Planning

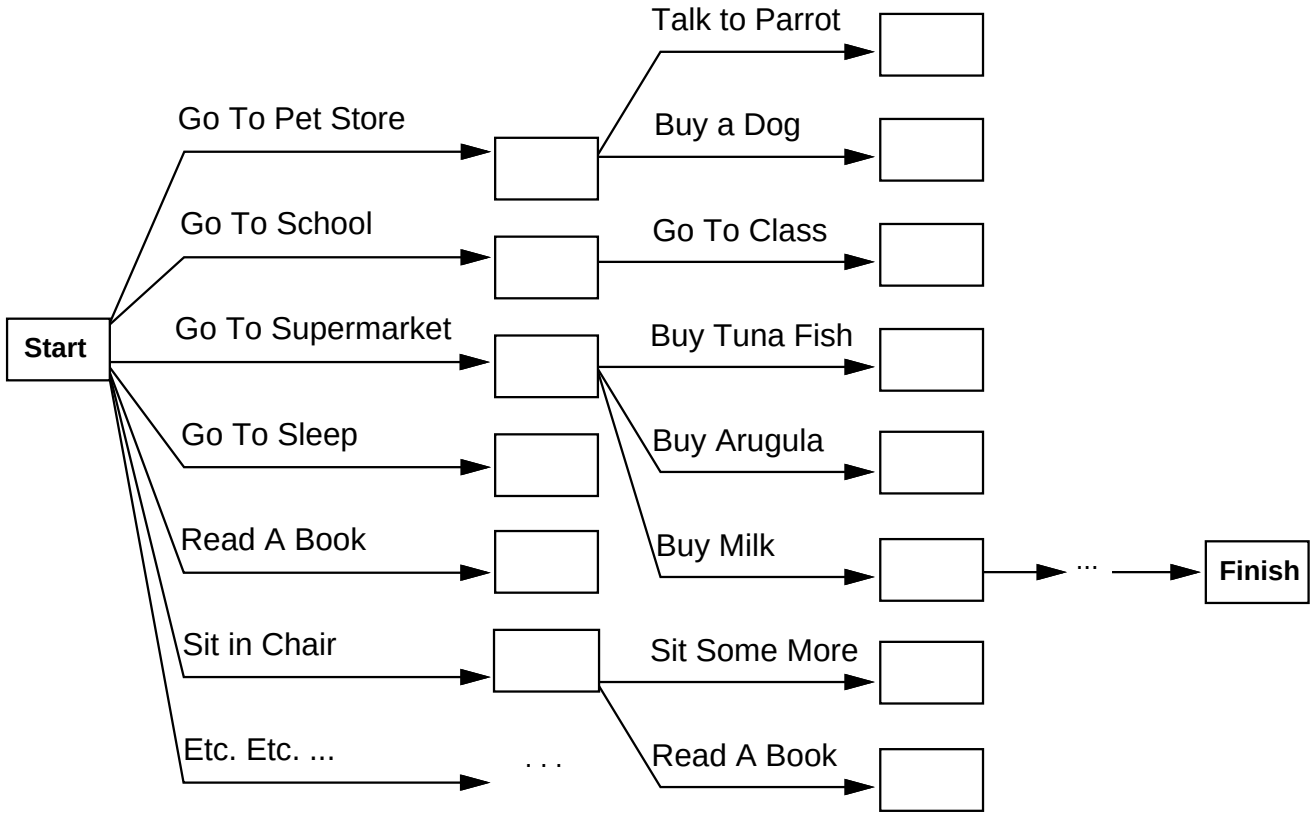
Chapter 11

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:

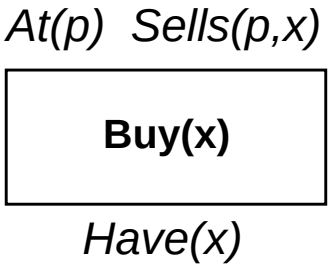
1) open up action and goal representation to allow selection
2) divide-and-conquer by subgoaling
3) relax requirement for sequential construction of solutions

	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

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

A complete set of STRIPS operators can be translated into a set of successor-state axioms

