# Introduction to Artificial Intelligence

## Planning

Chapter 11

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# Outline

◇ Search vs. planning

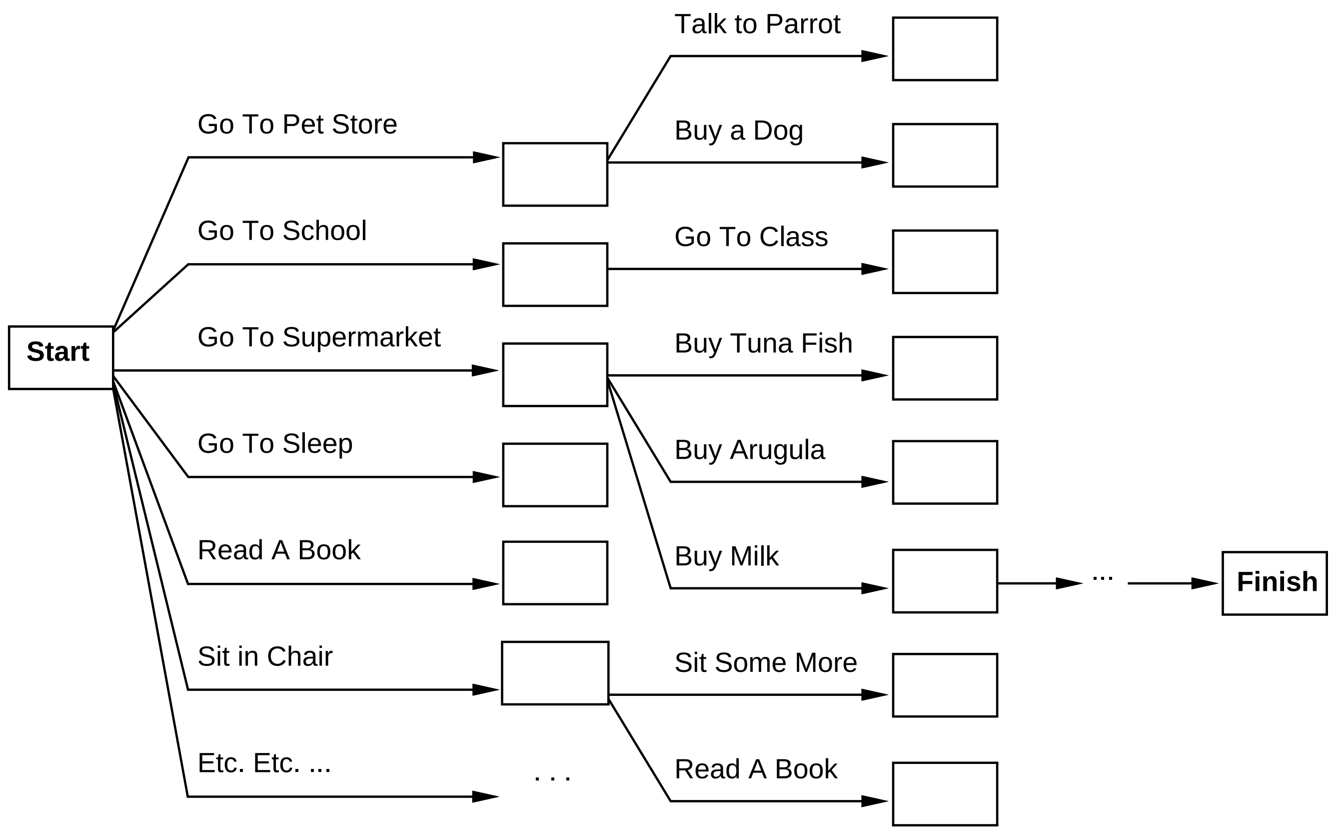
◇ STRIPS operators

◇ 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** $At(Home, S_0) \wedge \neg Have(Milk, S_0) \wedge \ldots$

**Actions** as Successor State axioms

$Have(Milk, Result(a, s)) \;\; \Leftrightarrow$

$[(a = Buy(Milk) \wedge At(Supermarket, s)) \vee (Have(Milk, s) \wedge a \neq \ldots)]$

