

CS 2710 Foundations of AI
Lecture 13

Planning

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Administration

- **PS-6:**
 - **Due on Thursday, October 28, 2004**
- **Midterm:**
 - **Back on Tuesday, next week**

Planning

Planning problem:

- find a sequence of actions that achieves some goal
- An instance of a search problem

Methods for modeling and solving a planning problem:

- State space search
- Situation calculus based on FOL
 - Inference rules
 - Resolution refutation

Planning problems

Properties of many (real-world) planning problems:

- The description of the state of the world is very complex
- Many possible actions to apply in any step
- Actions are typically local
 - - they affect only a small portion of a state description
- Goals are defined as conditions referring only to a small portion of state
- Plans consists of a large number of actions

The state space search and situation calculus frameworks may be

- too cumbersome and inefficient to represent and solve the planning problems

Situation calculus: problems

Frame problem refers to:

- The need to represent a large number of frame axioms

Solution: combine positive and negative effects in one rule

$$On(u, v, DO(MOVE(x, y, z), s)) \Leftrightarrow (\neg((u = x) \wedge (v = y)) \wedge On(u, v, s)) \vee \\ \vee (((u = x) \wedge (v = z)) \wedge On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s))$$

Inferential frame problem:

- We still need to derive properties that remain unchanged

Other problems:

- **Qualification problem** – enumeration of all possibilities under which an action holds
- **Ramification problem** – enumeration of all inferences that follow from some facts

Solutions

- **Complex state description and local action effects:**
 - avoid the enumeration and inference of every state component, focus on changes only
- **Many possible actions:**
 - Apply actions that make progress towards the goal
 - Understand what the effect of actions is and reason with the consequences
- **Sequences of actions in the plan can be too long:**
 - Many goals consists of independent or nearly independent sub-goals
 - Allow goal decomposition & divide and conquer strategies

STRIPS planner

- Defines a restricted representation language as compared to the situation calculus

Advantage: leads to more efficient planning algorithms.

- State-space search with structured representations of states, actions and goals
- Action representation avoids the frame problem

STRIPS planning problem:

- much like a standard search (planning) problem;

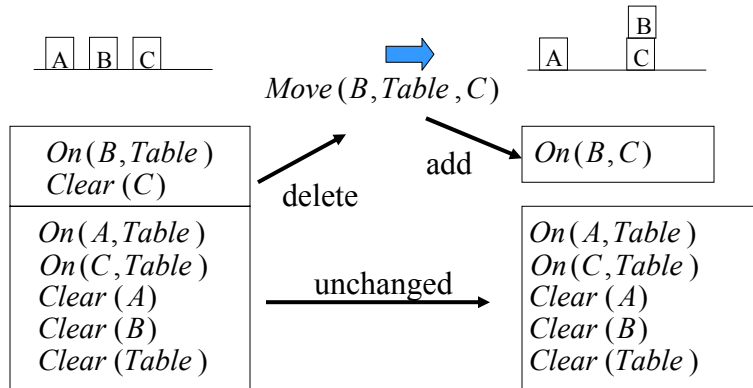
STRIPS planner

- **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:** $On(x,y), Clear(z)$



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STRIPS planning

Initial state:

- Conjunction of literals that are true

Goals in STRIPS:

- A goal is a partially specified state
- Is defined by a conjunction of ground literals
 - No variables allowed in the description of the goal

Example:

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

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Search in STRIPS

Objective:

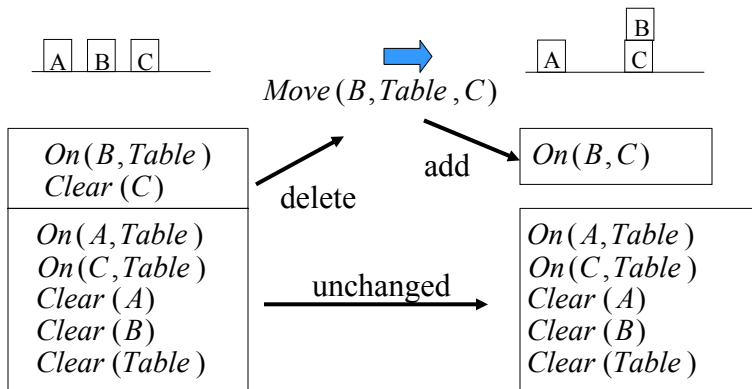
Find a sequence of operators (a plan) from the initial state to the state satisfying the goal

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 to reach the goal

Forward search (goal progression)

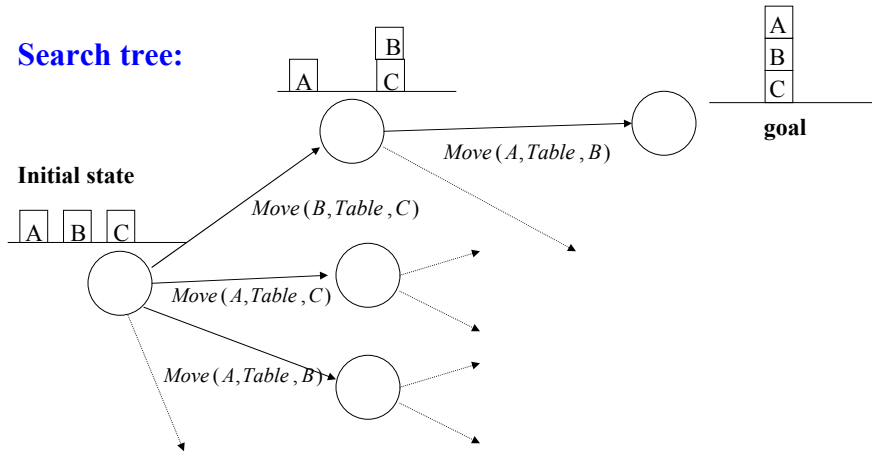
- Idea: Given a state s
 - Unify the preconditions of some operator a with s
 - Add and delete sentences from the add and delete list of an operator a from s to get a new state (can be repeated)



