

CS 1571 Introduction to AI
Lecture 18a

Planning: nonlinear planners

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Planning

Planning problem:

- find a sequence of actions that achieves some goal
- an instance of a search problem
- the state description is typically **very complex and relies on a logic-based representation**

Methods for modeling and solving a planning problem:

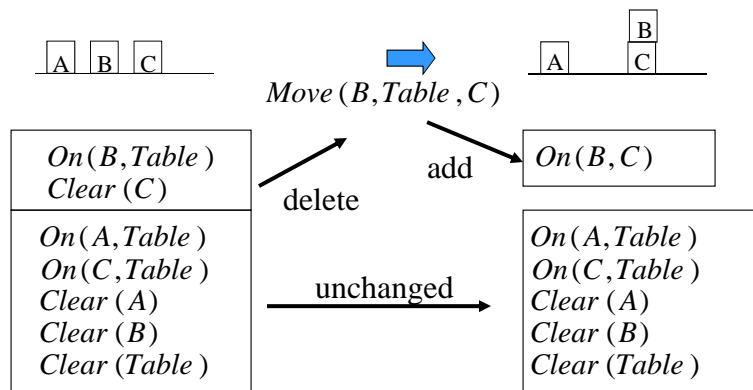
- Situation calculus based on FOL
- STRIPS – state-space search algorithm
- Partial-order planning algorithms

STRIPS planner

- **States:**
 - conjunction of literals, e.g. $On(A,B)$, $On(B,Table)$, $Clear(A)$
 - represent facts that are true at a specific point in time
- **Actions (operators):**
 - **Action:** $Move(x,y,z)$
 - **Preconditions:** conjunctions of literals with variables
 $On(x,y)$, $Clear(x)$, $Clear(z)$
 - **Effects.** Two lists:
 - **Add list:** $On(x,z)$, $Clear(y)$
 - **Delete list:** $On(x,y)$, $Clear(z)$
 - Everything else remains untouched (is preserved)

STRIPS planning

- Operator:** $Move(x,y,z)$
- **Preconditions:** $On(x,y)$, $Clear(x)$, $Clear(z)$
 - **Add list:** $On(x,z)$, $Clear(y)$
 - **Delete list:** $On(x,y)$, $Clear(z)$



Search in STRIPS

Objective:

Find a sequence of operators (a plan) from the initial state to the state satisfying the goal

Two approaches to build a plan:

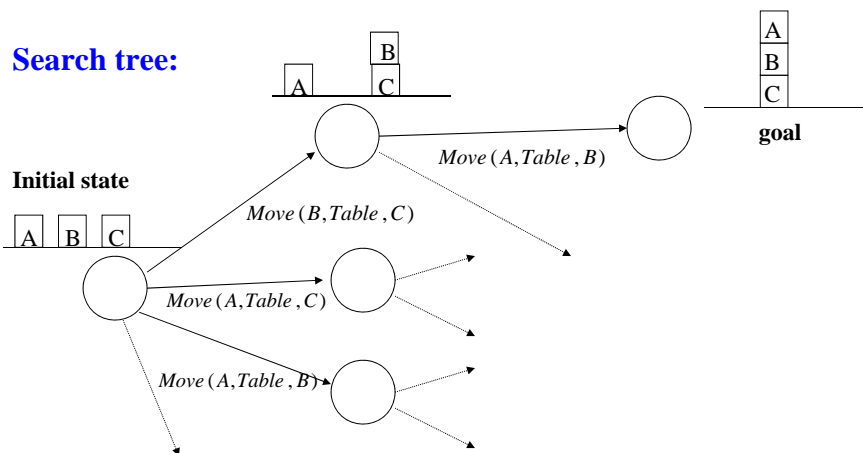
- **Forward state space search (goal progression)**
 - Start from what is known in the initial state and apply operators in the order they are applied
- **Backward state space search (goal regression)**
 - Start from the description of the goal and identify actions that help us to reach the goal

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Forward search (goal progression)

- Use operators to generate new states to search
- Check new states whether they satisfy the goal



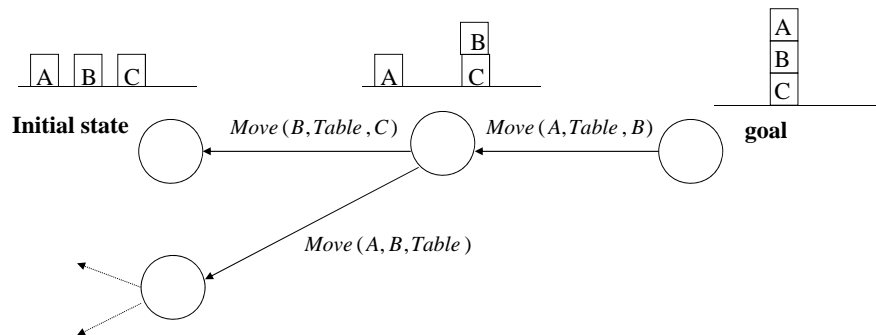
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Backward search (goal regression)

- Use operators to generate new goals
- Check whether the initial state satisfies the goal

Search tree:



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State-space search

- **Forward and backward state-space planning approaches:**
 - Work with strictly linear sequences of actions



- **Disadvantages:**
 - They cannot take advantage of the **problem decompositions** in which the goal we want to reach consists of a set of independent or nearly independent sub-goals
 - Action sequences cannot be **built from the middle**
 - No mechanism to represent **least commitment** in terms of the action ordering

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Divide and conquer

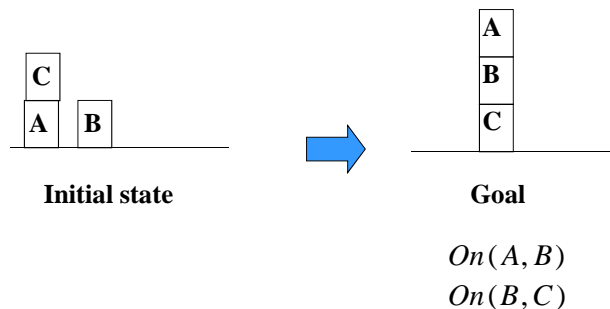
- **Divide and conquer strategy:**
 - divide the problem to a set of smaller sub-problems,
 - solve each sub-problem independently
 - combine the results to form the solution

In planning we would like to satisfy a set of goals

- **Divide and conquer in planning:**
 - Divide the planning goals along individual goals
 - Solve (find a plan for) each of them independently
 - Combine the plan solutions in the resulting plan
- Is it always safe to use divide and conquer?
 - No. There can be interacting goals.

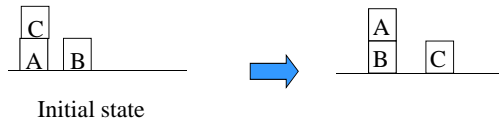
Sussman's anomaly.

