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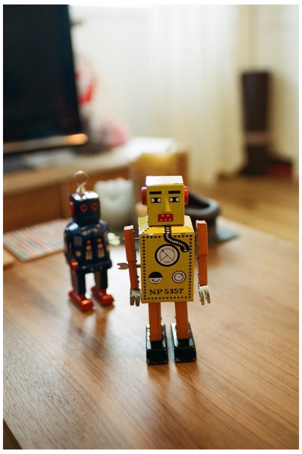
Planning & Multi-agent systems

Lecture 3 - 3.04.2024



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Today's lecture

- Planning (in general)
- Multi-agent system

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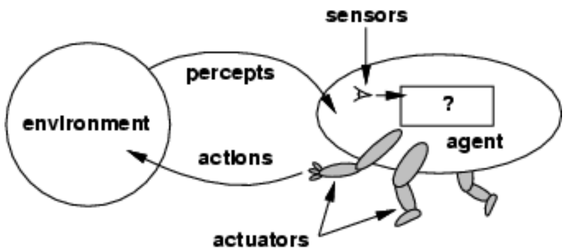
Remember the agent abstraction



- The agent perceives the current **state** via sensors
  - The **state** reflects the agent's and the environment's **status**.
- The agent takes action(s) to change the **status** of itself and/or the environment

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Different problem classifications

- Deterministic <-> non-deterministic
  - In deterministic, the outcome of an action is known
- Finite (search) space <-> infinite (search) space
- Static <-> dynamic
  - In static only the agent can change the world, thus the environment cannot change itself

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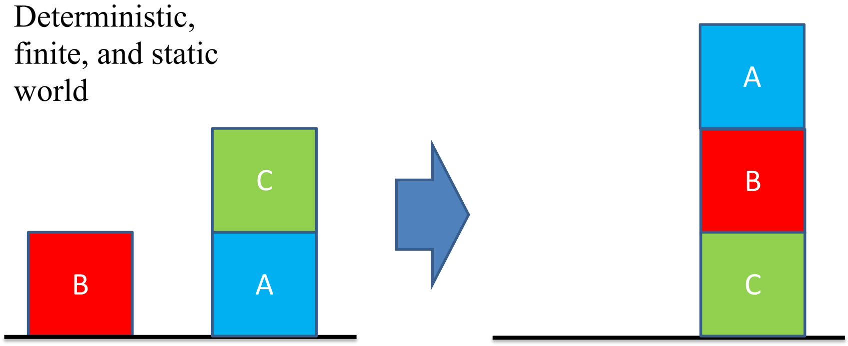
The Block World problem

Deterministic, finite, and static world



Start Goal

A benchmark problem about creating a plan from **Start** to **Goal**.

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The STRIPS formalism

- Stanford Research Institute Problem Solver
- Symbolic representation of the world
  - Deterministic, finite, and static world
  - **Closed World Assumption:**
    Fact not listed in a state are assumed to be false.
    We assume that the agent has full observability.

By the way, STRIPS is very handy for the problem in LAB 4

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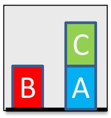
Representing the states

- **World states** are represented as sets of facts. We will also refer to facts as propositions.

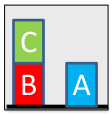


on(C,A)
clear(C)
clear(B)
on(B, table)
on(A, table)

State 1

on(C,B)
clear(C)
clear(A)
on(B, table)
on(A, table)

State 2



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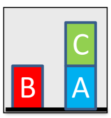
Semantics of STRIPS Actions (1/2)

- **Goals** are also represented as sets of facts.



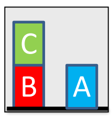
on(C,A)
clear(C)
clear(B)
on(B, table)
on(A, table)

State 1

MoveFBlock(C,A,B)

on(C,B)
clear(C)
clear(A)
on(B, table)
on(A, table)

State 2



- Set Goal to { on(C,B) }
- State 1 <u>does not</u> fulfil the goal. In State 2 the goal is fulfilled.

