Planning

Chapter 11

Outline

◇ Search vs. planning

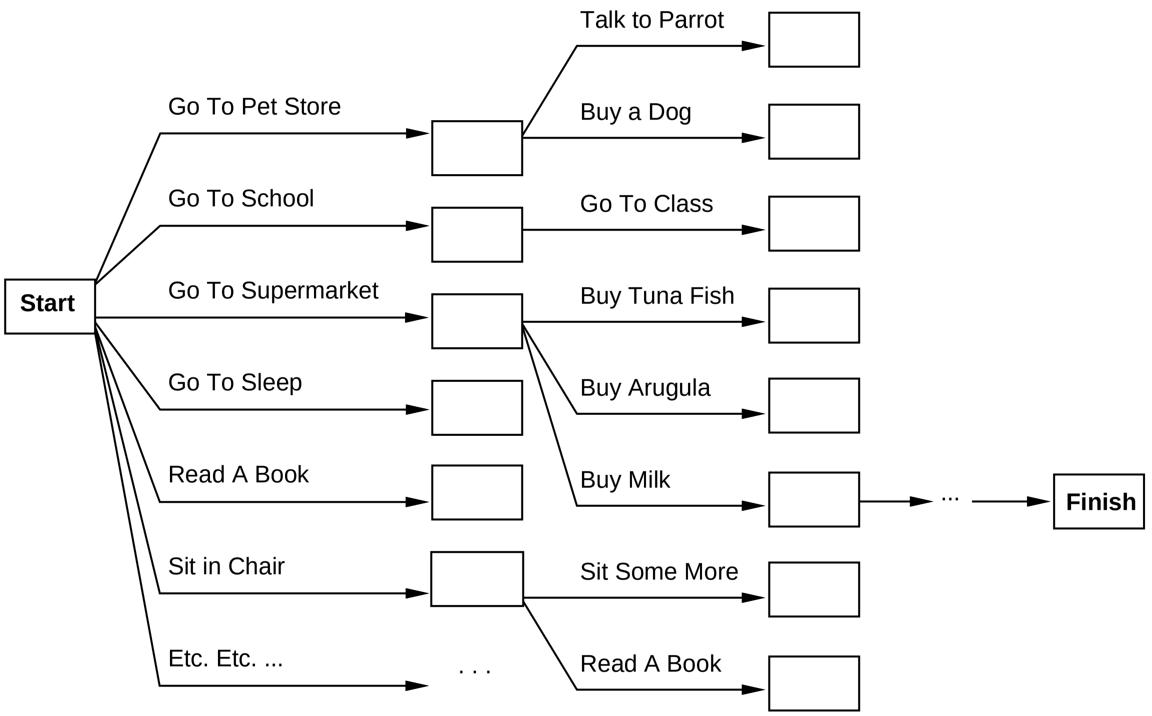
◇ STRIPS operators

◇ Partial-order planning

Search vs. planning

Consider the task *get milk, bananas, and a cordless drill*

Standard search algorithms seem to fail miserably:



After-the-fact heuristic/goal test inadequate

Search vs. planning contd.

Planning systems do the following:

1) open up action and goal representation to allow selection
2) divide-and-conquer by subgoaling
3) relax requirement for sequential construction of solutions

	Search	**Planning**
States	Lisp data structures	Logical sentences
Actions	Lisp code	Preconditions/outcomes
Goal	Lisp code	Logical sentence (conjunction)
Plan	Sequence from S_0	Constraints on actions

Planning in situation calculus

$PlanResult(p, s)$ is the situation resulting from executing p in s

$$PlanResult([], s) = s$$
$$PlanResult([a|p], s) = PlanResult(p, Result(a, s))$$

Initial state $At(Home, S_0) \land \neg Have(Milk, S_0) \land \ldots$

Actions as Successor State axioms
$Have(Milk, Result(a, s)) \;\Leftrightarrow$
$[(a = Buy(Milk) \land At(Supermarket, s)) \lor (Have(Milk, s) \land a \neq \ldots)]$