- An example from the blocks world in which the divide and conquer strategy for goals fails due to interacting goals



Sussman's anomaly

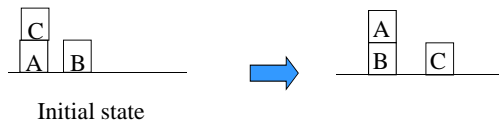
1. Assume we want to satisfy $On(A, B)$ first



But now we cannot satisfy $On(B, C)$ without undoing $On(A, B)$

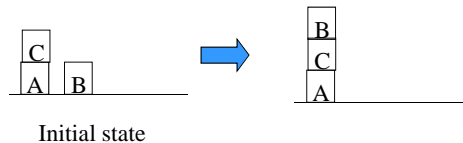
Sussman's anomaly

1. Assume we want to satisfy $On(A, B)$ first



But now we cannot satisfy $On(B, C)$ without undoing $On(A, B)$

2. Assume we want to satisfy $On(B, C)$ first.



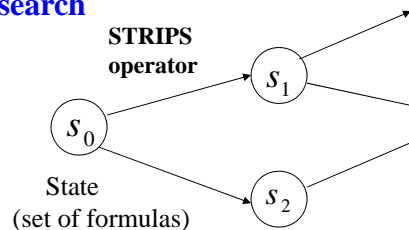
But now we cannot satisfy $On(A, B)$ without undoing $On(B, C)$

State space vs. plan space search

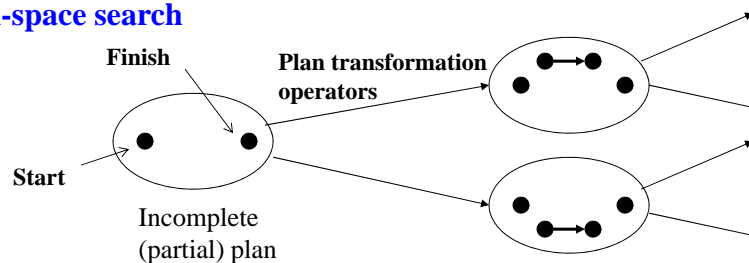
- An alternative to planning algorithms that search states (configurations of world)
- **Plan:** Defines a sequence of operators to be performed
- **Partial plan:**
 - plan that is not complete
 - Some plan steps are missing
 - some orderings of operators are not finalized
 - Only relative order is given
- **Benefits of working with partial plans:**
 - We do not have to build the sequence from the initial state or the goal
 - We do not have to commit to a specific action sequence
 - We can work on sub-goals individually (divide and conquer)

State-space vs. plan-space search

State-space search



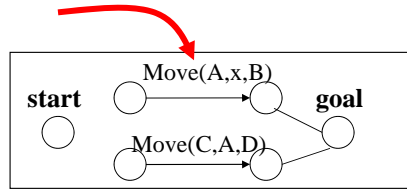
Plan-space search



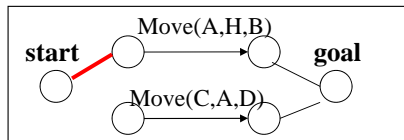
Plan transformation operators

Examples of :

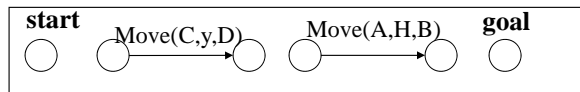
- Add an operator to a plan so that it satisfies some open condition



- Add link (+ instantiate)



- Order (reorder) operators



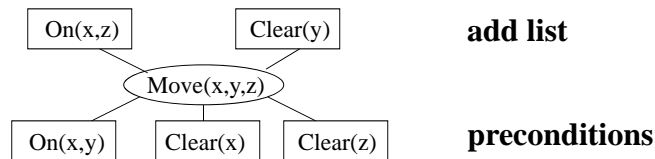
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Partial-order planners (POP)

- also called **Non-linear planners**
- Use STRIPS operators

Graphical representation of an **operator** $\text{Move}(x,y,z)$



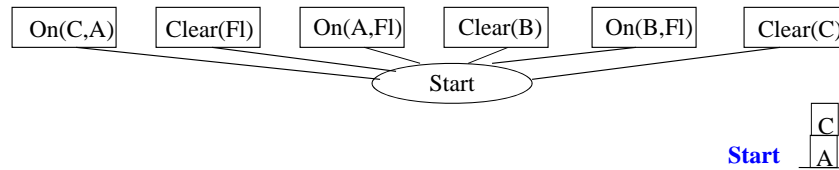
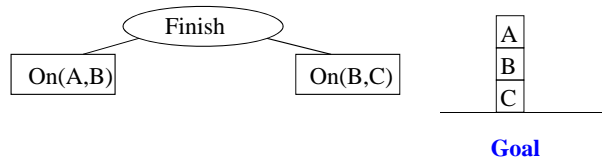
Delete list is not shown !!!

Illustration of a POP on the Sussman's anomaly case

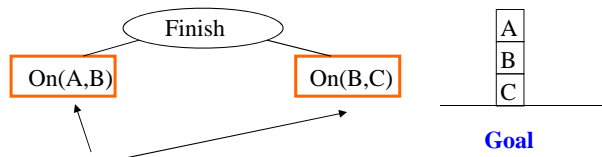
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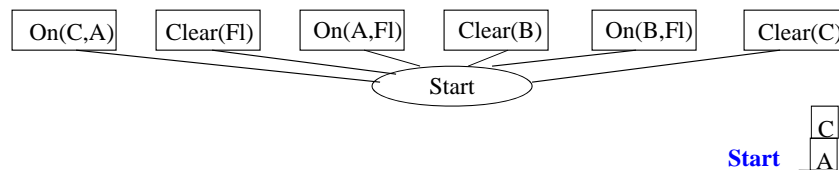
Partial order planning. Start and finish.