State space vs. plan space

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

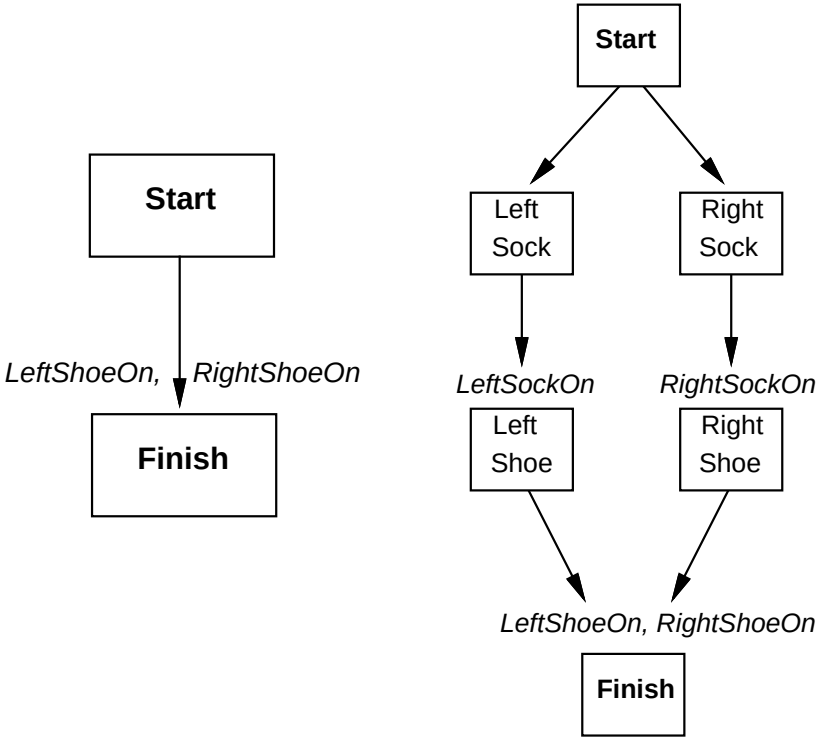
Defn: open condition is a precondition of a step not yet fulfilled

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*
  $S_{need},\ c \leftarrow$ 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($plan$)

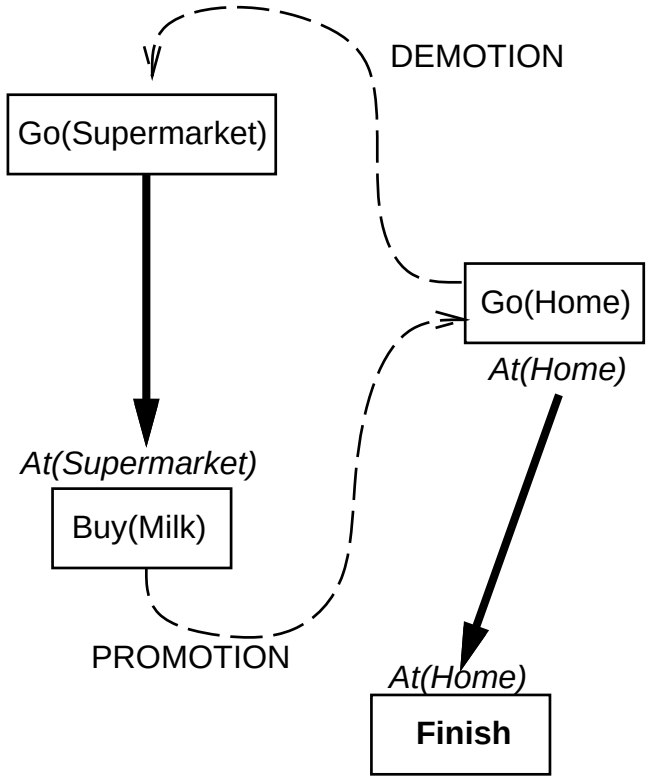
---

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

Clobbering and promotion/demotion

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



Demotion: put before $Go(Supermarket)$

Promotion: put after $Buy(Milk)$

Properties of POP

Nondeterministic algorithm: backtracks at choice points on failure:

- choice of S_{add} to achieve S_{need}
- choice of demotion or promotion for clobberer
- selection of S_{need} is irrevocable

