watch** command, and performing periodic garbage collection.

The method CLIPS uses to perform periodic garbage collection merits some discussion. Garbage collection and ephemeral “items” have already been discussed to some extent as they relate to the Symbol Module (symbol.c) and the Evaluation Module (evaluatn.c). Garbage within CLIPS comes in several varieties. The first variety is garbage that can be immediately discarded when it is no longer in use. As an example of this, consider the following command sequence.

```
CLIPS> (open "temp.txt" temp "w")
TRUE
CLIPS> (printout temp "Hello World" crlf)
CLIPS> (close temp)
TRUE
CLIPS>
```

When the file "temp.txt" is opened using the **open** command, data structures are allocated which associate the logical name temp with the newly opened file. When the **close** command is used to close the file, the data structure previously allocated are no longer needed and can be *immediately* returned to the pool of free memory. In this case, garbage collection occurs for the data structures at the same time the garbage is created. Deleting constructs is another example of this type of garbage collection since the memory used by these constructs is almost always immediately returned to the pool of free memory (with some exceptions such as deleting an executing rule).

The second type of garbage collection occurs when an item appears to be garbage (but it cannot yet be determined), or an item is garbage but is temporarily being referred to by another data structure. As an example of this, consider the following command sequence.

```
CLIPS> (assert (colors red green))
CLIPS>
(defrule remove-fact
  ?f <- (colors ?x ?y)
  =>
  (retract ?f)
  (printout t "Colors: " ?x " " ?y crlf))
CLIPS> (run)
CLIPS>
```

When the fact (color red green) is retracted by the *remove-fact* rule, the symbols *red* and *green* become garbage since they are no longer permanently referred to by any data structure. However, these values are still needed for the *printout* command which follows the *retract* command so the values cannot be garbage collected just yet. Once the rule has completed execution the values can be safely garbage collected.

Garbage collection *can* occur at the completion of each rule, deffunction, generic function, or message-handler that is executed, however, it does not always occur each time one of these boundaries is encountered. CLIPS uses some heuristics to determine if garbage collection should actually take place. First, either the size of number of items subject to garbage collection must exceed a specified value. That is, CLIPS will not garbage collect to reclaim 120 bytes of memory. Second, if garbage collection does not free enough memory at a specified evaluation depth, then garbage collection at that depth will not be repeated until a larger amount of garbage has been created. This prevents garbage collection from being repeatedly attempted on items that cannot yet be freed.

GLOBAL VARIABLES

AddressesToStrings

PURPOSE: Boolean flag which indicates whether addresses (external, fact, or instance) should be printed using the notation for addresses or should be printed with quotes surrounding them. This is used by functions such as **save-facts** which are not capable of reloading addresses and so must convert the addresses to a safe form.

CurrentEphemeralCountMax

PURPOSE: The current maximum number of ephemeral items allowed before periodic garbage collection is attempted.

CurrentEphemeralSizeMax

PURPOSE: The current maximum amount of memory used by ephemeral items before periodic garbage collection is attempted.

EphemeralItemCount

PURPOSE: The current number of “items” that can be potentially garbage collected.

EphemeralItemSize

PURPOSE: The amount of memory used by all of the “items” the can be potentially garbage collected.

PreserveEscapedCharacters

PURPOSE: Boolean flag which indicates whether the backslash escape character should be reembedded within a string when the string is printed.

INTERNAL VARIABLES

ListOfCleanupFunctions

PURPOSE: Contains a list of functions to be called when a periodic cleanup is performed.

ListOfPeriodicFunctions

PURPOSE: Contains a list of functions to be called when a periodic cleanup is checked. These function are always called whenever **PeriodicCleanup** is called. The **ListOfCleanupFunction** is only called if the cleanup heuristics indicate that a periodic cleanup should be performed. These functions are useful for updating displays or checking for events in machine specific interfaces layered on top of the CLIPS kernel.

ListOfWatchItems

PURPOSE: Contains a list of structures that represent the items that can be watched using the **watch** command.

GLOBAL FUNCTIONS

AddCleanupFunction

PURPOSE: Adds a function to the **ListOfCleanupFunctions**.

ARGUMENTS: A name to be associated with the function, a pointer to the function, and the priority of the cleanup item.

AddPeriodicFunction

PURPOSE: Adds a function to the **ListOfPeriodicFunctions**.

ARGUMENTS: A name to be associated with the function, a pointer to the function, and the priority of the periodic item.

AddWatchItem

PURPOSE: Adds a watch item to the **ListOfWatchItems**.

ARGUMENTS: The name of the watch item, a pointer to the integer in which the watch item's value is stored, and the priority of the watch item.

AppendNToString

PURPOSE: Appends a specified number of characters from one string to another. Expands the appended string, if necessary, to create enough space.

ARGUMENTS: A pointer to the appending string, a pointer to the string to be appended, a pointer to the current length of the appended string, a pointer to the maximum length that the appended string can contain, and the maximum number of characters that are to be appended to the string.

RETURNS: The new appended string. The string that is appended may be dynamically reallocated to create a larger string. The current length and maximum length values are updated by this routine.

AppendToString

PURPOSE: Appends one string to another. Expands the appended string, if necessary, to create enough space.

ARGUMENTS: A pointer to the appending string, a pointer to the string to be appended, a pointer to the current length of the appended string, and a pointer to the maximum length that the appended string can contain.

RETURNS: The new appended string. The string that is appended may be dynamically reallocated to create a larger string. The current length and maximum length values are updated by this routine.

AtomDeinstall

PURPOSE: Decrements the count value for a single primitive data type.

ARGUMENTS: The type of the primitive data type and the value of the primitive data type.

AtomInstall

PURPOSE: Increments the count value for a single primitive data type.

ARGUMENTS: The type of the primitive data type and the value of the primitive data type.

GetConstructName

PURPOSE: Checks for an appropriate symbolic name as the argument to a function call during run-time. Used by functions such as **ppdefrule** and **undefrule** which require a symbolic value as the name of a defrule. A name must be a symbol, not a string.

ARGUMENTS: Expected number of arguments, name of function being executed, position in the argument where the name should occur, and a string describing the name type being sought (i.e., "defrule name", "deffacts name").

RETURNS: Returns the symbolic value (a string) found in the position. If an error occurs, returns NULL.

CLIPSSystemError

PURPOSE: Standard error message used to indicate that a CLIPS internal error has been detected.

ARGUMENTS: A string indicating the module in which the error was detected and an ID number associated with error.

ExpandStringWithChar

PURPOSE: Adds a character to a string, expanding the string if necessary.

ARGUMENTS: Character to be added, destination string, a pointer to the integer representing the insertion point in the string, a pointer to the integer representing the maximum size of the string, and new size for the string if it must be expanded.

RETURNS: A string with the character added to it. The string that is returned may have been dynamically reallocated to create a larger string. The current length and maximum length values are updated by this routine.

ExpectedTypeError

PURPOSE:	Standard error message used when wrong type of argument has been used in an expression.
ARGUMENTS:	Name of function, position of argument, and string containing a description of the expected type.

ExpectedCountError

PURPOSE:	Standard error message used when the wrong number of arguments has been used in the argument list of a function call.
ARGUMENTS:	Name of function, relation value for arguments being checked (EXACTLY, AT LEAST, NO MORE THAN), and comparison value for arguments being checked.

FloatToString

PURPOSE:	Converts a float to a string using the CLIPS numeric format. CLIPS uses the %g format option from the C library routine **sprintf** to print floating point numbers. This format selects either scientific notation or prints all the digits of the number (whichever ends up taking less space). In addition, CLIPS makes sure that all floats are printed with at least one digit following the decimal point.
ARGUMENTS:	A floating-point number.
RETURNS:	A string.
OTHER NOTES:	Return value is stored in a static data area. Subsequent calls to this function will write over this data area. If the return value must be stored, it should be duplicated.

GetFileName

PURPOSE:	Checks for an appropriate file name as the argument of a function call during run-time. A file name must be a string or a symbol.
ARGUMENTS:	Name of function being executed and the position of the argument in the argument list that contains the file name.
RETURNS:	File name.

GetLogicalName

PURPOSE: Checks for an appropriate logical name in an expression during run-time.

ARGUMENTS: The position of the argument in the argument list that contains the logical name and the logical name to be used if the default logical name, **t**, is found.

RETURNS: A string representing the logical name. If found, the value designated as the default logical name is returned. Returns NULL if the argument is unacceptable as a logical name.

GetNthWatchName

PURPOSE: Given an index, returns the name of the nth item in the **ListOfWatchItems** (which is useful for constructing a menu).

ARGUMENTS: An integer index.

RETURNS: The name of the nth watch item (a character string).

GetNthWatchValue

PURPOSE: Given an index, returns the value of the nth item in the **ListOfWatchItems**.

ARGUMENTS: An integer index.

RETURNS: The boolean value of the nth watch item.

GetWatchItem

PURPOSE: Returns the value of a watch item.

ARGUMENTS: The name of the watch item.

LongIntegerToString

PURPOSE: Converts a long integer to a string.

ARGUMENTS: A long integer.

RETURNS: A string.

OTHER NOTES: Return value is stored in a static data area. Subsequent calls to this function will write over this data area. If return value must be stored, it should be duplicated.

OpenErrorMessage

PURPOSE: Standard error message used when a function cannot open a file.

ARGUMENTS: The name of the function and the file name that could not be opened.

PeriodicCleanup

PURPOSE: Returns ephemeral garbage to the pool of free memory. When this function is called and it is determined that there is sufficient garbage to warrant a cleanup, then each of the functions in the **ListOfCleanupFunctions** will be called to perform garbage collection.

ARGUMENTS: Two boolean values. The first value indicates whether all evaluation depths should cleaned up. Normally, garbage collection only occurs for items that have an evaluation depth greater than the current evaluation depth. If this boolean argument is TRUE, however, the current evaluation depth will be temporarily set to a value which forces garbage collection for all depths. The second boolean value is used to determine whether heuristics are used in performing the garbage collection.

PrintAtom

PURPOSE: Prints a CLIPS primitive data type (which does not include multifield values).

ARGUMENTS: Logical name to which output is sent, the type of the primitive data type, and the value of the primitive data type.

PrintFloat

PURPOSE: Prints a number to a logical name using the CLIPS print format for numbers.

ARGUMENTS: A floating-point number and a logical name.

PrintInChunks

PURPOSE: Prints a string in chunks to accommodate systems which have a limit on the maximum size of a string which can be printed.

ARGUMENTS: String to be printed and logical name to which the string is to be printed.

PrintLongInteger

PURPOSE: Prints a long integer to a logical name using CLIPS print format for numbers.

ARGUMENTS: A long integer and a logical name.

PrintTally

PURPOSE: Standard message for functions which print a message indicating the number of items displayed (e.g. the **facts** command).

ARGUMENTS: The logical name to which output is to be sent, the number of items tallied, and singular and plural strings for the items tallied (e.g. "fact" and "facts").

OTHER NOTES: No message is printed if the number of items tallied is zero.

RemoveCleanupFunction

PURPOSE: Removes a function from the **ListOfCleanupFunctions**.

ARGUMENTS: Name associated with the cleanup item.

RemovePeriodicFunction

PURPOSE: Removes a function from the **ListOfPeriodicFunctions**.

ARGUMENTS: Name associated with the periodic item.

RestoreAllWatchItems

PURPOSE: Restores the old value of each watch items that was saved when the **SaveAllWatchItems** function was called.

SetAllWatchItems

PURPOSE: Sets all of the watch items to a particular value and remembers the old value of each watch item.

ARGUMENTS: The new boolean value to which all watch items are set.

SetWatchItem

PURPOSE: Sets the value of a watch item.

ARGUMENTS: The name of the watch item and the new boolean value. The string “all” may be used to set all watch items to a particular value.

SyntaxErrorMessage

PURPOSE: Standard error message used for syntax errors.

ARGUMENTS: The type of syntax error that occurred (e.g. “defrule”, “conditional elements”, etc.).

INTERNAL FUNCTIONS

AddCPFunction

PURPOSE: Driver routine for implementing the functions **AddCleanupFunction** and **AddPeriodicFunction**.

ARGUMENTS: A name to be associated with the function, a pointer to the function, the priority of the item, and a pointer to a pointer to the list to which the function is to be added.

RemoveCPFunction

PURPOSE: Driver routine for implementing the functions **RemoveCleanupFunction** and **RemovePeriodicFunction**.

ARGUMENTS: Name associated with the periodic item and a pointer to a pointer to the list from which the function is to be removed.

Fact Manager Module

The Fact Manager Module (factmngr.c) provides the necessary functionality to maintain, update, and browse facts. It also provides top-level implementation of the assert and retract commands. Functions for displaying and browsing facts are likewise provided. The other major functionality provided by this module is a hash table containing facts. Unlike OPS5, the CLIPS inferencing paradigm does not allow two occurrences of the same fact to be in the fact-list. A fact hash table provides a convenient method for determining if a fact is already in the fact-list.

GLOBAL VARIABLES

ChangeToFactList

PURPOSE:	Boolean flag. If TRUE, indicates that the **FactList** has been altered. Updates to TRUE whenever a fact is asserted or retracted.

INTERNAL VARIABLES

AssertRetractInProgress

PURPOSE:	Boolean flag. If TRUE, an assertion or retraction of a fact is currently occurring.

FactDuplication

PURPOSE:	Boolean flag. If TRUE, duplications of facts are allowed in the **FactList**.

FactHashTable

PURPOSE:	Stores all facts used by CLIPS.
C IMPLEMENTATION:	Implemented as an array. Each entry corresponds to a list of fact table entries. Collisions are resolved by adding the fact entry to the list of entries.
OTHER NOTES:	Information about facts is also stored in the **FactList**. Used primarily to quickly determine if a fact is already in the **FactList**.

FactList

PURPOSE:	Stores all facts used by CLIPS.
C IMPLEMENTATION:	Implemented as a list.

GarbageFacts

PURPOSE: Points to the list of facts that can be returned to free memory. These facts have typically been retracted but need to remain in memory because there are outstanding references to them (e.g. they are needed for the duration of a rule firing in case a variable access within the fact is made or other facts might refer to them).

LastFact

PURPOSE: Points to the last fact in the **FactList**.

ListOfSegments

PURPOSE: Contains the list of multifield values that have been dynamically created.

NextFactIndex

PURPOSE: Long Integer value to be used as the fact-index for the next asserted fact.

NumberOfFacts

PURPOSE: Contains an integer count of the number of facts in the **FactList**.

WatchFacts

PURPOSE: Boolean flag. If TRUE, indicates that fact assertions and retractions should be displayed.

GLOBAL FUNCTIONS

AddFact

PURPOSE: Coordinates assertion of a fact into the **FactList**.

ARGUMENTS: A fact.

AddHashedFact

PURPOSE: Adds a fact to the **FactHashTable**.

ARGUMENTS: A fact and the hash value of that fact.

OTHER NOTES: Does not check to determine if the fact is already in the **FactHashTable**.

AddToSegmentList

PURPOSE: Adds a fact to the **ListOfSegments**. Can be used in conjunction with the **CreateFact** function to perform the same functionality as **CreateMultifield**.

ARGUMENTS: A pointer to a fact.

AssertString

PURPOSE: Converts a string to a fact and then asserts it. Uses the functions **StringToFact** and **AddFact**.

ARGUMENTS: A string.

RETURNS: A pointer to the the newly asserted fact.

CreateFact

PURPOSE: Allocates the data structures necessary for a fact containing a specified number of fields.

ARGUMENTS: Number of fields in the fact.

RETURNS: A fact of the appropriate size.

CreateMultifield

PURPOSE: Allocates the data structures necessary for a multifield containing the specified number of fields and adds the newly created multifield to the **ListOfSegments**.

ARGUMENTS: Number of fields in the multifield.

RETURNS: A multifield of the appropriate size. Note that the structures used for the multifields are identical to the fact structures.

DecrementFactCount

PURPOSE: Decrements the count value for a fact.

ARGUMENTS: A pointer to a fact.

DuplicateSegment

PURPOSE: Copies the contents of a multifield value to another multifield value.

ARGUMENTS: A pointer to the source multifield and a pointer to the destination multifield.

FactCompare

PURPOSE: Determines if two facts are identical.

ARGUMENTS: Two facts.

RETURNS: Boolean value. True if facts are identical; otherwise false.

FactDeinstall

PURPOSE: Called when a fact is garbage collected (not when it is retracted). Decrements the **NumberOfFacts** and calls **SegmentDeinstall**.

ARGUMENTS: A fact.

FactExists

PURPOSE: Determines if a fact exists in the **FactHashTable**.

ARGUMENTS: A fact and the hash value of that fact.

RETURNS: A pointer to the fact in the **FactHashTable** if it already exists, otherwise NULL.

FactInstall

PURPOSE: Called when a fact is newly created. Increments the **NumberOfFacts** and calls **SegmentInstall**.

ARGUMENTS: A fact.

FindIndexedFact

PURPOSE: Finds a fact by fact-index.

ARGUMENTS: The fact-index of the fact being sought.

RETURNS: A pointer to the fact with the specified fact-index or NULL if a fact with the specified fact-index does not exist.

FlushSegments

PURPOSE: Removes any multifield values from the **ListOfSegments** that have a zero count and an evaluation depth greater than the current evaluation depth.

ARGUMENTS: A fact.

GetFactDuplication

PURPOSE: Returns the current value of the **FactDuplication** flag.

RETURNS: A boolean value.

GetFactIndex

PURPOSE: Returns fact-index associated with a fact.

ARGUMENTS: A pointer to a fact.

RETURNS: The fact-index of the fact (an integer value).

GetFactListChanged

PURPOSE: Returns the value of **ChangeToFactList**.

GetFactPPForm

PURPOSE: Returns the pretty print representation of a fact.

ARGUMENTS: A pointer to a fact, a pointer to a buffer in which to store the pretty print representation, and the size of the buffer.

RETURNS: No return value. The buffer passed as an argument is used to store the pretty print representation.

GetNextFact

PURPOSE: Returns a pointer to the “next” fact in the **FactList**.

ARGUMENTS: A pointer to a fact in the **FactList**.

RETURNS: Next fact after the fact passed as an argument. If a NULL pointer is used, the first fact in the **FactList** is returned.

GetNumberOfFacts

PURPOSE: Returns the value of the **NumberOfFacts**.

RETURNS: An integer value.

HashFact

PURPOSE: Computes a hash value for a fact.

ARGUMENTS: A fact .

RETURNS: An integer hash value less than the array size of the **FactHashTable**.

IncrementFactCount

PURPOSE: Increments the count value for a fact.

ARGUMENTS: A pointer to a fact.

InitializeFacts

PURPOSE: Performs all necessary initialization for facts (initializing the **FactHashTable**, adding reset and clear functions, adding the facts watch item, and calling **DefineFunction** to add fact related commands).

ListFacts

PURPOSE: Displays all of the fact in the **FactList** to the logical name **wdisplay**.

PrintFact

PURPOSE: Displays the fields of a fact enclosed within parentheses.

ARGUMENTS: A fact and logical name to which output is to be sent.

PrintFactWithIdentifier

PURPOSE: Displays the fact-index of a fact followed by the fact. Uses the function **PrintFact**.

ARGUMENTS: A fact and logical name to which output is to be sent.

RemoveAllFacts

PURPOSE: Removes all facts from the **FactList**.

RemoveHashedFact

PURPOSE: Removes a fact from the **FactHashTable**.

ARGUMENTS: A fact.

RemoveOldFacts

PURPOSE: Returns facts in the list of **GarbageFacts** to the memory manager. Facts are only returned if there are no outstanding references to them (e.g. they are not being used by the currently executing rule or other facts do not refer to them) and the evaluation depth at which they were created is greater than the current evaluation depth.

RetractFact

PURPOSE: Coordinates retraction of a fact from the **FactList**.

ARGUMENTS: A fact.

ReturnElements

PURPOSE: Returns the data structures associated either with a fact or a multifield to the memory manager.

ARGUMENTS: A fact or a multifield (both use the same structures).

OTHER NOTES: Fact or multifield should be deinstalled using **FactDeinstall** or **SegmentDeinstall** respectively before removal.

SegmentDeinstall

PURPOSE: Decrements count values for the constant values (symbols, strings, integers, floats, etc.) found in a multifield value. Decrements the number of references to the multifield by one.

ARGUMENTS: A multifield (which is stored using fact data structures).

SegmentInstall

PURPOSE: Increments count values for the constant values (symbols, strings, integers, floats, etc.) found in a multifield value. Increments the number of references to the multifield by one.

ARGUMENTS: A multifield (which is stored using fact data structures).

SetFactDuplication

PURPOSE: Sets the current value of the **FactDuplication** flag.

ARGUMENTS: A boolean value (the new value of the flag).

RETURNS: A boolean value (the old value of the flag).

SetFactID

PURPOSE: Sets the value of **NextFactID**.

ARGUMENTS: An integer.

SetFactListChanged

PURPOSE: Sets value of **ChangeToFactList**.

ARGUMENTS: Boolean value.

StringToFact

PURPOSE: Parses a string and converts it to a fact. The string should be a series of constants and should not contain enclosing parentheses.

ARGUMENTS: A string.

RETURNS: A pointer to the newly created fact.

StringToMultifield

PURPOSE: Parses a string and converts it to a multifield value. The string should be a series of constants and should not contain enclosing parentheses.

ARGUMENTS: A string.

RETURNS: A pointer to the newly created multifield value.

INTERNAL FUNCTIONS

InitializeFactHashTable

PURPOSE: Initializes the **FactHashTable**.

ResetFacts

PURPOSE: Resets the facts whenever a **reset** command is performed. This functions is also used for the **clear** command.

Fact Commands Module

The Fact Commands Module (factcom.c) provides a number of commands for manipulating and examining facts. The commands provided are **assert**, **retract**, **save-facts**, **load-facts**, **facts**, **fact-index**, **dependencies**, **dependents**, **set-fact-duplication**, and **get-fact-duplication**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

InitFactCommands

PURPOSE:	Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Fact Commands

PURPOSE:	A series of commands which define the fact commands listed above. See the *Basic Programming Guide* for more detail on individual functions.
OTHER NOTES:	Some functionality for these commands is provided in other modules.

Deffacts Manager Module

The Deffacts Manager Module (deffacts.c) manages all aspects of deffacts construct including parsing, execution, and removal. For a description of the deffacts construct, see the *Basic Programming Guide*. The deffacts construct capability can be removed by using the appropriate compile flag in the setup header file.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DeffactsArray

PURPOSE: A pointer to an array of deffacts loaded using the **bload** command.

DeletionsLegal

PURPOSE: A boolean flag indicating whether deffacts can be deleted (deffacts cannot be deleted while they are being reset).

LastDeffacts

PURPOSE: A pointer to the last deffacts in the **ListOfDeffacts**.

ListOfDeffacts

PURPOSE: A linked list of all the currently defined deffacts.

NumberOfDeffacts

PURPOSE: An integer count of the number of facts in the **ListOfDeffacts**.

GLOBAL FUNCTIONS

CreateInitialFactDeffacts

PURPOSE: Creates the initial-fact deffacts.

DeleteDeffacts

PURPOSE: Deletes a deffacts from the **ListOfDeffacts**.

ARGUMENTS: A pointer to the deffacts to be deleted.

RETURNS: Boolean value. TRUE if the deffacts was found and deleted, otherwise FALSE.

DeleteNamedDeffacts

PURPOSE: Deletes a named deffacts from the **ListOfDeffacts**.

ARGUMENTS: The name of the deffacts to be deleted.

RETURNS: Boolean value. TRUE if the deffacts was found and deleted, otherwise FALSE.

FindDeffacts

PURPOSE: Finds a named deffacts in the **ListOfDeffacts**.

ARGUMENTS: The name of the deffacts to be found.

RETURNS: A pointer to the deffacts if found, otherwise NULL.

GetDeffactsName

PURPOSE: Returns the name of a deffacts.

ARGUMENTS: A pointer to a deffacts.

RETURNS: String name of the deffacts.

GetDeffactsPPForm

PURPOSE: Returns the pretty print representation of a deffacts.

ARGUMENTS: A pointer to a deffacts.

RETURNS: The string pretty print representation of the deffacts.

GetNextDeffacts

PURPOSE: Allows access to the **ListOfDeffacts**.

ARGUMENTS: A pointer to a deffacts in the **ListOfDeffacts**.

RETURNS: If passed a NULL pointer, returns the first deffacts in the **ListOfDeffacts**. Otherwise, returns the next deffacts following the deffacts passed as an argument.

InitializeDeffacts

PURPOSE: Initializes the deffacts construct. Creates the initial-fact deffacts, adds **reset**, **clear**, **save**, **bload**, **bsave**, and **constructs-to-c** functions for deffacts, and defines the functions **undeffacts**, **list-deffacts**, and **ppdeffacts**.

IsDeffactsDeletable

PURPOSE: Indicates whether a deffacts can be deleted.

ARGUMENTS: A pointer to a deffacts.

RETURNS: Boolean value. TRUE if the deffacts can be deleted, otherwise FALSE.

ListDeffacts

PURPOSE: Displays the **ListOfDeffacts**.

ListDeffactsCommand

PURPOSE: Implements the **list-deffacts** command. Uses the driver function **ListDeffacts**.

PPDeffacts

PURPOSE: Pretty prints a deffacts.

ARGUMENTS: Name of deffacts to be pretty printed and logical name of the output source.

PpdeffactsCommand

PURPOSE: Implements the **ppdeffacts** command. Uses the driver function **PPDeffacts**.

RemoveAllDeffacts

PURPOSE: Removes all deffacts from the **ListOfDeffacts**.

SetListOfDeffacts

PURPOSE: Sets the **ListOfDeffacts** to the specified value. Normally used when initializing a run-time module or when bloading a binary file to install the **ListOfDeffacts**.

ARGUMENTS: A pointer to a linked list of deffacts.

UndeffactsCommand

PURPOSE: Implements the **undeffacts** command.

INTERNAL FUNCTIONS

ClearDeffacts

PURPOSE: Deffacts construct clear function. Removes all deffacts and creates the initial-fact deffacts.

Deffacts Bload/Bsave Functions

PURPOSE: A set of functions used by the **bload** and **bsave** commands to process the deffacts construct. These functions are made available to the **bload** and **bsave** commands by calling the function **AddBinaryItem**.

Deffacts Constructs-To-C Functions

PURPOSE: A set of functions used by the **constructs-to-c** command to process the deffacts construct. These functions are made available to the **constructs-to-c** command by calling the function **AddCodeGeneratorItem**.

ParseDeffacts

PURPOSE: Coordinates all actions necessary for the construction of a deffacts into the current environment. Called to parse a deffacts construct.

ARGUMENTS: Logical name from which deffacts input is read.

OTHER NOTES: Makes use of parsing functions from other modules such as the **GetConstructNameAndComment** function and the **BuildRHSAssert** function.

ResetDeffacts

PURPOSE: Deffacts construct reset function. Asserts all facts associated with deffacts into the **FactList**.

SaveDeffacts

PURPOSE: Deffacts construct save function. Pretty prints all deffacts to the given logical name.

ARGUMENTS: A logical name to which output is sent.

Defglobal Manager Module

The Defglobal Manager Module (defglobl.c) manages all aspects of defglobal construct including parsing, execution, and removal. For a description of the defglobal construct, see the *Basic Programming Guide*. The defglobal construct capability can be removed by using the appropriate compile flag in the setup header file.

GLOBAL VARIABLES

ChangeToGlobals

PURPOSE: Boolean flag. If TRUE, indicates that a new global variable has been added or an existing global variable has been altered.

INTERNAL VARIABLES

BDefglobalArray

PURPOSE: A pointer to an array of defglobal data structures loaded using the **bload** command. This variable is the bload equivalent of the **DefglobalArray** variable.

BDefglobalPointersArray

PURPOSE: A pointer to an array containing pointers to the defglobal data structures loaded using the **bload** command. This variable is the bload equivalent of the **DefglobalPointersArray** variable.

DefglobalArray

PURPOSE: A pointer to an array containing the defglobal data structures. Global variables in stored in the array so that they can be referred to by integer indexes for quick reference.

ListOfDefglobals

PURPOSE: A linked list of structures containing pointers to all the currently defined defglobals.

NumberOfDefglobals

PURPOSE: An integer count of the number of global variables in the **ListOfDefglobals** and the **DefglobalArray**.

ResetGlobals

PURPOSE: Boolean flag. If TRUE, indicates that globals will be reset to their original values when a **reset** command is performed. By being reset, the original expression associated with the global variable is reevaluated and then assigned to the global variable. If this flag is FALSE, then global variable values are not changed during a reset.

SizeOfDefglobalArray

PURPOSE: An integer count of the maximum number of global variables which can be stored in the **DefglobalArray**.

WatchGlobals

PURPOSE: Boolean flag. If TRUE, indicates that changes to globals should be displayed.

GLOBAL FUNCTIONS

ClearDefglobals

PURPOSE: Defglobals construct clear function. Removes all defglobals.

FindDefglobal

PURPOSE: Finds a named defglobal in the **DefglobalArray**.

ARGUMENTS: The name of defglobal to be found.

RETURNS: A pointer to the defglobal if found, otherwise NULL.

GetActualDefglobal

PURPOSE: Given a pointer returned by **FindDefglobal** or **GetNextDefglobal**, returns a pointer to the data structure where the global variable information is actually stored.

ARGUMENTS: A pointer to a **ListOfDefglobals** data structure which contains a pointer to a defglobal data structure.

RETURNS: A pointer to a defglobal data structure.

GetDefglobalValue

PURPOSE: Gets the value of a global variable.

ARGUMENTS: The name of the global variable and a pointer to a data structure in which the value of the global variable is to be stored.

RETURNS: Boolean value. TRUE if the global variable was found, otherwise FALSE.

GetDefglobalName

PURPOSE: Returns the name of a defglobal.

ARGUMENTS: A pointer to a defglobal.

RETURNS: String name of the defglobal.

GetDefglobalPPForm

PURPOSE: Returns the pretty print representation of a defglobal and its original expression value when it was defined.

ARGUMENTS: A pointer to a buffer in which to store the pretty print representation, the size of the buffer, and a pointer to a defglobal.

RETURNS: No return value. The buffer passed as an argument is used to store the pretty print representation.

GetDefglobalValueForm

PURPOSE: Returns the pretty print representation of a defglobal and its current value.

ARGUMENTS: A pointer to a buffer in which to store the pretty print representation, the size of the buffer, and a pointer to a defglobal.

RETURNS: No return value. The buffer passed as an argument is used to store the pretty print representation.

GetGlobalsChanged

PURPOSE: Returns the value of **ChangeToGlobals**.

GetIndexedDefglobal

PURPOSE: Given an integer index *n*, returns a pointer to the *n*th defglobal data structure in the **DefglobalsArray**.

ARGUMENTS: An integer index.

RETURNS:	A pointer to a defglobal data structure.

GetNextDefglobal

PURPOSE:	Allows access to the **ListOfDefglobals**.
ARGUMENTS:	A pointer to a defglobal in the **ListOfDefglobals**.
RETURNS:	If passed a NULL pointer, returns the first defglobal in the **ListOfDefglobals**. Otherwise, returns the next defglobal following the defglobal passed as an argument.

GetNumberOfDefglobals

PURPOSE:	Returns the value of the **NumberOfDefglobals**.
RETURNS:	An integer value.

GetResetGlobals

PURPOSE:	Returns the current value of the **ResetGlobals** flag.
RETURNS:	A boolean value.

GetResetGlobalsCommand

PURPOSE:	Implements the **get-reset-globals** command.

GlobalRtnUnknown

PURPOSE:	Access function placed within CLIPS expressions to retrieve the values of global variables.
ARGUMENTS:	A pointer to a data structure in which to return a value. The integer index which indicates which global value to retrieve is stored in the argument list of this function's expression.
RETURNS:	No value. The value of the defglobal is stored in the data structure passed as an argument.

InitializeDefglobal

PURPOSE:	Initializes the defglobal construct. Creates the globals watch item, adds **reset**, **clear**, **save**, **bload**, **bsave**, and **constructs-to-c** functions for defglobals, and defines the functions **set-reset-globals** and **get-reset-globals**.

ListDefglobals

PURPOSE: Displays the **ListOfDefglobals** allow with their current values.

ListDefglobalsCommand

PURPOSE: Implements the **list-defglobals** command.

PpdefglobalCommand

PURPOSE: Implements the **ppdefglobal** command.

QFindDefglobal

PURPOSE: Finds a named defglobal in the **DefglobalArray**.

ARGUMENTS: The name of defglobal to be found. This argument is specified as a pointer to a **SymbolTable** entry rather than a character string.

RETURNS: A pointer to the defglobal if found, otherwise NULL.

QGetDefglobalValue

PURPOSE: Gets the value of a global variable.

ARGUMENTS: The integer index of the global variable and a pointer to a data structure in which the value of the global variable is to be stored.

OTHER NOTES: This function is quicker than **GetDefglobalValue** since the position of the global variable in the **DefglobalArray** does not have to be determined.

QSetDefglobalValue

PURPOSE: Sets the value of a global variable.

ARGUMENTS: The integer index of the global variable and a pointer to a data structure in which the new value of the global variable is stored.

RETURNS: Boolean value. TRUE if the global variable was found and its value changed, otherwise FALSE.

OTHER NOTES: This function is quicker than **SetDefglobalValue** since the position of the global variable in the **DefglobalArray** does not have to be determined.

ReplaceGlobalVariable

PURPOSE: Replaces a reference to a global variable within an expression with a function call to **GlobalRtnUnknown** that refers to the variable by an index for quick reference.

ARGUMENTS: A pointer to an expression.

RETURNS: Boolean value. TRUE if the global variable reference was replace, otherwise FALSE (the global could not be found).

ResetDefglobals

PURPOSE: Defglobals construct reset function. If the **ResetGlobals** flag is TRUE, then all global variables are reset to their original values.

SetDefglobalValue

PURPOSE: Sets the value of a global variable.

ARGUMENTS: The name of the global variable and a pointer to a data structure in which the new value of the global variable is stored.

RETURNS: Boolean value. TRUE if the global variable was found and its value changed, otherwise FALSE.

SetGlobalsChanged

PURPOSE: Sets value of **ChangeToGlobals**.

ARGUMENTS: Boolean value.

SetListOfDefglobals

PURPOSE: Sets the **ListOfDefglobals**, **DefglobalArray**, and **NumberOfDefglobals**, and **SizeOfDefglobalArray** to the specified values. Normally used when initializing a run-time module or when bloading a binary file.

ARGUMENTS: A pointer to a linked list of defglobals, an array in which the defglobal values are stored, and the number of defglobals contained in the array (which is also the size of the array).

SetResetGlobals

PURPOSE: Sets the current value of the **ResetGlobals** flag.

ARGUMENTS: A boolean value (the new value of the flag).

RETURNS: A boolean value (the old value of the flag).

SetResetGlobalsCommand

PURPOSE: Implements the **set-reset-globals** command.

INTERNAL FUNCTIONS

AddDefglobal

PURPOSE: Adds a global variable to the **ListOfDefglobals** and the **DefglobalArray**. If the global variable already exists, then it is replaced.

ARGUMENTS: The name of the global variable, a pointer to a data structure in which the global's initial value is stored, and a pointer to the expression to be evaluated to determine the global's value whenever it is reset.

OTHER NOTES: The **DefglobalArray** is dynamically expanded if the **SizeOfglobalArray** is not large enough to contain the new global variable.

Defglobal Bload/Bsave Functions

PURPOSE: A set of functions used by the **bload** and **bsave** commands to process the defglobal construct. These functions are made available to the **bload** and **bsave** commands by calling the function **AddBinaryItem**.

Defglobal Constructs-To-C Functions

PURPOSE: A set of functions used by the **constructs-to-c** command to process the defglobal construct. These functions are made available to the **constructs-to-c** command by calling the function **AddCodeGeneratorItem**.

GetVariableDefinition

PURPOSE: Parses a single variable definition within a defglobal construct. If no errors occur while defining the variable, the function **AddDefglobal** is called to add the new global variable to the **ListOfDefglobals**.

ARGUMENTS: Logical name from which defglobal input is read and a pointer to an integer error flag.

RETURNS: Boolean value. FALSE if an error occurred while parsing, otherwise TRUE. The value of the error flag passed as an argument is also set by this function.

OTHER NOTES: Uses the function **ParseAtomOrExpression** to parse the expression assigned to the global variable. The function **EvaluationExpression** is then called to determine the initial value of the variable.

ParseDefglobal

PURPOSE: Coordinates all actions necessary for the construction of a defglobal into the current environment. Called to parse a defglobal construct.

ARGUMENTS: Logical name from which defglobal input is read.

RETURNS: Boolean value. TRUE if an error occurred while parsing, otherwise FALSE.

OTHER NOTES: Uses the function **GetVariableDefinition** to perform the majority of parsing.

SaveDefglobals

PURPOSE: Defglobal construct save function. Pretty prints all defglobals to the given logical name.

ARGUMENTS: A logical name to send output.

Defrule Parser Module

The Defrule Parser Module (ruleprsr.c) coordinates the parsing of the LHS of the rule (as well as providing functions for parsing the RHS of a rule). LHS conditional elements are represented internally using the following format:

```
1st Conditional Element   -->   CE information
         |
         |
2nd Conditional Element   -->   CE information
         |
         |
3rd Conditional Element   -->   CE information

         •
         •
         •

nth Conditional Element   -->   CE information
```

If the conditional element is a **test** CE, the CE information will be an expression stored using the standard format for an expression. The CE information for a connected conditional element (an **and** CE, **or** CE, or **logical** CE) follows the format shown above. The information for a **pattern** CE or a **not** CE is used to represent the fields of the pattern.

As an examples, the conditional elements for the following rule

```
(defrule example
  (pattern 1)
  (or (pattern 2a)
      (pattern 2b))
  (not (pattern 3))
  (pattern 4)
  =>)
```

would be stored as

```
pattern CE   -->   pattern 1 information
     |
     |
  or CE      -->   pattern CE   -->   pattern 2a information
     |                   |
     |                   |
     |             pattern CE   -->   pattern 2b information
     |
     |
  not CE     -->   pattern 3 information
     |
     |
pattern CE   -->   pattern 4 information
```

The CE information for **pattern** CEs and **not** CEs is stored using the following format:

```
1st field   -->   2nd field   -->   3rd field   ...  nth field
    |                 |                 |                |
    |                 |                 |                |
field info        field info        field info       field info
```

Information for each field is stored in the following format:

```
first variable (if any)
          |
          |
1st | connective constraint   -->   & connective constraints
          |
          |
2nd | connective constraint   -->   & connective constraints

          •
          •
          •

nth | connective constraint   -->   & connective constraints
```

The first-binding occurrence of a variable is stored first in the structure (if it exists). A first-binding occurrence of a variable for a field in a pattern is a variable by itself or a variable followed by an **&** connective constraint. The variable cannot be negated. First occurrences of the variable ?x in a field of a pattern would include

```
?x
?x&blue|green
```

but not

```
~?x
?x|?y
red&?x
```

The structure to contain the first binding variable is also used to indicate whether the field should match a single field value or a multifield value. Fields without a binding variable are considered to match against a single field value.

The subsequent bottom links connected to the binding variable structure contain information about the list of **|** connective constraints found within the field. Each **|** connective constraint of a field can be accessed through the bottom link of the structure. The first structure to the immediate right of each **|** connective constraint represents the first constraint associated with the **|** connective constraint. Structures to the right of this first constraint represent other constraints associated with the **|** connective constraint through the use of the **&** connective constraint. Individual constraints can be literal constraints, predicate constraints, return value constraints, and/or variable constraints. Any of these constraints may be negated using the **~** connective constraint. When grouping constraints, the **|** connective constraint in a field constraint is given a lower precedence than the **&** connective constraint.

For example, the following field found in a pattern

```
?x&:numberp(?x)&=(+ ?y 3)|:wordp(?x)&~red&~green
```

would be represented as

```
single field variable x
    |
    |
numberp(?x) --> =(+ ?y 3)
    |
    |
wordp(?x)   --> ~red  --> ~green
```

GLOBAL VARIABLES

GlobalSalience

PURPOSE: An integer used to store the evaluated value of the salience when the rule is defined (i.e. the evaluated value of the variable **SalienceExpression** when the rule is defined).

SalienceExpression

PURPOSE: A pointer to the expression used in the salience declaration of a rule (which may either be a constant integer, global variable, or a function call).

INTERNAL VARIABLES

LHSError

PURPOSE: A global boolean value used to indicate whether an error has occurred in one of the rule parsing routines.

GLOBAL FUNCTIONS

ParseRuleLHS

PURPOSE: Coordinates all the actions necessary for parsing the LHS of a rule including the reordering of pattern conditional elements to conform with the CLIPS Rete topology.

ARGUMENTS: Logical name from which rule input is read and a pointer to a token structure in which scanned tokens are placed.

RETURNS: A pointer to a linked structure containing the intermediate LHS representation of a rule. If an error has occurred during parsing, a null pointer is returned.

ParseRuleRHS

PURPOSE: Coordinates all the actions necessary for parsing the RHS of a rule.

ARGUMENTS: Logical name from which rule input is read.

RETURNS: An expression structure representing the RHS of a rule.

RestrictionParse

PURPOSE: Parses a single field within a pattern. This field may either be a single field wildcard, a multifield wildcard, a single field variable, a multifield variable, or a series of connected constraints.

ARGUMENTS: Logical name from which input is read and a pointer to a token structure.

RETURNS: Intermediate LHS representation of the field.

INTERNAL FUNCTIONS

AssignmentParse

PURPOSE: Finishes the parsing of **pattern** conditional elements that have been bound to a variable.

ARGUMENTS: Logical name from which input is read, and name of the variable (or the fact address) to which the **pattern** CE is bound.

RETURNS: Intermediate LHS representation of the assigned pattern conditional element.

ConjunctiveRestrictionParse

PURPOSE: Parses a single constraint field in a pattern that is not a single field wildcard, multifield wildcard, or multifield variable. The field may consist of a number of subfields tied together using the **&** connective constraint and/or the **|** connective constraint.

ARGUMENTS: Logical name from which input is read, and a pointer to a token structure.

RETURNS: Intermediate LHS representation of the field.

ConnectedPatternParse

PURPOSE: Handles parsing of the connected conditional elements (i.e. those conditional elements that may contain one or more other conditional elements). The connected conditional elements include the **and** CE, the **or** CE, and the **logical** CE.

ARGUMENTS: Logical name from which input is read, and a pointer to a token structure.

RETURNS: Intermediate LHS representation of the connected conditional element.

CreateInitialPattern

PURPOSE: Creates an LHS representation of the pattern (initial-fact) for rules which do not contain an LHS.

RETURNS: Intermediate LHS representation of the pattern (initial-fact).

DeclarationParse

PURPOSE: Parses a defrule declaration. Only salience declarations are currently allowed.

ARGUMENTS: Logical name from which input is read.

RETURNS: Nothing. Sets value of the variables **GlobalSalience** and **SalienceExpression**.

GroupPatterns

PURPOSE: Groups a series of connected conditional elements together.

ARGUMENTS: Logical name from which input is read, type of token which terminates the CE grouping, and string representation of the terminating token.

RETURNS: Intermediate LHS representation of the grouped patterns.

LHSPattern

PURPOSE: Parses a single conditional element found on the LHS of a rule. Conditional element types include **pattern** CEs (which may be assigned to a variable), **test** CEs, **not** CEs, **logical** CEs, **and** CEs, and **or** CEs.

ARGUMENTS: Logical name from which input is read, and the type of token which terminates the conditional element grouping in which the conditional element is found (e.g. a **pattern** CE parsed within an **and** CE is terminated by a parenthesis while a **pattern** CE not enclosed by another CE is terminated by the **=>** symbol.

RETURNS: Intermediate LHS representation of the LHS conditional element.

LiteralRestrictionParse

PURPOSE: Parses a subfield of a field. The subfield may be a literal constraint, a predicate constraint, a return value constraint, or a variable constraint. The constraints may also be negated using the **~** connective constraint.

ARGUMENTS: Logical name from which input is read, and a pointer to a token structure.

RETURNS: Intermediate LHS representation of the subfield.

NotPatternParse

PURPOSE: Handles parsing of **not** conditional elements.

ARGUMENTS: Logical name from which input is read.

RETURNS: Intermediate LHS representation of the **not** conditional element.

RuleBodyParse

PURPOSE: Parses the LHS of a rule, but does not reorder any of the LHS patterns to conform with the CLIPS Rete Topology.

ARGUMENTS: Logical name from which rule input is read and a pointer to a token structure in which scanned tokens are placed.

RETURNS: A pointer to a linked structure containing the intermediate LHS representation of a rule. If an error has occurred during parsing, a null pointer is returned.

SequenceRestrictionParse

PURPOSE: Parses a sequence of constraint fields found within a pattern. This function recognizes deftemplate patterns and will call the appropriate routines to parse these types of patterns.

ARGUMENTS: Logical name from which input is read, and a pointer to a token structure.

RETURNS: Intermediate LHS representation of the sequence of fields.

SimplePatternParse

PURPOSE: Parses a simple pattern (an opening parenthesis followed by one or more fields followed by a closing parenthesis).

ARGUMENTS: Logical name from which input is read, and a pointer to a token structure.

RETURNS: Intermediate LHS representation of the simple pattern conditional element.

TagLHSLogicalNodes

PURPOSE: Marks all **and** and **or** conditional elements contained within a logical conditional element as having the properties associated with a **logical** CE.

ARGUMENTS: The LHS representation of a **logical** conditional element.

TestPattern

PURPOSE: Handles parsing of **test** conditional elements.

ARGUMENTS: Logical name from which input is read.

RETURNS: Intermediate LHS representation of the **test** conditional element.

Reorder Module

Basic Rete topology only allows a pattern conditional element to stand by itself or to be modified with the **not** conditional element. In addition, the LHS is enclosed within an implied **and** conditional element. Combinations of **and** conditional elements and **or** conditional elements are not allowed using basic Rete topology. CLIPS allows these conditional elements to be used in combination by generating multiple rules which conform to basic Rete topology from single instances of rules which do not conform to basic Rete topology. The Reorder Module (reorder.c) reorders a single LHS which may or may not conform to basic Rete topology into one or more LHSs which do conform to basic Rete topology. Reordered LHSs have a single top-level **or** pattern conditional element (with each argument of the **or** conditional element representing a separate rule which must be generated) with multiple **and** conditional elements containing one or more pattern conditional elements or **not** conditional elements but no other types of conditional elements. For the purposes of reordering, the **logical** conditional element behaves identically to the **and** conditional element.

Reordering involves two major steps: transformation and reduction. Transformation involves changing a conditional element from one form to another equivalent form. The transformation performed when reordering patterns involves replacing **and**/**or** conditional elements with equivalent **or**/**and** conditional elements. For example,

```
(and (or (a) (b))
     (or (c) (d)))
```

can be replaced with

```
(or (and (a)
         (or (c) (d)))
    (and (b)
         (or (c) (d))))
```

This transformation makes use of the observation that the conditional elements contained within (or (a) (b)) can be extracted and combined individually with an **and** conditional element with copies of the (or (c) (d)) conditional element. The resulting set of conditional elements can then be placed together using an **or** conditional element. This transformation stated more generally is

```
(and (<CE-a-1> ...
      (or <CE-o-1> ... <CE-o-n>) ...
      <CE-a-n>)
```

can be replaced with

```
(or (and <CE-a-1> ... <CE-o-1> ... (pattern an)) ...
    (and <CE-a-1> ... <CE-o-n> ... (pattern an)))
```

Reduction involves simplifying conditional elements. The reduction used when reordering conditional elements involves removing redundant information. For example, a CE such as (and (and <CE-1> <CE-2>) can be simplified to (and <CE-1>

<CE-2>). This type of reduction will be referred to as adjacency reduction. As another example,

```
(or (and (and (a) (b)) (and (c) (d))))
```

can be converted to

```
(or (and (a) (b)) (and (c) (d)))
```

Note that, for this type of simplification, the **and**/**or** conditional elements must be adjacent. For example, the following CE would not be simplified by this type of reduction:

```
(or (and (or (a))))
```

As a point of interest, advanced Rete topology allows the **and** conditional element to be incorporated directly into the Rete Join Network. This feature, called joins from the right, is discussed in further detail in an article by IBM. Currently, joins from the right are not implemented in CLIPS but, if added, would require changes to the manner in which the reordering of conditional elements is accomplished.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

CopyNodes

PURPOSE: Copies a set of patterns.

ARGUMENTS: Patterns to be copied.

RETURNS: A copy of the patterns.

GetNode

PURPOSE: Creates an empty node structure used for building patterns.

RETURNS: A pointer to an empty node structure initialized with default values.

ReorderPatterns

PURPOSE: Reorders a group of patterns to accommodate CLIPS Rete topology.

ARGUMENTS: A group of patterns.

RETURNS: A modified group of patterns that contains a single top-level **or** conditional element followed by one or more **and** conditional elements.

ReturnNodes

PURPOSE: Returns a set of patterns to the free pool of memory.

ARGUMENTS: Patterns to be returned.

INTERNAL FUNCTIONS

AdjacentReduction

PURPOSE: Performs adjacency reduction on a group of patterns.

ARGUMENTS: A group of patterns.

RETURNS: A modified group of patterns.

ReverseOR

PURPOSE: Performs a transformation on logical **and**/**or** pattern operators to change them to logical **or**/**and** pattern operators.

ARGUMENTS: A group of patterns.

RETURNS: A modified group of patterns.

Variable Manager Module

The Variable Manager Module (variable.c) provides a set of access functions which are used to retrieve the results of the analysis of the LHS of a rule. Some of the functions provided can be used to determine the location of a variable on the LHS of a rule and to obtain the expressions generated for the pattern and join networks. These access functions are utilized by the Build Module when it adds a rule to the rule network.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

AnalysisExpressions

PURPOSE: Maintains a list for each pattern of the expressions to be evaluated in the pattern and join networks.

CurrentPatternInfo

PURPOSE: Maintains a list of information about patterns and the variables contained within them.

GLOBAL FUNCTIONS

CountJoins

PURPOSE: Determines number of joins needed for the LHS of a rule

RETURNS: An integer representing the number of joins needed for the LHS of a rule (in essence, the number of patterns on the LHS of the rule).

OTHER NOTES: Accesses **AnalysisExpressions** to derive the information.

OTHER NOTES: Accesses **AnalysisExpressions** to derive the information.

CountPatternFields

PURPOSE: Determines the number of fields in a pattern.

ARGUMENTS: Pattern number.

RETURNS: An integer representing number of fields in the pattern.

OTHER NOTES: Accesses the variable **AnalysisExpressions** to derive the information.

ExpressionComplexity

PURPOSE: Determines the complexity of an expression for use with the lex, mea, simplicity, and complexity conflict resolution strategies.

ARGUMENTS: An pointer to an expression.

RETURNS: An integer value representing the complexity of the expression. Each function call contained within an expression adds one to the complexity of the expression (with an initial complexity of zero). Calls to the **and**, **or**, and **not** functions do not increase the complexity of an expression, but function calls made within these functions do.

FindVariable

PURPOSE: Searches for the location of the first binding occurrence of a variable on the LHS of a rule available to a specific pattern or expression. Such a variable must occur before the pattern and field in which the reference is made (with the exception of variables in deftemplate patterns for which forward referencing is allowed since the position of the fields in the pattern will be rearranged).

ARGUMENTS: Name of the variable being sought, first pattern in which to begin looking for the variable, current pattern and field with which the variable is associated (with a field value of -1 indicating that forward references are allowed), and a value indicating whether the variable is “inside” or “outside” the pattern (i.e. a variable inside a **not** conditional element can refer to other variables within that CE, but variables outside of a **not** CE cannot refer to variables within a **not** CE).

RETURNS: A pointer to a variable information structure if the variable is found; otherwise NULL.

OTHER NOTES: Starting pattern and inside/outside values are very useful. By setting the starting pattern to the current pattern, it can be determined whether a variable reference within a pattern can be compared to another variable within the same pattern as opposed to using a variable in a previous pattern. This information is useful when determining which expressions can be placed in the pattern network. The inside/ outside value allows strict scoping of variables within **not** CEs. For example, a **test** CE following a **not** CE is outside of the **not** CE and may not reference any of the variables within the **not** CE, while an expression associated with a predicate constraint used within the **not** CE is inside the **not** CE and may reference variables used within the **not** CE. If the field index is set to -1, forward references of variables within a pattern will be allowed. This is allowed for template patterns since the variables may be referenced in the proper order within the original pattern but might be rearranged in an improper order when the actual pattern to be used is generated.

FlushAnalysisExpressions

PURPOSE: Returns structures associated with the global variable **AnalysisExpressions** and sets the variable to NULL.

FlushVariableAnalysis

PURPOSE: Purges all current information about patterns and variables.

GetFactAddressPosition

PURPOSE: Returns the pattern number (ranging from one to the number of patterns) corresponding to a fact address variable.

ARGUMENTS: Name of the fact address variable.

RETURNS: Pattern position to which the fact address variable is bound (or zero if not found).

GetJoinLogic

PURPOSE: Returns RHS join logic for a particular pattern.

ARGUMENTS: Pattern number.

RETURNS: A character. The character '-' is returned if the connected pattern is within a **not** CE and '+' is returned if the connected pattern is not within a **not** CE. A '?' is returned if the pattern number does not correspond to an analyzed join.

GetNodeType

PURPOSE: Returns pattern network logic for a field of a given pattern.

ARGUMENTS: Pattern and field number.

RETURNS: Logic type. If it can be found, it will be SINGLE, MULTIFIELD, or STOP. If it cannot be found, it will return UNKNOWN to signal an error.

OTHER NOTES: Accesses the variable **AnalysisExpressions** to derive the information.

GetNotJoinExpression

PURPOSE: Returns secondary join network expression for a particular pattern. The secondary expression is needed when test expressions are used after a **not** conditional element.

ARGUMENTS: Pattern number.

RETURNS: Secondary join network expression.

OTHER NOTES: Returns original copy of the expression and sets pointer to the expression to null. Hence, subsequent calls with the same pattern number will return null. Accesses **AnalysisExpressions** to derive the information.

GetPatternExpression

PURPOSE: Returns pattern network test for a particular pattern and field.

ARGUMENTS: Pattern and field number.

RETURNS: Pattern network expression.

OTHER NOTES: Returns original copy of the expression and sets pointer to the expression to NULL. Hence, subsequent calls with the same arguments will return NULL. Accesses **AnalysisExpressions** to derive the information.

GetPrimaryJoinExpression

PURPOSE: Returns the primary join network expression for a particular pattern.

ARGUMENTS: Pattern number.

RETURNS: Primary join network expression.

OTHER NOTES: Returns original copy of the expression and sets pointer to the expression to NULL. Hence, subsequent calls with the same pattern number will return NULL. Accesses **AnalysisExpressions** to derive the information.

GetRelationForPattern

PURPOSE: Returns the relation name (if any) associated with the first field of an LHS pattern.

ARGUMENTS: An integer index representing the pattern to be checked.

RETURNS: A pointer to the relation name symbol if it exists; otherwise NULL.

GetVariableInformation

PURPOSE: Returns the value of the variable **CurrentPatternInfo**.

RETURNS: The variable **CurrentPatternInfo**.

PatternHasTemplate

PURPOSE: Determines whether a pattern on the LHS of a rule has an associated deftemplate.

