Utility functions and Concrete architectures: deductive agents

CS7ET03: AI for IET

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Abstract Architectures (ctd.)

- An agent's behaviour is encoded as its *history*:

$$h : s_0 \xrightarrow{a_0} s_1 \xrightarrow{a_1} \ldots \xrightarrow{a_{u-1}} s_u \xrightarrow{a_u} \ldots$$

- Define:
  - H^A: set of all histories which end with an *action*
  - H^S: histories which end in *environment states*
- A *state transformer* function $\tau : H^A \rightarrow \wp(S)$ represents the effect an agent has on an environment.
- So we may represent environment dynamics by a triple:

$$Env =< S, s_0, \tau >$$

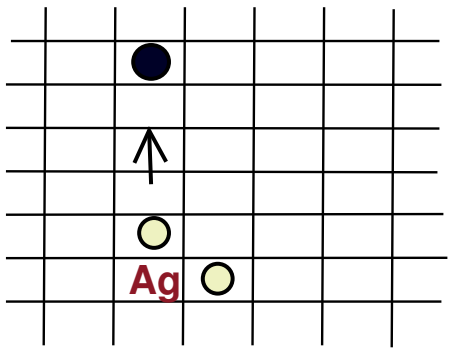
- And similarly, agent dynamics as

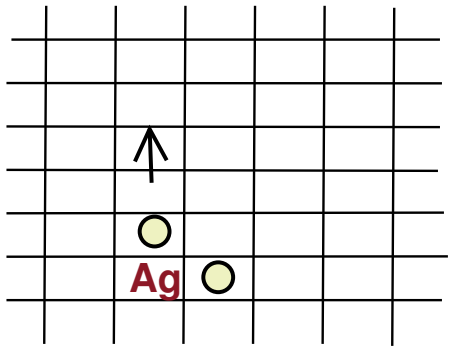
$$Ag : H^S \rightarrow A$$

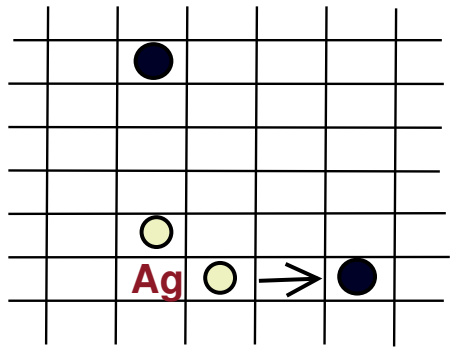
Utility functions

- Problem: how to "tell agents what to do"? (when exhaustive specification is impractical)
- Decision theory (see [Russell and Norvig, 1995, ch. 16]):
  - associate *utilities* (a performance measure) to states:
    $$u : S \to \mathbb{R}$$
  - Or, better yet, to *histories*:
    $$u : H \to \mathbb{R}$$

Example: The Tileworld







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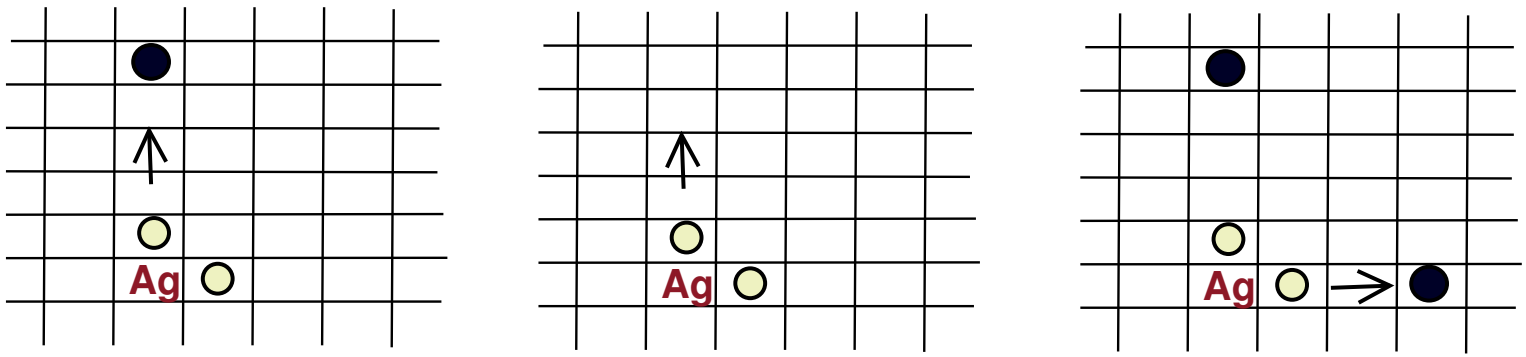