Forward search (goal progression)

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

Search tree:

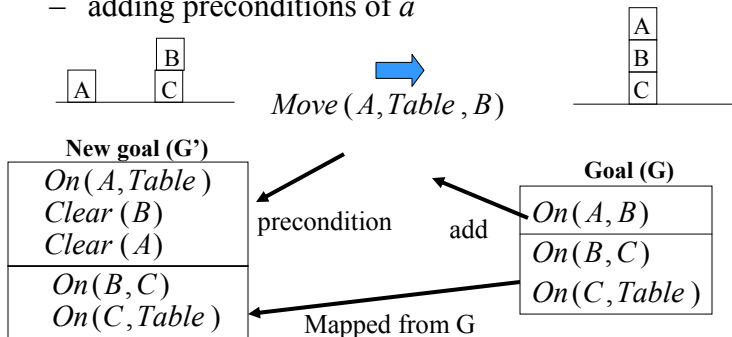


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Backward search (goal regression)

Idea: Given a goal G

- Unify the add list of some operator a with a subset of G
- If the delete list of a does not remove elements of G , then the goal regresses to a new goal G' that is obtained from G by:
 - deleting add list of a
 - adding preconditions of a

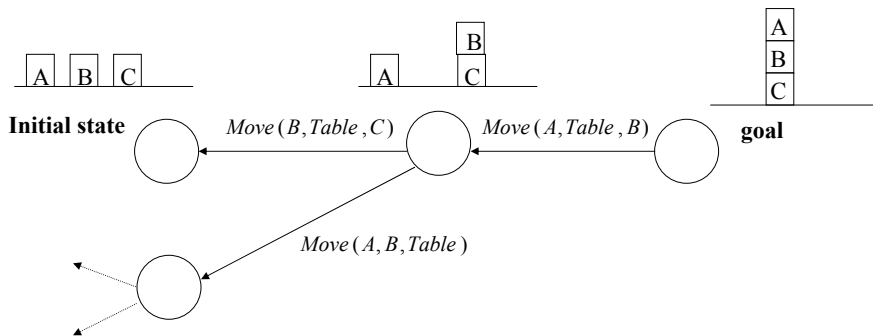


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Backward search (goal regression)

- 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

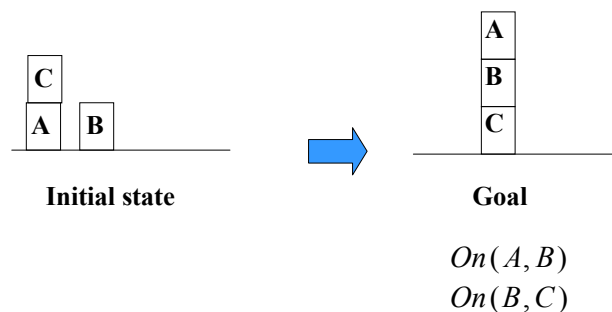
In planning we would like to satisfy a set of goals

- **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.

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Sussman's anomaly.

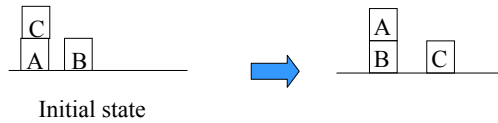
- An example from the blocks world in which divide and conquer fails due to interacting goals



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Sussman's anomaly

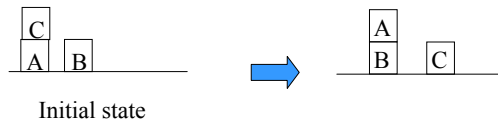
1. Assume we want to satisfy $On(A, B)$ first



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

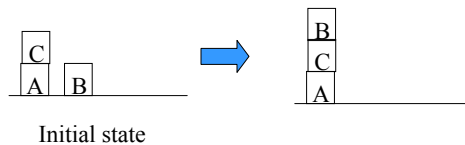
Sussman's anomaly

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 $On(B, C)$

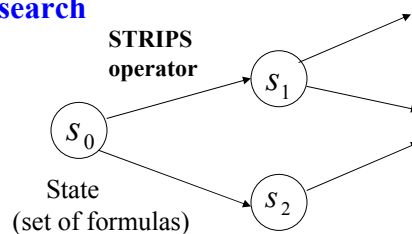
State space vs. plan space search

- 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)

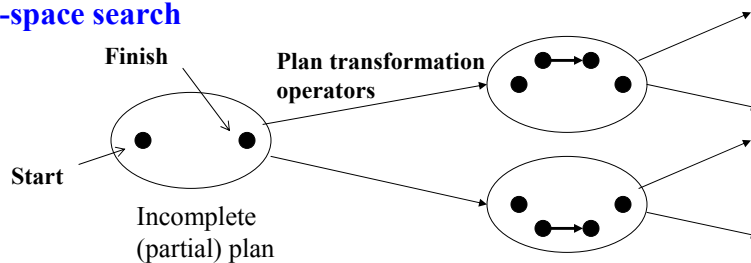
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State-space vs. plan-space search

