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

01

- behavior:

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

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

$\texttt{fired} \longrightarrow \{\texttt{cond} \longrightarrow \texttt{act}, \text{ where } \texttt{cond} \longrightarrow \texttt{act} \in \mathcal{P} \text{ and } \texttt{act} \subseteq \mathcal{A}c\}$

  for each $\texttt{cond} \longrightarrow \texttt{act} \in \texttt{fired}$ do

    if $\nexists\ \texttt{cond}' \longrightarrow \texttt{act}' \in \texttt{fired}$ such that $\texttt{cond}' \longrightarrow \texttt{act}' \prec \texttt{cond} \longrightarrow \texttt{act}$

      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

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

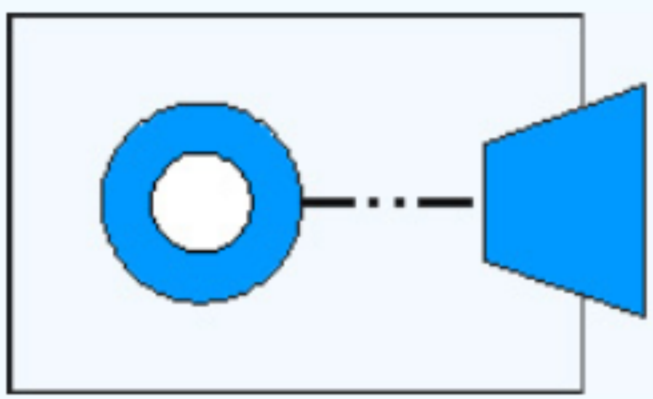
```
((and carrying-samples (not at-base))
       (and #drop-2-crumbs #'travel-up))                   r6
((detect-crambs (and #'pick-up-1-crumb #'travel-down)      r7
```

