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A4M33MAS - Multiagent Systems
Intelligent agents architectures

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In parts based on Michal Pechoucek: Multi-Agent Systems, Lecture course at State University of New York, University at Binghamton

Towards Architectures for IA

- Reactive Architectures
- Deliberative Architectures

Subsumption Architecture

best known reactive agents architecture developed by R. Brooks:

- Two key ideas:
  - situatedness and embodiment of intelligence: real intelligence is situated in the world it is not disembodied such as expert system or theorem prover
  - intelligence and emergence: intelligence arises from the agent x environment interaction, intelligence is not an isolated property
- Task accomplishing behavior: a function that maps the percept into action as there is no representation/reasoning the task accomplishing behaviors are implemented as rules:

$$\texttt{situation} \longrightarrow \texttt{action}$$

- the rules are fired simultaneously – the rules are structures into subsumption hierarchy: layers of different levels of abstraction of the behavior (where each layer inhibit the higher level layer)

Subsumption Architecture

- behavior:

$$\text{Beh} = \{\text{cond} \rightarrow \text{act}, \text{ where cond} \subseteq \mathcal{P} \text{ and act} \subseteq \mathcal{A}c\}$$

- inhibition relation:
  - for rules in Beh, there is a binary relation – a strict total ordering on Beh (i.e. transitive, irreflexive and antisymetric)

```
fired → {cond → act, where cond → act ∈ P and act ⊆ Ac}
  for each  cond → act ∈ fired do
   if ∄ cond′ → act′ ∈ fired such that cond′ → act′ ≺ cond → act
     then return act
   end-if
  end-for
return  null
```

Subsumption Architecture

- Example of rock sample collecting robots (Steels), inspired by ants:
  - noncooperative agents

```
(cond (detect-an-obstacle #'change-direction)                r1
       ((and carrying-samples at-base) #'drop-samples)       r2
       ((and carrying-samples (not at-base)) #'travel-up)    r3
       ((detect-a-sample #'pick-up-sample)                   r4
       (t #move-randomly)                                    r5
    )
```

$$r1 \prec r2 \prec r3 \prec r4 \prec r5$$

Subsumption Architecture

01

- if samples in clusters, collaborative property is desirable
  - direct/indirect communication
- stigmergy: ant-inspired collaborative decision making

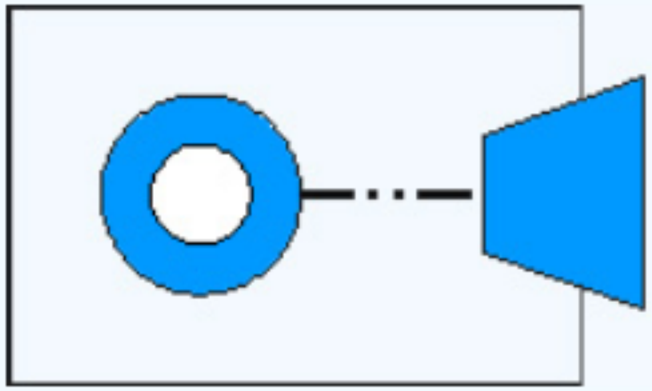
```
((and carrying-samples (not at-base))
       (and #drop-2-crumbs #'travel-up))                    r6
((detect-crambs (and #'pick-up-1-crumb #'travel-down)       r7
```

