



## Planning

**Planning problem:** find sequence of actions that lead to a goal

– Is a classical search problem

- **Typical (real-world) planning problem:**

– Large state descriptions: may represent a number entities and relations that hold in the world at specific point in time

– Large number of operators (actions) one can apply at any point

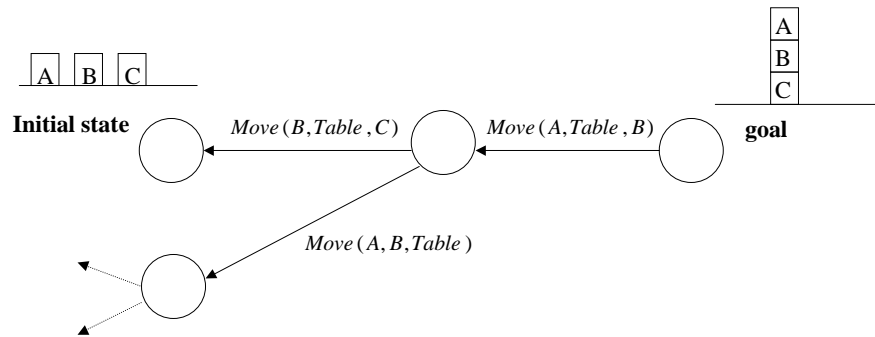
– Goals may be conditions on only a few entities, relations of the world.

- **Problem:** an extremely large search problem

- **Solution:** Open state, action and goal representations to allow selection, reasoning. Make things visible and expose the structure. Use the structure actively in the solution.

## Backward search (goal regression)

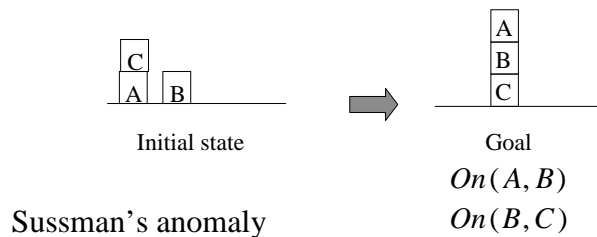
- Use operators to generate new goals
- Check whether the initial state satisfies the goal



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## Divide and conquer - Sussman's anomaly

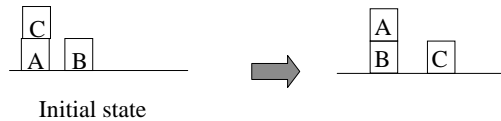
- **Divide and conquer strategy** – divide the problem to a set of smaller subproblems
  - Can be applied safely if we can achieve each of the goals separately while not affecting other goals
- Case in which there is no order in which goals can be solved:



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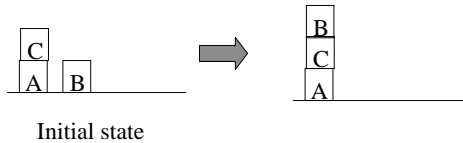
## Sussman's anomaly

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



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

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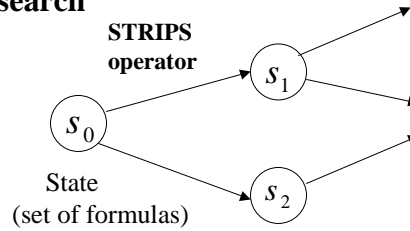
## State-space vs. plan-space

- An alternative to planning algorithms that search states (configurations of world) is to search the space of plans
- **Plan:**
  - Defines sequences of operators to be performed
- **Partial plans:**
  - plans are not complete
  - Some orderings of operators are not finalized
- **State-space vs Plan-space search:**
  - State-space search – a node is a configuration of the world
  - Plan-space search – a node is a partial plan