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

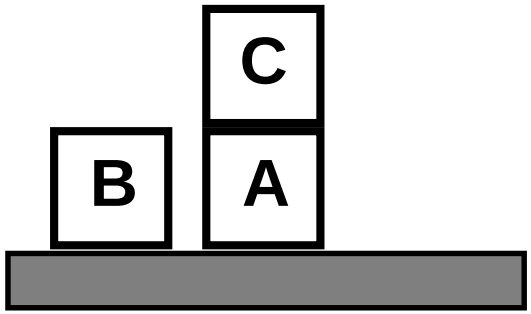
Extensions for disjunction, universals, negation, conditionals

Can be made efficient with good heuristics derived from problem description

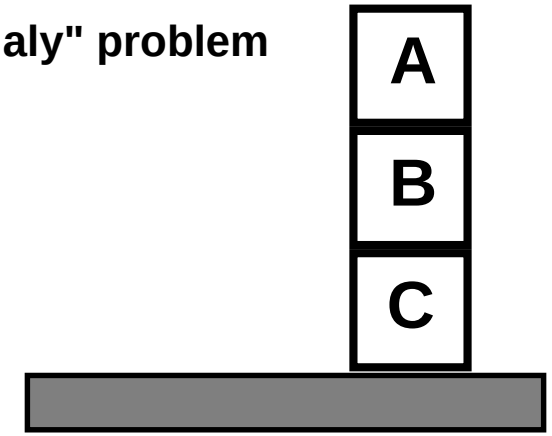
Particularly good for problems with many loosely related subgoals

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)

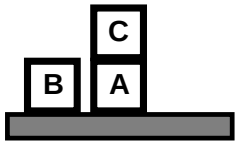
~On(x,z) Clear(z) On(x,Table)

+ several inequality constraints

Example contd.