State-space search



Plan-space search

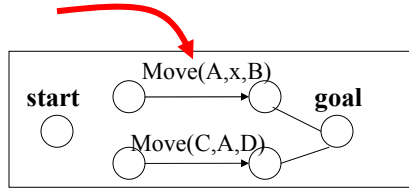


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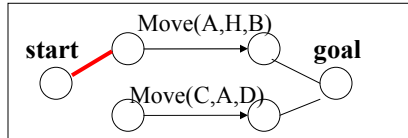
Plan transformation operators

Examples of :

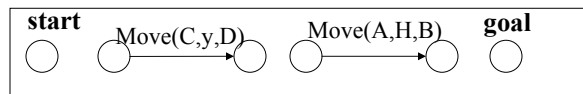
- Add an operator to a plan so that it satisfies some open condition



- Add link (+ instantiate)



- Order (reorder) operators

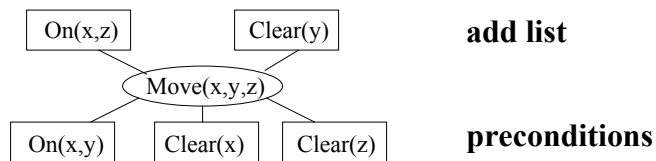


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Partial-order planners (POP)

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

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

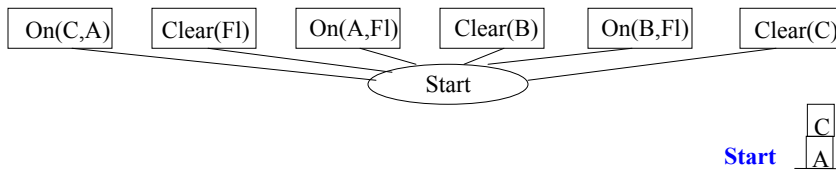
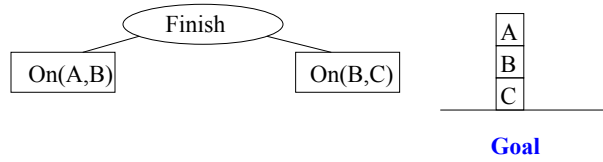


Delete list is not shown !!!

Illustration of POP on the Sussman's anomaly case

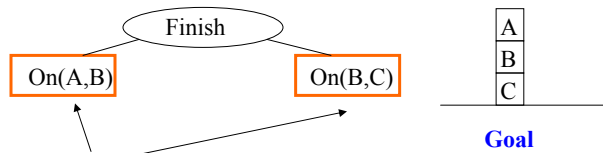
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Partial order planning. Start and finish.

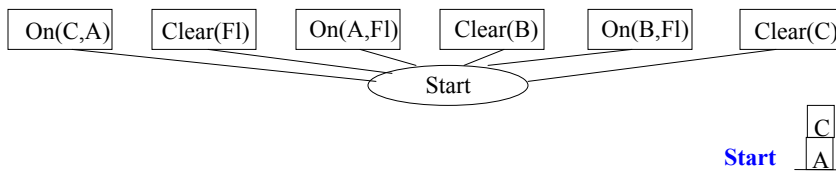


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Partial order planning. Start and finish.