$$r1 \prec r2 \prec r6 \prec r4 \prec r7 \prec r5$$

Subsumption Architecture

- S-agents

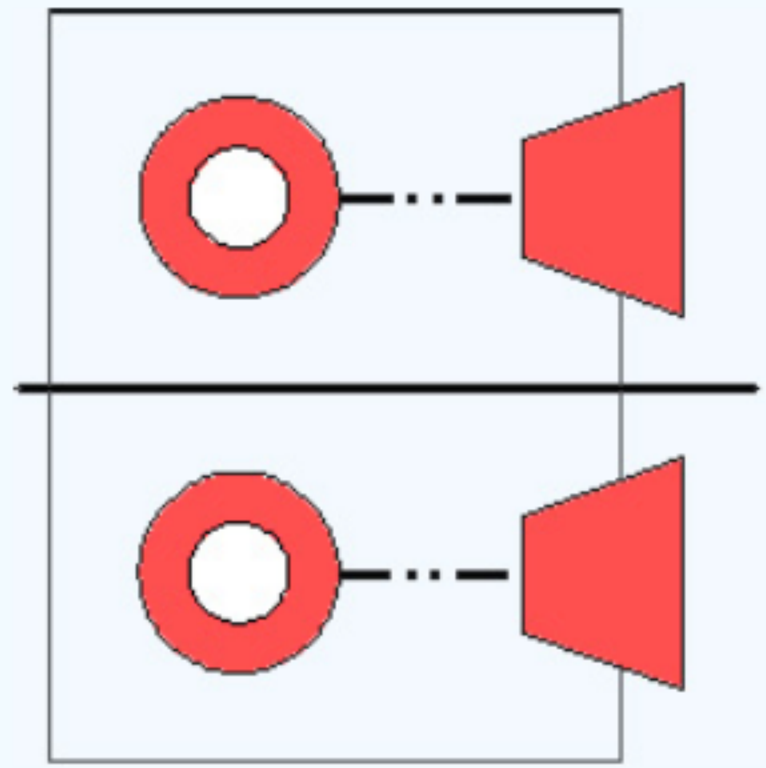
```
(cond
        (light-in-front-increasing #move-forward-faster)
)
```



Subsumption Architecture

01

- S-agents: composition



Subsumption Architecture

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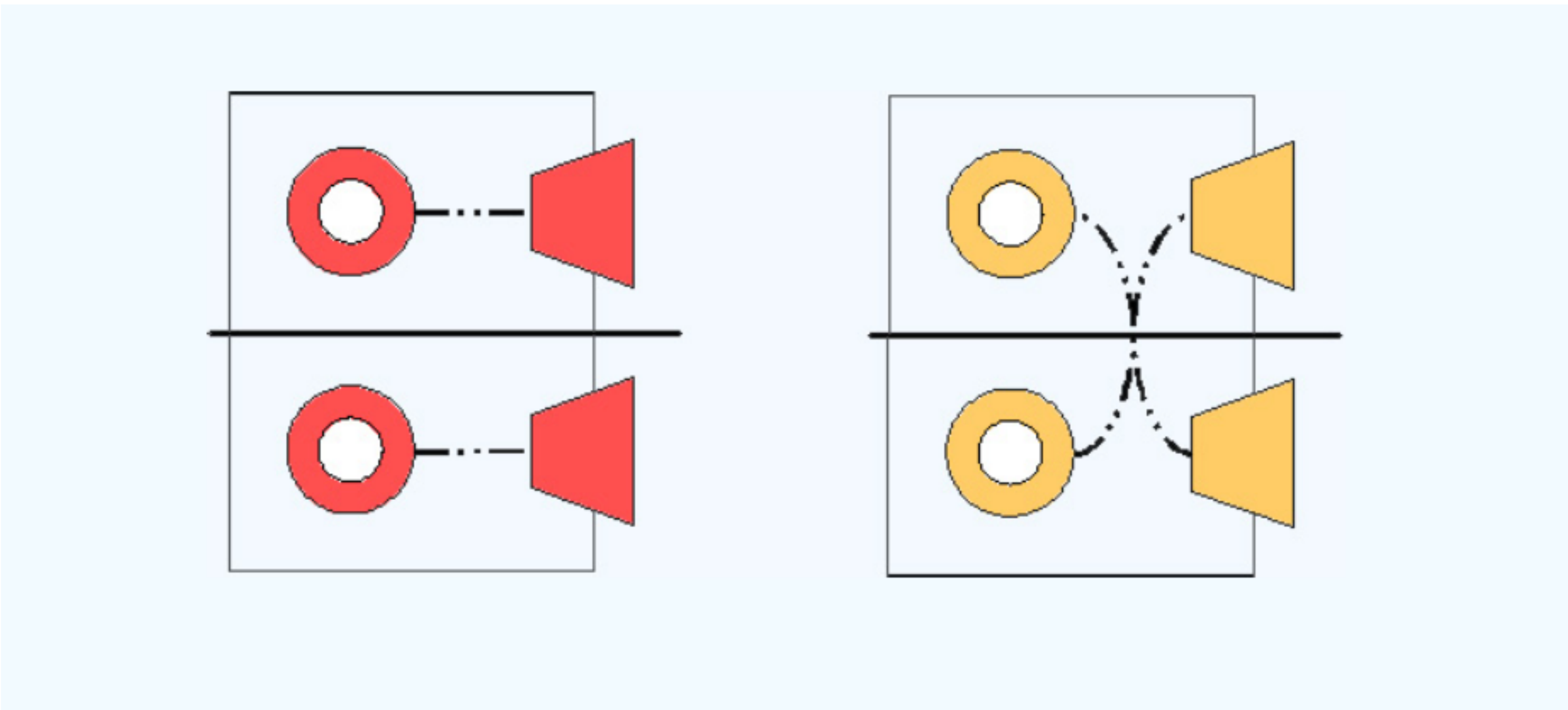