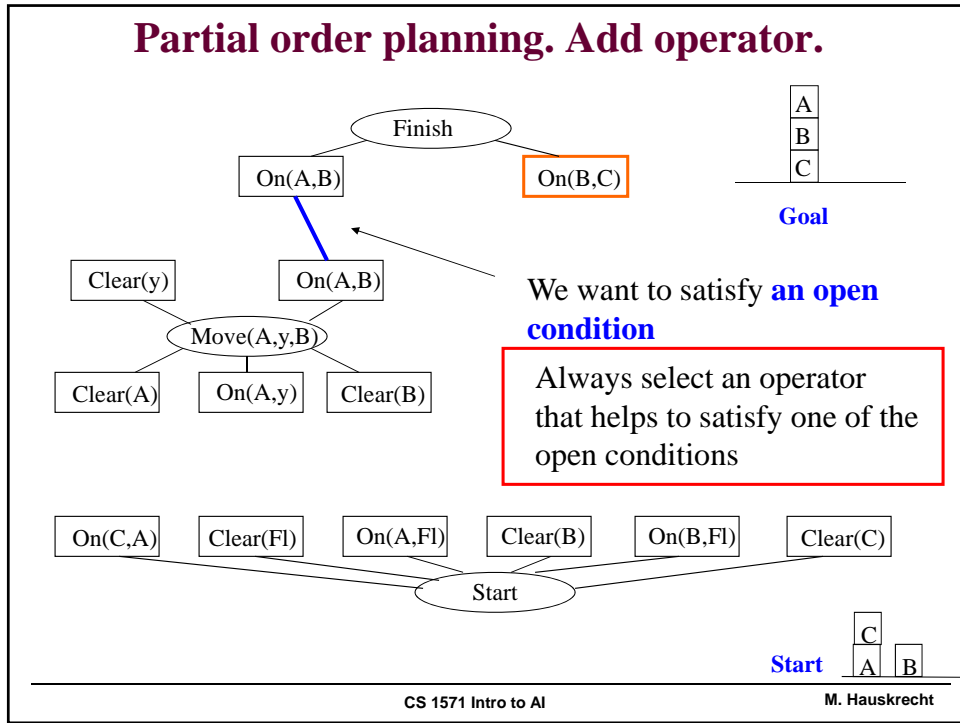
Partial order planning. Start and finish.



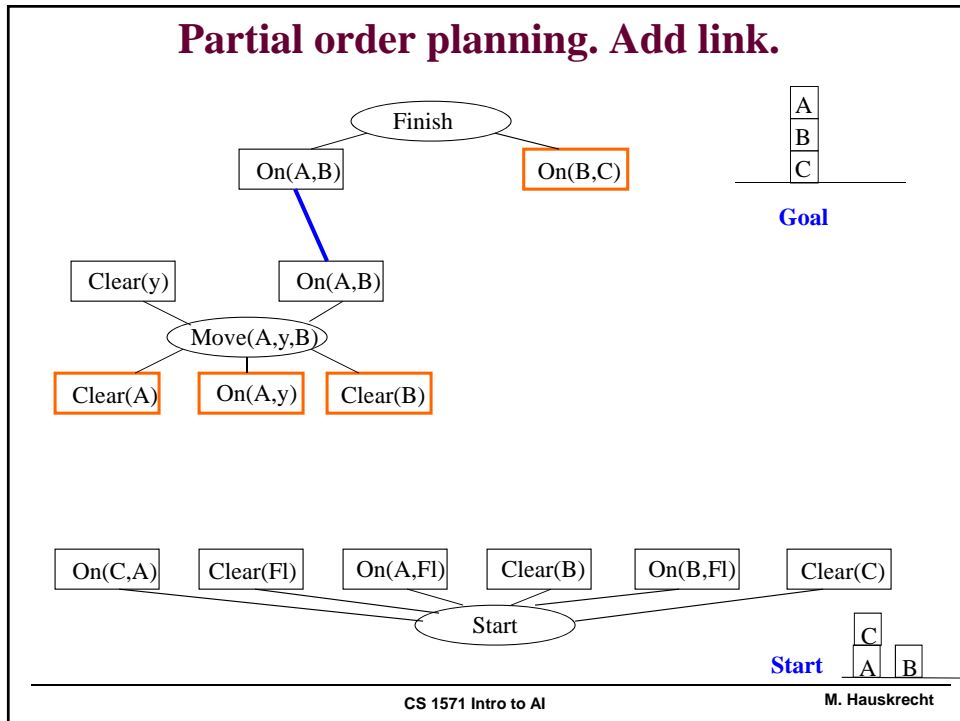
Open conditions: conditions yet to be satisfied



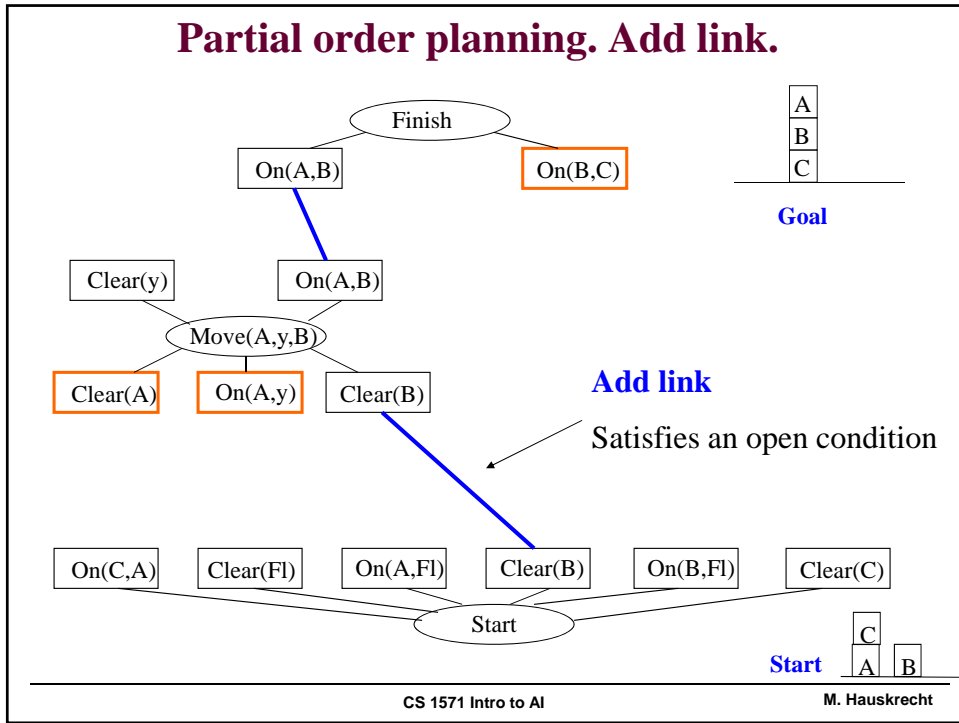
Partial order planning. Add operator.



