CS 1571 Introduction to AI
Lecture 17

Planning

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

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

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

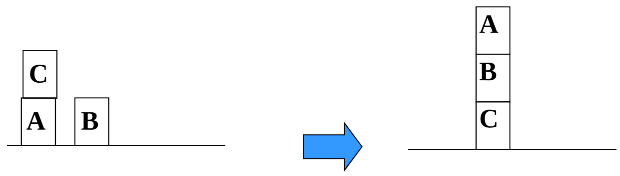
In planning we would like to satisfy a set of goals

- **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 fails due to interacting goals

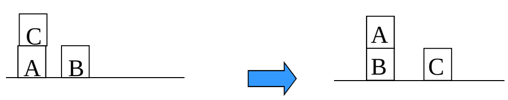


Initial state **Goal**

$On(A,B)$
$On(B,C)$

Sussman's anomaly

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

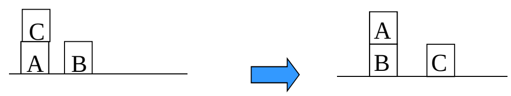


Initial state

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

Sussman's anomaly

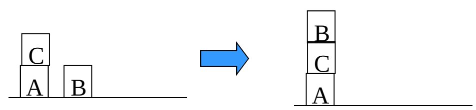
1. Assume we want to satisfy $On(A,B)$ first



Initial state

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

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



Initial state

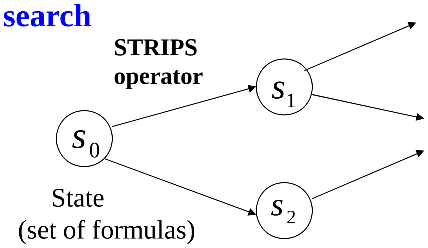
But now we cannot satisfy $On(A,B)$ without undoing $On(B,C)$

State space vs. plan space search

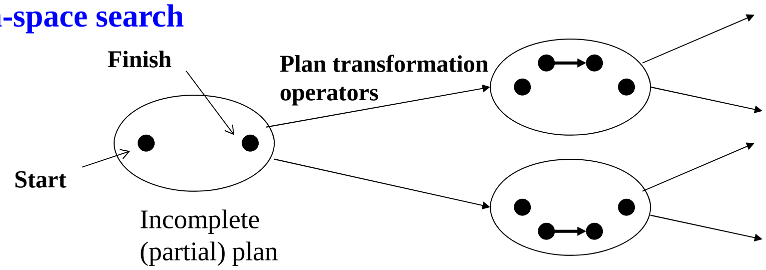
- An alternative to planning algorithms that search states (configurations of world)
- **Plan:** Defines a sequence of operators to be performed
- **Partial plan:**
  - plan that is not complete
    - Some plan steps are missing
  - some orderings of operators are not finalized
    - Only relative order 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



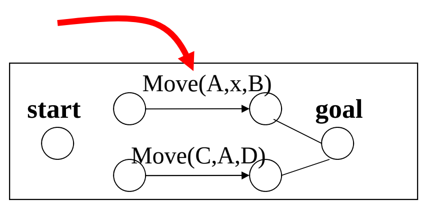
Plan-space search



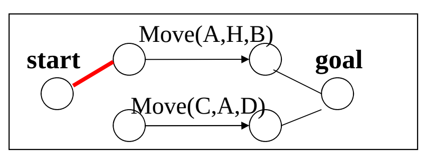
Plan transformation operators

Examples of :

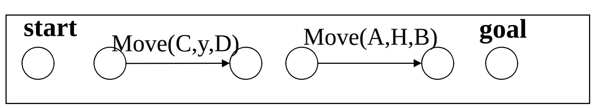
- **Add an operator to a plan so that it satisfies some open condition**



- **Add link (+ instantiate)**



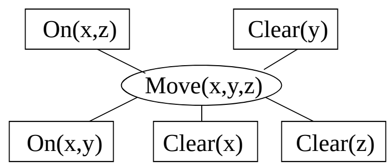
- **Order (reorder) operators**



Partial-order planners (POP)

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

Graphical representation of an **operator** **Move(x,y,z)**



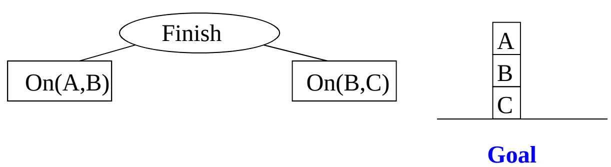
add list

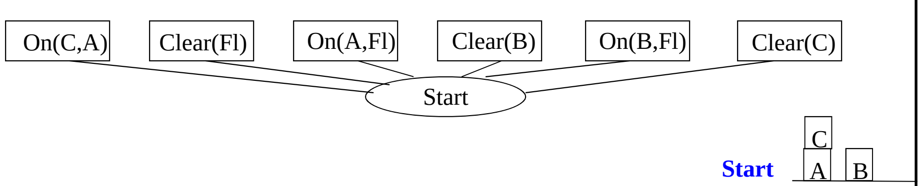
preconditions

Delete list is not shown !!!