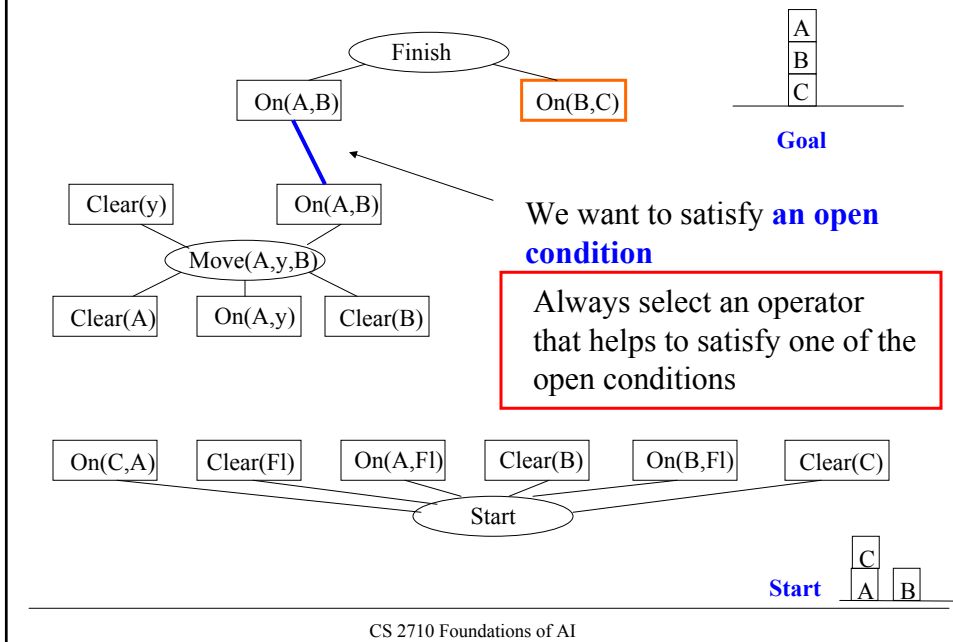


Open conditions: conditions yet to be satisfied

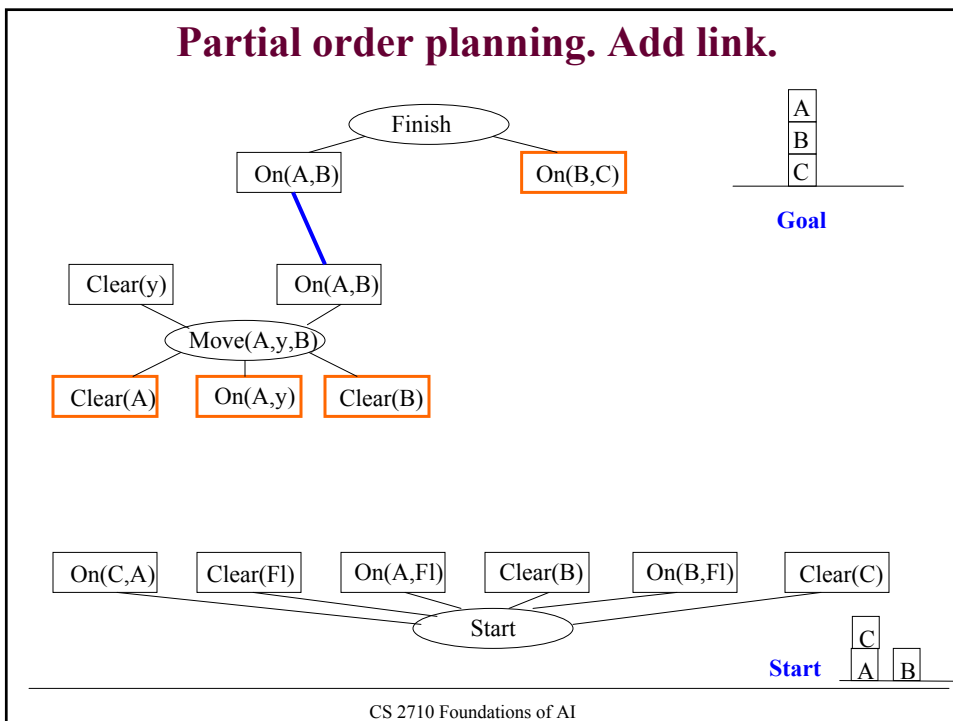


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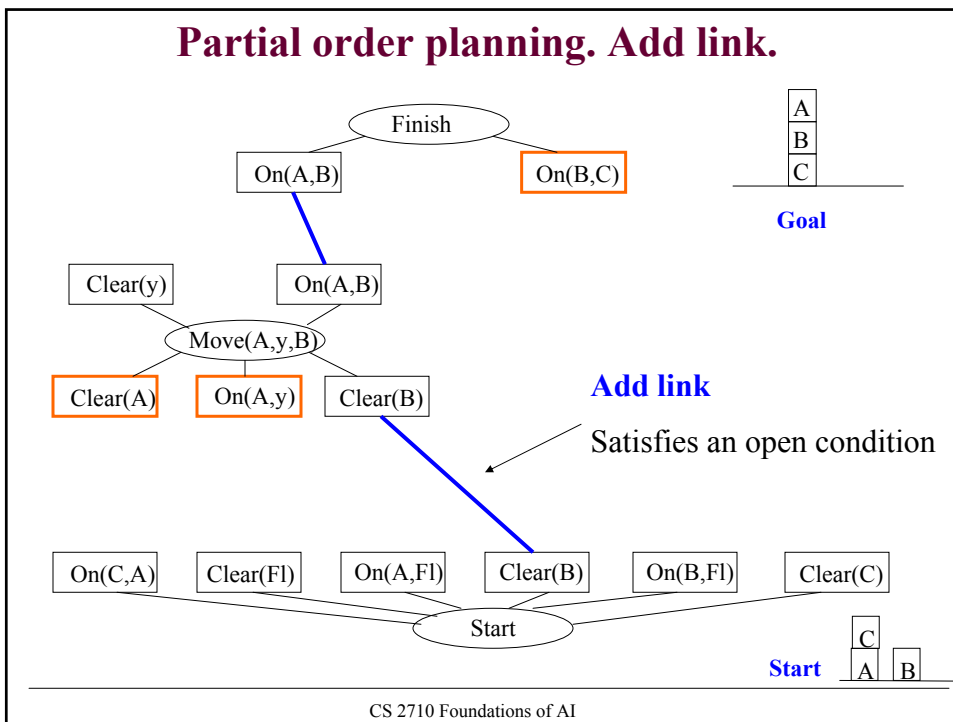
Partial order planning. Add operator.



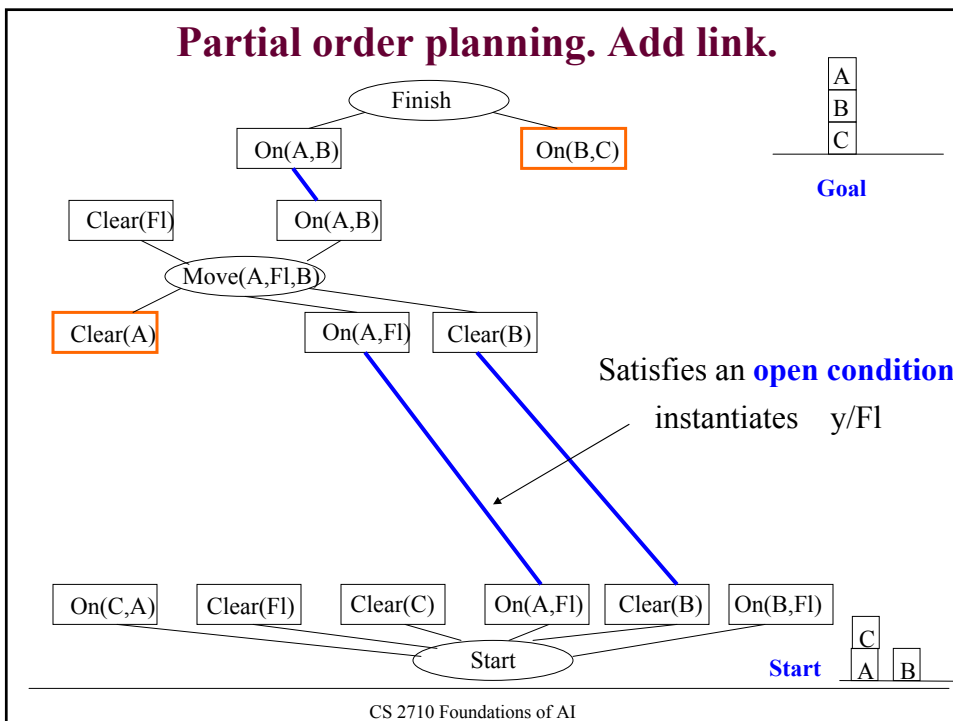
Partial order planning. Add link.