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

Subsumption Architecture

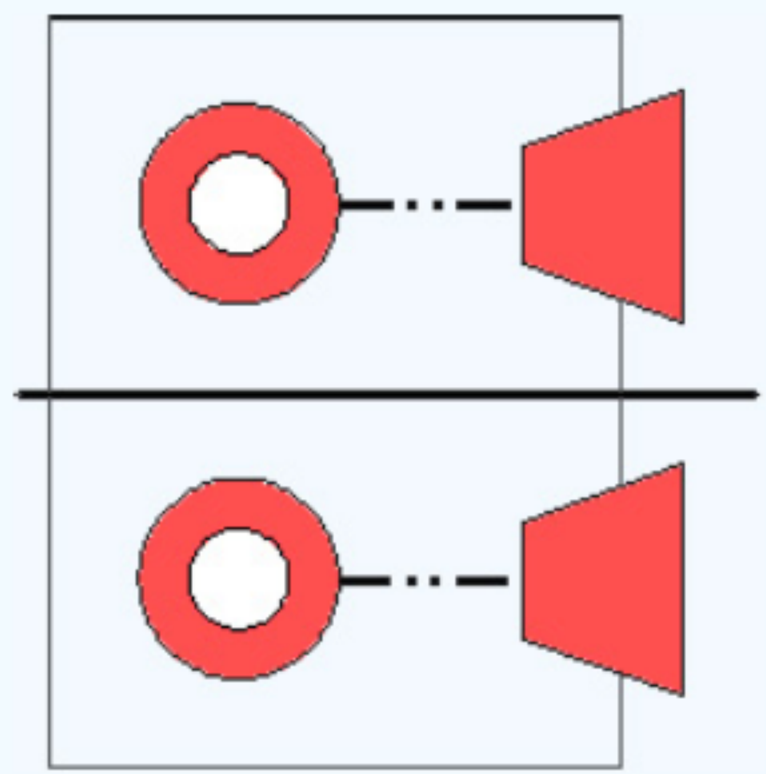
- S-agents

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



Subsumption Architecture

- S-agents: composition



Subsumption Architecture

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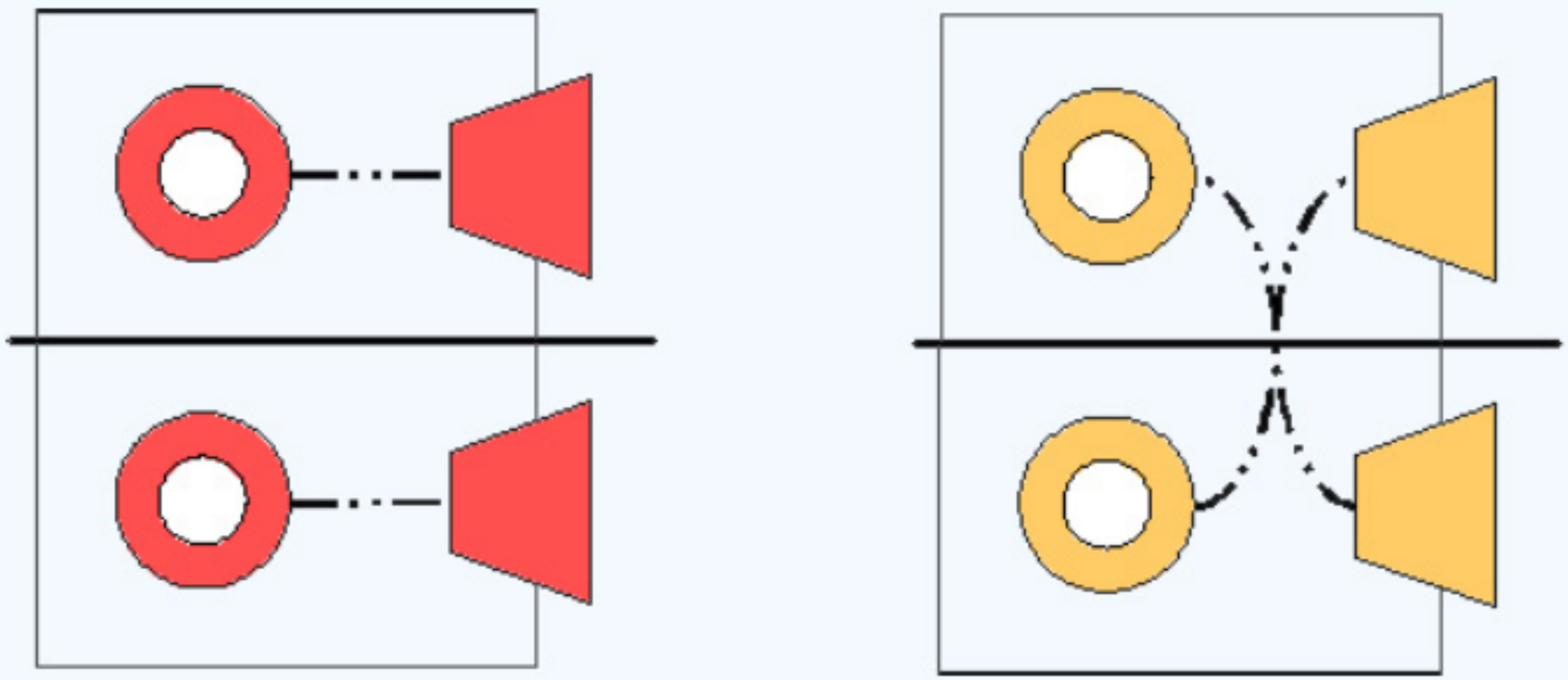
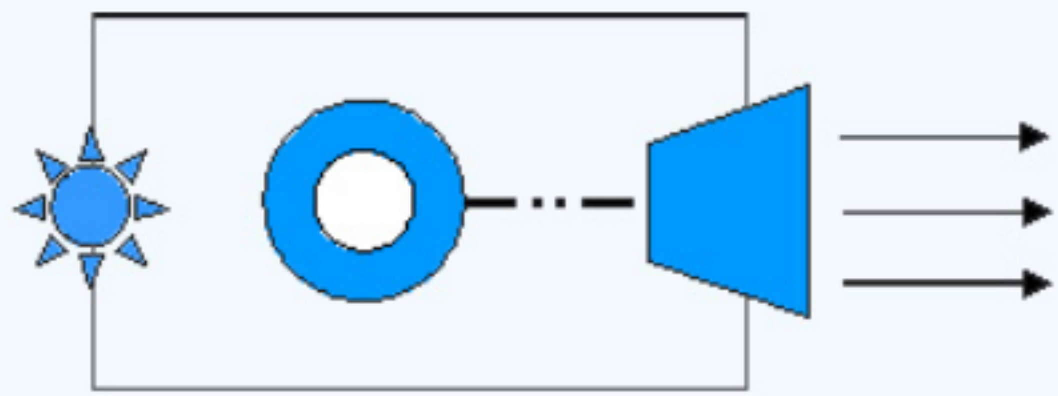