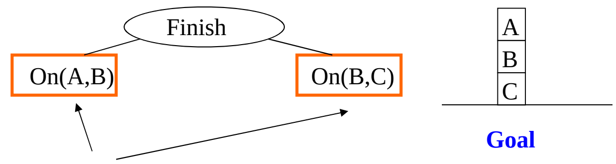
Illustration of a POP on the Sussman's anomaly case

Partial order planning. Start and finish.

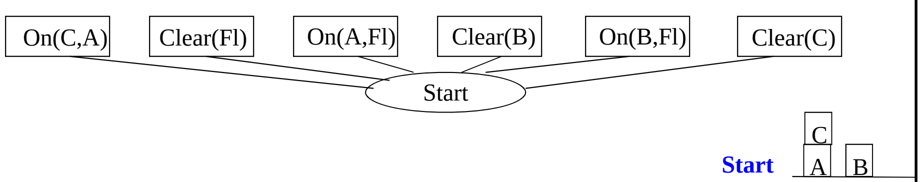




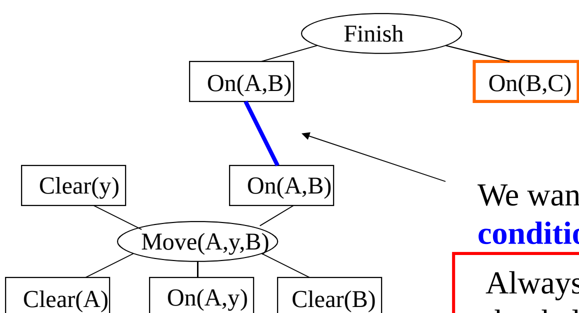
Partial order planning. Start and finish.

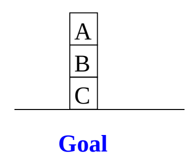


Open conditions: conditions yet to be satisfied



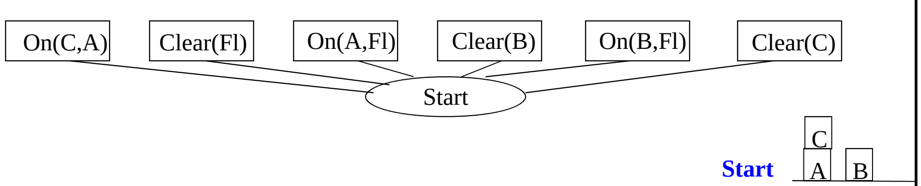
Partial order planning. Add operator.



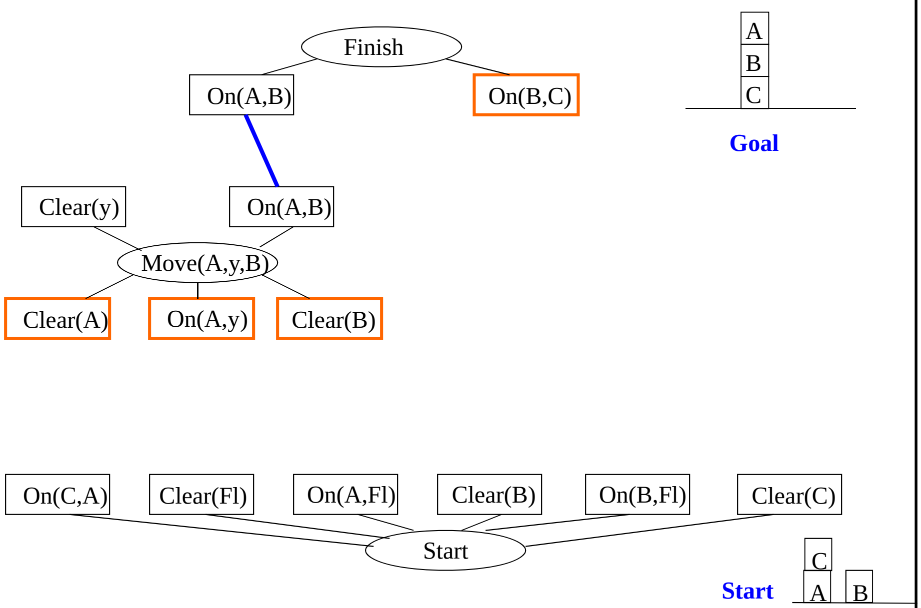


We want to satisfy **an open condition**

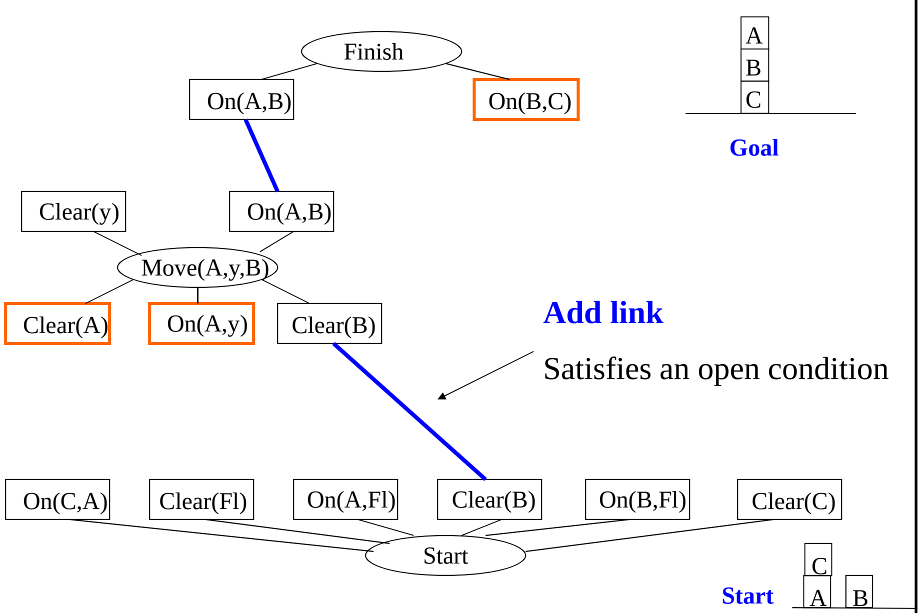
Always select an operator that helps to satisfy one of the open conditions