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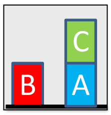
Semantics of STRIPS Actions (2/2)



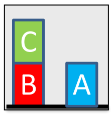
on(C,A)
clear(C)
clear(B)
on(B, table)
on(A, table)

State 1

MoveFBlock(C,A,B)

on(C,B)
clear(C)
clear(A)
on(B, table)
on(A, table)

State 2



- A STRIPS action definition specifies:
  1) a set of **preconditions** facts (PRE)
  2) a set of **addition effect** facts (ADD)
  3) a set of **deletion effect** facts (DEL)

MoveFblock(C,A,B):
PRE: {On(C,A) ^ Clear(C) ^ Clear(B) }
ADD: {On(C,B) ^ Clear(A)}
DEL: {On(C,A) ^ Clear(B) }

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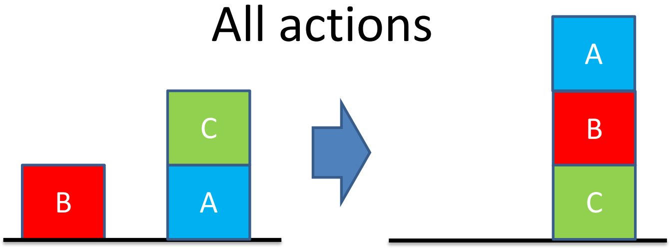
All actions



MoveOnTable(x, y):
Precondition: On(x,y) ∧ Clear(x)
Effect: On(x,table) ∧ Clear(y) ∧ ¬ On(x,y)

MoveFBlock(x, z, y):
Precondition: On(x,z) ∧ Clear(x) ∧ Clear(y)
Effect: On(x,y) ∧ Clear(z) ∧ ¬ On(x,z) ∧ ¬ Clear(y)

MoveFTable(x, y):
Precondition: On(x,table) ∧ ¬ Clear(x) ∧ ¬ Clear(y)
Effect: On(x,y) ∧ ¬ Clear(y) ∧ ¬ On(x,table)

More complex problem with a robot arm:
- *holding(Arm, Block)*
- *-free(ARM)*

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Two Basic Plan Solvers

- Both do state-space search
  - **Forward state space search:** start with initial state, apply actions until goal is reached
  - **Backward state space search:** start from goal, move backwards to find predecessor states until one predecessor is satisfied by the initial state.

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Forward State-Space Search (1/2)

Key: Unify the preconditions of actions with the sentences of a state to find out which actions are applicable to the state. Then apply the same unifier to the effect of an applicable action to get the information about its successor state

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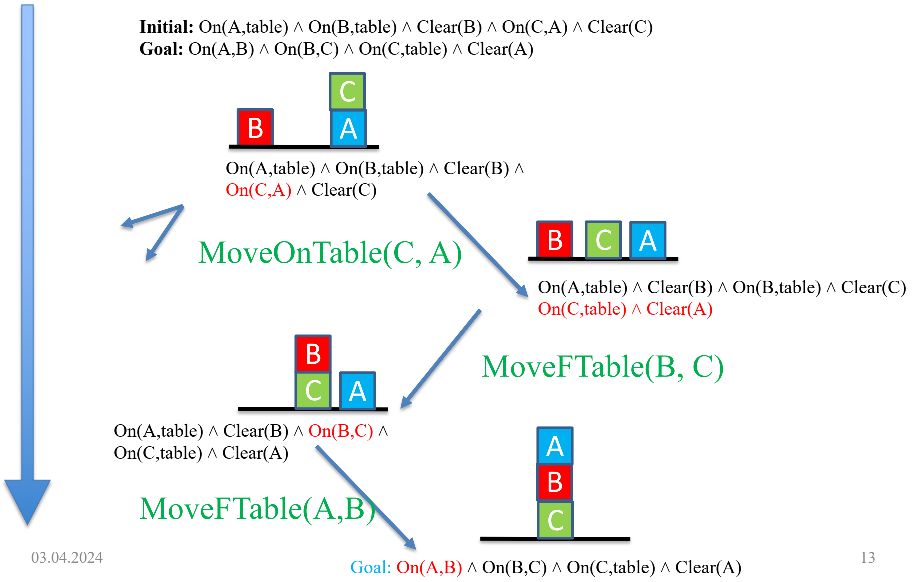
Forward State-Space Search (2/2)