Subsumption Architecture

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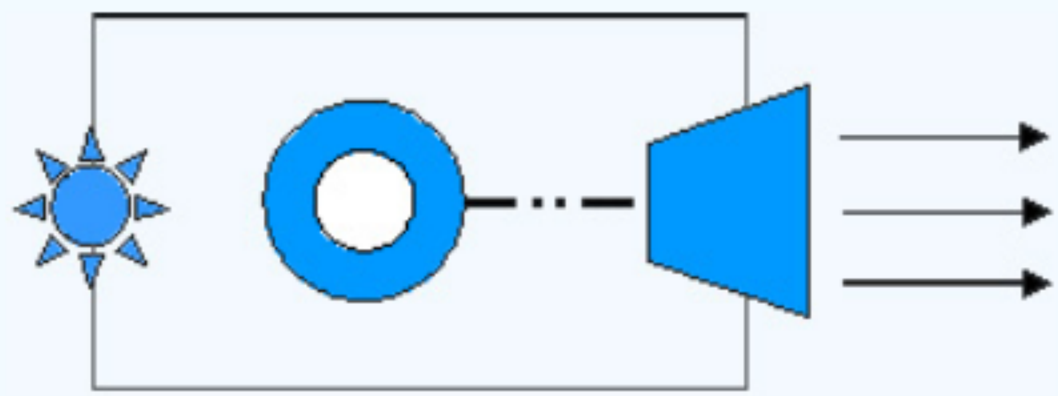