Query

$$s = PlanResult(p, S_0) \land At(Home, s) \land Have(Milk, s) \land \ldots$$

Solution

$$p = [Go(Supermarket), Buy(Milk), Buy(Bananas), Go(HWS), \ldots]$$

Principal difficulty: unconstrained branching, hard to apply heuristics

STRIPS operators

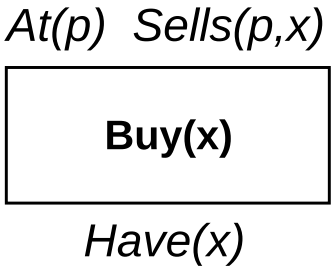
Tidily arranged actions descriptions, restricted language

ACTION: $Buy(x)$
PRECONDITION: $At(p), Sells(p,x)$
EFFECT: $Have(x)$

[Note: this abstracts away many important details!]

Restricted language $\Rightarrow$ efficient algorithm

Precondition: conjunction of positive literals
Effect: conjunction of literals



State space vs. plan space

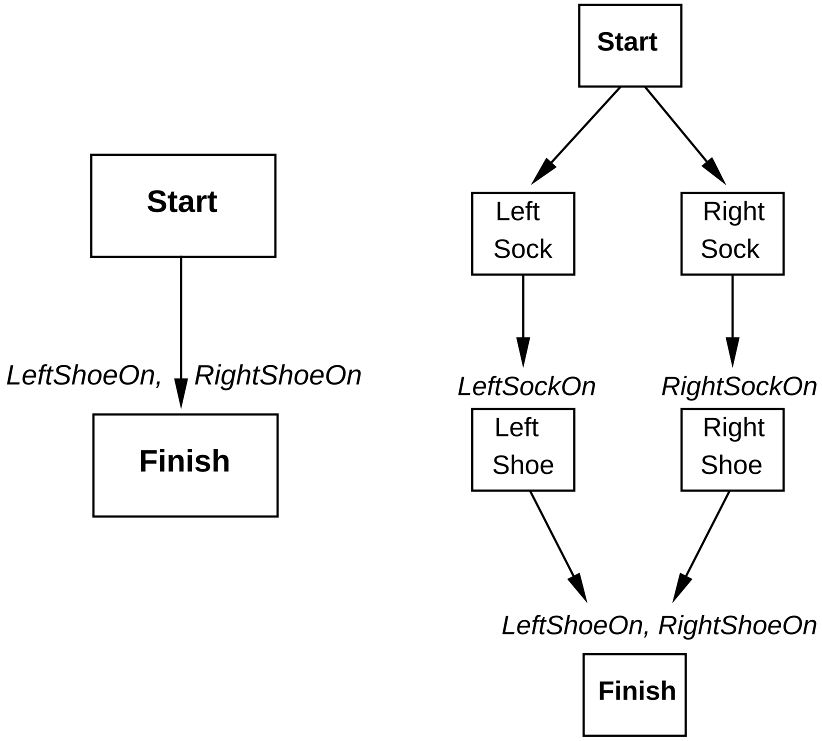
Standard search: node = concrete world state
Planning search: node = partial plan

Defn: open condition is a precondition of a step not yet fulfilled

Operators on partial plans:
add a link from an existing action to an open condition
add a step to fulfill an open condition
order one step wrt another

Gradually move from incomplete/vague plans to complete, correct plans

Partially ordered plans



A plan is complete iff every precondition is achieved

A precondition is achieved iff it is the effect of an earlier step and no possibly intervening step undoes it

POP algorithm sketch

```
function POP(initial, goal, operators) returns plan

   plan ← MAKE-MINIMAL-PLAN(initial, goal)
   loop do
      if SOLUTION?(plan) then return plan
      $S_{need}$, c ← SELECT-SUBGOAL(plan)
      CHOOSE-OPERATOR(plan, operators, $S_{need}$, c)
      RESOLVE-THREATS(plan)
   end
```

```
function SELECT-SUBGOAL(plan) returns $S_{need}$, c

   pick a plan step $S_{need}$ from STEPS(plan)
      with a precondition c that has not been achieved
   return $S_{need}$, c
```