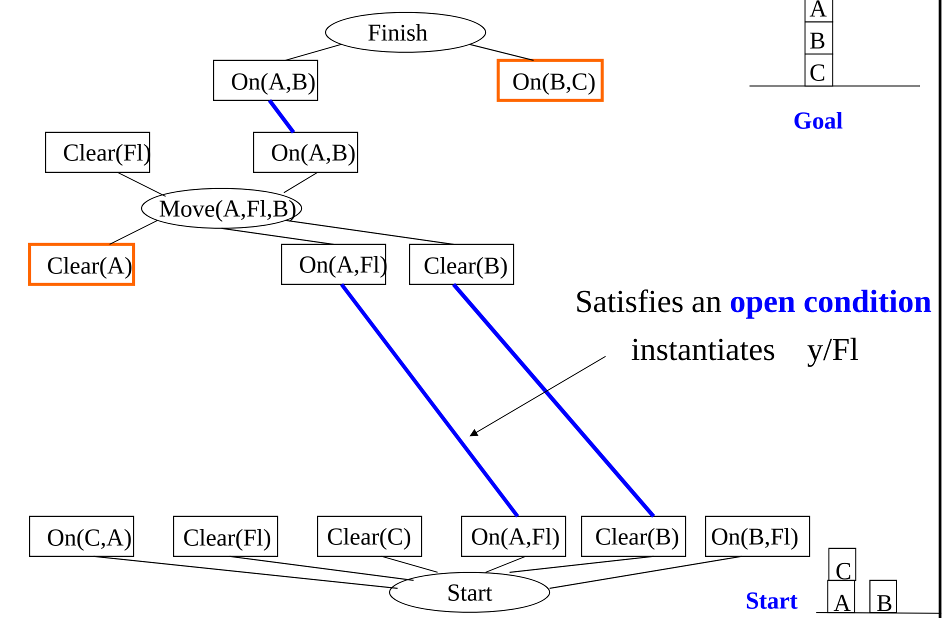
Partial order planning. Add link.



Partial order planning. Add link.



Partial order planning. Add link.



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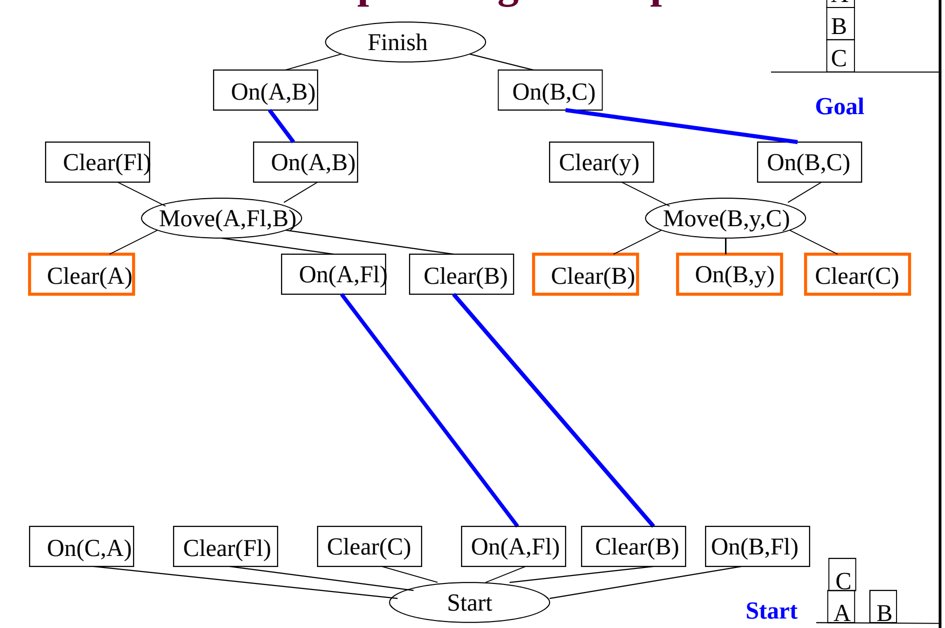
Partial order planning. Add operator.