ARGUMENTS: An integer index representing the pattern to be checked.

RETURNS: Boolean value. True if the first field of the LHS pattern is associated with a deftemplate; otherwise false.

RuleComplexity

PURPOSE: Determines the complexity of a rule for use with the lex, mea, simplicity, and complexity conflict resolution strategies.

ARGUMENTS: None. The complexity is computed for the rule being currently analyzed. The variable **AnalysisExpressions** is used to derive the complexity information.

RETURNS: An integer value representing the complexity of the rule. The rule complexity is the sum of the complexity of each expression associated with the join or pattern network for the rule computed using the function **ExpressionComplexity**.

SetRuleInformation

PURPOSE: Sets the value of the variable **AnalysisExpressions**.

ARGUMENTS: The new value.

SetVariableInformation

PURPOSE: Sets the value of the variable **CurrentPatternInfo**.

ARGUMENTS: The new value.

INTERNAL FUNCTIONS

None.

Analysis Module

The Analysis Module (analysis.c) creates the appropriate function calls to be embedded in the join and pattern network. It also uses both the Variable Module and the Build Module to create expressions to be placed in the network. When the LHS representation of a rule is passed to the rule analysis function, several steps in the generation of an expression occur.

First, the Analysis Module determines the location of variables within the patterns and if any semantic errors involving the use of variables have occurred. It analyzes the set of LHS patterns to determine where variables are being bound. It keeps track of fact address variables the patterns to which they are bound and detects errors in the usage of variables.

Each pattern has the following information stored about it: Which pattern is it (first, second, third)? Is the pattern bound to a fact address variable; and, if so, what is the name of the variable? Is the pattern logically negated? Which variables are bound in this pattern?

Bound variables are variables which either stand alone in a field or are the first subfield of a field and are immediately followed by an **&** connective constraint. Bound variables have the following information stored about them: the variable name, the pattern and field numbers in which they are found, and whether the variable is a single- or multifield variable.

The typical error detected by the Analysis Module is a reference to a variable before it has been bound. The following rules all incorrectly reference the variable ?x.

```
(defrule error1
   (fact ~?x)
   =>)

(defrule error2
   (not (fact ?x))
   (data ?x)
   =>)

(defrule error3
   (data ?y)
   (test (> ?x ?y))
   =>)

(defrule error4
   (not (fact ?x))
   (test (> ?x 4))
   =>)

(defrule error5
   (data ?x | all)
   =>)
```

Rules error1 and error3 simply make a reference to the variable x before the variable has been bound. Rules error2 and error4 demonstrate that the scope of a variable first bound within a **not CE** is limited strictly to within the **not CE**. Rule error4 can be corrected by placing the test within the **not CE** using `&:(> ?x 4)`. Rule error5 also makes an unbound reference to ?x. Variable ?x is the first variable in the field; however, it is connected with a **|** connective constraint and, therefore, is not considered to be a binding occurrence of the variable.

Note that the deftemplate construct generates *normal* LHS patterns from the LHS template patterns used in a rule. Because fields may be listed in any order in a template pattern, it is possible for a converted template pattern to access a variable before that variable is defined. For example, given the following deftemplate,

```
(deftemplate temp
   (field x)
   (field y))
```

the following two rules properly use the template patterns:

```
(defrule example-1
  (temp (x ?x) (y ?y&~?x))
  =>)

(defrule example-2
  (temp (y ?y) (x ?x&~?y))
  =>)
```

Notice that, in the template patterns of both rules, variables are defined before they are used. However, when the conversion from LHS template patterns to normal LHS patterns is performed, the rules appear as follows:

```
(defrule example-1
  (temp ?x ?y&~?x)
  =>)

(defrule example-2
  (temp ?x&~?y ?y)
  =>)
```

Rule example-1 has no forward references to variables; however, rule example-2 references the variable ?y before it is defined. Because fields in a template pattern may be specified in any order and the specified fields may be rearranged in generating the actual LHS pattern to be used, forward references to variables in a template pattern are allowed so long as the variable is contained somewhere within the pattern in which it is referenced first.

Once the variables within the patterns have been identified, the Generate Module can then be used to generate expressions for the pattern and join networks. Many factors must be considered when generating expressions for evaluation in the networks. Several examples bear mentioning.

```
(defrule example1
   (foo ?x)
   (not (bar ?x))
   (test (> ?x 4))
   =>)
```

Rule example1 demonstrates that two separate expressions can be needed for joins with a **not CE**. The first expression needed for the **not CE** is performed on the pattern itself. This expression checks to see if the ?x in the *bar* fact is the same as the ?x in the *foo* fact. The expression (> ?x 4) references ?x in the *foo* fact but should not be associated with the other expression. This is necessary for the case where no *bar* facts exist. The expression comparing ?x in *foo* to ?x in *bar* does not have to be performed in this case. If the (> ?x 4) expression was associated with the other expression, the existence of any *foo* fact along with no *bar* facts would cause the rule to be activated. The rule should be activated only for foo's with ?x greater than 4.

```
(defrule example2
   (foo ?x)
   (bar ?x ?x)
   =>)
```

Rule *example2* has two expressions which must be performed for the second pattern. The first expression ensures that the ?x in the *bar* fact is the same as the ?x in the *foo* fact. The second expression ensures that the ?x in the second field of the *bar* fact is the same as the ?x in the third field of the *bar* fact. The expression comparing across patterns must be done in the join network. The expression comparing ?x's within the *bar* pattern can be performed in the pattern network, however.

```
(defrule example3
   (foo ?x)
   (bar ?x | all)
   =>)
```

Rule *example3* demonstrates an example of an expression that must be moved from the pattern network to the join network. Because the second field in the *bar* fact has a comparison to a value first bound in another pattern, the expression for this field must be moved into the join network. An expression for the constant *all* cannot be performed in the pattern network because the element can either bind to *all* or to some as of yet unspecified value ?x.

```
(defrule example4
   (foo ?x&:(numberp ?x))
   =>)
```

Rule *example4* is another example of an expression that can be evaluated in the pattern network since all arguments of numberp can be accessed in the pattern.

```
(defrule example5
   (bar ?y)
   (foo ?x&:(> ?x ?y))
   =>)
```

Rule *example5* shows a predicate constraint which must be evaluated in the join network because of the reference to ?y bound outside of the pattern.

The Analysis Module generates a pattern network expression for every field in a pattern and a join network expression for every pattern. **Not CE**s may also have an additional join network expression. The Analysis Module determines which expressions are performed in the pattern network and which are done in the join network. When possible, expressions should be evaluated in the pattern network.

If a particular field has no **|** connective constraints, few restrictions apply to expressions which can be evaluated in the pattern network. All tests for constants can be evaluated in the pattern network. Predicate constraints and return value constraints can be evaluated in the pattern network as long as references to variables in other patterns are not made. Expressions comparing two references of the same variable can be evaluated in the pattern network if both references are found in the same pattern and one reference is to a bound variable. All other expressions that reference variables outside of the pattern must be made in the join network. Note that **test CE**s are always performed in the join network whereas predicate constraints and return value constraints may be performed either in the pattern or join network depending on the variables referenced.

If a field has an **|** connective constraint in it and references are made to a variable bound in another pattern that is not bound in this pattern, all expressions for this field must be performed in the join network. Rule example3 is an example of this type of reference.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DeftemplatePattern

PURPOSE:	Used to indicate whether a pattern being analyzed has an associated deftemplate.

GLOBAL FUNCTIONS

CheckExpression

PURPOSE:	Verifies that variables within an expression have been referenced properly. All variables within an expression must have been previously defined.
ARGUMENTS:	A pointer to the expression, the first pattern that can be checked for a variable reference, the current pattern and element with which the expression is associated, and a value indicating whether the expression is “inside” or “outside” the pattern.
RETURNS:	If no error is detected, a pointer to the expression; otherwise null.

CheckVariables

PURPOSE: Verifies the proper use of variables on the LHS of a rule. Checks that fact addresses are not reused or used as variables within patterns and that variables within patterns are referenced properly.

ARGUMENTS: The LHS representation of the patterns (which contains no embedded **and CE**s or **or CE**s).

RETURNS: Boolean value. TRUE if an error is detected; otherwise FALSE.

LogicalAnalysis

PURPOSE: Analyzes for the correct use of **logical CE**s on the LHS of a rule. Gaps may not exist between **logical CE**s and **logical CE**s must occurs before other CEs on the LHS of the rule.

ARGUMENTS: A pointer to the intermediate LHS representation of a rule (which contains no embedded **and CE**s or **or CE**s).

RETURNS: -1 if an error was detected, otherwise the integer index of last **logical CE** on the LHS of the rule (ranging from one to the number of patterns in the rule). If the rule has no **logical CE**s, then zero is returned.

RuleAnalysis

PURPOSE: Analyzes a set of patterns for variable bindings, performs semantic error checking on the use of variables, and determines expressions which will be evaluated in the pattern and join networks.

ARGUMENTS: A pointer to the intermediate LHS representation of a rule.

RETURNS: Boolean value. TRUE if a semantic error occurred; otherwise FALSE.

VariableAnalysis

PURPOSE: Analyzes a set of patterns to determine the position of each pattern in the rule, whether the pattern is contained within a **not CE**, and if the pattern is bound to a fact address.

ARGUMENTS: The LHS representation of the patterns (which contains no embedded **and CE**s or **or CE**s).

OTHER NOTES: Creates the data structures and then calls the function **SetVariableInformation**.

INTERNAL FUNCTIONS

AllVariablesInPattern

PURPOSE: Determines if all variable references made in a field can be found within the containing pattern in previous fields. This is important for determining whether certain expressions can be evaluated in the pattern network as opposed to the join network.

ARGUMENTS: A pointer to the field and the pattern and field integer index numbers.

RETURNS: A boolean value. TRUE if all variable references are contained within the pattern; otherwise FALSE.

BuildNetworkExpressions

PURPOSE: Constructs an entry for each **pattern CE** and **test CE** associated with that **pattern CE** in the LHS of a rule. The entry contains information about pattern network expressions associated with each field and primary and secondary join expressions associated with the pattern.

ARGUMENTS: A pointer to the intermediate LHS representation of a rule.

OTHER NOTES: Creates the data structures and then calls the function **SetRuleInformation**.

CheckFactAddress

PURPOSE: Verifies that a fact address has not been used more than once and has not been used as a variable name.

ARGUMENTS: Name of fact address variable and pattern index to which it is bound.

RETURNS: Boolean value. TRUE if an error is detected; otherwise FALSE.

CheckPattern

PURPOSE: Verifies that variables within a pattern have been referenced properly (i.e. that variables have been previously bound if they are not a binding occurrence).

ARGUMENTS: The LHS representation of the pattern and the pattern index of the pattern.

RETURNS: Boolean value. TRUE if an error is detected; otherwise FALSE.

ExtractAnds

PURPOSE: Loops through a single set of subfields bound together by an **&** connective constraint in a field and generates expressions needed for testing conditions in the pattern and join network.

ARGUMENTS: A pointer to the intermediate LHS representation of the subfields connected by the **&** connective constraint, the integer index of the pattern and field in which the subfields occur, a boolean flag indicating whether certain tests may be performed in the pattern network, and a pointer to a data structure in which expressions to be used in the pattern and join network will be returned.

RETURNS: No formal return parameter. Returns expressions to be evaluated in the pattern network and expressions to be evaluated in the join network in a data structure passed as an argument.

OTHER NOTES: Uses Generate Module to build subfield expressions.

FieldConversion

PURPOSE: Generates expressions to be evaluated in the pattern network and join network for a field in a pattern. Uses function **ExtractAnds** to generate subfield expressions, then combines the subfield expressions together.

ARGUMENTS: A pointer to the intermediate LHS representation of the pattern field, the integer index of the pattern and field in the LHS of the rule, and a pointer to a data structure in which expressions to be used in the pattern and join network will be returned.

RETURNS: No formal return parameter. Returns expressions to be evaluated in the pattern network and expressions to be evaluated in the join network in a data structure passed as an argument.

GetVariables

PURPOSE: Extracts the variable references from a single pattern.

ARGUMENTS:	Intermediate LHS representation of the pattern and the pattern index number (e.g., first, second, or third pattern in the rule).
RETURNS:	A linked list of structures containing information about each variable in the pattern.

Generate Module

The Generate Module (generate.c) transforms the basic syntax primitives of a pattern into expressions which will be placed in the pattern and join networks. **&** and **|** connectives are respectively replaced with the equivalent function call to the **and** function or the **or** function. Other primitives bear mentioning as to the type of replacements that are made.

Access to specific variables from the join network or RHS uses the **getvar** function.

```
(getvar <pattern-m> <field-n>)
```

Access to specific variables from the pattern network uses the **getfield** function, which only requires a field specification since the specific pattern is implied by the current fact.

```
(getfield <field-m>)
```

Comparison of variables in the join network uses **eqvar** and **neqvar** to test, respectively, if a set of variables is either equal or not equal. The pattern associated with the first field in the comparison is assumed to be the pattern entering from the RHS of the join in which the expression is located. The depth field of the join structure is used to determine this pattern index.

```
(eqvar field-n pattern-x field-y)
(neqvar field-n pattern-x field-y)
```

Equivalent functions for the pattern network are **eqfield** and **neqfield**.

```
(eqfield field-m field-n)
(neqfield field-m field-n)
```

Constants are evaluated in the pattern network using the **constant** and **notconstant** functions.

```
(constant <value>)
(notconstant <value>)
```

Constants are evaluated in the join network using the following functions. Note that the calls to **eq**, **neq**, and **getvar** could be removed and a single-level function could be used.

```
(eq (getvar <pattern> <field>) <value>)
(neq (getvar <pattern> <field>) <value>)
```

The pattern primitive

```
=(expression)
```

is replaced with

```
(eq (getvar <pattern> <field>) (expression))
```

in the join network and with

```
(eq (getfield <pattern>) (expression))
```

in the pattern network. For an inequality comparison (i.e., ~=), **neq** and **neqfield** can be used. The primitive expression

```
:(expression)
```

is replaced with

```
(expression)
```

The join network uses **getvar** calls to resolve references, and the pattern network uses **getfield** to resolve references. For an constraint used in conjunction with the **~** connective constraint (e.g., ~:), the **not** function can be wrapped around the expression.

GLOBAL VARIABLES

PTR_AND

PURPOSE: A pointer to the data structure for the **and** function.

PTR_CONSTANT

PURPOSE: A pointer to the data structure for the **constant** function.

PTR_EQ

PURPOSE: A pointer to the data structure for the **eq** function.

PTR_EQ_FIELD

PURPOSE: A pointer to the data structure for the **eq_field** function.

PTR_GET_FIELD

PURPOSE: A pointer to the data structure for the **get_field** function.

PTR_NEQ

PURPOSE: A pointer to the data structure for the **neq** function.

PTR_NEQ_FIELD

PURPOSE: A pointer to the data structure for the **neq_field** function.

PTR_NOP

PURPOSE: A pointer to the data structure for the **nop** function.

PTR_NOT

PURPOSE: A pointer to the data structure for the **not** function.

PTR_NOTCONSTANT

PURPOSE: A pointer to the data structure for the **notconstant** function.

PTR_OR

PURPOSE: A pointer to the data structure for the **or** function.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

CombineExpressions

PURPOSE: Combines two expressions into a single equivalent expression. Mainly serves to merge expressions containing **and** and **or** expressions without unnecessary duplication of the **and** and **or** expressions (i.e., two **and** expressions can be merged by placing them as arguments within another **and** expression, but it is more efficient to add the arguments of one of the **and** expressions to the list of arguments for the other **and** expression).

ARGUMENTS: Two expressions.

RETURNS: An expression.

OTHER NOTES: Modifies argument expressions to produce the final expression, so the original expressions are no longer valid after a call to this function. Null expressions are properly handled.

GenAnd

PURPOSE: Generates an **and** function call with no arguments.

RETURNS: An expression.

GenConstant

PURPOSE: Produces a constant (such as a symbol, integer, or function call stub).

ARGUMENTS: The type and value of the constant.

RETURNS: An expression.

GenFourIntegers

PURPOSE: Generates an argument list consisting of four integers.

ARGUMENTS: Four integer indices.

RETURNS: An expression.

GenGetfield

PURPOSE: Produces an expression of the form (getfield <field-index>).

ARGUMENTS: Field index.

RETURNS: An expression.

GenGetvar

PURPOSE: Produces an expression of the form (getvar <pattern-index> <field-index>).

ARGUMENTS: Pattern and field indices.

RETURNS: An expression.

GenGetvarValue

PURPOSE: Produces the integer indices for a getvar call.

ARGUMENTS: Pattern and field indices.

RETURNS: A void pointer value containing the encoded integer indices.

GenJNColon

PURPOSE: Generates a join network expression for testing a predicate constraint. The subfield :<function-call> is converted to the expression <function-call> and the subfield ~:<function-call> is converted to the expression (not <function-call>). References to variables in the expression are replaced with **getvar** calls.

ARGUMENTS: A flag indicating whether the subfield value is negated, the <function-call> associated with the subfield, the field and pattern indices of the subfield to be tested, and a flag indicating whether forward references to variables are allowed in the expression (for deftemplate patterns only).

RETURNS: An expression.

GenJNConstant

PURPOSE: Generates a join network expression for use in comparing subfield values to constants. The subfield <value> is converted to the expression (eq (getvar <pattern-index> <field-index>) <value>) and the subfield ~<value> is converted to the expression (neq (getvar <pattern-index> <field-index>) <value>).

ARGUMENTS: A flag indicating whether the subfield value is negated, the type and value of the subfield, and the field and pattern indices of the subfield to be tested.

RETURNS: An expression.

GenJNEq

PURPOSE: Generates a join network expression for testing a return value constraint. The subfield =<function-call> is converted to the expression (eq (getvar <pattern-index> <field-index>) <function-call>) and the subfield ~=<function-call> is converted to the expression (neq (getvar <pattern-index> <field-index>) <function-call>). References to variables in the expression are replaced with **getvar** calls.

ARGUMENTS: A flag indicating whether the subfield value is negated, the <function-call> associated with the subfield, the field and pattern indices of the subfield to be tested, and a flag indicating whether forward references to variables are allowed in the expression (for deftemplate patterns only).

RETURNS: An expression.

GenJNVariableComparison

PURPOSE: Generates a join network expression testing the equality or inequality of variables bound to the fields of a pattern. Produces expressions of the form (eqvars <field-index-1> <pattern-index-2> <field-index-2>) when two fields must be equal and (neqvars <field-index-1> <pattern-index-1> <field-index-2>) when two fields must be unequal. The pattern associated with <field-index-1> in the comparison is assumed to be the pattern entering from the RHS of the join in which the expression is located. The depth field of the join structure is used to determine this pattern index.

ARGUMENTS: A flag indicating whether the variable is negated, the name of the variable, the pattern and field indices representing the pattern and field in which the variable was found, and a flag indicating whether forward references to variables are allowed in the expression (for deftemplate patterns only).

RETURNS: An expression.

GenOr

PURPOSE: Generates an **or** function call with no arguments.

RETURNS: An expression.

GenPNColon

PURPOSE: Generates a pattern network expression for testing a predicate constraint. The subfield :<function-call> is converted to the expression <function-call> and the subfield ~:<function-call> is converted to the expression (not <function-call>). References to variables in the expression are replaced with **getfield** calls.

ARGUMENTS: A flag indicating whether the subfield value is negated, the <function-call> associated with the subfield, and the field and pattern indices of the subfield to be tested.

RETURNS: An expression.

GenPNConstant

PURPOSE: Generates a pattern network expression for use in comparing subfield values to constants. The subfield <value> is converted to the expression (constant <value>) and the subfield ~<value> is converted to the expression (notconstant value).

ARGUMENTS: A flag indicating whether the subfield value is negated and the type and value of the subfield.

RETURNS: An expression.

GenPNEq

PURPOSE: Generates a pattern network expression for testing a return value constraint. The subfield =<function-call> is converted to the expression (eq (getfield <field-index>) <function-call>) and the subfield ~=<function-call> is converted to the expression (neq (getfield <field-index>) <function-call>). References to variables in the expression are replaced with **getfield** calls.

ARGUMENTS: A flag indicating whether the subfield value is negated, the <function-call> associated with the subfield, and the field and pattern indices of the subfield to be tested.

RETURNS: An expression.

GenPNVariableComparison

PURPOSE: Generates a pattern network expression testing the equality or inequality of variables bound to the fields of a pattern. Produces expressions of the form (eqfield <field-index-1> <field-index-2>) when two fields must be equal and (neqfield <field-index-1> <field-index-2>) when two fields must be unequal.

ARGUMENTS: A flag indicating whether the variable is negated, the name of the variable, and the pattern and field indices representing the pattern and field in which the variable was found.

RETURNS: An expression.

GenTwoIntegers

PURPOSE: Generates an argument list consisting of two integers.

ARGUMENTS: Two integer indices.

RETURNS: An expression.

GetfieldReplace

PURPOSE: Replaces variable references in an expression with appropriate **getfield** calls.

ARGUMENTS: A pointer to the expression to be modified and pattern and field indices representing the pattern and field from which the expression was extracted.

RETURNS: Nothing; however, the expression passed as a parameter is modified.

GetvarReplace

PURPOSE: Replaces variable references in an expression with appropriate **getvar** calls.

ARGUMENTS: A pointer to the expression to be modified, the pattern and field indices representing the pattern and field from which the expression was extracted, and a flag indicating whether forward references to variables are allowed in the expression (for deftemplate patterns only).

RETURNS: Nothing; however, the expression passed as a parameter is modified.

InitGenModule

PURPOSE: Initializes the global **Function Pointers** by calling **FindFunction** to locate each of the functions to be later referenced and setting the global value to the return value.

INTERNAL FUNCTIONS

None.

Build Module

Information and expressions generated during the analysis phase of rule compilation have to be integrated into the pattern and join networks. This integration takes advantage of the potential to share common expressions among patterns and joins where possible. The Build Module (build.c) uses information created by the Analysis Module and accessed through the Variable Manager Module to add a rule into the rule network consisting of the pattern and join networks.

The pattern network is conceptually represented as a tree structure. The root node represents the starting point of a pattern match before any elements of either the fact or pattern network have been "consumed." The set of nodes after the root node represents all pattern expressions found as the first field in a pattern. The children of these nodes represent all second fields found in patterns. Each level of the pattern tree represents the set of all fields of a particular position in all patterns. As the pattern tree is traversed downward, fact fields are consumed as expressions are evaluated. Standard single field expressions consume one fact field when exited traversing downward in the tree. Multifield nodes consume all combinations of zero or more fact fields.

The pattern network structure allows patterns to share identical sequences of fields beginning at the front of the pattern. The two patterns

```
(data red ?)
(data green ?)
```

would share a common pattern node for their first field, *data*. If the pattern

```
(data green blue ?)
```

were now added, it would share the common pattern node, *data*, with the two patterns above. In addition, it would share the pattern node, *green*, with the second pattern.

For a given field in a pattern to be shared with a currently existing pattern field, two conditions must be met. First, all previous fields in the pattern must have been shared in the pattern network. Second, the expression generated for the field of the pattern must be identical to an expression already in place at the current level of addition in the pattern network. Note that variables generally do not create expressions that are tested in the pattern network unless they refer to a variable previously bound in the same pattern.

Sharing in the join network for a particular join of a rule occurs under three conditions. First, all previous joins must be shared. Second, the expression generated for the join must be identical to an expression already in place at the current level of addition in the join network. Third, the join to be shared must be entered from the same location in the pattern network. The following two rules illustrate some examples of sharing:

```
(defrule example1
   (data red ?x)
   (data green ?x)
   =>)

(defrule example2
   (data red ?x)
```

```
   (data blue ?x)
   =>)
```

Many examples of pattern sharing occur. All four patterns share a common node testing for the constant value *data*. In addition, the first pattern in both rules can share all pattern nodes. The join for the first pattern in both rules also can be shared. The second join for both rules, however, cannot be shared. The expression for the second join in both rules is identical (i.e., (eqvars 2 1 2)); however, the joins must be entered from different patterns and, therefore, cannot be shared.

The following rule:

```
(defrule example3
   (data red ?y)
   (data blue ?y)
   (info ?z)
   =>)
```

would be able to share nodes in the pattern and join networks. Its first two patterns already exist in the pattern network. The third pattern would require the addition of two new nodes in the pattern network. The first two joins for this rule could be shared with the joins used for rule *example2*. A third join for rule *example3* would have to be added for the last pattern. Note that the use of different variable names does not affect the ability to share. As long as the expressions generated are identical, sharing will occur. Variable names serve only as positional references.

Information about sharing in join network is displayed when a rule is being loaded if the watch compilations flag is on. New additions to the join network is signaled with +j and reuse of existing nodes is indicated with =j.

The CLIPS join topology differs slightly from the “standard” Rete topology used by OPS5. First, each pattern corresponds to its own join. In standard Rete topology, the first two patterns will form a two-input join. If only one pattern exists, this pattern will form a single one-input join. Thus, using this topology, the number of joins needed for n patterns is n - 1 with a minimum of 1 join. In CLIPS, the first pattern always creates a one-input join. This simplifies the algorithms used considerably since a pattern always enters the join from the RHS. Given this simplification, the beta memory of a join can never be associated with a pattern contained in **not CE**.

Standard Rete topology also makes a test in the pattern network for the length of a fact. The use of multifield variables in CLIPS eliminates much of the usefulness of making this test. Each level of the pattern network corresponds directly to specific indexed fields in a pattern.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

PatternNetworkPointer

PURPOSE:	A pointer to the root node of pattern network. This provides access to the entire rule network.

GLOBAL FUNCTIONS

ConstructJoins

PURPOSE:	Integrates a set of pattern and join tests associated with a rule into the pattern and join networks.
ARGUMENTS:	A pointer to the pointer of the top node in the pattern network and a pointer to the structure storing information about the rule to be added.
RETURNS:	A pointer to the last join that was added.
OTHER NOTES:	Prints informational messages to indicate join network sharing. If a new node has to be added to the join network, +j is printed. If a join node can be reused, =j is printed. Information about pattern and join expressions is retrieved from the Variable Manager Module.

DetachJoins

PURPOSE:	Removes a join node and all of its parent nodes from the join network. Nodes are only removed if they are no longer shared (i.e. a join that has more than one child node is shared). Any partial matches associated with the join are also removed. A rule's joins are typically removed by removing the bottom most join used by the rule and then removing any parent joins which are not shared by other rules.
ARGUMENTS:	A pointer to a join node.

NetworkPointer

PURPOSE:	Returns the value of the **PatternNetworkPointer**.
RETURNS:	A pointer to a pattern node.

SetNetworkPointer

PURPOSE:	Sets the value of the **PatternNetworkPointer**.
ARGUMENTS:	A pointer to a pattern node.

INTERNAL FUNCTIONS

DetachPattern

PURPOSE: Removes a pattern node and all of its parent nodes from the pattern network. Nodes are only removed if they are no longer shared (i.e. a pattern node that has more than one child node is shared). A pattern from a rule is typically removed by removing the bottom most pattern node used by the pattern and then removing any parent nodes which are not shared by other patterns.

ARGUMENTS: A pointer to a pattern node.

PlacePattern

PURPOSE: Integrates a pattern into the pattern network.

ARGUMENTS: Current level in the pattern network at which the new pattern is being integrated, the previous level in the pattern network at which the new pattern has already been integrated, an integer index indicating which pattern from the rule is being integrated, an integer index indicating which field of the pattern is being integrated, an integer value indicating the number of fields in the pattern, and a pointer to the variable which points to the root node in the pattern network. Information about pattern expressions is obtained from the Variable Manager Module.

RETURNS: A pointer to the last pattern node in the pattern network for the pattern just added.

RemoveIntranetworkLink

PURPOSE: Removes the link between a join node in the join network and its corresponding pattern node in the pattern network. If the pattern node is then no longer associated with any other joins, it is removed using the function **DetachPattern**.

ARGUMENTS: A pointer to a join node.

ReuseJoin

PURPOSE: Determines whether a join exists that can be reused for the join currently being added to the join network.

ARGUMENTS: A pointer to the list of possible joins that can be reused, a flag indicating whether the join to be added is the first join for the rule, a flag indicating whether the pattern associated with the join is contained with a **not CE**, the primary and secondary join expressions for the join to be added, and a pointer to the list of joins connected to the pattern associated with the join being added.

RETURNS: A pointer to the join that can be reused if one exists; otherwise NULL.

Drive Module

The Drive Module (drive.c) contains the major functionality for updating the join network when a fact has been asserted into the knowledge base. This update will also be referred to as “driving” a set of partial matches through the join network. When a fact has matched a pattern in the pattern network, a partial match consisting of that single fact is created. This partial match is then sent to each join in the join network connected to that pattern. The partial match “enters” through the RHS of the join. Depending upon the type of the join (i.e. associated with the first conditional element, a **not** conditional element, etc.), the entering partial match will be compared with the beta memory of the join. New partial matches may be created from this comparison and sent to the descendent joins of the current join. New partial matches would enter from the LHS of the descendent joins. Note that all pattern conditional elements enter joins from the RHS, but all joins enter other joins from the LHS. The algorithm for driving partial matches through the join network is described as follows.

The function **Drive** handles high-level updating of the join network when a fact is asserted. If the join being updated is a terminator join (i.e., the last join of a rule which connects the join to the actions of a rule), a rule activation has occurred. An activation is added to the agenda and the current level of recursive descent into the join network is terminated. If the join was entered from the LHS, the partial match is stored in the beta memory of the join. Partial matches entering from the RHS are already stored in the alpha memory in the pattern network.

If the join being updated is a single-entry join (i.e. the join associated with the first conditional element in a rule), then the single-entry join algorithm is used for updating the join network. First, it is determined if the primary join expression evaluates to TRUE or FALSE. If no expression exists, the evaluation is automatically TRUE. If the expression is FALSE, the join update is completed.

If LHS entry is from a **pattern** conditional element, a copy of the alpha partial match is made and sent to all the child joins of the current join using the **Drive** algorithm.

If LHS entry is from a **not** conditional element and the count of facts matching the CE is greater than zero, then the count associated with the join is incremented by one. In effect, other facts are already preventing the **not** CE from being satisfied, so just keep track of the fact that there is one more fact prevent the CE from being satisfied. If, however, the count was less than zero (indicating that previous facts had been asserted which matched the CE), the join's count is set to one and all partial matches containing the pseudo-fact ID which was stored as the join's count are removed from all of the descendent joins of the current join.

For double-entry joins, a loop is used to compare each set of partial matches in the opposite memory (beta memory for RHS entry and alpha memory for LHS entry) to the entering partial match. If the join was entered from the RHS, each partial match in the beta memory is compared to the entering partial match. If the join was entered from the LHS, each partial match in the alpha memory (stored in the pattern network) is compared to the entering partial match. For each pair of partial matches that is compared, the primary join expression is evaluated for its boolean value. If no expression exists, the evaluation is considered TRUE. If the join expression evaluates to TRUE, one of three algorithms is performed. The three algorithms correspond to the following cases: positive RHS entry and positive LHS entry, positive RHS entry and negative LHS entry (meaning the conditional element associated with this join is a **not** conditional element) with the partial match entering from the LHS, and positive RHS entry and negative LHS entry with the partial match entering from the RHS. Algorithms for each of these cases are described below.

The double-entry join algorithm for joins with positive RHS entry and positive LHS entry works as follows. The beta partial match and alpha partial match are merged to form a new partial match with the alpha partial match attached to the end of the beta partial match. This new partial match is then sent to all the child joins of the current join using the **Drive** algorithm.

The double-entry join algorithm for joins associated with a **not** conditional element in which a partial match enters from the LHS works as follows. The count value associated with the beta partial match is incremented by one. This count is originally set to zero when the beta partial match enters the join. If it is still zero at completion of all memory comparisons, a partial match will be created by merging the beta partial match with a pseudo-fact ID.

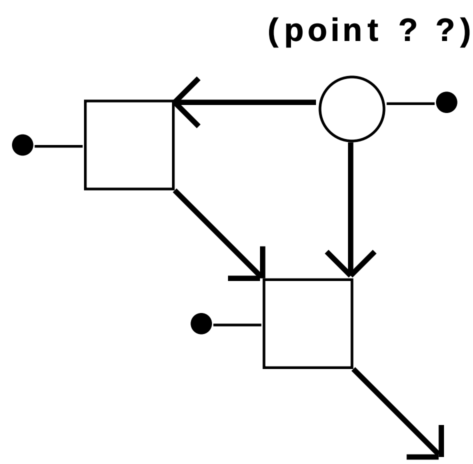
The double-entry join algorithm for joins associated with a **not** conditional element in which a partial match enters from the RHS works as follows. If the count associated with the beta memory partial match is greater than zero, increment the count by one. If the count was less than zero, set the beta memory count to one and remove all partial matches containing the pseudo-fact ID previously associated with the beta memory partial match from all of the descendent joins of the current join

Upon completion of the alpha and beta memory comparisons, a final test is performed. If the RHS join entry is associated with a **not** conditional element, the join was entered from the LHS, and the number of alpha memory partial matches which satisfied the primary join expression was zero, then a new partial match may need to be created. The secondary join expression is evaluated. If it evaluates to TRUE, a partial match consisting of a pseudo-fact identification (ID) number and the beta memory partial match is created. The pseudo-fact identification ID number is negative. The count value of the beta memory partial match is set to this pseudo-fact ID. The count value represents the number of alpha memory partial matches which satisfied the primary join expression for a particular beta memory partial match. A negative value indicates that no alpha partial matches satisfied the join expression. The new partial match create from the pseudo-fact ID and the beta memory partial match is sent to all the descendent joins of the current join using the **Drive** algorithm. Note that, if the beta memory count had been greater than zero, this would have indicated that facts in the alpha memory of the join conflicted with the beta memory and prevented a partial match for this join.

As an example, consider the following rule:

```
(defrule match ""
  (point ?x ?)
  (point ? ?x)
  =>)
```

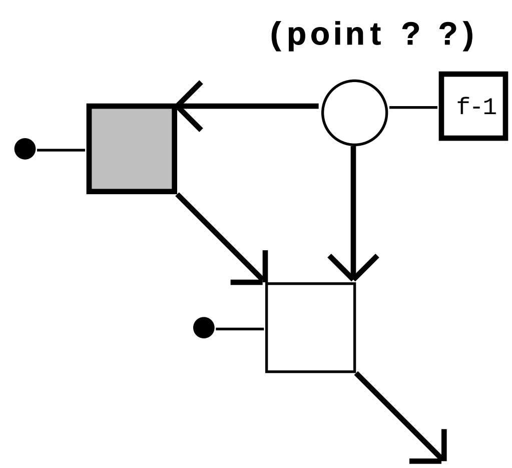
The following diagram illustrates the join network for this rule. The two boxes represent joins. The top box is the join associated with the first pattern CE (point ?x ?). The bottom box is the join associated with the second pattern CE (point ? ?x). The line terminated with a dark circle to the left of each join represents the contents of the beta memory of the joins. As shown here, the beta memory for both joins is empty. The circle represents the pattern node signifying the completion of the pattern (point ? ?). This pattern is used for both (point ?x ?) and (point ? ?x) since variables in this case cannot be checked in the pattern network.The alpha memory is represented by the line terminated with a dark circle connected to the right of the pattern node. The alpha memory is also empty. Note that the expressions associated with each join are not shown. The top join has no expression and will allow any partial match to filter down to the next join. The bottom join must verify that the value of the second field of the fact bound to the first pattern is equal to the value of the third field of the fact bound to the second pattern. This diagram assumes that the match rule is the only rule in the rule network (hence, no sharing). Count values for partial matches are not shown since these are applicable only to joins that are attached to **not** CEs. The terminator join for the rule is not shown in the diagram. This last join of the rule stores the partial matches which satisfy all CEs of the rule. A link between these partial matches and their corresponding activations on the agenda is also maintained.



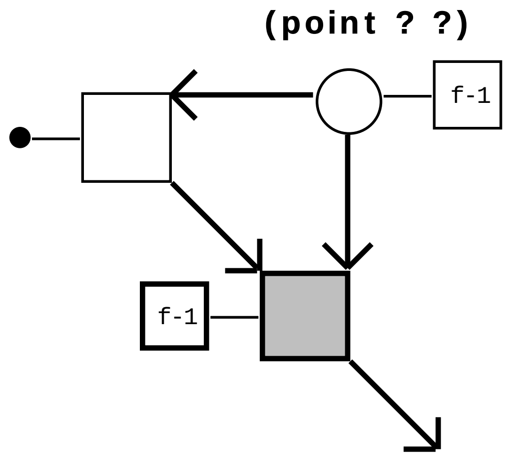
Suppose that the following fact were entered into the fact-list:

```
f-1   (point 3 4)
```

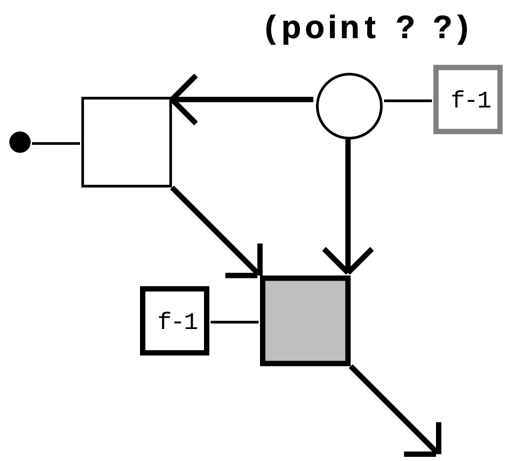
This fact would match the pattern (point ? ?) and be placed in the alpha memory of the pattern node. The pattern node must then pass this partial match to the two joins to which it is connected. First, the partial match is sent to the top join as shown below.



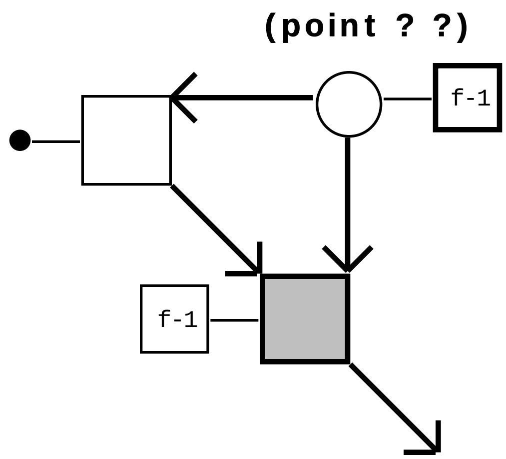
Since the top join has no expression, the partial match is sent down to the next join.



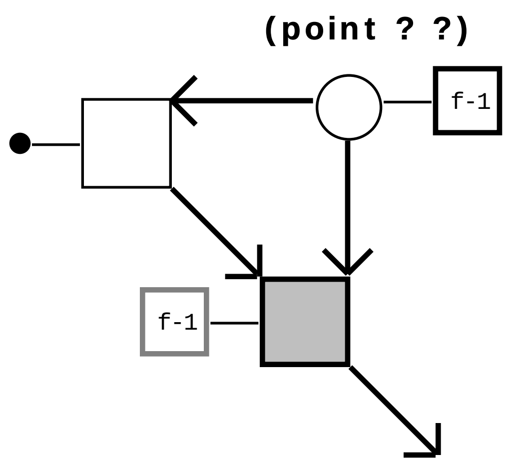
A comparison now takes place between the partial match in the beta memory and all partial matches in the alpha memory associated with this join. Currently, only one partial match is in the alpha memory. For the second join, the partial match in the alpha memory is the fact bound to the first pattern, and the partial match in the beta memory is the fact bound to the second pattern. Evaluating the join expression will produce a FALSE result since the value bound to ?x in the first pattern is 3 and the value bound to ?x in the second pattern is 4.



The process of updating the top join is complete. Now the partial match in the alpha memory is sent to the bottom join.



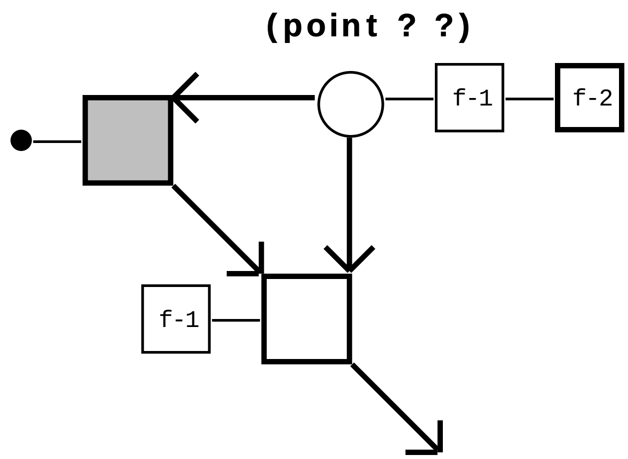
Once again, a comparison is made between the facts to check proper variable bindings. As before, this comparison will fail.



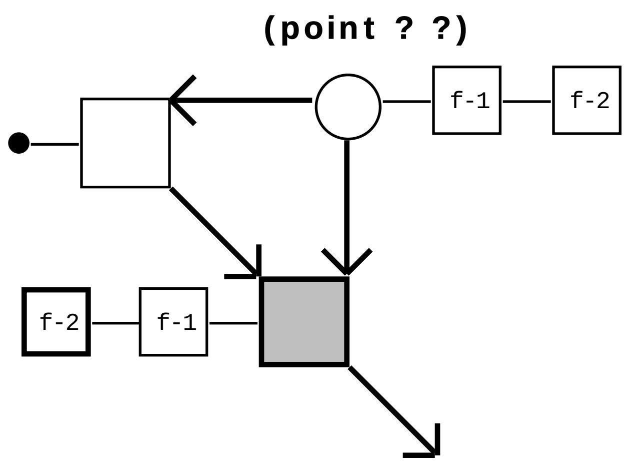
Suppose that an additional fact were entered into the fact-list.

```
f-2   (point 4 3)
```

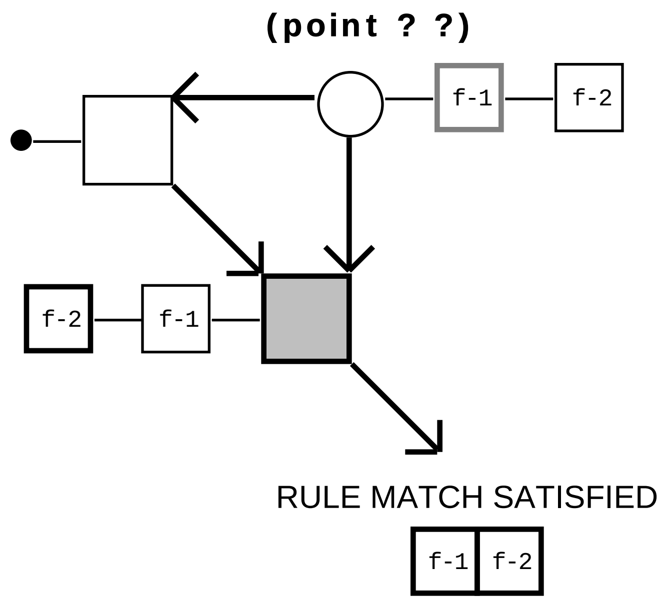
This fact would match the pattern (point ? ?) and be placed in the alpha memory of the pattern node. The pattern node must then pass this partial match to the two joins to which it is connected. First, the partial match is sent to the top join as shown following.



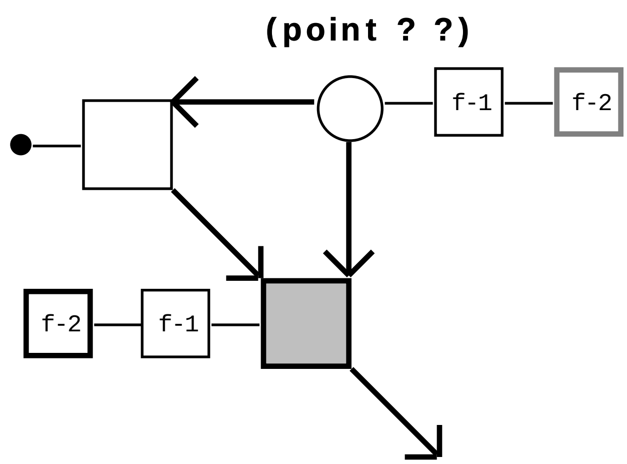
Since the top join has no expression, the partial match is sent down to the next join.



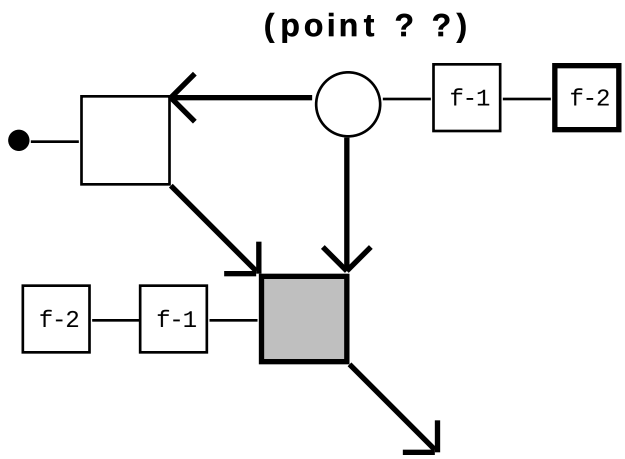
A comparison now takes place between the partial match in the beta memory and all partial matches in the alpha memory associated with this join. The first comparison is between f-2 in beta memory and f-1 in alpha memory. This comparison succeeds. The value of ?x in f-1 (the second field) is 3 and the value of ?x in f-2 (the third field) is also 3. A partial match consisting of f-1 and f-2 is created and sent to the next join. Since this next join is a terminator join, the rule that is matched has been satisfied with f-1 bound to the first pattern and f-2 bound to the second pattern. This activation would be placed on the agenda.



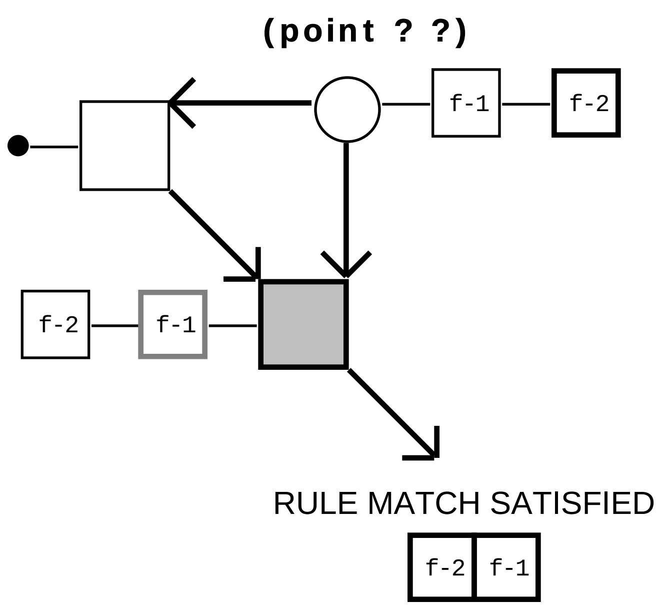
The next comparison now takes place. The value of ?x in the first pattern (the second field of f-2) is 4; however, the value of ?x in the second pattern (the third field of f-2) is 3. The comparison fails and no new partial match is created.



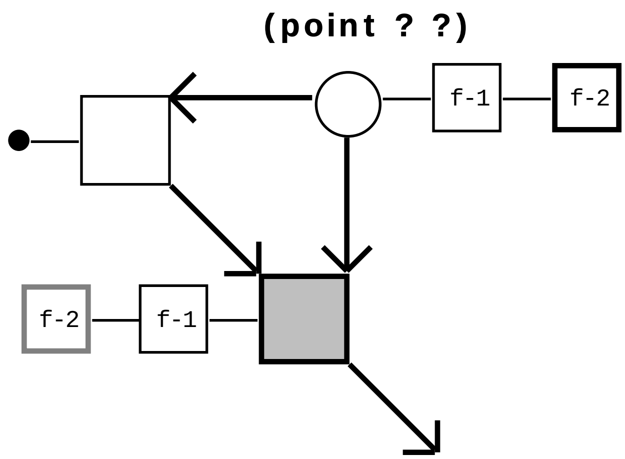
The process of updating the top join is complete. Now the partial match in the alpha memory is sent to the bottom join.



A comparison now takes place between the partial match in the alpha memory associated with this join and all partial matches in the beta memory of the join. The first comparison is between f-1 in beta memory and f-2 in alpha memory. This comparison succeeds. The value of ?x in the first pattern (the second field of f-2) is 4 and the value of ?x in the second pattern (the third field of f-1) is also 4. A partial match consisting of f-2 and f-1 is created and sent to the next join. Since this next join is a terminator join, the rule that is matched has been satisfied with f-2 bound to the first pattern and f-1 bound to the second pattern. This activation would be placed on the agenda.



The next comparison now takes place. The value of ?x in the first pattern (the second field of f-2) is 4; however, the value of ?x in the second pattern (the third field of f-2) is 3. The comparison fails and no new partial match is created.



The process of updating the bottom join for the addition of f-2 is complete. Notice that the beta memory of the top join never contains any partial matches. Joins that correspond to the first pattern of a rule will never make use of the beta memory.

GLOBAL VARIABLES

IncrementalReset

PURPOSE: Boolean flag. If TRUE, an incremental reset is performed whenever a new rule is defined.

IncrementalResetFlag

PURPOSE: Boolean flag. If TRUE, an incremental reset is currently being performed.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

Drive

PURPOSE: Primary routine for driving a partial match through the join network.

ARGUMENTS: A pointer to a partial match, a pointer to the join which the partial match is entering, and the side of the join being entered (an integer value representing either the LHS or RHS of the join).

OTHER NOTES: Calls the functions **AddActivation**, **EmptyDrive**, **EvaluateJoinExpression**, **PPDrive**, **PNLDrive**, and

PNRDrive as necessary to process the addition of the partial match.

EvaluateJoinExpression

PURPOSE: Evaluates join expressions. Performs a faster evaluation for join expressions than if **EvaluateExpression** were used directly. Function calls to **eq_vars**, **neq_vars**, **and**, and **or** are evaluated directly. All other function calls are evaluated using **EvaluateExpression**.

ARGUMENTS: A pointer to the expression to be evaluated, pointers to the partial matches from the alpha and beta memory associated with the expression, and a pointer to the join associated with the expression.

RETURNS: Boolean value. The result of the evaluation of the expression.

GetIncrementalReset

PURPOSE: Returns the current value of the **IncrementalReset** flag.

RETURNS: A boolean value.

PNLDrive

PURPOSE: Handles the entry of a partial match from the LHS of a join that has positive LHS entry and negative RHS entry (meaning the conditional element associated with this join is a **not** conditional element). An new partial match is created by combining the match from the beta memory with a “pseudo” partial match corresponding to the facts which didn't match the **not** CE. Once merged, the new partial match is sent to each child join of the join from which the merge took place.

ARGUMENTS: A pointer to the join being processed and a pointer to the partial match from the join's beta memory that entered from the LHS of the join.

SetIncrementalReset

PURPOSE: Sets the current value of the **IncrementalReset** flag.

ARGUMENTS: A boolean value (the new value of the flag).

RETURNS: A boolean value (the old value of the flag).

INTERNAL FUNCTIONS

ClearLowerBetaMemory

PURPOSE: Removes all partial matches from the beta memory of a join and all joins which descend from that join.

ARGUMENTS: A pointer to the join at which the removal of partial matches should begin.

EmptyDrive

PURPOSE: Handles the entry of a alpha memory partial match from the RHS of a join that is the first join of a rule (i.e. a join that cannot be entered from the LHS). Both positive and negative RHS join entry are handled.

ARGUMENTS: A pointer to the join being processed and a pointer to the partial match from the join's alpha memory that entered from the RHS of the join.

JoinNetErrorMessage

PURPOSE: Prints an informational message indicating which join of a rule generated an error when a join expression was being evaluated.

ARGUMENTS: A pointer to the join being processed when the error occurred.

PNRDrive

PURPOSE: Handles the entry of a partial match from the RHS of a join that has positive LHS entry and negative RHS entry (meaning the conditional element associated with this join is a **not** conditional element). Entry of the alpha memory partial match will cause the count value of the associated beta memory partial match to be incremented. This in turn may cause partial matches associated with the beta memory partial match to be removed from the network.

ARGUMENTS: A pointer to the join being processed and a pointer to the partial match from the join's beta memory that entered from the LHS of the join.

PPDrive

PURPOSE: Handles the merging of an alpha memory partial match with a beta memory partial match for a join that has positive LHS entry and positive RHS entry. The partial matches being merged have previously been checked to determine that they satisfy the constraints for the join. Once merged, the new partial match is sent to each child join of the join from which the merge took place.

ARGUMENTS: Pointers to the partial matches from the alpha and beta memory being merged and a pointer to the join from which the partial matches originated.

Engine Module

The Engine Module (engine.c) provides functionality for browsing, maintaining, updating, and executing the agenda.

GLOBAL VARIABLES

AgendaChanged

PURPOSE: Boolean flag. If TRUE, indicates that the **Agenda** has been altered. Updated to TRUE whenever an activation is added to, removed from, or moved on the **Agenda**.

DeletedFiringRule

PURPOSE: Boolean value. If TRUE, the currently executing rule has been deleted.

ExecutingRule

PURPOSE: A pointer to the rule information data structure of the currently executing rule. If NULL, then no rules are executing.

HaltRules

PURPOSE: Boolean value. If TRUE, rule execution should be halted.

TheLogicalJoin

PURPOSE: A pointer to the join for a rule at which the partial matches needed to set up logical dependencies are stored. If a rule contains no logical conditional elements, then this value is NULL.

INTERNAL VARIABLES

Agenda

PURPOSE: Pointer to the list of rule activations which have not yet fired.

CurrentTimetag

PURPOSE: Integer value used to provide a unique identification number for each activation added to the **Agenda**. Initially zero, this value is incremented by one each time an activation is added to the agenda.

ListOfRunFunctions

PURPOSE: A list of functions which are to be executed after each rule firing.

NumberOfActivations

PURPOSE: Integer value representing the number of activations currently on the **Agenda**.

RuleFiring

PURPOSE: A pointer to the name of the currently executing rule.

SalienceEvaluation

PURPOSE: An integer value representing the current type of salience evaluation (either when defined, when activated, or every cycle).

Strategy

PURPOSE: An integer value representing the current conflict resolution strategy (either depth, breadth, lex, mea, complexity, simplicity, or random).

WatchActivations

PURPOSE: Boolean flag. When TRUE, enables printing of messages indicating addition and removal of activations to the **Agenda**.

WatchStatistics

PURPOSE: Boolean flag. When TRUE, statistical information such as the number of rule firings is printed after the **run** command is executed.

GLOBAL FUNCTIONS

ActivationBasis

PURPOSE: Returns the partial match associated with an activation.

ARGUMENTS: A generic pointer to an activation.

RETURNS: A pointer to a partial match.

AddActivation

PURPOSE: Creates a rule activation to be added to the **Agenda** and links the activation with its associated partial match. The function **PlaceActivation** is then called to place the activation on the **Agenda**. Typically called when all patterns on the LHS of a rule have been satisfied.

ARGUMENTS: The last join of the rule associated with the activation and a pointer to the partial match which activated the rule.

AddBreakpoint

PURPOSE: Adds a breakpoint for the specified rule.

ARGUMENTS: A generic pointer to a defrule structure.