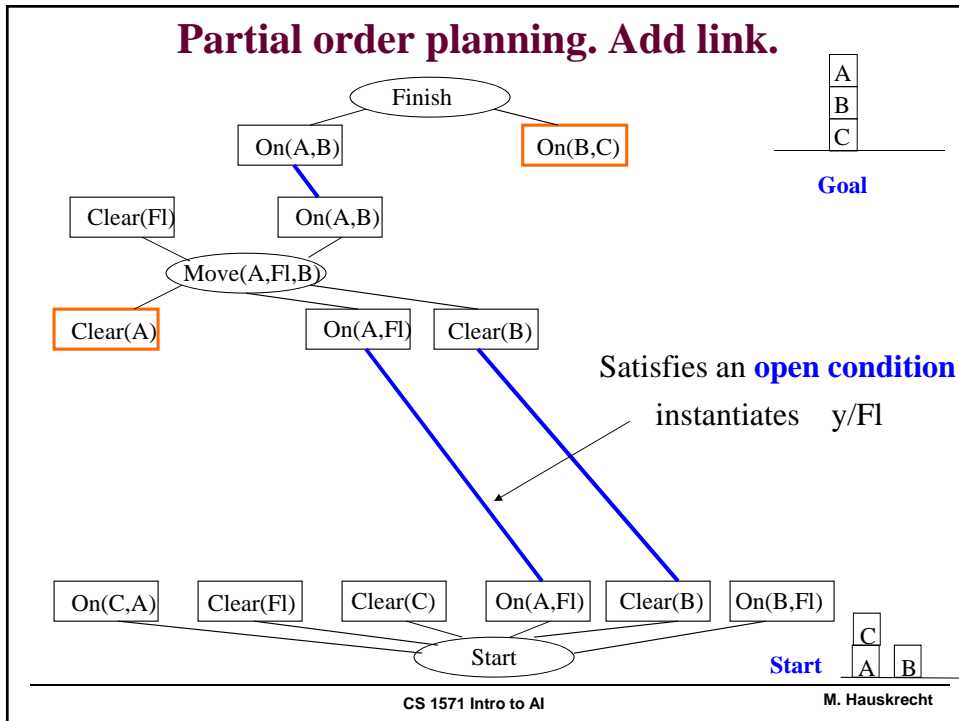
Partial order planning. Add link.

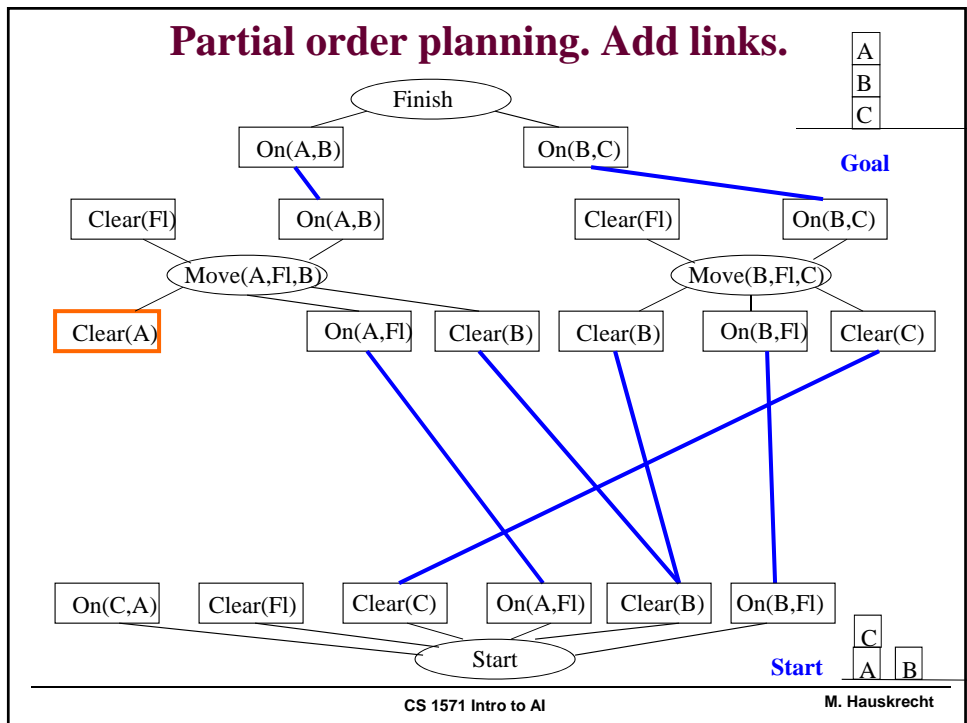
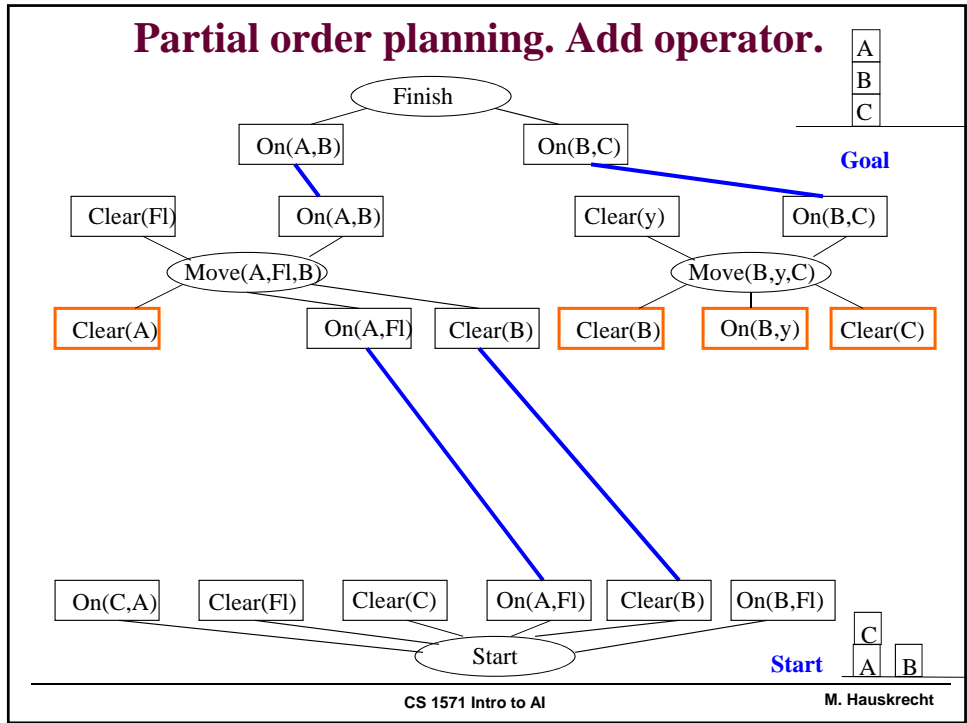


