LECTURE 3: DEDUCTIVE REASONING AGENTS

An Introduction to MultiAgent Systems
http://www.csc.liv.ac.uk/~mjw/pubs/imas

Topics

- Agent Architectures
- Logically Reasoning Agents
- Agent Programming Languages
  - Agent0 and PLACA
  - Concurrent MetateM

Agent Architectures

- An *agent* is a computer system capable of *flexible autonomous action*…

- Types of agent *architecture*:
  - Symbolic Reasoning
    - Deductive Reasoning
    - Practical Reasoning
  - Reactive
  - Hybrid

Agent Architectures

- We want to build agents, that enjoy the properties of autonomy, reactiveness, pro-activeness, and social ability that we talked about earlier
- This is the area of *agent architectures*
- Maes defines an agent architecture as:

  '[A] particular methodology for building [agents]. It specifies how… the agent can be decomposed into the construction of a set of component modules and how these modules should be made to interact. The total set of modules and their interactions has to provide an answer to the question of how the sensor data and the current internal state of the agent determine the actions… and future internal state of the agent. An architecture encompasses techniques and algorithms that support this methodology.'

Agent Architectures

- Originally (1956-1985), pretty much all agents designed within AI were *symbolic reasoning* agents
- Its purest expression proposes that agents use *explicit logical reasoning* in order to decide what to do
- Problems with symbolic reasoning led to a reaction against this — the so-called *reactive agents* movement, 1985–present
- From 1990-present, a number of alternatives proposed: *hybrid* architectures, which attempt to combine the best of reasoning and reactive architectures

Symbolic Reasoning Agents

- The classical approach to building agents is to view them as a particular type of knowledge-based system, and bring all the associated methodologies of such systems to bear
- This paradigm is known as *symbolic AI*
- We define a deliberative agent or agent architecture to be one that:
  - contains an explicitly represented, symbolic model of the world
  - makes decisions (for example about what actions to perform) via symbolic reasoning

Symbolic Reasoning Agents

- If we aim to build an agent in this way, there are two key problems to be solved:

☞*The transduction problem*:
that of translating the real world into an accurate, adequate symbolic description, in time for that description to be useful…vision, speech understanding

☞*The reasoning problem*:
that of how to get agents to reason with this information in time for the results to be useful… automated reasoning, automatic planning

Symbolic Reasoning Agents

- Most researchers accept that neither problem is anywhere near solved
- Underlying problem lies with the complexity of symbol manipulation algorithms in general: many (most) search-based symbol manipulation algorithms of interest are *highly intractable*
- Because of these problems, some researchers have looked to alternative techniques for building agents; we look at these later

Deductive Reasoning Agents

- Basic idea is to use logic to encode a theory stating the *best* action to perform in any given situation
- The theory defines what it means for the behavior of an agent to be “rational”.
- The theory also expresses behavioral constraints that should be observed by “rational agents”.
- The agent then uses theorem proving to decide what to do.

Deductive Reasoning Agents

/* *try to find an action explicitly prescribed* */
for each $a \in Ac$ do
    if $\Delta \vdash_\rho Do(a)$ then
        return a
    end-if
end-for
/* *try to find an action not excluded* */
for each $a \in Ac$ do
    if $\Delta \nvdash_\rho \neg Do(a)$ then
        return a
    end-if
end-for
return *null* /* *no action found* */

Deductive Reasoning Agents

- Let:
  - ρ be this theory (typically a set of rules)
  - Δ be a logical database that describes the current state of the world
  - Ac be the set of actions the agent can perform
  - $\Delta \vdash_{\rho} \phi$ mean that ϕ can be proved from Δ using ρ

Agent Oriented Programming

- Much of the interest in agents from the AI community has arisen from Shoham's notion of *agent oriented programming* (AOP)
- AOP a 'new programming paradigm, based on a societal view of computation'
- The key idea that informs AOP is that of directly programming agents in terms of intentional notions like belief, commitment, and intention
- The motivation behind such a proposal is that, as we humans use the intentional stance as an *abstraction* mechanism for representing the properties of complex systems.
  In the same way that we use the intentional stance to describe humans, it might be useful to use the intentional stance to program machines.