POP algorithm contd.

```
procedure CHOOSE-OPERATOR($plan, operators, S_{need}, c$)
    choose a step $S_{add}$ from $operators$ or STEPS($plan$) that has $c$ as an effect
    if there is no such step then fail
    add the causal link $S_{add} \xrightarrow{c} S_{need}$ to LINKS($plan$)
    add the ordering constraint $S_{add} \prec S_{need}$ to ORDERINGS($plan$)
    if $S_{add}$ is a newly added step from $operators$ then
        add $S_{add}$ to STEPS($plan$)
        add $Start \prec S_{add} \prec Finish$ to ORDERINGS($plan$)
```

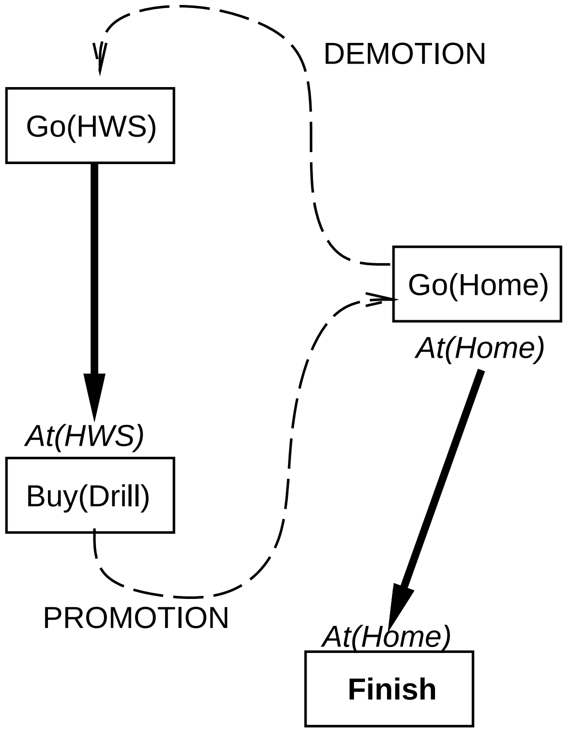
```
procedure RESOLVE-THREATS($plan$)
    for each $S_{threat}$ that threatens a link $S_i \xrightarrow{c} S_j$ in LINKS($plan$) do
        choose either
            Demotion: Add $S_{threat} \prec S_i$ to ORDERINGS($plan$)
            Promotion: Add $S_j \prec S_{threat}$ to ORDERINGS($plan$)
        if not CONSISTENT($plan$) then fail
    end
```

POP is sound, complete, and systematic (no repetition)

Extensions for disjunction, universals, negation, conditionals

Clobbering and promotion/demotion

A <u>clobberer</u> is a potentially intervening step that destroys the condition achieved by a causal link. E.g., $Go(Home)$ clobbers $At(HWS)$:

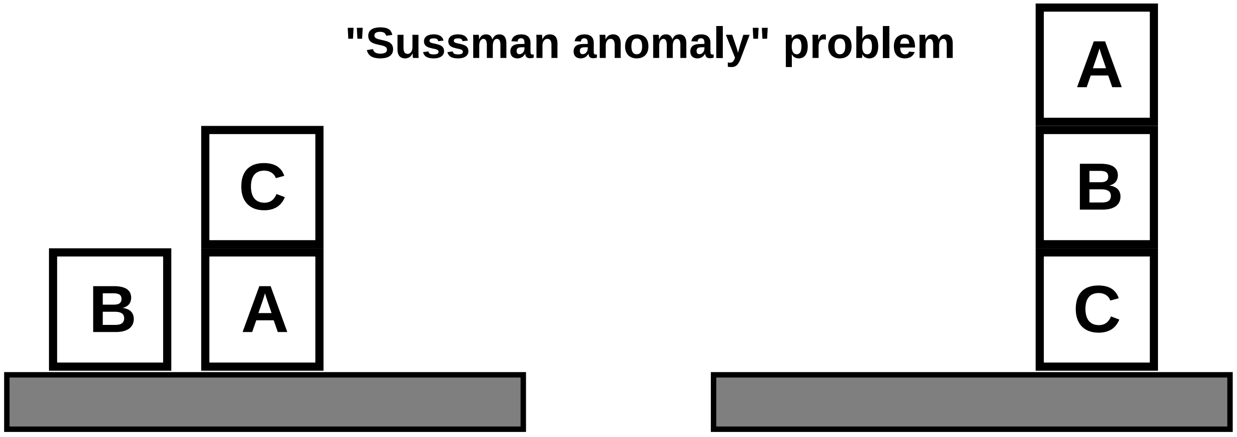


<u>Demotion</u>: put before $Go(HWS)$

<u>Promotion</u>: put after $Buy(Drill)$

Example: Blocks world

"Sussman anomaly" problem



Start State

Goal State

Clear(x) On(x,z) Clear(y)