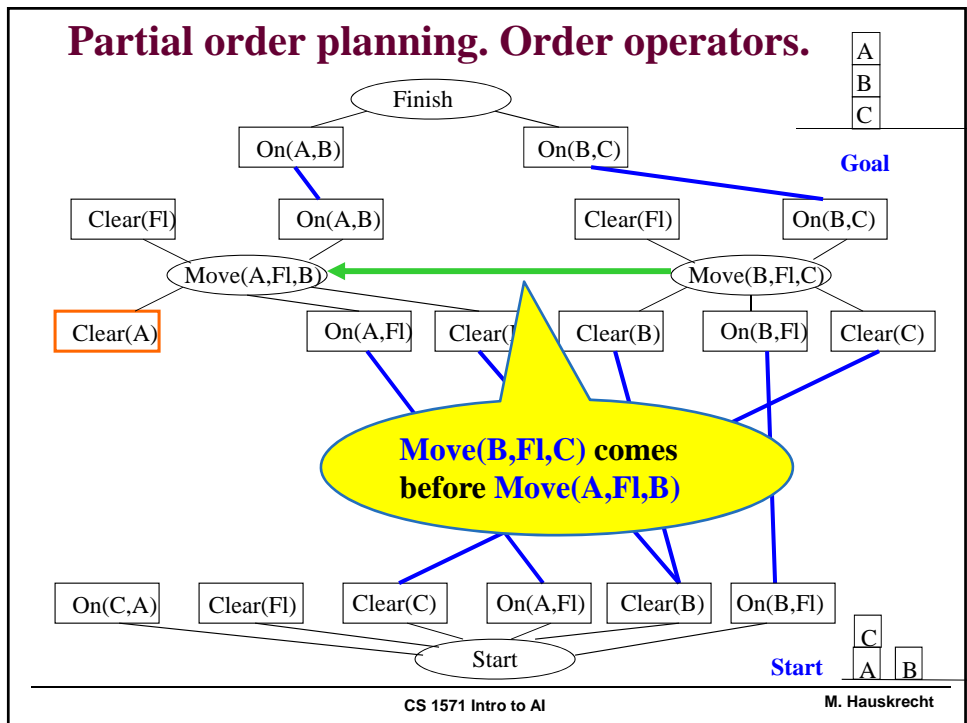
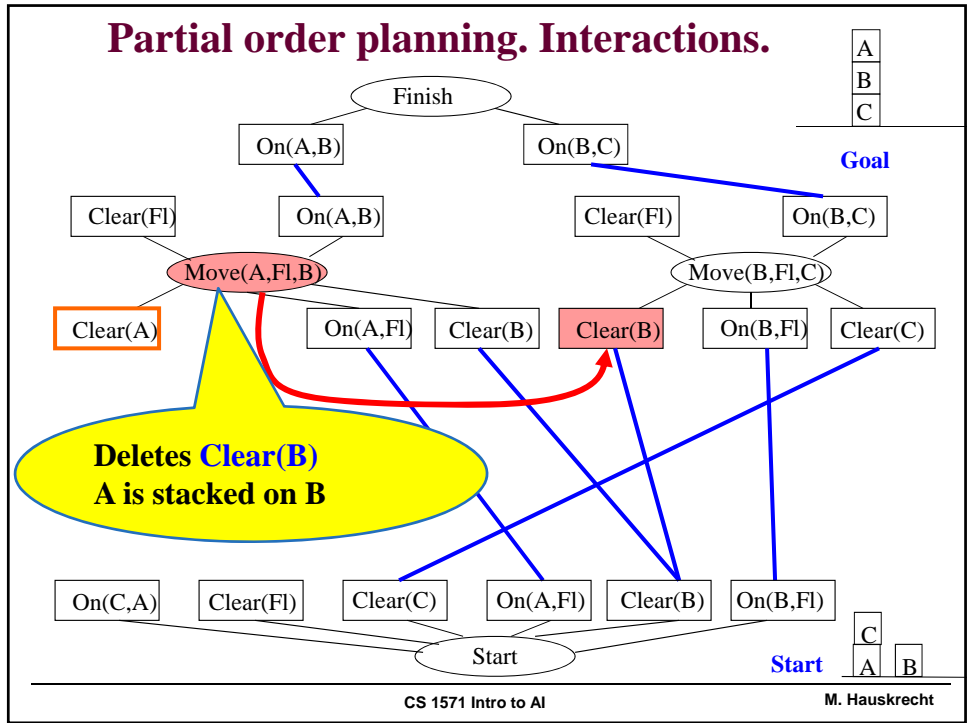
Partial order planning. Add link.

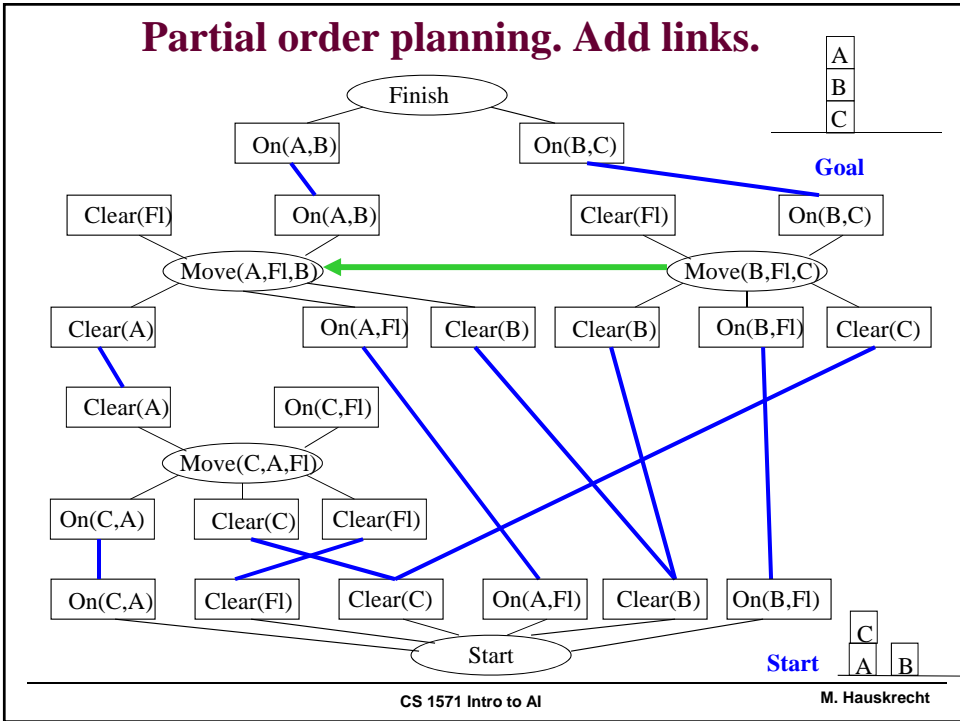
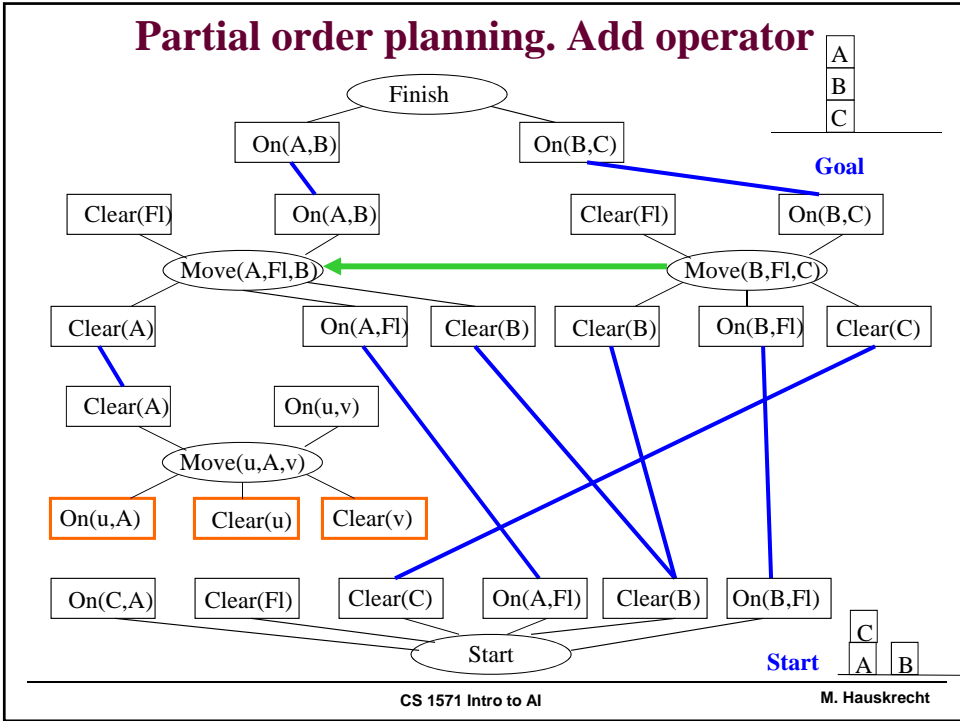