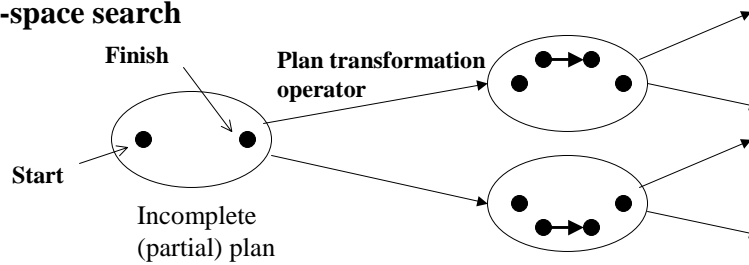
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## State-space vs. plan-space search

### State-space search



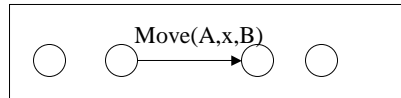
### Plan-space search



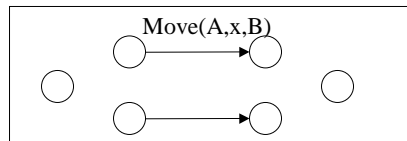
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## Plan transformation operators

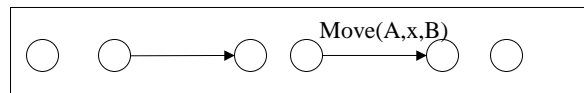
### Examples:



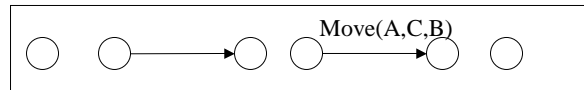
- Add an operator to a plan



- Order (reorder) operators



- Instantiate an operator



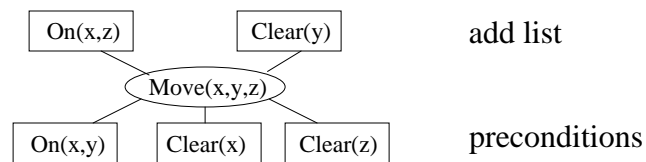
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## Partial-order planners

- Also called Non-linear planners
- STRIPS-like operators

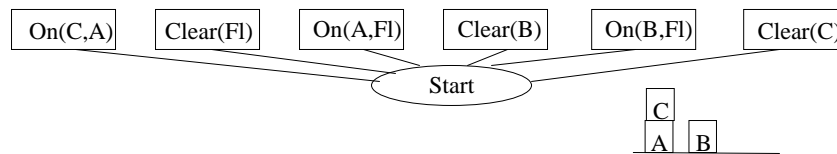
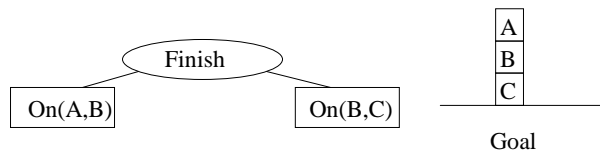
Illustration on Sussman's anomaly case

Graphical representation of an operator



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## Partial order planning - Start and finish