**Query**

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

**Solution**

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

Principal difficulty: unconstrained branching, hard to apply heuristics

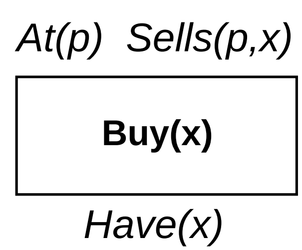
# STRIPS operators

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**

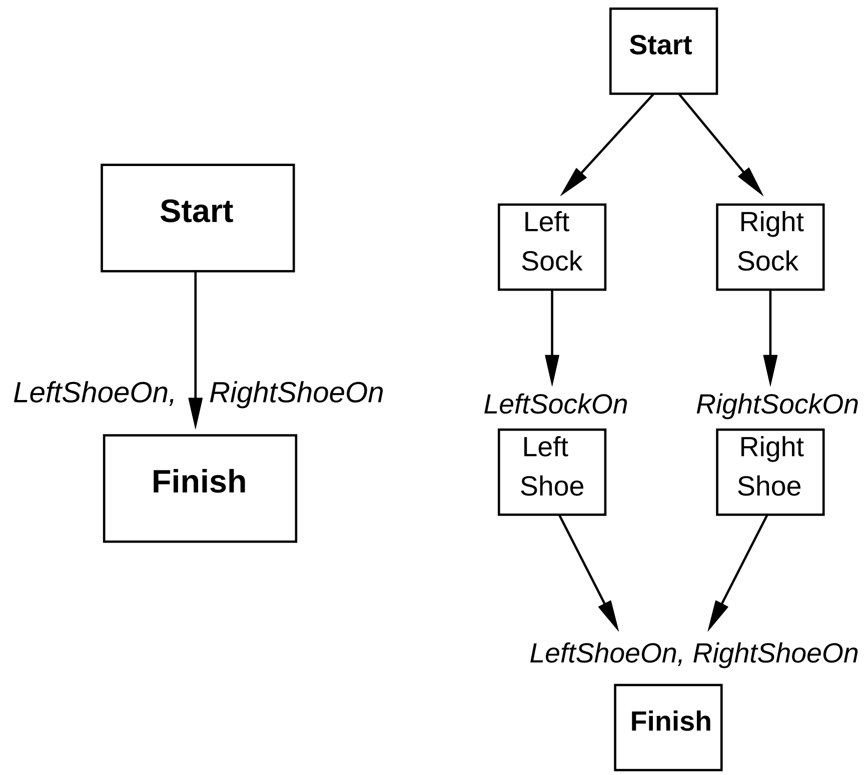
Defn: **open condition** is a precondition of a step not yet fulfilled

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**

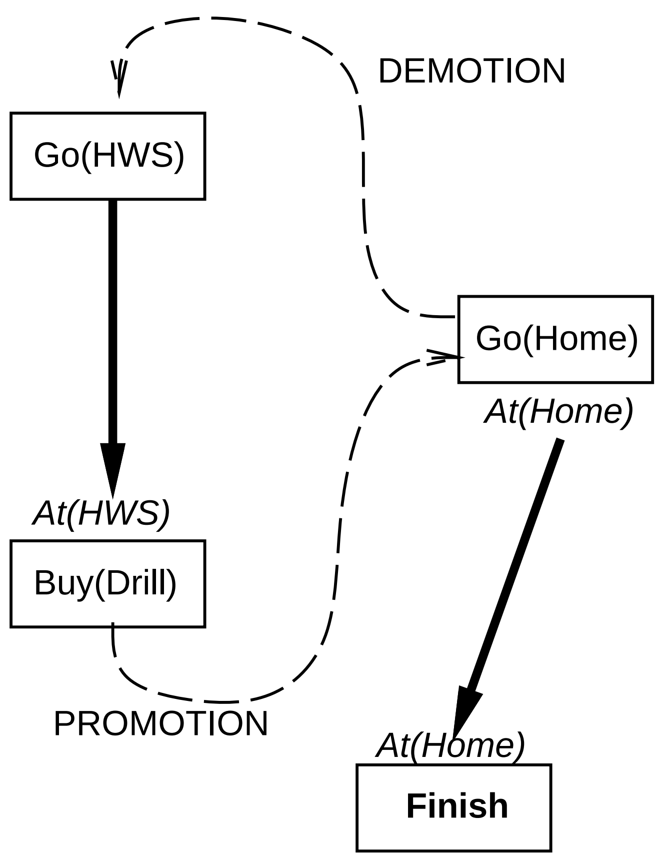
# POP algorithm contd.