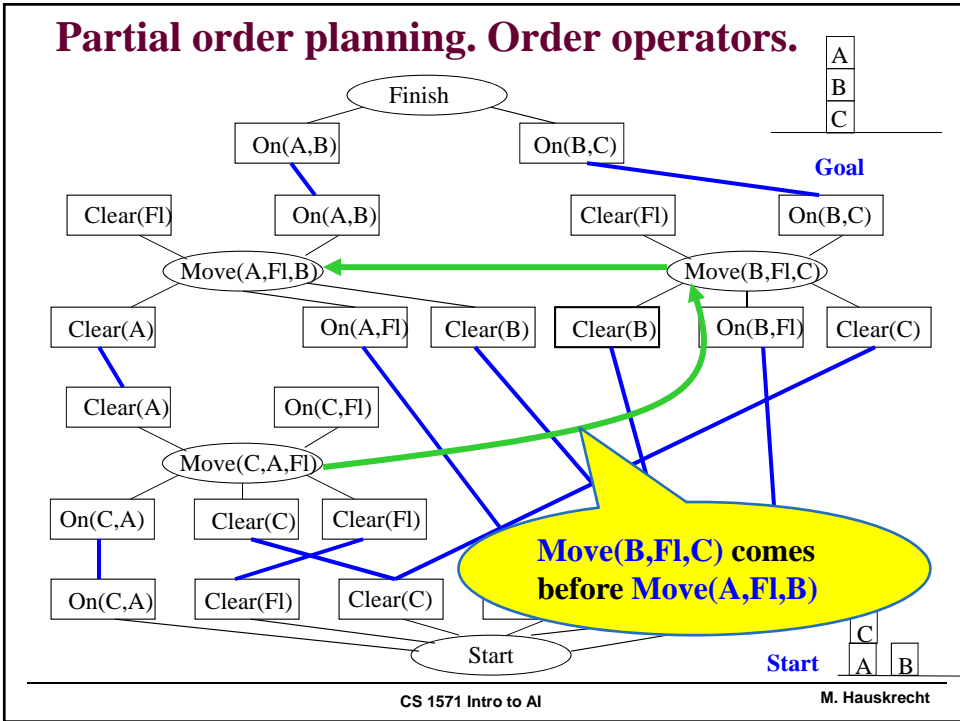
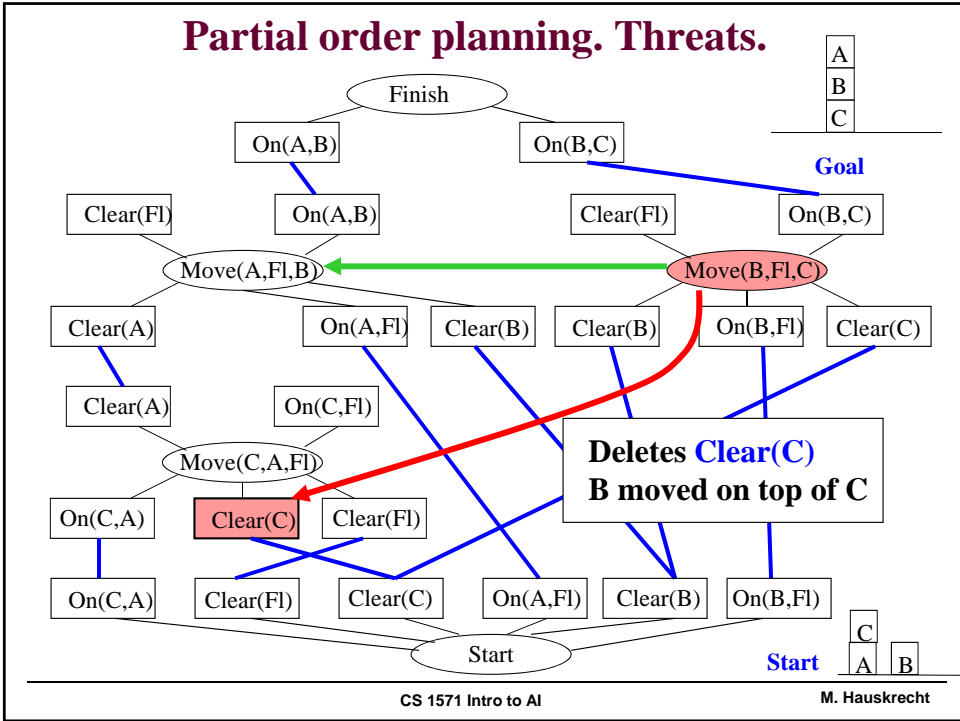
Partial order planning. Add link.