AddRunFunction

PURPOSE: Adds a function to the **ListOfRunFunctions**.

ARGUMENTS: A name to be associated with the function, a pointer to the function, and the priority of the run item.

ClearRuleFromAgenda

PURPOSE: Removes all activations of a specified rule from the **Agenda**.

ARGUMENTS: Name of the rule.

DefruleHasBreakpoint

PURPOSE: Indicates whether the specified rule has a breakpoint set.

ARGUMENTS: A generic pointer to a defrule structure.

RETURNS: Boolean value. TRUE if the defrule has a breakpoint set, otherwise FALSE.

DeleteActivation

PURPOSE: Deletes the specified activation from the agenda.

ARGUMENTS: A pointer to an activation or NULL to remove all activations.

RETURNS: Boolean Value. TRUE, if the specified activation exists and was deleted from the agenda, otherwise FALSE.

GetActivationName

PURPOSE: Returns the name of the rule associated with an activation.

ARGUMENTS: A generic pointer to an activation.

RETURNS: The name of a rule.

GetActivationPPForm

PURPOSE: Returns the pretty print representation of an activation.

ARGUMENTS: A character buffer in which to store the pretty print representation, the size of the buffer in characters, and a generic pointer to an activation.

RETURNS: No return value. The pretty print representation is stored in the character buffer passed as an argument.

GetActivationSalience

PURPOSE: Returns the salience value of an activation.

ARGUMENTS: A generic pointer to an activation.

RETURNS: An integer value.

GetAgendaChanged

PURPOSE: Returns the value of the variable **AgendaChanged**.

RETURNS: Boolean value (TRUE or FALSE).

GetNextActivation

PURPOSE: Returns an activation from the **Agenda**.

ARGUMENTS: A generic pointer to an activation. If the pointer is NULL, the first activation in the **Agenda** is returned. If the pointer is not NULL, the next activation after the pointer is returned.

RETURNS: A generic pointer to an activation. A NULL pointer indicates that there are no further activations in the **Agenda**.

GetNumberOfActivations

PURPOSE: Returns the value of the variable **NumberOfActivations**.

RETURNS: An integer value.

GetRuleFiring

PURPOSE: Returns the value of the variable **RuleFiring**.

RETURNS: The name of a rule.

GetSalienceEvaluation

PURPOSE: Returns the value of the variable **SalienceEvaluation**.

RETURNS: An integer value.

GetStrategy

PURPOSE: Returns the value of the variable **Strategy**.

RETURNS: An integer value.

InitializeEngine

PURPOSE: Initializes the *activations* and *statistics* watch items.

ListAgenda

PURPOSE: Lists all of the activations on the agenda to the logical name *wdisplay*.

ListBreakpoints

PURPOSE: Lists all of the breakpoints to the logical name *wdisplay*.

MoveActivationToTop

PURPOSE: Moves the specified activation in the agenda to the top of the agenda.

ARGUMENTS: A pointer to an activation.

RETURNS: Boolean Value. TRUE, if the specified activation exists and was moved to the top of the agenda, otherwise FALSE.

PrintActivation

PURPOSE: Prints an activation in a “pretty” format. Salience, rule name, and the partial match which activated the rule are printed.

ARGUMENTS: Logical name to which output is sent and a pointer to an activation.

PrintCRSVActivation

PURPOSE: Prints an activation in a CRSV trace file compatible format.

ARGUMENTS: Logical name to which output is sent and a pointer to an activation.

RefreshAgenda

PURPOSE: Recomputes the salience values for all activations on the **Agenda** and then reorders the **Agenda**.

RemoveActivation

PURPOSE: Returns an activation and its associated data structures to the Memory Manager. Links to other activations and partial matches may also be updated.

ARGUMENTS: A pointer to an activation, a flag indicating whether the links between activations on the agenda should be updated, and a flag indicating whether the links between the activation and its corresponding partial match should be updated.

ReorderAgenda

PURPOSE: Reorders the **Agenda** based on the current conflict resolution strategy.

RemoveAllActivations

PURPOSE: Removes all activations from the **Agenda**.

RemoveAllBreakpoints

PURPOSE: Removes all breakpoints.

RemoveBreakpoint

PURPOSE: Removes a breakpoint for the specified rule.

ARGUMENTS: A generic pointer to a defrule structure.

RETURNS: Boolean value. TRUE if the breakpoint was found and removed, otherwise FALSE.

RemoveRunFunction

PURPOSE: Removes a function from the **ListOfRunFunctions**.

ARGUMENTS: Name associated with the run function.

RunCLIPS

PURPOSE: Begins execution of rules on the **Agenda**.

ARGUMENTS: An integer representing the maximum number of rules that can be fired. If run limit is less than zero, rules will be executed until the agenda is empty. If run limit is greater than zero, rules will be executed until either the **Agenda** is empty or the run limit has been reached.

RETURNS: Number of rules fired.

SetActivationSalience

PURPOSE: Sets the salience value of an activation.

ARGUMENTS: A generic pointer to an activation and the new salience value.

RETURNS: The old salience value.

SetAgendaChanged

PURPOSE: Sets the value of the variable **AgendaChanged**.

ARGUMENTS: Boolean value (TRUE or FALSE).

SetSalienceEvaluation

PURPOSE: Sets the value of the variable **SalienceEvaluation**.

ARGUMENTS: An integer value representing the new type of salience evaluation (either when defined, when activated, or every cycle).

RETURNS: An integer value representing the old type of salience evaluation.

SetStrategy

PURPOSE: Sets the value of the variable **Strategy** and then calls the **ReorderAgenda** function to update the **Agenda**.

ARGUMENTS: An integer value representing the new conflict resolution strategy (either depth, breadth, lex, mea, complexity, simplicity, or random).

RETURNS: An integer value representing the old conflict resolution strategy.

INTERNAL FUNCTIONS

CompareBindings

PURPOSE: Compares two activations using the lex conflict resolution strategy to determine which activation should be placed first on the agenda. This lexicographic comparison function is used for both the lex and mea strategies.

ARGUMENTS: Two pointers to the activations to be compared.

RETURNS: An integer value indicating whether the first activation has higher, lesser priority, or equivalent priority to the second activation.

PlaceActivation

PURPOSE: Coordinates placement of an activation on the **Agenda** based on the current conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

PlaceBreadthActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the breadth conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

PlaceComplexityActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the complexity conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

PlaceDepthActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the depth conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

PlaceLEXActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the lex conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

PlaceMEAActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the mea conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

PlaceRandomActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the random conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

PlaceSimplicityActivation

PURPOSE: Determines where an activation should be placed on the **Agenda** for the simplicity conflict resolution strategy.

ARGUMENTS: A pointer to an activation.

RETURNS: A pointer to an activation already on the **Agenda** after which the new activation should be placed. If NULL, then the activation should be placed at the beginning of the **Agenda**.

SortBindings

PURPOSE: Copies a partial match and then sorts the fact-indices in the copied partial match in ascending order.

ARGUMENTS: A pointer to a partial match.

RETURNS: A copied version of the partial match with sorted fact-indices.

Match Module

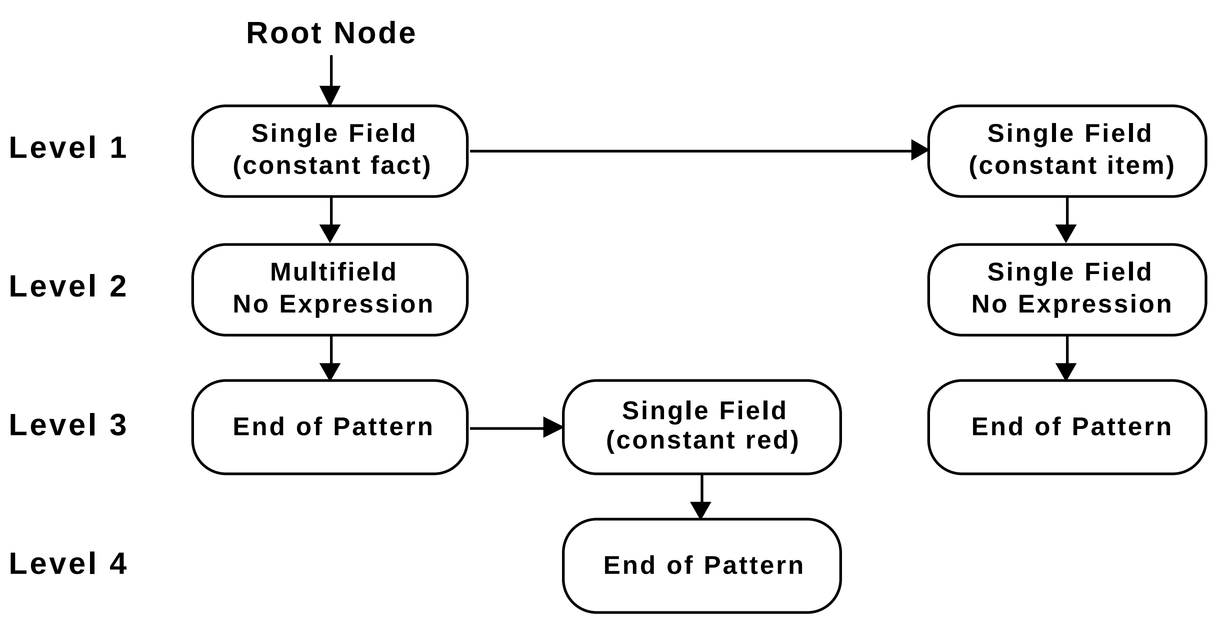
The Match Module (match.c) contains the functionality necessary for traversing the pattern network. The pattern network determines which patterns a fact has matched. The pattern network is organized as a tree structure. Pattern network levels correspond directly to the sequential order of fields found in patterns. That is, all pattern constraints occurring in the first field of a pattern are found in the first level of the pattern network. All pattern constraints that occur in the second field of a pattern are found in the second level of the pattern network. The leaf nodes of the pattern network represent the end of a pattern. These leaf nodes connect the pattern network to the join network.

Each pattern node contains several pieces of information. A pointer is stored to the next and previous sibling nodes as well as a pointer to the parent node and the first child node. The child nodes of a pattern node can be determined by following the first child node value and then following the next sibling node value of each child. Each pattern node contains information about whether it is intended to match a single field or multiple fields of a fact. Only multifield variables and wildcards can match multiple fields. Each node may also contain an expression which, when evaluated, determines whether a field has satisfied a pattern constraint. In addition, an end-of-pattern leaf node contains a pointer to an alpha memory which stores a list of all facts that matched the pattern and a pointer to the list of joins in the join network that are to be entered from the leaf node when a fact has matched the pattern.

As an example, the following patterns (possibly found in one or more rules)

```
(fact $?)
(fact $?x red $?y)
(item ?x)
(item ?y)
```

would produce the following pattern network:



Notice that the patterns (item ?x) and (item ?y) are treated as the same pattern in the pattern network. The patterns (fact $?) and (fact $?x red $?y) share their first two fields in the pattern network. The left-most "end of pattern" node is the node associated with the successful pattern match of the pattern (fact $?). The middle "end of pattern" node is the node associated with the successful pattern match of the pattern (fact $?x red $?y). The right-most "end of pattern" node is the node associated with the successful pattern match of the patterns (item ?x) and (item ?y).

When a new fact is added to the fact-list, it must traverse the pattern network to determine which patterns it has matched. A traversal of the pattern network must be complete. That is, all patterns that have been matched must be found. Traversal involves testing fields of the fact against pattern expressions found in the pattern network. As stated previously, the first level of the pattern network performs tests for the first fields of the patterns, the second level of the pattern network performs tests for the second fields of the patterns, and so on. In general, this means that the first level of the pattern network performs tests against the first field of the newly asserted fact, the second level of the pattern network performs tests against the second field of the newly asserted fact, and so on. Pattern nodes that can match against multiple fields can throw this strict correspondence off. Levels below a multifield pattern node do not correspond directly to a field in the fact; however, they still correspond directly to a field in the pattern.

Pattern network traversal begins by assigning one pointer the value of the first field of the newly asserted fact. Hereafter, this pointer will be called the fact field pointer. Another pointer is assigned the value of the "upper-left," "top-most," or "root" node in the pattern network. Hereafter, this pointer will be called the current pattern pointer.

If the pattern node is intended to match a single field and no expression is associated with the pattern node, the fact field pointer is "incremented" to point to the next field of the fact. Matching then proceeds to the first child node of the current pattern node.

If the single-field pattern node has an expression associated with it, that expression must be evaluated. If the expression evaluates to true, the fact field pointer is "incremented" and matching proceeds to the first child node of the current pattern node. If the expression evaluates to false, the matching attempt for this pattern node has failed and backtracking must take place. For example, if the expression associated with a pattern node was (constant red), the matching process could only proceed past this pattern node if the field pointed to by the fact field pointer had the value of red.

If at any point either the current pattern node is a leaf node and the fact field pointer is pointing at a remaining field in the fact or the current pattern node is not a leaf node and the fact field pointer is empty (i.e., no more fields are left in the fact), the matching process has failed. The length of the fact does not match the length of the pattern currently being matched. Backtracking takes place when this occurs.

If a leaf node is reached and the fact field pointer is empty, a pattern has been matched. The fact id of the fact being matched is stored in the alpha memory of the pattern node and the partial match containing the single-fact id is sent to all joins in the join network connected to this pattern node. Backtracking then takes place to find other pattern matches.

Multifield variables and wildcards add another level of complexity to the pattern matching process. The process for matching a multifield pattern node is similar to the single-field pattern nodes, with the exception that there is usually more than one way in which a multifield pattern node can match against a fact. To accommodate multifield matches (which match multifield pattern nodes to zero or more fields of a fact), the pattern matching algorithm is entered recursively for each of all possible ways in which the multifield node can match. For example, if a multifield node is entered and two fields remain in the fact, the match algorithm is recursively entered three times with the multifield being bound respectively to zero, one, and two fields of the fact.

Multifield markers are used to keep track of the fields matched by a multifield variable or wildcard. That is, if a multifield variable were the third field of a pattern, a multifield marker might contain the information "The third field of the pattern matched the third through sixth fields of the fact." Multifield markers are chained together as multifield pattern nodes are encountered.

If a failure ever occurs while pattern matching or a leaf node has been successfully reached, backtracking must occur in an attempt to find other matches. If the current pattern node has a right-sibling node, the current pattern node is set to the right-sibling node. Otherwise, continue setting the current pattern node to the parent of the current pattern node until a node is reached that has a right sibling. For each level backtracked, the fact-field pointer and pattern field pointer need to be decremented. If there is no pattern node (i.e., the parent of the root node) or a multifield node is reached, a return should be made from this recursive level of the pattern network traversal. Multifield markers are unchained when returning from a level of recursion in the pattern matching process.

The pattern matching process also makes use of some shortcuts to increase speed. For example, all expression that test for field equality against a single constant value are placed toward the "right" or "end" of the list of siblings. Whenever a test against one of these nodes succeeds, it is not necessary to backtrack to the right-sibling nodes since the tests for these nodes are mutually exclusive. In addition, a multifield node that has only a single "end of pattern" node as a child does not have to generate all possible matches. The multifield node must bind to all remaining fields in the fact.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

CurrentPatternFact

PURPOSE: A pointer to the fact currently being matched.

CurrentPatternMarks

PURPOSE: A list of multifield markers for the fact currently being matched.

GLOBAL FUNCTIONS

GetFieldSysFunction

PURPOSE: Extracts a specified field value from a fact during the pattern matching process for the purpose of expression evaluation. This is the C implementation of the **getfield** function discussed in the Generate Module.

ARGUMENTS: A pointer to a DATA_OBJECT structure in which the field value will be stored.

RETURNS: Value of the variable extracted from the fact

OTHER NOTES: Uses the global variables **CurrentPatternFact** and **CurrentPatternMarks** to extract the value.

PatternMatch

PURPOSE: Filters a fact through the pattern network searching for all patterns matches by the fact.

ARGUMENTS: A pointer to the fact being matched, a pointer to the current element in the fact being matched, a pointer to the pattern node being matched against, an index for the depth traversed into the pattern network, an index to the current field being matched in the fact, a pointer to the list of multifield markers, and a pointer to the last multifield marker in the list of multifield markers.

OTHER NOTES: Some parameters provide redundant information. See above for description of compare algorithm.

PatternNetErrorMessage

PURPOSE: Prints an error message when a error occurs as the result of evaluating an expression in the pattern network. Prints the fact currently being matched against and the field in the pattern which caused the problem, then calls the function **TraceErrorToPattern** to further isolate the error.

ARGUMENTS: A pointer to the pattern node being matched against when the error occurred.

TraceErrorToRule

PURPOSE: Prints an error message when a error occurs as the result of evaluating an expression in the pattern network. Used to indicate which rule caused the problem.

ARGUMENTS: A pointer to the join node associated with the pattern being matched against when the error occurred and an integer value indicating the number of spaces that should be printed before the rule name.

LOCAL FUNCTIONS

CopySegmentMarkers

PURPOSE: Copies a list of multifield markers.

ARGUMENTS: A pointer to a list of multifield markers.

RETURNS: A pointer to a copied list of multifield markers.

EvaluatePatternExpression

PURPOSE: Evaluates an expression found in a node the pattern network which is used to determine if a field in a fact matches the pattern node. For example, the expression may indicate that the field of the fact must either be the constant *red* or the constant *green*.

ARGUMENTS: A pointer to the current field in the fact being tested, an expression to be evaluated, and a pointer to the pattern node with which the expression is associated.

RETURNS: Boolean value. TRUE if the expression evaluates to TRUE and FALSE if the expression evaluates to FALSE.

OTHER NOTES: Implemented as a separate function from the general purpose function **EvaluateExpression** to allow a fast evaluation of common pattern network expressions. Functions evaluated are **constant** and **notconstant** (which determine respectively whether a field is equal or not equal to a particular constant), **eqfield** and **neqfield** (which determine respectively whether two fields in the same fact are either equal or not equal), and the functions **and** and **or**. All other functions are evaluated using the function **EvaluateExpression**.

TraceErrorToPattern

PURPOSE: Prints an error message when a error occurs as the result of evaluating an expression in the pattern network. Used to indicate which patterns caused the problem (e.g. 1st pattern of a rule, 2nd pattern of a rule, etc). Calls the function **TraceErrorToRule** to further isolate the error.

ARGUMENTS: A pointer to the pattern node being matched against when the error occurred.

Retract Module

The Retract Module (retract.c) handles the major functionality of updating the join network when a fact has been retracted from the knowledge base. The algorithm for retracting a fact from the knowledge base is described as follows.

As pattern matching occurs, information is stored with each fact to indicate which patterns have matched a given fact. Thus, it is not necessary to perform pattern matching during retraction of a fact as all matched patterns are already known. Given the list of patterns matched by a fact to be retracted, the Retract Module will loop through the list of patterns and perform appropriate retraction operations for that pattern. Each pattern matched has an associated “end of pattern” node which is connected to a series of joins. Joins entered from a **not pattern** CE will use different algorithms for handling a fact retraction than joins entered from a **pattern** CE. In addition, retraction from the join associated with the first CE of a rule is handled differently. Each algorithm will be discussed in greater detail in the following paragraphs. Once retraction has been performed for all joins associated with a specific pattern node, the alpha memory partial match corresponding to the retracted fact can be removed from the alpha memory of the pattern node.

The first algorithm for retraction occurs when the join being entered has a **pattern** CE associated with its RHS. If the join was entered from the RHS, the partial match containing the retracted fact is known to exist in the alpha memory associated with this join (and will be removed later). Otherwise, the beta memory of the join is searched to find and delete all partial matches containing the fact. If the fact is not found in the join, then retraction for this portion of the join network is complete. Otherwise, this algorithm is used to recursively retract the fact from all child joins of the current join. Note that a level of recursion is removed from this algorithm by performing retraction recursively for all but one of the child joins attached to the current join. This last join is handled non-recursively within the main loop of the algorithm. Thus, in the event that every join has a single child join, this algorithm will stay within a relatively tight loop avoiding recursion.

The second algorithm for retraction occurs when the join is associated with a **not pattern** CE that is the first CE of a rule. First, the number of occurrences of the fact in partial matches found in the alpha memory associated with this join is determined. These occurrences represent the facts preventing the **not pattern** CE from being satisfied. The id slot of the join (which in the top-most join represents the number of facts preventing the **not pattern** CE from being satisfied) can then be decremented by the number of fact occurrences found in the alpha memory. If, after decrementing, the join id is not zero, then the **not pattern** CE still has facts preventing it from being satisfied and the retraction process for this join is completed. Otherwise, the **not pattern** CE has been satisfied. If the secondary join expression (for **test** CEs following a **not pattern** CE) associated with the join is also satisfied, a pseudo-fact partial match for the **not pattern** CE can be created and sent to all the child joins connected to this join. The newly created partial match is indirectly sent to the others joins by using the **DriveRetractions** function.

The third algorithm for retraction occurs when the join is associated with a **not pattern** CE that is not the first CE of a rule. This algorithm is similar to the second algorithm. The major exception is that the count for the number of facts preventing the join from being satisfied is stored in the beta memory partial matches. This algorithm uses a double loop, looping through the alpha memory in the outer loop and the beta memory in the inner loop. Within the inner loop, if the alpha memory partial match being tested corresponds to the fact being retracted, the primary join expression is evaluated for the current alpha and beta memory partial matches. If the expression evaluates to TRUE (or was non-existent), the alpha memory partial match conflicted with the beta memory partial match. The count of conflicting facts in the beta memory partial match can be decremented by one. If the beta memory count reaches zero and the second join expression associated with the join evaluates to TRUE, a new partial match consisting of a pseudo-fact partial match and the beta memory partial match combined is created and sent to all the child joins connected to this join. The newly created partial match is indirectly sent to the others joins by using the **DriveRetractions** function.

GLOBAL VARIABLES

GarbageAlphaMatches

PURPOSE: Maintains a list of data structures which represent the pseudo-facts that matched **not** CEs if no real facts matched the CE. Like facts, these data structures are not thrown away during rule execution, since the rule may still refer to the data structure.

GarbagePartialMatches

PURPOSE: Maintains a list of partial matches associated with a **not** CE or an alpha memory. Like facts, these data structures are not thrown away during rule execution, since the rule may still refer to the data structure.

INTERNAL VARIABLES

DriveRetractionList

PURPOSE: Maintains a list of partial matches that are to be driven through the join network as the result of a **not** CE being satisfied by a retraction.

GLOBAL FUNCTIONS

DeletePartialMatches

PURPOSE: Searches through a list of partial matches and removes any partial match that contains the specified fact-index.

ARGUMENTS: A fact-index, a list of partial matches, and a pointer to an integer flag which indicates if any partial matches were deleted, an integer indicating the position in the partial match to be searched for the fact-index, and an integer flag indicating whether the list of partial matches is associated with an alpha or beta memory.

RETURNS: Returns the modified list of partial matches. The integer flag is set to TRUE if any partial matches were deleted. Otherwise, it is set to FALSE.

FlushGarbagePartialMatches

PURPOSE: Returns partial matches and associated structures that were removed as part of a retraction. It is necessary to postpone returning these structures to memory because RHS actions retrieve their variable bindings directly from the fact data structure through the alpha memory bindings.

ARGUMENTS: None. Makes use of the **GarbageAlphaMatches** and **GarbagePartialMatches** variables.

NetworkRetract

PURPOSE: Coordinates the retraction of a fact from the join and pattern networks.

ARGUMENTS: A list of the patterns that the fact matched and the fact-index of the fact being retracted.

OTHER NOTES: See algorithm above.

PosEntryRetract

PURPOSE: Handles removing partial matches from a join and all child joins that contain a specified fact. Used for joins that's RHS entry is associated with a **pattern** CE.

ARGUMENTS: Direction from which the join was entered, a pointer to the join, the fact-index of the fact to be removed from the join, and the position where the fact-index should be found in the partial matches.

ReturnPartialMatch

PURPOSE: Returns a partial match and its associated data structures to the CLIPS memory manager. If the partial match is busy (i.e. it is currently in use) it is placed on the list of **GarbagePartialMatches**.

ARGUMENTS: A pointer to a partial match.

INTERNAL FUNCTIONS

DriveRetractions

PURPOSE: Drives partial matches generated by the retraction of a fact through the join network.

ARGUMENTS: None. Uses the **DriveRetractionList** to determine new partial matches to be driven through the join network.

OTHER NOTES: The retraction of a fact can generate new partial matches that must be driven through the join network if that fact matched a **not** CE. However, such a fact may also match **pattern** CEs in the same rule. Therefore, to prevent partial matches being generated from facts that are to be retracted, propagation of new partial matches through the join network is delayed until all partial matches containing a fact to be retracted have been removed from the join and pattern networks.

NegEntryRetract

PURPOSE: Handles retractions from the RHS for joins associated with a **not** CE that are not associated with the first pattern of a rule.

ARGUMENTS: A pointer to a join and the fact ID of the fact to be retracted.

ReturnMarkers

PURPOSE: Returns the list of data structures associated with an alpha memory partial match that indicate how multifield variables matched the pattern associated with the partial match.

ARGUMENTS: A list of data structures.

TopNegJoinRetract

PURPOSE: Handles retractions from the RHS for top-level joins (i.e. joins associated with the first pattern of a rule) associated with a **not** CE.

ARGUMENTS: A pointer to a top-level join and the fact-index of the fact to be retracted.

Rete Utility Module

The Rete Utility Module (reteutil.c) contains a number of functions that are useful to other modules for implementing the Rete algorithm.

GLOBAL VARIABLES

GlobalLHSBinds

PURPOSE: A pointer to the partial match currently being examined on the LHS of a join as part of the pattern matching process. Also used to point to the partial match associated with the activation for the currently executing rule. This variable is used by a number of functions (such as the **get_var** function) to extract a value from the LHS of a rule for use in a function call.

GlobalRHSBinds

PURPOSE: A pointer to the partial match currently being examined on the RHS of a join as part of the pattern matching process. This variable is used by a number of functions (such as the **get_var** function) to extract a value from the LHS of a rule for use in a function call.

INTERNAL VARIABLES

PseudoFactIndex

PURPOSE: Contains the next fact index to be used when creating a “pseudo” fact. Pseudo facts are used in the pattern matching process to indicate that a **not** conditional element has no facts matching it. Pseudo facts have a fact index which is less than zero.

GLOBAL FUNCTIONS

AddSingleMatch

PURPOSE: Adds an additional alpha match to a partial match.

ARGUMENTS: A pointer to a partial match and a pointer to an alpha match from the pattern network.

RETURNS: A pointer to a new partial match which consists of the single alpha match appended to the first partial match (the original partial match is unaffected).

AdjustFieldPosition

PURPOSE: Given the number of fields each multifield variable or wildcard in a pattern has actually matched, determines the actual index of a variable within a pattern in the matching fact. For example, given the pattern (data $?x c $?y ?z) and the fact (data a b c d e f x), the actual index in the fact for the 5th item in the pattern (the variable ?z) would be 8 since $?x binds to 2 fields and $?y binds to 3 fields.

ARGUMENTS: A pointer to a list of data structures describing the fields that each multifield variable or wildcard has matched, an integer indicating the position of the variable within the pattern, and a pointer to an integer which stores the extent of the variable (the number of fields the variable has matched—zero or greater for multifield variables).

RETURNS: The index of the variable within the fact matched by the pattern. The extent of the variable (if it is a multifield) is also stored in one of the calling arguments (which should be initialized either to 1 if there is no need to distinguish between the extent of single field and multifield variables or -1 if there is a need).

ClearPatternMatches

PURPOSE: Removes all links between a pattern and the facts that have matched that pattern.

ARGUMENTS: A pointer to a pattern node (which should be an end of pattern pattern node).

CopyPartialMatch

PURPOSE: Copies a partial matches.

ARGUMENTS: A pointer to a partial matches to be copied.

RETURNS: A pointer to a copy of the partial match.

FindFactInPartialMatch

PURPOSE: Searches for a specified fact index in a partial match.

ARGUMENTS: Fact index for which to search and a pointer to a partial match.

RETURNS: Boolean value. TRUE if the fact index is found; otherwise FALSE.

FlushAlphaBetaMemory

PURPOSE: Returns all partial matches in a list of partial matches either directly to the pool of free memory or to the list of **GarbagePartialMatches**.

ARGUMENTS: A pointer to a list of partial matches.

IncrementPseudoFactIndex

PURPOSE: Decrements the current value of **PseudoFactIndex** and returns the previous value.

RETURNS: The current value of the global variable **PseudoFactIndex**.

MarkRuleNetwork

PURPOSE: Marks each node in the pattern and join networks with a boolean value (typically indicating whether a action has been taken for that node). This mark value is used by binary save and the construct compiler.

ARGUMENTS: The boolean value that the nodes are to be marked with (TRUE or FALSE).

RETURNS: No return value. The boolean value is stored in the marked slot of the pattern and join nodes.

MergePartialMatches

PURPOSE: Combines two partial matches into a single partial match.

ARGUMENTS: A pointer to a partial match and another pointer to a partial match.

RETURNS: A pointer to a new partial match which consists of the second partial matched appended to the first partial match (the original partial matches are unaffected).

NewPseudoFactPartialMatch

PURPOSE: Creates a partial match consisting of a pseudo fact index associated with a **not** CE.

RETURNS: A partial match consisting of the pseudo fact index. The value of **PseudoFactIndex** is also decremented by this function.

GetNumericArgument

PURPOSE: Directly evaluates a numeric expression under certain conditions.

ARGUMENTS: A pointer to an expression to evaluate, the name of the function being executed, a pointer to a DATA_OBJECT structure in which to store the result of the evaluation, a boolean flag indicating whether integer results should be converting to floating point, and an integer value representing the position of the expression within the argument list of the function being executed.

RETURNS: Boolean value. TRUE if the result of the expression evaluation was a number, otherwise FALSE. The value of the number is also stored in the DATA_OBJECT structure.

OTHER NOTES: Used to provide fast evaluate of arguments to basic arithmetic functions. If the argument is a number or a variable, it is evaluated immediately, otherwise, **EvaluateExpression** is used.

PrimeJoin

PURPOSE: Updates a join in a rule for an incremental reset. Joins are updated by “priming” them only if the join is shared with other rules that have already been incrementally reset. A join for a new rule will be updated if it is marked for initialization and either its parent join or its associated entry pattern node has not been marked for initialization.

ARGUMENTS: A pointer to a join.

PrintPartialMatch

PURPOSE: Prints out a list of fact indices associated with a partial match or rule instantiation.

ARGUMENTS: A logical name to which output is sent and a pointer to a partial match.

ResetDeployedRuleImage

PURPOSE: Incrementally resets a runtime image created using the construct compiler. This function is called by the **InitCImage** function associated with the runtime image.

ResetNotedJoin

PURPOSE: Determines if a given join is associated with a **not** CE that is the first pattern of a rule and also whether it should be initialized. If the join needs to be initialized a partial match for the join is created. This function is called as part of an incremental reset.

ARGUMENTS: A pointer to a join node.

ResetNotedPatterns

PURPOSE: Searches for and generates partial matches for **not** CEs that are the first pattern of a rule. This function is called as part of an incremental reset for runtime images create with the construct compiler and is called by the function **ResetDeployedRuleImage**.

ARGUMENTS: A pointer to a pattern node in the pattern network. This function uses recursion to traverse the pattern network. This first call to this function should pass the root node of the pattern network as its argument.

SetPseudoFactIndex

PURPOSE: Sets the value of the global variable **PseudoFactIndex**.

ARGUMENTS: New integer starting value for pseudo fact indices (which must be less than zero).

TagRuleNetwork

PURPOSE: Assigns a unique integer value to each pattern node in the pattern network and each join node in the join network. This ID value is used by binary save and the construct compiler.

ARGUMENTS: A pointer to an integer value containing the number of pattern nodes encountered and the number of join nodes encountered. The value of these integer variables should be set to zero before this function is called.

RETURNS: No return value. The pointers passed as arguments have their values respectively set to the number of pattern nodes and join nodes found in the rule network.

C IMPLEMENTATION: The integer ID value is stored in the bsaveID slot of the pattern and join nodes.

INTERNAL FUNCTIONS

None.

Logical Dependencies Module

The Logical Dependencies Module (lgcldpnd.c) provides the support routines necessary for the implementation of the **logical** conditional element. A fact asserted by a rule without **logical** CEs in the rule's LHS is unconditionally supported. A fact that is unconditionally supported can only be explicitly retracted (i.e. it cannot be retracted as the direct result of retracting another fact). Facts asserted by deffacts, from the top-level command prompt, or as the result of actions occurring outside the scope of a executing rule containing **logical** CEs are also unconditionally supported. A fact asserted by a rule with **logical** CEs in the rule's LHS is logically supported by that rule. The group of facts contained within the logical CE provide the logical support for the asserted fact.

Since the logical CEs must appear as the first patterns on the LHS of a rule and there can be no gaps between logical CEs, there exists a partial match for the rule containing all of the facts providing logical support in the beta memory of one of the rule's joins. Logical dependencies are implemented by maintaining two types of links. First, links are created between a partial match and each fact which receives logical support from that partial match. Second, reverse links are created between facts and the partial matches which provide logical support to them.

When a defrule is parsed that contains **logical** CEs, the location of the join that will contain the partial matches providing logical support is computed. A pointer to this join is saved as part of the defrule's data structure. When the rule is then executed, the pointer to the join is stored in the global variable **TheLogicalJoin**. Assertions that occur from the RHS of the executing rule can then create the appropriate links between the partial match stored in the join referenced by **TheLogicalJoin** and the facts to which it provides logical support. When partial matches are removed from the beta memories of a join (either as the result of a retract or an assert), then the links between that partial match and the facts it supports are updated. If a fact loses all of its logical support, then it is automatically retracted.

The following two rules will be used to illustrate the links used to support logical dependencies.

```
(defrule Example-1
   (logical (a)
            (b))
   (d)
   =>
   (assert (e) (f)))

(defrule Example-2
   (logical (b)
            (c))
   (d)
   =>
   (assert (f) (g)))
```

Assuming the rules have already been loaded, the following commands will execute the rules creating three new facts which are logically supported.

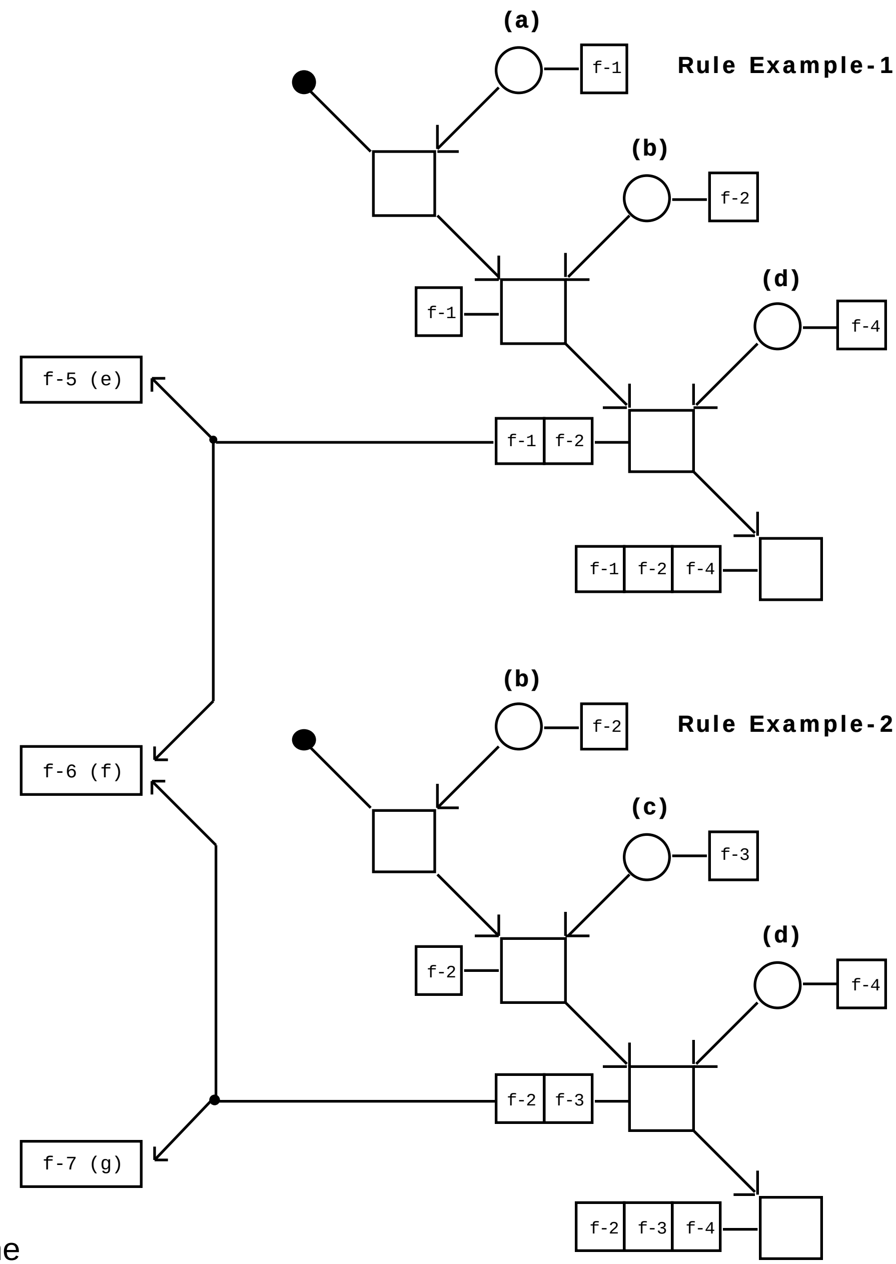
```
CLIPS> (reset)
```

```
CLIPS> (assert (a) (b) (c) (d))
CLIPS> (run)
CLIPS>
```

The following commands illustrate the logical dependency links between the facts.

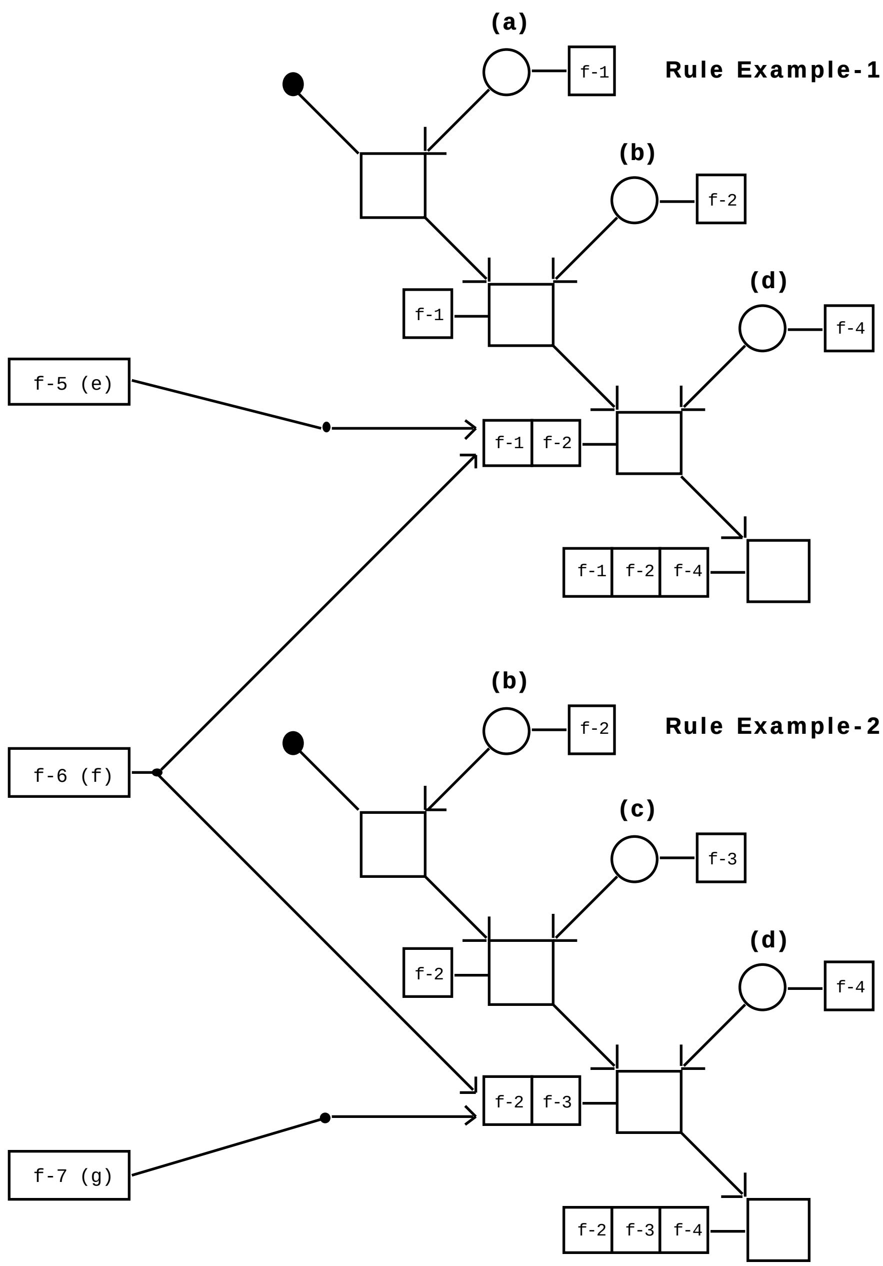
```
CLIPS> (facts)
f-0     (initial-fact)
f-1     (a)
f-2     (b)
f-3     (c)
f-4     (d)
f-5     (e)
f-6     (f)
f-7     (g)
For a total of 8 facts.
CLIPS> (dependencies 5)
f-1,f-2
CLIPS> (dependencies 6)
f-2,f-3
f-1,f-2
CLIPS> (dependencies 7)
f-2,f-3
CLIPS>
```

The logical support links between the partial matches and the facts dependent upon the partial match are shown in the following diagram. The facts (e) and (f) asserted by rule Example-1 are logically dependent upon the partial match containing facts (a) and (b). Similarly, the facts (f) and (g) asserted by rule Example-2 are logically dependent upon the partial match containing facts (b) and (c). Note that each partial match supports two different facts.



the

The logical support links between the facts and the partial matches from which they receive logical are shown in the following diagram. Fact (e) is logically supported by the partial match containing facts (a) and (b) from rule Example-1. Fact (f) is logically supported by the partial match containing facts (a) and (b) from rule Example-1 and the partial match containing facts (b) and (c) from rule Example-2. Fact (g) is logically supported by the partial match containing facts (b) and (c) from rule Example-2. Note that fact (f) receives logical support from two different partial matches.



GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DependencyList

PURPOSE: A list of pointers to facts that are to be removed because all of their logical support has been removed.

GLOBAL FUNCTIONS

AddLogicalDependencies

PURPOSE: Adds the logical dependency links between a fact and the partial match which logically supports that fact. If a fact is unconditionally asserted (i.e. the global variable **TheLogicalJoin** is NULL), then existing logical support for the fact is no longer needed and it is removed. If a fact is already unconditionally supported and the fact is conditionally asserted (i.e. the global variable **TheLogicalJoin** is not NULL), then the logical support is ignored. Otherwise, the partial match is linked to the fact and the fact is linked to the partial match.

ARGUMENTS: A pointer to a fact and a boolean flag indicating if the fact already exists. If a fact already exists, it just receives additional logical support.

RETURNS: Boolean value. TRUE if the fact should be asserted, otherwise FALSE. A value of FALSE is returned when the logical support for a fact is removed before the fact is asserted (e.g. by retracting a fact contained in a **logical** CE of a rule before asserting the fact dependent on the partial match associated with the **logical** CE).

AddToDependencyList

PURPOSE: Removes the dependency links between a partial match and the facts it logically supports. Also removes the associated links from the facts which point back to the partial match by calling **DetachAssociatedFactDependencies**. If a fact has all of its logical support removed as a result of this procedure, the dependency link from the partial match is added to the **DependencyList** so that the fact will be retracted as a result of losing its logical support.

ARGUMENTS: A pointer to a partial match.

ForceLogicalRetractions

PURPOSE: Retracts the first fact found on the **DependencyList** by calling **RetractFact**. This retraction will then trigger the retract of the remaining facts on the **DependencyList** since RetractFact will call **GetNextLogicalRetraction**. This function is called by **AddFact** after a new fact has been processed because the addition of a new fact may cause partial matches associated with a not conditional element to be removed. **RetractFact** does not call this function since it automatically processes the retraction of facts that lose their logical support.

GetNextLogicalRetraction

PURPOSE: Returns the next fact on the **DependencyList** that is to be retracted because all of its logical support has been removed.

RETURNS: A pointer to a fact. The **DependencyList** is also modified (the first item on the list is removed).

ListDependencies

PURPOSE: Lists the partial matches from a specified fact receives logical support.

ARGUMENTS: A pointer to a fact.

ListDependents

PURPOSE: Lists all facts which receive logical support from a specified fact.

ARGUMENTS: A pointer to a fact.

RemoveFactDependencies

PURPOSE: Removes all logical support links from a fact that point to any partial matches. Also removes the associated links from the partial matches which point back to the fact by calling **DetachAssociatedPMDependencies**.

RemovePMDependencies

PURPOSE: Removes all logical support links from a partial match that point to any facts. Also removes the associated links from the facts which point back to the partial match by calling **DetachAssociatedFactDependencies**.

ARGUMENTS: A pointer to a fact.

LOCAL FUNCTIONS

DetachAssociatedFactDependencies

PURPOSE: Removes all logical support links from a fact that point to a specified partial match. Does not remove links which may point back to the fact from the partial match.

ARGUMENTS: A pointer to a fact and a pointer to a partial match.

DetachAssociatedPMDependencies

PURPOSE: Removes all logical support links from a partial match that point to a specified fact. Does not remove links which may point back to the partial match from the fact.

ARGUMENTS: A pointer to a partial match and a pointer to a fact.

FindLogicalBind

PURPOSE: Finds the partial match associated with the **logical** CE which will provide logical support for a fact asserted from the currently executing rule. The function is called by **AddLogicalDependencies** when creating logical support links between the facts and supporting partial matches. It compares each partial match found at a specified join to the partial match associated with a rule activation until it finds the partial match that generated the rule activation.

ARGUMENTS: A pointer to a join data structure and a partial match. Called by the function **AddLogicalDependencies** with the values **TheLogicalJoin** and **GlobalLHSBinds**.

RETURNS: A pointer to a partial match (or NULL if the appropriate partial match could not be found).

Defrule Manager Module

The Defrule Manager Module (defrule.c) contains a set of functions which initialize and provide high level support for the defrule construct.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DeletedRuleHadBreakpoint

PURPOSE: Boolean flag. If TRUE, the last rule deleted had a breakpoint set. This flag is used to restore the breakpoint status of a rule that is redefined.

DeletionsAllowed

PURPOSE: Boolean flag. If TRUE, indicates that rules can be deleted. Rules cannot be deleted during certain operations such as assertion and retraction of facts.

LastDefrule

PURPOSE: A pointer to the last defrule in the **ListOfDefrules**.

ListOfDefrules

PURPOSE: A linked list of all the currently defined defrules.

WatchRules

PURPOSE: Boolean flag. If TRUE, indicates that rule firings should be displayed.

GLOBAL FUNCTIONS

ClearDefrules

PURPOSE: Defrule construct clear function. Deletes all defrules.

DeleteDefrule

PURPOSE: Deletes a defrule from the **ListOfDefrules**.

ARGUMENTS: A pointer to the defrule to be deleted.

RETURNS: Boolean value. TRUE if the defrule was found and deleted, otherwise FALSE.

DeleteNamedDefrule

PURPOSE: Deletes a named defrule from the **ListOfDefrules**.

ARGUMENTS: The name of the defrule to be deleted.

RETURNS: Boolean value. TRUE if the defrule was found and deleted, otherwise FALSE.

EvaluateSalience

PURPOSE: Returns the salience value of the specified defrule. If salience evaluation is currently set to when-defined, then the current value of the rule's salience is returned. Otherwise the salience expression associated with the rule is reevaluated, the value is stored as the rule's current salience, and it is then returned.

ARGUMENTS: A pointer to a defrule data structure.

RETURNS: The current salience value of the rule. The slot value for the defrule's current salience value is also changed if needed.

FindDefrule

PURPOSE: Finds a named defrule in the **ListOfDefrules**.

ARGUMENTS: The name of the defrule to be found.

RETURNS: A pointer to the defrule if found, otherwise NULL.

GetDefruleName

PURPOSE: Returns the name of a defrule.

ARGUMENTS: A pointer to a defrule.

RETURNS: String name of the defrule.

GetDefrulePPForm

PURPOSE: Returns the pretty print representation of a defrule.

ARGUMENTS: A pointer to a defrule.

RETURNS: The string pretty print representation of the defrule.

GetDisjunctIndex

PURPOSE: Returns the disjunct index of a defrule. Disjuncts are created when **or** conditional elements are used on the LHS of a rule. Each disjunct acts as a separate rule and handles one permutation created by the **or** CEs on the LHS of the rule.

ARGUMENTS: A pointer to a defrule data structure (the disjunct that's index is being sought).

RETURNS: An integer value. If the disjunct cannot be found -1 is returned. Otherwise an integer value ranging from zero to one less than the number of disjuncts for the rule.

GetIndexedDefrule

PURPOSE: Allows access to the **ListOfDefrules** by returning a pointer to nth defrule in the **ListOfDefrules**.

ARGUMENTS: Integer index of the rule desired in the **ListOfDefrules**.

RETURNS: A pointer to the specified defrule. If the index is greater than the number of rules in the **ListOfDefrules**, a NULL pointer is returned.

GetNextDefrule

PURPOSE: Allows access to the **ListOfDefrules**.

ARGUMENTS: A pointer to a deffacts in the **ListOfDefrules**.

RETURNS: If passed a NULL pointer, returns the first defrule in the **ListOfDefrules**. Otherwise, returns the next defrule following the defrule passed as an argument.

GetRuleDeletions

PURPOSE: Returns the current value of the **RuleDeletions** flag.

RETURNS: A boolean value.

GetRulesWatch

PURPOSE: Returns the current value of the **WatchRules** flag.

RETURNS: A boolean value.

InitializeDefrules

PURPOSE: Initializes the defrule construct. Adds the rules watch item, adds **reset**, **clear**, and **save** functions for defrules, and calls the functions **DefruleCommands** and **InitializeEngine** to define other defrule related commands and features.

IsDefruleDeletable

PURPOSE: Indicates whether a defrule can be deleted.

ARGUMENTS: A pointer to a defrule.

RETURNS: Boolean value. TRUE if the defrule can be deleted, otherwise FALSE.

ListMatches

PURPOSE: Prints all of the partial matches and activations for a specified defrule.

ARGUMENTS: A pointer to the defrule for which matches are to be listed.

RETURNS: Boolean value. TRUE if the matches were listed, otherwise FALSE.

RefreshDefrule

PURPOSE: Refreshes a defrule. Activations of the rule that have already been fired are added to the agenda.

ARGUMENTS: A pointer to the defrule to be refreshed.

RETURNS: Boolean value. TRUE if the defrule was successfully refreshed, otherwise FALSE.

ReturnDefrule

PURPOSE: Returns a defrule data structure to the CLIPS memory manager.

ARGUMENTS: A pointer to a defrule data structure.

RETURNS: Boolean value. TRUE if the data structure was successfully returned to the CLIPS memory manager, otherwise FALSE.

SalienceInformationError

PURPOSE: Prints an informational message indicating which rule's salience declaration caused an error when a salience value was being evaluated.

ARGUMENTS: The name of a rule.

SetListOfDefrules

PURPOSE: Sets the **ListOfDefrules** to the specified value. Normally used when initializing a run-time module or when bloading a binary file to install the **ListOfDefrules**.

ARGUMENTS: A pointer to a linked list of defrules.

SetRuleDeletions

PURPOSE: Sets the current value of the **RuleDeletions** flag.

ARGUMENTS: A boolean value (the new value of the flag).

RETURNS: A boolean value (the old value of the flag).

LOCAL FUNCTIONS

AddDefrule

PURPOSE: Adds a defrule to the **ListOfDefrules** and updates the value of the variable **LastDefrule**.

ARGUMENTS: A pointer to the defrule data structure.

AddTerminatorJoin

PURPOSE: Creates the final join for a rule which contains the partial matches for the activations of the rule.

RETURNS: A pointer to a join node data structure.

CheckForPrimableJoins

PURPOSE: Updates the joins of a rule for an incremental reset if portions of that rule are shared with other rules that have already been incrementally reset. A join for a new rule will be updated if it is marked for initialization and either its parent join or its associated entry pattern node has not been marked for initialization. The function **PrimeJoin** is used to update joins which meet these criteria.

ARGUMENTS: A pointer to a defrule data structure.

IncrementalReset

PURPOSE: Incrementally resets the specified rule. First, any rules containing **not** CEs as the first CE are checked to see if that CE is satisfied. Second, if a rule shares patterns or joins with other rules, it may be necessary to update the join network based on existing partial matches. Third, existing facts are driven through the new portions of the pattern and join networks.

ARGUMENTS: A pointer to a defrule data structure.

MarkNetworkForIncrementalReset

PURPOSE: Used to set the initialization flags of the pattern and join nodes for a specified rule before and after an incremental reset is performed.

ARGUMENTS: A pointer to a defrule data structure and a boolean value to be assigned to the pattern and join nodes.

OTHER NOTES: The assignment of the initialization value is partially dependent upon certain joins already having their initialization flags set to TRUE.

ParseDefrule

PURPOSE: Coordinates all actions necessary for the construction of a defrule into the current environment. Called to parse a defrule construct.

ARGUMENTS: Logical name from which defrule input is read.

RETURNS: Boolean value. TRUE if an error occurred while parsing the defrule, otherwise FALSE.

OTHER NOTES: Makes use of parsing functions from other modules such as **GetConstructNameAndComment**, **ParseRuleLHS**, and **ParseRuleRHS**.

RemoveRuleNetwork

PURPOSE: Removes the pattern and join nodes for a specified rule from the pattern and join networks.

ARGUMENTS: A pointer to a defrule data structure.

OTHER NOTES: Uses the function **DetachJoins** to remove the rule from the pattern and join networks.

ReplaceExpressionVariables

PURPOSE: Replaces all symbolic references to variables (local and global) found in an expression on the RHS of a rule with expressions containing function calls to retrieve the variable's value. Makes the final modifications necessary for handling the **modify** and **duplicate** commands.

ARGUMENTS: A pointer to an expression and a pointer to an integer for storing an error flag.

RETURNS: Nothing. If an error occurs the value of the error flag passed as a pointer is set to TRUE.

OTHER NOTES: Makes use the functions **ReplaceRHSVariable**, **ReplaceGlobalVariable**, and **UpdateModifyDuplicate** to update the expression.

RememberJoinsForRule

PURPOSE: Stores information for each rule of how it is attached to the pattern and join networks. This information is stored in a linked list attached to the defrule data structure for the rule.

ARGUMENTS: A pointer to the rule's terminator join, a pointer to the defrule data structure for the rule, and the depth index of the logical join for the rule.

ReplaceRHSVariable

PURPOSE: Replaces a symbolic reference to single- or multifield local variable found in an expression on the RHS of a rule with an expression containing a function call to retrieve the variable's value.

ARGUMENTS: A pointer to an expression.