- The *utility* of a course of action can be given by:

$$u(h) = \frac{\text{number of holes filled in h}}{\text{number of holes that appeared in h}}$$

- When the utility function has an upper bound (as above) then we can speak of *optimal agents*.

Optimal agents

- Let $P(h|Ag, Env)$ denote the probability that h occurs when agent Ag is placed in Env.
- Clearly

$$\sum_{h \in H} P(h|Ag, Env) = 1 \tag{1}$$

- An *optimal agent* Ag_{opt} in an environment Env will maximise expected utility:

$$Ag_{opt} = \arg \max_{Ag} \sum_{h \in H} u(h) P(h|Ag, Env) \tag{2}$$

From abstract to concrete architectures

- Moving from abstract to concrete architectures is a matter of further specifying *action* (e.g. by means of algorithmic description) and choosing an underlying form of representation.
- Different ways of specifying the *action* function and representing knowledge:
  - Logic-based: decision function implemented as a theorem prover (plus control layer)
  - Reactive: (hierarchical) condition $\rightarrow$ action rules
  - BDI: manipulation of data structures representing *Beliefs*, *Desires* and *Intentions*
  - Layered: combination of logic-based (or BDI) and reactive decision strategies

Logic-based architectures

- AKA *Deductive Architectures*
- Background: symbolic AI
  - Knowledge representation by means of logical formulae
  - "Syntactic" symbol manipulation
  - Specification in logic $\Rightarrow$ executable specification
- "Ingredients":
  - Internal states: sets of (say, first-order logic) formulae
    - $\Delta = \{temp(roomA, 20), heater(on), ...\}$
  - Environment state and perception,
  - Internal state seen as a set of beliefs
  - Closure under logical implication ($\Rightarrow$):
    - $closure(\Delta, \Rightarrow) = \{\varphi | \varphi \in \Delta \vee \exists \psi . \psi \in \Delta \wedge \psi \Rightarrow \varphi\}$
  - (is this a reasonable model of an agent's beliefs?)

Representing deductive agents

- We will use the following objects:
  - L: a set of sentences of a logical system
    - As defined, for instance, by the usual wellformedness rules for first-order logic
  - $D = \wp(L)$: the set of *databases* of L
  - $\Delta_0, ..., \Delta_n \in D$: the agent's internal states (or *beliefs*)
  - $\models_\rho$: a deduction relation described by the deduction rules ρ chosen for L:
    We write $\Delta \models_\rho \varphi$ if $\varphi \in \mathit{closure}(\Delta, \rho)$

Describing the architecture

- A logic-based architecture is described by the following structure:

$$\boxed{Arch_L =< L, A, P, D, action, env, see, next >} \quad (3)$$

- The update function consists of additions and removals of facts from the current database of internal states:
  - $next : D \times P \rightarrow D$
    - *old*: removal of "old" facts
    - *new*: addition of new facts (brought about by *action*)

Pseudo-code for *action*

```
1.   function action(Δ : D) : A
2.   begin
3.         for each a ∈ A do
4.               if Δ ⊨_ρ do(a) then
5.                     return a
6.               end if
7.         end for
8.         for each a ∈ A do
9.               if Δ ⊭_ρ ¬do(a) then
10.                    return a
11.              end if
12.        end for
13.        return noop
14.  end function action
```