Subsumption Architecture

- S-agents: composition



Subsumption Architecture

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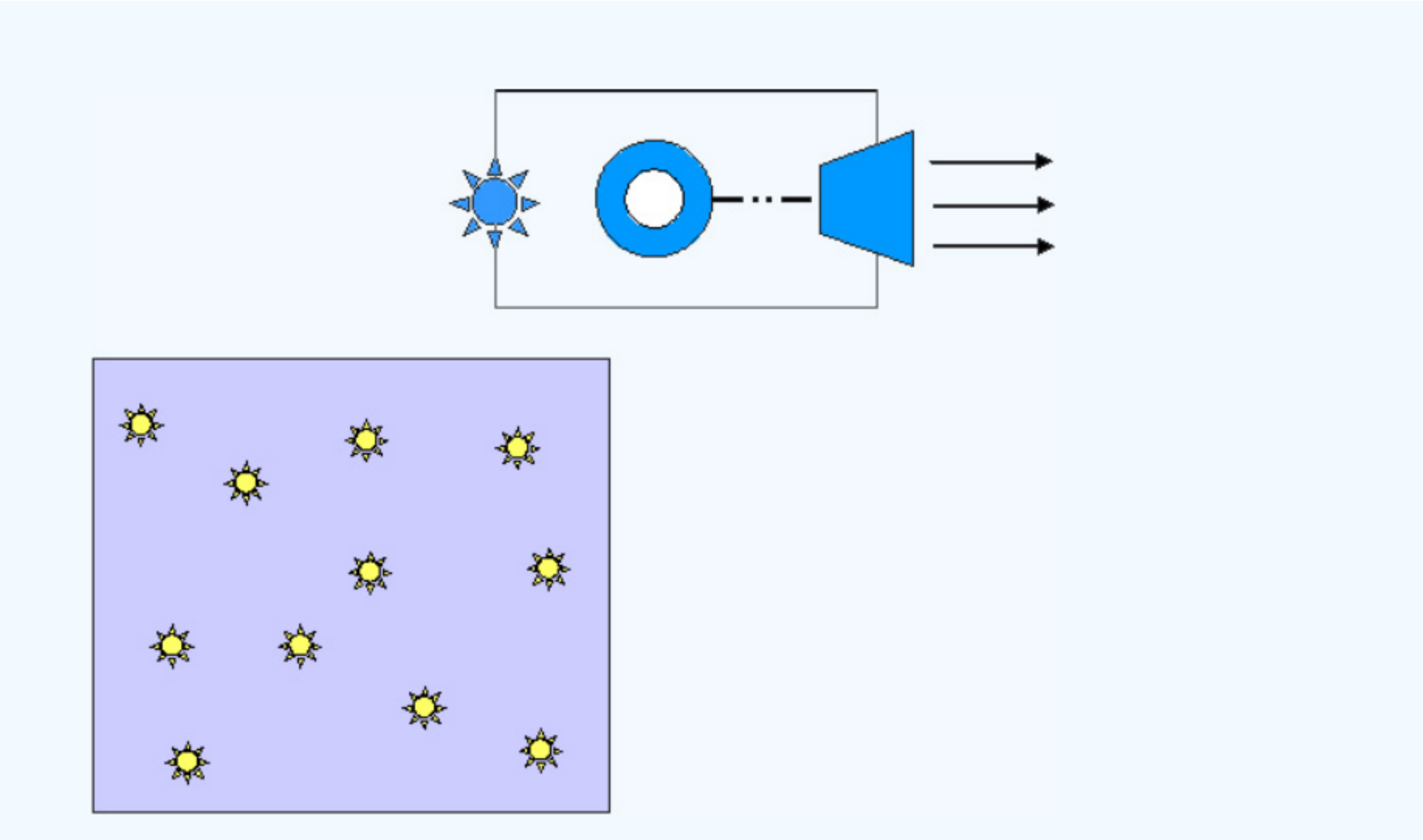