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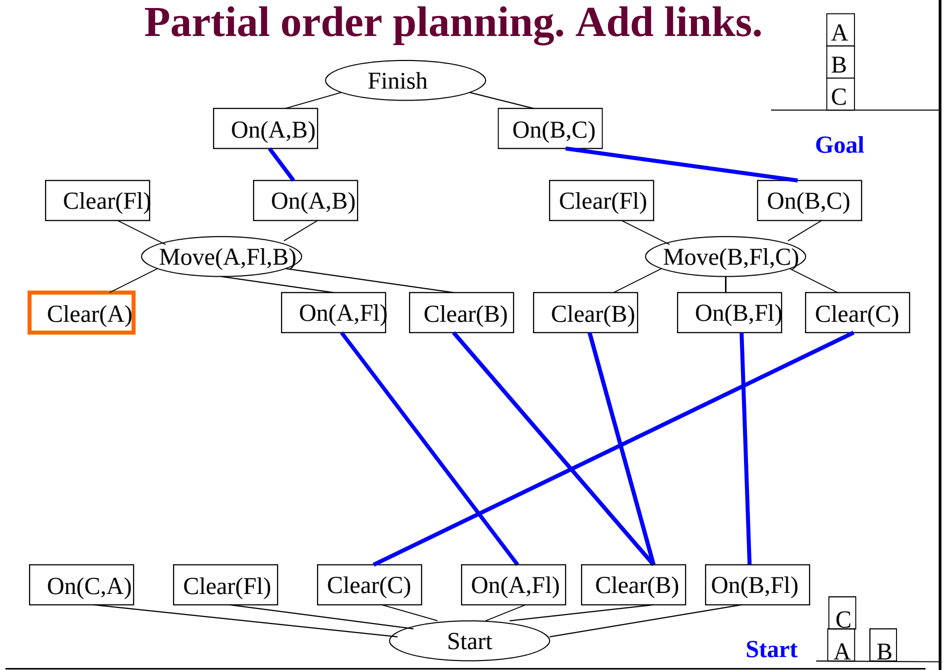
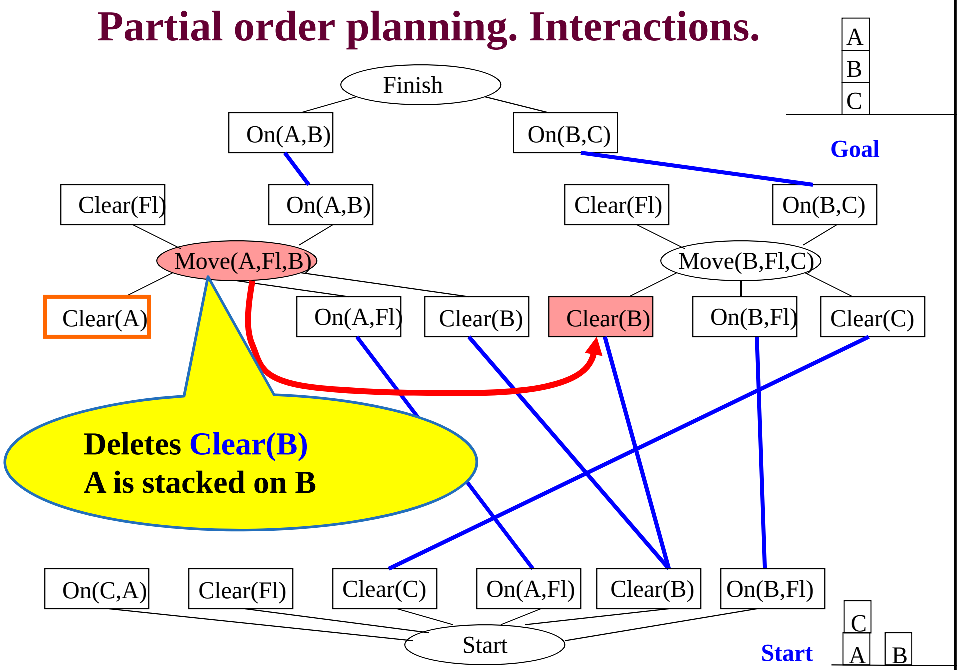
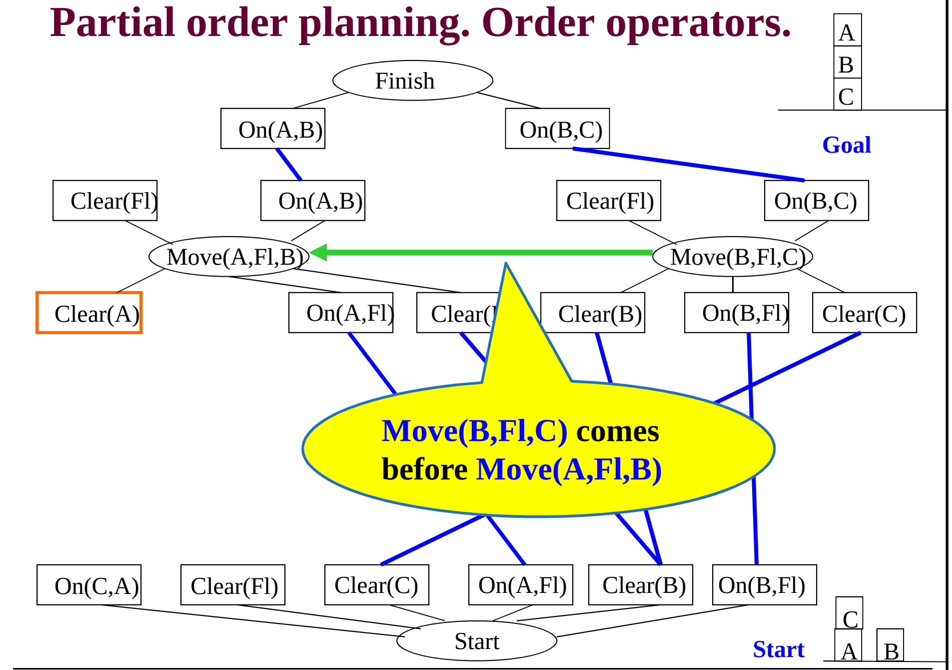
Partial order planning. Add links.