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

Extensions for disjunction, universals, negation, conditionals

# 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 $At(HWS)$:

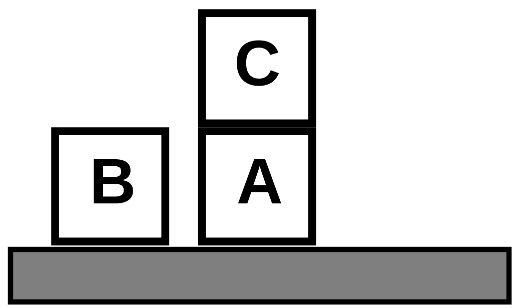



**Demotion**: put before $Go(HWS)$

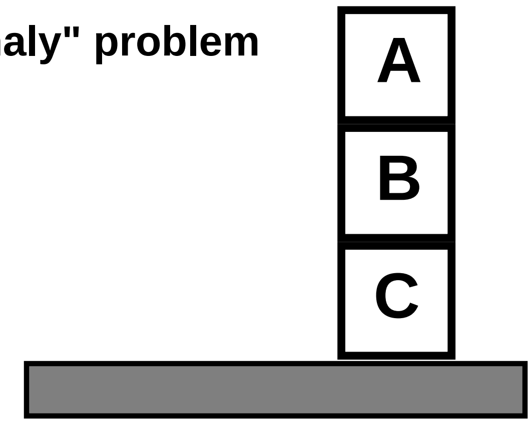
**Promotion**: put after $Buy(Drill)$

# Example: Blocks world

**"Sussman anomaly" problem**




Start State