RETURNS: Boolean value. TRUE if the variable reference was successfully replaced, otherwise FALSE.

ResetDefrules

PURPOSE: Defrule construct reset function. Reinitializes rules that have a **not** conditional element as their first conditional element.

SaveDefrules

PURPOSE:	Defrule. construct save function. Pretty prints all defrules to the given logical name.
ARGUMENTS:	A logical name to which output is sent.

Defrule Deployment Module

The Defrule Deployment Module (drulebin.c) provides the functionality for implementing the **bload**, **bsave**, and **constructs-to-c** functions for the defrule construct.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DefruleArray

PURPOSE:	A pointer to an array of defrule data structures loaded using the **bload** command.

JoinArray

PURPOSE:	A pointer to an array of join node data structures loaded using the **bload** command.

NumberOfDefrules

PURPOSE:	An integer count of the number of defrule data structures in the **DefruleArray**.

NumberOfJoins

PURPOSE:	An integer count of the number of join node data structures in the **JoinArray**.

NumberOfPatternPointers

PURPOSE:	An integer count of the number of pattern pointer data structures in the **PatPtrArray**.

NumberOfPatterns

PURPOSE:	An integer count of the number of pattern node data structures in the **PatternArray**.

PatPtrArray

PURPOSE:	A pointer to an array of pattern pointer data structures loaded using the **bload** command.

PatternArray

PURPOSE: A pointer to an array of pattern node data structures loaded using the **bload** command.

GLOBAL FUNCTIONS

DefruleBinarySetup

PURPOSE: Initializes the **bload**, **bsave**, and **constructs-to-c** functions for the defrule construct.

INTERNAL FUNCTIONS

Defrule Bload/Bsave Functions

PURPOSE: A set of functions used by the **bload** and **bsave** commands to process the defrule construct. These functions are made available to the **bload** and **bsave** commands by calling the function **AddBinaryItem**.

Defrule Constructs-To-C Functions

PURPOSE: A set of functions used by the **constructs-to-c** command to process the defrule construct. These functions are made available to the **constructs-to-c** command by calling the function **AddCodeGeneratorItem**.

Defrule Commands Module

The Defrule Commands Module (rulecom.c) provides a number of commands for manipulating and examining defrules. The commands provided are **run**, **undefrule**, **refresh**, **halt**, **rules**, **ppdefrule**, **get-incremental-reset**, **set-incremental-reset**, **set-break**, **remove-break**, **show-breaks**, **matches**, **agenda**, **get-strategy**, **set-strategy**, **get-salience-evaluation**, **set-salience-evaluation**, and **refresh-agenda**,

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

DefruleCommands

PURPOSE:	Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Defrule Commands

PURPOSE:	A series of commands which define the defrule commands listed above. See the *Basic Programming Guide* for more detail on individual functions.
OTHER NOTES:	Some functionality for these commands is provided in other modules.

Deftemplate Commands Module

The Deftemplate Commands Module (deftmcom.c) manages commands associated with the deftemplate construct. These commands include **undeftemplate**, **ppdeftemplate**, **list-deftemplates**, **modify**, **duplicate**, **set-dynamic-deftemplate-checking**, and **get-dynamic-deftemplate-checking**. Extensions for the **save**, **clear**, **bload**, **bsave**, and **constructs-to-c** commands are defined by this module. Several support functions for deftemplates are also provided by this module. For a description of the deftemplate construct, see the *CLIPS Reference Manual*. The deftemplate construct capability can be removed by using the appropriate compile flag in the setup header file.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DeftemplateArray

PURPOSE:	A pointer to an array of deftemplate data structures loaded using the **bload** command.

DeftemplateHashTable

PURPOSE:	Stores all deftemplates used by CLIPS.
C IMPLEMENTATION:	Implemented as an array. Each position in the array corresponds to a list of deftemplate entries. Collisions are resolved by adding the deftemplate entry to the list of entries.
OTHER NOTES:	Information about deftemplates is also stored in the **ListOfDeftemplates**. This table is primarily used to quickly locate a deftemplate.

DynamicDeftemplateChecking

PURPOSE:	Boolean flag. If TRUE, indicates that dynamic deftemplate constraint checking is performed for newly asserted deftemplate facts. If this flag is FALSE, then no checking is performed when a fact is asserted.

LastDeftemplate

PURPOSE:	A pointer to the last deftemplate in the **ListOfDeftemplates**.

ListOfDeftemplates

PURPOSE: A linked list of all the currently defined deftemplates.

NumberOfDeftemplates

PURPOSE: An integer count of the number of deftemplate data structures in the **DeftemplateArray**.

NumberOfTemplateSlots

PURPOSE: An integer count of the number of slot data structures in the **SlotArray**.

SlotArray

PURPOSE: A pointer to an array of slot data structures loaded using the **bload** command.

GLOBAL FUNCTIONS

AddDeftemplate

PURPOSE: Adds a deftemplate to the **ListOfDeftemplates**, then installs the deftemplate using **InstallDeftemplate**.

ARGUMENTS: A pointer to a deftemplate data structure.

CheckSlotAllowedValues

PURPOSE: Determines if a primitive data type satisfies the allowed-... attributes of a slot.

ARGUMENTS: The type of the primitive data type, the value of the primitive data type, and a pointer to a deftemplate slot data structure.

RETURNS: Boolean value. FALSE if the allowed-... attribute is violated, otherwise TRUE.

CheckSlotRange

PURPOSE: Determines if a primitive data type satisfies the range attribute of a slot.

ARGUMENTS: The type of the primitive data type, the value of the primitive data type, and a pointer to a deftemplate slot data structure.

RETURNS: Boolean value. FALSE if the range attribute is violated, otherwise TRUE.

CheckSlotType

PURPOSE: Determines if a primitive data type satisfies the type attribute of a slot.

ARGUMENTS: The type of the primitive data type and a pointer to a deftemplate slot data structure.

RETURNS: Boolean value. FALSE if the type attribute is violated, otherwise TRUE.

ClearDeftemplates

PURPOSE: Deftemplates construct clear function. Removes all deftemplates from the **ListOfDeftemplates**.

DeleteDeftemplate

PURPOSE: Deletes a deftemplate from the **ListOfDeftemplates**.

ARGUMENTS: A pointer to the deftemplate to be deleted.

RETURNS: Boolean value. TRUE if the deftemplate was found and deleted, otherwise FALSE.

DeleteNamedDeftemplate

PURPOSE: Deletes a named deftemplate from the **ListOfDeftemplates**.

ARGUMENTS: The name of deftemplate to be deleted.

RETURNS: Boolean value. TRUE if the deftemplate was found and deleted, otherwise FALSE.

DuplicateCommand

PURPOSE: Implements the **duplicate** command. Calls the function **DuplicateModifyCommand** with a value of FALSE to execute the command.

FindDeftemplate

PURPOSE: Finds a named deftemplate in the **ListOfDeftemplates**.

ARGUMENTS: The name of deftemplate to be found.

RETURNS: A pointer to the deftemplate if found, otherwise NULL.

FindSlot

PURPOSE: Finds the specified slot in a deftemplate.

ARGUMENTS: The name of the slot to be found and a pointer to a deftemplate data structure.

RETURNS: A pointer to a slot data structure if the slot is valid for the specified deftemplate, otherwise NULL.

FindSlotItem

PURPOSE: Given a list of slot assignments, finds the assignment which matches a specified slot.

ARGUMENTS: A pointer to a slot data structure and a list of slot assignments.

RETURNS: The slot assignment matching the specified slot data structure, or NULL if there was no match.

FindSlotPosition

PURPOSE: Returns the integer position of the specified slot for facts using a specified deftemplate. Single-field slots are ordered in the same position that they were defined and the multifield slot is positioned after all other slots.

ARGUMENTS: A pointer to a deftemplate data structure and the name of a slot.

RETURNS: An integer index ranging from 1 to the number of slots in the deftemplate. Zero is returned is the slot is not associated with the specified deftemplate.

GetDeftemplateName

PURPOSE: Returns the name of a deftemplate.

ARGUMENTS: A pointer to a deftemplate.

RETURNS: String name of the deftemplate.

GetDeftemplatePPForm

PURPOSE: Returns the pretty print representation of a deftemplate.

ARGUMENTS: A pointer to a deftemplate.

RETURNS: The string pretty print representation of the deftemplate.

GDDCommand

PURPOSE: Implements the **get-dynamic-deftemplate-checking** command.

GetDynamicDeftemplateChecking

PURPOSE: Returns the current value of the **DynamicDeftemplateChecking** flag.

RETURNS: A boolean value.

GetNextDeftemplate

PURPOSE: Allows access to the **ListOfDeftemplates**.

ARGUMENTS: A pointer to a deftemplate in the **ListOfDeftemplates**.

RETURNS: If passed a NULL pointer, returns the first deftemplate in the **ListOfDeftemplates**. Otherwise, returns the next deftemplate following the deftemplate passed as an argument.

InitializeDeftemplates

PURPOSE: Initializes the deftemplate construct. Adds **clear**, **save**, **bload**, **bsave**, and **constructs-to-c** functions for defglobals, and calls **DeftemplateCommands** to define functions associated with deftemplates.

IsDeftemplateDeletable

PURPOSE: Indicates whether a deftemplate can be deleted.

ARGUMENTS: A pointer to a deftemplate.

RETURNS: Boolean value. TRUE if the deftemplate can be deleted, otherwise FALSE.

ListDeftemplates

PURPOSE: Displays the **ListOfDeftemplates**.

ListDeftemplatesCommand

PURPOSE: Implements the **list-deftemplates** command. Uses the driver function **ListDeftemplates**.

ModifyCommand

PURPOSE: Implements the **modify** command. Calls the function **DuplicateModifyCommand** with a value of TRUE to execute the command.

PPDeftemplate

PURPOSE: Pretty prints a deftemplate.

ARGUMENTS: Name of deftemplate to be pretty printed and logical name of the output source.

PPDeftemplateCommand

PURPOSE: Implements the **ppdeftemplate** command. Uses the driver function **PPDeftemplate**.

PrintTemplateFact

PURPOSE: Prints a fact using the deftemplate format for displaying facts.

ARGUMENTS: A logical name to send the output and a pointer to a fact.

RETURNS: Boolean value. TRUE if the fact was successfully printed using the deftemplate format (i.e. a deftemplate was found that corresponded to the first field of the fact), otherwise FALSE.

QFindDeftemplate

PURPOSE: Finds a named deftemplate in the **ListOfDeftemplates**.

ARGUMENTS: The name of deftemplate to be found. This argument is specified as a pointer to a **SymbolTable** entry rather than a character string.

RETURNS: A pointer to the deftemplate if found, otherwise NULL.

QSetListOfDeftemplates

PURPOSE: Sets the **ListOfDeftemplates** to the specified value.

ARGUMENTS: A pointer to a linked list of deftemplates.

ReturnSlots

PURPOSE: Returns a linked list of slot data structures to the CLIPS memory manager.

ARGUMENTS: A linked list of slot data structures.

SDDCommand

PURPOSE: Implements the **set-dynamic-deftemplate-checking** command.

SetDynamicDeftemplateChecking

PURPOSE: Sets the current value of the **DynamicDeftemplateChecking** flag.

ARGUMENTS: A boolean value (the new value of the flag).

RETURNS: A boolean value (the old value of the flag).

SetListOfDeftemplates

PURPOSE: Sets the **ListOfDeftemplates** to the specified value. Normally used when initializing a run-time module or when bloading a binary file to install the **ListOfDeftemplates**. Adds each deftemplate in the new list to the **DeftemplateHashTable** by calling the function **AddHashDeftemplate**.

ARGUMENTS: A pointer to a linked list of deftemplates.

UndeftemplateCommand

PURPOSE: Implements the **undeftemplate** command.

INTERNAL FUNCTIONS

AddHashDeftemplate

PURPOSE: Adds a deftemplate to the **DeftempateHashTable**.

ARGUMENTS: A pointer to a deftemplate.

DeftemplateCommands

PURPOSE: Defines the commands **undeftemplate**, **ppdeftemplate**, **list-deftemplates**, **duplicate**, **modify**,

get-dynamic-deftemplate-checking, and **set-dynamic-deftemplate-checking**.

Deftemplate Bload/Bsave Functions

PURPOSE: A set of functions used by the **bload** and **bsave** commands to process the deftemplate construct. These functions are made available to the **bload** and **bsave** commands by calling the function **AddBinaryItem**.

Deftemplate Constructs-To-C Functions

PURPOSE: A set of functions used by the **constructs-to-c** command to process the deftemplate construct. These functions are made available to the **constructs-to-c** command by calling the function **AddCodeGeneratorItem**.

DeinstallDeftemplate

PURPOSE: Decrements all occurrences in the **SymbolTable** of symbols found in an deftemplate, calls **DeinstallExpression** for all expressions used by the deftemplate, and removes the deftemplate from the **DeftempateHashTable**.

ARGUMENTS: A pointer to a deftemplate.

DuplicateModifyCommand

PURPOSE: Implements the **duplicate** and **modify** commands. The fact being duplicated or modified is first copied to a new fact. Replacements to the fields of the new fact are then made. If a **modify** command is being performed, the original fact is retracted. Lastly, the new fact is asserted.

ARGUMENTS: Boolean value. If TRUE, the original fact used to duplicate the newly asserted fact is retracted (for the **modify** command). If FALSE, the original fact is not retracted (for the **duplicate** command). Other arguments to the command are retrieved using the argument access functions.

InitializeDeftemplateHashTable

PURPOSE: Initializes the **DeftemplateHashTable**.

InstallDeftemplate

PURPOSE: Increments all occurrences in the **SymbolTable** of symbols found in an deftemplate, calls **InstallExpression** for all expressions used by the deftemplate, and adds the deftemplate to the **DeftempateHashTable**.

ARGUMENTS: A pointer to a deftemplate.

RemoveHashDeftemplate

PURPOSE: Removes a deftemplate from the **DeftempateHashTable**.

ARGUMENTS: A pointer to a deftemplate.

RETURNS: Boolean value. TRUE if the deftemplate was removed, otherwise FALSE.

SaveDeftemplates

PURPOSE: Deftemplate construct save function. Pretty prints all deftemplates to the given logical name.

ARGUMENTS: A logical name to send output.

TemplateMultifieldSlotReplace

PURPOSE: Replaces the multifield value slot of a deftemplate fact. Called by **DuplicateModifyCommand** when replacing slot values.

ARGUMENTS: A pointer to the list of expressions to be evaluated and stored in the multifield slot, and pointer to the fact in which the new multifield value is to be stored, and a pointer to the deftemplate corresponding to the fact.

RETURNS: A pointer to a fact. If the previous size of the fact did not exactly match the exact amount of space needed for the new multifield value, then a new fact of the exact size is dynamically allocated and the old fact is discarded.

Deftemplate Functions Module

The Deftemplate Functions Module (deftmfun.c) provides parsing routines for the **modify** and **duplicate** commands and the template patterns used in the **assert** command. Template patterns found within these commands are referred to as RHS patterns (since these commands are typically used from the RHS of a rule). For a description of the **modify** and **duplicate** commands and using template patterns within the **assert** command, see the *CLIPS Basic Programming Guide*. The Deftemplate Function Module also provides the functionality for dynamic deftemplate checking. The deftemplate construct capability can be removed by using the appropriate compiler flag in the setup header file.

Template patterns are converted by CLIPS into regular positional patterns through a set of simple translation rules. By using field keywords, the fields of a template pattern can be specified in any order. The keywords fields, however, will be translated into a fixed positional order. The single-field values of a RHS template pattern retain the same order that they are given in their corresponding deftemplate. A multifield value in a RHS template pattern is always placed at the end of a pattern regardless of the position of the field definition in the deftemplate. For example, given the following deftemplate,

```
(deftemplate example
   (multifield z)
   (field x (default 3))
   (field y))
```

The RHS pattern used in the following assert

```
(assert (example (z c d e) (y b) (x a)))
```

would be translated to

```
(assert (example a b c d e))
```

If a value is not specified in a template pattern, an appropriate value for the pattern will be used. A RHS template pattern used with an assert will use the default value for any unspecified fields. If a default value was not specified for a field, CLIPS provides a default value based on the allowed types for the field and the cardinality of the field (single-field or multifield). Unspecified fields in a RHS template pattern for the modify or duplicate command will be replaced with the current value of the field for the fact being modified. For example, the RHS pattern used in the following assert

```
(assert (example (y 4)))
```

would be translated to

```
(assert (example 3 4))
```

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

CheckTemplateFact

PURPOSE: Performs dynamic deftemplate checking on individual fields of a deftemplate facts.

ARGUMENTS: The type of the field being checked, the value of the field being checked, a pointer to the slot data structure to which the field is being assigned, and a pointer to the fact in which the field is contained.

RETURNS: Boolean value. TRUE if a constraint error is detected, otherwise FALSE. Also sets the value of **EvaluationError** if a constraint error is detected.

OTHER NOTES: Calls the functions **CheckSlotType**, **CheckSlotRange**, and **CheckSlotAllowedValues** to perform the constraint checking.

DuplicateParse

PURPOSE: Coordinates all actions necessary to parse the **duplicate** command.

ARGUMENTS: Logical name from which input is read and a pointer to the expression function call.

RETURNS: Expression representing the **duplicate** command.

OTHER NOTES: The expression returned by this function may later be modified by the function **UpdateModifyDuplicate**. This function uses the **ModAndDupParse** function to actually parse the command.

GetMultiSlotPosition

PURPOSE: Given the relation name of a fact (the first field), determines if the fact is a deftemplate fact and if so which position in the fact corresponds to the beginning of the multifield slot.

ARGUMENTS: The relation name of a fact (a pointer to a symbol).

RETURNS: An integer value. -1 if the relation name is not associated with a deftemplate, 0 if the relation name is associated with a deftemplate that does not contain a multifield slot, and the position of the multifield slot (a value greater than 0) for deftemplates containing a multifield slot.

ModifyParse

PURPOSE: Coordinates all actions necessary to parse the **modify** command.

ARGUMENTS: Logical name from which input is read and a pointer to the expression function call.

RETURNS: Expression representing the **modify** command.

OTHER NOTES: The expression returned by this function may later be modified by the function **UpdateModifyDuplicate**. This function uses the **ModAndDupParse** function to actually parse the command.

MultiIntoSingleFieldSlotError

PURPOSE: Determines if a multifield value is being placed into a single field slot of a deftemplate fact.

ARGUMENTS: The positional index of the slot being changed and the relation name of the fact (a pointer to a symbol).

RETURNS: Nothing, however, the **EvaluationError** is set to TRUE and an error message is printed if a multifield value is placed in a single field slot.

ParseAssertTemplate

PURPOSE: Coordinates all actions necessary to parse template patterns found in assert commands and deffacts constructs.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to integer flag in which a boolean value is to be stored indicating whether a multifield value was used in the assert, a pointer to integer flag in which a boolean value is to be stored indicating whether an error occurred while parsing, a pointer to the symbol containing the deftemplate name that was parsed from the first field of the fact, an integer value indicating the type of token that terminates the template (e.g. right parenthesis), and a boolean flag indicating if only constants are allowed within the template (to be used with functions such as **load-facts**).

RETURNS: An expression representing the list of values to be asserted. The error flag and multifield value flag passed as parameters may also be set.

UpdateModifyDuplicate

PURPOSE: Changes the **modify** and **duplicate** commands such that the integer positions of the slots are stored in the command rather than the slot name. This allows quicker replacement of slots. This replacement can only take place when the deftemplate is specified using a fact-address bound on the LHS of a rule.

ARGUMENTS: A pointer to a **modify** or **duplicate** command and the name of the command being updated.

RETURNS: Boolean value. TRUE if the command was successfully modified (or could not be modified because a fact-address was not used) and FALSE if an error occurred while modifying the command. The expression passed as an argument is also directly modified.

INTERNAL FUNCTIONS

AssertSlotsMultiplyDefined

PURPOSE: Determines if the same slot was specified more than once in a deftemplate assert pattern.

ARGUMENTS: A pointer to a list of slot assignments.

RETURNS: Boolean value. TRUE if a slot was specified more than once, otherwise FALSE.

CheckRHSSlotTypes

PURPOSE: Checks the validity of a change to a slot as the result of an **assert**, **modify**, or **duplicate** command. This checking is performed statically (i.e. when the command is being parsed).

ARGUMENTS: A pointer to the list of values to be stored in a slot, a pointer to a slot data structure, and the name of the command modifying the slot.

RETURNS: Boolean value. FALSE if the values do not satisfy slot restrictions and TRUE if they do satisfy slot restrictions.

FieldCheckTemplate

PURPOSE: Checks a slot from a template fact to make sure that it doesn't violate any of the deftemplate's constraints.

ARGUMENTS: The type of the slot's value, a pointer to the slot's value, a pointer to the slot data structure, and a pointer to the fact from which the slot's value was extracted.

RETURNS: Boolean value. TRUE if one of the deftemplate's constraints is violated.

GetSlotAssertValues

PURPOSE: Returns the assigned slot value for a specified slot. If no slot value has been assigned, then a default value is returned.

ARGUMENTS: A pointer to a slot data structure and a pointer to a list of slot assignments.

RETURNS: A pointer to an expression.

ModAndDupParse

PURPOSE: Handles parsing of the **modify** and **duplicate** commands.

ARGUMENTS: Logical name from which input is read, a pointer to the expression function call, and the name of the command being parsed.

RETURNS: A pointer to an expression.

OTHER NOTES: Calls the function **GetAssertArgument** to retrieve individual values to be changed in the slots.

ModifySlotsMultiplyDefined

PURPOSE: Determines if the same slot was specified more than once in a **modify** or **duplicate** command.

ARGUMENTS: A pointer to a list of slot assignments.

RETURNS: Boolean value. TRUE if a slot was specified more than once, otherwise FALSE.

ParseAssertSlotValues

PURPOSE: Parses the values to be asserted for a specified slot.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to a slot data structure, a pointer to integer flag in which a boolean value is to be stored indicating whether a multifield value was used in the assert, a pointer to integer flag in which a boolean value is to be stored indicating whether an error occurred while parsing, and a boolean flag indicating if only constants are allowed as slot values.

RETURNS: A pointer to the list of assert values for the slot. The error flag and multifield value flag passed as parameters may also set.

OTHER NOTES: Used by the **ParseAssertTemplate** function. Calls the function **GetAssertArgument** to retrieve individual values to be stored in the slot.

ParseSlotLabel

PURPOSE: Parses the beginning of a slot definition. Checks for an opening left parenthesis and a valid slot name.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to a deftemplate data structure (for determining slot validity), a pointer to integer flag in which a boolean value is to be stored indicating whether an error occurred while parsing, and an integer value indicating the type of token that terminates the template (e.g. right parenthesis).

RETURNS: A pointer to the slot data structure referenced by the slot label. The error flag passed as a parameter may also be set.

OTHER NOTES: Used by the **ParseAssertTemplate** function.

ReorderAssertSlotValues

PURPOSE: Reorders a list of slot assignments for an assert command from a template ordering to a positional ordering. Unspecified slots are assigned default values.

ARGUMENTS: A pointer to a deftemplate data structure and a pointer to a list of slot assignments.

RETURNS: Returns a list of expressions which can directly be attached as the argument list to an **assert** command.

ReturnSAPs

PURPOSE:	Returns intermediate data structures used for parsing an deftemplate assert pattern to the CLIPS memory manager.
ARGUMENTS:	A pointer to a list of slot assignments.

Deftemplate Parser Module

The Deftemplate Parser Module (deftmpsr.c) contains the function necessary for parsing a deftemplate construct. The BNF for the deftemplate construct is shown in Appendix G of the *CLIPS Basic Programming Guide*.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

DeftemplateError

PURPOSE: Indicates whether an error was encountered during parsing of a deftemplate construct.

GLOBAL FUNCTIONS

ParseDeftemplate

PURPOSE: Coordinates all actions necessary for the construction of a deftemplate into the current environment. Called to parse a deftemplate construct.

ARGUMENTS: Logical name from which deftemplate input is read.

OTHER NOTES: Uses the functions **GetConstructNameAndComment** and **SlotDeclarations** to perform the parsing.

INTERNAL FUNCTIONS

CheckSlotConflicts

PURPOSE: Checks to determine if any of a slot's attributes conflict with each other (e.g. declaring a slot to be of type integer but declaring the default value to be a symbol).

ARGUMENTS: A pointer to the slot declaration structure.

RETURNS: Boolean value. FALSE indicates a conflict exists while TRUE indicates no conflict exists.

DefinedSlots

PURPOSE: Builds a new slot declaration and coordinates the parsing of the slot 's attributes.

ARGUMENTS: Logical name from which input is read, the name of the slot, a boolean flag indicating if the slot is a multifield, and a pointer to a token structure in which scanned tokens are placed.

RETURNS: A pointer to the data structure which represents the slot declaration.

OTHER NOTES: Uses the **ParseRangeAttribute**, **ParseTypeAttribute**, **ParseDefault**, and **ParseAllowedValuesAttribute** functions to parse individual slot attributes.

MultiplyDefinedSlots

PURPOSE: Determines if two slots in a deftemplate construct have been given identical names.

ARGUMENTS: A pointer to a list of slot declaration structures.

RETURNS: Boolean value. TRUE indicates that slots have been multiply defined, while FALSE indicates that slots have not been multiply defined.

ParseAllowedValuesAttribute

PURPOSE: Parses the allowed-values, allowed-integers, allowed-floats, allowed-numbers, allowed-symbols, and allowed-strings slot attributes.

ARGUMENTS: Logical name from which input is read, a pointer to the slot declaration structure, and the name of the slot attribute being parsed.

RETURNS: Boolean value. FALSE indicates an error occurred while parsing the type attribute, TRUE indicates no error occurred. The range fields of the slot declaration structure are also modified based upon the range declaration.

ParseDefault

PURPOSE: Parses the default slot attribute.

ARGUMENTS: Logical name from which input is read, a boolean flag indicating if the slot is a multifield, and a pointer to a token structure in which scanned tokens are placed.

RETURNS: A pointer to an expression containing the default slot value(s).

ParseRangeAttribute

PURPOSE: Parses the range slot attribute.

ARGUMENTS: Logical name from which input is read and a pointer to the slot declaration structure.

RETURNS: Boolean value. FALSE indicates an error occurred while parsing the type attribute, TRUE indicates no error occurred. The range fields of the slot declaration structure are also modified based upon the range declaration.

ParseSlot

PURPOSE: Coordinates the parsing of an individual slot declaration.

ARGUMENTS: Logical name from which input is read and a pointer to a token structure in which scanned tokens are placed.

RETURNS: A pointer to the data structure which represents the slot declaration.

OTHER NOTES: Uses the function **DefinedSlots** to coordinate parsing of individual slot attributes.

ParseTypeAttribute

PURPOSE: Parses the type slot attribute.

ARGUMENTS: Logical name from which input is read and a pointer to the slot declaration structure.

RETURNS: Boolean value. FALSE indicates an error occurred while parsing the type attribute, TRUE indicates no error occurred. The allowed type fields of the slot declaration structure are also modified based upon the type declaration.

SlotDeclarations

PURPOSE: Coordinates the parsing of all of the slot declarations (i.e. field and multifield specifications) for a deftemplate construct.

ARGUMENTS: Logical name from which input is read and a pointer to a token structure in which scanned tokens are placed.

RETURNS: A linked list of data structures which represent the slot declarations.

OTHER NOTES:	Uses the function **ParseSlot** to parse individual slot declarations.

Deftemplate LHS Module

The Deftemplate LHS Module (deftmlhs.c) provides routines for parsing deftemplate pattern found in the LHS of a rule. For a description of using template patterns on the LHS of a rule, see the *CLIPS Basic Programming Guide*.

Template patterns are converted by CLIPS into regular positional patterns through a set of simple translation rules. By using field keywords, the fields of a template pattern can be specified in any order. The keywords fields, however, will be translated into a fixed positional order. The single-field values of a LHS template pattern retain the same order that they are given in their corresponding deftemplate. A multifield value in a LHS template pattern is always placed at the end of a pattern regardless of the position of the field definition in the deftemplate. For example, given the following deftemplate,

```
(deftemplate example
   (multifield z)
   (field x (default 3))
   (field y))
```

the LHS pattern shown following

```
(example (z $?z) (y ?y) (x ?x))
```

would be translated to

```
(example ?x ?y $?z)
```

If a value is not specified in a template pattern, an appropriate value for the pattern will be used. If a LHS template pattern has an unspecified value, that value will be replaced with ? for single-field slots and $? for multifield slots. For example, the LHS template pattern shown following

```
(example (y 3))
```

would be translated to

```
(example ? 3 $)
```

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

DeftemplateLHSParse

PURPOSE: Parses a deftemplate pattern found on the LHS of a rule.

ARGUMENTS: Logical name from which input is read and the name of the deftemplate corresponding to the first field of the pattern being parsed.

RETURNS: A pointer to a linked structure containing the intermediate LHS representation of the pattern. If an error has occurred during parsing, a NULL pointer is returned.

OTHER NOTES: The intermediate LHS representation is built using the functions **GetLHSSlots**, **MultiplyDefinedLHSSlots**, and **ReorderLHSSlotValues**.

INTERNAL FUNCTIONS

CheckLHSSlotTypes

PURPOSE: Determines if a slot constraint satisfies slot restrictions (e.g. type, range, and value).

ARGUMENTS: A pointer to the slot constraints for a slot and a pointer to a corresponding slot data structure.

RETURNS: Boolean value. TRUE, if the slot restrictions are satisfied (i.e. have not been violated), otherwise FALSE.

GetLHSSlots

PURPOSE: Parses the list of slot constraints associated with a LHS deftemplate pattern.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to the deftemplate data structure for the pattern being parsed, and a pointer to an integer flag in which an error status is stored.

RETURNS: Returns a linked list of the slot constraints for the pattern (which could be a NULL pointer if there are no slot constraints). If an error occurs, the integer flag passed as an argument is set to TRUE.

OTHER NOTES: Builds the list of slot constraints using the functions **GetSingleLHSSlot** and **CheckLHSSlotTypes**.

GetSingleLHSSlots

PURPOSE: Parses a single slot constraint associated with a LHS deftemplate pattern.

ARGUMENTS: Logical name from which input is read, a pointer to a token structure in which scanned tokens are placed, a pointer to the slot data structure for the slot being parsed, and a pointer to an integer flag in which an error status is stored.

RETURNS: Returns the slot constraints for the slot. If an error occurs, the integer flag passed as an argument is set to TRUE and a NULL pointer is returned.

OTHER NOTES: Primarily uses the function **RestrictionParse** to parse the slot constraints

MultiplyDefinedLHSSlots

PURPOSE: Determines if two slot constraints in a deftemplate LHS pattern have been given for the same slot name.

ARGUMENTS: A pointer to a list of slot constraints.

RETURNS: Boolean value. TRUE indicates that slots have been multiply defined, while FALSE indicates that slots have not been multiply defined.

ReorderLHSSlotValues

PURPOSE: Reorders a list of slot constraints for a LHS deftemplate pattern from a template ordering to a positional ordering. Unspecified slots match against wildcards (for single field slots) and multifield wildcards (for multifield slots).

ARGUMENTS: A pointer to the list of slots for a deftemplate, a pointer to the list of specified slot constraints for the pattern, and a pointer to the current intermediate LHS representation of the deftemplate pattern (which contains only the deftemplate name).

RETURNS: A pointer to the LHS representation of the deftemplate pattern containing the slot constraints in the appropriate order with unspecified slots replaced with wildcards.

ReturnSLPs

PURPOSE: Returns intermediate data structures used for parsing an deftemplate LHS pattern to the CLIPS memory manager.

ARGUMENTS: A pointer to a list of slot constraints.

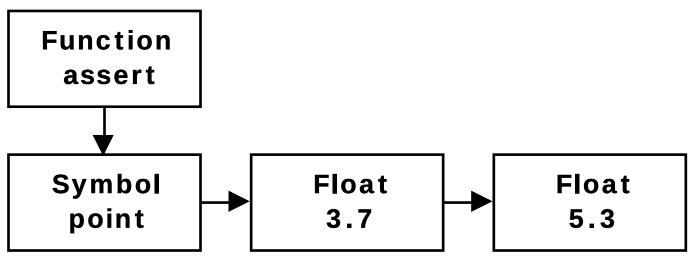
Binary Save Module

The Binary Save Module (bsave.c) provides the functionality for the **bsave** command. To illustrate how a binary save is performed, the following code will be used as example:

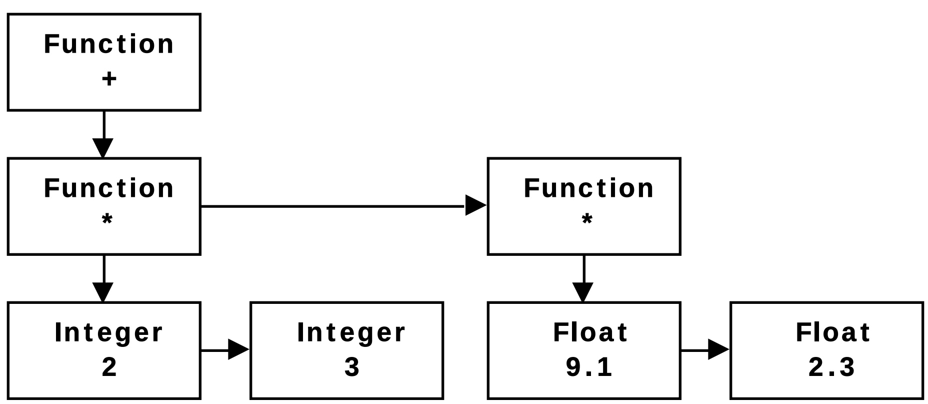
```
(deffacts start-info
   (point 3.7 5.3))

(deffunction compute ()
   (+ (* 2 3) (* 9.1 2.3)))
```

For future reference, the expressions associated with the deffacts *start-info* and the deffunction *compute* are show below. Note that there are some differences between the representation shown below and the actual representation in CLIPS. For example, the body of a deffunction is enclosed within a **progn** function, but this is not shown in diagram below.



Deffacts *start-info* Expression



Deffunction *compute* Expression

In the proceeding descriptions, it will be assumed that integers and pointers occupy four bytes of memory storage and that double precision floating pointer numbers occupy four bytes of memory storage. Characters always occupy one byte of memory storage regardless of the C implementation.

The first step in creating a binary image file is to write a binary header to the file so that the **bsave** command can verify that the file is CLIPS binary file and determine which version of CLIPS created the file. The binary header is written in two distinct parts. The first part indicates that the file is a CLIPS binary file and contains control characters to help prevent a text file as being mistaken for a binary file. The second part contains the version number of CLIPS that was used to create the binary file. An example binary header is shown following:

"\1\2\3\4CLIPS"	"V5.00"

In the second step, all functions, symbols, integers, and floats within CLIPS have a status flag set to FALSE to indicate that each of these items is not needed by the binary image. Then, each construct that has been registered using the **AddBinaryItem** function has its specified function called which is used to mark which functions, symbols, integers, floats are need to save the binary image for that construct. Finally, after all constructs have had the opportunity to mark needed items, each needed symbol, integer, and float is assigned a unique integer id that will be used as a reference in the binary image. In the example shown previously, the functions *assert*, +, and * are needed, the symbols *start-info*, *compute*, and *point* are needed, the floats 3.7, 5.3, 9.1, and 2.3 are needed, and the integers 2 and 3 are needed.

In step three, each of the needed functions is written out to the binary image. The number of functions needed is written, followed by the amount of space for all of the function names, followed by each of the function names as a NULL terminated string. Functions are given indexes at this point. Note that these are not written in any specific order with relation to which binary item needs them. A function is only written once (regardless of the number of binary items which use it—it's either needed or its not). For the example shown previously, the following output would be written to the binary file.

3	4 bytes: Number of Functions
11	4 bytes: Total Size of Function Names
"+"	2 bytes: Space for Function #0
"*"	2 bytes: Space for Function #1
"assert"	7 bytes: Space for Function #2

In step four, each of the needed symbols is written out to the binary image. The number of symbols needed is written, followed by the amount of space for all of the symbol names, followed by each of the symbol names as a NULL terminated string. For the example shown previously, the following output would be written to the binary file.

3	4 bytes: Number of Symbols
26	4 bytes: Total Size of Symbols
"start-info"	12 bytes: Space for Symbol #0
"compute"	8 bytes: Space for Symbol #1
"point"	6 bytes: Space for Symbol #2

In step five, each of the needed floats is written out to the binary image. The number of floats needed is written followed by each of the floats needed. For the example shown previously, the following output would be written to the binary file.

4	4 bytes: Number of Floats
9.1	8 bytes: Space for Float #0
2.3	8 bytes: Space for Float #1
3.7	8 bytes: Space for Float #3
5.3	8 bytes: Space for Float #4

In step six, each of the needed integers is written out to the binary image. The number of integers needed is written followed by each of the integers needed. For the example shown previously, the following output would be written to the binary file.

4	4 bytes: Number of Integers
2	4 bytes: Space for Integer #0
3	4 bytes: Space for Integer #1

In step seven, each of the expressions needed by the constructs is written out to the binary image. First, the total number of expression structures is written out to the binary image and then each registered construct is called to dump its expressions to the file. Each expression is written to the binary image using the following format.

TYPE	INDEX VALUE	ARGUMENT LIST	NEXT ARGUMENT

The *type* field corresponds directly to its value in the CLIPS expression data structure. The *index value*, *argument list*, and *next argument* fields are pointers in the CLIPS expression data structure, but are converted to integers indexes when saved to the binary image. For example, the *index value* for the symbol point would be 2 since it is the third item saved in the the symbol section of the binary image (note that the nth item in a C array is referenced by n-1). Pointers other expressions or data structures are converted to integer indexes as well. A NULL pointer is converted to the value -1. For the example shown previously, the following output would be written to the binary file for saving the expressions.

10				4 bytes: Number of Expressions
FUNCTION	2	1	-1	16 bytes: Function assert #0
SYMBOL	2	-1	2	16 bytes: Symbol point #1
FLOAT	2	-1	3	16 bytes: Float 3.7 #2
FLOAT	3	-1	-1	16 bytes: Float 5.3 #3
FUNCTION	0	5	-1	16 bytes: Function + #4
FUNCTION	1	6	8	16 bytes: Function * #5
INTEGER	0	-1	7	16 bytes: Integer 2 #6
INTEGER	1	-1	-1	16 bytes: Integer 3 #7
FUNCTION	1	9	-1	16 bytes: Function * #8
FLOAT	0	-1	10	16 bytes: Float 9.1 #9
FLOAT	1	-1	-1	16 bytes: Float 2.3 #10

In step eight, each registered construct is written to the binary image. First, the name of the construct is written to the binary image (up to a specified number of characters). The bsave function for the construct is then called. The bsave function for the construct is first responsible for writing the amount space required by it (in case the construct must be skipped over when bloaded). It then can write out any data structures that it needs.

If the deffacts construct was defined using the following C data structure,

```
struct deffacts
  {
   struct symbol *name;
   char *ppForm;
   struct expression *assertItems;
   struct deffacts *next;
  };
```

then the following format could be used in writing the deffacts constructs to the binary image.

NAME	PRETTY PRINT	DEFFACTS EXPRESSION	NEXT DEFFACTS

The *name* field would be the integer index of a symbol, the *ppForm* field could be given an index of -1 (since pretty print forms are not loaded with binary images), the *assertItems* field would be given the appropriate index for the expression saved previously, and the *next* field would contain the integer index to the next deffacts in the binary image (-1 for the last deffacts). For the example shown previously, the following output would be written to the binary file for saving the deffacts.

"deffacts"	20 bytes: Deffacts Header
20	4 bytes: Total Size of Deffacts
1	4 bytes: Number of Deffacts
0 | -1 | 0 | -1	16 bytes: Deffacts #0

Similarly, if the deffunction construct was defined using the following C data structure,

```
struct deffunction
  {
   struct symbol *name;
   char *ppForm;
   struct expression *code;
   int numberOfParameters;
   struct deffunction *next;
  };
```

then the following format could be used in writing the deffunction constructs to the binary image.

NAME	PRETTY PRINT	DEFFUNCTION BODY	NUMBER OF ARGUMENTS	NEXT DEFFUNCTION

The *name* field would be the integer index of a symbol, the *ppForm* field could be given an index of -1 (since pretty print forms are not loaded with binary images), the *code* field would be given the appropriate index for the expression saved previously, the *numberOfParameters* field would be given its actual integer value, and the *next* field would contain the integer index to the next deffunction in the binary image (-1 for the last deffunction). For the example shown previously, the following output would be written to the binary file for saving the deffunctions.

"deffunction"	20 bytes: Deffunction Header
24	4 bytes: Total Size of Deffunctions
1	4 bytes: Number of Deffunctions
1 | -1 | 4 | 0 | -1	20 bytes: Deffacts #0

The final step in saving a binary image is to write a binary footer to identify the end of the binary image. This binary footer is identical to the first part of the binary header. An example binary footer is shown following:

"\1\2\3\4CLIPS"

GLOBAL VARIABLES

ExpressionCount

PURPOSE: An integer value representing the number of expression data structures which have been encountered or processed.

ListOfBinaryItems

PURPOSE: Contains a list of data structures used to call functions for various constructs which generate output or read input for the **bsave**/**bload** commands.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

AddBinaryItem

PURPOSE: Adds an item to the **ListOfBinaryItems**. Every construct that generates output for **bsave** must use this function to install functions that will be called whenever a **bsave** command is executed.

ARGUMENTS: A name to be associated with the binary item, the priority of the item, a pointer to a function which is called to mark items needed by the binary item (symbols, floats, integers, and functions), a pointer to function which will write all expressions needed by a binary item to the binary output file, a pointer to a function which writes other data required by a binary item to the binary output file, a pointer to a function which is call to load input from a binary file when a **bload** is performed, a pointer to a function which initializes the data for a binary item after a bload has been performed (e.g. converting indices to actual addresses), and a pointer to a function which is called when a **clear** command is executed while a binary image is loaded.

RETURNS: Boolean value. TRUE if the binary item was successfully added, otherwise FALSE.

Bsave

PURPOSE: Main driver routine for coordinating binary output to a file for the **bsave** function.

ARGUMENTS: The name of the file in which to store the binary representation of the constructs currently loaded in the CLIPS environment.

RETURNS: Boolean value. TRUE, if the binary file was successfully created, otherwise FALSE.

BsaveCommand

PURPOSE: Converts CLIPS constructs currently loaded into the CLIPS environment into a binary representation stores them in a file. This function is the driver routine for the CLIPS function **bsave**. The function **Bsave** is called by this function to perform the code generation.

ARGUMENTS: No actual arguments. The CLIPS arguments passing routines are used to extract arguments when this function is called from the CLIPS environment.

BsaveExpression

PURPOSE: Writes the binary representation of an expression to a file.

ARGUMENTS: A pointer to a file and a pointer to an expression.

OTHER NOTES: Uses and increments the value of the global variable **ExpressionCount** to convert the pointers (to other expressions) found in the expression to integer index values. Symbols, floats, integers, functions, and pointers to other constructs (such as generic functions) already have index values computed for them. The index values for the expression are converted back to addresses when a **bload** is performed.

GenWrite

PURPOSE: Provides a generic capability for writing binary output to a file.

ARGUMENTS: A pointer to the data to be written, the length of the data, and a pointer to a file.

MarkNeededItems

PURPOSE: Given an expression, marks the symbols, floats, integers, and functions contained within the expression as being needed by this binary image.

ARGUMENTS: A pointer to an expression.

INTERNAL FUNCTIONS

BsaveAllExpressions

PURPOSE: Called by function **Bsave** to write the binary representation of all expressions used by this binary image. Calls the expression function for each entry in the **ListOfBinaryItems** to allow the binary entry to write out needed expressions to the binary file.

ARGUMENTS: A pointer to a file.

OTHER NOTES: Sets the value of **ExpressionCount** to zero before calling any of the expression functions for the binary items. This value is then incremented as each binary item calls **BsaveExpression** to save its expressions.

FindNeededFunctionsAndAtoms

PURPOSE: Calls the find function for each entry in the **ListOfBinaryItems** to allow the binary entry to mark the symbols, floats, integers, and functions which should be saved as part of the binary image since they are needed by the entry. Conversely unneeded symbols, floats, integers, and functions will not be marked and thus will not be saved as part of the binary image. This is important since it allows binary images to be saved from versions of CLIPS customized with user defined functions and then loaded into non-customized versions as long as the user defined functions were not referenced by the saved binary image.

FunctionBinarySize

PURPOSE: Computes the total number of bytes in string space for all the required function names needed by the binary image.

RETURNS: A long integer.

MarkBuckets

PURPOSE: Replaces the bucket slot of each entry in the **SymbolTable**, **IntegerTable**, and **FloatTable** with an integer index that will be used to refer to that value. For example, the seventh symbol in the **SymbolTable** has the value 7 stored in its bucket slot (which would normally indicate the location in the **SymbolTable** that the symbol is stored).

MarkNeededFlags

PURPOSE: Marks every symbol, float, integer, and function as being unneeded by this binary image. This function is called before the binary items in the **ListOfBinaryItems** are allowed to mark symbols, floats, integers, and functions as being needed.

UnmarkBuckets

PURPOSE: Restores the bucket slot of each entry in the **SymbolTable**, **IntegerTable**, and **FloatTable** with its appropriate value. This function is called to reverse the changes made by **MarkBuckets**.

WriteBinaryFooter

PURPOSE: Writes the global variable **BinaryPrefixID** to the specified file to indicate that the end of a binary file has been reached.

ARGUMENTS: A pointer to a file.

WriteBinaryHeader

PURPOSE: Writes the global variables **BinaryPrefixID** and **BinaryVersionID** to the specified file to indicate that the file is a binary file. The **BinaryPrefixID** is used to indicate that the file is a binary file and the **BinaryVersionID** is used to indicate which version of CLIPS created the file.

ARGUMENTS: A pointer to a file.

WriteNeededIntegers

PURPOSE: Called by function **Bsave** to write the binary representation of all the integers required by this binary image.

ARGUMENTS: A pointer to a file.

OTHER NOTES: The number of integers required by this image is written to the binary file followed by the integers written in their binary representation (not their ASCII string representation).

WriteNeededFloats

PURPOSE: Called by function **Bsave** to write the binary representation of all the floats required by this binary image.

ARGUMENTS: A pointer to a file.

OTHER NOTES: The number of floats required by this image is written to the binary file followed by the floats written in their binary representation (not their ASCII string representation).

WriteNeededFunctions

PURPOSE: Called by function **Bsave** to write the binary representation of all the functions required by this binary image. This function also assigns each required function an integer index which is used in place of the function's address to refer to the function in the binary image.

ARGUMENTS: A pointer to a file.

OTHER NOTES: The number of functions required by this image is written to the binary file, followed by the total amount of space in bytes of all the required function names, followed by the names of the functions written as C strings.

WriteNeededSymbols

PURPOSE: Called by function **Bsave** to write the binary representation of all the symbols required by this binary image.

ARGUMENTS: A pointer to a file.

OTHER NOTES: The number of symbols required by this image is written to the binary file, followed by the total amount of space in bytes of all the required symbols, followed by the symbols written as C strings.

Binary Load Module

The Binary Load Module (bload.c) provides the functionality for the **bload** command. Binary Images which are loaded must first have been saved as a binary image using the Binary Save Module (bsave.c). The following steps describe how a binary image is loaded. A knowledge of how the binary save works is assumed.

The first step in loading a binary image is to load the binary header from the file to determine if indeed the file is a binary image and whether it was created by the same version of CLIPS that is loading it. Next the CLIPS environment is cleared. The needed functions names are then loaded from the binary image. If any of these functions are unavailable, then the binary load is aborted. It is possible to save a binary image from a customized version of CLIPS which has additional functions not available in the standard version of CLIPS and then load the binary image in a standard or differently customized version of CLIPS as long as no customized functions are used. After the needed function names have been loaded, the need symbols, floats, and integers are loaded from the binary image, followed by all of the needed expressions.

Once these basic items have been loaded from the binary image, construct information is then loaded. A construct name is loaded from the binary image and then the appropriate function for the registered construct is called to load the construct's binary image. If the construct is not registered, then the construct information in the binary image is skipped. This makes it possible to load part of a binary image into a customized version of CLIPS if all the needed constructs are not available. After a construct's binary image is read, the process is repeated to load another construct. This process continues until the binary footer is encountered.

Finally, integer index references to symbols, floats, integers, and expressions are replaced with actual pointer values to the specified data structures. Each registered construct is also allowed to replace integer index references to data structures that it references.

GLOBAL VARIABLES

BinaryPrefixID

PURPOSE: The character string that is placed at the beginning and end of a binary file.

BinaryVersionID

PURPOSE: The character string **BinaryVersionID** placed after the **BinaryPrefixID** at the beginning of a binary file to indicate which version of CLIPS created the file.

ExpressionArray

PURPOSE: The array containing the expressions used by the current binary image.

FloatArray

PURPOSE: The array containing pointers to the floats required by the current binary image.

FunctionArray

PURPOSE: The array containing pointers to the functions required by the current binary image.

IntegerArray

PURPOSE: The array containing pointers to the integers required by the current binary image.

SymbolArray

PURPOSE: The array containing pointers to the symbols required by the current binary image.

INTERNAL VARIABLES

AbortBloadFunctions

PURPOSE: Contains a list of functions to be called whenever a **bload** command is aborted due to an error.

AfterBloadFunctions

PURPOSE: Contains a list of functions to be after a binary image has been loaded and refreshed during a **bload** command. These functions are used for initialization unrelated to loading the binary image (such as incremental reset for rules).

BeforeBloadFunctions

PURPOSE: Contains a list of functions to be called before a binary image is loaded during a **bload** command. These functions are called after the environment has been cleared, but before the binary image is loaded.

BinaryFileHandle

PURPOSE: Reference value for the binary file currently being loaded on the IBM PC.

BinaryRefNum

PURPOSE: Reference value for the binary file currently being loaded on the Macintosh.

BinaryFP

PURPOSE: Reference value for the binary file currently being loaded on machines other than the Macintosh or IBM PC.

BloadActive

PURPOSE: Boolean value indicating whether a binary image is currently loaded into the CLIPS environment.

BloadReadyFunctions

PURPOSE: Contains a list of functions to be called after the **BeforeBloadFunctions** are called to determine if the **bload** should continue or be aborted.

ClearBloadReadyFunctions

PURPOSE: Contains a list of functions to be called before a **clear** command of a binary image to determine if the clear should even be attempted.

NumberOfExpressions

PURPOSE: Integer value indicating the number of expression data structures contained in the **ExpressionArray**.

GLOBAL FUNCTIONS

AddAbortBloadFunction

PURPOSE: Adds a function to the list of **AbortBloadFunctions**.

ARGUMENTS: A name to be associated with the abort function, the priority of the function, and a pointer to a function to be called whenever a **bload** is aborted.

AddAfterBloadFunction

PURPOSE: Adds a function to the list of **AfterBloadFunctions**.

ARGUMENTS: A name to be associated with the abort function, the priority of the function, and a pointer to a function after a **bload** is performed.

AddBeforeBloadFunction

PURPOSE: Adds a function to the list of **BeforeBloadFunctions**.

ARGUMENTS: A name to be associated with the abort function, the priority of the function, and a pointer to a function before a **bload** is performed.

AddBloadReadyFunction

PURPOSE: Adds a function to the list of **BloadReadyFunctions**.

ARGUMENTS: A name to be associated with the abort function, the priority of the function, and a pointer to a function to call to determine if a **bload** command should be performed.

AddClearBloadReadyFunction

PURPOSE: Adds a function to the list of **ClearBloadReadyFunctions**.

ARGUMENTS: A name to be associated with the abort function, the priority of the function, and a pointer to a function to call to determine if the current binary image can be cleared.

Bload

PURPOSE: Main driver routine for coordinating the loading of a binary file for the **bload** function.

ARGUMENTS: The name of the CLIPS binary file to be loaded.

RETURNS: Boolean value. TRUE, if the binary file was successfully created, otherwise FALSE.

BloadCommand

PURPOSE: Loads a CLIPS binary file into the CLIPS environment. This function is the driver routine for the CLIPS function **bload**. The function **Bload** is called by this function to load the binary image.

ARGUMENTS: No actual arguments. The CLIPS arguments passing routines are used to extract arguments when this function is called from the CLIPS environment.

Bloaded

PURPOSE: Indicates whether a binary image is currently loaded in the CLIPS environment.

OTHER NOTES: Boolean value. Returns the value of the **BloadActive** variable.

GenRead

PURPOSE: Provides a generic capability for reading binary input from a file.

ARGUMENTS: A pointer to the storage area in which the data is to be read and an integer indicating the amount of data to read. The data is read from the file indicated by one of the variables **BinaryRefNum**, **BinaryFileHandle** or **BinaryFP** depending upon the machine on which CLIPS is running.

INTERNAL FUNCTIONS

AbortBload

PURPOSE: Handles error recovery if an error occurs while performing a **bload** command. Calls the abort function for each binary item.

AddBloadFunctionToList

PURPOSE: Adds a function to a list of functions. Called by routines such as **AddBloadReadyFunction**.

ARGUMENTS: A name to be associated with the abort function, the priority of the function, a pointer to a function, and a pointer to the head of the list on which the function is to be placed.

RETURNS: A pointer to the new head of the list of functions (if the function was added at the beginning of the list), otherwise the old head of the list is returned. In either case, the function is added to the list.

BloadExpressions

PURPOSE: Called by function **Bload** to load all of the expressions used by the binary image into an array.

RETURNS:	A pointer to an array containing all the expression data structures used by this binary image. The global variable **NumberOfExpressions** is set by this function.

ClearBload

PURPOSE:	Clears a binary image from the CLIPS environment.
RETURNS:	Boolean value. TRUE if the binary image was successfully cleared, otherwise FALSE.

FastFindFunction

PURPOSE:	Searches for the data structure associated with a specified function name.
ARGUMENTS:	A pointer to the name of the function and a pointer to a function data structure in the **ListOfFunctions**.
RETURNS:	A pointer to the function data structure of the specified function if the function was found, otherwise NULL.
OTHER NOTES:	This function is faster than **FindFunction** because the functions required by the binary image should have been written out in the same order that they appear in the the **ListOfFunctions**. Since the starting location of the search can be specified, the last value returned by **FastFindFunction** can be used as starting location for the next search.

GenClose

PURPOSE:	Provides a generic capability for closing a binary file.
ARGUMENTS:	None. Closes the file specified by one of the global variables **BinaryRefNum**, **BinaryFileHandle** or **BinaryFP** depending upon the machine on which CLIPS is running.

GenOpen

PURPOSE:	Provides a generic capability for opening a binary file.
ARGUMENTS:	The name of the file to be opened.
RETURNS:	Boolean value. TRUE if the file was successfully opened, otherwise, FALSE. Also sets the machine specific global variables storing the pointers or values which refer to the file just opened. For the Macintosh, the variable **BinaryRefNum** is set. For the IBM PC, the variable

BinaryFileHandle is set. For all other machines, the variable **BinaryFP** is set.

ReadNeededFloats

PURPOSE: Called by function **Bload** to generate an array containing the pointers to floats required by the binary image being loaded. The required floats are first loaded from the CLIPS binary file, then the function **AddDouble** is used to add the float to the **FloatTable**. A pointer to the float's data structure is then stored in an array.

ARGUMENTS: A pointer to an integer in which the number of floats required by this binary image is stored.