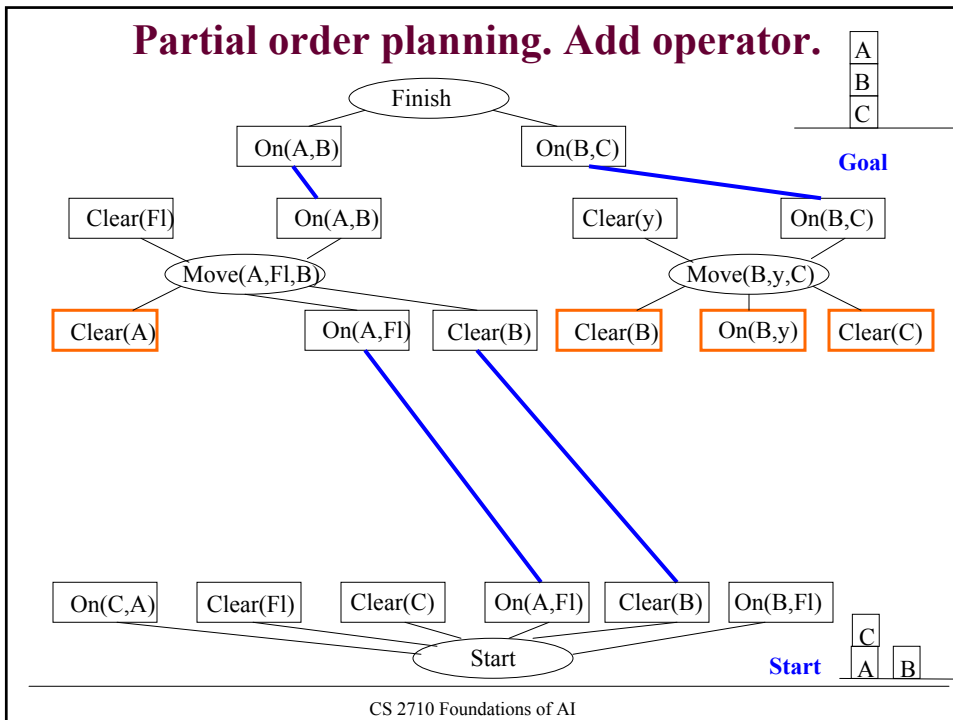
Partial order planning. Add link.



Partial order planning. Add link.

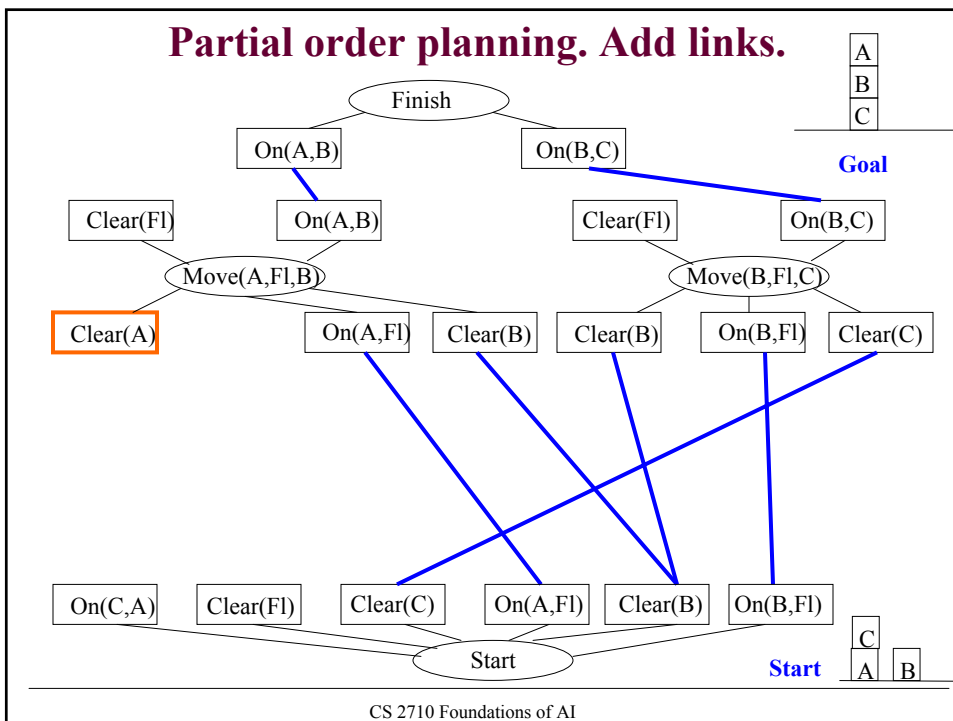


Partial order planning. Add operator.