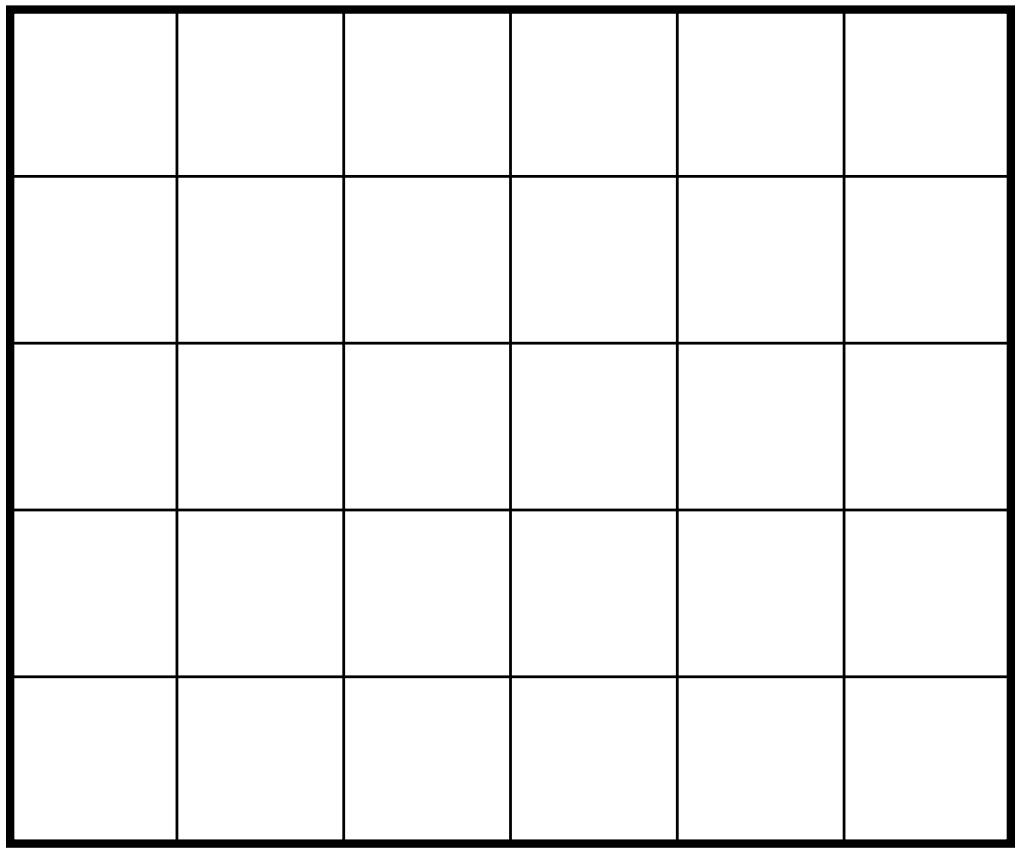
Environment and Belief states

- The environment change function, *env*, remains as before.
- The belief database update function could be further specified as follows

$$\boxed{next(\Delta, p) = (\Delta \setminus old(\Delta)) \cup new(\Delta, p)} \tag{4}$$

where $old(\Delta)$ represent beliefs no longer held (as a consequence of *action*), and $new(\Delta, p)$ new beliefs that follow from facts perceived about the new environmental conditions.