Partial order planning. Interactions.



Partial order planning. Order operators.



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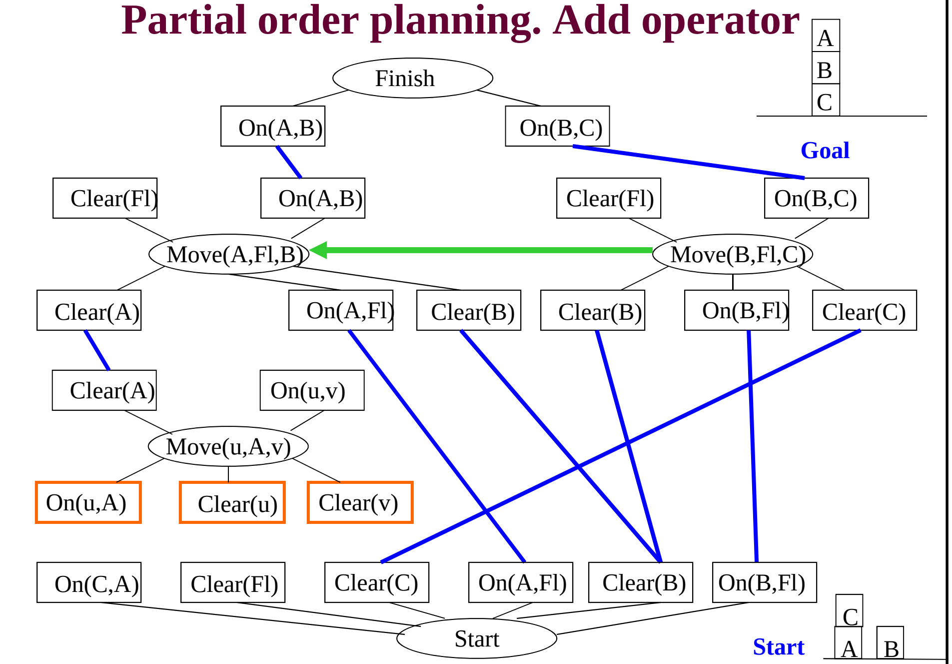
Partial order planning. Add operator