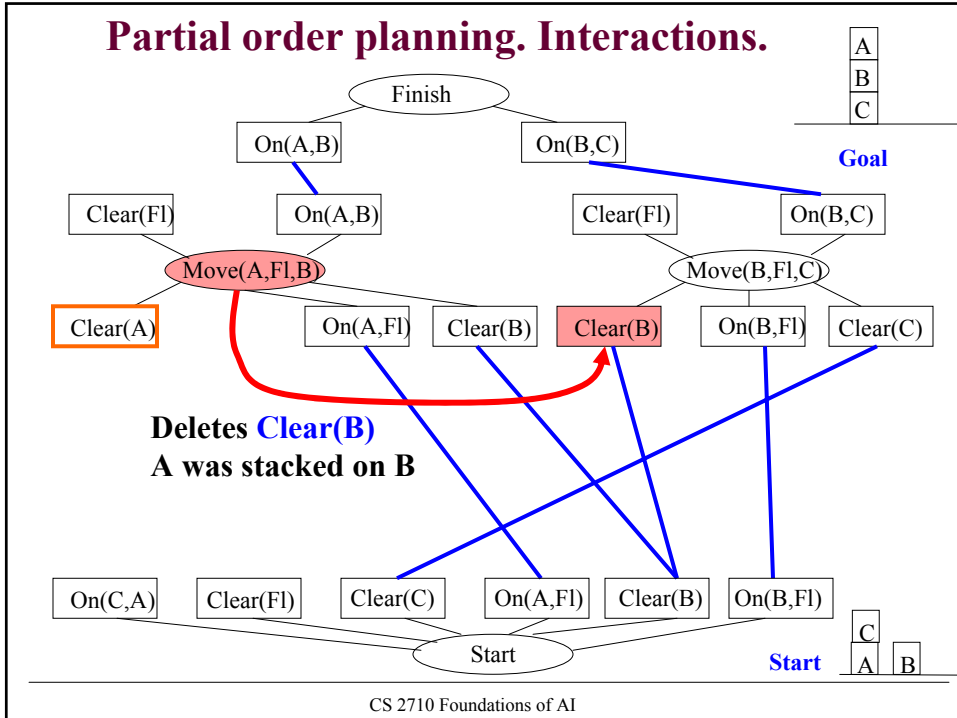
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Partial order planning. Add links.