Example: The Vacuum world



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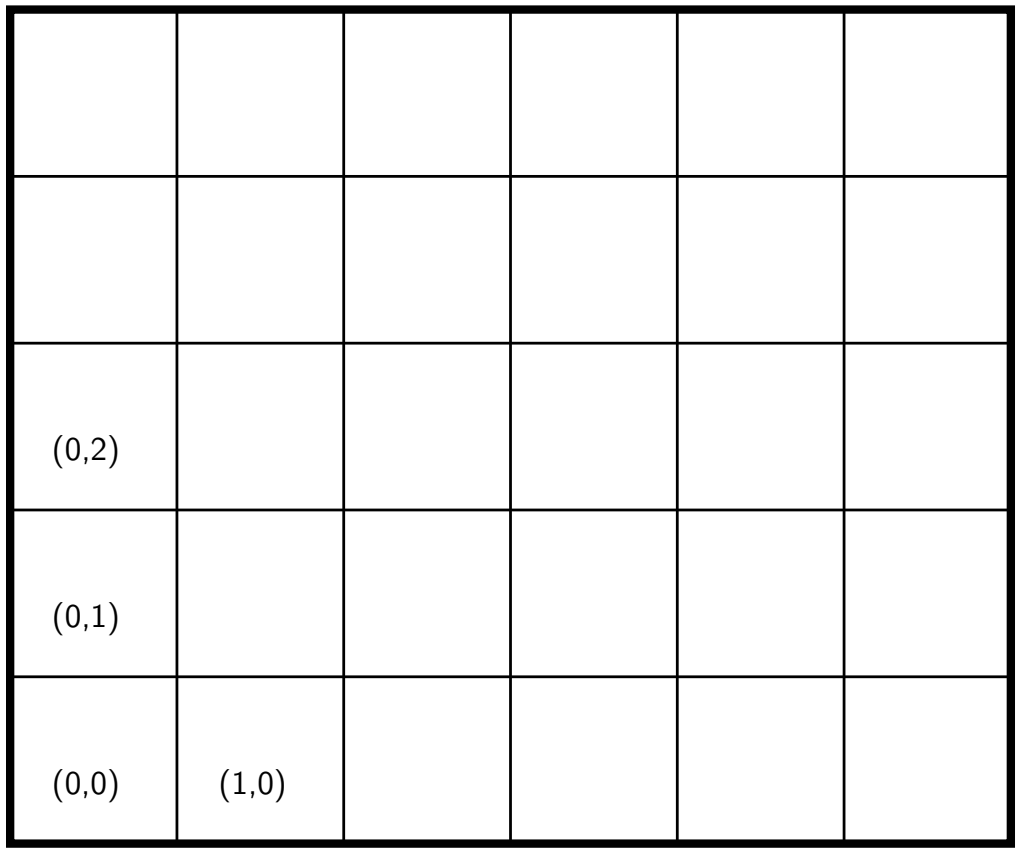

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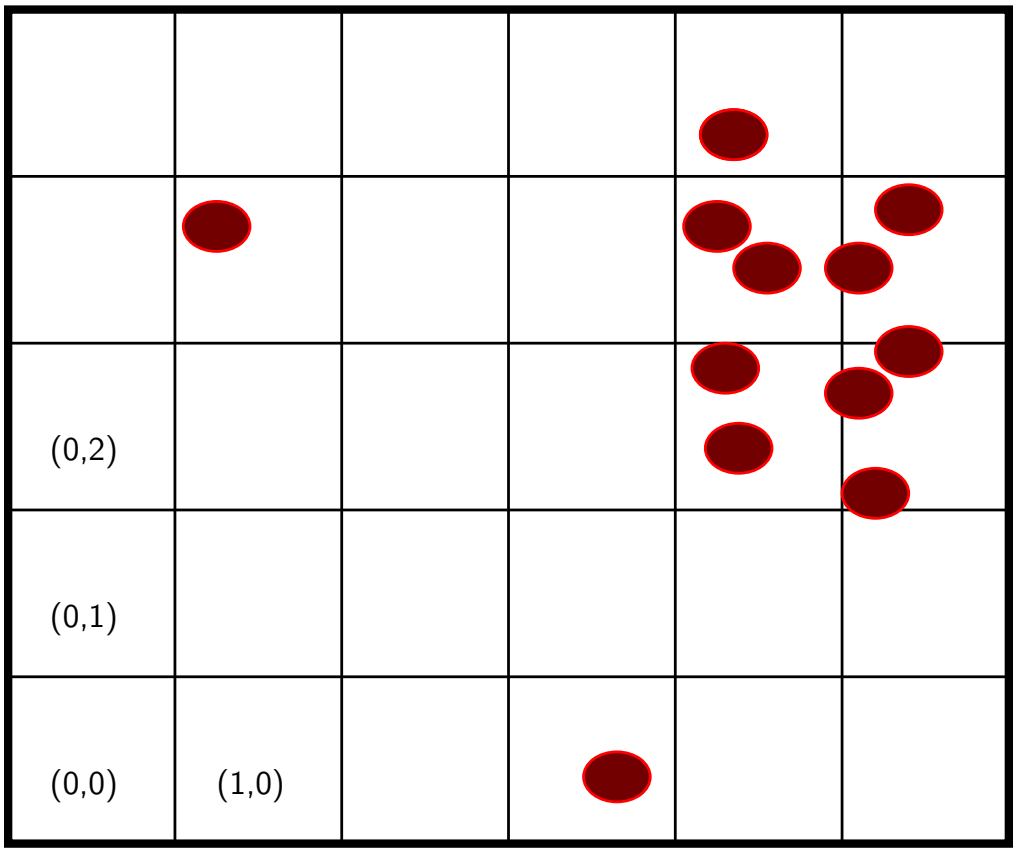