RETURNS: A pointer to an array containing the pointers to floats required by this binary image. The number of floats argument is also assigned a value by this function.

ReadNeededFunctions

PURPOSE: Called by function **Bload** to generate an array containing the pointers to functions required by the binary image being loaded. The names of the required functions are first loaded from the CLIPS binary file, then the function **FastFindFunction** is used to locate the data structure corresponding to each function name. A pointer to the function's data structure is then stored in an array.

ARGUMENTS: A pointer to an integer in which the number of functions required by this binary image is stored and a pointer to an integer flag in which an error value is stored.

RETURNS: A pointer to an array containing the pointers to functions required by this binary image. Both arguments to this function are also assigned values. The error flag will be set to TRUE if any of the functions required by this binary image could not be found.

ReadNeededIntegers

PURPOSE: Called by function **Bload** to generate an array containing the pointers to integers required by the binary image being loaded. The required integers are first loaded from the CLIPS binary file, then the function **AddLong** is used to add the integer to the **IntegerTable**. A pointer to the integer's data structure is then stored in an array.

ARGUMENTS: A pointer to an integer in which the number of integers required by this binary image is stored.

RETURNS: A pointer to an array containing the pointers to integers required by this binary image. The number of integers argument is also assigned a value by this function.

ReadNeededSymbols

PURPOSE: Called by function **Bload** to generate an array containing the pointers to symbols required by the binary image being loaded. The required symbols are first loaded from the CLIPS binary file, then the function **AddSymbol** is used to add the symbol to the **SymbolTable**. A pointer to the symbol's data structure is then stored in an array.

ARGUMENTS: A pointer to an integer in which the number of symbols required by this binary image is stored.

RETURNS: A pointer to an array containing the pointers to symbols required by this binary image. The number of symbols argument is also assigned a value by this function.

RefreshExpressions

PURPOSE: Converts all of the integer index values found in expressions in the **ExpressionArray** to actual addresses.

Construct Compiler Module

The Construct Compiler Module (conscomp.c) provides the functionality for the **constructs-to-c** command by generating a set of C source code files representing the constructs currently loaded in the CLIPS environment. The files can then be compiled and linked with a runtime version of CLIPS specifically compiled for use with files generated by the construct compiler. The runtime version of CLIPS is smaller than standard version of CLIPS since a significant amount of code used for parsing constructs is removed.

The construct compiler works in a manner similar to a binary save and load. However, instead of dumping CLIPS constructs to a file as binary data, the construct compiler dumps the C code representation of the constructs to a C source file which is converted to binary data by a compiler. Since the resulting object file can be linked directly with CLIPS, there is no need to load the constructs. In addition, saving a binary image requires that pointer references be converted to integer indexes which must be converted back to pointer references when the binary image is loaded. When generating C code using the construct compiler, pointer references can be directly expressed as pointer references which can be automatically resolved by the compiler and linker.

As an example of how the construct compiler works, assume that the following deffacts has been entered into the CLIPS knowledge base.

```
(deffacts start-info
   (point 3.7 5.3))
```

In addition, the following *initial-facts* deffacts is automatically entered into the CLIPS knowledge base.

```
(deffacts initial-fact
   (initial-fact))
```

Now, assume that the user entered the following command.

```
CLIPS> (constructs-to-c xmp 3)
CLIPS>
```

The first step taken by the construct compiler is to generate a header file which will be used by the C source files which will be generated. Since the symbol *xmp* was given a the prefix symbol, the header file “xmp.h” will be generated. Initially, all extern definitions for user and system defined functions are written to this header file. Later, as needed, other extern definitions for data structures will be written to this file so that other files can access the data structures.

Next, all symbols, floats, integers, and user-defined and system function definitions (those defined using **DefineFunction**) are written out to files. When creating file names, a naming convention is used by construct compiler. The first number appended to the file name prefix indicates the general contents of the file and the second number appended indicates the nth file of that type. For example, if three files were required to save all symbols and the number used to indicate symbol files was 2, then the files would be name “xmp2_1.c,” “xmp2_2.c,” and “xmp2_3.c.”

Once all basic data types have been written to files, each construct that was registered with the construct compiler using the **AddCodeGeneratorItem** function is called so that it can generate its own C files. Each construct is only responsible for generating the code for the data structures that it has defined. References to symbols, floats, and integers are resolved by calling the functions **PrintSymbolReference**, **PrintFloatReference**, and **PrintIntegerReference** which will print the appropriate reference to the data item in the C file being generated by the construct. Each construct must also call the **ExpressionToCode** function for any expressions that it needs saved. This function will generate the appropriate code for the expression and print a reference to the expression in the C file being generated by the construct. Finally, although constructs are not required to, they should attempt to honor the limit on the maximum number of array elements which should be placed in a file.

Once all constructs have generated code, the initialization function is written and each construct is given the opportunity to add code to this function. For the example above, the initialization function would be named **InitCImage_3**.

Returning to the deffacts example shown previously, if the deffacts data structure were defined as follows

```
struct deffacts
  {
   struct symbol *name;
   char *ppForm;
   struct expression *assertItems;
   struct deffacts *next;
  };
```

then the following source code might be generated to represent all deffacts constructs.

```
#include "xmp.h"

struct deffacts dft3_1[] = {
{&shn3_1[166],NULL,&exp3_1[0],&dft3_1[1]},
{&shn3_1[287],NULL,&exp3_1[2],NULL}};
```

The first line of code includes the header file “xmp.h”. This file is needed in order to access the data structures representing symbols and expressions. The array name dft3_1 indicates that the image ID for the files generated by the construct compiler is 3 and that this is the first file containing deffacts structures. The reference &shn3_1[166] would be a pointer to the symbol data structure for the *initial-facts* symbol. Similarly, the reference &shn3_1[287] would be a pointer to the symbol data structure for the *start-info* symbol. The references &exp3_1[0] and &exp3_1[2] point to the expressions which assert the facts specified by the deffacts. Finally, the first dft3_1 array element contains the reference &dft3_1[1] which is simply a pointer to the next deffacts in the list.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

ExpressionCount

PURPOSE: An integer value representing the number of expression data structures which have been written to the current **ExpressionFP** file.

ExpressionFP

PURPOSE: A pointer to the file to which code for expression is currently being written.

ExpressionHeader

PURPOSE: Boolean flag indicating whether an array declaration needs to be written before expression data structures can be written to the current **ExpressionFP** file.

ExpressionVersion

PURPOSE: An integer value representing the number of different **ExpressionFP** files that have been opened for the module being generated.

FilePrefix

PURPOSE: A pointer to the file name prefix string used to generate the file names for storing the C code (the first argument to **constructs-to-c**).

HeaderFP

PURPOSE: A pointer to the header file for the code module being generated.

ImageID

PURPOSE: Integer value containing the module ID number for the generated code (the second argument to **constructs-to-c**).

ListOfCodeGeneratorItems

PURPOSE: Contains a list of data structures used to call functions for various constructs which generate C code.

MaxIndices

PURPOSE: Integer value containing the preferred maximum number of array elements to store in a single file (the third argument to **constructs-to-c**).

GLOBAL FUNCTIONS

AddCodeGeneratorItem

PURPOSE: Adds an item to the **ListOfCodeGeneratorItems**. Every construct that generates code for **constructs-to-c** must use this function to install functions that will be called whenever a **constructs-to-c** command is executed.

ARGUMENTS: A name to be associated with the code generator item, the priority of the item, a pointer to a function which is called before **constructs-to-c** begins generating code, a pointer to a function which is called for generating the C code data structures for the item, and a pointer to a function which is called to generate initialization C code for the **InitCImage_<id>** function.

ConstructsToCCommand

PURPOSE: Converts CLIPS constructs currently loaded into the CLIPS environment into C data structures and stores them in a file. This function is the driver routine for the CLIPS command **constructs-to-c**. The function **GenerateCode** is called by this function to perform the code generation.

ARGUMENTS: No actual arguments. The CLIPS arguments passing routines are used to extract arguments when this function is called from the CLIPS environment.

ConstructsToCCommandDefinition

PURPOSE: Sets up the definition of **constructs-to-c** command.

ExpressionToCode

PURPOSE: Prints a C code reference to an expression to a specified file and writes the C code representation of an expression to the current file storing expressions.

ARGUMENTS: A pointer to an open file and a pointer to an expression. The C code reference to the expression is written to the file pointer passed as a parameter and the C code representation of the expression (to which the reference refers) is written to the file stored in the **ExpressionFP** global variable.

RETURNS: Integer value. 1 if the C code representation was successfully generated and written to the file, 0 if a NULL expression pointer was passed as an argument (in which case the C code representation is not written but the string “NULL” is written as the code reference), and -1 if the C code was not successfully generated.

OTHER NOTES: The function **DumpExpression** is called to write the C code representation of the expression.

NewCFile

PURPOSE: Opens a new file for writing C code.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code, an integer suffix indicating the general contents of the file (e.g. 4 for defrules), and another integer suffix indicating the count of files for this type (e.g. the 5th file containing defrule information). For example, the file name “mab4_5.c” would be generated for the prefix string “mab” for the 5th file containing defrule information (assuming that 4 was the identification number for defrules).

RETURNS: A pointer to the newly opened file or NULL if the file could not be opened.

PrintDeffunctionReference

PURPOSE: Prints the C code representation of a pointer to a deffunction to a file.

ARGUMENTS: A pointer to an open file and a pointer to a deffunction.

PrintFloatReference

PURPOSE: Prints the C code representation of a **FloatTable** entry pointer to a file.

ARGUMENTS: A pointer to an open file and a pointer to a **FloatTable** entry.

PrintFunctionReference

PURPOSE: Prints the C code representation of a pointer to a function defined using **DefineFunction**.

ARGUMENTS: A pointer to an open file and a pointer to function.

PrintGenericFunctionReference

PURPOSE: Prints the C code representation of a pointer to a generic function to a file.

ARGUMENTS: A pointer to an open file and a pointer to a generic function.

PrintIntegerReference

PURPOSE: Prints the C code representation of an **IntegerTable** entry pointer to a file.

ARGUMENTS: A pointer to an open file and a pointer to a **IntegerTable** entry.

PrintSymbolReference

PURPOSE: Prints the C code representation of a **SymbolTable** entry pointer to a file.

ARGUMENTS: A pointer to an open file and a pointer to a **SymbolTable** entry.

INTERNAL FUNCTIONS

DumpExpression

PURPOSE: Prints a C code reference to an expression to a file.

ARGUMENTS: A pointer to an expression. The file the expression is written to is stored in the **ExpressionFP** global variable.

FloatsToCode

PURPOSE: Called by function **GenerateCode** to write the C code representation of all **FloatTable** entries to one or more files.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code and an integer starting value for the file count ID. In generating file names, the name prefix is appended by the characters “1_” followed by an integer file count ID. The extension “.c” is then added to the file name.

RETURNS: Integer value. If the C code was successfully generated and written to the file(s), then the file count ID for the next file to be generated is returned, otherwise zero is returned. If only one file is generated the value returned will be one greater than the file count ID passed as an argument.

FunctionsToCode

PURPOSE: Called by function **GenerateCode** to write the C code representation of all functions defined using **DefineFunction** to one or more files.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code. In generating file names, the name prefix is appended by the characters “2_” followed by an integer file count ID. The extension “.c” is then added to the file name.

RETURNS: Boolean value. TRUE, if the C code was successfully generated and written to the file(s), otherwise FALSE.

GenerateCode

PURPOSE: Main driver routine for coordinating code generation for the **constructs-to-c** function.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code (the first argument to **constructs-to-c**), the module ID number for the generated code (the second argument to **constructs-to-c**), and the preferred maximum number of array elements to store in a single file (the third argument to **constructs-to-c**).

RETURNS: Boolean value. TRUE, if the C code was successfully generated and written to the file(s), otherwise FALSE.

HashTablesToCode

PURPOSE: Called by function **GenerateCode** to write the C code representation of the **IntegerTable**, **FloatTable**, and **SymbolTable** each to its own file.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code. In generating file names, the name prefix is appended by the characters “1_” followed by an integer file count ID (1 for the **SymbolTable**, 2 for the **FloatTable**, and 3 for the **IntegerTable**). The extension “.c” is then added to the file name.

RETURNS: Boolean value. TRUE, if the C code was successfully generated and written to the files, otherwise FALSE.

IntegersToCode

PURPOSE: Called by function **GenerateCode** to write the C code representation of all **IntegerTable** entries to one or more files.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code and an integer starting value for the file count ID. In generating file names, the name prefix is appended by the characters "1_" followed by an integer file count ID. The extension ".c" is then added to the file name.

RETURNS: Integer value. If the C code was successfully generated and written to the file(s), then the file count ID for the next file to be generated is returned, otherwise zero is returned. If only one file is generated the value returned will be one greater than the file count ID passed as an argument.

ListUserFunctions

PURPOSE: Writes C code extern declarations for all functions defined using **DefineFunction** in the header file for the construct module being generated.

ARGUMENTS: A file pointer to the header file for the construct module being generated.

MarkBuckets

PURPOSE: Replaces the bucket slot of each entry in the **SymbolTable**, **IntegerTable**, and **FloatTable** with an integer index that will be used to refer to that value. For example, the seventh symbol in the **SymbolTable** has the value 7 stored in its bucket slot (which would normally indicate the location in the **SymbolTable** that the symbol is stored).

PrintCString

PURPOSE: Prints the C code representation of a string replacing backslashes, quotation marks, and carriage returns with the appropriate character escape sequences.

ARGUMENTS: A pointer to an open file and a pointer to a string.

SetUpInitFile

PURPOSE: Writes the C code function needed for the initialization of a runtime module to a file. The function written is the

InitCImage_<id> function described in section 5 of the *Advanced Programming Guide*.

ARGUMENTS: A pointer to the file name prefix string used to generate the file name for storing the C code. In generating the file name, the name prefix is appended by a ".c" extension.

RETURNS: Boolean value. TRUE, if the C code was successfully generated and written to the file(s), otherwise FALSE.

SymbolsToCode

PURPOSE: Called by function **GenerateCode** to write the C code representation of all **SymbolTable** entries to one or more files.

ARGUMENTS: A pointer to the file name prefix string used to generate the file names for storing the C code and an integer starting value for the file count ID. In generating file names, the name prefix is appended by the characters "1_" followed by an integer file count ID. The extension ".c" is then added to the file name.

RETURNS: Integer value. If the C code was successfully generated and written to the file(s), then the file count ID for the next file to be generated is returned, otherwise zero is returned. If only one file is generated the value returned will be one greater than the file count ID passed as an argument.

UnmarkBuckets

PURPOSE: Restores the bucket slot of each entry in the **SymbolTable**, **IntegerTable**, and **FloatTable** with its appropriate value. This function is called to reverse the changes made by **MarkBuckets**.

Primary Functions Module

The Primary Functions Module (sysprime.c) provides a set of environment commands and procedural functions. Commands and functions provided are **watch**, **unwatch**, **clear**, **reset**, **exit**, **if**, **while**, **bind**, **progn**, **return**, and **break**. In addition, several functions for CLIPS internal use are defined in this module. These functions are **nop**, **constant**, **nonconstant**, **neq_field**, **eq_field**, **get_bind**, **pointer**, **get_field**, and **get_end**.

GLOBAL VARIABLES

BreakContext

PURPOSE: An integer flag indicating when the **break** function can be validly called. This flag is saved and cleared upon entry into a deffunction, generic function method or message-handler and restored on exit.

ReturnContext

PURPOSE: An integer flag indicating when the **return** function can be validly called. This flag is saved and set upon entry into a deffunction, generic function method or message-handler and restored on exit.

ReturnFlag

PURPOSE: An integer flag set when the **return** function is called and **ReturnContext** is set. The flag is cleared by the enclosing deffunction, generic function method or message-handler.

INTERNAL VARIABLES

BreakFlag

PURPOSE: An integer flag set when the **break** function is called and **BreakContext** is set. The flag is cleared by the enclosing **while** loop.

GLOBAL FUNCTIONS

Primary Function Definitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Primary and Internal Functions

PURPOSE:	A series of functions which defines the primary CLIPS RHS actions and internal functions listed above. See the *Basic Programming Guide* for more detail on individual functions.
OTHER NOTES:	Some functionality for these functions is contained in other modules.

Predicate Functions Module

The Predicate Functions Module (syspred.c) provides a number of predicates and simple mathematical functions commonly used in CLIPS. Predicate functions provided are **eq**, **neq**, **symbolp**, **stringp**, **lexemep**, **integerp**, **floatp**, **numberp**, **oddp**, **evenp**, **multifieldp**, **pointerp**, **and**, **or**, **not**, **=**, **<>**, **>**, **<**, **>=**, and **<=**. Mathematical functions provided are *****, **/**, **+**, **-**, **div**, **set-auto-float-dividend**, and **get-auto-float-dividend**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

AutoFloatDividend

PURPOSE: Boolean flag which indicates whether the dividend of a division operation is automatically converted to a floating pointer number. By default, this behavior is enabled.

GLOBAL FUNCTIONS

PredicateFunctionDefinitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Predicate and Math Functions

PURPOSE: A series of functions which defines predicate and mathematical functions listed above. See the *Basic Programming Guide* for more detail on individual functions.

I/O Functions Module

The I/O Functions Module (sysio.c) provides a number of functions convenient for performing I/O. Among these are **open**, **close**, **read**, **readline**, **printout**, and **format**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

IOFunctionDefinitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

LOCAL FUNCTIONS

I/O Functions

PURPOSE: A series of functions which defines I/O functions listed above. See the *Basic Programming Guide* for more detail on the individual functions.

Secondary Functions Module

The Secondary Functions Module (syssecnd.c) provides a set of useful functions that perform a wide variety of useful tasks. Functions provided are **trunc**, **integer**, **float**, **abs**, **min**, **max**, **str-assert**, **setgen**, **gensym**, **gensym***, **system**, **length**, **time**, **random**, **seed**, **conserve-mem**, **release-mem**, **mem-used**, **mem-requests**, and **options**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

GensymNumber

PURPOSE: An integer value used by **gensym** and **gensym*** in creating symbols.

GLOBAL FUNCTIONS

SecondaryFunctionDefinitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Secondary Functions

PURPOSE: A series of functions which defines secondary CLIPS RHS actions listed above. See the *Basic Programming Guide* for more detail on individual functions.

OTHER NOTES: Some functionality for these functions is contained in other modules.

Multifield Functions Module

The Multifield Functions Module (multivar.c) provides a set of useful functions for use with multifield values. Functions provided are **nth**, **member**, **subset**, **mv-subseq**, **mv-delete**, **mv-append**, **mv-replace**, **str-explode**, and **str-implode**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

MultifieldFunctionDefinitions

PURPOSE:	Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Multifield Functions

PURPOSE:	A series of functions which defines the CLIPS multifield functions listed above. See the *Basic Programming Guide* for more detail on individual functions.

String Functions Module

The String Functions Module (strings.c) provides a set of useful functions for manipulating strings. Functions provided are **str-length**, **str-compare**, **upcase**, **lowcase**, **sub-string**, **str-index**, **str-cat**, **sym-cat**, **eval**, and **build**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

StringFunctionDefinitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

String Functions

PURPOSE: A series of functions which define the CLIPS string functions listed above. See the *Basic Programming Guide* for more detail on individual functions.

Math Functions Module

The Math Functions Module (math.c) provides a set of useful math functions beyond the basic math functions provided by the Predicate Functions Module. Functions provided are **cos**, **sin**, **tan**, **sec**, **csc**, **cot**, **acos**, **asin**, **atan**, **asec**, **acsc**, **acot**, **cosh**, **sinh**, **tanh**, **sech**, **csch**, **coth**, **acosh**, **asinh**, **atanh**, **asech**, **acsch**, **acoth**, **mod**, **exp**, **log**, **log10**, **sqrt**, **pi**, **deg-rad**, **rad-deg**, **deg-grad**, **grad-deg**, ******, and **round**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

MathFunctionDefinitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Math Functions

PURPOSE: A series of functions which defines extended math functions listed above. See the *Basic Programming Guide* for more detail on individual functions.

OTHER NOTES: The Math Module does some checking to verify that illegal arguments are not passed to some functions since actions taken when an error occurs in these math functions can be machine dependent.

Text Processing Functions Module

The Text Processing Module (textpro.c) provides a set of useful functions for building and accessing a hierarchical lookup system for multiple external files. Functions which provide on-line help are also available. The functions provided are **help**, **help-path**, **fetch**, **toss**, and **print-region**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

None.

GLOBAL FUNCTIONS

HelpFunctionDefinitions

PURPOSE:	Makes appropriate **DefineFunction** calls to notify CLIPS of functions defined in this module.

INTERNAL FUNCTIONS

Text Processing Functions

PURPOSE:	A series of functions which define the text processing and help functions listed above. See the *Basic Programming Guide* for more detail on individual functions.

File Commands Module

The File Commands Module (intrfile.c) provides a set of useful interface commands that performs certain file operations not associated with standard file I/O operations. The functions provided are **batch**, **load**, **save**, **bload**, **bsave**, **dribble-on**, **dribble-off**, **crsv-trace-on**, and **crsv-trace-off**.

GLOBAL VARIABLES

None.

INTERNAL VARIABLES

Batch and Dribble Globals

PURPOSE: Several variables containing information for batch and dribble commands.

GLOBAL FUNCTIONS

FileFunctionDefinitions

PURPOSE: Makes appropriate **DefineFunction** calls to notify CLIPS of commands defined in this module.

INTERNAL FUNCTIONS

File Commands

PURPOSE: A series of functions which define the file-oriented commands listed above. See the *Basic Programming Guide* for more detail on individual functions.

OTHER NOTES: Some functionality for these commands is provided in other modules. The load command is one example of this.

Deffunction Module

The Deffunction Module (deffnctn.c) manages all aspects of the deffunction construct including parsing, execution, and removal. For a description of the deffunction construct, see the *Basic Programming Guide*. The deffunction construct capability can be removed by using the appropriate compile flag in the setup header file. The deffunction data structure is summarized in the following diagram:

Name (Symbol Pointer)
Busy Count (int)
Execution Count (int)
Minimum Parameters (int)
Maximum Parameters (int)
Actions (Expression Pointer)
Pretty-Print Form (array of char)
Bload/Bsave Index (long int)
Previous Link (Deffunction Pointer)
Next Link (Deffunction Pointer)

The internal data structure of a deffunction construct primarily consists of: a symbolic name, two integers which indicate the minimum and maximum number of arguments the deffunction will accept respectively and a sequence of expressions which comprise the body of the deffunction. If a deffunction has a wildcard parameter (i.e. the deffunction will accept any number of arguments greater than or equal to the minimum number of arguments), the maximum number of arguments field will have the value -1. A busy count for each deffunction reflects how many other expressions in other constructs refer to that deffunction. This busy count must be zero before it is safe to delete the deffunction.

Similarly, an execution count for each deffunction reflects how many times a deffunction has been called. This execution count must be zero before a deffunction can be modified. Other fields in the deffunction data structure include: the pretty-print form, an index for use in binary load/save and the construct compiler, and pointers for double links to other deffunctions. A new deffunction is added to the list of deffunctions, **DFList**, before its actions are parsed so that it may be recursive, if desired.

When a deffunction is called, if the number of arguments is outside the acceptable range, the call is immediately terminated and an error is generated. Otherwise, all the actions of the deffunction are evaluated in order as if they were grouped in a **progn**. The evaluation of the last expression in the deffunction body is returned as the value of the deffunction, unless an error occurs or the **return** function is used (see the *Basic Programming Guide*).

Deffunction calls are represented by an expression data structure where the type field is PCALL (for procedure call) and the value field is the address of the corresponding deffunction construct. The expressions for the arguments of the deffunction are chained together via "next argument" pointers, and the whole chain is attached to the "argument list" pointer of the deffunction call. When such an expression is evaluated, the routines in the Evaluation Module call a special function,

CallDeffunction, to actually evaluate the arguments and perform the actions contained within the body of the deffunction.

The arguments of a deffunction are evaluated and stored in order in an array of data objects called the deffunction parameter array. Variable references within the body of a deffunction are replaced when the construct is loaded with function calls which either access the bind list (see the Primary Functions Module), get the value of a global variable (see the Defglobal Manager Module) or positionally access the deffunction parameter array. For example, references to the second parameter of a deffunction are replaced with a call to the function **DFRtnUnknown**, which accesses the second data object in the parameter array at run-time.

A wildcard parameter allows the deffunction to accept any number of arguments. All references to the wildcard parameter are replaced with a call to a special function, **DFWildargs**, which groups all of the data objects in the parameter array starting at the position of the wildcard parameter to the end of the array into a multifield data object.

If a parameter (including a wildcard parameter) is rebound anywhere within the body of the deffunction, all references to that parameter are replaced with calls to a special function, **DeffunctionGetBind**, which first checks the bind list before accessing the parameter array.

GLOBAL VARIABLES

deffunctionArray

PURPOSE: A pointer to an array of deffunction data structures loaded using the **bload** command. When **bload** is in effect, **DFList** and **DFBot** will point to the first and last elements of this array respectively.

INTERNAL VARIABLES

CurrentDeffunctionName

PURPOSE: A symbol indicating the name of the currently executing deffunction used for error and trace messages.

DeffunctionError

PURPOSE: A flag used to indicate when deffunction parsing errors occur.

Deffunction Trace Strings

PURPOSE: **BEGIN_TRACE** and **END_TRACE** are the strings used in trace printouts to indicate the beginning and end of execution of a deffunction.

OTHER NOTES: Implemented as preprocessor constants.

DFBot

PURPOSE: A pointer to the last node in the list of all currently defined deffunctions.

DFCount

PURPOSE: An intermediary counter used for deffunction data structures during binary loads and saves.

DFInputToken

PURPOSE: An intermediary variable used for scanned tokens by the deffunction parsing routines during a **load**.

DFList

PURPOSE: A pointer to the first node in the list of all currently defined deffunctions.

DFParamArray

PURPOSE: A pointer to an array of data objects which are the evaluated arguments for the currently executing deffunction.

DFParamSize

PURPOSE: An integer indicating the number of data objects in the currently executing deffunction's parameter array.

WatchDeffunctions

PURPOSE: An integer flag indicating whether or not to print out trace information whenever a deffunction begins and ends execution. This flag is used by the **watch** command.

GLOBAL FUNCTIONS

CallDeffunction

PURPOSE: This routine is called by **EvaluateExpression** in the Evaluation Module to process a deffunction call.

ARGUMENTS:
1) A pointer to a deffunction.
2) A list of expressions forming the deffunction arguments.
3) A pointer to a data object which will hold the return value of the deffunction.

OTHER NOTES: Following is a summary of **CallDeffunction**:

1. Count and check the number of arguments.
2. Save previous values of globals, such as **CurrentDeffunctionName**, and set them for the new deffunction.
3. Increment the evaluation depth (see the Evaluation Module).
4. Evaluate the arguments and store them in the deffunction parameter array.
5. Save the state of the bind list and then destroy it.
6. Save the states of the **return** and **break** contexts and set them to FALSE.
7. Increment the execution count of the deffunction.
8. Call **EvaluateExpression** for the actions of the deffunction and capture the result.
9. Restore all global values to their previous states.
10. Decrement the execution count of the deffunction.
11. Decrement the evaluation depth.
12. Clear **ReturnFlag**.
13. Adjust the evaluation depth of the return value (see **PropogateReturnValue** in the Evaluation Module).
14. Perform garbage collection.

CmdListDeffunctions

PURPOSE: Lists all the currently defined deffunctions.

OTHER NOTES: Implementation of the CLIPS function **list-deffunctions**.

CmdPPDeffunction

PURPOSE: Displays the pretty-print form of the deffunction specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **ppdeffunction**.

CmdUndeffunction

PURPOSE: Removes a deffunction.

OTHER NOTES: Implementation of the CLIPS function **undeffunction**.

DeffunctionGetBind

PURPOSE: Determines the value of a specified variable reference within the body of a deffunction. The symbolic name of the variable and an index indicating if the variable is a deffunction parameter are CLIPS supplied arguments. If the variable is on the bind list, that value is returned. Otherwise, the value of the parameter specified by the index is returned. In the event that the variable is neither on the bind list nor a parameter, an error will be generated.

ARGUMENTS: A pointer to a data object which will hold the value of the bound variable.

OTHER NOTES: Implementation of the internal CLIPS function **(df-getbind)**.

Used for general variable references, including bind list variables and deffunction parameters which are rebound within the actions of the deffunction. If the index is zero, the variable is not a deffunction parameter. The absolute value of the index minus one is the position of the parameter in the deffunction parameter array. If the index is less than zero, the variable corresponds to the wildcard parameter.

DFRtnUnknown

PURPOSE: Gets the value of the specified element of the deffunction parameter array, where the element index plus one is given as a CLIPS supplied argument.

ARGUMENTS: A pointer to a data object which will hold the value of the bound variable.

OTHER NOTES: Implementation of the internal CLIPS function **(df-runknown)**.

Used for references to regular deffunction parameters which are never rebound within the actions of the deffunction.

DFWildargs

PURPOSE: Gets the values of the specified elements of the deffunction parameter array and groups them into a multifield data object, where the range of elements is given by a CLIPS supplied argument minus one to the end of the deffunction parameter array.

ARGUMENTS: A pointer to a data object which will hold the value of the bound variable.

OTHER NOTES: Implementation of the internal CLIPS function **(df-wildargs)**.

Used for references to a wildcard deffunction parameter which is never rebound within the actions of the deffunction.

Embedded Access for Deffunctions

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*: **DeleteDeffunction**, **FindDeffunction**, **GetDeffunctionName**, **GetDeffunctionPPForm**, **GetNextDeffunction**, **IsDeffunctionDeletable** and **ListDeffunctions**.

FindDeffunctionBySymbol

PURPOSE: Determines the address of a specified deffunction.

ARGUMENTS: A pointer to a symbol.

RETURNS: A pointer to a deffunction.

InitializeDeffunctions

PURPOSE: Defines all functions and commands for the deffunction construct. Sets up all necessary **load**, **clear**, **save**, **watch**, **constructs-to-c** and **bload/bsave** interfaces.

OTHER NOTES: Initialization differs between standard and run-time configurations.

SetListOfDeffunctions

PURPOSE: Initializes the global variables **DFList** and **DFBot** to point to the top and bottom respectively of the given list of deffunctions.

ARGUMENTS: A pointer to the top of a list of deffunctions.

OTHER NOTES: This function is used only in a run-time version of CLIPS.

INTERNAL FUNCTIONS

AddDeffunction

PURPOSE: Support routine for **ParseDeffunction** which allocates, initializes and attaches a new deffunction to the list of deffunctions.

ARGUMENTS:
1) The symbolic name of the new deffunction.
2) A list of expressions forming the actions of the deffunction.
3) The minimum number of parameters the deffunction will

accept.
4) The maximum number of parameters the deffunction will accept (-1 if the deffunction has a wildcard parameter).
5) An integer code indicating if the deffunction being added is a forward declaration (non-zero) or not (zero).

RETURNS: A pointer to the added deffunction.

CheckDeffunctionCall

PURPOSE: Determines if the number of CLIPS supplied arguments to a particular deffunction call is appropriate.

ARGUMENTS: 1) A pointer to the deffunction.
2) The number of arguments passed.

RETURNS: The integer zero for an incorrect number of arguments, non-zero otherwise.

ClearDeffunctions

PURPOSE: Used by the **clear** command to remove all currently defined deffunctions.

RETURNS: The integer zero if not all deffunctions were successfully cleared, non-zero otherwise.

OTHER NOTES: Deffunctions are removed after all other constructs except defgenerics, for this insures that the deffunctions are no longer in use. The use of priorities in **AddClearFunction** accomplishes this ordering.

Deffunction Bload/Bsave Functions

PURPOSE: A set of functions used by the **bload** and **bsave** commands to process the deffunction construct.

Deffunction Constructs-To-C Functions

PURPOSE: A set of functions used by the **constructs-to-c** command to process the deffunction construct.

EvaluateDFParameters

PURPOSE: Support routine for **CallDeffunction** which evaluates all the CLIPS supplied argument expressions for a deffunction call and stores the resulting data objects in the deffunction parameter array (**DFParamArray**).

ARGUMENTS: 1) The list of parameter name expressions.
2) The number of parameters.

RETURNS: A pointer to an array of data objects containing the evaluations of the deffunction argument expressions.

FindParameter

PURPOSE: Support routine for **ParseDeffunction** used to determine if a parameter occurs more than once in a deffunction parameter list.

ARGUMENTS: 1) The symbolic name of a parameter.
2) The list of parameters parsed so far.

RETURNS: The integer zero if the named parameter is not already in the list, otherwise the position of the parameter in the list.

GrabWildargs

PURPOSE: Stores the deffunction parameter array elements from the specified beginning index minus one to the end of the array in the caller's multifield data object.

ARGUMENTS: 1) A pointer to a data object to hold the resulting multifield value.
2) The index (one is the beginning) from which to start copying the parameter array.

ParseDeffunction

PURPOSE: Used by the **load** command to parse a deffunction.

ARGUMENTS: The logical name of the input source.

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

ParseParameters

PURPOSE: Support routine for **ParseDeffunction** which parses a deffunction parameter list.

ARGUMENTS: 1) The logical name of the input source.
2) A buffer for holding a pointer to the symbolic name of a

wildcard parameter (if any).
3) A buffer for an integer code indicating any parsing errors.

RETURNS: A linked list of expressions containing the symbolic names of the deffunction parameters.

RemoveDeffunction

PURPOSE: Removes a specified deffunction.

ARGUMENTS: A pointer to a deffunction.

ReplaceParameters

PURPOSE: Support routine for **ParseDeffunction** which replaces all variable references in the deffunction actions with appropriate function calls that access the bind list, the deffunction parameter array or global variables at run-time.

ARGUMENTS:
1) The list of action expressions.
2) The list of parameter name expressions.
3) The symbolic name of a wildcard parameter (if any).

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

SaveDeffunctions

PURPOSE: Used by the **save** command to write out the pretty-print forms of all the currently defined deffunctions.

ARGUMENTS: The logical name of the output destination.

SaveDeffunctionHeaders

PURPOSE: Used by the **save** command to write out forward declarations of all deffunctions before other constructs in the event that the deffunctions are called from these other constructs.

ARGUMENTS: The logical name of the output destination.

TraceDeffunction

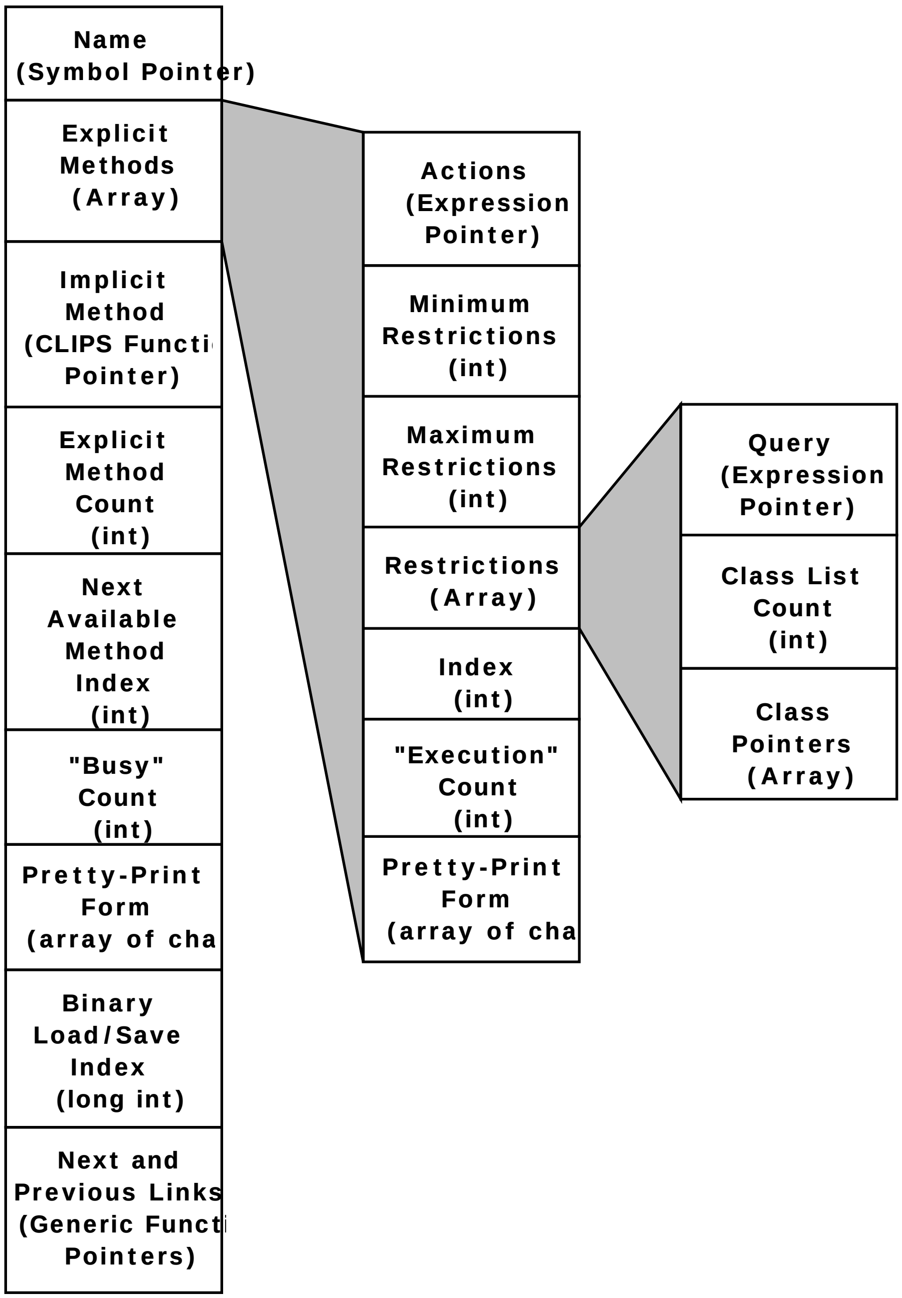
PURPOSE: Used by the **watch** command to print out trace messages when a deffunction begins and ends execution.

ARGUMENTS: A string indicating the beginning or end of execution of a deffunction.

Generic Function Commands Module

The Generic Function Commands Module (genrccom.c) manages the parsing and general interface aspects of the defgeneric and defmethod constructs. For a description of the defgeneric and defmethod constructs, see the *Basic Programming Guide*. The generic function capability can be removed by using the appropriate compile flag in the setup header file.

The generic function data structures are summarized in the following diagram:



The internal data structure of a defgeneric construct primarily consists of: a symbolic name, an array of defmethod constructs (the explicit methods), a pointer to a system or user-defined external function (if any), which is overloaded by the generic function (the implicit method) and an integer indicating the next available index for a new method. A busy count for each generic function reflects how many other expressions in other constructs refer to that generic function and how many times the generic function has been called. This busy count must be zero before it is safe to delete the generic function. Other fields in the generic function data structure include: the number of methods, the pretty-print form, an index for use in binary load/save and the construct compiler and pointers for double links to other generic functions. A new defgeneric is added to the list of generic functions, **GenericList**, before the actions of any its methods are parsed so that it may be recursive, if desired.

The internal data structure of a defmethod construct primarily consists of: two integers which indicate the minimum and maximum number of arguments the method will accept respectively, an array of parameter restriction data structures and a sequence of expressions which comprise the body of the method. Each parameter restriction data structure consists of: a sequence of classes, the number of classes in this sequence and a query expression. The corresponding run-time generic function argument must be an instance of one of these classes (if any) and the boolean query (if any) must be true in order for the restriction to be satisfied. If a method has a wildcard parameter (i.e. the method will accept any number of arguments greater than or equal to the minimum number of arguments), the maximum number of arguments field will have the value -1. Similarly, an execution count for each method reflects how many times a method has been called as well as how many outstanding generic function calls to which this method is applicable. This execution count must be zero before any methods for the generic function to which this method belongs can be modified. Other fields in the method data structure include: the pretty-print form and an identifying index.

As each new method is defined and inserted into the appropriate generic function's method array, the method array is maintained in sorted order according to precedence. This eases the burden on the generic dispatch at run-time. The Generic Function Functions Module covers method precedence in detail.

Generic function calls are represented by an expression data structure where the type field is GCALL and the value field is the address of the corresponding defgeneric construct. The expressions for the arguments of the generic function are chained together via "next argument" pointers, and the whole chain is attached to the "argument list" pointer of the generic function call. When such an expression is evaluated, the routines in the Evaluation Module call a special function, **GenericDispatch**, to actually evaluate the arguments and execute the method(s) of the generic function. The Generic Function Functions Module covers the generic dispatch in detail.

The arguments of a generic function are evaluated and stored in order in an array of data objects called the method parameter array. Variable references within the body of a defmethod are replaced when the construct is loaded with function calls which either access the bind list, get the value of a global variable or positionally access the method parameter array. For example, references to the second parameter of a method are replaced with calls to the function **RtnGenericUnknown** which access the second data object in the parameter array at run-time.

A wildcard parameter allows a method to accept any number of arguments. All references to the wildcard parameter are replaced with a call to a special function, **GetGenericWildargs**, which groups all of the data objects in the parameter array starting at the position of the wildcard parameter to the end of the array into a multifield data object.

If a parameter (including a wildcard parameter) is rebound anywhere within the body of a method, all references to that parameter are replaced with calls to a special function, **GetGenericBind**, which first checks the bind list before accessing the parameter array.

INTERNAL VARIABLES

GenericInputToken

PURPOSE: An intermediary variable used for scanned tokens by the generic function parsing routines during a **load**.

GLOBAL FUNCTIONS

CmdListDefgenerics

PURPOSE: Lists all defgenerics in the system.

OTHER NOTES: Implementation of the CLIPS function **list-defgenerics**.

CmdListDefmethods

PURPOSE: Lists the methods of the generic function(s) specified by the CLIPS supplied arguments.

OTHER NOTES: Implementation of the CLIPS function **list-defmethods**.

CmdUndefgeneric

PURPOSE: Removes a generic function and all associated methods.

OTHER NOTES: Implementation of the CLIPS function **undefgeneric**.

CmdUndefmethod

PURPOSE: Removes a generic function method.

OTHER NOTES: Implementation of the CLIPS function **undefmethod**.

Embedded Access for Generic Functions

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*: **DeleteDefgeneric**, **DeleteDefmethod**, **FindDefgeneric**, **GetNextDefgeneric**,

GetDefgenericName, **GetDefgenericPPForm**, **GetDefmethodDescription**, **GetNextDefmethod**, **GetDefmethodPPForm**, **IsDefgenericDeletable**, **IsDefmethodDeletable**, **ListDefgenerics** and **ListDefmethods**.

GetGenericBind

PURPOSE: Determines the value of a specified variable reference within the body of a method. The symbolic name of the variable and an index indicating if the variable is a method parameter are CLIPS supplied arguments. If the variable is on the bind list, that value is returned. Otherwise, the value of the parameter specified by the index is returned. In the event that the variable is neither on the bind list nor a parameter, an error will be generated.

ARGUMENTS: A pointer to a data object to hold the variable's value.

OTHER NOTES: Implementation of the internal CLIPS function **(gnrc-bind)**.

Used for general variable references, including bind list variables and method parameters which are rebound within the actions of the method. If the index is zero, the variable is not a method parameter. The absolute value of the index minus one is the position of the parameter in the method parameter array. If the index is less than zero, the variable corresponds to the wildcard parameter.

GetGenericWildargs

PURPOSE: Gets the values of the specified elements of the method parameter array and groups them into a multifield data object, where the range of elements is given by a CLIPS supplied argument minus one to the end of the method parameter array.

ARGUMENTS: A pointer to a data object to hold the variable's value.

OTHER NOTES: Implementation of the internal CLIPS function **(gnrc-wildargs)**.

Used for references to a wildcard method parameter which is never rebound within the actions of the method.

PPDefgeneric

PURPOSE: Displays the pretty-print form of the defgeneric specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **ppdefgeneric**.

PPDefmethod

PURPOSE: Displays the pretty-print form of the generic function method specified by the CLIPS supplied arguments.

OTHER NOTES: Implementation of the CLIPS function **ppdefmethod**.

RtnGenericUnknown

PURPOSE: Gets the value of the specified element of the method parameter array, where the element index plus one is given as a CLIPS supplied argument.

ARGUMENTS: A pointer to a data object to hold the variable's value.

OTHER NOTES: Implementation of the internal CLIPS function **(gnrc-runknown)**.

Used for references to regular method parameters which are never rebound within the actions of the method.

SetupGenericFunctions

PURPOSE: Defines all functions and commands for the defgeneric and defmethod constructs. Sets up all necessary **load**, **clear**, **save**, **watch**, **constructs-to-c** and **bload/bsave** interfaces.

OTHER NOTES: Initialization differs between standard and run-time configurations.

TypeOf

PURPOSE: Determines the type (class) of the CLIPS supplied argument.

ARGUMENTS: A pointer to a data object to hold the symbolic name of the class of the CLIPS supplied argument.

OTHER NOTES: This function implements the CLIPS function **type** function when COOL is not available. When COOL is available, the functions **type** and **class** are implemented by **GetInstanceClassCmd** (see the Instance Commands Module).

INTERNAL FUNCTIONS

AddParameter

PURPOSE: Support routine for **ParseParameters** which links intermediate information for a method parameter and its restrictions to the list of other method parameters.

ARGUMENTS:
1) The top of the parameter expression list.
2) The bottom of the parameter expression list.
3) The parameter symbolic name.
4) A pointer to a parameter restriction data structure.

RETURNS: The (new) top of the parameter expression list.

CheckGenericExists

PURPOSE: Determines if a specified generic function exists.

ARGUMENTS:
1) The name of the calling function.
2) The name of the generic function.

RETURNS: A pointer to the generic function (NULL if not found).

CheckMethodExists

PURPOSE: Determines if a specified method of a generic function exists.

ARGUMENTS:
1) The name of the calling function.
2) A pointer to the generic function.
3) The index of the method.

RETURNS: The method array index (-1 if not found).

DeleteTempRestricts

PURPOSE: Support routine for **ParseParameters** which deallocates intermediate data structures used for method parameter restrictions.

ARGUMENTS: The list of parameter expressions.

DuplicateParameters

PURPOSE: Support routine for **ParseParameters** which determines if a method's parameter list contains any duplicate names.

ARGUMENTS:
1) The list of parameter name expressions.
2) Buffer for address of last node searched (can be used to

later attach new parameter).
3) The symbolic name of the parameter being checked.

RETURNS: A non-zero integer if duplicates are found, zero otherwise.

FindParameter

PURPOSE: Support routine for **ReplaceParameters** which determines the position of a particular parameter in the list of all method parameters.

ARGUMENTS: 1) The symbolic name of a parameter.
2) The list of parameters parsed so far.

RETURNS: The integer zero if the named parameter is not already in the list, otherwise the position of the parameter in the list.

GrabGenericWildargs

PURPOSE: Stores the method parameter array elements from the specified beginning index minus one to the end of the array in the caller's multifield data object.

ARGUMENTS: 1) A pointer to a data object to hold the resulting multifield value.
2) The index (one is the beginning) from which to start copying the parameter array.

PackRestrictionTypes

PURPOSE: Support routine for **ParseRestriction** which packs the class restrictions for a method parameter into a contiguous array for easy reference.

ARGUMENTS: 1) The restriction data structure.
2) The types expression list

OTHER NOTES: If COOL is not present, then the types are integer codes representing the CLIPS types. -1 means all types are acceptable.

ParseDefgeneric

PURPOSE: Used by the **load** command to parse a defgeneric.

ARGUMENTS: The logical name of the input source.

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

ParseDefmethod

PURPOSE: Used by the **load** command to parse a defmethod.

ARGUMENTS: The logical name of the input source.

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

ParseMethodName

PURPOSE: Support routine for **ParseDefgeneric** which parses a generic function name.

ARGUMENTS: The logical name of the input source.

RETURNS: The symbolic name of the method.

ParseMethodNameAndIndex

PURPOSE: Support routine for **ParseDefmethod** which parses a method name and optional index.

ARGUMENTS: 1) The logical name of the input source.
2) Buffer for method index (0 if not specified).

RETURNS: The symbolic name of the method.

ParseParameters

PURPOSE: Support routine for **ParseDefmethod** which parses a method parameter list.

ARGUMENTS: 1) The logical name of the input source.
2) Buffer for the parameter name list.
3) Buffer for wildcard symbol (if any).

RETURNS: The number of parameters, or -1 on errors.

ParseRestriction

PURPOSE: Support routine for **ParseParameters** which parses the restrictions for a given method parameter.

ARGUMENTS: The logical name of the input source.

RETURNS: A pointer to a parameter restriction data structure, NULL on errors.

RemoveGeneric

PURPOSE: Removes a specified generic function and all its methods.

ARGUMENTS: A pointer to the generic function.

RETURNS: The integer one if successful, zero otherwise

RemoveGenericMethod

PURPOSE: Removes a specified method of a generic function.

ARGUMENTS: 1) A pointer to the generic function.
2) The array index of the method.

ReplaceParameters

PURPOSE: Support routine for **ParseDefmethod** which replaces all variable references in the method actions with appropriate function calls that access the bind list, the method parameter array or global variables at run-time.

ARGUMENTS: 1) The list of action expressions.
2) The list of parameter name expressions.
3) The symbolic name of a wildcard parameter (if any).

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

SaveDefgenerics

PURPOSE: Used by the **save** command to write out forward declarations of all generic functions before other constructs in the event that the generic functions are called from these other constructs.

ARGUMENTS: The logical name of the output destination.

SaveDefmethods

PURPOSE: Used by the **save** command to write out the pretty-print forms of all the methods of currently defined generic functions.

ARGUMENTS: The logical name of the output destination.

ValidType

PURPOSE: Support routine for **ParseRestriction** which determines if a class restriction list for a method parameter is comprised of existing classes.

ARGUMENTS: The symbolic name of the restriction class.

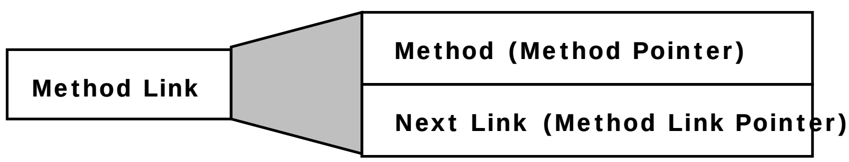
RETURNS: When COOL is present, an expression containing a pointer to the class, otherwise an expression list containing the integer codes of the CLIPS types (see constant.h) corresponding to the class, NULL on errors.

Generic Function Functions Module

The Generic Function Functions Module (genrcfun.c) establishes the precedence between different methods of a generic function when they are defined, manages the generic dispatch and provides support routines for other internal manipulations of generic functions and methods, such as allocation and deletion. For a description of the defgeneric and defmethod constructs, see the *Basic Programming Guide*. The generic function capability can be removed by using the appropriate compile flag in the setup header file.

Whenever a new method for a generic function is defined, the method array for that generic function is reallocated to make room for the new method information. The new method is inserted into the array such that a sorted order according to precedence is maintained. Section 8.5.2 in the *Basic Programming Guide* explains the method precedence rules in detail. The precedence between any two methods is determined by comparing field per field the parameter restrictions of the two methods.

When a generic function is called, CLIPS uses the generic function's arguments to find and execute the appropriate method. This process is termed the **generic dispatch**. The generic dispatch first forms a list of all the applicable methods to the generic function call. The methods in this list are linked using a temporary data structure called a **method link**:



The first field is a pointer to an applicable method, and the second is a pointer to another method link.

For every method in the method array of the generic function, the parameter restriction list is checked against the actual arguments.

If the number of arguments is outside the acceptable range, the call is immediately terminated and an error is generated. Otherwise, all the actions of the method are evaluated in order as if they were grouped in a **progn**. The evaluation of the last expression in the deffunction body is returned as the value of the deffunction, unless an error occurs or the **return** function is used (see the *Basic Programming Guide*). The mechanics of a generic dispatch are outlined in the description of the function **GenericDispatch**.

GLOBAL VARIABLES

CurrentGeneric

PURPOSE: A pointer to the currently executing generic function.

CurrentMethod

PURPOSE: A pointer to the currently executing method.

GenericList

PURPOSE: A pointer to the first node in the list of all currently defined generic functions.

GenericListBottom

PURPOSE: A pointer to the last node in the list of all currently defined generic functions.

GenericStackFrame

PURPOSE: A pointer to an array of expressions which are the evaluated arguments for the currently executing generic function. This variable is also referred to as the method parameter array.

OTHER NOTES: The method parameter array is stored as an array of expressions rather than data objects so that implicit methods (i.e. system functions) can easily be called with these arguments.

GenericStackSize

PURPOSE: An integer indicating the number of data objects in the currently executing generic function's method parameter array.

WatchGenerics

PURPOSE: An integer flag indicating whether or not to print out trace information whenever a generic function begins and ends execution. This flag is used by the **watch** command.

WatchMethods

PURPOSE: An integer flag indicating whether or not to print out trace information whenever an individual method begins and ends execution. This flag is used by the **watch** command.

INTERNAL VARIABLES

Generic Function Trace Codes

PURPOSE: **SYSTEM_NO** and **SYSTEM_YES** are integer codes used in trace printouts to indicate whether the method is an explicit defmethod or a system function.

OTHER NOTES: Implemented as preprocessor constants.

Generic Function Trace Strings

PURPOSE: **BEGIN_TRACE** and **END_TRACE** are the strings used in trace printouts to indicate the beginning and end of execution of a generic function or a method.

OTHER NOTES: Implemented as preprocessor constants.

Method Precedence Codes

PURPOSE: Three integer codes are used by **FindMethodByRestrictions** to indicate the relative precedence between two methods: **HIGHER_PRECEDENCE**, **IDENTICAL** and **LOWER_PRECEDENCE**.

OTHER NOTES: Implemented as preprocessor constants.

NextInCore

PURPOSE: A method link to the method shadowed by the currently executing method.

OldGenericBusySave

PURPOSE: An integer variable used to preserve the busy count of a generic function when a new method is added or deleted. Methods which recursively call the generic function to which they apply do not increment the generic function's busy count. This makes it possible to tell when it is safe to delete a generic function and its methods (i.e. when no other constructs refer to the generic function and none of the generic function's methods are executing).

TopOfCore

PURPOSE: The first method link of a linked list of methods which are applicable to the current generic function call. The list is in order according to method precedence.

GLOBAL FUNCTIONS

AddGeneric

PURPOSE: Support routine for **ParseDefgeneric** and **ParseDefmethod** in the Generic Function Commands Module. Adds a new generic function header to the list of generic functions.

ARGUMENTS: 1) Symbolic name of the new generic function.
2) Buffer for flag indicating if generic function is new or not.

RETURNS: A pointer to the (new) generic function.

AddMethod

PURPOSE: Support routine for **ParseDefmethod** in the Generic Function Commands Module. Stores all parsed information for a new method in the method array for the generic function.

ARGUMENTS: 1) A pointer to the generic function.
2) Old method address (can be NULL).
3) Old method array position (can be -1).
4) Method index to assign (0 if don't care).
5) Parameter expression-list.
6) The number of parameters.
7) The wildcard symbol (NULL if none).
8) Method action expressions.
9) Method pretty-print form.

RETURNS: A pointer to the (new) method.