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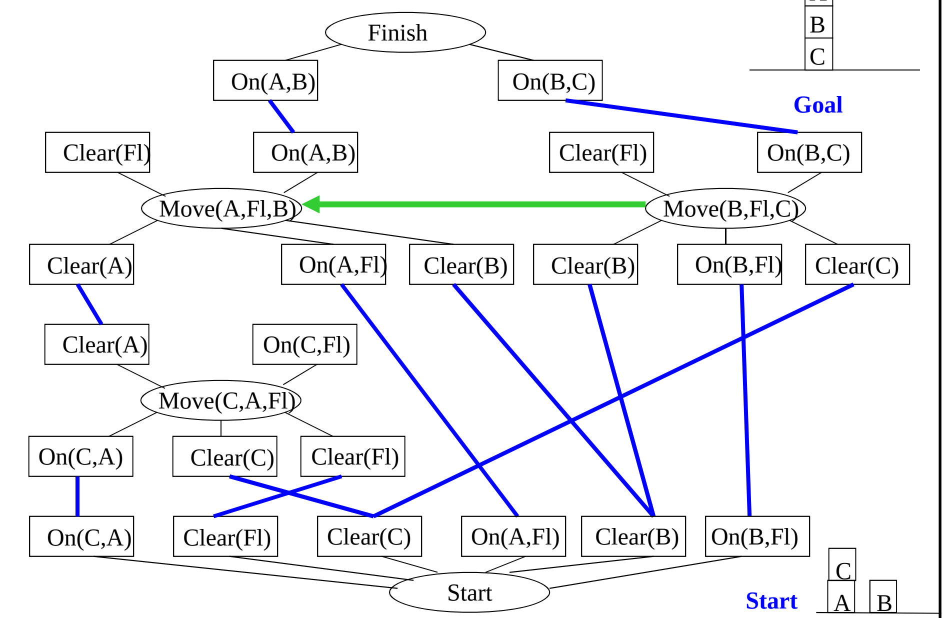
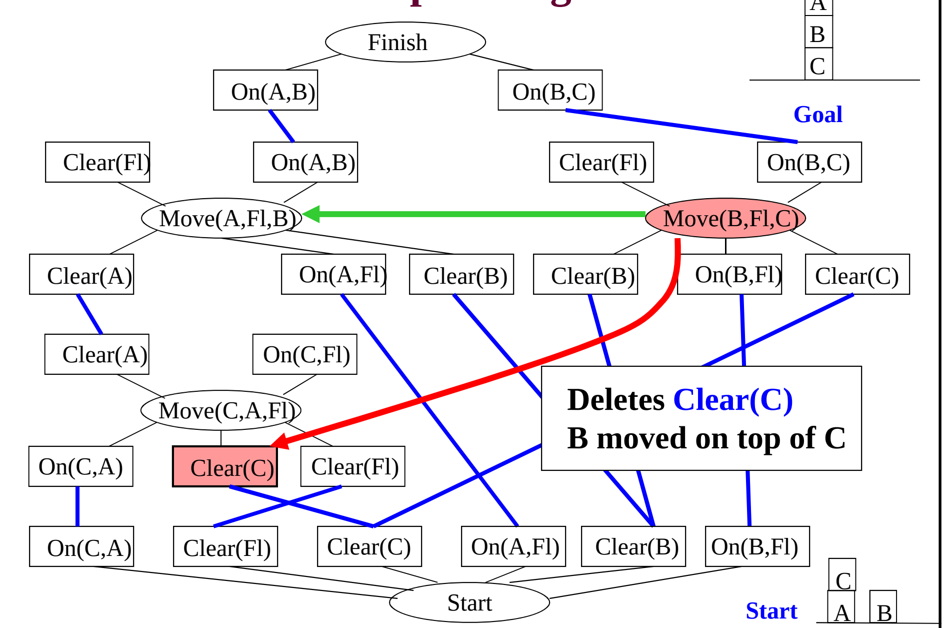
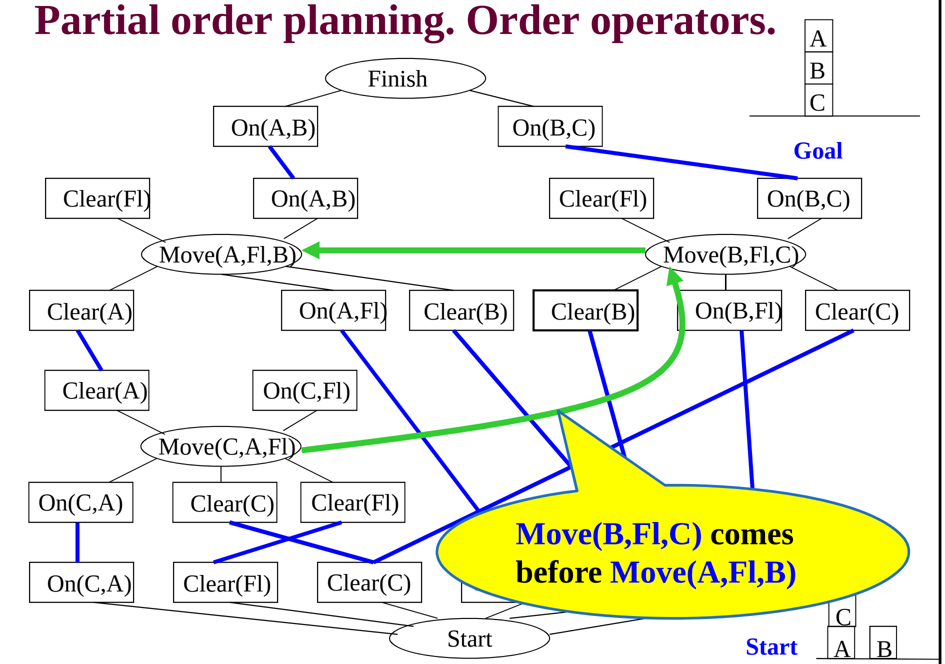
Partial order planning. Add links.



Partial order planning. Threats.



Partial order planning. Order operators.



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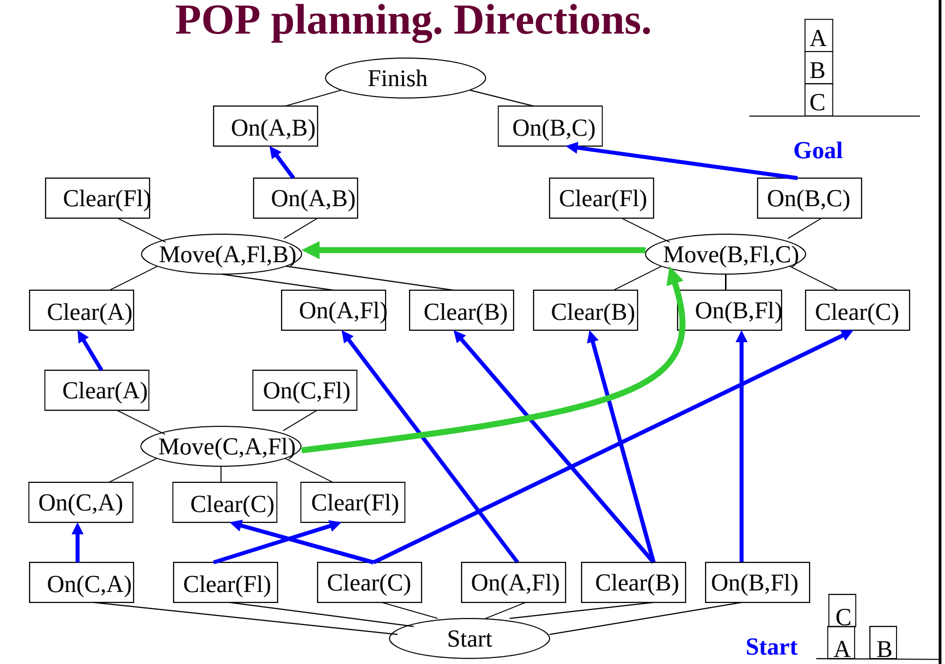
POP planning. Directions.