PutOn(x,y)

~On(x,z) ~Clear(y)
Clear(z) On(x,y)

Clear(x) On(x,z)

PutOnTable(x)

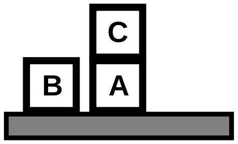
~On(x,z) Clear(z) On(x,Table)

+ several inequality constraints

Example contd.

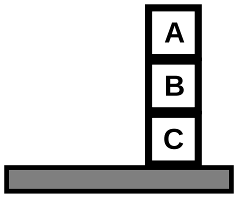
START

On(C,A) On(A,Table) Cl(B) On(B,Table) Cl(C)

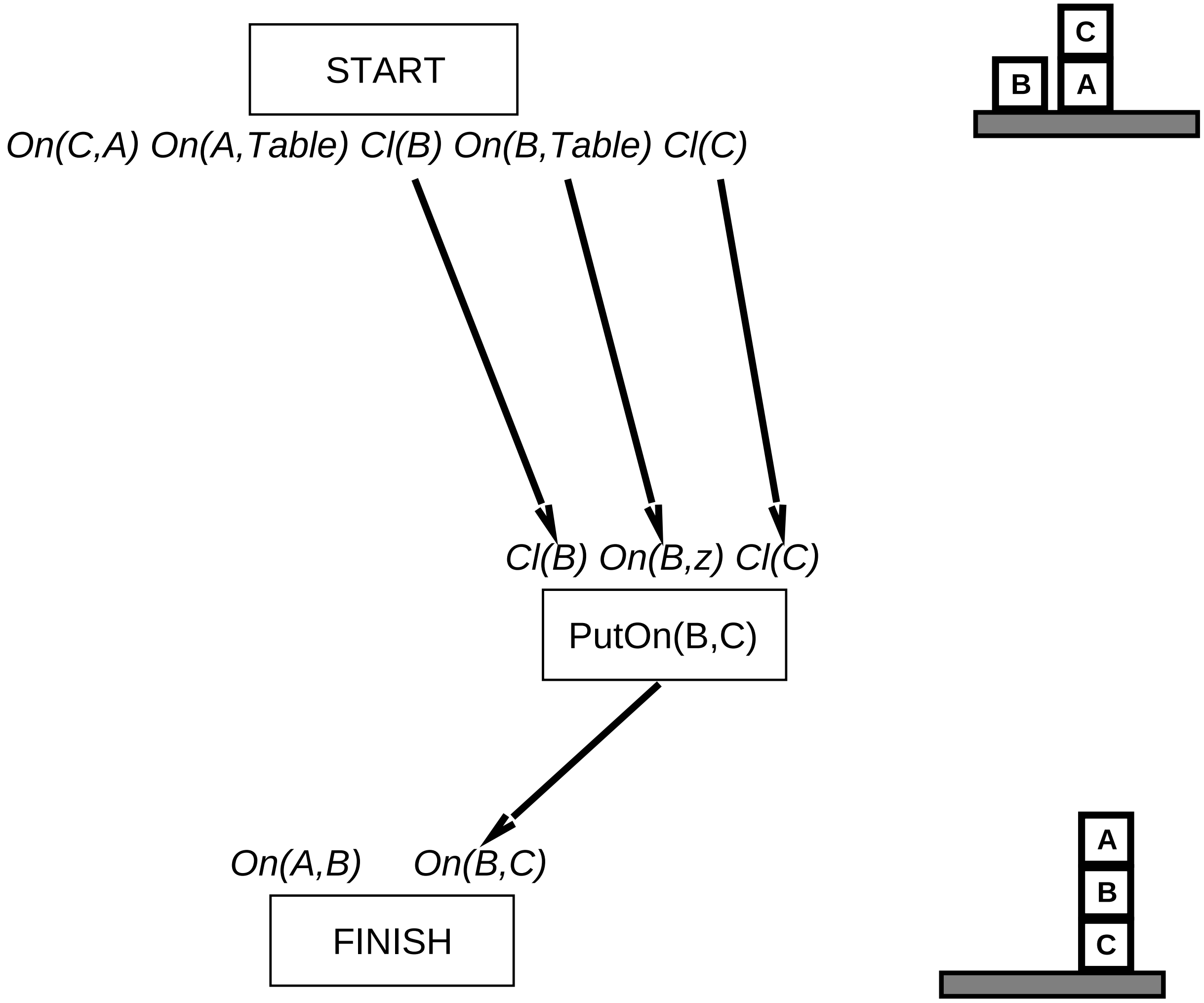


On(A,B)   *On(B,C)*

FINISH



Example contd.



START

On(C,A) On(A,Table) Cl(B) On(B,Table) Cl(C)

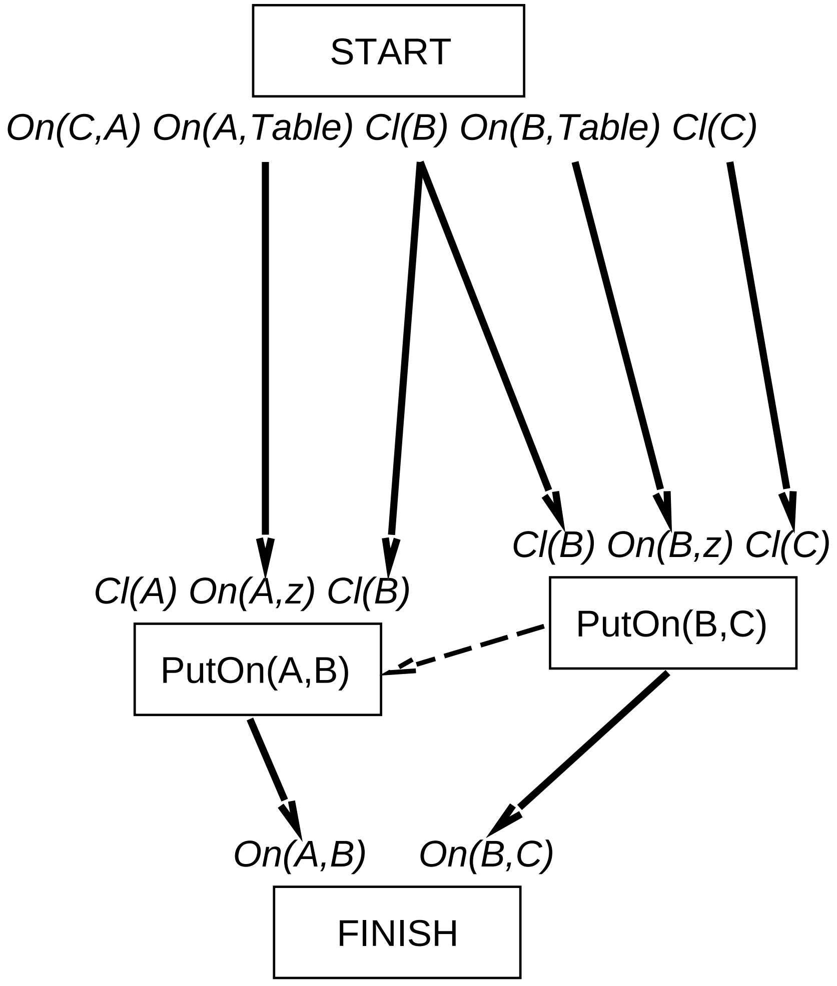
Cl(B) On(B,z) Cl(C)

PutOn(B,C)

On(A,B) *On(B,C)*

FINISH

Example contd.