AGENT0

- Shoham suggested that a complete AOP system will have 3 components:
  - a logic for specifying agents and describing their mental states
  - an interpreted programming language for programming agents
  - an 'agentification' process, for converting 'neutral applications' (e.g., databases) into agents
- Results only reported on first two components.
- Relationship between logic and programming language is *semantics*
- We will skip over the logic(!), and consider the first AOP language, AGENT0

AGENT0

- AGENT0 is implemented as an extension to LISP
- Each agent in AGENT0 has 4 components:
  - a set of capabilities (things the agent can do)
  - a set of initial beliefs
  - a set of initial commitments (things the agent will do)
  - a set of *commitment rules*
- The key component, which determines how the agent acts, is the commitment rule set

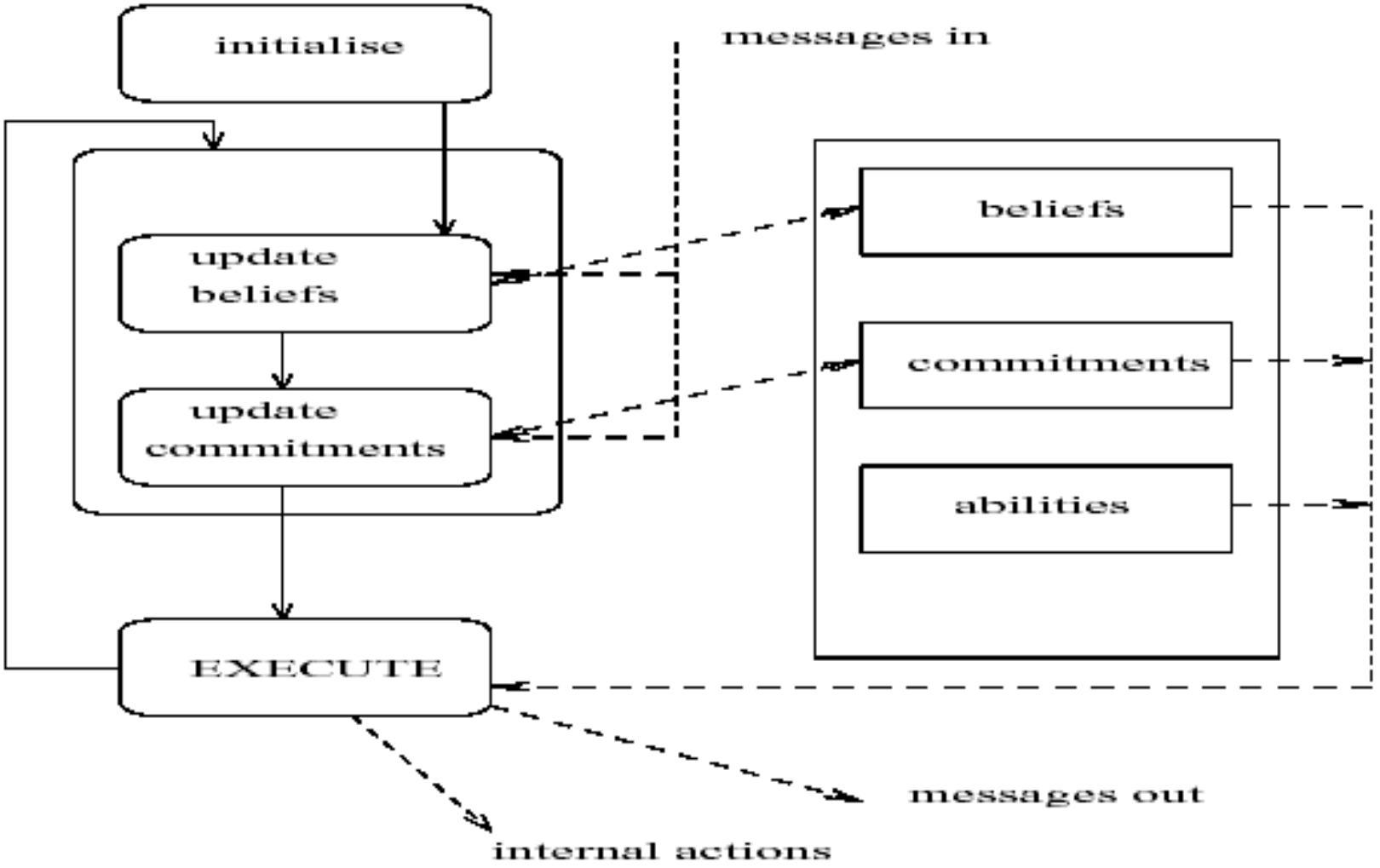
AGENT0

- Each commitment rule contains
  - a *message condition*
  - a *mental condition*
  - an action
- On each ‘agent cycle’…
  - The message condition is matched against the messages the agent has received
  - The mental condition is matched against the beliefs of the agent
  - If the rule fires, then the agent becomes committed to the action (the action gets added to the agent’s commitment set)

AGENT0

- Actions may be
  - *private*:
    an internally executed computation, or
  - *communicative*:
    sending messages
- Messages are constrained to be one of three types:
  - “requests” to commit to action
  - “unrequests” to refrain from actions
  - “informs” which pass on information

AGENT0


initialise
messages in
update beliefs
update commitments
beliefs
commitments
abilities
EXECUTE
messages out
internal actions

AGENT0

- A commitment rule:

```
COMMIT(
        ( agent, REQUEST, DO(time, action)
        ), ;;; msg condition
        ( B,
                [now, Friend agent] AND
                CAN(self, action) AND
                NOT [time, CMT(self, anyaction)]
        ), ;;; mental condition
        self,
        DO(time, action)
)
```

AGENT0

- This rule may be paraphrased as follows:
  if I receive a message from *agent* which requests me to do *action* at *time*, and I believe that:
  - *agent* is currently a friend