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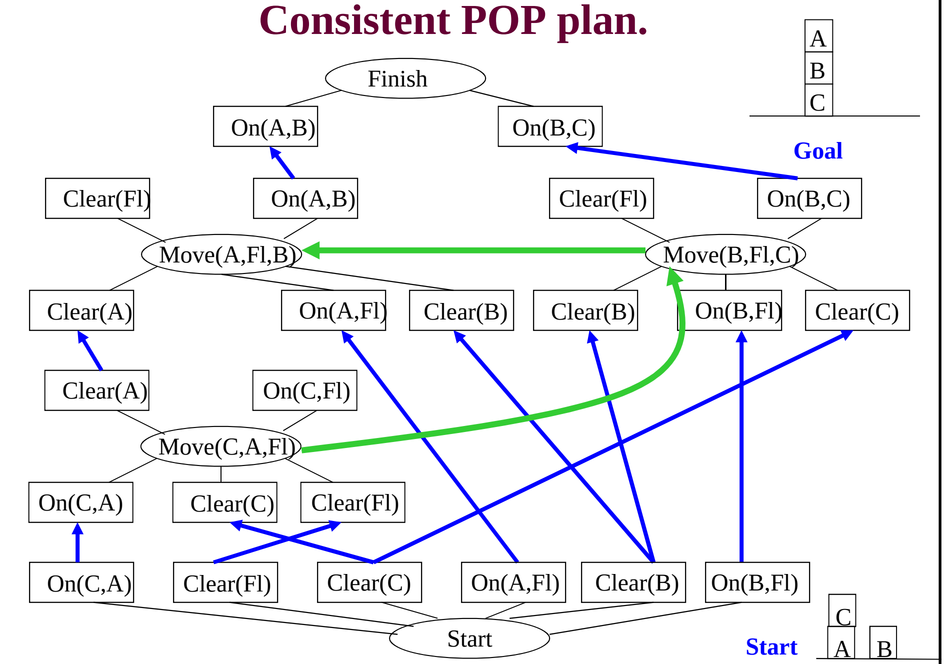
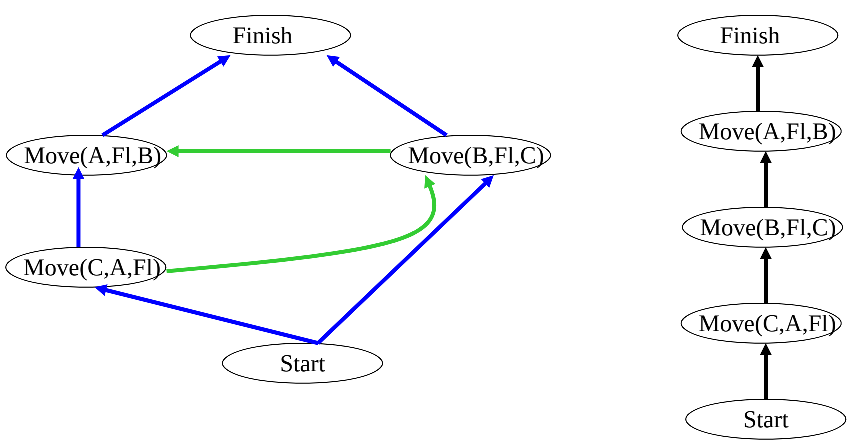
Consistent POP plan.



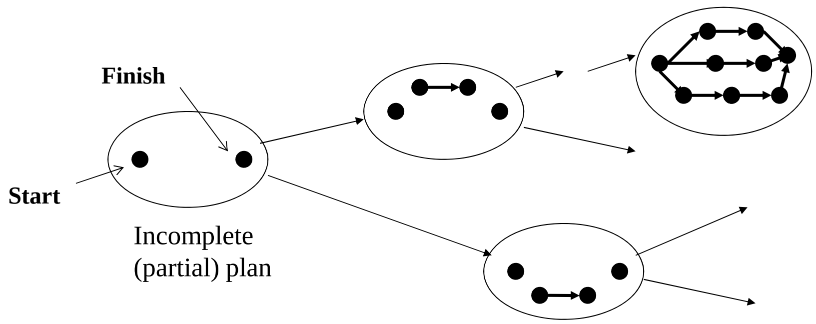
Partial order planning. Result plan.

Plan: a topological sort of a graph



Partial order planning.

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



- POP: **is sound and complete**

Hierarchical planners

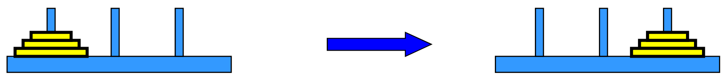
Extension of STRIPS planners.