CallNextMethod

PURPOSE: Executes a method shadowed by the currently executing method. This function can only be called from the actions of currently executing method.

ARGUMENTS: A pointer to a data object to store the return value of the shadowed method.

OTHER NOTES: Following is a summary of **CallNextMethod**:

1*. Save the state of the bind list and then destroy it.
2. If an explicit shadowed method (see **NextInCore**) is not available, go to step 4.
3. Call **EvaluateExpression** for the actions of shadowed method, capture result and go to step 5.
4. If there is an implicit method, call it with **EvaluateExpression**, and capture the result.
5. Clear **ReturnFlag**.
6*. Restore the previous bind list.

*A bug exists in CLIPS version 5.1 that allows shadowed methods to affect locally bound variables of methods which are shadowing them. This is because Steps 1 and 6 are not present in the CLIPS 5.1 implementation of

CallNextMethod.

Implementation of the CLIPS function **call-next-method**.

ClearDefgenerics

PURPOSE: Used by the **clear** command to remove all currently defined generic functions.

RETURNS: The integer zero if not all generic functions and methods were successfully cleared, non-zero otherwise.

OTHER NOTES: Methods are removed before other constructs which may use generic functions, for this insures that those constructs are no longer in use by any methods. Generic functions are cleared after the other constructs to insure that they are no longer in use by the other constructs. The use of priorities in **AddClearFunction** accomplishes this ordering.

ClearDefmethods

PURPOSE: Used by the **clear** command to remove all currently defined generic function methods.

RETURNS: The integer zero if not all methods were successfully cleared, non-zero otherwise.

DeleteMethodInfo

PURPOSE: Deallocates internal data structures associated with a method but does not remove the method from the generic function's method array.

ARGUMENTS: 1) A pointer to a generic function.
2) A pointer to a method.

FindDefgenericBySymbol

PURPOSE: Determines the address of a specified generic function.

ARGUMENTS: A pointer to a symbol.

RETURNS: A pointer to a generic function.

FindMethodByIndex

PURPOSE: Support routine for **ParseDefmethod** in the Generic Function Commands Module. Determines if a method of the specified index already exists for the generic function.

ARGUMENTS: 1) A pointer to a generic function.
2) A method index.

RETURNS: The position of the method in the generic function's method array, -1 if not found.

FindMethodByRestrictions

PURPOSE: Support routine for **ParseDefmethod** in the Generic Function Commands Module. Examines the parsed parameter restrictions for the new method and determines if a method with matching parameter restrictions already exists for the generic function.

ARGUMENTS: 1) A pointer to a generic function.
2) Parameter expression list.
3) Number of parameters.
4) Wildcard symbol (can be NULL).
5) Buffer for holding array position of where to add new method (-1 if method already present).

RETURNS: A pointer to the method if found, NULL otherwise.

GenericDispatch

PURPOSE: This routine is called by **EvaluateExpression** in the Evaluation Module to process a generic function call.

ARGUMENTS: 1) A pointer to a generic function.
2) A list of expressions forming the generic function arguments.
3) A pointer to a data object which will hold the return value of the generic function.

OTHER NOTES: Following is a summary of **GenericDispatch**:

1. Save previous values of globals, such as **CurrentGeneric**, and set them for the new generic function.
2. Increment the evaluation depth (see the Evaluation Module).
3. Count and evaluate the arguments and store them in the method parameter array.
4. Save the state of the bind list and then destroy it.
5. Save the states of the **return** and **break** contexts and set them to FALSE.
6. Increment the busy count of the generic function.
7. Determine the set of applicable explicit methods (see **FindApplicableMethods**). If there are no applicable

explicit methods, go to step 9.
8. Call **EvaluateExpression** for the actions of explicit method with the highest precedence, capture the result and go to step 11.
9. If there is an implicit method, call it with **EvaluateExpression**, capture the result and go to step 11.
10. Generate an error indicating that there are no applicable methods for the generic function call.
11. Restore all global values to their previous states.
12. Decrement the execution count of the deffunction.
13. Decrement the evaluation depth.
14. Clear **ReturnFlag**.
15. Adjust the evaluation depth of the return value (see **PropogateReturnValue** in the Evaluation Module).
16. Perform garbage collection.

MethodAlterError

PURPOSE: Displays an error message when an attempt is made to modify an executing method.

ARGUMENTS: The name of the generic function.

MethodsExecuting

PURPOSE: Determines if any of the methods of a generic function are currently executing.

ARGUMENTS: A pointer to a generic function.

RETURNS: The integer zero if no methods are executing, non-zero otherwise.

NextMethodP

PURPOSE: Determines if a shadowed generic function method is available for execution.

RETURNS: The integer zero if there is no method available, non-zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **next-methodp**.

PreviewGeneric

PURPOSE: Displays all the applicable methods for a particular generic function call. The generic function and arguments are supplied by CLIPS.

OTHER NOTES: Implementation of the CLIPS function **preview-generic**.

PrintMethod

PURPOSE: Support routine for use with trace messages and debugging displays which lists a brief description of the parameter restrictions for a method.

ARGUMENTS: 1) Buffer for method text description.
2) Buffer size (not including space for null character).
3) A pointer to a method.

SetGenericList

PURPOSE: Initializes the global variables **GenericList** and **GenericListBottom** to point to the top and bottom respectively of the given list of generic functions.

ARGUMENTS: A pointer to the top of a list of generic functions.

OTHER NOTES: This function is used only in a run-time version of CLIPS.

INTERNAL FUNCTIONS

AddGenericMethod

PURPOSE: Support routine for **AddMethod** which inserts an initialized method into the specified position of the method array.

ARGUMENTS: 1) A pointer to a generic function.
2) Position in the method array to add the new method.
3) The method index (0 if don't care).

RETURNS: A pointer to the new method.

DestroyMethodLinks

PURPOSE: Deallocates the linked list of applicable methods for a particular generic function call.

ARGUMENTS: A method link.

DetermineRestrictionClass

PURPOSE: Support routine for **IsMethodApplicable** which determines the class of a particular generic function argument.

ARGUMENTS: A pointer to an expression.

RETURNS: A pointer to the class of the argument, or NULL on errors.

OTHER NOTES: This function is used only when COOL is present. When COOL is not present, the CLIPS type integer codes found in constant.h are used in lieu of classes.

DisplayGenericCore

PURPOSE: Support routine for **PreviewGeneric** which displays the linked list of applicable methods for a particular generic function call.

ARGUMENTS: 1) A pointer to the generic function.
2) A method link for the list of applicable methods.

EvaluateGenericParameters

PURPOSE: Support routine for **GenericDispatch** which evaluates all the CLIPS supplied argument expressions for a generic function call and stores the resulting values in the method parameter array (**GenericStackFrame**).

ARGUMENTS: 1) The list of parameter name expressions.
2) The number of parameters.

RETURNS: A pointer to an array of expressions containing the evaluations of the generic function argument expressions.

FindApplicableMethods

PURPOSE: Support routine for **GenericDispatch** which determines the set of methods which are applicable to a particular generic function call.

ARGUMENTS: A pointer to a generic function.

RETURNS: A series of method links (**TopOfCore**), ranked according to precedence, which are applicable to the generic function call.

OTHER NOTES: The method array of the generic function is examined in order, and each method that has parameter restrictions which are satisfied by the generic function arguments are attached to the end of a list of applicable methods. Since the method array is in order according to precedence, the final list of applicable methods is automatically ranked appropriately.

IsMethodApplicable

PURPOSE: Support routine for **FindApplicableMethods** which determines if the parameter restrictions of a particular method are satisfied by the generic function arguments.

ARGUMENTS: A pointer to the method.

RETURNS: The integer zero if the method is not applicable, non-zero otherwise.

NewGeneric

PURPOSE: Support routine for **AddGeneric** which allocates and initializes a new generic function.

RETURNS: A pointer to an initialized generic function.

RestoreBusyCount

PURPOSE: Uses the internal variable **OldGenericBusySave** to restore the busy count of a generic function.

ARGUMENTS: A pointer to a generic function.

OTHER NOTES: Implemented as a preprocessor macro.

RestrictionsCompare

PURPOSE: Support routine for **FindMethodByRestrictions** which compares a new restriction expression list for the method currently being parsed with the parameter restrictions of an existing method to determine which set of restrictions has higher precedence.

ARGUMENTS:
1) The parameter restriction expression list.
2) The number of minimum restrictions.
3) The number of maximum restrictions (-1 if unlimited).
4) A pointer to a method with which to compare restrictions.

RETURNS: An integer code indicating the precedence between the two restriction sets:
-1: New restrictions have higher precedence.
 0: New restrictions are identical.
 1: New restrictions have lower precedence.

SaveBusyCount

PURPOSE: Uses the internal variable **OldGenericBusySave** to save the busy count of a generic function.

ARGUMENTS: A pointer to a generic function.

OTHER NOTES: Implemented as a preprocessor macro.

TraceGeneric

PURPOSE: Used by the **watch** command to print out trace messages when a generic function begins and ends execution.

ARGUMENTS: A string indicating the beginning or end of execution of a generic function.

TraceMethod

PURPOSE: Used by the **watch** command to print out trace messages when a method begins and ends execution.

ARGUMENTS: 1) A string indicating the beginning or end of execution of a method.
2) A flag indicating whether the method being traced is an explicit or implicit method.

TypeListCompare

PURPOSE: Support routine for **RestrictionsCompare** which determines the precedence between the class lists on two parameter restrictions.

ARGUMENTS: 1) A pointer to the first restriction data structure.
2) A pointer to the second restriction data structure.

RETURNS: An integer code indicating the precedence between the two parameter restrictions' class lists:
-1: First restriction class list precedes the second.
 0: Restriction class lists are identical.
 1: Second restriction class list precedes the first.

Generic Function Construct Compiler Interface Module

The Generic Function Construct Compiler Interface Module (genrccmp.c) provides the functionality for implementing the **constructs-to-c** functions for the defgeneric and defmethod constructs.

Generic Function Binary Load/Save Interface Module

The Generic Function Binary Load/Save Interface Module (genrcbin.c) provides the functionality for implementing the **bload** and **bsave** functions for the defgeneric and defmethod constructs.

Generic function methods can contain pointers to defclasses in their restrictions. To insure that the binary save files are identical whether or not COOL is present for methods which use only the system-defined primitive type classes, integer codes are used to represent the classes. If COOL is not present, these integer codes correspond to the CLIPS type codes found in constant.h. Otherwise, these integer codes are indices into an array of defclasses. The primitive type classes are stored in the same order as reflected in the values of the codes in constant.h (see the description of **ClassList** in the Class Functions Module).

Class Commands Module

The Class Commands Module (classcom.c) manages the parsing and general interface aspects of the defclass construct. For a description of the defclass construct, see the *Basic Programming Guide*. The defclass construct capability, along with the other features of the CLIPS Object-Oriented Language (COOL), can be removed by using the appropriate compile flag in the setup header file.

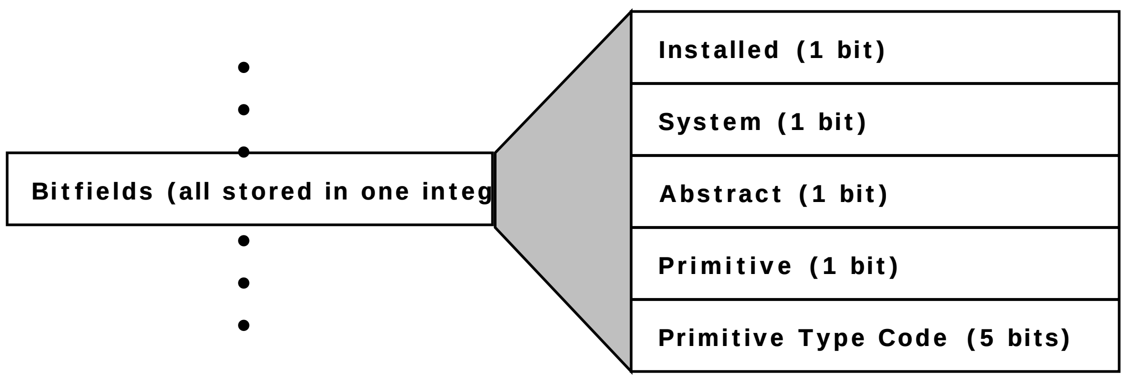
The class data structures are summarized in the following diagrams:

Name (Symbol Pointer)
Hash Value (int)
Binary Load/Save Index (long int)
Busy Count (int)
Predecessor Count (int)
Pretty-Print Form (array of char)
Traversal IDs (array of char)
Instance List (Instance Pointer)
Bitfields
Inheritance Links
Class List and Hash Table Links
Slot Information
Handler Information

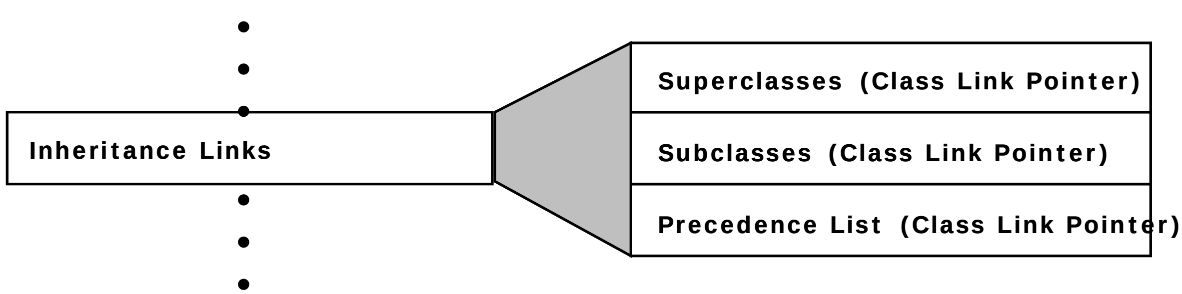
The last five boxes in italics are expanded in further diagrams.

The internal data structure of a defclass construct consists primarily of: a symbolic name, a pointer to the first direct instance (see the Instance Commands Module for details on the instance data structures), links to the superclasses, subclasses and class precedence list of the class, an array of slot descriptors, a template of slot pointers available to direct instances and an array of message-handlers. A busy count for each class reflects how many other expressions in other constructs refer to that class, how many direct instances of the class exist and how many times the class is in use by various other COOL access functions. This busy count must be zero for a class and all its subclasses before it is safe to delete the class. Other fields in the defclass data structure include: a hash value indicating the position of the class in the hash table, a predecessor class count for use in determining the precedence list for a class and its subclasses, a bitmap where each bit corresponds to a unique class hierarchy traversal, a series of bitfields indicating such things as whether the class is a system class, links connecting the class to the global class list and hash table, the pretty-print form and an index for use in binary load/save and the construct compiler.

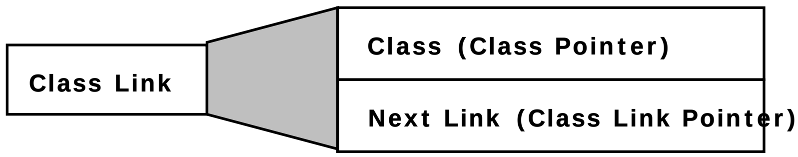
The traversal id bitmap is an array of **TRAVERSAL_BYTES** (see the Instance-Set Queries Module) characters. The number of bits in this map indicate how many simultaneous class hierarchy traversals can examine a class at once. Many of the COOL access routines use recursive descent to access the subclasses of a class, e.g. **instances** when listing the indirect instances of a class. Due to multiple inheritance, it is possible for a class to be reached more than once via a straightforward recursive descent on subclasses. Thus, it is necessary to mark classes once they have been visited so that that branch of the search will not be repeated. However, since there may be more than one class hierarchy traversal occurring at a time (e.g. nested instance-set query functions), it is necessary to have unique markers for each class per traversal. When a class hierarchy traversal begins, a unique traversal id is requested via **GetTraversalID**. The bit corresponding to this id is cleared in the traversal maps of all classes. When a traversal comes to a class, it first checks the traversal bitmap against its traversal id with **TestTraversalID**. If the bit is already set, then it is known that this branch has already been explored. Otherwise, **SetTraversalID** is used to mark the class, and the traversal continues downwards. When a traversal is complete, **ReleaseTraversalID** makes the id available for use for another traversal. All of the variables, constants and functions dealing with traversal ids can be found in the Instance-Set Queries Module.



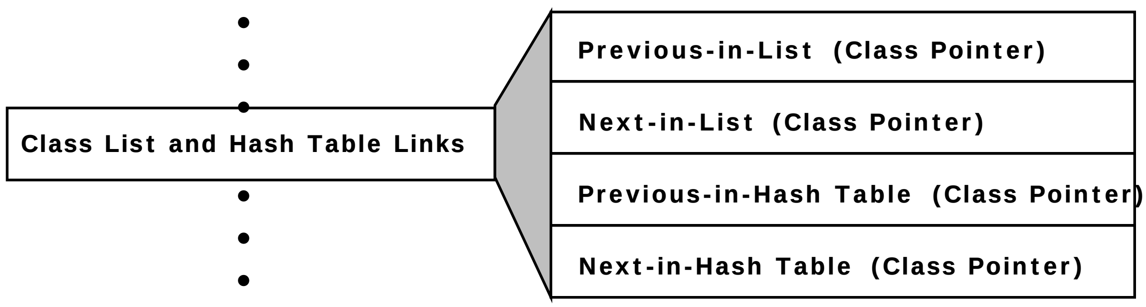
The bitfields are stored in a single integer and indicate the following information about a class: whether all the atoms and construct references within the defclass have had their busy counts incremented (i.e. whether the class has been installed), whether the class is a predefined system class, whether the class can have direct instances, whether the class corresponds to one of the primitive types defined in constant.h (SYMBOL, INTEGER, etc.) and the primitive type code for the class if the "primitive" bitfield is set.



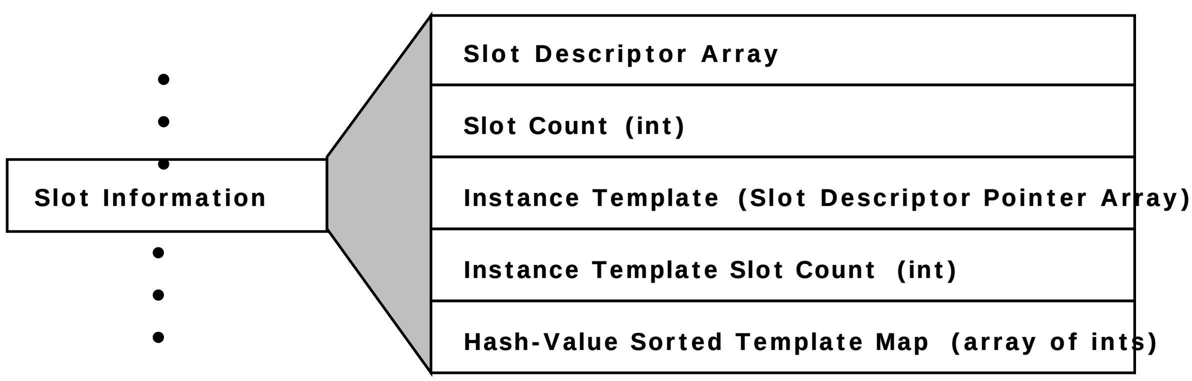
The inheritance links are lists of the direct superclasses, direct subclasses and inheritance precedence list of a class. All three of these lists are formed using an intermediary data structure called a **class link**. These lists are not formed using direct class pointers in the defclass itself because a particular class can be a superclass or subclass (direct or indirect) of many different classes.



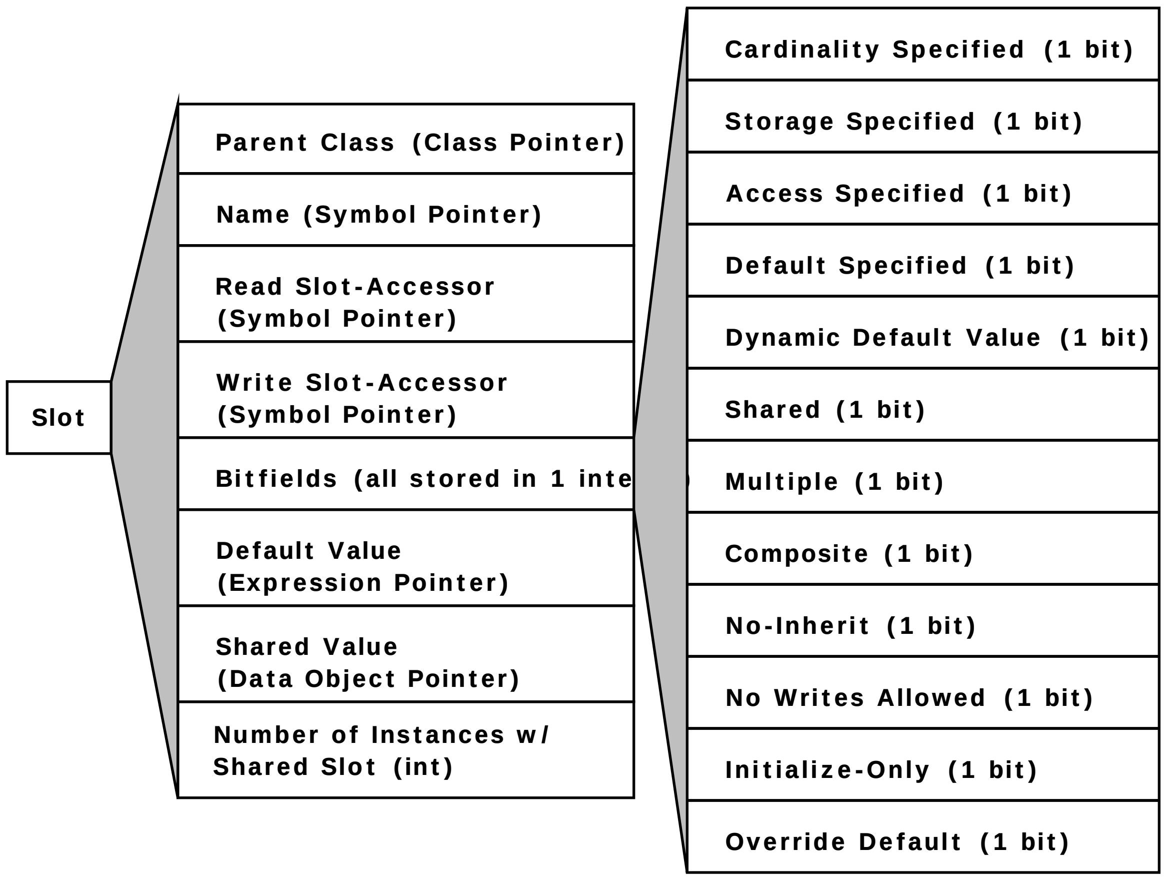
The first field of this data structure is a pointer to a defclass, and the second is a pointer to another link. The three inheritance links in a defclass are all class link pointers. The inheritance links are built when the defclass is parsed (see **ParseDefclass**). In particular, the precedence list is formed by **FindPrecedenceList**, which is explained in detail in the Class Functions Module.



Unlike the inheritance links, the links which place a class in the global class list (**ClassList**) and class hash table (**ClassTable**) are implemented with direct class pointers in the defclass. This is because these links are unique to a class.

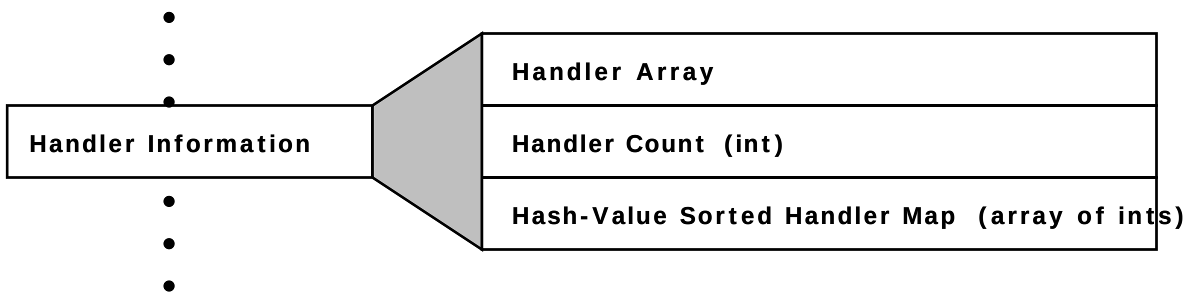


The slot information for a class is comprised of: an array of slot descriptors, which includes information for all the slots directly defined in a class; the number of slot descriptors; a template of all the slots which will be present in instances of a class, including slots directly inherited from the class and indirectly inherited from superclasses; the number of slots in the template; and an array of integer indices into the instance template which gives the order of the template slots according to the hash value of the symbolic names of the slots. The instance template is a contiguous array of slot descriptor pointers sorted by inheritance from least specific to most specific (slots from the same class are in the order they appeared in the defclass). The sorted template map allows an instance slot to be found easily by performing a binary search on the symbolic hash value of the slot name. All direct instances of a class share the same instance template; each instance only needs to have its own array of slot values (see the general notes in the Instance Commands Module).



Each slot descriptor is comprised of the following: a pointer to the class in which this slot is directly defined, a symbolic name, a symbolic name of a read slot-accessor of the form **get-<slot-name>**, a symbolic name of a write slot-accessor of the form **put-<slot-name>**, a series of bitfields indicating the facets, an expression which yields the default value for a slot when evaluated during a **make-instance** call, a pointer to the data object holding the value of a **shared** slot at run-time and the number of instances of referencing a **shared** slot. If a slot is not shared, the last two fields will always be NULL and zero respectively. **Local** slot values are stored with the instances (see the general notes in the Instance Commands Module). The count of the number of instances sharing a slot is used to determine when to automatically initialize or erase a **shared** slot.

The bitfields are stored in a single integer and indicate the following information about a slot descriptor: whether a cardinality facet (**single** or **multiple**) was specified in the defclass, whether a storage facet (**shared** or **local**) was specified in the defclass, whether an access facet (**read-write**, **read-only** and **initialize-only**) was specified in the defclass, whether a default value facet (**default** or **default-dynamic**) was specified in the defclass, whether the default value (if any) is dynamic, whether the slot has shared or local storage, whether the slot has single or multiple cardinality, whether the slot gets facets exclusively from the direct parent class or compositely from indirect superclasses as well, whether the slot is propagated to subclasses, whether the slot can be written, whether the slot can be written only during initialization of an instance and whether a slot has a default value override during a **make-instance** call.



The message-handler information for a class is comprised of: an array of handlers, the number of handlers and an array of integer indices into the handler array which gives the order of the handlers according to the hash value of their symbolic names. The sorted handler map allows a handler to be found easily by performing a binary search on the symbolic hash value of the handler name. For details on the message-handler data structure, see the Message-Handler Commands Module.

GLOBAL VARIABLES

ObjectParseToken

PURPOSE:	An intermediary variable used for scanned tokens by the COOL parsing routines during a **load**.

INTERNAL VARIABLES

Defclass Constants

PURPOSE:	The following are constants used in to determine when qualifiers in the defclass construct are duplicated: **CARDINALITY_BIT**, **STORAGE_BIT**, **ACCESS_BIT**, **INHERIT_BIT** and **COMPOSITE_BIT**.
OTHER NOTES:	Implemented as preprocessor constants.

Defclass Keywords

PURPOSE:	The following are keywords used in parsing a defclass: **SUPERCLASS_RLN**, **ABSTRACT_RLN**, **CONCRETE_RLN**, **HANDLER_DECL**, **SLOT_RLN**, **SLOT_DEF_RLN**, **SLOT_DEF_DYN_RLN**, **SLOT_NOINH_RLN**, **SLOT_INH_RLN**, **SLOT_RDONLY_RLN**, **SLOT_RDWRT_RLN**,

SLOT_SHARE_RLN, **SLOT_LOCAL_RLN**, **SLOT_MULT_RLN**, **SLOT_SGL_RLN**, **SLOT_INIT_RLN**, **SLOT_COMPOSITE_RLN** and **SLOT_EXCLUSIVE_RLN**.

OTHER NOTES: Implemented as preprocessor constants.

GLOBAL FUNCTIONS

BrowseClassesCmd

PURPOSE: Displays an inheritance "graph" of the subclasses of defclass specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **browse-classes**.

ClassHandlersCmd

PURPOSE: Groups the message-handler names of a class specified by the CLIPS supplied argument into a multifield variable..

ARGUMENTS: A pointer to a data object to hold the resulting multifield.

OTHER NOTES: Implementation of the CLIPS function **class-message-handlers**.

ClassHasHandler

PURPOSE: Determines if a message-handler is present in a class. Both arguments are supplied by CLIPS.

RETURNS: A non-zero integer if the message-handler is present in the class, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **class-message-handler-existp**.

ClassHasSlot

PURPOSE: Determines if a slot is present in a class. Both arguments are supplied by CLIPS.

RETURNS: A non-zero integer if the slot is present in the class, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **class-slot-existp**.

ClassSlotsCmd

PURPOSE: Groups the slot names of a class specified by the CLIPS supplied argument into a multifield variable.

ARGUMENTS: A pointer to a data object to hold the resulting multifield.

OTHER NOTES: Implementation of the CLIPS function **class-slots**.

ClassSubclassesCmd

PURPOSE: Groups the subclass names of a class specified by the CLIPS supplied argument into a multifield variable.

OTHER NOTES: Implementation of the CLIPS function **class-subclasses**.

ClassSuperclassesCmd

PURPOSE: Groups the superclass names of a class specified by the CLIPS supplied argument into a multifield variable.

ARGUMENTS: A pointer to a data object to hold the resulting multifield.

OTHER NOTES: Implementation of the CLIPS function **class-superclasses**.

CmdListDefclasses

PURPOSE: Lists all the currently defined defclasses.

OTHER NOTES: Implementation of the CLIPS function **list-defclasses**.

CmdUndefclass

PURPOSE: Removes a defclass as well as any subclasses and associated instances and message-handlers.

OTHER NOTES: Implementation of the CLIPS function **undefclass**.

DescribeClassCmd

PURPOSE: Displays the detailed information about the defclass specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **describe-class**.

DoesClassExist

PURPOSE: Determines if a class specified by the CLIPS supplied argument exists.

RETURNS: A non-zero integer if the class exists, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **class-existp**.

Embedded Access for Defclasses

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*: **BrowseClass**, **DeleteDefclass**, **DescribeClass**, **FindDefclass**, **GetClassMessageHandlers**, **GetClassSlots**, **GetClassSubclasses**, **GetClassSuperclasses**, **GetDefclassName**, **GetDefclassPPForm**, **GetNextDefclass**, **GetSlotFacets**, **GetSlotSources**, **IsClassAbstract**, **IsDefclassDeletable** and **ListDefclasses**.

HasSuperclass

PURPOSE: Determines is a class is a subclass of a second class.

ARGUMENTS: Pointers to two defclasses.

RETURNS: A non-zero integer if the first class is a subclass of the second class, zero otherwise.

OTHER NOTES Support routine for superclass and subclass determinant routines in the Class Commands, Generic Function Commands and Generic Function Functions Modules.

IsClassAbstractCmd

PURPOSE: Determines if direct instances of a class specified by the CLIPS supplied argument can be made.

RETURNS: The integer zero if the class is abstract, non-zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **class-abstractp**.

IsSubclass

PURPOSE: Determines if a class is a subclass of a second class. Both arguments are supplied by CLIPS.

RETURNS: A non-zero integer if the first class is a subclass of the second class, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **subclassp**.

IsSuperclass

PURPOSE: Determines if a class is a superclass of a second class. Both arguments are supplied by CLIPS.

RETURNS: A non-zero integer if the first class is a superclass of the second class, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **superclassp**.

ObjectsRunTimeInitialize

PURPOSE: Initializes COOL constructs in a run-time image.

ARGUMENTS: 1) Pointer to new class list.
2) Pointer to new definstances list.
3) Pointer to new class hash table.

PPDefclass

PURPOSE: Displays the pretty-print form of the defclass specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **ppdefclass**.

SetupClasses

PURPOSE: Defines all functions and commands for the defclass construct. Sets up all necessary **load**, **clear**, **save**, **watch**, **constructs-to-c** and **bload/bsave** interfaces.

OTHER NOTES: Initialization differs between standard and run-time configurations.

SetupObjectSystem

PURPOSE: Initializes all COOL constructs, functions and data structures.

SlotFacetsCmd

PURPOSE: Groups the facet names of a class slot specified by the CLIPS supplied arguments into a multifield variable.

ARGUMENTS: A pointer to a data object to hold the resulting multifield.

OTHER NOTES: Implementation of the CLIPS function **slot-facets**.

SlotSourcesCmd

PURPOSE: Groups the source class names of a class slot specified by the CLIPS supplied arguments into a multifield variable.

ARGUMENTS: A pointer to a data object to hold the resulting multifield.

OTHER NOTES: Implementation of the CLIPS function **slot-sources**.

INTERNAL FUNCTIONS

CheckClass

PURPOSE: Support routine for **PPDefclass** and **DescribeClassCmd** which verifies the existence of a class.

ARGUMENTS: 1) The name of the calling function.
2) The name of the class.

RETURNS: A pointer to the class, NULL on errors.

CheckClassAndSlot

PURPOSE: Support routine for **ClassHasSlot**, **SlotFacetsCmd** and **SlotSourcesCmd** which parses a class name and a slot name.

ARGUMENTS: 1) The name of the calling function.
2) A buffer for the class pointer.

RETURNS: The symbolic name of the slot, NULL on errors.

CheckTwoClasses

PURPOSE: Support routine for **IsSuperclass** and **IsSubclass** which parses two class arguments.

ARGUMENTS: 1) The name of the calling function.
2) A buffer for the first class pointer.
3) A buffer for the second class pointer.

RETURNS: A non-zero integer if both classes successfully parsed, zero otherwise.

ClassInfoFnxArgs

PURPOSE:	Support routine for **ClassSlotsCmd**, **ClassSuperclassesCmd**, **ClassSubclassesCmd** and **ClassHandlersCmd** which checks the class argument.
ARGUMENTS:	1) Name of the calling function. 2) Data object buffer (which is initialized to the symbol FALSE) 3) A buffer for an integer flag indicating if the keyword "inherit" was present in the function call.
RETURNS:	A pointer to the class, NULL on errors.

CountSubclasses

PURPOSE:	Support routine for **GetClassSubclasses** which counts the number of subclasses for a class.
ARGUMENTS:	1) A pointer to a class. 2) An integer flag indicating whether to include (one) or exclude (zero) indirectly inherited subclasses. 3) A unique traversal integer identifier to prevent loops when examining the class hierarchy (see the general notes for the Class Commands Module)
RETURNS:	The number of direct or indirect subclasses (depending on the second argument).

DisplayHandlersInLinks

PURPOSE:	Support routine for **DescribeClass** which displays the message-handlers for a list of classes.
ARGUMENTS:	A list of classes.
RETURNS:	A non-zero integer if any message-handlers were listed, zero otherwise.

EvaluateDefaultSlots

PURPOSE:	Support routine for **ParseDefclass** which evaluates the default value expressions for class slots and converts them to constant expressions.
ARGUMENTS:	A pointer to the class.
RETURNS:	A non-zero integer if there are no errors, zero otherwise.

GetClassName

PURPOSE: Support routine for **CmdUndefclass**, **PPDefclass** and **DescribeClassCmd** which parses a class name.

ARGUMENTS: The name of the calling function.

RETURNS: The name of the class, NULL on errors.

ParseDefclass

PURPOSE: Used by the **load** command to parse a defclass.

ARGUMENTS: The logical name of the input source.

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

ParseDefclassName

PURPOSE: Support routine for **ParseDefclass** which parses a defclass name and optional comment.

ARGUMENTS: The logical name of the input source.

RETURNS: A pointer to the symbolic name of the new class, NULL on errors.

ParseSlot

PURPOSE: Support routine for **ParseDefclass** which parses slots of a new class.

ARGUMENTS: 1) The logical name of the input source.
2) A pointer to the current list of slots.

RETURNS: A pointer to the new list of slots, NULL on errors.

ParseSlotValue

PURPOSE: Support routine for **ParseSlot** which parses the value expression for a new slot.

ARGUMENTS: 1) The logical name of the input source.
2) A buffer for an error boolean flag.

RETURNS: An pointer to an expression.

ParseSuperclasses

PURPOSE: Support routine for **ParseDefclass** which parses the direct superclass list of a new class.

ARGUMENTS: 1) The logical name of the input source.
2) The symbolic name of the new class.

RETURNS: A pointer to a list of classes, NULL on errors.

PrintClassBrowse

PURPOSE: Support routine for **BrowseClass** which displays the subclasses of a specified class.

ARGUMENTS: 1) A pointer to the root class from which to start the graph.
2) The depth in the graph from the base class.

PurgeUserClassStuff

PURPOSE: Used by the **clear** command to remove all currently defined defclasses anc their instances.

OTHER NOTES: Defclasses are removed after defmethods but before defgenerics because methods can refer to classes but classes can refer to generic functions. The use of priorities in **AddClearFunction** accomplishes this ordering.

SaveDefclasses

PURPOSE: Used by the **save** command to write out the pretty-print forms of all the currently defined defclasses.

ARGUMENTS: The logical name of the output destination.

StoreSubclasses

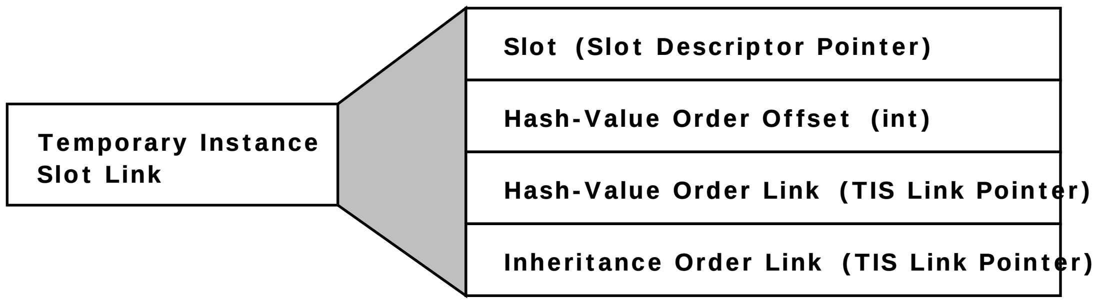
PURPOSE: Support routine for **GetClassSubclasses** which stores the subclasses of a class in a multifield.

ARGUMENTS: 1) A multifield buffer to store the subclass names.
2) An index into the multifield buffer indicating where to start the storage of subclass names.
3) A pointer to a class.
4) An integer flag indicating whether to include (one) or exclude (zero) indirectly inherited subclasses.
5) A unique traversal integer identifier to prevent loops when examining the class hierarchy (see the general notes for the Class Commands Module)

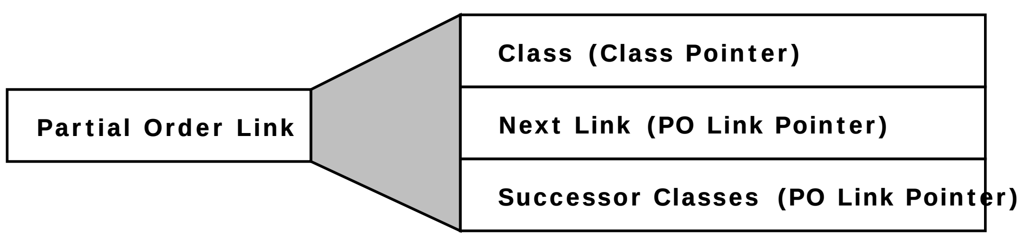
RETURNS:	The number of direct or indirect subclasses stored in the multifield (depending on the second argument).

Class Functions Module

The Class Functions Module (classfun.c) handles all the internal manipulations of classes including the construction of class precedence lists from multiple inheritance. For a description of the defclass construct, see the *Basic Programming Guide*. The defclass construct capability, along with the other features of the CLIPS Object-Oriented Language (COOL), can be removed by using the appropriate compile flag in the setup header file.



Temporary Instance Slot Link is an intermediary data structure used to create a template of all the slots which will be present in instances of a class, including slots directly inherited from the class and indirectly inherited from superclasses. **FormInstanceTemplate** calls **MergeSlots** for each class in the precedence list to make a list of these temporary slot links. Once the list is complete, the list is converted into the contiguous arrays described in the Class and Instance Commands Modules and then destroyed. The fields of a slot link are: a slot descriptor pointer, an integer index into the inheritance order of the slots (used only when creating the contiguous hash-value map), a link chaining the slots together in order according to increasing hash value of the slot name symbols and a link chaining the slots together in order according to least specific to most specific inheritance.



Partial Order Link is an intermediary data structure used to build the class precedence list for a class from the multiple inheritance rules given in the *Basic Programming Guide*. A partial order for two classes is an assertion that class A must come before or after class B. The multiple inheritance rules are recursively applied to the direct superclasses of a new class to generate a set of partial order links called the partial order table. These partial orders are then topologically sorted according to the algorithm given later in this section to generate the final class precedence list. A partial order table node is comprised of a pointer to a class indicating how many classes (of the ones in the table) must precede that class, and a list of classes which must succeed that class. Specifically, the fields of a partial order link are: a pointer to a class (the predecessor count is stored with class), a link to the next unrelated partial order and a link to the successor partial orders for this class.

The precedence determination and cycle detection algorithms are adapted from the topological sorting algorithms given in *The Art of Computer Programming - Vol. I (Fundamental Algorithms)* by Donald Knuth.

Each class and its direct superclasses are recursively entered in order into a table of partial orders. A class is only entered once. The order reflects a pre-order depth-first recursive traversal of the classes direct superclass lists, and this order will be followed as closely as possible to preserve the "family" heuristic when constructing the class precedence list.

Attached to each node is a count indicating the number of classes which must precede this class and a list of classes which must succeed this class. These predecessor counts and successor lists indicate the partial orderings given by the rules of multiple inheritance for the classes as given in the *Basic Programming Guide*.

Rules of Multiple Inheritance:

1. A class must precede all its superclasses.
2. A class determines the precedence of its direct superclasses.

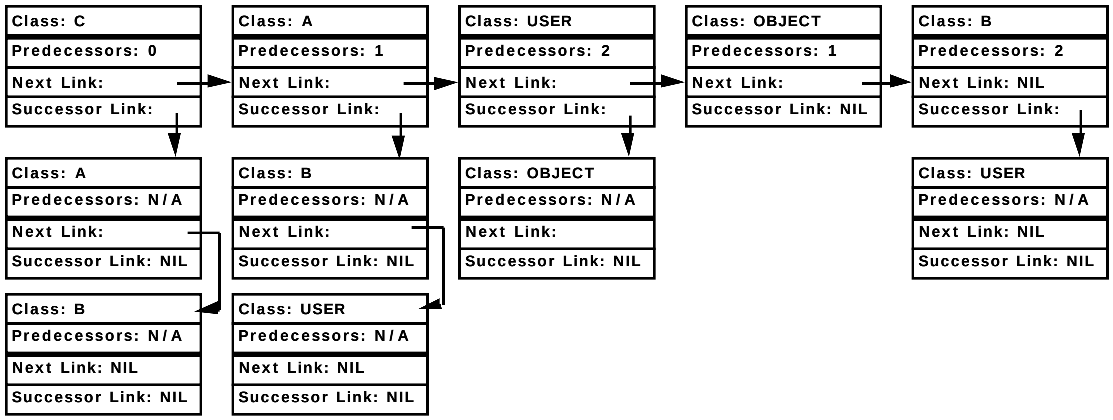
For example, the following class definitions:

```
(defclass A (is-a USER))
(defclass B (is-a USER))
(defclass C (is-a A B))
```

would give the following partial orders:

Partial Order	Reason
C < A	Rule 1
C < B	Rule 1
A < B	Rule 2
B < USER	Rule 1
A < USER	Rule 1
USER < OBJECT	Rule 1

Entering these partial orders into a table using partial order links would yield the following (note that the predecessor count is actually stored in the defclass data structure, not the partial order link):

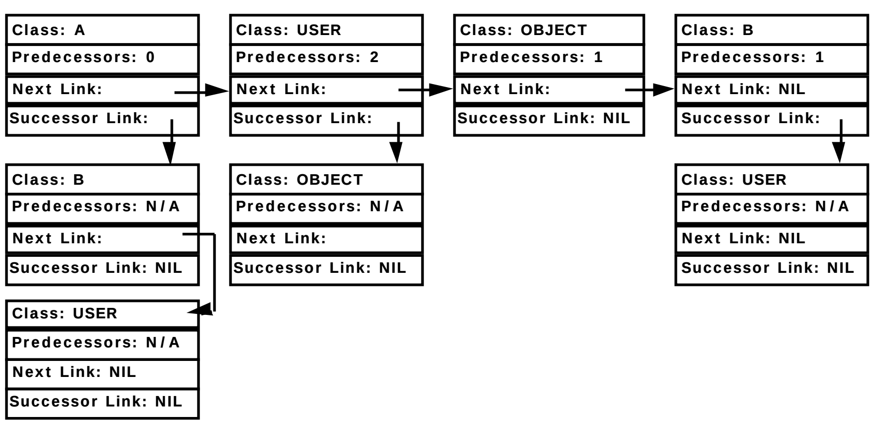


To generate a precedence list for the class C, pick the first class (scanning from left to right) with a predecessor count of 0, append it to the precedence list, and decrement the counts of all its successors. Continue scanning for a zero from where the last scan left off. If there are no classes left with a predecessor count of zero, then there is no solution. The function **PrintPartialOrderLoop** implements a straightforward algorithm to print out a cyclical dependency in the partial orders when an error is detected.

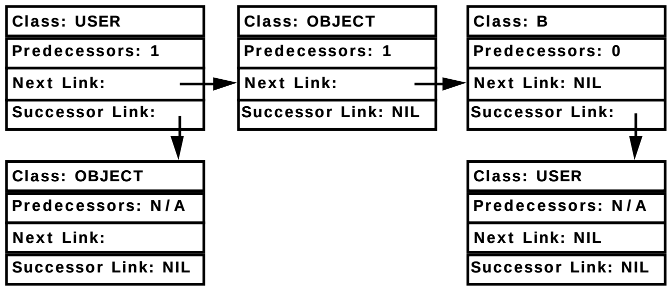
If the algorithm were not concerned about preserving the "family" heuristic (i.e. trying to match pre-order depth-first traversal as closely as possible), neither the order in which the classes were entered into the table nor the order in which the table was scanned for classes with predecessor counts of zero would matter. Picking only classes which have a predecessor count of zero guarantees a solution (if it exists) that satisfies the two multiple inheritance rules. The modifications to Knuth's algorithm allow the additional heuristic to be observed.

The following diagrams show the partial order table after each class is entered onto the precedence list:

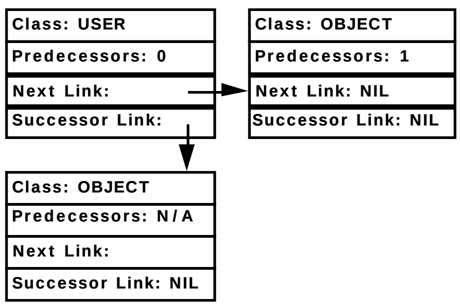
Precedence List so far: C



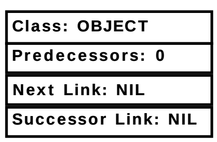
Precedence List so far: C A



Precedence List so far: C A B



Precedence List so far: C A B USER



Final Precedence List: C A B USER OBJECT

GLOBAL VARIABLES

ClassList

PURPOSE:	A pointer to the first node in the list of all currently defined defclasses.
OTHER NOTES:	The primitive CLIPS type classes come first in this list according to the integer codes in constant.h. For example, the codes for FLOAT and INTEGER are 0 and 1, thus those classes come first and second on the list respectively. The purpose of this ordering is to make the binary save files identical for generic functions whether or not COOL is installed (see the Generic Functions Binary Load/Save Interface Module for more details). The order of primitive type classes in PrimitiveClassMap is a mirror image of this mapping.

ClassTable

PURPOSE: An array of class lists where each class in a particular list has the same hash value. This data structure enables fast lookups of classes by name. The class name is hashed to generate a hash value. and then compared to the names of all the classes in the chain at the hash value index of the class table.

CLASS_TABLE_HASH_SIZE

PURPOSE: The number of chains in the class lookup table. A chain is a list of classes where the name of each class generates the same hash value according to the formula in **HashClass**.

OTHER NOTES: Implemented as a preprocessor constant in classfun.h.

OBJECT_CLASS_STRING

PURPOSE: The name of the root class of all classes in COOL; this class has no superclasses.

OTHER NOTES: Implemented as a preprocessor constant in classfun.h.

PrimitiveClassMap

PURPOSE: An array of class pointers for the basic CLIPS primitive types where the position of the array corresponds to the integer code of the type found in constant.h. For example, the pointer to the EXTERNAL-ADDRESS class is found in PrimitiveClassMap[5] since the code for EXTERNAL-ADDRESS is 5.

OTHER NOTES: The order of primitive type classes in **ClassList** is a mirror image of this mapping.

USER_CLASS_STRING

PURPOSE: The name of the base class of user-defined classes; this class has all the predefined message-handlers attached to it.

OTHER NOTES: Implemented as a preprocessor constant in classfun.h.

INTERNAL VARIABLES

BIG_PRIME

PURPOSE:	Large prime number used in the calculations of widely distributed hash values for classes.
OTHER NOTES:	Implemented as a preprocessor constant.

ClassListBottom

PURPOSE:	A pointer to the last node in the list of all currently defined defclasses.

Instance Template Codes

PURPOSE:	Integer codes used by the function **MergeSlots** to indicate that a list of slots are being inherited by a new class from a direct (**DIRECT**) or indirect (**INDIRECT**) superclass.
OTHER NOTES:	Used in connection with the **no-inherit** facet for a slot. Implemented as preprocessors constants.

GLOBAL FUNCTIONS

AddClass

PURPOSE:	Support routine for **ParseDefclass** in the Class Commands Module which inserts a new class into the global list and hash table and deletes an old definition, if necessary.
ARGUMENTS:	A pointer to a new class.
OTHER NOTES:	For a class redefinition, old message-handlers which do not conflict with new slot-accessors are reattached to the new class.

ClassExistError

PURPOSE:	Prints out an error message when a class cannot be found for various functions.
ARGUMENTS:	1) The name of the calling function. 2) The name of the non-existent class.

ClearDefclasses

PURPOSE: Deletes all user-defined classes and message-handlers.

ARGUMENTS: An integer code indicating whether to ignore (zero) or delete (non-zero) user-defined message-handlers attached to system classes.

RETURNS: A non-zero integer if all user-defined classes and message-handlers are deleted, zero otherwise.

OTHER NOTES: Classes which is in use will not be deleted.

DeleteClassLinks

PURPOSE: Support routine for **ParseDefclass** in the Class Commands Module which deallocates a temporary set of links forming a list of classes.

ARGUMENTS: A pointer to a class link node.

DeleteClassUAG

PURPOSE: Removes a class and all its subclasses.

ARGUMENTS: A pointer to a class.

RETURNS: A non-zero integer if the class and its subclasses, including associated message-handlers, are deleted, zero otherwise.

OTHER NOTES: A class which is in use will not be deleted.

DeleteSlots

PURPOSE: Support routine for **ParseDefclass** in the Class Command Module which deletes a list of slots.

ARGUMENTS: The list of slots.

OTHER NOTES: The "shared value" data object field of the slots is temporarily used as a "next" pointer to chain together slots in the list.

FindClassSlot

PURPOSE: Determines the address of a specified class slot.

ARGUMENTS: 1) A pointer to a class.
2) A symbolic slot name.

RETURNS: A pointer to a class slot.

FindDefclassBySymbol

PURPOSE: Determines the address of a specified class.

ARGUMENTS: A pointer to a symbol.

RETURNS: A pointer to a class.

FindPrecedenceList

PURPOSE: Support routine for **ParseDefclass** in the Class Commands Module which determines the class precedence list for a new class using the multiple inheritance rules explained in Section 9.3.1.1 of the *Basic Programming Guide*. Using these rules, partial orders between the superclasses of the new class are generated. A topological sort is used to establish a linear ordering of all the superclasses from the partial orders; this ordering is referred to as the class precedence list. The algorithm is explained in detail in the general notes for the Class Functions Module.

ARGUMENTS: 1) A pointer to the old class for which the precedence list is being redefined (NULL if this is a new class).
2) A list of direct superclasses.

RETURNS: A list of classes forming the precedence list, or NULL on errors.

InitializeClasses

PURPOSE: Allocates and initializes class hash table and creates system classes.

InsertSlot

PURPOSE: Support routine for **ParseDefclass** in the Class Commands Module which inserts a new slot into the list of slots for a new class and verifies that it is not a duplicate.

ARGUMENTS: 1)The top of the slot list.
2) A pointer to a slot.

RETURNS: The top of the slot list.

OTHER NOTES: The "shared value" data object field of the slots is temporarily used as a "next" pointer to chain together slots in the list.

InstancesPurge

PURPOSE: Removes all instances of user-defined classes.

IsClassBeingUsed

PURPOSE: Recursively checks to see if a class or any of its subclasses are in use.

ARGUMENTS: A pointer to a class.

RETURNS: A non-zero integer if the class or any of its subclasses is busy, zero otherwise.

IsSystemClassName

PURPOSE: Support routine for **ParseDefclass** in the Class Commands Module which determines if a name matches that of one of the predefined system classes.

ARGUMENTS: The symbolic name of a class.

RETURNS: A non-zero integer if the name matches a system class name, zero otherwise.

NewClass

PURPOSE: Allocates and initializes a new class.

RETURNS: A pointer to an initialized class.

OTHER NOTES: A traversal id map of size **TRAVERSAL_BYTES** (see the Instance-Set Queries Module) is allocated for the class.

NewSlot

PURPOSE: Allocates and initializes a new slot.

ARGUMENTS: The symbolic slot name.

RETURNS: A pointer to a new slot.

OTHER NOTES: Creates two new symbols called "get-"<slot-name> and "put-"<slot-name> and initializes the "related symbol" fields of these symbols to point to the original slot name. This is to help with fast lookup of implicit slot accessor message-handlers during a message dispatch (see the Message Functions Module).

ObjectSystemPurge

PURPOSE: Removes all definstances and user-defined classes and associated instances.

PackSlots

PURPOSE: Support routine for **ParseDefclass** in the Class Commands Module which packs a list of slots into a contiguous array for easy reference.

ARGUMENTS: 1) A pointer to the class.
2) A list of slots.

PutClassInTable

PURPOSE: Inserts a class into the class hash table.

ARGUMENTS: A pointer to a class.

ReinitializeClasses

PURPOSE: Initializes (but does not allocate) class hash table and creates system classes.

SetClassList

PURPOSE: Initializes the global variables **ClassList** and **ClassListBottom** to point to the top and bottom respectively of the given list of classes.

ARGUMENTS: A pointer to the top of a list of classes.

OTHER NOTES: This function is used only in a run-time version of CLIPS.

INTERNAL FUNCTIONS

AddSystemClass

PURPOSE: Support routine for **CreateSystemClasses** which allocates and initializes a new system class and inserts into the class hash table.

ARGUMENTS: 1) The name of the class.
2) The CLIPS type integer code found in constant.h which corresponds to this class (any value if this does not apply, e.g. the USER class).
3) An integer flag indicating if the new class corresponds to a

CLIPS primitive type (1) or not (0).
4) A pointer to the parent class , or NULL if there is none.