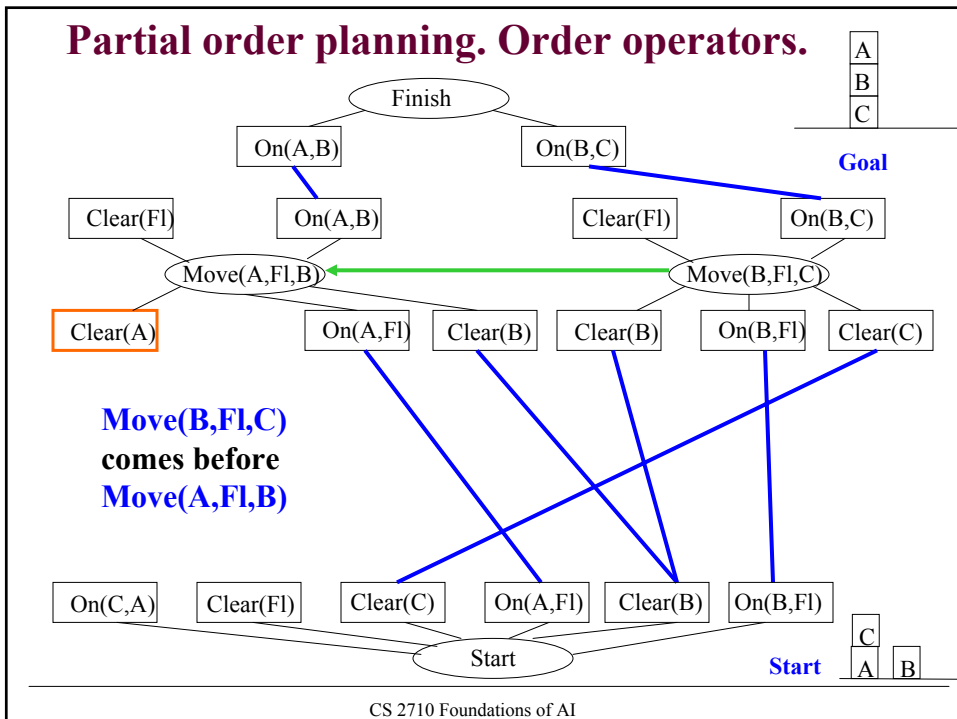


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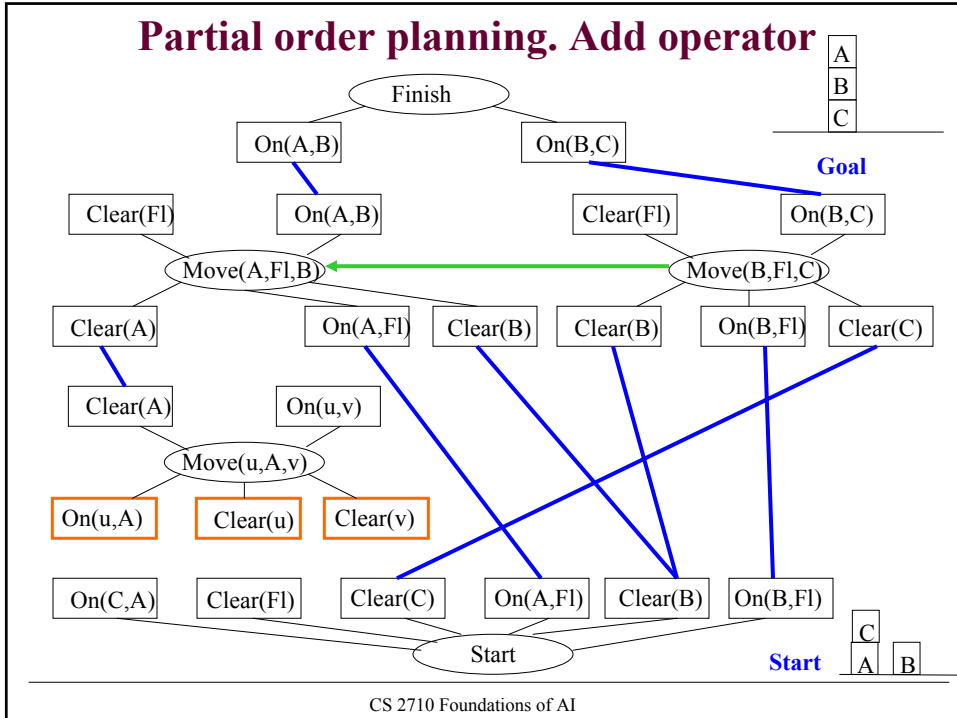
Partial order planning. Interactions.



Partial order planning. Order operators.

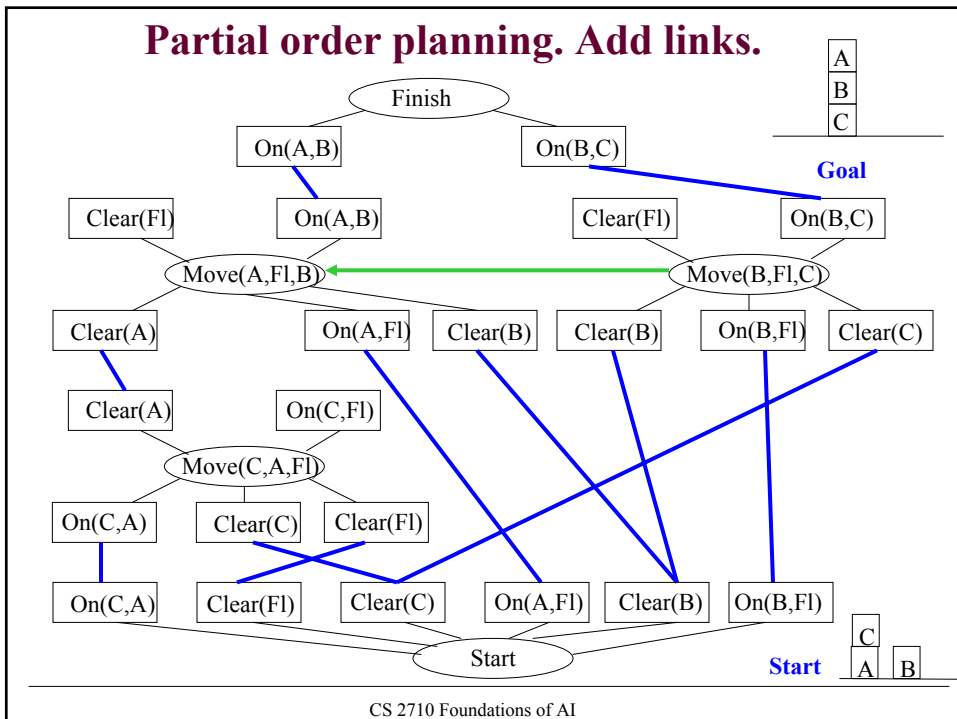


Partial order planning. Add operator



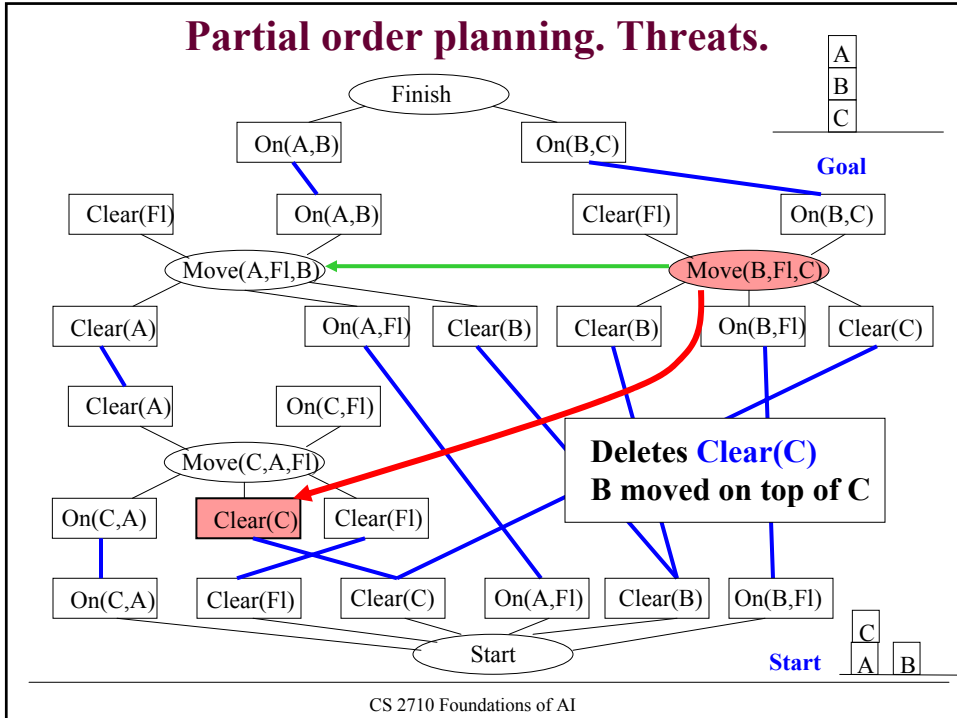
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Partial order planning. Add links.