Subsumption Architecture

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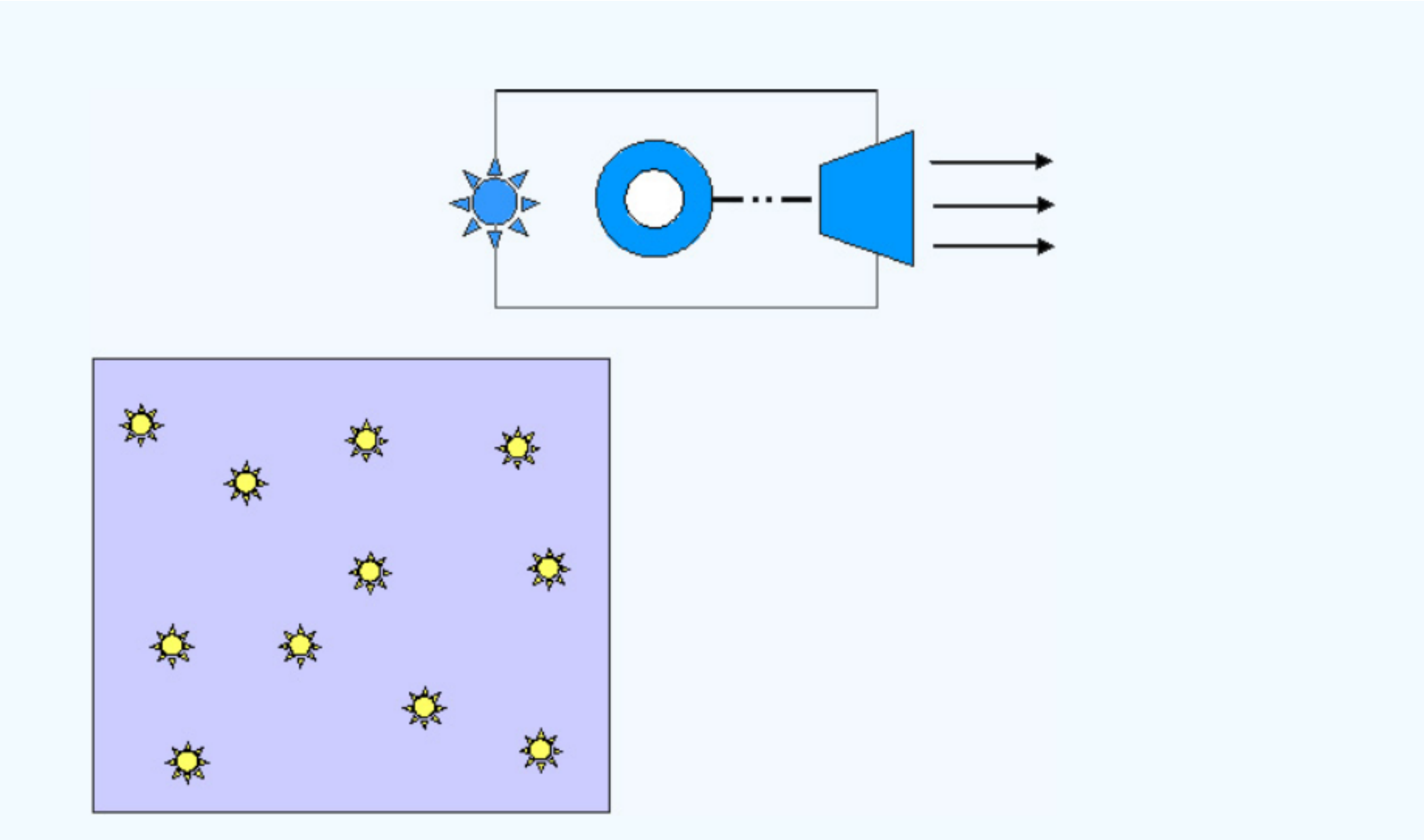
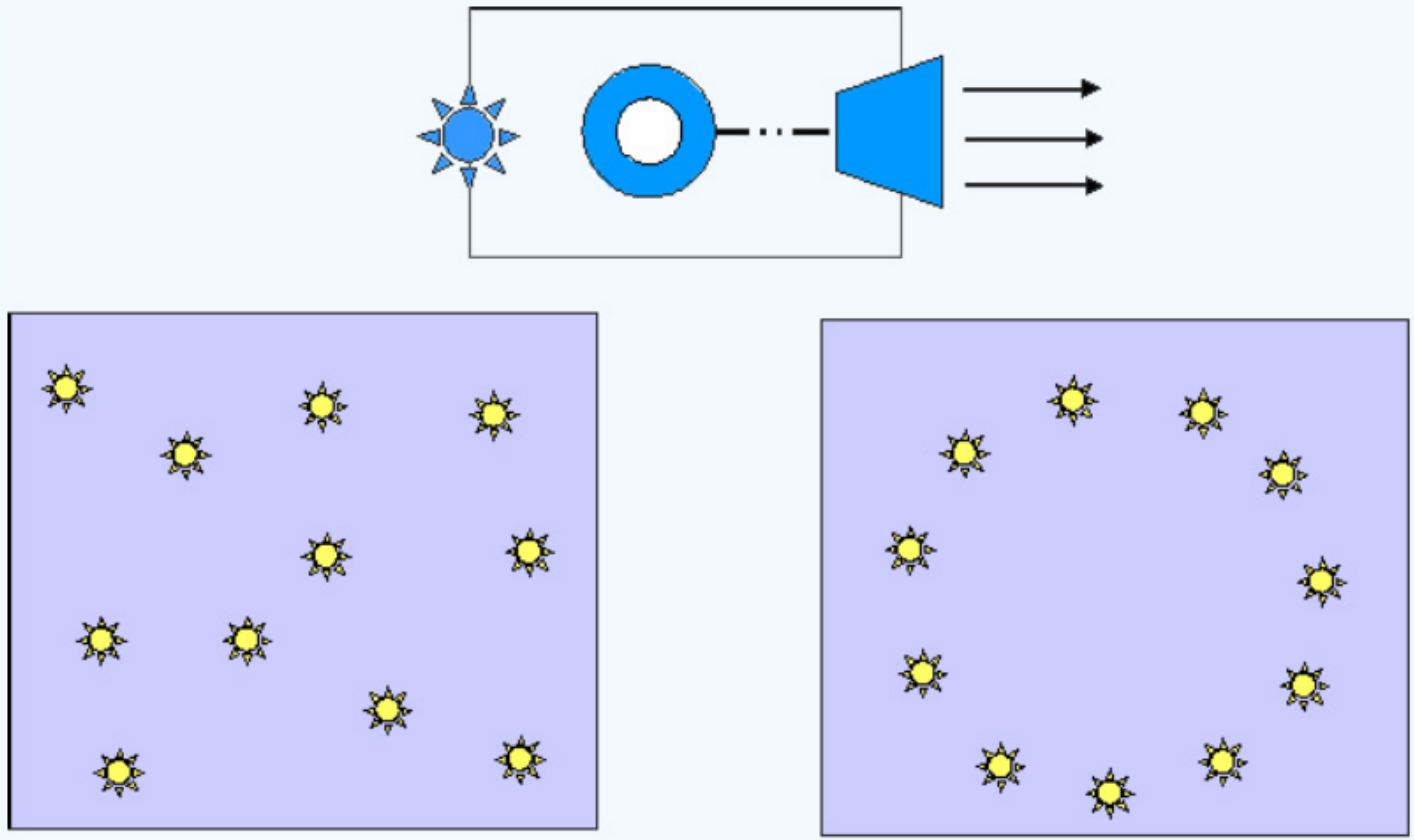