RETURNS: A pointer to a class.

OTHER NOTES: This function assumes simple single inheritance for the system classes and builds class precedence lists accordingly.

AddToClassList

PURPOSE: Support routine for **CreateSystemClasses** which adds a class to the end of the global class list.

ARGUMENTS: A pointer to the class.

BuildPartialOrders

PURPOSE: Support routine for **FindPrecedenceList** which builds a table of the partial orders between the superclasses of a new class based on the multiple inheritance rules and "family" heuristic specified in section 9.3.1.1 of the *Basic Programming Guide*. See the general notes for the Class Functions Module for more details.

ARGUMENTS: 1) The partial order table, which is a series of partial order links (see the general notes).
2) The list of superclasses.

RETURNS: The partial order table.

OTHER NOTES: If a class is being redefined, the Multiple Inheritance Rule 1 partial orders between the class and its direct superclasses will have already been recorded in the table prior to the calling of this function. Otherwise, the partial order table will be empty. This is done to prevent cyclical dependencies.

BuildSubclassLinks

PURPOSE: Support routine for **AddClass** which attaches subclass links from each superclass of a class to itself.

ARGUMENTS: A pointer to a class.

CopyClassLinks

PURPOSE: Support routine for **AddSystemClass** which copies a list of classes to aid in creating the class precedence list for a new system class.

ARGUMENTS: A list of classes.

CreateSystemClasses

PURPOSE: Creates the predefined system classes and adds them to the global class list and hash table.

OTHER NOTES: The order in which the system classes are defined is important. See the notes on the Class Functions Module global variables **ClassList** and **PrimitiveClassMap**.

DeleteClass

PURPOSE: Support routine for **ObjectSystemPurge**, **ClearDefclasses** and **DeleteClassUAG** which deinstalls (see **InstallClass**) and deallocates a class and its message-handlers.

ARGUMENTS: A pointer to a class.

RETURNS: A non-zero integer if the class was successfully deleted, zero otherwise.

OTHER NOTES: This routine will fail if there are any outstanding references to the class (e.g. instances or subclasses still exist).

DeleteSublink

PURPOSE: Support routine for **DeleteClass** which removes the subclass link to a class from one of its superclasses.

ARGUMENTS: 1) A pointer to the superclass.
2) A pointer to the subclass.

FormInstanceTemplate

PURPOSE: Support routine for **AddClass** which creates a template of all the slots which will be present in instances of a class, including slots directly inherited from the class and indirectly inherited from superclasses. This template is a contiguous array of class slot pointers sorted by inheritance from least specific to most specific (slots from the same class are in the order they appeared in the defclass). This ordering is used when listing slot information about the class. This data structure is explained in detail in the Class and Instance Commands Modules. All direct instances of a class share the same instance template; each instance only needs to have its own array of slot values.

ARGUMENTS: A pointer to the class.

OTHER NOTES: This routine also creates a map of integer indices into the instance template which gives the order according to the hash values of the symbolic names of the slots. Thus, slots for an instance can be easily found by performing a binary search on the symbolic hash value of the slot name.

Temporary instance slot links are used as an intermediary data structure.

HashClass

PURPOSE: Generates an index into the class hash table for a given class.

ARGUMENTS: The symbolic name of a class.

RETURNS: The hash table index for the class.

OTHER NOTES: The hash table index is derived from the symbol hash table index (see the Symbol Manager Module).

InstallClass

PURPOSE: Support routine for **AddClass** and **DeleteClass** which increments or decrements the "in use" counts of all atoms (e.g. symbols) and construct references (e.g. deffunction calls) found in the definitions of a class and its associated message-handlers. This insures that all of these items persist at least as long as the class definition does.

ARGUMENTS: 1) A pointer to a class.
2) An integer code indicating whether to increment (1) or decrement (0) "in use" counts.

OTHER NOTES: Only deinstallation of message-handlers is performed by this routine; installation is done by **ParseDefmessageHandler** in the Message Commands Module.

MergeSlots

PURPOSE: Support routine for **FormInstanceTemplate** which appends slots from a class to a temporary list of slots inherited from more specific classes. Only slots which have not already been specified will be added, and slots with **no-inherit** facets will only be added from the direct parent class, not indirect superclasses.

ARGUMENTS:	1) The current list of temporary slot links. 2) A pointer to a class with the new slots. 3) Buffer for the number of slots in the list. 4) An integer flag indicating if the new slots to be added are from the direct parent class (1) or not (0). 5) Buffer for holding the top of the list according to most specific order by inheritance.
RETURNS:	The new list of temporary instance slot links.
OTHER NOTES:	The temporary link data structure uses a "next" field for indicating the symbolic hash value order and an "inherit" field for indicating the most specific inheritance order.

PrintPartialOrderLoop

PURPOSE:	Support routine for **FindPrecedenceList** which prints a dependency loop in the partial orders when a precedence list cannot be found which satisfies the multiple inheritance rules. Details are given in the general notes.
ARGUMENTS:	The table of partial orders.
OTHER NOTES:	There may be more than one dependency loop between the partial orders, but this routine will only print the first one it finds.

RecordPartialOrder

PURPOSE:	Support routine for **FindPrecedenceList** and **BuildPartialOrders** which enters a partial order between two classes into the partial order table, e.g. class A has precedence over class B. According to the topological sorting algorithm given in the Class Function Module's general notes, the successor class is entered on the predecessor class's successor list, and the successor class's predecessor count is incremented.
ARGUMENTS:	1) A partial order link node containing a pointer to the predecessor class. 2) The successor class.

ResetCompositeSlots

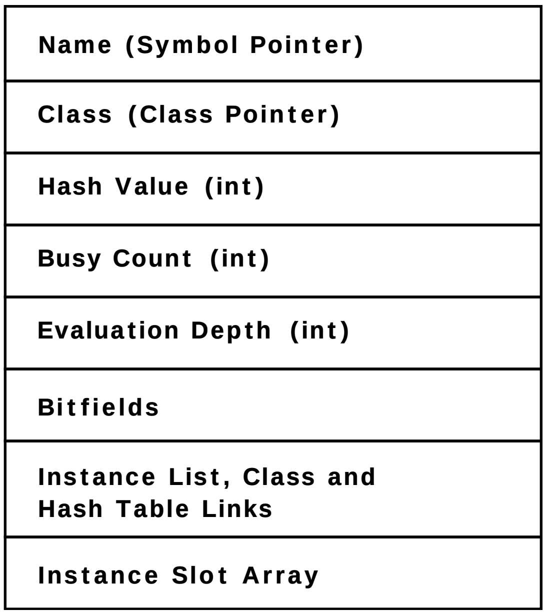
PURPOSE:	Support routine for **AddClass** which gets facet values for **composite** slots in a new class from its superclasses. See the *Basic Programming Guide* for details on the **composite** slot facet.

ARGUMENTS: A pointer to a class.

OTHER NOTES: Since all superclasses are completely defined before a new class based on them is created, this routine need only examine the immediately next most specific class in the class precedence list for extra facet values. Even if the superclass slot is also **composite**, the other facets have already been filtered down from the more general superclasses. However, if the superclass slot has a **no-inherit** facet, the next most specific class must be examined.

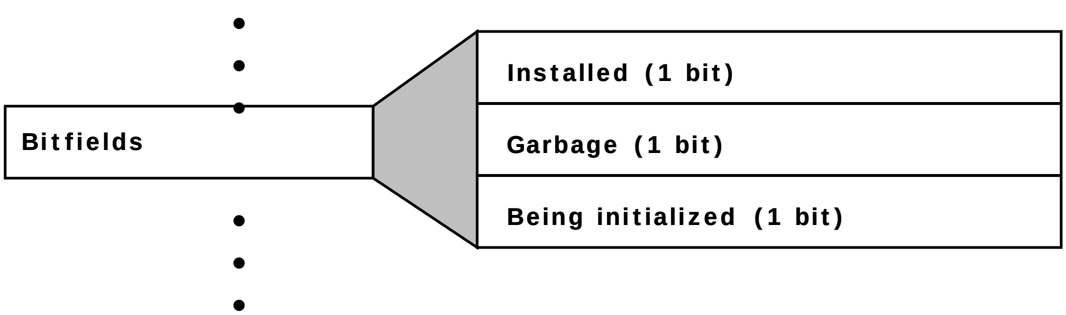
Instance Commands Module

The Instance Commands Module (inscom.c) manages the parsing and general interface aspects for instances of user-defined classes. For a description of how to manipulate instances, see the *Basic Programming Guide*.

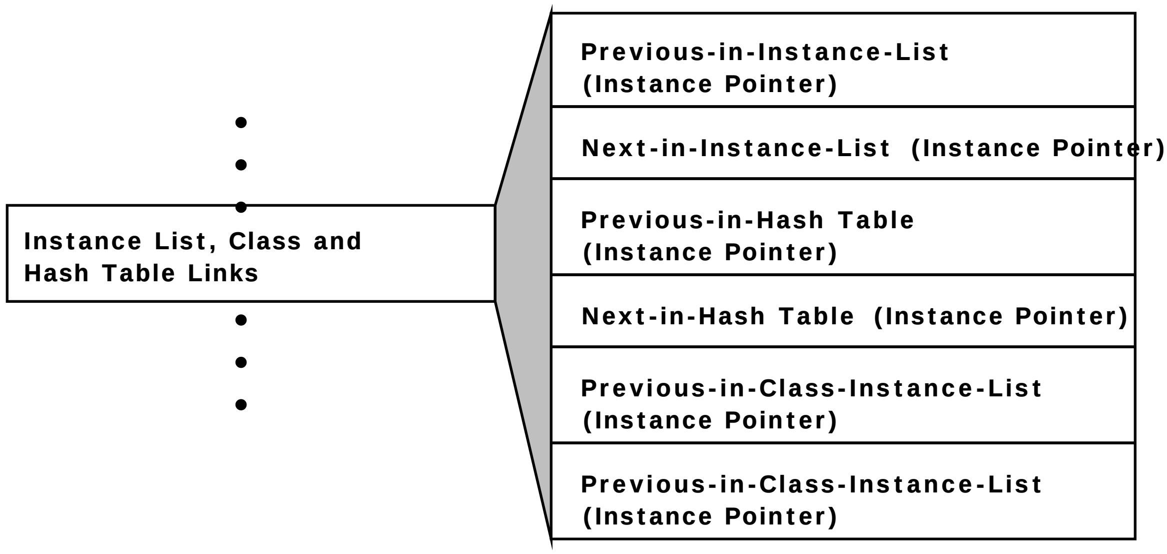


The internal data structure of an instance consists primarily of: a symbolic name, a pointer to the class (see the Class Commands Module for details on the defclass construct) and an array of slot values corresponding one to one with the instance template array in the class. A busy count for each instance reflects how many outstanding pointer references there are to an instance. This busy count must be zero it is safe to deallocate the instance. Note that the instance may appear to be deleted while the busy count is greater than zero, for it might be on the garbage collection list (see the notes in the Instance Functions Module).

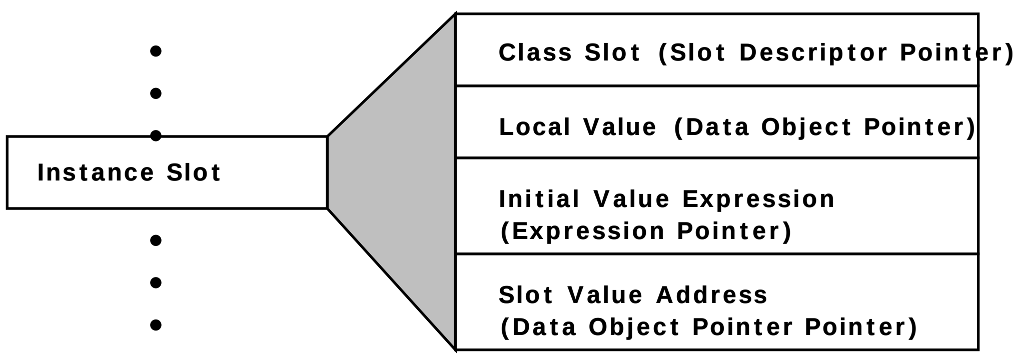
Other fields in the instance structure include: a hash value indicating the position of the instance in the hash table; the evaluation depth at which the instance was created (see the Evaluation Module), which is used in determining when it is safe to garbage collect an instance; a series of bitfields indicating such things as whether the instance is on the garbage list; and links connecting the instance to the global instance list and hash table.



The bitfields are stored in a single integer and indicate the following information about an instance: whether all the atoms within the instance have had their busy counts incremented (i.e. whether the instance has been installed), whether the instance has been functionally deleted (i.e. the instance on the garbage list) and whether the instance is in the process of being initialized by **make-instance** or **initialize-instance**.



The links which place an instance in the global instance list (**InstanceList**), the instance hash table (**InstanceTable**) and the list of instances for the parent class are implemented with direct instance pointers in the instance.



Each instance has an array of instance slots that correspond one to one with the template of slot descriptor pointers in the instance's class. In this way, slot information which is common to all instances of a class, such as the slot name and facets, is only stored once. The mapping is one to one so that an instance slot may be accessed by looking it up by name in the class template and then using the same index to reference the instance slot array. The instance slots contain information about slots which are specific to each instance.

An instance slot contains the following fields: a pointer to the slot descriptor giving the name and facets; a data object buffer holding the slot value, if the slot is **local**; an expression for the initial value of a slot used during **make-instance** and **initialize-instance**; and a pointer to the data object buffer holding the slot value. This last field will point to the local value field if the slot is not a **shared** slot. Otherwise, it will point to the shared value field in the slot descriptor of the class. This field is used to access the slot value indirectly COOL routines to avoid repetitive checks as to whether the slot is shared or not.

INTERNAL VARIABLES

ALL_QUALIFIER

PURPOSE: Keyword which tells **CmdListInstances** to list indirect instances of a class.

OTHER NOTES: Implemented as a preprocessor constant.

CLASS_RLN

PURPOSE: Keyword in instance creation routines **ParseInitializeInstance** and **ParseSimpleInstance** indicating that a class name follows.

OTHER NOTES: Implemented as a preprocessor constant.

ObjectParseToken

PURPOSE: An intermediary variable used for scanned tokens by the COOL parsing routines during a **load**.

GLOBAL FUNCTIONS

CmdListInstances

PURPOSE: Lists instances of a class.

OTHER NOTES: Implementation of the CLIPS function **instances**.

DeleteInstance

PURPOSE: Deletes the active instance, i.e. the instance which is the object of the current message.

OTHER NOTES: Implementation of the CLIPS function **delete-instance**.

DestroyAllInstances

PURPOSE: Sends **delete** messages to all instances.

DoesInstanceExist

PURPOSE: Determines if the instance specified by the instance name or address in the CLIPS supplied argument exists.

RETURNS: A non-zero integer if the instance exists, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **instance-existp**.

DoesSlotExist

PURPOSE: Determines if a slot of a particular instance, specified by CLIPS supplied arguments, exists.

RETURNS: A non-zero integer if the slot exists, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **slot-existp**.

Embedded Access for Instances

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*: **CLIPSDeleteInstance**, **CLIPSGetSlot**, **CLIPSMakeInstance**, **CLIPSPutSlot**, **CLIPSTestSlot**, **CLIPSUnmakeInstance**, **CreateRawInstance**, **FindInstance**, **GetInstanceName**, **GetInstanceClass**, **GetInstancePPForm**, **GetNextInstance**, **GetNextInstanceInClass ListInstances**, **LoadInstances**, **SaveInstances** and **ValidInstanceAddress**.

OTHER NOTES: There are additional embedded access functions for instances in the Instances Functions Module.

GetInstanceAddressCmd

PURPOSE: Determines the address of an instance specified by a CLIPS supplied argument.

ARGUMENTS: A data object buffer to hold the instance address.

OTHER NOTES: Implementation of the CLIPS function **instance-address**.

GetInstanceClassCmd

PURPOSE: Determines the class of an instance specified by a CLIPS supplied argument.

ARGUMENTS: A data object buffer to hold the class name.

OTHER NOTES: Implementation of the CLIPS functions **class** and **type** (see the Generic Function Command Module).

GetInstanceNameCmd

PURPOSE: Determines the name of an instance specified by a CLIPS supplied argument.

ARGUMENTS: A data object buffer to hold the instance name.

OTHER NOTES: Implementation of the CLIPS function **instance-name**.

InstanceNameToSymbol

PURPOSE: Converts an instance name specified by a CLIPS supplied argument to a symbol.

ARGUMENTS: A data object buffer for holding the symbol.

OTHER NOTES: Implementation of the CLIPS function **instance-name-to-symbol**.

IsInstance

PURPOSE: Determines if the CLIPS supplied argument is an instance name or address.

RETURNS: A non-zero integer if the argument is an instance, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **instancep**.

IsInstanceAddress

PURPOSE: Determines if the CLIPS supplied argument is an instance address.

RETURNS: A non-zero integer if the argument is an instance address, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **instance-addressp**.

IsInstanceName

PURPOSE: Determines if the CLIPS supplied argument is an instance name.

RETURNS: A non-zero integer if the argument is an instance name, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **instance-namep**.

IsSlotBound

PURPOSE: Determines if the slot of an instance, specified by CLIPS supplied arguments, has a bound value.

RETURNS: A non-zero integer if the slot is bound, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **slot-boundp**.

IsSlotInitable

PURPOSE: Determines if the slot of an instance, specified by CLIPS supplied arguments, can be initialized.

RETURNS: A non-zero integer if the slot can be initialized, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **slot-initablep**.

IsSlotWritable

PURPOSE: Determines if the slot of an instance, specified by CLIPS supplied arguments, can be written.

RETURNS: A non-zero integer if the slot can be written, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **slot-writablep**.

LoadInstancesCommand

PURPOSE: Loads instances from a file.

OTHER NOTES: Implementation of the CLIPS function **load-instances**.

MultifieldSlotDelete

PURPOSE: Deletes fields from a multifield slot value of an instance.

ARGUMENTS: A data object buffer to hold the symbol TRUE or FALSE depending on the success of the deletion.

OTHER NOTES: Implementation of the CLIPS function **mv-slot-delete**.

MultifieldSlotInsert

PURPOSE: Inserts fields into a multifield slot value of an instance.

ARGUMENTS: A data object buffer to hold the symbol TRUE or FALSE depending on the success of the insertion.

OTHER NOTES: Implementation of the CLIPS function **mv-slot-insert**.

MultifieldSlotReplace

PURPOSE: Replaces fields in a multifield slot value of an instance.

ARGUMENTS: A data object buffer to hold the symbol TRUE or FALSE depending on the success of the replacement.

OTHER NOTES: Implementation of the CLIPS function **mv-slot-replace**.

ParseInitializeInstance

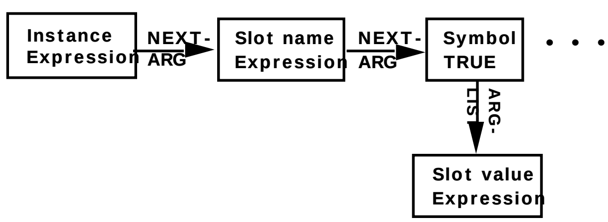
PURPOSE: Parses **initialize-instance** and **make-instance** function calls into a series of expressions that can later be evaluated by **InitializeInstance** or **MakeInstance** in the Instance Functions Module.

ARGUMENTS: 1) An expression node containing the **initialize-instance** or **make-instance** function call.
2) The logical name of the input source.

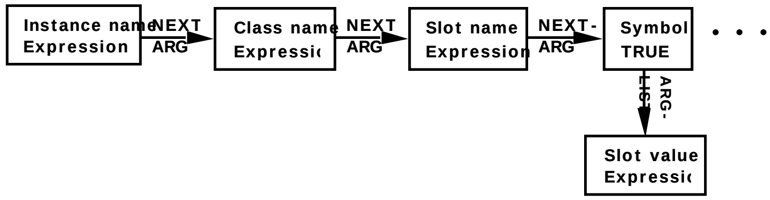
RETURNS: The top of series of expressions representing the **initialize-instance** or **make-instance** function call, or NULL on errors.

OTHER NOTES: This special function parser is required because these two functions do not follow the standard format of CLIPS functions, e.g. the slot-overrides would look like function calls to the standard CLIPS function parser.

(initialize-instance <instance> <slot-override>*) is parsed to the following:



(make-instance <instance-name> of <class> <slot-override>*) is parsed to the following:



PPInstance

PURPOSE: Displays the pretty-print form of an instance.

OTHER NOTES: Implementation of the CLIPS function **ppinstance**.

SaveInstancesCommand

PURPOSE: Saves instances to a file.

OTHER NOTES: Implementation of the CLIPS function **save-instances**.

SetupInstances

PURPOSE: Support routine for **SetupObjectSystem** in the Class Commands Module which defines all functions and commands for instances. Sets up all necessary **watch** and garbage collection interfaces.

OTHER NOTES: Initialization differs between standard and run-time configurations.

SymbolToInstanceName

PURPOSE: Converts a symbol specified by a CLIPS supplied argument to an instance name.

ARGUMENTS: A data object buffer for holding the instance name.

OTHER NOTES: Implementation of the CLIPS function **symbol-to-instance-name**.

UnmakeInstance

PURPOSE: Sends a **delete** message to the instance specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **unmake-instance**.

INTERNAL FUNCTIONS

CheckInstanceAndSlot

PURPOSE:	Support routine for **DoesSlotExist**, **IsSlotBound**, **IsSlotWritable** and **IsSlotInitable** which determines the the address of a slot of an instance, both given by CLIPS supplied arguments.
ARGUMENTS:	1) The name of the calling function. 2) A buffer for holding the slot address (will contain NULL if the slot does not exist). 3) An integer flag indicating whether to signal an error (0) if the slot does not exists or not (1).
RETURNS:	The address of the instance, NULL on errors.

CheckMultifieldSlotInstance

PURPOSE:	Support routine for **MultifieldSlotDelete**, **MultifieldSlotInsert** and **MultifieldSlotReplace** which checks the number of arguments and determines the address of the instance specified by the CLIPS supplied argument.
ARGUMENTS:	1) Name of the calling function. 2) Integer code representing a restriction on the number of arguments (EXACTLY, AT_LEAST, NO_MORE_THAN, etc.) 3) The expected number of arguments.
RETURNS:	The address of the instance, NULL on errors.

FindISlotByName

PURPOSE:	Support routine for **CLIPSTestSlot**, **CLIPSGetSlot** and **CLIPSPutSlot** which determines the address of a named slot.
ARGUMENTS:	1) The address of an instance. 2) The name of a slot.
RETURNS:	The address of the instance slot, NULL on errors.

ParseSimpleInstance

PURPOSE:	Support routine for **LoadInstances** and **CLIPSMakeInstance** which parses a simple **make-instance** call.

ARGUMENTS: 1) An expression node containing the **make-instance** function call.
2) The logical name of the input source.

RETURNS: The top of series of expressions representing the **make-instance** function call, or NULL on errors.

OTHER NOTES: This routine is similar in functionality to **ParseInitializeInstance**, except that it is always available (even in a run-time or binary load only configuration). It is more constraining than **ParseInitializeInstance** in that the instance name, class name and the slot names and slot values in slot-overrides must all be constant expressions.

ParseSlotOverrides

PURPOSE: Support routine for **ParseInitializeInstance** which parses slot-overrides in an **initialize-instance** or **make-instance** function call.

ARGUMENTS: 1) The logical name of the input source.
2) An integer buffer for holding a an error code: non-zero on errors, zero otherwise.

RETURNS: A series of expressions representing the slot-overrides.

PrintInstance

PURPOSE: Support routine for **PPInstance** and **GetInstancePPForm** which prints the name, class and slot values of an instance.

ARGUMENTS: 1) Logical name of the output destination.
2) Address of the instance.
3) String to print between slots.

TabulateInstances

PURPOSE: Support routine for **ListInstances** which lists and counts all the instances of a class.

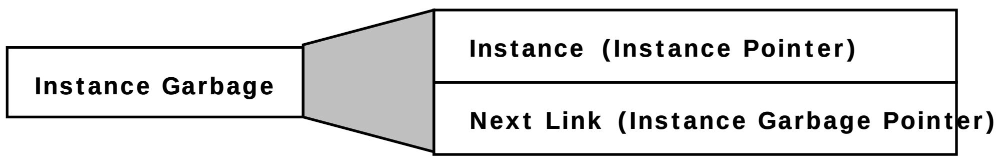
ARGUMENTS: 1) A unique traversal integer identifier to prevent loops when examining the class hierarchy (see the general notes for the Class Commands Module)
2) The logical name of the output destination.
3) A pointer to a class.
4) An integer flag indicating whether to print indirect instances of the class (1) or not (0).

RETURNS: The number of instances listed.

Instance Functions Module

The Instance Functions Module (insfun.c) deals with the internal details of creating, accessing and deleting instances.

When an instance is deleted but its busy count is still greater than zero or its creation evaluation depth is less than the current one, it is removed from its class's instance list, the global instance list and hash table, and it is placed in a special delayed garbage collection queue. An intermediary data structure is used to build this garbage list:



The first field is a pointer to the deleted instance, and the second is a pointer to the next node in the garbage list. Whenever an instance is deleted, regardless of whether it is busy or not, all of the internal data of the instance, such as the slot values, are immediately deallocated. However, the external links of the instance are left intact so that any outstanding internal references to the instance can still follow these links without getting an unexpected pointer violation. CLIPS functions available to the user will not be able to access this address anymore, even if the address was bound to a CLIPS variable, because CLIPS recognizes that the instance no longer effectively exists and treats references to it accordingly. This is accomplished through the use of the "garbage" bitfield in the instance (see the notes in the Instance Commands Module). At a later time, when garbage collection is performed and the instance is no longer busy, the actual instance data structure will be deallocated. The Utility and Evaluation Modules provide more details on CLIPS garbage collection.

GLOBAL VARIABLES

ChangesToInstances

PURPOSE: Internal flag used by the functions **GetInstancesChanged** and **SetInstancesChanged**, which are documented in the *Advanced Programming Guide*.

InstanceList

PURPOSE: A pointer to the top of the list of currently defined instances.

INSTANCE_TABLE_HASH_SIZE

PURPOSE: The number of chains in the instance lookup table. A chain is a list of instances where the name of each instance generates the same hash value according to the formula in **HashInstance**.

OTHER NOTES: Implemented as a preprocessor constant in insfun.h.

MaintainGarbageInstances

PURPOSE: When this global integer flag is non-zero, instances which are on the garbage collection list cannot be deleted and any newly deleted instances go onto the garbage collection list regardless of whether they are busy or not. This flag is used as a convenient mechanism by various instance manipulation functions to insure that instance addresses remain valid during a certain interval.

Multifield Slot Function Codes

PURPOSE: Integer codes used by **CheckMultifieldSlotModify** to determine which function called it. The codes are: **DELETE**, **INSERT** and **REPLACE**.

OTHER NOTES: Implemented as preprocessor constants in insfun.h.

OverrideSlotProtection

PURPOSE: When this integer flag is non-zero, slot protection such as **read-only** and **initialize-only** facets are ignored during slot writes. This flag is used by the **LoadInstances** function in the Instance Commands Module to insure that instances can be reloaded from a file exactly as they were saved.

Slot Value Expression Evaluation Codes

PURPOSE: Integer codes used by **EvaluateAndStoreInDataObject** to indicate the result of evaluating an expression for a slot value: **MULTI_CLEAR** for a NIL value and **MULTI_SET** for a non-NIL value.

OTHER NOTES: Implemented as preprocessor constants in insfun.h.

Slot Value Set Codes

PURPOSE: Integer codes used by **PutSlotValue** to indicate the result of setting a slot: **SLOT_EMPTY** for clearing the slot, **SLOT_FILLED** for setting the slot and **SLOT_ERROR** on errors.

OTHER NOTES: Implemented as preprocessor constants in insfun.h.

WatchInstances

PURPOSE: An integer flag indicating whether or not to print out trace information whenever an instance is created or deleted. This flag is used by the **watch** command.

WatchSlots

PURPOSE: An integer flag indicating whether or not to print out trace information whenever a slot changes value. This flag is used by the **watch** command.

WithinInit

PURPOSE: This integer flag is non-zero when an instance is being initialized. This lets other COOL routines know when it is permissible to write to slots which are protected by the **initialize-only** facet.

INTERNAL VARIABLES

BIG_PRIME

PURPOSE: Large prime number used in the calculations of widely distributed hash values for instances.

OTHER NOTES: Implemented as a preprocessor constant.

CurrentInstance

PURPOSE: A pointer to the instance which is currently being created.

InstanceGarbageList

PURPOSE: A pointer to the top of the list of instances which are functionally deleted but still remain to be garbage collected. Instances will remain on this list as long as their busy count is non-zero; this to insure that there are no dangling pointers.

InstanceListBottom

PURPOSE: A pointer to the bottom of the list of currently defined instances.

InstanceTable

PURPOSE: An array of instance lists where each instance in a particular list has the same hash value. This data structure enables fast lookups of instances by name. The instance name is hashed to generate a hash value. and then compared to the names of all the instances in the chain at the hash value index of the instance table.

GLOBAL FUNCTIONS

BuildInstance

PURPOSE: Support routine for **CreateRawInstance** in the Instance Commands Module and **MakeInstance** which creates an uninitialized instance and inserts it into the class's instance list and the global instance list and hash table.

ARGUMENTS: 1) Symbolic name of the new instance.
2) Symbolic name of a class.

RETURNS: The address of the new instance, NULL on errors.

OTHER NOTES: If an instance of the specified name already exists, it is sent a **delete** message. If the deletion fails, the new creation is aborted.

CheckMultifieldSlotModify

PURPOSE: Support routine for the functions **MultifieldSlotDelete**, **MultifieldSlotInsert** and **MultifieldSlotReplace** in the Instance Commands Module and **HandlerDeleteSlot**, **HandlerInsertSlot** and **HandlerDeleteSlot** in the Message-Handler Commands Module which gets the slot address, field range indices and new field values (if any) for these functions.

ARGUMENTS: 1) A code indicating the type of operation (see **Multifield Slot Function Codes**):
INSERT: Requires one index
REPLACE: Requires two indices
DELETE: Requires two indices
2) Name of the calling function.
3) Pointer to the instance being modified.
4) Argument expressions for the calling function.
5) Integer buffer for the range start index.
6) Integer buffer for the range end index (can be NULL if argument #1 is INSERT).

7) Data object buffer for the new value to be inserted or used as a replacement (can be NULL if argument #1 is DELETE).

RETURNS: The address of the instance slot to modify, NULL on errors.

OTHER NOTES: A multifield value is allocated and added to the ephemeral segment list if more than one new field value is specified.

CleanupInstances

PURPOSE: This function is called by the CLIPS garbage collector, **PeriodicCleanup** in the Utility Module, to deallocate garbage collectied instances which are not busy and which were created at an evaluation depth greater than the current one.

CoreInitializeInstance

PURPOSE: Support routine for **InitializeInstance** and **MakeInstance** which performs the following steps to initialize an instance:

1) Get all default slot value expressions from the class definition.
2) Replace default slot value expressions with slot-overrides as appropriate.
3) Evaluate slot-overrides with **put** messages.
4) Evaluate remaining default slot values via **init** message.

ARGUMENTS: 1) A pointer to the instance.
2) A series of slot-override expressions.

RETURNS: A non-zero integer if the instance is successfully initialized, zero otherwise.

OTHER NOTES: This function does not need to be global; it will be made an internal function in the next release of CLIPS.

DecrementInstanceDepth

PURPOSE: Support routine for **PropogateReturnValue** in the Evaluation Module which decrements the evaluation depth of an instance.

ARGUMENTS: A pointer to an instance.

Embedded Access for Instances

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*:

DecrementInstanceCount, **GetInstancesChanged**, **IncrementInstanceCount** and **SetInstancesChanged**.

OTHER NOTES: There are additional embedded access functions for instances in the Instances Commands Module.

EvaluateAndStoreInDataObject

PURPOSE: Support routine for **EvaluateDefaultSlots** in the Class Commands Module, **HandlerPutSlot** in the Message-Handler Commands Module, **EvaluateInstanceSlots** and **CheckMultifieldSlotModify** which evaluates a series of expressions and stores the result in a data object.

ARGUMENTS: 1) An integer code indicating whether to store the result in an atomic data object (0) or a multifield data object (1), if the expression is atomic (i.e. the "next argument" pointer is NULL).
2) The series of expressions to evaluate.
3) A data object buffer to hold the result.

RETURNS: The integer zero if there are any errors while evaluating the expressions, **MULTI_CLEAR** (1) if the expression list is NULL, or **MULTI_SET** (2) otherwise (see **Slot Value Expression Evaluation Codes**).

EvaluateInstanceSlots

PURPOSE: Directly evaluates class default slot expressions for slot values which were not specified by slot-overrides (i.e. the "override" flag was not set for the slot; see the general notes in the Instance Commands Module) in the **make-instance** or **initialize-instance** call.

ARGUMENTS: A data object buffer which holds the instance address if there were no errors, the symbol FALSE otherwise. This will be the CLIPS return value of the **init** message in the absence of any other user-defined message-handlers.

OTHER NOTES: Implementation of the CLIPS function **init-slots**.

This function operates on the active instance. This function will normally be called as a result of **CoreInitializeInstance** sending an **init** message to an instance. This allows the user to define other message-handlers to perform actions before and after slot default initialization as described in the *Basic Programming Guide*.

The "initialization evaluation" flag for the instance (see the general notes in the Instance Commands Module) will be set if the appropriate prologue has been performed. The prologue is outlined in the description of **CoreInitializeInstance**. This function clears that flag to inform **CoreInitializeInstance** that the initialization is complete.

FindInstanceBySymbol

PURPOSE: Uses a hash table lookup to determine the address of the specified instance.

ARGUMENTS: The symbolic name of the instance.

RETURNS: The address of the instance, NULL if not found.

FindInstanceSlot

PURPOSE: Determines the address of the specified slot.

ARGUMENTS: 1) The address of the instance.
2) The symbolic name of the slot.

RETURNS: The address of the instance slot, NULL if not found.

FindInstanceTemplateSlot

PURPOSE: Uses a binary search on the symbolic hash value of the slot name to find the index of the specified slot in a class's instance slot template array.

ARGUMENTS: 1) The address of the class.
2) The symbolic name of the slot.

RETURNS: An integer index into the class's instance slot template array, -1 if not found.

InitializeInstance

PURPOSE: Initializes an instance. The descriptions of **ParseInitializeInstance** in the Instance Commands Module and **CoreInitializeInstance** give more details.

ARGUMENTS: A data object buffer for holding the result: the instance name on success or the symbol FALSE otherwise.

OTHER NOTES: Implementation of the CLIPS function **initialize-instance**.

InitializeInstanceTable

PURPOSE: Support routine for **SetupInstances** in the Instance Commands Module which allocates and initializes the instance hash table.

MakeInstance

PURPOSE: Creates and initializes a new instance. The descriptions of **ParseInitializeInstance** in the Instance Commands Module and **CoreInitializeInstance** give more details.

ARGUMENTS: A data object buffer for holding the result: the instance name on success or the symbol FALSE otherwise.

OTHER NOTES: Implementation of the CLIPS function **make-instance**.

NoInstanceError

PURPOSE: Displays an error message when an instance cannot be found for a function call.

ARGUMENTS: 1) The name of the instance.
2) The name of the calling function.

PutSlotValue

PURPOSE: Stores a new value in a slot of an instance. All slot writing is passed through this central routine.

ARGUMENTS: 1) Address of the instance.
2) Address of the instance slot.
3) Data object holding the new slot value.
4) An integer code indicating whether to print **watch** messages for slot changes (1) or not (0).

RETURNS: An integer code indicating the result: **SLOT_ERROR**, **SLOT_EMPTY** or **SLOT_FILLED** (see **Slot Value Set Codes**).

OTHER NOTES: Old slot values are deinstalled and deallocated, and new slot values are installed. (De)installing a slot value means (de)incrementing the "in use" counts of all atoms in the data object. If the new value is a multifield, the a duplicate of the segment is assigned to the slot.

QuashInstance

PURPOSE: Removes an instance from its class's instance list and the global instance list and hash table. Also, all slot values are deinstalled (see **InstallInstance**) and erased. If the instance is not busy, it is deallocated, otherwise is it is added to the instance garbage collection list (see **InstanceGarbageList**).

ARGUMENTS: A pointer to the instance.

RETURNS:` A non-zero integer if the instance was successfully deleted, zero otherwise.

OTHER NOTES: The links going out from the instance to its class's list and the global class list and instance table are left unchanged; this allows outstanding pointers to this instance to still use it to follow links.

SlotExistError

PURPOSE: Prints out an appropriate error message when a slot cannot be found for a function.

ARGUMENTS: 1) The slot name.
2) The name of the calling function.

SlotValueExpression

PURPOSE: Support routine for **EvaluateDefaultSlots** in the Class Commands Module which generates an expression (or series of expressions in the case of a multifield) equivalent to a data object value for storage as a class slot default value.

ARGUMENTS: A data object address.

RETURNS: The equivalent expression(s).

StaleInstanceAddress

PURPOSE: Prints out an appropriate error message when an attempt is made to access an instance which is on the garbage collection list via a previously bound address.

ARGUMENTS: The name of the calling function.

ValidSlotValue

PURPOSE: Determines if a value is comprised of legal atoms for an instance slot. If it is not, the function generates an evaluation error and prints out an error message.

ARGUMENTS: 1) A data object pointer.
2) The name of the calling function.

RETURNS: A non-zero integer if the value is acceptable, zero otherwise.

INTERNAL FUNCTIONS

BuildDefaultSlots

PURPOSE: Support routine for **BuildInstance** which allocates an array of instance slots for a new instance.

OTHER NOTES: The new slots are attached to the instance indicated by the global **CurrentInstance**.

The address to hold the actual value of each slot is initialized according to the **shared** facet (see the general notes in the Instance Commands Module).

HashInstance

PURPOSE: Generates an index into the instance hash table for a given instance.

ARGUMENTS: The symbolic name of a instance.

RETURNS: The hash table index for the instance.

OTHER NOTES: The hash table index is derived from the symbol hash table index (see the Symbol Manager Module).

InsertSlotOverrides

PURPOSE: Support routine for **CoreInitializeInstance** which sends **put** messages for each slot-override.

ARGUMENTS: 1) A pointer to the instance.
2) A series of slot-override expressions.

RETURNS: A non-zero integer if successful, zero otherwise.

OTHER NOTES: The "slot override" flag is set for each slot with an override. These flags are later used by **EvaluateInstanceSlots** determine which slots need class default values and should be cleared by that function.

InstallInstance

PURPOSE: Support routine for **BuildInstance** which increments or decrements the "in use" counts of all atoms (e.g. symbols) associated with an instance, i.e the instance name and the slot values. This insures that all of these items persist at least as long as the instance does.

ARGUMENTS: 1) A pointer to an instance.
2) An integer code indicating whether to increment (1) or decrement (0) "in use" counts.

InstanceLocationInfo

PURPOSE: Support routine for **BuildInstance** which where a new instance belongs in the instance hash table.

ARGUMENTS 1) The symbolic name of the new instance.
2) A buffer for holding the address of the instance previous to the new one in the hash table.
3) A buffer for the hash value of the new instance.

RETURNS: A pointer to an old instance of the same name, NULL if none.

InstanceSizeHeuristic

PURPOSE: Support routine for **CleanupInstances** and **QuashInstance** which determines the amount of memory required by an instance. This amount is added or subtracted from a global count when the instance is added or removed from the instance garbage collection list respectively.

ARGUMENTS: The address of an instance.

RETURNS: The amount of memory required by the instance.

OTHER NOTES: Implemented as a preprocessor macro.

CLIPS normally allows garbage memory to accumulate to a certain level before bothering to release it back to the system. This drastically improves performance.

NewInstance

PURPOSE: Support routine for **BuildInstance** which allocates a new instances data structure and initializes all the fields.

RETURNS: The address of anew instance.

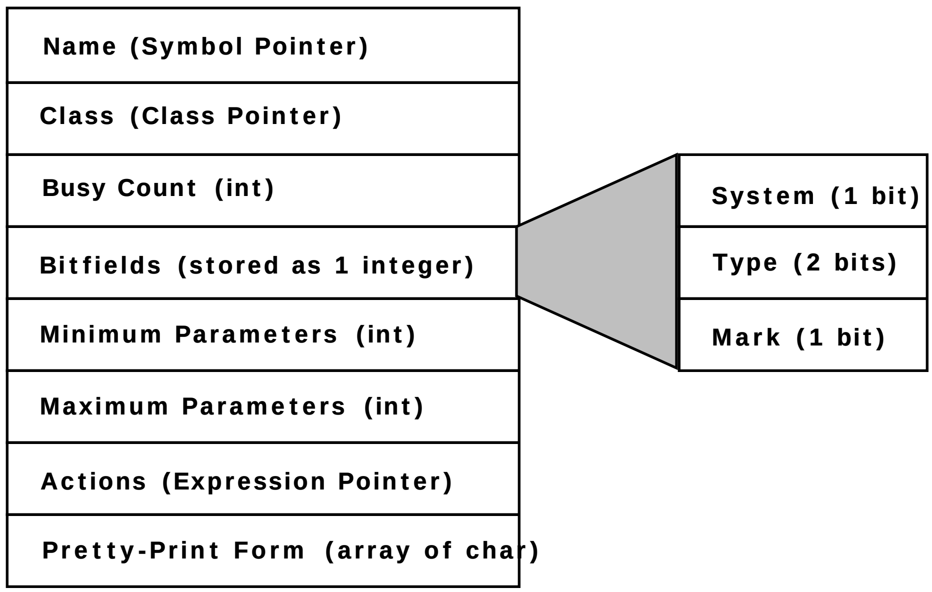
StoreValuesInMultifield

PURPOSE: Support routine for **EvaluateAndStoreInDataObject** which creates a multifield and stores a series of values in it.

ARGUMENTS: 1) A series of atomic data objects chained together via their "next" fields.
2) A data object buffer to hold the resulting multifield.
3) The number of data objects in the source list.

Message-Handler Commands Module

The Message-Handler Commands Module (msgcom.c) contains the parsing and general interface routines for the procedural attachments (message-handlers) to classes. For a description of the defmessage-handler construct, see the *Basic Programming Guide*. The defmessage-handler construct capability, along with the other features of the CLIPS Object-Oriented Language (COOL), can be removed by using the appropriate compile flag in the setup header file. The message-handler data structure is summarized in the following diagram:



The internal data structure of a defmessage-handler construct primarily consists of: a symbolic name; a pointer to the parent class; two integers, which indicate the minimum and maximum number of arguments the handler will accept respectively; and a sequence of expressions which comprise the body of the handler. If a handler has a wildcard parameter (i.e. the handler will accept any number of arguments greater than or equal to the minimum number of arguments), the maximum number of arguments field will have the value -1. A busy count for each handler reflects how many times a handler is executing on behalf of a message. This busy must be zero before any of the handlers of the class to which this handler belongs can be modified. Other fields in the handler data structure include: the pretty-print form and bitfields. The bitfields are stored in a single integer and indicate the following information about a handler: whether the handler is one of the predefined ones attached to the USER class, the type code (see **Message-Handler Type Codes** in the Message-Handler Functions Module) and whether the handler has been marked for deletion.

When a handler is called during a message dispatch (see the Message-Handler Functions Module), if the number of arguments is outside the acceptable range, the entire message is immediately terminated and an error is generated. Otherwise, all the actions of the handler are evaluated in order as if they were grouped in a **progn**. The evaluation of the last expression in the handler body is returned as the value of the handler, unless an error occurs or the **return** function is used (see the *Basic Programming Guide*).

The arguments of a handler are evaluated and stored in order in an array of data objects called the message parameter array (**CurrentMessageFrame**). Variable references within the body of a handler are replaced when the construct is loaded with function calls which either access the bind list (see the Primary Functions Module), get the value of a global variable (see the Defglobal Manager Module) or positionally access the message parameter array (**HandlerRtnUnknown**). For example, references to the second parameter of a handler are replaced with function calls which access the second data object in the parameter array at run-time.

A wildcard parameter allows the handler to accept any number of arguments. All references to the wildcard parameter are replaced with a call to a special function, **HandlerWildargs**, which groups all of the data objects in the parameter array starting at the position of the wildcard parameter to the end of the array into a multifield data object.

If a parameter (including a wildcard parameter) is rebound anywhere within the body of the deffunction, all references to that parameter are replaced with calls to a special function, **HandlerGetBind**, which first checks the bind list before accessing the parameter array.

GLOBAL VARIABLES

DELETE_STRING

PURPOSE:	Lexeme for **DELETE_SYMBOL**.
OTHER NOTES:	Implemented as a preprocessor constant in msgcom.h.

DELETE_SYMBOL

PURPOSE:	A symbol used in constructing direct **delete** messages sent to instances by various internal COOL routines, such as **MakeInstance.**

INIT_STRING

PURPOSE:	Lexeme for **INIT_SYMBOL**.
OTHER NOTES:	Implemented as a preprocessor constant in msgcom.h.

INIT_SYMBOL

PURPOSE:	A symbol used in constructing direct **init** messages sent to an instances by **MakeInstance.**

INTERNAL VARIABLES

PRINT_STRING

PURPOSE: Name of the predefined system message-handler attached to the USER class which pretty-prints an instance.

OTHER NOTES: Implemented as a preprocessor constant.

SELF_LEN

PURPOSE: Length of **SELF_STRING**.

OTHER NOTES: Implemented as a preprocessor constant.

SELF_SLOT_REF

PURPOSE: The string used to attach a direct slot reference to active instance parameter in a message-handler.

OTHER NOTES: Implemented as a preprocessor constant.

SELF_STRING

PURPOSE: Lexeme for **SELF_SYMBOL**.

OTHER NOTES: Implemented as a preprocessor constant.

SELF_SYMBOL

PURPOSE: The symbol used to represent the active instance parameter.

GLOBAL FUNCTIONS

AddSystemHandlers

PURPOSE: Support routine for **SetupMessageHandlers** which defines the three system message-handlers for initialization, deletion and printing and attaches them to the USER class.

CheckHandlerAgainstSlots

PURPOSE: Support routine for **AddClass** in the Class Functions Module and **ParseDefmessageHandler** which insures that a message-handler does not conflict with the implicit handlers (slot-accessors) for a class. For example, if a class has a slot called **bar**, it is illegal to define an explicit primary handler called **get-bar** or **put-bar**.

ARGUMENTS: 1) A pointer to a class.
2) The symbolic name of the message-handler.
3) An integer code representing the type of the handler (see **Message-Handler Type Codes** in the Message-Handler Functions Module).

RETURNS: A non-zero integer if the handler does not conflict with any of the slots, zero otherwise.

OTHER NOTES: The new handler will be illegal only if it is primary and it conflicts with one of the direct slots of a class. Primary handlers with same name as an inherited slot will shadow the slot-accessor. The *Basic Programming Guide* gives a complete explanation of handler shadowing.

CmdListDefmessageHandlers

PURPOSE: Lists message-handlers for a class.

OTHER NOTES: Implementation of the CLIPS function **list-defmessage-handlers**.

CmdUndefmessageHandler

PURPOSE: Removes a message-handler from a class.

OTHER NOTES: Implementation of the CLIPS function **undefmessage-handler**.

Embedded Access for Defmessage-Handlers

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*: **DeleteDefmessageHandler**, **FindDefmessageHandler**, **GetDefmessageHandlerName**, **GetDefmessageHandlerPPForm**, **GetDefmessageHandlerType**, **GetNextDefmessageHandler**, **IsDefmessageHandlerDeletable**, **ListDefmessageHandlers**, **PreviewMessage** and **WildDeleteHandler**.

OTHER NOTES: There are additional embedded access functions for message-handlers in the Message-Handler Functions Module.

GroupHandlerWildargs

PURPOSE: Stores the message parameter array elements from the specified beginning index minus one to the end of the array in the caller's multifield data object.

ARGUMENTS: 1) A pointer to a data object to hold the resulting multifield value.
2) The index (one is the beginning) from which to start copying the parameter array.

HandlerDeleteSlot

PURPOSE: Deletes fields from a multifield slot value of the active instance.

RETURNS: A non-zero integer if the slot was modified successfully, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **direct-mv-delete**.

HandlerGetBind

PURPOSE: Determines the value of a specified variable reference within the body of a handler. The symbolic name of the variable and an index indicating if the variable is a handler parameter are CLIPS supplied arguments. If the variable is on the bind list, that value is returned. Otherwise, the value of the parameter specified by the index is returned. In the event that the variable is neither on the bind list nor is it a parameter, an error will be generated.

ARGUMENTS: A pointer to a data object which will hold the value of the bound variable.

OTHER NOTES: Implementation of the internal CLIPS function **(hndgetbind)**.

Used for general variable references, including bind list variables and handler parameters which are rebound within the actions of the handler. If the index is zero, the variable is not a handler parameter. The absolute value of the index minus one is the position of the parameter in the message parameter array. If the index is less than zero, the variable corresponds to the wildcard parameter.

HandlerGetSlot

PURPOSE: Directly reads the slot specified by the CLIPS supplied argument of the active instance.

ARGUMENTS: Data object buffer for holding the slot value.

OTHER NOTES: Implementation of the CLIPS function **get**.

Direct slot references in a handler are replaced with calls to this function when the handler is parsed (see **ReplaceHandlerParameters**).

HandlerInsertSlot

PURPOSE: Inserts fields into a multifield slot value of the active instance.

RETURNS: A non-zero integer if the slot was modified successfully, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **direct-mv-insert**.

HandlerPutSlot

PURPOSE: Directly writes a value to the slot (both specified by CLIPS supplied arguments) of the active instance.

RETURNS: A non-zero integer if the write was successful, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **put**.

HandlerReplaceSlot

PURPOSE: Replaces fields in a multifield slot value of the active instance.

RETURNS: A non-zero integer if the slot was modified successfully, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **direct-mv-replace**.

HandlerRtnUnknown

PURPOSE: Gets the value of the specified element of the message parameter array, where the element index plus one is given as a CLIPS supplied argument.

ARGUMENTS: A pointer to a data object which will hold the value of the bound variable.

OTHER NOTES: Implementation of the internal CLIPS function **(hndunknown)**.

Used for references to regular handler parameters which are never rebound within the actions of the handler.

HandlerWildargs

PURPOSE: Gets the values of the specified elements of the message parameter array and groups them into a multifield data object, where the range of elements is given by a CLIPS supplied argument minus one to the end of the message parameter array.

ARGUMENTS: A pointer to a data object which will hold the value of the bound variable.

OTHER NOTES: Implementation of the internal CLIPS function **(hndwildargs)**.

Used for references to a wildcard handler parameter which is never rebound within the actions of the handler.

PPDefmessageHandler

PURPOSE: Displays the pretty-print form of a message-handler.

OTHER NOTES: Implementation of the CLIPS function **ppdefmessage-handler**.

PreviewMessageCmd

PURPOSE: Displays all the applicable message-handlers for a particular **send** call. The message and arguments are supplied by CLIPS.

OTHER NOTES: Implementation of the CLIPS function **preview-send**.

SetupMessageHandlers

PURPOSE: Defines all functions and commands for the defmessage-handler construct. Sets up all necessary **load** and **watch** interfaces.

OTHER NOTES: Initialization differs between standard and run-time configurations.

INTERNAL FUNCTIONS

CheckHandlerBindList

PURPOSE: Support routine for **ParseDefmessageHandler** which insures that a message-handler makes no attempt to rebind the active instance parameter or direct slot references.

RETURNS: A no-zero integers if all the binds were legal, zero otherwise.

FindHandlerParameter

PURPOSE: Support routine for **ReplaceHandlerParameters** which determines the position of a particular parameter in the list of all message-handler parameters.

ARGUMENTS:
1) The symbolic name of a parameter.
2) The list of parameters parsed so far.

RETURNS: The integer zero if the named parameter is not already in the list, otherwise the position of the parameter in the list.

InsertHandlerHeader

PURPOSE: Support routine for **ParseDefmessageHandler** and **NewSystemHandler** which appends a new handler into the array of handlers for a class.

ARGUMENTS:
1) A pointer to the class.
2) The symbolic name of the handler.
3) An integer code representing the type of the handler (see **Message-Handler Type Codes** in the Message-Handler Functions Module).

RETURNS: A pointer to the new handler.

OTHER NOTES: This routine also creates a map of integer indices into the handler array which gives the order according to the hash values of the symbolic names of the handlers. Thus, handlers for a class can be easily found by performing a binary search on the symbolic hash value of the handler name.

NewSystemHandler

PURPOSE: Support routine for **AddSystemHandlers** which adds a new message-handler to the handler array of the USER class. A system handler is assumed to be of type primary. The handler has zero or one explicit parameters, and the body contains one function call which either takes no arguments or takes the one explicit handler parameter as an argument.

ARGUMENTS: 1) Name of the system class.
2) Name of the system message-handler.
3) Name of the CLIPS function called in the body of this handler.
4) An integer code indicating if argument #3 requires a parameter (1) or not (0).
5) The address of a CLIPS function for accessing handler parameters (see **HandlerRtnUnknown**).

OTHER NOTES: In CLIPS 5.1, there are no system handlers which require the use of a handler parameter. Thus, the third and fourth arguments to this function are unnecessary and will be eliminated in the next release.

The CLIPS syntax for the three system message-handlers are:

```
(defmessage-handler USER init primary ()
(init-slots))

(defmessage-handler USER delete primary ()
(delete-instance))

(defmessage-handler USER print primary ()
(ppinstance))
```

ParseDefmessageHandler

PURPOSE: Used by the **load** command to parse a defmessage-handler.

ARGUMENTS: The logical name of the input source.

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

OTHER NOTES: Installation of the message-handler symbolic name and action expressions is handled by this routine; deinstallation is handled by **DeallocateMarkedHandlers** in the Message-Handler Functions Module or **InstallClass** in the Class Functions Module.

ParseHandlerParameters

PURPOSE: Support routine for **ParseDefmessageHandler** which parses a message-handler parameter list.

ARGUMENTS: 1) The logical name of the input source.
2) Buffer for wildcard symbol (if any).
3) Buffer to hold scanned tokens.

RETURNS: A series of expressions containing the parameter names, NULL on errors.

OTHER NOTES: The active instance parameter is prepended to the list of parameters.

This routine insures that there are no duplicate parameters or parameters which look like direct slot references.

ReplaceHandlerParameters

PURPOSE: Support routine for **ParseDefmessageHandler** which replaces all variable references in the message-handler actions with appropriate function calls that access the bind list, the message parameter array or global variables at run-time. Direct slot references are replaced with calls to the function **get**.

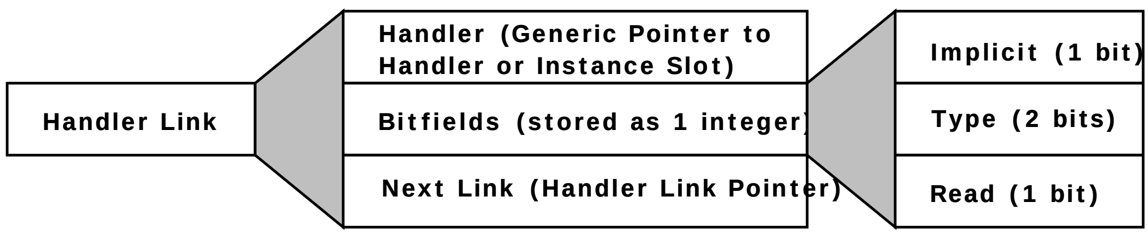
ARGUMENTS: 1) The list of action expressions.
2) The list of parameter name expressions.
3) The symbolic name of a wildcard parameter (if any).