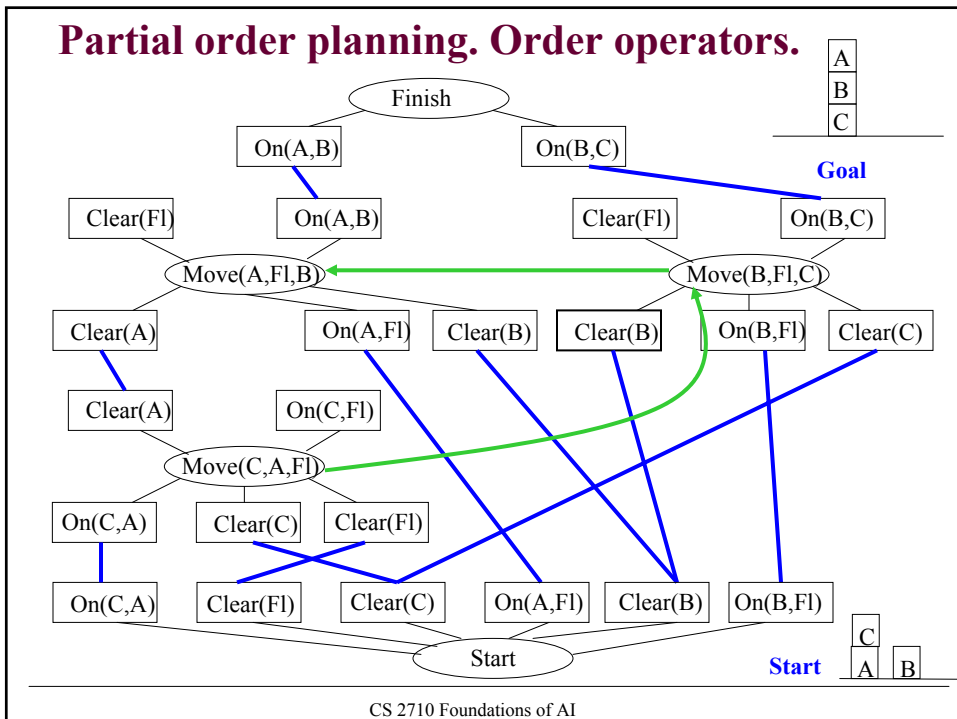


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Partial order planning. Threats.

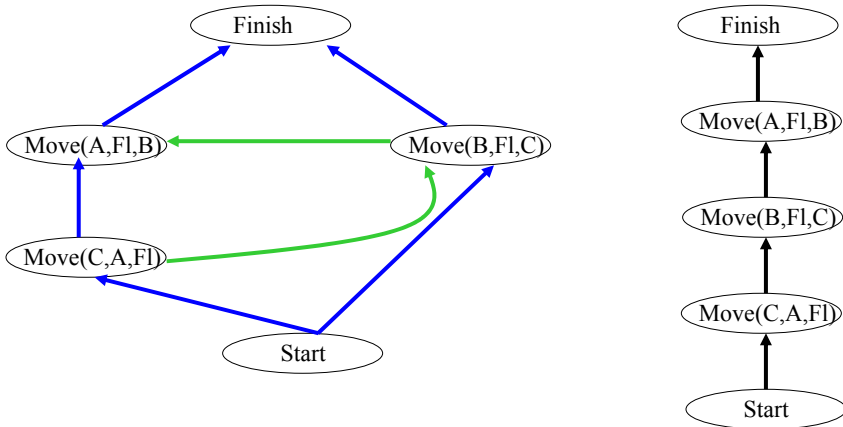


Partial order planning. Order operators.



Partial order planning. Result plan.

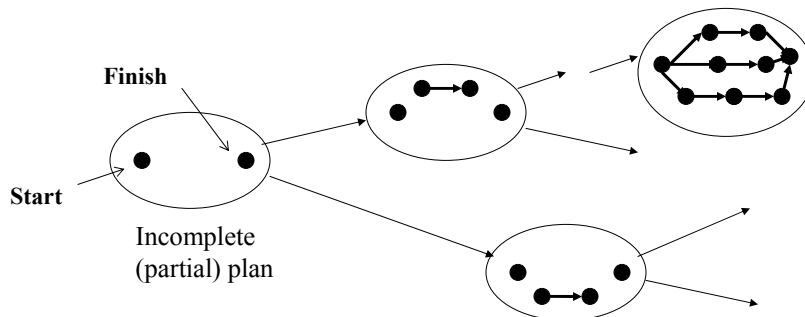
Plan: a topological sort of a graph



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Partial order planning.

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



- POP: **is sound and complete**

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