- 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

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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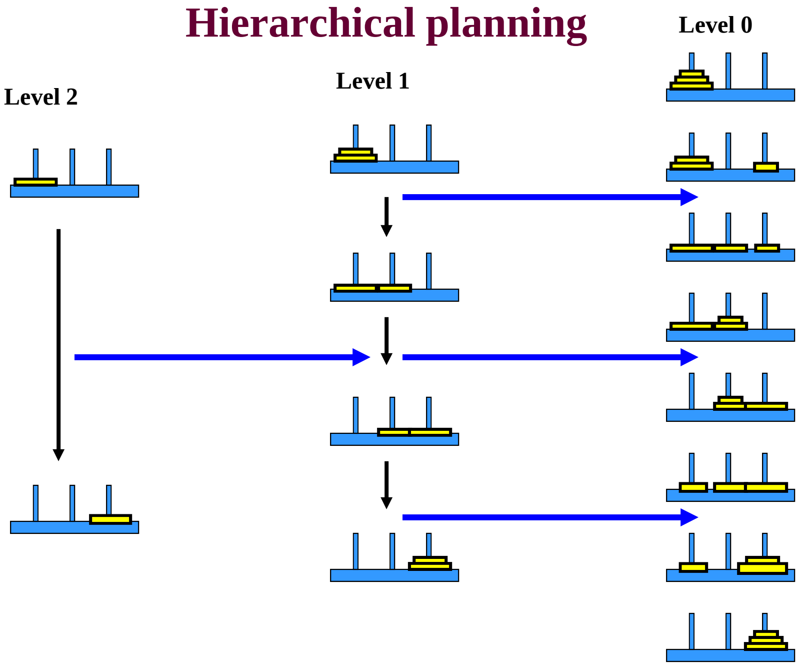
Hierarchical planning



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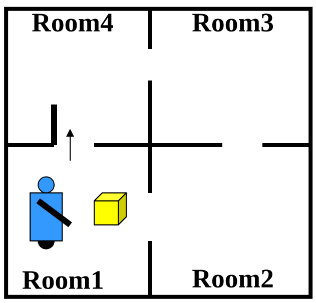
Planning with incomplete information

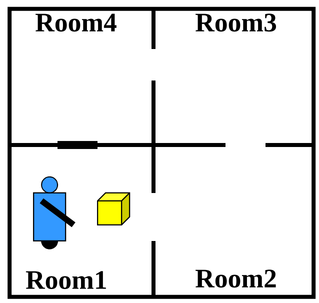
Some conditions relevant for planning can be:

- **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

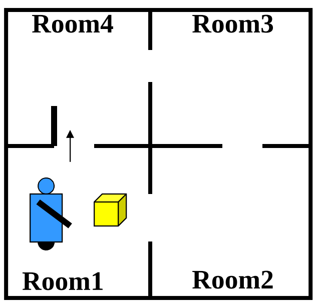


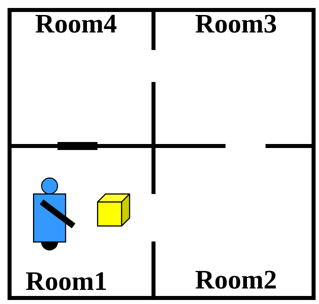


Planning with incomplete information

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

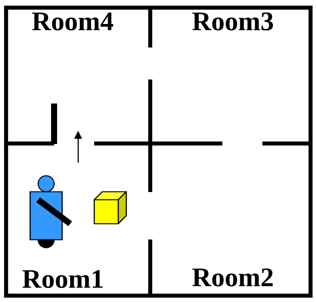
- **Different plans:**
  - **If not closed**: pick the block, go to room 4, drop the block
  - **If closed**: pick the block, go to room2, then room3 then room4 and drop the block

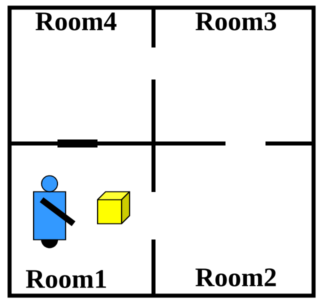




Conditional planners

- 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**





Sensing actions

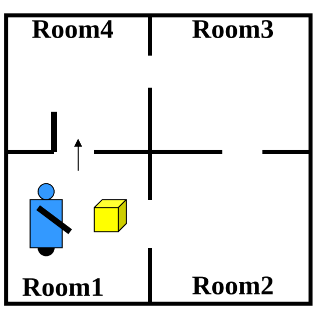
Example:

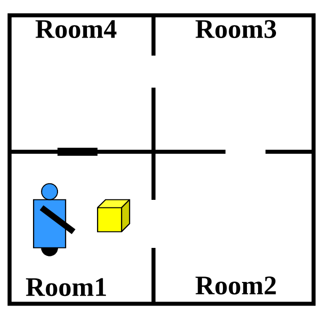
CheckDoor(d): checks the door d

Preconditions: Door(d,x,y) – one way door between x and y

& At(Robot,x)

Effect: (Closed(d) v ¬Closed(d)) - one will become true





Conditional plans

Sensing actions and conditions incorporated within the plan: