

# PLANNING

## CHAPTER 11

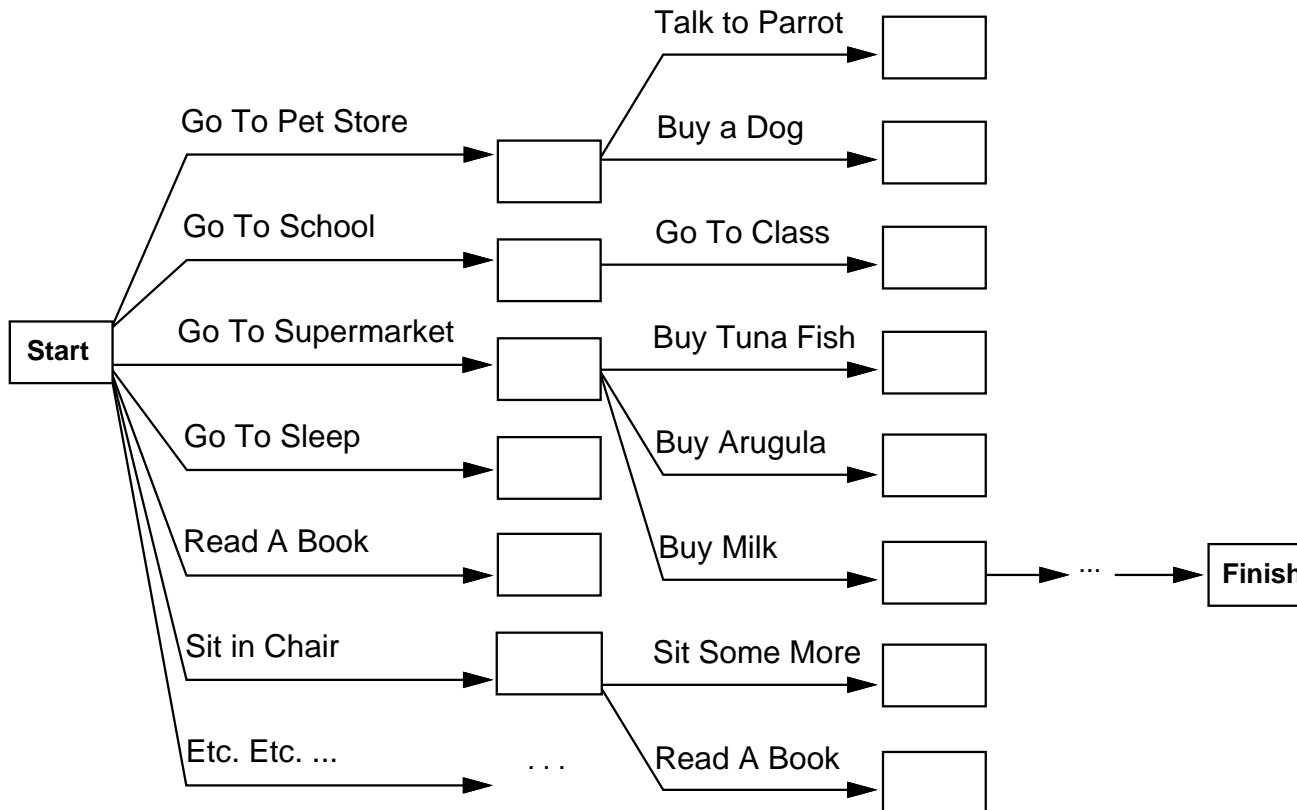
# Outline

- ◇ 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
<b>States</b>	Lisp data structures	Logical sentences
<b>Actions</b>	Lisp code	Preconditions/outcomes
<b>Goal</b>	Lisp code	Logical sentence (conjunction)
<b>Plan</b>	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:  $Have(x)$

$At(p) \quad Sells(p, x)$

**Buy(x)**

$Have(x)$

[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

## Partially ordered plans

*Partially ordered* collection of steps with

*Start step* has the initial state description as its effect

*Finish step* has the goal description as its precondition

*causal links* from outcome of one step to precondition of another

*temporal ordering* between pairs of steps

*Open condition* = precondition of a step not yet causally linked

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

# Example

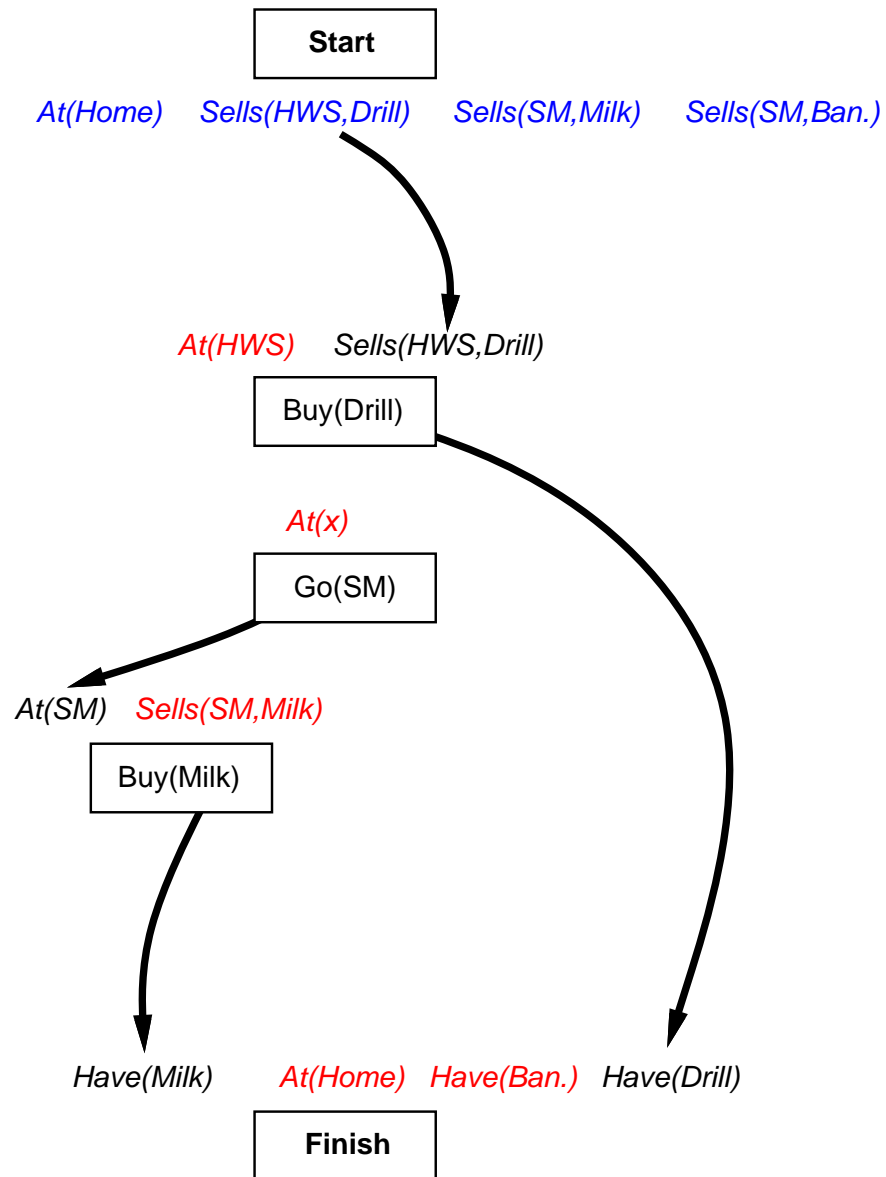
**Start**

*At(Home)   Sells(HWS,Drill)   Sells(SM,Milk)   Sells(SM,Ban.)*

*Have(Milk)   At(Home)   Have(Ban.)   Have(Drill)*

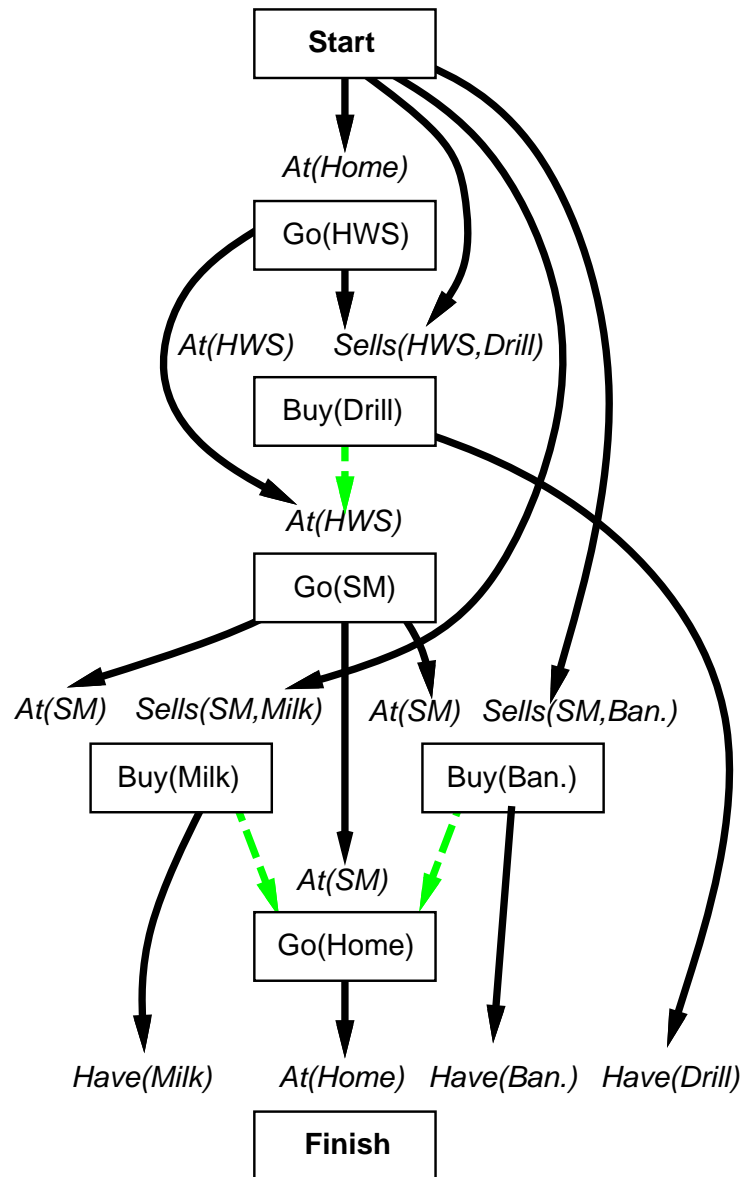
**Finish**

# Example





# Example



## Planning process

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 to remove possible conflicts

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

Backtrack if an open condition is unachievable or

if a conflict is unresolvable

## POP algorithm sketch

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

*plan*  $\leftarrow$  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*)

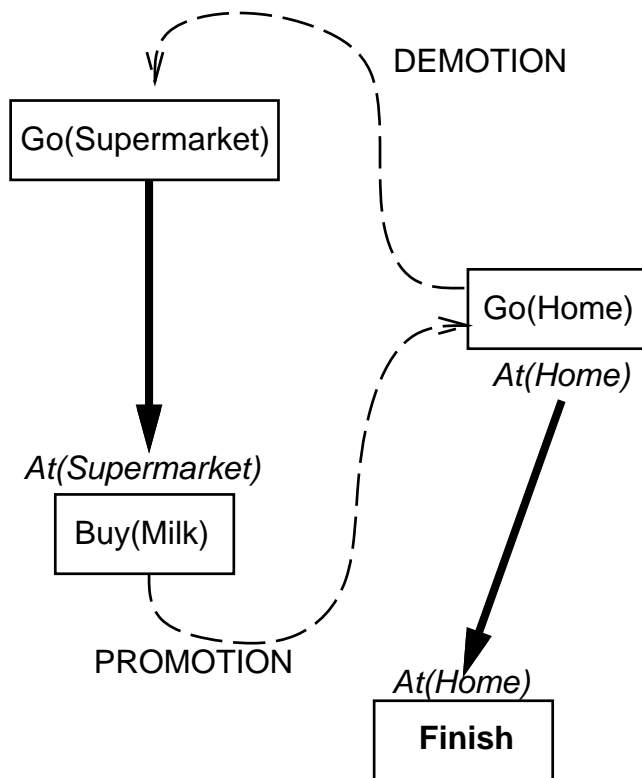
*Promotion*: Add  $S_j \prec S_{threat}$  to ORDERINGS(*plan*)

**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)

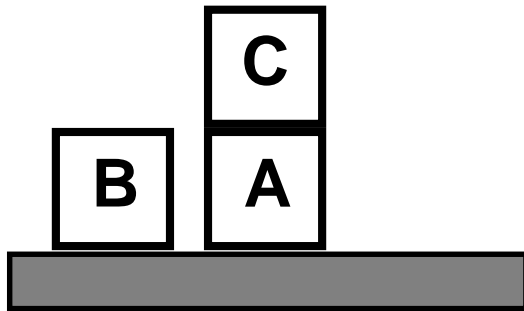
Extensions for disjunction, universals, negation, conditionals

Can be made efficient with good heuristics derived from problem description

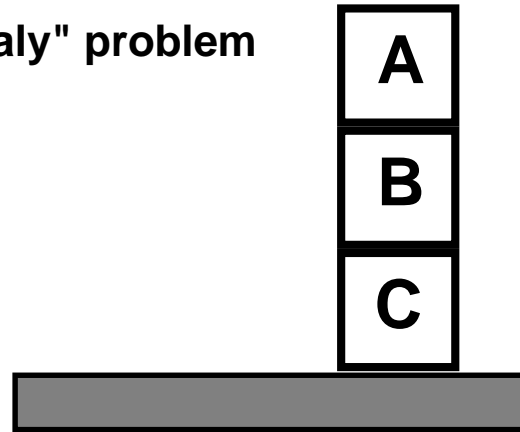
Particularly good for problems with many loosely related subgoals

## Example: Blocks world

"Sussman anomaly" problem



Start State



Goal State

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

PutOn(x,y)

$\sim On(x,z) \ \sim Clear(y)$   
 $Clear(z) \ On(x,y)$

$Clear(x) \ On(x,z)$

PutOnTable(x)

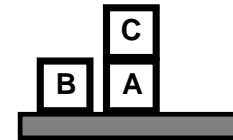
$\sim On(x,z) \ Clear(z) \ On(x, Table)$

+ several inequality constraints

## Example contd.

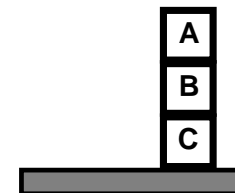
START

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



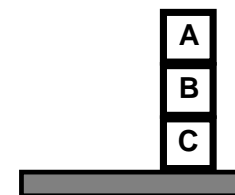
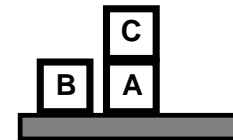
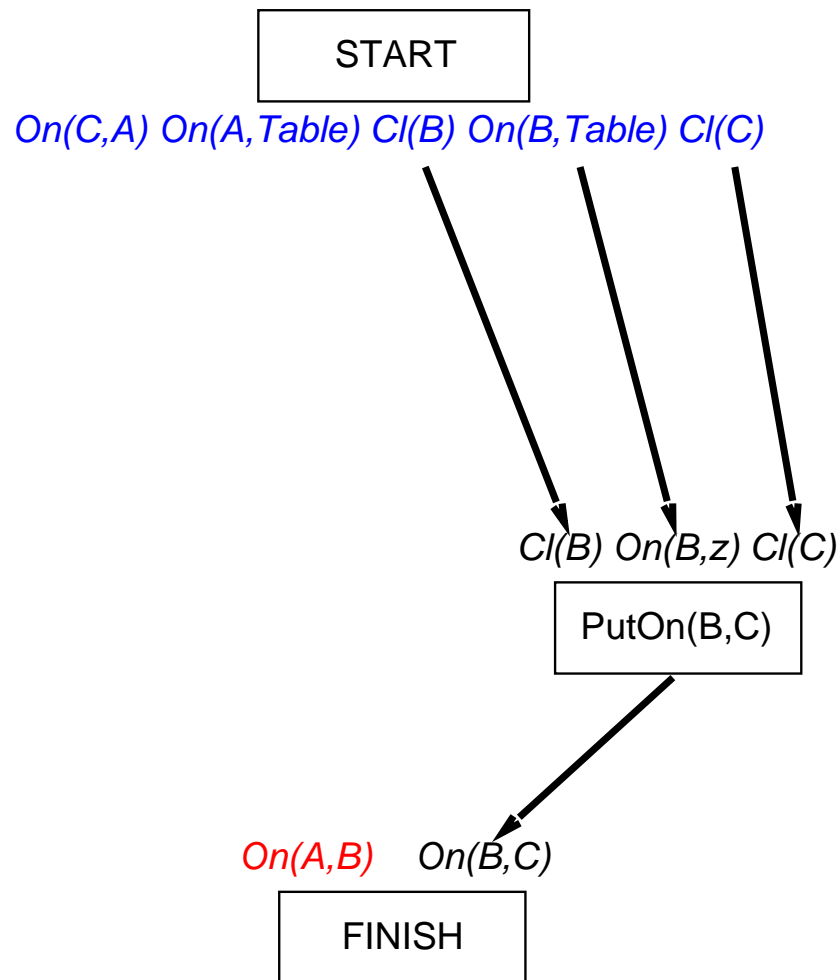
*On(A,B) On(B,C)*

FINISH

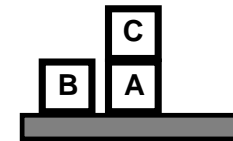
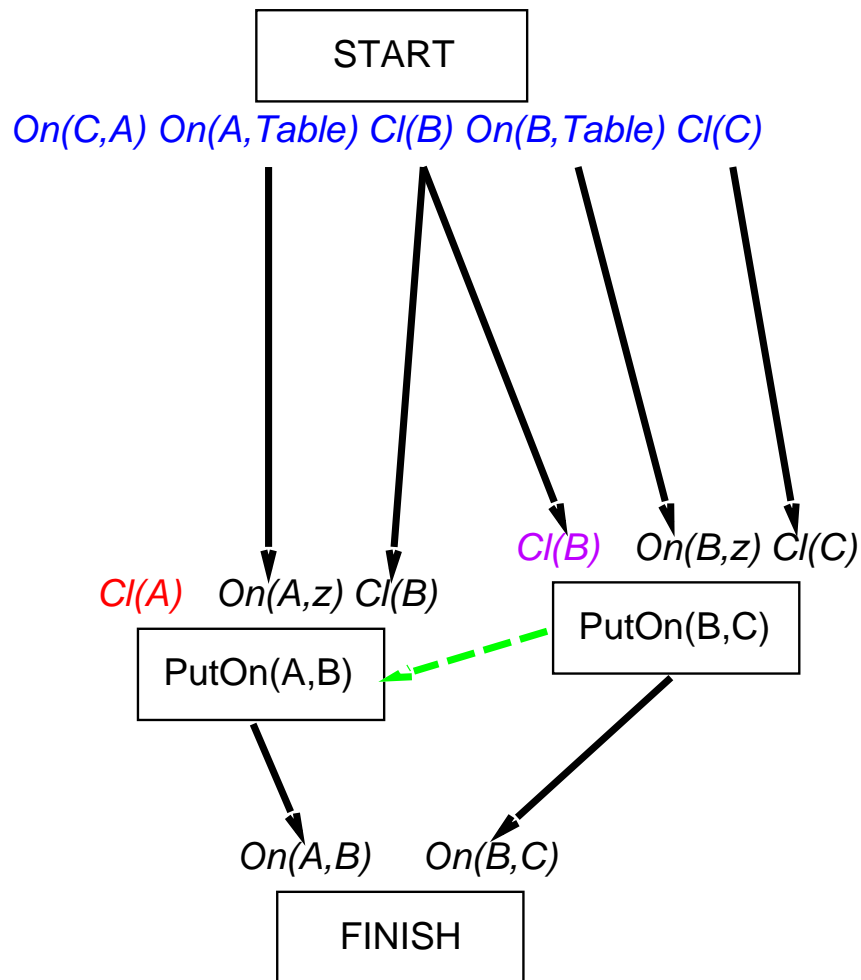




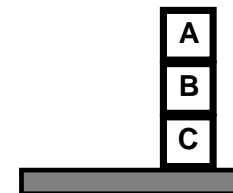
## Example contd.