START

On(C,A) On(A,Table) Cl(B) On(B,Table) Cl(C)

Cl(A) On(A,z) Cl(B)

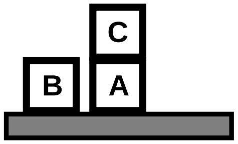
PutOn(A,B)

Cl(B) On(B,z) Cl(C)

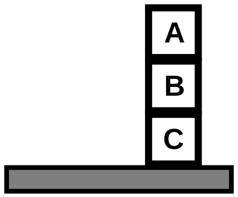
PutOn(B,C)

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

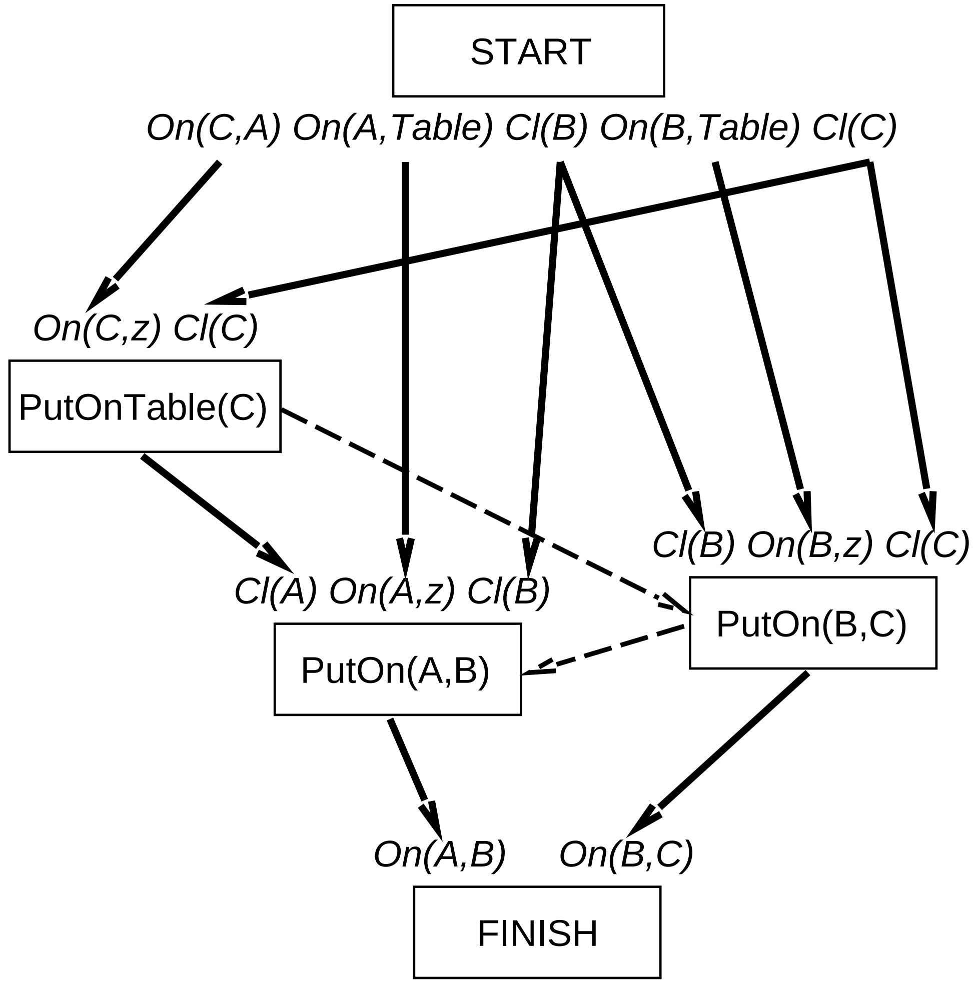
FINISH



PutOn(A,B)
clobbers Cl(B)
=> order after
PutOn(B,C)



Example contd.



START

On(C,A) On(A,Table) Cl(B) On(B,Table) Cl(C)

On(C,z) Cl(C)

PutOnTable(C)

Cl(B) On(B,z) Cl(C)

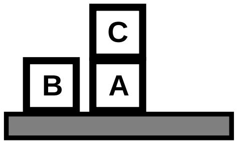
PutOn(B,C)

Cl(A) On(A,z) Cl(B)

PutOn(A,B)

On(A,B) *On(B,C)*

FINISH



**PutOn(A,B)
clobbers Cl(B)
=> order after
PutOn(B,C)**

**PutOn(B,C)
clobbers Cl(C)
=> order after
PutOnTable(C)**