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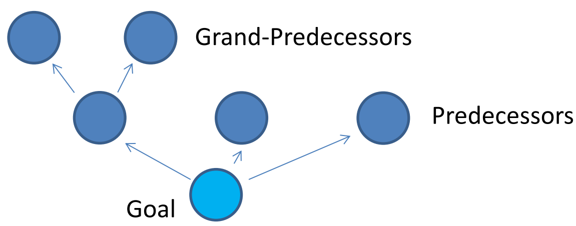
Backward State-Space Search (1/2)



- Acquire predecessors of the goal. A predecessor is the state that can be transited to the goal with a single action
- Select one predecessor as the new goal , generate the predecessors of this new goal
- The process continues until when a new generated state is satisfied by the initial state
- The task of generating predecessors can be considered as expansion of a node. Which node to expand for generation of its predecessors depends on search algorithm

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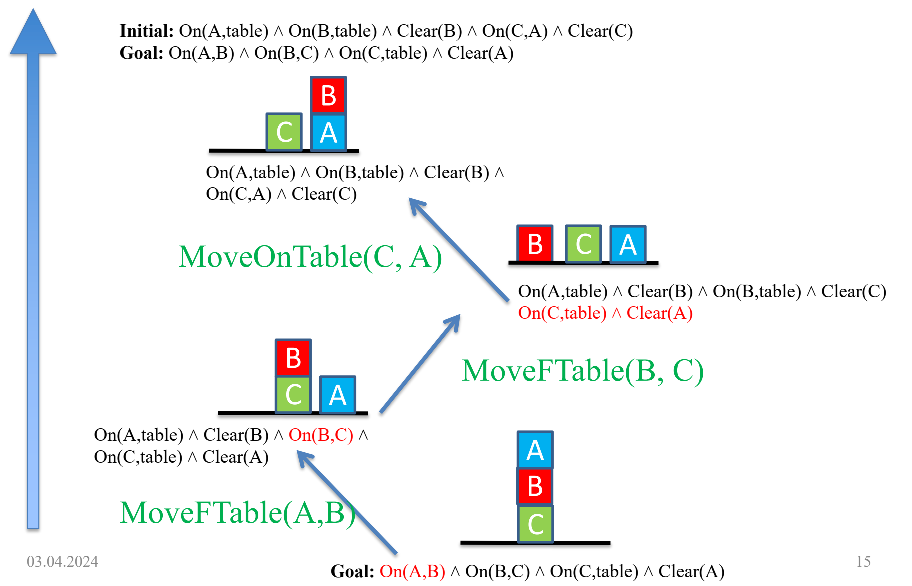
Backward State-Space Search (2/2)



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A side note related to the next lecture

- Backward state-search is how the **Prolog** language is designed. And remember:
  - **Prolog** is based on logic, thus a program consists of facts and rules. Just like the Block World definition above!
- Most common **Expert systems** are based on Forward state-search. So there is the link between them
  - You can still implement Forward state-search in Prolog if you want a common Expert system

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Multi-agent systems (MAS)

- What is MAS about?
  - Agents that, together with other agents, make decision in an environment
  - The environment can be physical, virtual, or mixed
  - Homogeneous architecture: Agents can be very different (drones, ground vehicles, having different sets of sensors/actuators, etc.)
- Why is MAS interesting from the perspective of AI?
  - Intelligence through interaction and collaboration
  - Many less costly agents (or robotics systems)
  - Beneficial when a large area will be monitored

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One Agent versus MAS (1/3)