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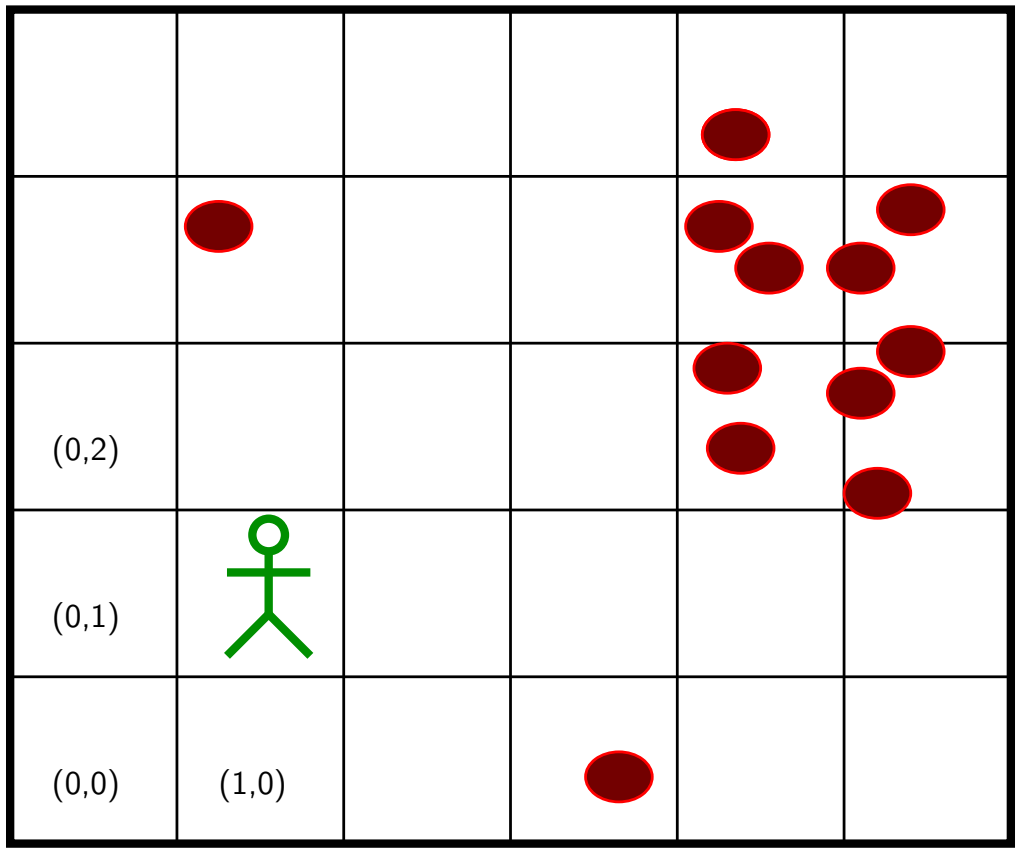


[Russell and Norvig, 1995, Weiss, 1999]