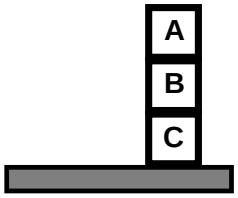
START

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

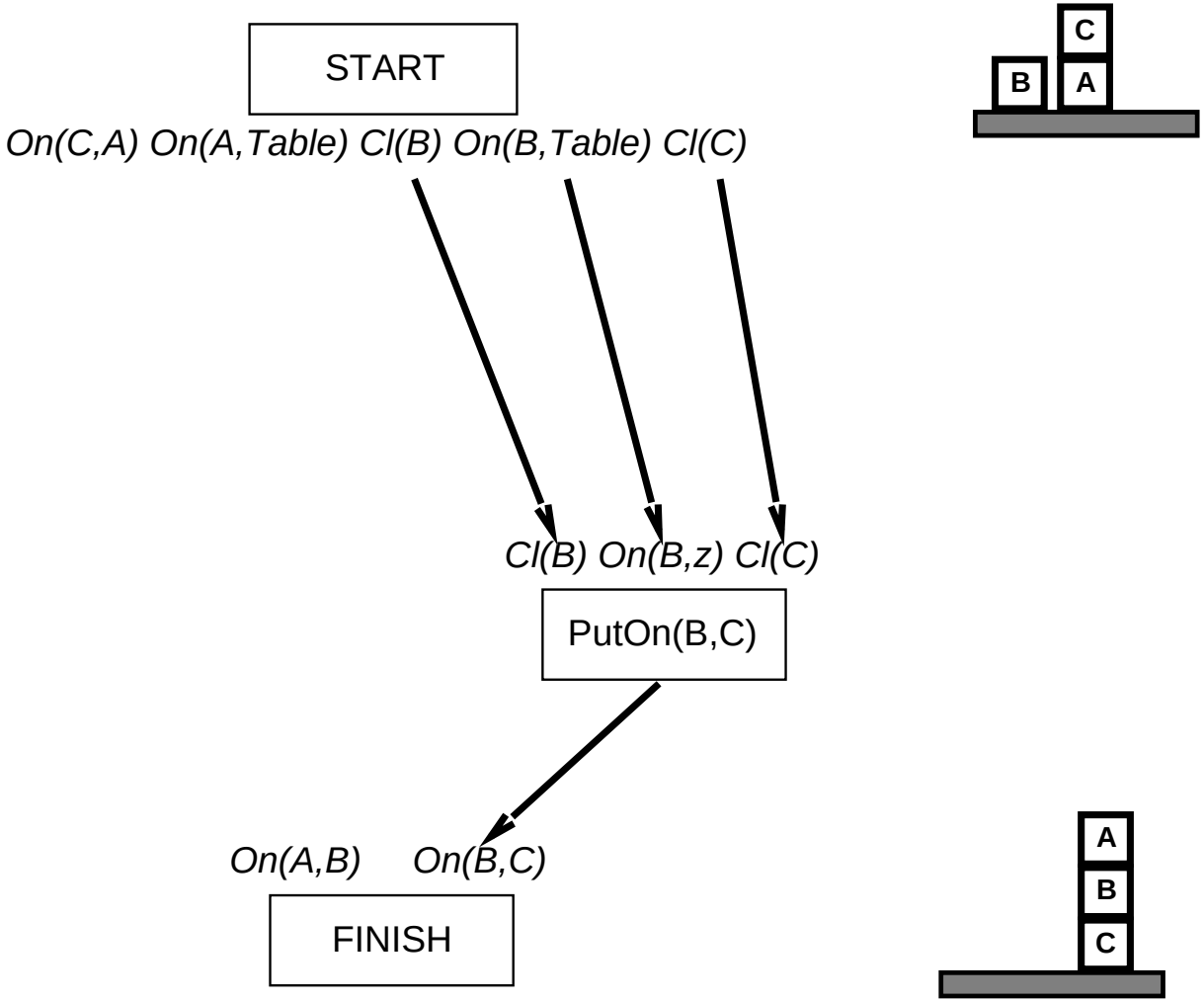


On(A,B) On(B,C)

FINISH



Example contd.