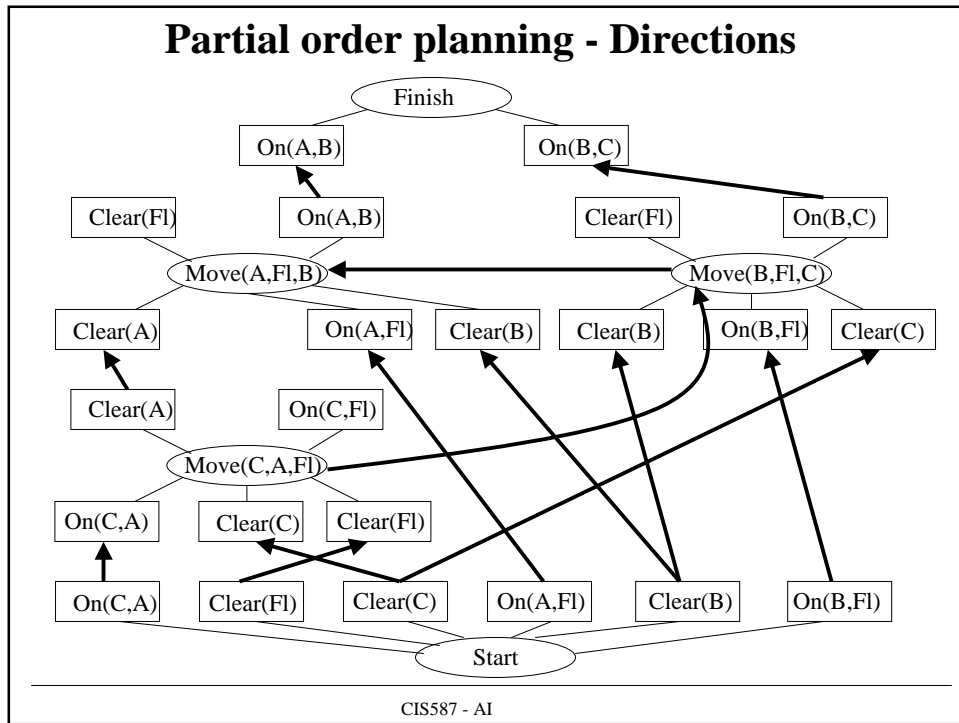


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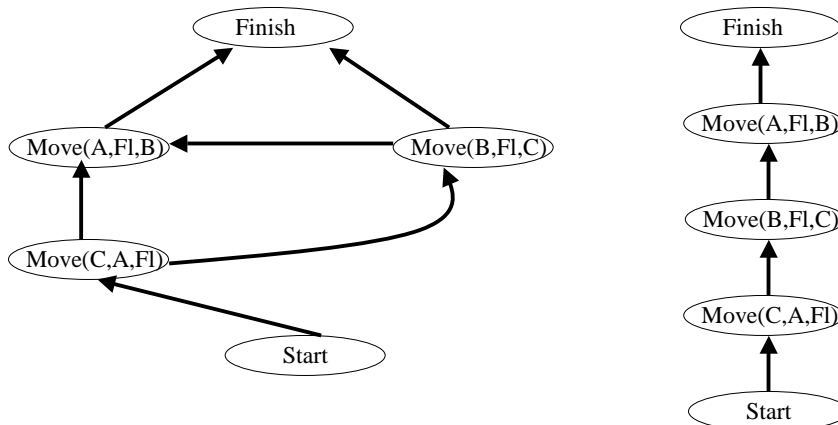


## Partial order planning - Directions



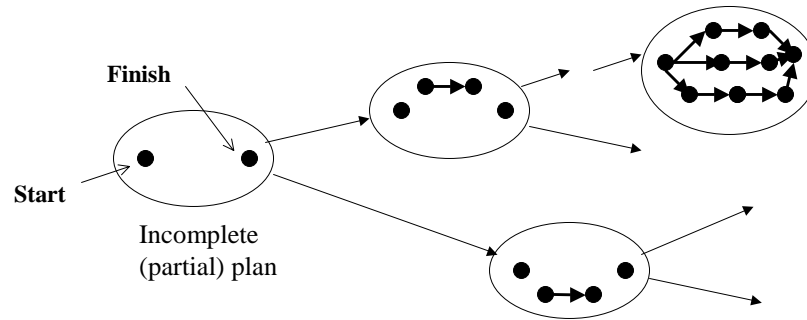
## Partial order planning-Result plan

Plan: a topological sort of a graph



## Partial order planning

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



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## Hierarchical planners

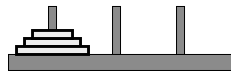
Extension of STRIPS planners. Example ABSTRIPS.

### Idea:

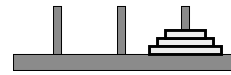
- Assign criticality level to each conjunct in preconditions of the operator
- Planning process refines the plan gradually based on criticality threshold, starting from the highest criticality value:
  - Develop the plan ignoring preconditions of criticality less than the criticality threshold value (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

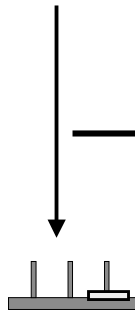
the medium disk – criticality level 1

the smallest disk – criticality level 0

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## Hierarchical planning

Level 2



Level 1



Level 0



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