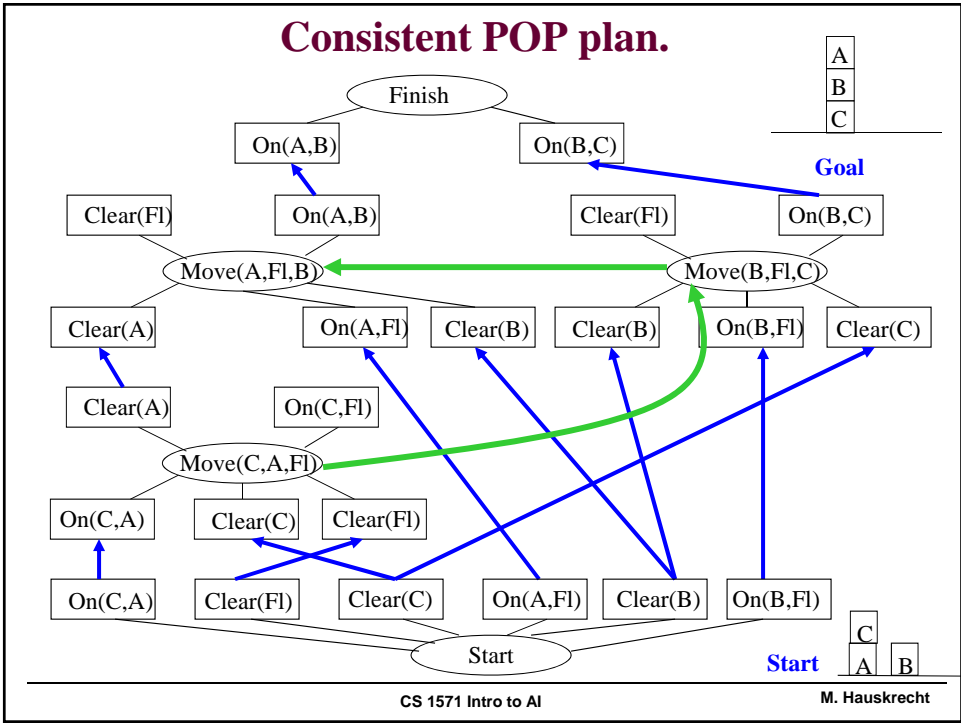
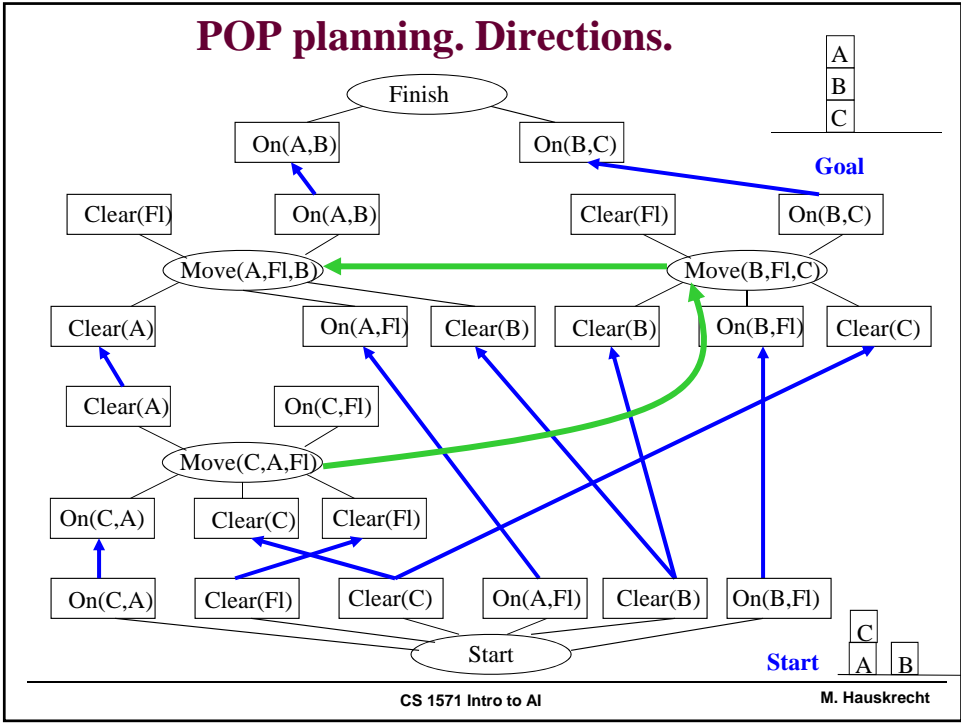






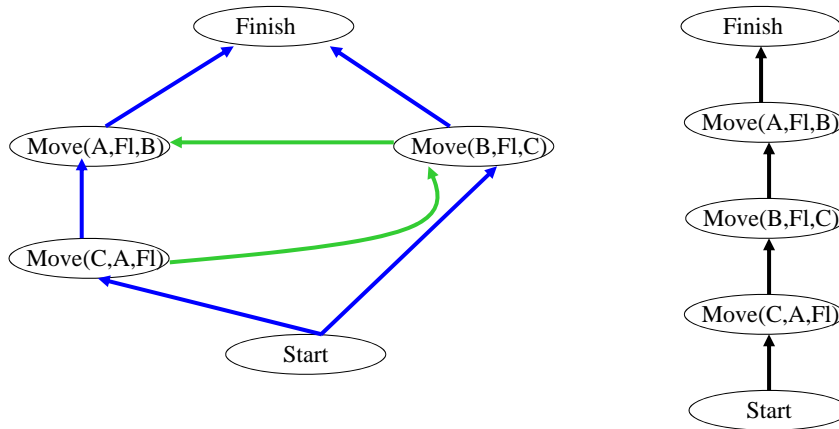






Partial order planning. Result plan.

Plan: a topological sort of a graph

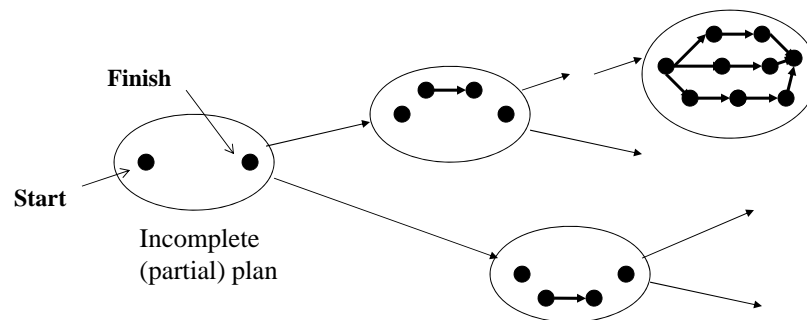


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Partial order planning.

- **Remember** we search the space of partial plans



- POP: **is sound and complete**

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Hierarchical planners

Extension of STRIPS planners.

- Example planner: ABSTRIPS.