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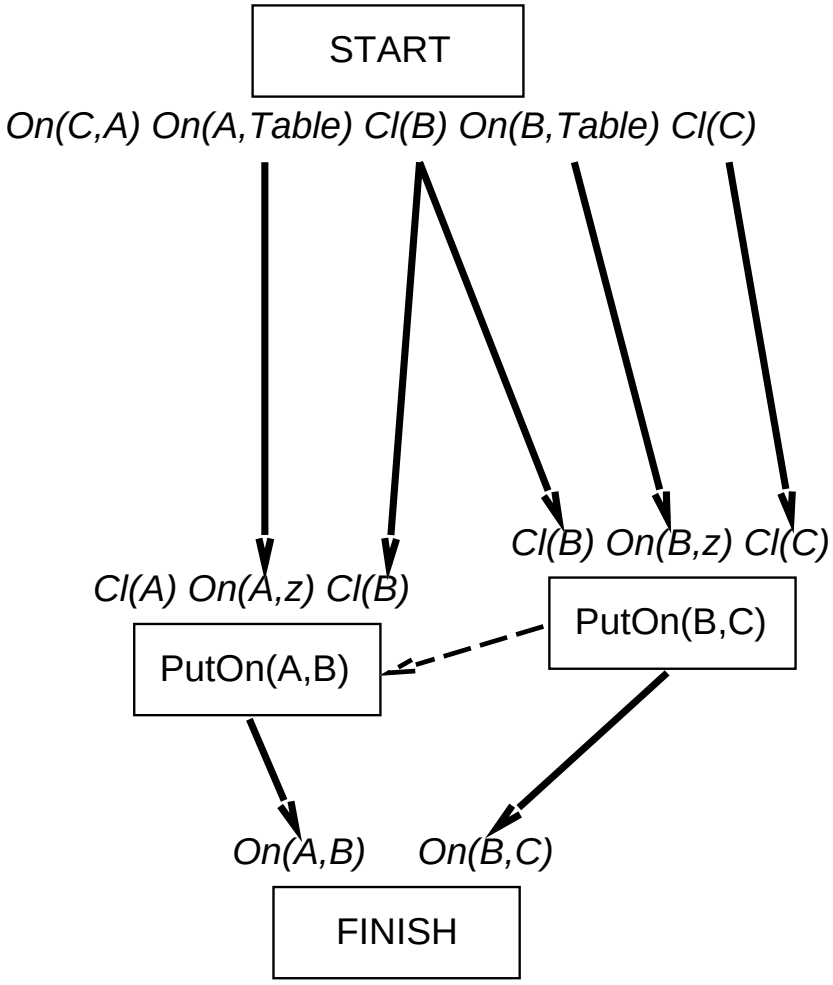
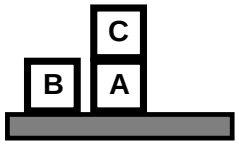
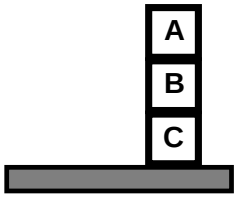
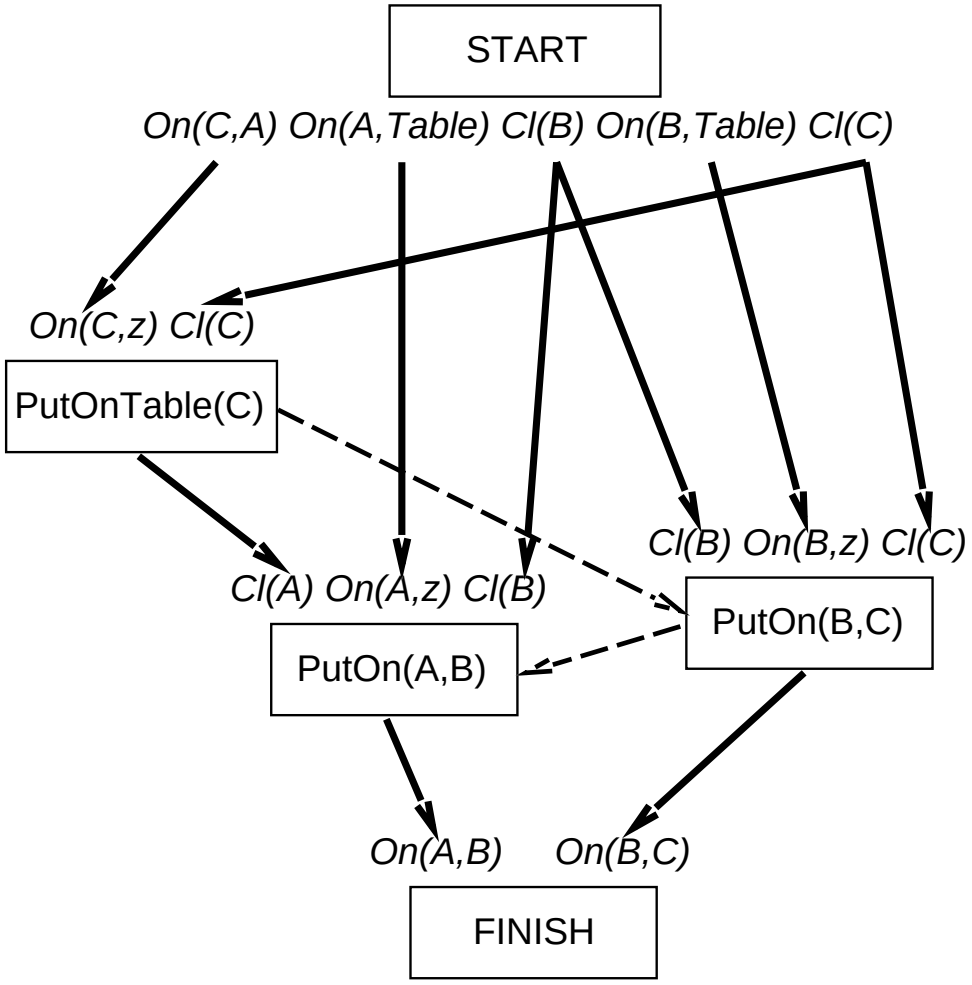


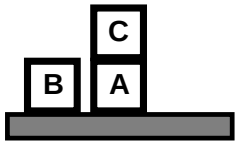


PutOn(A,B) clobbers Cl(B) => order after PutOn(B,C)



Example contd.





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

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