Subsumption Architecture

- S-agents: composition



Deliberative architectures

1. Planning architectures
2. Deductive architectures
3. Models of practical reasoning

Planning Agents

Planning Agents

- Basic architecture:
  1. Plan(s_0, s_g, O) → π
  2. Execute (π) → sg

Planning Agents

01

- Basic architecture:
  1. Plan(s_0, s_g, O) → π
  2. Execute (π) → sg

- Reactive planning architecture:
  1. s_0 → s_n
  2. Plan(s_n, s_g, O) → π
  3. Read(Execute(*Head*(π))) → s_n
  4. if $s_n \neq s_g$ *GOTO* 2.

Planning Agents

- Basic architecture:
  1. <u>Plan</u>(s_0, s_g, O) → π
  2. <u>Execute</u> (π) → sg

- Reactive planning architecture:
  1. s_0=s_n
  2. <u>Plan</u>(s_n, s_g, O) → π
  3. <u>Read</u>(<u>Execute</u>(*Head*(π))) → s_n
  4. if $s_n \neq s_g$ *GOTO* 2.

∗ *For <u>Plan</u> see to A4M36PAH or related*

Deductive Agents

- Models of deductive reasoning:

– constantly running a **reasoning loop** that is try to prove that there is an action that shall, or at least is allowed to be carried out – given agent's knowledge Δ, and its goal $\mathcal{G}$ we shall instantiate a variable α in a predicate $\mathtt{do}(\alpha)$ when proving ${}_{\Delta,\mathcal{G}} \vdash \exists\alpha\, \mathtt{do}(\alpha)$ – where $\mathtt{shall\text{-}be\text{-}done}(\alpha) \vee \mathtt{may\text{-}be\text{-}done}(\alpha) \Rightarrow \mathtt{do}(\alpha)$

– or prove what is the **best reaction** to a new piece of information $\mathcal{P}$ sensed from the environment ${}_{\Delta,\mathcal{G}} \vdash \exists\alpha\, \mathtt{react}(\mathcal{P}, \alpha)$

Reasoning rules are here the rules of mathematical logic. The agent's knowledge Δ contain agents' model of the environment and its ($\mathtt{if\text{-}then}$) decision making rules.

Deductive Agents

- Implementation of deductive agents:

:: **Firstly,**

we shall find the proper logical language (e.g. FOPL) for representing agents model of its environment and than design a solid system that will represent the environmental objects that the agent may model, relation between them etc.