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

Message-Handler Functions Module

The Message-Handler Functions Module (msgfun.c) implements the message dispatch when a message is actually sent to an object and maintains the internal details of the defmessage-handler construct. For a description of the defmessage-handler construct, see the *Basic Programming Guide*. The defmessage-handler construct capability, along with the other features of the CLIPS Object-Oriented Language (COOL), can be removed by using the appropriate compile flag in the setup header file.

When a message is dispatched with the **send** function, CLIPS creates the message parameter array, which is comprised of the message object and arguments, and forms a list of all the applicable methods to the message. The handlers in this list are linked using a temporary data structure called a **handler link**:



A handler contains: a generic pointer, which is a pointer to an explicit defmessage-handler or an instance slot if the handler is a slot-accessor, bitfields and a pointer to the next handler link. The bitfields indicate the following: whether the handler is a slot-accessor (i.e implicit); the type of the handler (see **Message-Handler Type Codes**); and, if the handler is a slot-accessor, whether it is for reading or for writing. The details of forming the list of applicable handlers are given in the description of the function **FindApplicableHandlers**. The mechanics of a message dispatch are outlined in the description of the function **DispatchMessage**.

GLOBAL VARIABLES

CurrentMessageFrame

PURPOSE: A pointer to an array of data objects which are the evaluated arguments for the currently executing message.

CurrentMessageName

PURPOSE: A symbol indicating the name of the currently executing message used for error and trace messages.

CurrentMessageSize

PURPOSE: An integer indicating the number of data objects in the currently executing message's parameter array.

hndquals

PURPOSE: An array of strings giving the textual descriptions of the message-handler types (see **Message-Handler Type Codes**). A handler type is an integer code, and the string corresponding to a type n is in the nth position of the array, e.g. hndquals[MAROUND] is "around". This array is used in printing out trace and error messages as well as parsing handler types.

Message-Handler Lookup Codes

PURPOSE: The integer codes **LOOKUP_HANDLER_ADDRESS** and **LOOKUP_HANDLER_INDEX** are used by the function **FindHandler** to determine whether to return message-handler addresses or indices into the class's handler array.

OTHER NOTES: Implemented as preprocessor constants in msgfun.h.

Message-Handler Type Codes

PURPOSE: MAFTER, MAROUND, MBEFORE, MPRIMARY and MERROR (see the description of **around**, **before**, **after** and **primary** handlers in the *Basic Programming Guide*)..

OTHER NOTES: Implemented as preprocessor constants in msgfun.h.

Slot-Accessor Prefix Strings

PURPOSE: **GSM_PREFIX** is the string prepended to all slot names to yield the name of the read slot-accessor, and **GSMP_LEN** is the length of that string. **PSM_PREFIX** is the string prepended to all slot names to yield the name of the write slot-accessor, and **PSMP_LEN** is the length of that string.

OTHER NOTES: Implemented as preprocessor constants in msgfun.h.

WatchHandlers

PURPOSE: An integer flag indicating whether or not to print out trace information whenever a message-handler begins and ends execution. This flag is used by the **watch** command.

WatchMessages

PURPOSE: An integer flag indicating whether or not to print out trace information whenever a message begins and ends execution. This flag is used by the **watch** command.

INTERNAL VARIABLES

CurrentCore

PURPOSE: A handler link to the currently executing message-handler.

Message Trace Strings

PURPOSE: **BEGIN_TRACE** and **END_TRACE** are the strings used in trace printouts to indicate the beginning and end of execution of a message or a message-handler.

OTHER NOTES: Implemented as preprocessor constants.

NextInCore

PURPOSE: A handler link to the next applicable message-handler after the currently executing handler.

PERFORM

PURPOSE: Unused preprocessor constant which will be removed in the next release.

PREVIEW

PURPOSE: Unused preprocessor constant which will be removed in the next release.

TopOfCore

PURPOSE: A handler link to the applicable message-handler with the highest precedence. The list is in order according to message-handler precedence.

GLOBAL FUNCTIONS

CallNextHandler

PURPOSE: Executes message-handlers shadowed by the currently executing handler. This function can only be called from the actions of the currently executing message-handler.

ARGUMENTS: A pointer to a data object to store the return value of the shadowed handlers.

OTHER NOTES: Implementation of the CLIPS functions **call-next-handler** and **override-next-handler**.

Following is a summary of **CallNextHandler**:

1. Immediately return with an error in all but the following scenarios:
1a) The currently executing handler (**CurrentCore**) is of type **around**, and there is at least one shadowed handler available, or
1b) The currently executing handler is of type **primary**, and the next available handler (**NextInCore**) is also of type **primary**.

2. If **override-next-handler** has been called, save the old message parameter array, and create a new one based on the function arguments.
3. Save the state of the bind list and then destroy it.
4. Save the values of **CurrentCore** and **NextInCore** and then advance them ahead one in the list of applicable handlers.
5. If the currently executing handler is of type **primary**, go to step 7.
6. If the next available handler is of type **around**, call **EvaluateExpression** for the actions of that handler and capture the result. Otherwise, call **CallHandlers** for the remaining core of handlers and capture the result. Go to step 8.
7. If the next available handler is not a slot-accessor, call **EvaluateExpression** for the actions of that handler and capture the result. Otherwise, call **PerformImplicitHandler** to execute the slot-accessor and capture the result.
8. Restore the previous bind list, the values of **CurrentCore** and **NextInCore** and the message parameter array (if necessary).
9. Clear **ReturnFlag**.

CheckCurrentMessage

PURPOSE: Insures that a message is currently executing for functions which operate on the active instance.

ARGUMENTS: 1) Name of the calling function.
2) An integer flag indicating if the function can operate on primitive type objects (0) or only instances of user-defined classes (1).

RETURNS: A non-zero integer if the active instance is valid, zero otherwise.

DeallocateMarkedHandlers

PURPOSE: Support routine for **ClearDefclasses** and **AddClass** in the Class Functions Module as well as **DeleteDefmessageHandler** in the Message Commands Module and **DeleteHandler** which removes marked handlers from a class's handler array.

ARGUMENTS: A pointer to the class.

OTHER NOTES: The "mark" fields of the handlers are assumed to have been set by the calling function.

A symbolic hash value sorted map of handlers is also kept with the class (see the general notes in the Class Commands Module). In order to update this map after the deletion of handlers, the "busy" field of a handler is temporarily used to count how many handlers before it in the array will be deleted. That handlers position in the map is then adjusted accordingly.

DeleteHandler

PURPOSE: Support routine for **WildDeleteHandler** which removes one or more handlers from a class.

ARGUMENTS: 1) A pointer to the class.
2) The symbolic name of the handler. If the name is "*", and there is no handler named "*" in the class, then all handlers matching the type will be deleted.
3) An integer code representing the type of the handler (see **Message-Handler Type Codes**). If the type is -1, then all message-handlers matching the name will be deleted.
4) An integer flag indicating whether to print error messages when matching handlers cannot be found (1) or not (0).

RETURNS: A non-zero integer if the handlers are successfully deleted, zero otherwise.

DestroyHandlerLinks

PURPOSE: Support routine for **PreviewMessage** in the Message Commands Module and **PerformMessage** which deallocates the temporary links between a core of handlers applicable to a message.

ARGUMENTS: A pointer to the top of the temporary handler links.

OTHER NOTES: The "busy" counts of the handlers and their classes, which were incremented by **FindApplicableHandlers**, are decremented.

DirectMessage

PURPOSE: Support routine for functions in the Instance Commands and Functions Modules which sends a message to an object, e.g. the **init** message in a **make-instance** call.

ARGUMENTS:
1) The first part of the message name in the form of a string (can be NULL).
2) The second part of the message name in the form of a symbol.
3) A pointer to an instance.
4) A data object buffer for storing the result of the message (can be NULL if irrelevant).
5) A series of expressions representing the message arguments.

OTHER NOTES: The message name is broken into two arguments so that slot-accessor messages can easily be formed from slot names. However, the slot-accessor symbol names are stored with the slot, so the symbol could be passed directly rather than requiring that this routine construct them. This routine will be enhanced in the next release.

DispatchMessage

PURPOSE: This routine is called by **EvaluateExpression** in the Evaluation Module to process a message. The message name, object and arguments are supplied by CLIPS. The message dispatch is described in detail in the *Basic Programming Guide*.

ARGUMENTS: A data object buffer to hold the result of the message.

OTHER NOTES: Implementation of the CLIPS function **send**.

This function determines the symbolic name of the message from the CLIPS arguments and prepends the message object expression to the other message arguments. The bulk of the message dispatch is done by the routines **PerformMessage**, **CallHandlers** and **CallNextHandler**.

DisplayCore

PURPOSE: Support routine for **PreviewMessage** in the Message Commands Module which recursively displays the set of applicable handlers for a particular message.

ARGUMENTS: 1) A list handler links to applicable handlers.
2) The level of indentation indicating the depth of handler shadowing.

Embedded Access for Defmessage-Handlers

PURPOSE: The function **CLIPSSendMessage** is provided for embedded access and is documented in the *Advanced Programming Guide*.

OTHER NOTES: There are additional embedded access functions for message-handlers in the Message-Handler Commands Module.

FindHandler

PURPOSE: Support routine for **ParseDefmessageHandler** and others in the Message Commands Module and **DeleteHandler** which looks up a message-handler.

ARGUMENTS: 1) A pointer to a class.
2) The symbolic name of the handler.
3) An integer code representing the type of the handler (see **Message-Handler Type Codes**).
4) An integer code indicating for the return value to be a handler address or an index into the class's handler array (see **Message-Handler Lookup Codes**).

RETURNS: If a handler address was requested, a generic pointer is returned which is the handler address, or NULL if not found. Otherwise, an integer typecast into a generic pointer is returned which is the index of the handler in the class's handler array, or -1 if not found.

FindHandlerNameGroup

PURPOSE: Support routine for **ListDefmessageHandlers** in the Message Commands Module, **FindHandler** and **FindApplicableOfName** which performs a binary search on the symbolic hash value of the handler name to find a group of handlers which names all have the same hash value as the given name.

ARGUMENTS: 1) A pointer to a class.
2) The symbolic name of a handler.

RETURNS: An index into the sorted hash value map of the class's handler array where handlers which names have the same hash value as the given name begin, -1 if there are none. The actual given name must be present in the group (e.g. they could all be handlers which names just happened to have the same hash value as the given name), or the return value will still be -1.

FindPreviewApplicableHandlers

PURPOSE: Support routine for **PreviewMessage** in the Message Commands Module which generates a ranked list of applicable message-handlers for a message.

ARGUMENTS: 1) A pointer to a class.
2) The symbolic name of the message.

RETURNS: The top of a list of temporary handler links forming the core of applicable handlers.

OTHER NOTES: This function differs from **FindApplicableHandlers** in that it uses **FindClassSlot** to find slot-accessor handlers rather than **FindInstanceSlot**.

HandlerDeleteError

PURPOSE: Support routine for **ClearDefclasses** in the Class Functions Module, **DeleteDefmessageHandler** in the Message Commands Module and **DeleteHandler** which prints out an error message when a message-handler cannot be deleted from a class.

ARGUMENTS: The name of the class.

HandlersExecuting

PURPOSE: Support routine for message-handler parsing and deletion routines which determines if any handlers attached to a class are currently executing..

ARGUMENTS: A pointer to the class.

RETURNS: A non-zero integer if any of the handlers of the class are executing, zero otherwise.

HandlerType

PURPOSE: Support routine for message-handler parsing and access routines which determines the integer code for a handler type given the string representation (see **Message-Handler Type Codes**).

ARGUMENTS: 1) The name of the calling function.
2) The string representation of the handler type, e.g. "primary"

RETURNS: The handler type code.

NewHandler

PURPOSE: This function is not used in CLIPS 5.1 and will be deleted in the next release.

NextHandlerAvailable

PURPOSE: Determines if a shadowed message-handler is available for execution by **call-next-handler** or **override-next-handler**. See the description of **CallNextHandler** for details.

RETURNS: A non-zero integer if a shadowed handler is available, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **next-handlerp**.

PrintAbbreviatedHandlerRemoval

PURPOSE: Support routine for **DeleteClass** in the Class Functions Module and **DeallocateMarkedHandlers** which a brief description of a message-handler being removed.

ARGUMENTS: A pointer to the handler.

PrintCurrentMessage

PURPOSE: Support routine for **HandlerGetBind** in the Message Commands Module which prints a synopsis of the currently executing message for unbound variable errors.

ARGUMENTS: Logical name of the output destination.

PrintHandler

PURPOSE: Support routine for **DisplayHandlersInLinks** in the Class Commands Module, **ListDefmessageHandlers** in the Message Commands Module, **PrintCurrentMessage**, **PrintPreviewHandler** and **TraceHandler** which displays a brief description of a message-handler.

ARGUMENTS:
1) Logical name of the output destination.
2) Name of the class.
3) Name of the handler.
4) Handler type string.

INTERNAL FUNCTIONS

CallHandlers

PURPOSE: Support routine for **PerformMessage** and **CallNextHandler** which executes all the **before**, **primary** and **after** message-handlers applicable to a message.

ARGUMENTS: A data object buffer to hold the result of executing the most specific **primary** handler.

OTHER NOTES: Following is a summary of **CallHandlers**:

1 Save the state of the bind list and then destroy it.
2. Save the values of **CurrentCore** and **NextInCore**.
3) Call **EvaluateExpression** for the actions of each **before** handler in order and advance **CurrentCore** and **NextInCore** appropriately.
4) Call **EvaluateExpression** for the actions of the first **primary** handler, capture the result and advance **CurrentCore** and **NextInCore** to skip over any other **primary** handlers. Other **primary** handlers are shadowed by the first, and **call-next-method** must be used within the body of the first **primary** handler to execute them.
5) Call **EvaluateExpression** for the actions of each **after** handler in order and advance **CurrentCore** and **NextInCore** appropriately.
6) Restore the bind list and the old values of **CurrentCore** and **NextInCore**.

The bind list is reset and **ReturnFlag** is cleared after the execution of each handler.

CheckHandlerArgCount

PURPOSE: Support routine for **PerformMessage**, **CallHandlers** and **CallNextHandler** which verifies that the current message parameter array satisfies the current handler's parameter count restriction.

RETURNS: A no-zero integer if the number of arguments is satisfactory, zero otherwise.

DisplayPrimaryCore

PURPOSE: Support routine for **DisplayCore** which recursively displays the set of applicable **primary** handlers for a particular message.

ARGUMENTS: 1) A list of handler links to applicable handlers.
2) The level of indentation indicating the depth of handler shadowing.

RETURNS: The handler link to the handler immediately following the **primary** handlers (if any).

EvaluateMessageParameters

PURPOSE: Support routine for **CallNextHandler** and **PerformMessage** which evaluates all the CLIPS supplied argument expressions for a message and stores the resulting values in the message parameter array (**CurrentMessageFrame**).

ARGUMENTS: 1) The list of parameter name expressions.
2) The number of parameters.

RETURNS: A pointer to an array of data objects containing the evaluations of the message argument expressions.

FindApplicableHandlers

PURPOSE: Support routine for **PerformMessage** which generates a ranked list of applicable handlers for a message.

ARGUMENTS: 1) A pointer to a class.
2) The symbolic name of the message.

RETURNS: The top of a list of temporary handler links forming the core of applicable handlers.

OTHER NOTES: The "related symbol" field of the message name is used to access the slot name symbol when checking if a slot-accessor handler is applicable to a message. A link in the core formed by this routine can point to an explicit defmessage-handler or an instance slot in the case of a slot-accessor.

A handler is applicable to a message if its name matches that of the message and it is attached to one of the classes of which the message object is an instance. All the applicable handlers are inserted into a "core" of applicable messages ordered in the following way:

1. All **around** handlers from the most specific class of the message object to the most general.
2. All **before** handlers from the most specific class of the message object to the most general.
3. All **primary** handlers from the most specific class of the message object to the most general.
4. All **after** handlers from the most general class of the message object to the most specific.

This ordering is accomplished by forming three queues for the **around**, **before** and **primary** handlers respectively and one stack for the **after** handlers. The class precedence list of the class of the message object is then examined in order from most specific to most general. The support routine **FindApplicableOfName** takes care of appending all applicable **around**, **before** and **primary** handlers from a class to the appropriate queues and pushing an applicable **after** handler onto the stack. When all classes have been processed, the support routine **JoinHandlerLinks** forms the core of applicable handlers by simply linking the three queues and one stack together.

The "busy" counts are incremented for each applicable handler and the class to which it belongs.

FindApplicableOfName

PURPOSE: Support routine for **FindPreviewApplicableHandlers** and **FindApplicableHandlers** which adds applicable handlers for a class to the handler type queues and stack.

ARGUMENTS: 1) A pointer to a class.
2) An array of pointers to the tops of the handler link type queues and stack.
3) An array of pointers to the bottoms of the handler link type

queues and stack.
4) The symbolic name of the message.

RETURNS: A no-zero integer if any applicable **primary** handlers were found for the class, zero otherwise.

JoinHandlerLinks

PURPOSE: Support routine for **FindPreviewApplicableHandlers** and **FindApplicableHandlers** which handler type queues and stack together to form the final ordered core of applicable message-handlers.

ARGUMENTS: 1) An array of pointers to the tops of the handler link type queues and stack.
2) An array of pointers to the bottoms of the handler link type queues and stack.
3) The symbolic name of the message.

RETURNS: The core list of applicable handlers, NULL on errors.

OTHER NOTES: If there are no applicable **primary** handlers, this routine deletes the queues and stack and issues an error message.

PerformImplicitHandler

PURPOSE: Support routine for **CallNextHandler** and **CallHandlers** which handles the execution of slot-accessor handlers (i.e. **get-** and **put-** messages).

ARGUMENTS: A data object buffer to hold the result of the slot access.

PerformMessage

PURPOSE: Support routine for **CLIPSSendMessage**, **DirectMessage** and **DispatchMessage** which is the main driver for a message dispatch.

ARGUMENTS: 1) A data object buffer to hold the result of the message.
2) A series of message argument expressions/
3) The symbolic name of the message.

OTHER NOTES: Following is a summary of **PerformMessage**:

1. Save previous values of globals, such as **CurrentMessageName** and **TopOfCore**, and set them for the new message.
2. Save the state of the bind list and then destroy it.
3. Save the states of the **return** and **break** contexts and set

them to FALSE.
4. Increment the evaluation depth (see the Evaluation Module).
5. Count and evaluate the arguments and store them in the message parameter array. The message object will always be the first element in the parameter array.
6. Increment the "busy" count of the message object if it is an instance of a user-defined class.
7. Call **FindApplicableHandlers** to determine the set of applicable handlers for the message.
8. If the first available handler is of type **around**, call **EvaluateExpression** for the actions of that handler and capture the result. Otherwise, call **CallHandlers** for the core of handlers and capture the result.
9. Deallocate the core of applicable handlers.
10. Restore all global values to their previous states.
11. Decrement the evaluation depth.
12. Clear **ReturnFlag**.
13. Adjust the evaluation depth of the return value (see **PropogateReturnValue** in the Evaluation Module).
14. Perform garbage collection.

PrintNoHandlerError

PURPOSE: Support routine for **CLIPSSendMessage** and **JoinHandlerLinks** which prints out an error message when no applicable **primary** handlers can be found for a message dispatch.

ARGUMENTS: The name of the message.

PrintPreviewHandler

PURPOSE: Support routine for **DisplayCore** and **DisplayPrimaryCore** which prints a synopsis of a handler.

ARGUMENTS:
1) A handler link in the list of applicable handlers.
2) The level of indentation indicating the depth of handler shadowing.
3) A string indicating the beginning or end of execution of a handler.

TraceHandler

PURPOSE: Used by the **watch** command to print out trace messages when a message-handler begins and ends execution.

ARGUMENTS:
1) The logical name of the output destination.
2) A handler link in the list of applicable handlers.

3) A string indicating the beginning or end of execution of a handler.

TraceMessage

PURPOSE: Used by the **watch** command to print out trace messages when a message begins and ends execution.

ARGUMENTS: 1) The logical name of the output destination.
2) A string indicating the beginning or end of execution of a message.

Instance-Set Queries Module

The Instance-Set Queries Module (insquery.c) provides the routines for a useful query system which can determine and perform actions on sets of instances of user-defined classes that satisfy user-defined criteria.

Instance-set member class restric

```
CLIPS>
(do-for-all-instances
  ((?car1 MASERATI BMW) (?car2 ROLLS-ROYCE))
  (> ?car1:price (* 1.5 ?car2:price))
  (printout t ?car1 crlf))
[Albert-Maserati]
CLIPS>
```

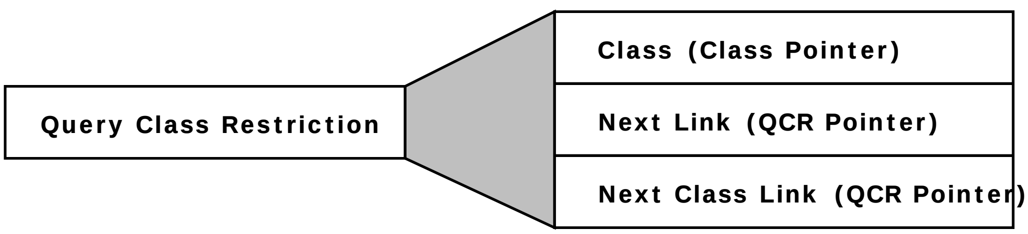
Instance-set templ

Instance-set que

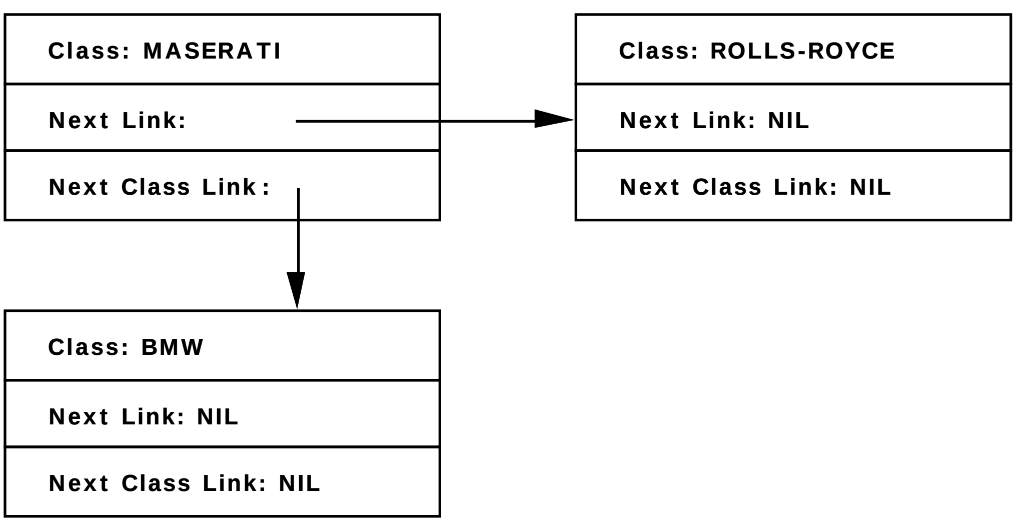
Instance-set distributed ac

Instance-set member varia

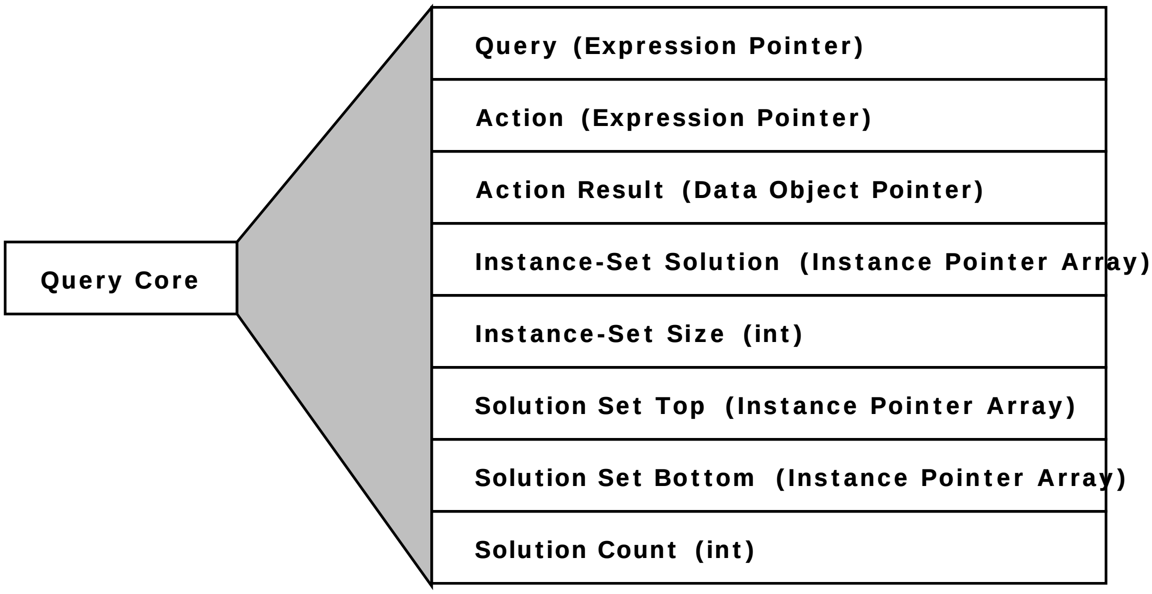
Above is an example excerpted from the *Basic Programming Guide* which shows a complete instance-set query function call. The instance-set template is internally represented by a series of data structures called **Query Class Restrictions**. The structure is summarized by following diagram:



The fields are: a pointer to a class, a pointer to the next class restriction list and a pointer to the next class in the current restriction list. Thus, for the example above, the instance-set template would look like:

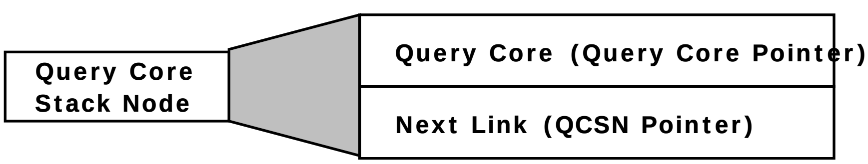


While an instance-set query function is executing, it uses a **Query Core** data structure to hold information about the query and instance-sets which satisfy the query. The data structure is summarized in the following diagram:



The fields are: the expression that must be satisfied for generated instance-sets, the action that will be performed for instance-sets which satisfy the query, a data object buffer to hold the results of evaluating the action, an intermediary array of instance pointers to hold the generated instance-sets, the number of instances in an instance-set, the top and bottom of a list of arrays of instance pointers to save instance-sets which satisfy the query and the number of instance-sets in the solution list. Actions are used only for: **do-for-instance**, **do-for-all-instances** and **delayed-do-for-all-instances**. The solution instance-sets need only be saved for **find-all-instances** and **delayed-do-for-all-instances**.

Instance-set query functions can be nested and can access variables outside their scope, including the member variables of other instance-set query functions in which they are nested. Thus, each executing instance-set query function must have its own unique query core. These cores are stored in a stack of **Query Stack Nodes**. The data structure is summarized in the following diagram:



The fields are: a pointer to a query core and a pointer to the next query stack node.

A detailed description of how instance-set query functions are parsed is given **ParseQueryAction**, **ParseQueryNoAction** and their associated functions. The mechanics of processing an instance-set query are given in **TestEntireChain**, **TestEntireClass**, **TestForFirstInChain**, **TestForFirstInChain**, **TestForFirstInstanceInClass** and their associated functions.

GLOBAL VARIABLES

BITS_PER_BYTE

PURPOSE: The number of bits in a byte. Used to determine the number of bytes necessary to store the traversal map for a class (see the general notes on the Class Commands Module).

OTHER NOTES: Implemented as a preprocessor constant in object.h.

QUERY_DELIMITER_STRING

PURPOSE: Lexeme for **QUERY_DELIMITER_SYMBOL**.

QUERY_DELIMITER_SYMBOL

PURPOSE: Symbol used to mark the ends of class restriction lists in the parsed form of an instance-set query function (see the functions **ParseQueryAction** and **ParseQueryNoAction**).

MAX_TRAVERSALS

PURPOSE: The maximum number of times a single class can be examined by simultaneous hierarchy traversals (see the general notes on the Class Commands Module and also see the descriptions of **CTID**, **GetTraversalID**, **SetTraversalID**, **TestTraversalID** and **ReleaseTraversalID**).

OTHER NOTES: Implemented as a preprocessor constant in object.h.

TRAVERSAL_BYTES

PURPOSE: The number of bytes necessary to store the traversal map for a single class (see the general notes on the Class Commands Module).

OTHER NOTES: Implemented as a preprocessor constant in object.h.

INTERNAL VARIABLES

AbortQuery

PURPOSE: An integer flag which is set when no instances are found for a particular instance-set template member which satisfy the query. When this flag is set, the instance-set query function being processed will be immediately terminated.

CTID

PURPOSE: The next available integer identifier for a class hierarchy traversal (see the general notes of the Class Commands Module). The bit corresponding to the value of this variable in the traversal map of a class will be set or cleared depending on whether the class has been examined on that traversal or not. **CTID** cannot equal or exceed the value of **MAX_TRAVERSALS** since this is the maximum number of bits in any class traversal map.

INSTANCE_SLOT_REF

PURPOSE: The string used to attach a direct slot reference to an instance-set member.

OTHER NOTES: Implemented as a preprocessor constant.

QueryCore

PURPOSE: A general state variable storing the test expression, distributed action expressions and the solution sets of instance addresses for the currently executing instance-set query function (see the general notes).

QueryCoreStack

PURPOSE: A pointer to a stack of instance-set query function "cores" (see **QueryCore**). The order of the stack indicates a nesting of instance-set query functions with the topmost core corresponding to the currently executing query (see the general notes).

GLOBAL FUNCTIONS

AnyInstances

PURPOSE: Determines if any instance-sets satisfy a query.

RETURNS: A non-zero integer if there were any instance-sets which satisfied the query, zero otherwise.

OTHER NOTES: Implementation of the CLIPS function **any-instancep**.

Bit Access Functions

PURPOSE: **testbit**, **setbit** and **clearbit** are used in parsing defclasses to check for qualifier duplication as well as in marking class hierarchy traversals (see the general notes on the Class Commands Module).

OTHER NOTES: Implemented as a preprocessor macros in object.h.

DelayedQueryDoForAllInstances

PURPOSE: Performs an action for each instance-set which satisfies a query after determining all such sets.

ARGUMENTS: A data object buffer to hold the result of evaluating the action on the last instance-set which satisfied the query.

OTHER NOTES: Implementation of the CLIPS function **delayed-do-for-all-instances**.

GetQueryInstance

PURPOSE: References to instance-set member variables within a query are replaced with calls to this function (see **ReplaceInstanceVariables**). The first CLIPS supplied argument is the nesting depth of the applicable query function and is used to find the appropriate query core The second argument is a positional index into the query core's solution array and is used to find the appropriate instance in an instance-set satisfying a query.

ARGUMENTS: A data object buffer to hold the name of the instance to which the instance-set member variable refers.

OTHER NOTES: Implementation of the internal CLIPS function **(query-instance)**.

GetQueryInstanceSlot

PURPOSE: Direct slot references of instance-set member variables within a query are replaced with calls to this function (see **ReplaceSlotReference**). The first CLIPS supplied argument is the nesting depth of the applicable query function and is used to find the appropriate query core The second argument is a positional index into the query core's solution array and is used to find the appropriate instance in an instance-set satisfying a query. The third argument is the symbolic name expression of the slot.

ARGUMENTS: A data object buffer to hold the value of the direct slot reference of the instance-set member variable.

OTHER NOTES: Implementation of the internal CLIPS function **(query-instance-slot)**.

GetTraversalID

PURPOSE: Gets a new unused integer id for a class hierarchy traversal. The bit corresponding to the new id is cleared in all the existing class traversal maps (see the general notes in the Class Commands Module).

RETURNS: An integer indicating the new class hierarchy traversal id.

OTHER NOTES: The global variable **CTID** is used for the new id. An error will be generated if **CTID** already equals or exceeds **MAX_TRAVERSALS**, for this means that all the bits in class traversal maps are in use. Uses the **clearbit** function.

QueryDoForAllInstances

PURPOSE: Performs an action for each instance-set which satisfies a query as each set is determined.

ARGUMENTS: A data object buffer to hold the result of evaluating the action on the last instance-set which satisfied the query.

OTHER NOTES: Implementation of the CLIPS function **do-for-all-instances**.

QueryDoForInstance

PURPOSE: Performs an action for the first instance-set which satisfies a query.

ARGUMENTS: A data object buffer to hold the result of evaluating the action for the instance-set which satisfied the query.

OTHER NOTES: Implementation of the CLIPS function **do-for-instance**.

QueryFindAllInstances

PURPOSE: Groups all instance-sets which satisfy a query into a multifield variable.

ARGUMENTS: A data object buffer to hold the multifield result.

OTHER NOTES: Implementation of the CLIPS function **find-all-instances**.

QueryFindInstance

PURPOSE:	Groups the first instance-set which satisfies a query into a multifield variable.
ARGUMENTS:	A data object buffer to hold the multifield result.
OTHER NOTES:	Implementation of the CLIPS function **find-instance**.

ReleaseTraversalID

PURPOSE:	The last allocated class hierarchy traversal id is released for later reuse.
OTHER NOTES:	the internal integer variable **CTID** is merely decremented.

SetTraversalID

PURPOSE:	This function is used when recursively examining classes to mark which ones have already been visited. This is to avoid examining any classes more than once due to multiple inheritance.
ARGUMENTS:	1) A class's hierarchy traversal map. 2) The traversal id to mark as used.
OTHER NOTES:	Implemented as a preprocessor macro in insquery.h. The bit corresponding to the id is set in the class's traversal map. Uses the **setbit** function.

SetupQuery

PURPOSE:	Support routine for **SetupObjectSystem** in the Class Commands Module which defines all functions and commands for instance-set queries.
OTHER NOTES:	Initialization differs between standard and run-time configurations.

TestTraversalID

PURPOSE:	This function is used when recursively examining classes to test if a particular class has already been visited. This is to avoid examining any classes more than once due to multiple inheritance.
ARGUMENTS:	1) A class's hierarchy traversal map. 2) The traversal id test.

OTHER NOTES: Implemented as a preprocessor macro in insquery.h. Uses the **testbit** function.

INTERNAL FUNCTIONS

AddSolution

PURPOSE: Support routine for **TestEntireClass** which takes the most recently found instance-set which satisfies the query (given by the "solutions" field of the query core) and adds it to a list of instance-sets which have all satisfied the query.

OTHER NOTES: This function is only called by **TestEntireClass** for query functions which require all the solutions to be grouped: **QueryFindAllInstances** and **DelayedQueryDoForAllInstances**.

The set of solutions is stored as a list of arrays of instance addresses. Each array in the list is an instance-set which satisfies the query, and each element in the array is the address of an instance that positionally matches the respective instance-set member variable. However, each array holds one extra element to be used as a pointer to the next instance-set.

DeleteQueryClasses

PURPOSE: Support routine for all the query functions which deallocates the list of lists of classes which form an instance-set template.

ARGUMENTS: A pointer to an instance-set template.

OTHER NOTES: The "busy" counts for the classes in the restriction lists are decremented.

DetermineQueryClasses

PURPOSE: Support routine for all the query functions which creates a series of query restriction classes to form an instance-set template.

ARGUMENTS: 1) A series of expressions representing the class restrictions for the instance-set members. Each class restriction list is separated by the special symbol expression **QUERY_DELIMITER_SYMBOL**.
2) The name of the calling function.
3) An integer buffer for the number of instance-set member

variables (each member of the set can have multiple class restrictions).

RETURNS: A pointer to the first instance-set template node, or NULL on errors.

FindQueryCore

PURPOSE: Support routine for **GetQueryInstance** and **GetQueryInstanceSlot** which finds a particular query core in the stack of cores for nested instance-set query functions.

ARGUMENTS: An integer indicating the number instance-set query functions which nest the core of the one of interest.

RETURNS: A pointer to the appropriate query core.

OTHER NOTES: A nesting depth of 0 gets the core directly from the **QueryCore** variable. Greater depths access the variable **QueryCoreStack** in a top-down fashion.

FormChain

PURPOSE: Support routine for **DetermineQueryClasses** which creates a new class pointer restriction node(s) to be added to a class restriction list in the instance-set template.

ARGUMENTS: 1) The name of the calling function.
2) A data object holding the symbolic name of a class or a multifield which fields are all symbolic names of classes.

RETURNS: A pointer to a instance-set template node, or NULL on errors.

OTHER NOTES: The "busy" counts for the class(es) in the restriction list is incremented.

IsQueryFunction

PURPOSE: Support routine for **ReplaceInstanceVariables** which determines if an action in an instance-set query function is a call to another nested instance-set query function. If it is, then all instance-set member variable references in the nested query function will reference a core with an index one greater than the one currently being parsed.

ARGUMENTS: A pointer to an action expression.

RETURNS: A non-zero integer if the expression is a call to one of the following functions: **AnyInstances**, **QueryFindInstance**, **QueryFindAllInstances**, **QueryDoForInstance**,

QueryDoForAllInstances or **DelayedQueryDoForAllInstances**. Otherwise, zero will be returned.

ParseQueryAction

PURPOSE: Parses **do-for-instance**, **do-for-all-instances** and **delayed-do-for-all-instances** function calls into a series of expressions that can later be evaluated by **EvaluateExpression**.

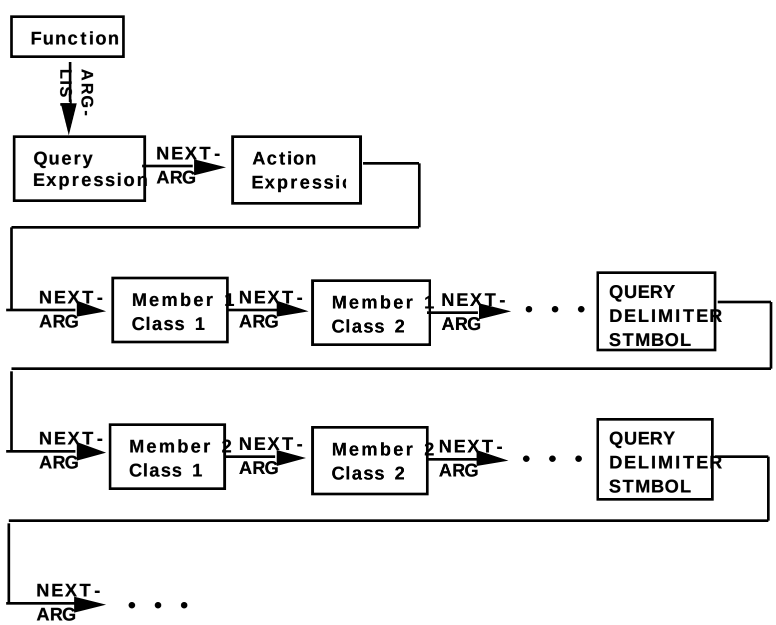
ARGUMENTS: 1) An expression node containing the function call.
2) The logical name of the input source.

RETURNS: The top of series of expressions representing the function call, or NULL on errors.

OTHER NOTES: This special function parser is required because these functions do not follow the standard format of CLIPS functions, e.g. instance-set template member variable's class restrictions would like function calls to the standard CLIPS function parser.

(<function> (<instance-set member>+)
<query> <action>)
<instance-set member> ::= (<variable> <class>+)

is parsed to the following:



ParseQueryActionExpression

PURPOSE: Support routine for **ParseQueryAction** which parses the distributed action for an instance-set query function.

ARGUMENTS: 1) A series of expressions that represent the parsed form of the instance-set query function so far.
2) The logical name of the input source.
3) A series of expressions (generated by **ParseQueryRestrictions**) listing the names of the instance-set member variables.

RETURNS: A non-zero integer if the action was parsed successfully, zero otherwise.

OTHER NOTES: A check is made to insure that no attempts are made in the action to rebind any instance-set member variables.

ParseQueryNoAction

PURPOSE: Parses **any-instancep**, **find-instance**and **find-all-instances** function calls into a series of expressions that can later be evaluated by **EvaluateExpression**.

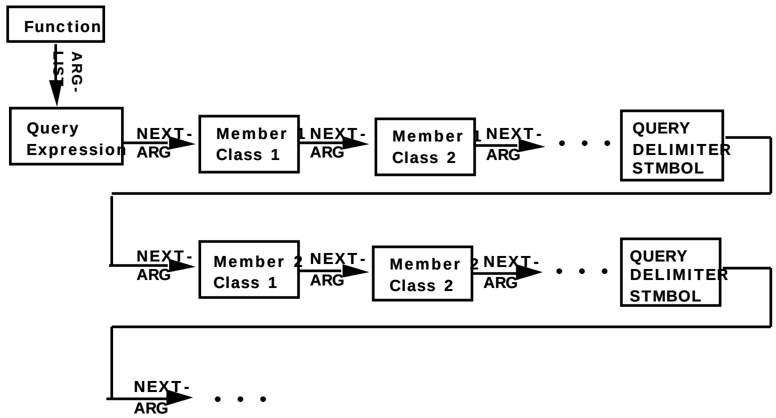
ARGUMENTS: 1) An expression node containing the function call.
2) The logical name of the input source.

RETURNS: The top of series of expressions representing the function call, or NULL on errors.

OTHER NOTES: This special function parser is required because these functions do not follow the standard format of CLIPS functions, e.g. instance-set template member variable's class restrictions would like function calls to the standard CLIPS function parser.

(<function> (<instance-set member>+)
<query>)
<instance-set member> ::= (<variable> <class>+)

is parsed to the following:



ParseQueryRestrictions

PURPOSE: Support routine for **ParseQueryAction** and **ParseQueryNoAction** which instance-set template for a query function, i.e instance-set member variables and their class restrictions.

ARGUMENTS: 1) A series of expressions that represent the parsed form of the instance-set query function so far.
2) The logical name of the input source.
3) A buffer to use for scanned tokens.

RETURNS: A series of expressions listing the names of the instance-set member variables.

OTHER NOTES: A check is made to insure there are no duplicate instance-set member variables.

In addition to generating the list for the return value, the class restriction lists are attached to the main expression (argument #1) as described in **ParseQueryAction** and **ParseQueryNoAction**.

ParseQueryTestExpression

PURPOSE: Support routine for **ParseQueryAction** and **ParseQueryNoAction** which parses the test expression for an instance-set query function.

ARGUMENTS: 1) A series of expressions that represent the parsed form of the instance-set query function so far.
2) The logical name of the input source.

RETURNS: A non-zero integer if the test expression was parsed successfully, zero otherwise.

OTHER NOTES: A check is made to insure that no binds occur in the test.

PopQueryCore

PURPOSE: Support routine for all the instance-set query functions which pops the first core of the query core stack (**QueryCoreStack**) and assigns it to the current query core (**QueryCore**).

OTHER NOTES: This routine is called at the end of every instance-set query function.

PushQueryCore

PURPOSE: Support routine for all the instance-set query functions which pushes the current query core (**QueryCore**) onto the query core stack (**QueryCoreStack**).

OTHER NOTES: This routine is called at the beginning of every instance-set query function.

ReplaceInstanceVariables

PURPOSE: Support routine for **ParseQueryAction** and **ParseQueryNoAction** which recursively replaces instance-set member variable references in the test and action expressions of an instance-set query function with appropriate calls to the internal functions **GetQueryInstance** and **GetQueryInstanceSlot**.

ARGUMENTS: 1) A series of expressions (generated by **ParseQueryRestrictions**) listing the names of the instance-set member variables.
2) The test or action expression in which to replace variable references.
3) An integer flag indicating whether to accept direct slot references (1) or not (0).
4) The number of instance-set query functions which nest the one currently being parsed.

OTHER NOTES: If a recursive call is made on an expression which is another instance-set query function call, that recursive call will be passed argument #4 plus one. This recursive "counting" mechanism will correspond one-to-one with the **PushQueryCore** and **PopQueryCore** calls when the instance-set query function is actually executed. This is why argument #4 is a valid index for which query core to select at run-time from the stack.

ReplaceSlotReference

PURPOSE: Support routine for **ReplaceInstanceVariables** which replaces direct slot references with calls to the internal function **GetQueryInstanceSlot**.

ARGUMENTS: 1) A series of expressions (generated by **ParseQueryRestrictions**) listing the names of the instance-set member variables.
2) The test or action expression in which to replace variable references.
3) The address of the CLIPS function **(query-instance-slot)**.
4) The number of instance-set query functions which nest the one currently being parsed.

TestEntireChain

PURPOSE: Support routine for **QueryFindAllInstances**, **QueryDoForAllInstances** and **DelayedQueryDoForAllInstances** which examines all the instances of classes (and their subclasses) in a class restriction list of a particular member variable in the instance-set template.

ARGUMENTS: 1) A pointer into the instance-set template indicating the class restriction list for the instance-set member variable being tested. The "next" link of the top node points to the top node of the next member variable's class restriction list, and the "chain" links form the class restriction list for this member variable.
2) The relative integer index of the instance-set member variable being tested.

OTHER NOTES: This function is mutually recursive with **TestEntireClass**.

The following is a synopsis of **TestEntireChain**:

1. Set the **AbortQuery** flag

2. For all classes in the class restriction list do:
2a. Clear the **AbortQuery** flag.
2b. Get a unique class traversal id.
2c. Call **TestEntireClass** for the class.
2d. Release the traversal id.

2e. Abort if this member variable or any after it did not have any instances which satisfied the query.

TestEntireClass

PURPOSE: Support routine for **TestEntireChain** which examines all the instances of a class and its subclasses.

ARGUMENTS: 1) A class hierarchy traversal id to use when recursively examining subclasses.
2) A pointer to the class.
3) A pointer into the instance-set template indicating the class restriction list for the instance-set member variable being tested.
4) The relative integer index of the instance-set member variable being tested.

OTHER NOTES: This function is self-recursive and mutually recursive with **TestEntireChain.** The self-recursion is to test subclasses. **TestEntireClass** calls **TestEntireChain** until it reaches the last class restriction list. In this manner, all permutations are examined, varying the the instances matching the last member variable first (as described in the *Basic Programming Guide*).

The following is a synopsis of **TestEntireClass**:

1. If this class has already been examined for this traversal id, immediately return. Otherwise, set the traversal id bit for this class.

2. Save and set the **MaintainGarbageInstances** flag (see the Instance Functions Module) to insure that instance links can be followed even in the event an instance is deleted as the result of an instance-set query or action.

3. For every instance of this class do:
3a. Place this instance in the appropriate position in the solution corresponding to the instance-set member variable being tested.
3b. If there are no instance-set member variables remaining to be tested on this pass through the template, go to 3d. Otherwise, call **TestEntireChain** for the class restriction list of the next instance-set member variable. Go to the beginning of 3.
3d. A complete instance-set has been generated. Evaluate the query expression. If it is satisfied, either evaluate the query action or add the instance-set to the list of solutions (see **AddSolution**), depending on which instance-set

query function is being executed.

4. Restore the **MaintainGarbageInstances** flag.

5. Call **TestEntireClass** for every subclass of the current class.

TestForFirstInChain

PURPOSE: Support routine for **AnyInstances**, **QueryFindInstance** and **QueryDoForInstance** which examines all the instances of classes (and their subclasses) in a class restriction list of a particular member variable in the instance-set template.

ARGUMENTS: 1) A pointer into the instance-set template indicating the class restriction list for the instance-set member variable being tested. The "next" link of the top node points to the top node of the next member variable's class restriction list, and the "chain" links form the class restriction list for this member variable.
2) The relative integer index of the instance-set member variable being tested.

RETURNS: A non-zero integer if an instance was found for the instance-set member variable which was part of an instance-set which satisfied the query.

OTHER NOTES: This function is mutually recursive with the **TestForFirstInstanceInClass**.

The following is a synopsis of **TestForFirstInChain**:

1. Set the **AbortQuery** flag

2. For all classes in the class restriction list do:
2a. Clear the **AbortQuery** flag.
2b. Get a unique class traversal id.
2c. Call **TestForFirstInstanceInClass**, and, if it indicates success, release the traversal id and return success.
2d. Release the traversal id.
2e. Return failure if this member variable or any after it did not have any instances which satisfied the query.

3. Return failure.

TestForFirstInstanceInClass

PURPOSE: Support routine for **TestForFirstInChain** which examines all the instances of a class and its subclasses.

ARGUMENTS:
1) A class hierarchy traversal id to use when recursively examining subclasses.
2) A pointer to the class.
3) A pointer into the instance-set template indicating the class restriction list for the instance-set member variable being tested.
4) The relative integer index of the instance-set member variable being tested.

RETURNS: A non-zero integer if an instance of the class was part of an instance-set which satisfied the query.

OTHER NOTES: This function is self-recursive and mutually recursive with **TestForFirstInChain.** The self-recursion is to test subclasses. **TestForFirstInstanceInClass** calls **TestForFirstInChain** until it reaches the last class restriction list. In this manner, all permutations are examined, varying the the instances matching the last member variable first (as described in the *Basic Programming Guide*).

The following is a synopsis of **TestForFirstInClass**:

1. If this class has already been examined for this traversal id, immediately return. Otherwise, set the traversal id bit for this class.

2. Save and set the **MaintainGarbageInstances** flag (see the Instance Functions Module) to insure that instance links can be followed even in the event an instance is deleted as the result of an instance-set query or action.

3. For every instance of this class do:
3a. Place this instance in the appropriate position in the solution corresponding to the instance-set member variable being tested.
3b. If there are no instance-set member variables remaining to be tested on this pass through the template, go to 3d. Otherwise, call **TestForFirstInChain** for the class restriction list of the next instance-set member variable, and, if success is returned, go to 4. Go to the beginning of 3.
3d. A complete instance-set has been generated. Evaluate the query expression. If it is satisfied, either evaluate the query action or do nothing, depending on which instance-set query function is being executed.

4. Restore the **MaintainGarbageInstances** flag.

5. Return success if an instance-set which satisfied the query was successfully completed within the step 3 loop.

6. Call **TestForFirstInClass** for every subclass of the current class and return success immediately if any return success.

7. Return failure.

Definstances Module

The Definstances Module (defins.c) provides the capability needed to implement the definstances construct. For a description of the definstances construct, see the *Basic Programming Guide*. The definstances construct capability, along with the other features of the CLIPS Object-Oriented Language (COOL), can be removed by using the appropriate compile flag in the setup header file. The definstances data structure is summarized in the following diagram:

Name (Symbol Pointer)
Busy Count (int)
Make-Instance Call (Expression Pointer)
Binary Load/Save Index (long int)
Pretty-Print Form (array of char)
Previous Link (Definstances Pointer)
Next Link (Definstances Pointer)

The internal data structure of a definstances consists of a symbolic name and a series of expressions forming a call to **make-instance**. A non-zero busy count for a definstances indicates that instances in that definstances are currently being created, and it is not safe to delete the definstances. Other fields in the structure include: the pretty-print form, an index for use in binary load/save and the construct compiler and pointers for double links to other definstances.

GLOBAL VARIABLES

DefinstancesList

PURPOSE: A pointer to the first node in the list of all currently defined definstances.

INTERNAL VARIABLES

DefinstancesListBottom

PURPOSE: A pointer to the first node in the list of all currently defined definstances.

GLOBAL FUNCTIONS

ClearDefinstances

PURPOSE: Used by the **clear** command to remove all currently defined definstances.

RETURNS: The integer zero if not all definstances were successfully cleared, non-zero otherwise.

CmdListDefinstances

PURPOSE: Lists all the currently defined definstances.

OTHER NOTES: Implementation of the CLIPS function **list-definstances**.

CmdUndefinstances

PURPOSE: Removes a definstances.

OTHER NOTES: Implementation of the CLIPS function **undefinstances**.

Embedded Access for Definstances

PURPOSE: The following functions are provided for embedded access and are documented in the *Advanced Programming Guide*: **DeleteDefinstances**, **FindDefinstances**, **GetDefinstancesName**, **GetDefinstancesPPForm**, **GetNextDefinstances**, **IsDefinstancesDeletable** and **ListDefinstances**.

PPDefinstances

PURPOSE: Displays the pretty-print form of the definstances specified by the CLIPS supplied argument.

OTHER NOTES: Implementation of the CLIPS function **ppdefinstances**.

SetDefinstancesList

PURPOSE: Initializes the global variables **DefinstancesList** and **DefinstancesListBottom** to point to the top and bottom respectively of the given list of definstances.

ARGUMENTS: A pointer to the top of a list of definstances.

OTHER NOTES: This function is used only in a run-time version of CLIPS.

SetupDefinstances

PURPOSE: Support routine for **SetupObjectSystem** in the Class Commands Module which defines all functions and commands for the definstances construct. Sets up all necessary **load**, **clear**, **save** and **reset** interfaces.

OTHER NOTES: Initialization differs between standard and run-time configurations.

INTERNAL FUNCTIONS

FindDefinstancesBySymbol

PURPOSE: Determines the address of a specified definstances.

ARGUMENTS: A pointer to a symbol.

RETURNS: A pointer to a definstances.

InitializeDefinstances

PURPOSE: Used by the **reset** command to delete all existing instances of user-defined classes (via **delete** messages) and create the ones in definstances (via **make-instance** calls).

ParseDefinstances

PURPOSE: Used by the **load** command to parse a definstances.

ARGUMENTS: The logical name of the input source.

RETURNS: The integer zero if there are no parsing errors, non-zero otherwise.

ParseDefinstancesName

PURPOSE: Support routine for **ParseDefinstances** which parses the definstances name and an optional comment.

ARGUMENTS: The logical name of the input source.

RETURNS: The symbolic name of the definstances, NULL on errors.

RemoveDefinstances

PURPOSE: Removes a definstances.

ARGUMENTS: A pointer to a definstances.

RETURNS: A no-zero integer if the definstances was successfully deleted, zero otherwise.

SaveDefinstances

PURPOSE: Used by the **save** command to write out the pretty-print forms of all the currently defined definstances.

ARGUMENTS: The logical name of the output destination.

Object Construct Compiler Interface Module

The Object Construct Compiler Interface (objcmp.c) Module provides the interface for COOL to the **constructs-to-c** command.

Object Binary Load/Save Interface Module

The Object Binary Load/Save Interface (objbin.c) Module provides the interface for COOL to the **bload**/**bsave** commands.

Main Module

The Main Module (main.c) contains the only functions which should have to be modified to add extensions or embed CLIPS under normal circumstances.

GLOBAL VARIABLES

None.

LOCAL VARIABLES

None.

GLOBAL FUNCTIONS

main

PURPOSE:	Startup function for CLIPS. Under normal operation, this function initializes CLIPS, checks for command line arguments, then calls the **CommandLoop** function. See the *Advanced Programming Guide* for details on embedding CLIPS.

UserFunctions

PURPOSE:	Called during CLIPS initialization. Allows users to insert their own function definition calls. See the *Advanced Programming Guide* for details on integrating CLIPS.

INTERNAL FUNCTIONS

None.

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