Subsumption Architecture

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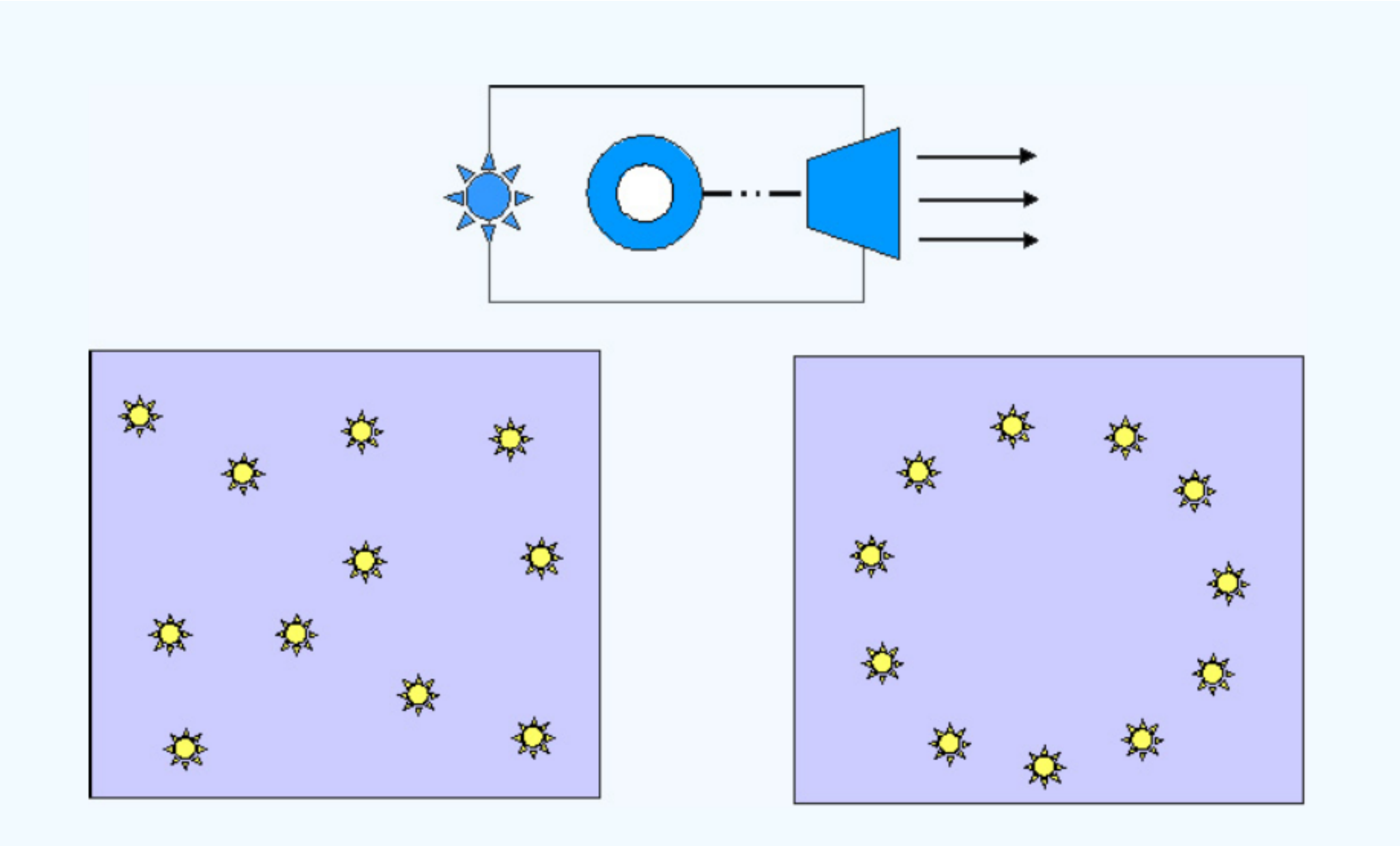