  - I can do the action
  - At *time*, I am not committed to doing any other action

  then commit to doing *action* at *time*

AGENT0 and PLACA

- AGENT0 provides support for multiple agents to cooperate and communicate, and provides basic provision for debugging…
- …it is, however, a *prototype*, that was designed to illustrate some principles, rather than be a production language
- A more refined implementation was developed by Thomas, for her 1993 doctoral thesis
- Her Planning Communicating Agents (PLACA) language was intended to address one severe drawback to AGENT0: the inability of agents to plan, and communicate requests for action via high-level goals
- Agents in PLACA are programmed in much the same way as in AGENT0, in terms of *mental change* rules

AGENT0 and PLACA

- An example mental change rule:

```
(((self ?agent REQUEST (?t (xeroxed ?x)))
   (AND (CAN-ACHIEVE (?t xeroxed ?x)))
        (NOT (BEL (*now* shelving)))
        (NOT (BEL (*now* (vip ?agent))))
   ((ADOPT (INTEND (5pm (xeroxed ?x)))))
   ((?agent self INFORM
        (*now* (INTEND (5pm (xeroxed ?x)))))))
```

- Paraphrased:
  if someone asks you to xerox something, and you can, and you don't believe that they're a VIP, or that you're supposed to be shelving books, then
  - adopt the intention to xerox it by 5pm, and
  - inform them of your newly adopted intention

Concurrent METATEM

- Concurrent METATEM is a multi-agent language in which each agent is programmed by giving it a *temporal logic* specification of the behavior it should exhibit
- These specifications are executed directly in order to generate the behavior of the agent
- Temporal logic is classical logic augmented by *modal operators* for describing how the truth of propositions changes over time

Concurrent METATEM

- For example. . .

  []important(agents)

  means “it is now, and will always be true that agents are important”

  ◊important(ConcurrentMetateM)

  means “sometime in the future, ConcurrentMetateM will be important”

  ⧫important(Prolog)

  means “sometime in the past it was true that Prolog was important”

  (¬friends(us)) U apologize(you)

  means “we are not friends until you apologize”

  ○apologize(you)

  means “tomorrow (in the next state), you apologize”.