Goal State

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

$\boxed{\text{PutOn(x,y)}}$

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

*Clear(x) On(x,z)*

$\boxed{\text{PutOnTable(x)}}$

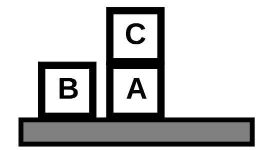
*~On(x,z) Clear(z) On(x,Table)*

+ several inequality constraints

# Example contd.

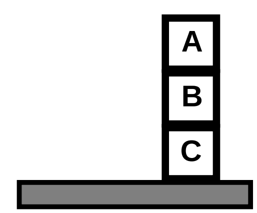
START

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




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

FINISH



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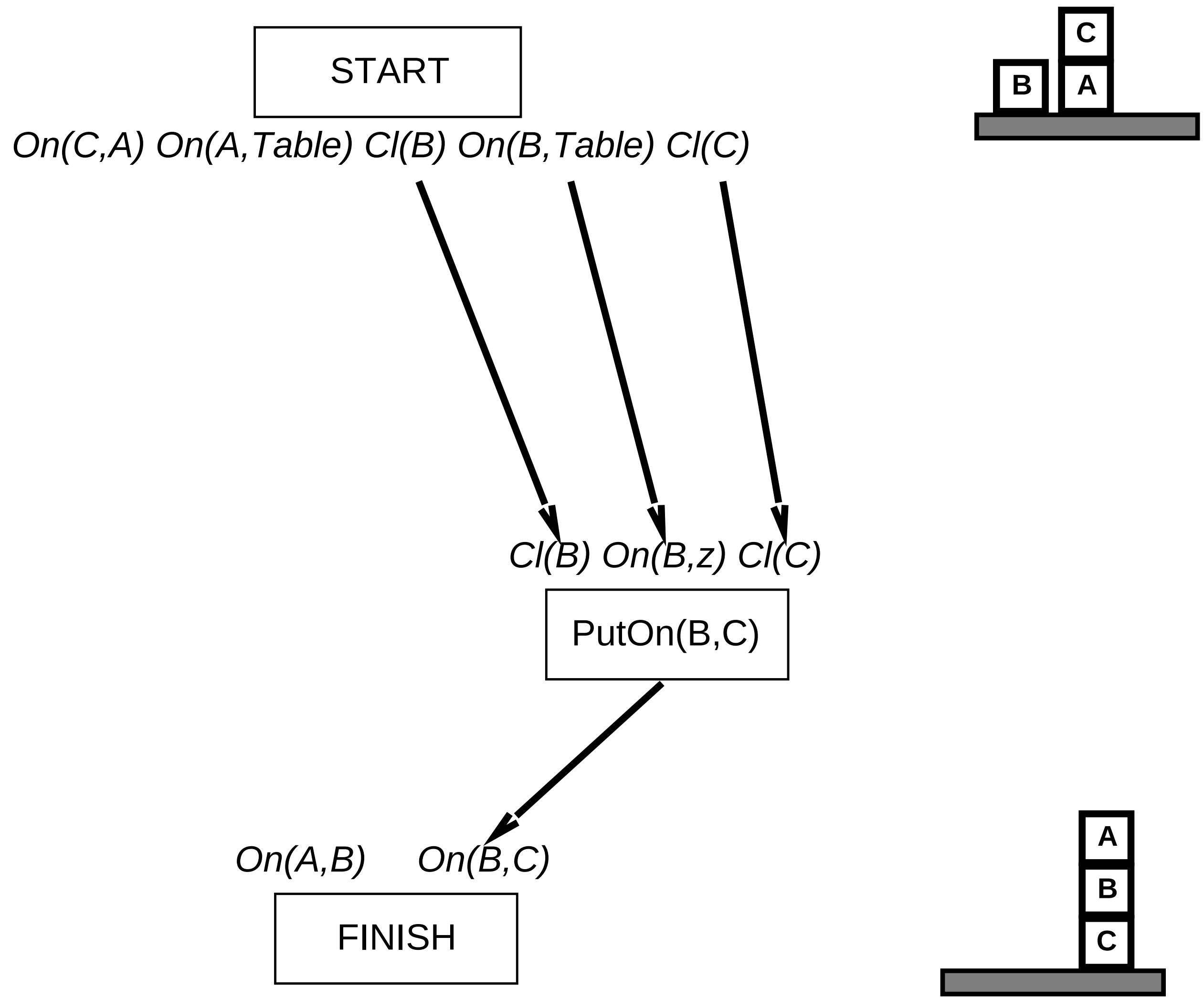
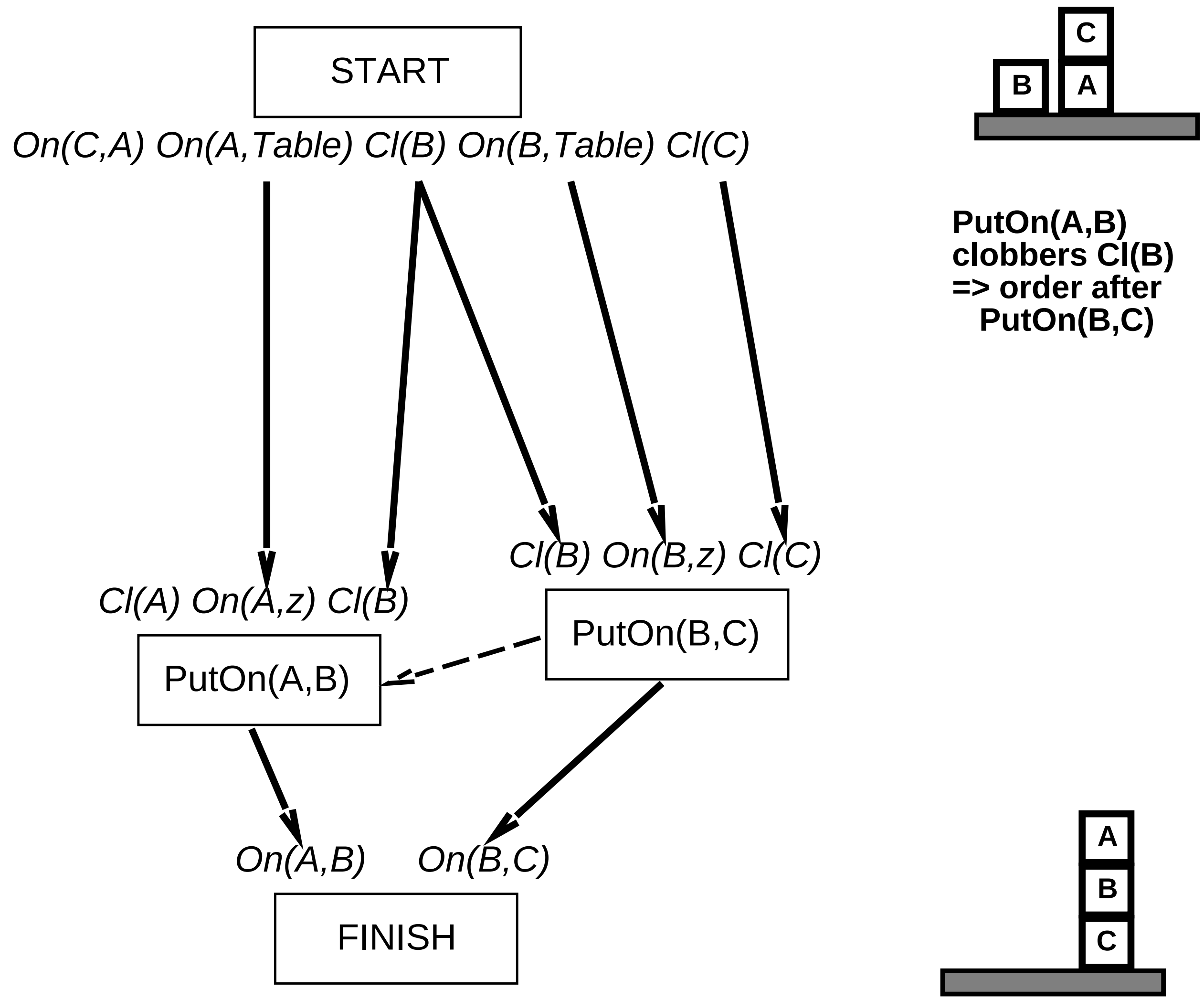
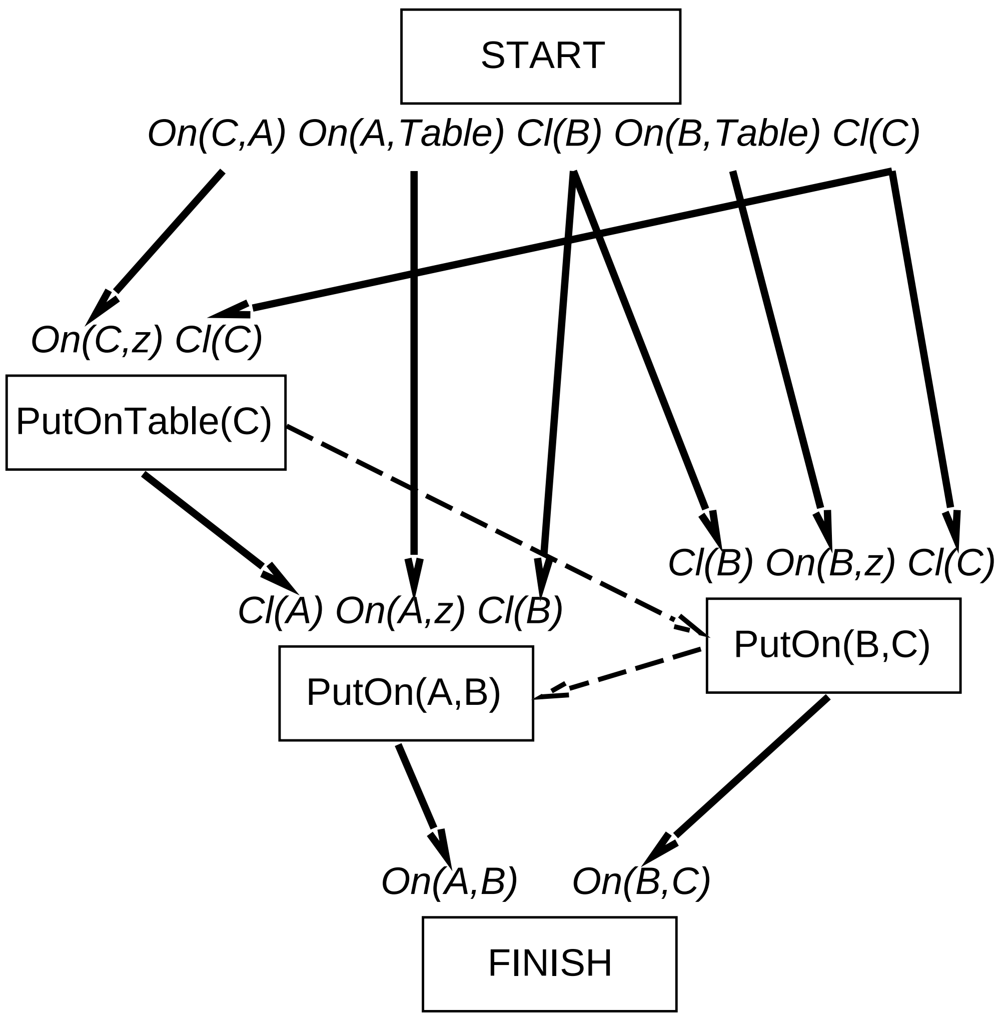


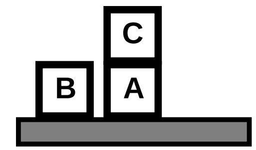
# Example contd.




**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)**