Deliberative architectures

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

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

∗ *For Plan see to A4M36PAH or related*

Deductive Agents

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- 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

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- 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.

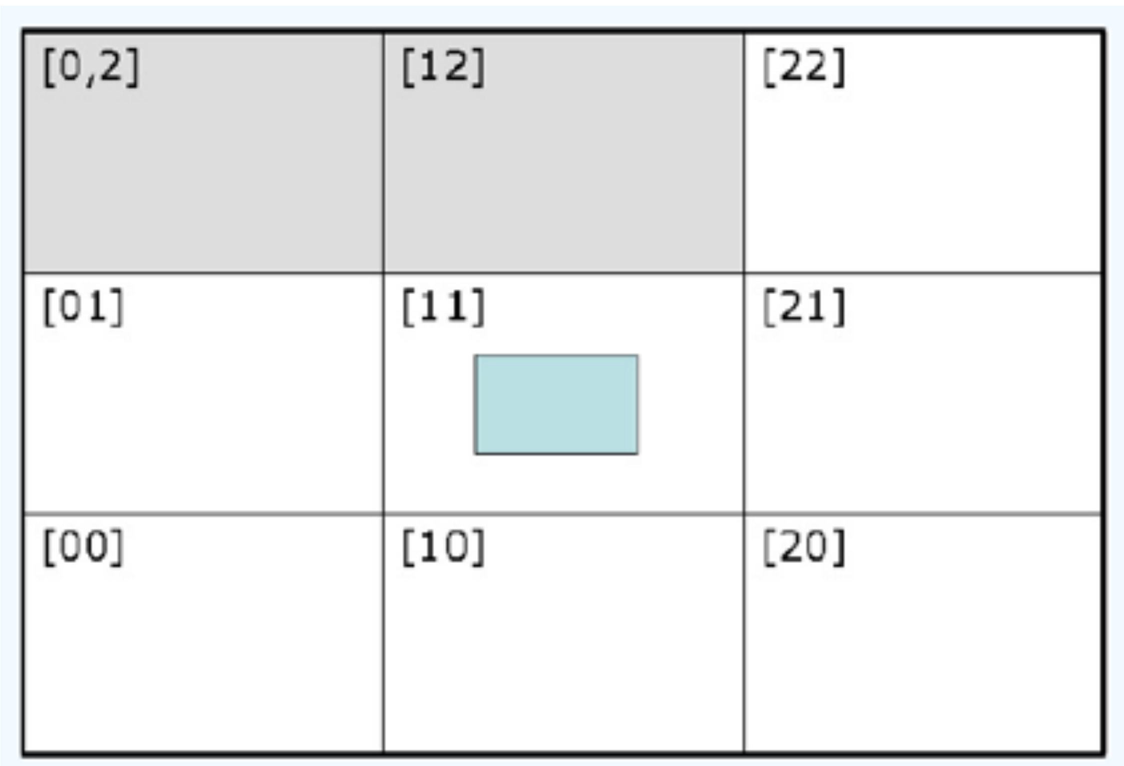
:: **Secondly,**

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

- 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

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

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

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

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

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

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

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

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*