Idea:

- Assign a **criticality level** to each conjunct in preconditions list of the operator
- Planning process refines the plan gradually based on criticality threshold, starting from the highest criticality value:
 - Develop the plan ignoring preconditions of criticality less than the criticality threshold value (assume that preconditions for lower criticality levels are true)
 - Lower the threshold value by one and repeat previous step

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Towers of Hanoi



Start position

Goal position

Hierarchical planning

Assume:

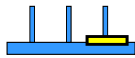
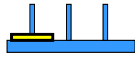
- the largest disk – criticality level 2
- the medium disk – criticality level 1
- the smallest disk – criticality level 0

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Hierarchical planning

Level 2

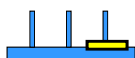
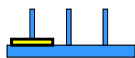


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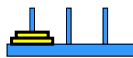
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Hierarchical planning

Level 2

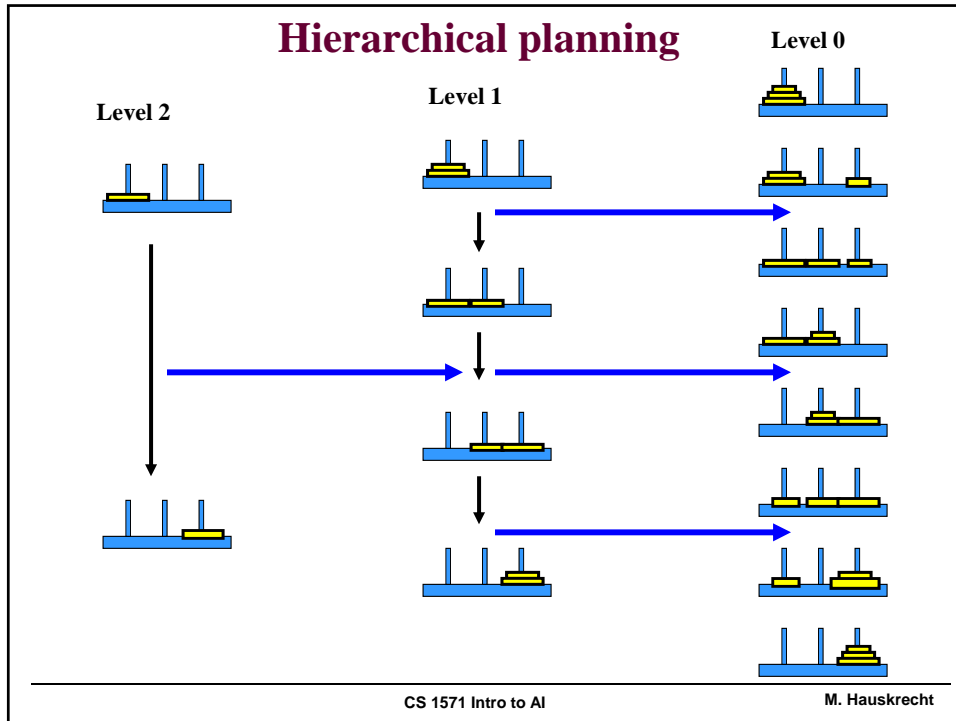


Level 1



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Planning with incomplete information

Some conditions relevant for planning can be:

- true, false or **unknown**

Example:

- Robot and the block is in Room 1
- **Goal:** get the block to Room 4
- **Problem:** The door between Room1 and 4 can be closed

Room4	Room3
↑	
Room1	Room2

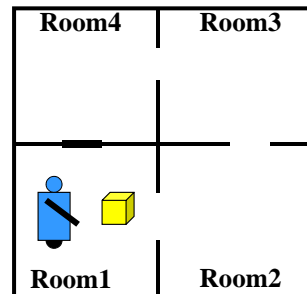
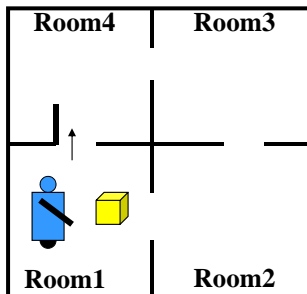
Room4	Room3
—	
Room1	Room2

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Planning with incomplete information

Initially we do not know whether the door is opened or closed:

- **Different plans:**
 - **If not closed:** pick the block, go to room 4, drop the block
 - **If closed:** pick the block, go to room2, then room3 then room4 and drop the block

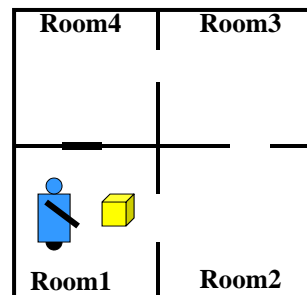
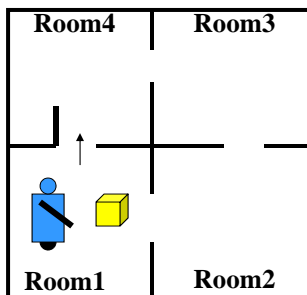


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Conditional planners

- Are capable to create conditional plans that cover all possible situations (contingencies) – also called **contingency planners**
- Plan choices are applied when the missing information becomes available
- Missing information can be sought actively through actions
 - **Sensing actions**



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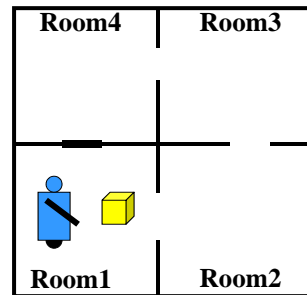
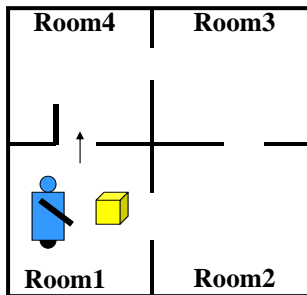
Sensing actions

Example:

CheckDoor(d): checks the door d

Preconditions: $\text{Door}(d,x,y)$ – one way door between x and y
 & $\text{At}(\text{Robot},x)$

Effect: $(\text{Closed}(d) \vee \neg \text{Closed}(d))$ - one will become true

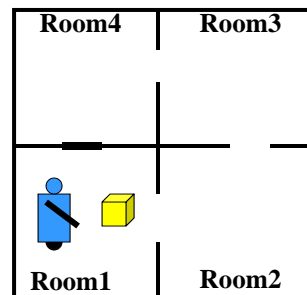
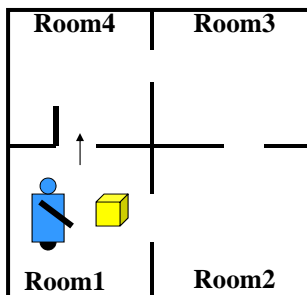
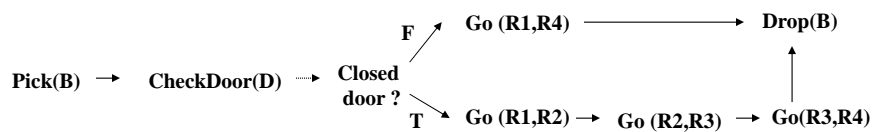


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Conditional plans

Sensing actions and conditions incorporated within the plan:



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