- One **intelligent** agent
  - Central computing
  - High computing power is needed
  - Mainly inspired by (human) cognitive science
  - Advanced, and usually expensive, sensors (3D vision)
  - Sometimes the robot has a human appearance
- Many **more primitive** agents (MAS)
  - Distributed intelligence
  - Limited computer power is enough
  - Inspired by ants (and other insects), more primitive animals
  - Cheap/unreliable sensor(s), low resolution
  - Different designs, sometimes built by 3D-printed parts, “LEGO” bricks, or other types of affordable material

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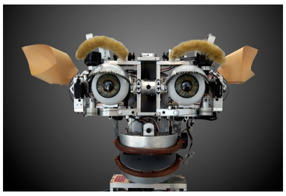
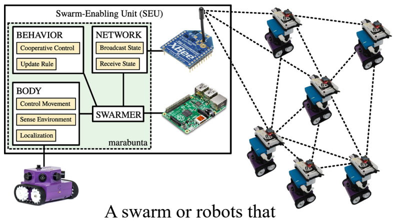
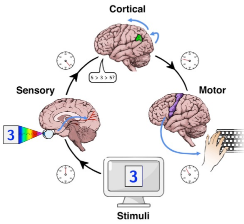
One Agent versus MAS (2/3)



Kismet robot Kismet is a robot head that can recognize and simulate emotions.



A swarm or robots that collaborate (pic.)



Inspiration from human brain and cognition (pic.)

Inspiration from primitive animals

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One agent versus MAS (3/3)

What is the motivation?

- One very “intelligent” agent
  - Research on human-robot interaction
  - Investigation of human behavior (children, etc.)
    - Home robotics in elderly care (product development)
  - Advanced (3D) vision research
- Many “less intelligent” agents (or MAS)
  - Research on robot-robot interaction
    - Group behavior analysis
  - Distributed intelligence for smart sensing (many sensors in a traffic junction)
    - Massively connected systems: 5G/6G, future internet
    - Information propagation in such systems (can they manage errors, noise, etc.)

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Decision making

- One decision maker
  - Central plan that is distributed to all
  - Non-planning agents are like actuators
- Multiple decision makers
  - One common goal versus all/some having different goals.

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Making collective decision

The contract net protocol

- **Task announcement:** An agent discovers a problem (a task), and becomes its manager
- **Biding:** All agents tell the manager if they have the capacity, and will to carry out the task
- **Awarding:** Successful bidders will try to carry out the task (and maybe divide it to smaller tasks…)

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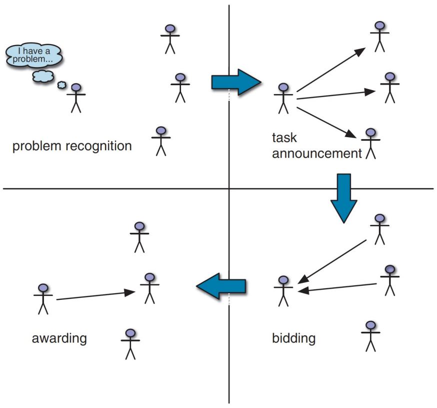
The contract net protocol



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Cooperative game theory (1/2)

- Agent can create coalitions for collaboration
  - How will the gain will be distributed between the agents?
  - What will make them to create a coalition?
  - Will there be a leader or will all be equal?
  - Can they leave a coalition to join another?
  - How can they be part of several coalitions?

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Cooperative game theory (2/2)

- Define
  - Costs for actions
  - A payoff/fitness function that tracts the performance of the agent
- Note that intelligence comes form the interactions, **not** advanced definitions for costs, and payoff/fitness functions

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Agents observing the world

- Having many agents means that many agents can change the world

  → Such problems are dynamic
- Every agent observe a part of the world
  - Their knowledge can be overlapping
  - Their observation can be overlapping
  - A change in the world can have **different meanings** for different agents based on their current knowledge

  → Such problems are non-deterministic

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Planning and MAS in LAB4

- You can choose between
  - STRIPS like behaviour in agents or
  - more primitive agents that collaborate more intensely
- LAB4's focus is on the whole system, and demonstrate intelligence by small less intelligent systems
  - The planning problem of building a house is simple! But this problem will demonstrate how complex MAS can be

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