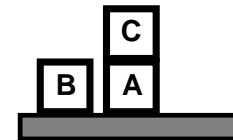
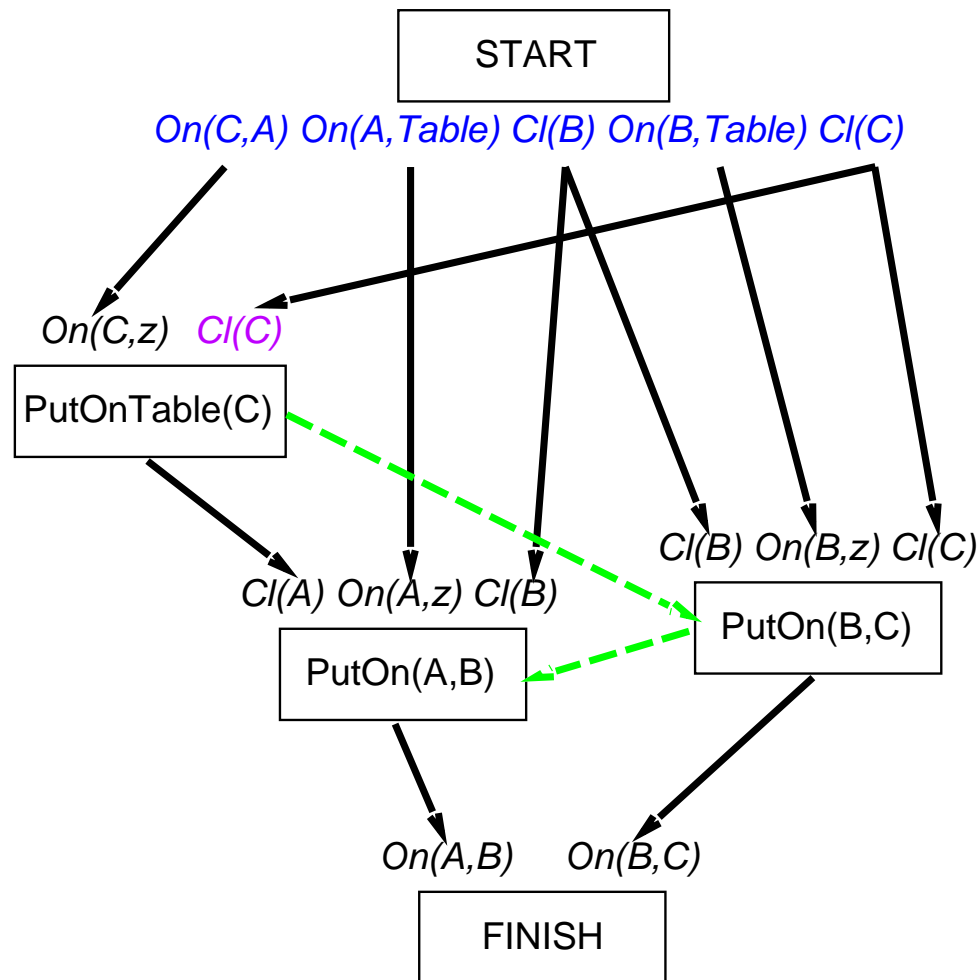
## Example contd.



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



## Example contd.



PutOn(A,B)  
clobbers  $Cl(B)$   
 $\Rightarrow$  order after  
PutOn(B,C)

PutOn(B,C)  
clobbers  $Cl(C)$   
 $\Rightarrow$  order after  
PutOnTable(C)