:: **Secondly,**

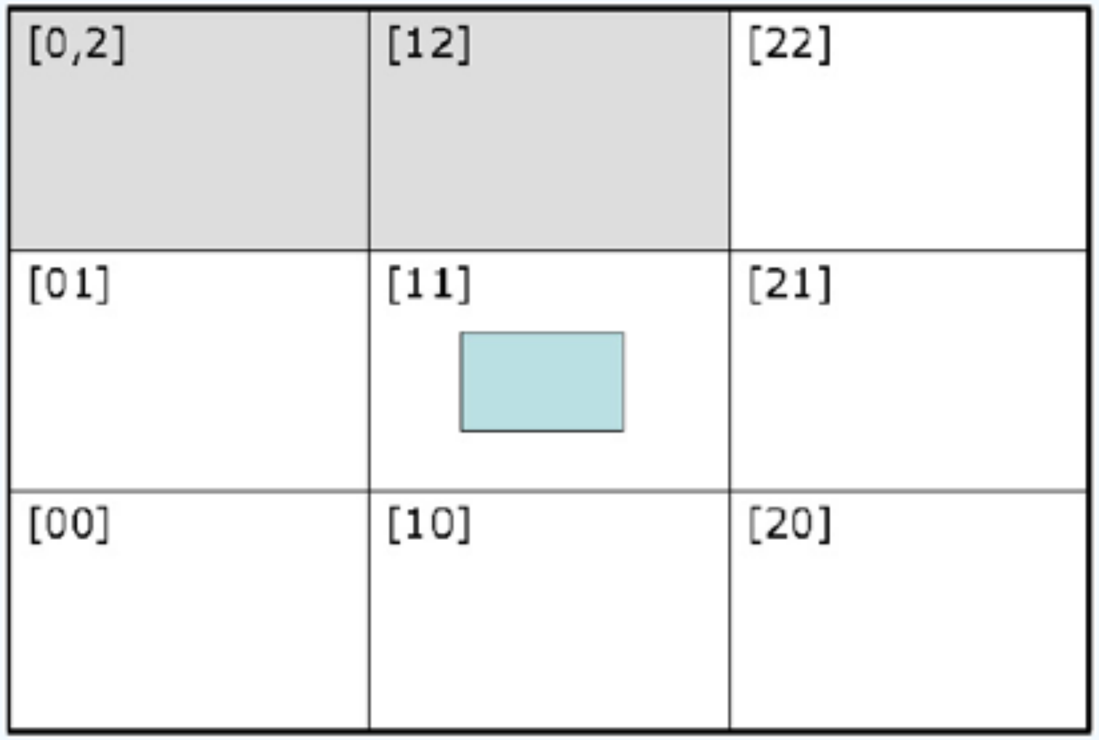
you have to design and implement/integrate an inference engine that will try compute (and instantiate) the logical consequence of the model in the $\mathtt{do}(\alpha)$ sense.

We will need a theorem proving system, e.g. based on resolution technique (implemented in Prolog, Otter, etc.)

Deductive Agents

01

- Example



We use 3 domain predicates in this exercise:

- $\texttt{In}(x, y)$ agent is at x, y
- $\texttt{Dirt}(x, y)$ there is dirt at x, y
- $\texttt{Facing}(d)$ the agent is facing direction d

Possible actions:

- $\texttt{Ac} = \{\texttt{turn}, \texttt{forward}, \texttt{suck}\}$

Deductive Agents

- Example

$$\texttt{In}(x, y) \land \texttt{dirt}(x, y) \rightarrow \texttt{do}(suck)$$

$$\texttt{In}(x, 0) \land \texttt{Facing}(north) \land \neg\texttt{dirt}(x, 0) \rightarrow \texttt{do}(forward)$$

$$\texttt{In}(x, 0) \land \neg\texttt{Facing}(north) \land \neg\texttt{dirt}(x, 0) \rightarrow \texttt{do}(turn) \land \texttt{do}(forward)$$

$$\texttt{In}(x, y) \land \neg\texttt{dirt}(x, y) \rightarrow \texttt{do}(forward)$$

$$\texttt{In}(x, 2) \land \texttt{Facing}(south) \land \neg\texttt{dirt}(x, 2) \rightarrow \texttt{do}(forward)$$

$$\texttt{In}(x, 2) \land \neg\texttt{Facing}(south) \land \neg\texttt{dirt}(x, 2) \rightarrow \texttt{do}(turn) \land \texttt{do}(forward)$$

$$\texttt{In}(2, 2) \land \texttt{do}(finish)$$

Problems with Deductive Agents

:: calculative rationality (CR) requirements

– an agent comply with calculative rationality requirements provided:

$$\forall \Delta_{1,2} :_{\Delta_1} \vdash \mathtt{do}(\alpha_1) \wedge_{\Delta_2} \vdash \mathtt{do}(\alpha_2) \Rightarrow \mathtt{time}(\Delta_1 \leadsto \Delta_2) > \mathtt{time}(\Delta_1 \vdash \mathtt{do}(\alpha_1))$$

:: **first order logic** is not expressive enough

– we need mechanisms for expressing functions, effects and dynamics of actions, higher level modalities such as time, obligation, knowledge and agents mutual mental positions

– all this can be done in different logics (e.g. temporal, deontic, dynamic) but automated theorem proving in such systems is very, very complex and CR requirements are likely to fail

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* *but we have modal logic*

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