Describing The Vacuum world

- Environment
  - perceptual input: *dirt*, *null*
  - directions: (facing) *north*, *south*, *east*, *west*
  - position: coordinate pairs (x, y)
- Actions
  - *move_forward*, *turn_90°_left*, *clean*
- Perception:

$$P = \{\{dirt(x, y), in(x, y), facing(d), ...\}, ...\}$$

Deduction rules

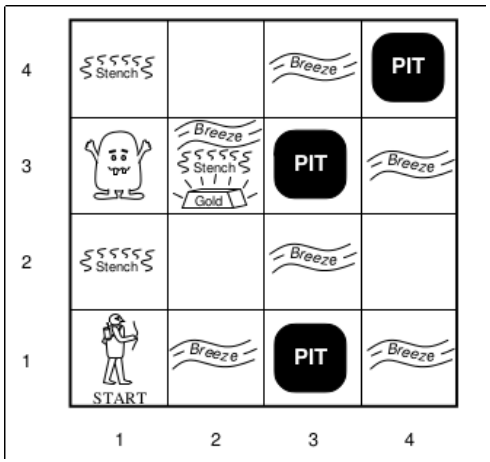
- Part of the decision function
- Format (for this example):
  - $P(...) \Rightarrow Q(...)$
- PROLOG fans may think of these rules as Horn Clauses.
- Examples:
  - $in(x, y) \wedge dirt(x, y) \Rightarrow do(clean)$
  - $in(x, 2) \wedge \neg dirt(x, y) \wedge facing(north) \Rightarrow do(turn)$
  - $in(0, 0) \wedge \neg dirt(x, y) \wedge facing(north) \Rightarrow do(forward)$
  - ...

Updating the internal state database

- $next(\Delta, p) = (\Delta \setminus old(\Delta)) \cup new(\Delta, p)$
- $old(\Delta) =$
  $\{(P(t_1, ..., t_n) | P \in \{in, dirt, facing\} \wedge P(t_1, ..., t_n) \in \Delta\}$
- $new(\Delta, p)$:
  - update agent's position,
  - update agent's orientation,
  - etc

The "Wumpus World"

- See [Russell and Norvig, 2003, section 7.2]
- BTW, Ch 7 is available online (last accessed Oct 2012) at `http://aima.cs.berkeley.edu/newchap07.pdf`



Shortcomings of logic-based agents

- Expressivity issues: problems encoding percepts (e.g. visual data) etc
- *Calculative rationality* in dynamic environments
- Decidability issues
- Semantic elegance vs. performance:
  - loss of "executable specification"
  - weakening the system vs. temporal specification
- etc

Existing (??) logic-based systems

- MetameM, Concurrent MetameM: specifications in temporal logic, model-checking as inference engine (Fisher, 1994)
- CONGOLOG: Situation calculus
- Situated automata: compiled logical specifications (Kaelbling and Rosenschein, 1990)
- AgentSpeak, ...
- (see [Weiss, 1999] or [Wooldridge, 2002] for more details)

BDI Agents

- Implement a combination of:
  - deductive reasoning (*deliberation*) and
  - planning (*means-ends reasoning*)

Planning

- Planning formalisms describe actions in terms of (sets of) *preconditions* (P_a), *delete lists* (D_a) and *add lists* (A_a):

$$< P_a, D_a, A_a >$$

- E.g. Action encoded in STRIPS (for the "block's world" example):

Stack(x,y):

pre: clear(y), holding(x)
del: clear(y), holding(x)
add: armEmpty, on(x,y)

Planning problems

- A planning problem $< \Delta, O, \gamma >$ is determined by:
  - the agent's *beliefs* about the initial environment (a set Δ)
  - a set of operator descriptors corresponding to the actions available to the agent:
    $$O = \{< P_a, D_a, A_a > | a \in A\}$$
  - a set of formulae representing the *goal/intention* to be achieved (say, γ)
- A plan $\pi =< a_i, ..., a_n >$ determines a sequence $\Delta_0, ..., \Delta_{n+1}$ where $\Delta_0 = \Delta$ and $\Delta_i = (\Delta_{i-1} \setminus D_{a_i}) \cup A_{a_i}$, for $1 \leq i \leq n$.

Suggestions

- Investigate the use of BDI systems and agents in games.
- See, for instance, [Norling and Sonenberg, 2004] which describe the implementation of interactive BDI characters for Quake 2.
- And [Wooldridge, 2002, ch. 4], for some background.
- There are a number of BDI-based agent platforms around. 'Jason', for instance, seems interesting:

  `http://jason.sourceforge.net/`

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