Concurrent METATEM

- MetateM is a framework for *directly executing* temporal logic specifications
- The root of the MetateM concept is Gabbay's *separation theorem*:
  Any arbitrary temporal logic formula can be rewritten in a logically equivalent *past* ⇒ *future* form.
- This *past* ⇒ *future* form can be used as *execution rules*
- A MetateM program is a set of such rules
- Execution proceeds by a process of continually matching rules against a "history", and *firing* those rules whose antecedents are satisfied
- The instantiated future-time consequents become *commitments* which must subsequently be satisfied

Concurrent METATEM

- Execution is thus a process of iteratively generating a model for the formula made up of the program rules
- The future-time parts of instantiated rules represent *constraints* on this model
- An example MetateM program: the resource controller…

$$\forall x \quad \bigcirc\, ask(x) \Rightarrow \Diamond\, give(x)$$

$$\forall x,y \quad give(x) \wedge give(y) \Rightarrow (x=y)$$

- First rule ensure that an ‘ask’ is eventually followed by a ‘give’
- Second rule ensures that only one ‘give’ is ever performed at any one time
- There are algorithms for executing MetateM programs that appear to give reasonable performance
- There is also *separated normal form*

Concurrent METATEM

- ConcurrentMetateM provides an operational framework through which societies of MetateM processes can operate and communicate
- It is based on a new model for concurrency in executable logics: the notion of executing a logical specification to generate individual agent behavior
- A ConcurrentMetateM system contains a number of agents (objects), each object has 3 attributes:
  - a name
  - an interface
  - a MetateM program

Concurrent METATEM

- An object's interface contains two sets:
  - environment predicates — these correspond to messages the object will accept
  - component predicates — correspond to messages the object may send
- For example, a 'stack' object's interface:

  stack(pop, push)[popped, stackfull]

  {pop, push} = environment preds
  {popped, stackfull} = component preds
- If an agent receives a message headed by an environment predicate, it accepts it
- If an object satisfies a commitment corresponding to a component predicate, it broadcasts it

Concurrent METATEM

- To illustrate the language Concurrent MetateM in more detail, here are some example programs…
- Snow White has some sweets (resources), which she will give to the Dwarves (resource consumers)
- She will only give to one dwarf at a time
- She will always eventually give to a dwarf that asks
- Here is Snow White, written in Concurrent MetateM:

Snow-White(ask)[give]:

$$\bigcirc\ ask(x) \Rightarrow \Diamond\ give(x)$$

$$give(x) \wedge give(y) \Rightarrow (x = y)$$

Concurrent METATEM

- The dwarf ‘eager’ asks for a sweet initially, and then whenever he has just received one, asks again

eager(give)[ask]:

start $\Rightarrow$ ask(eager)

$\bigcirc$ give(eager) $\Rightarrow$ ask(eager)

- Some dwarves are even less polite: ‘greedy’ just asks every time

greedy(give)[ask]:

start $\Rightarrow$ $\Box$ ask(greedy)

Concurrent METATEM

- Fortunately, some have better manners; ‘courteous’ only asks when ‘eager’ and ‘greedy’ have eaten

courteous(give)[ask]:

$$((\neg \text{ask(courteous)}\ \mathcal{S}\ \text{give(eager)}) \wedge (\neg \text{ask(courteous)}\ \mathcal{S}\ \text{give(greedy)})) \Rightarrow \text{ask(courteous)}$$

- And finally, ‘shy’ will only ask for a sweet when no-one else has just asked

shy(give)[ask]:

$$\begin{aligned} \mathit{start} &\Rightarrow \Diamond\, \text{ask(shy)} \\ \bigcirc\, \text{ask(x)} &\Rightarrow \neg\, \text{ask(shy)} \\ \bigcirc\, \text{give(shy)} &\Rightarrow \Diamond\, \text{ask(shy)} \end{aligned}$$

Concurrent METATEM

- Summary:
  - an(other) experimental language
  - very nice underlying theory…
  - …but unfortunately, lacks many desirable features — could not be used in current state to implement ‘full’ system
  - currently prototype only, full version on the way!