

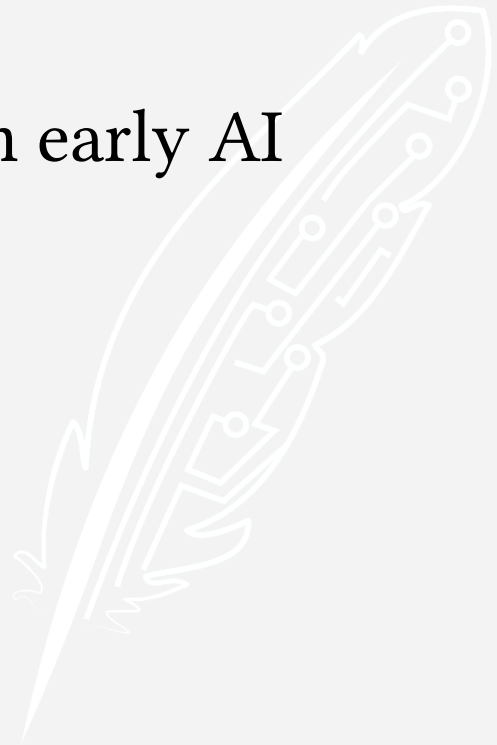
# Report on a General Problem Solving Program

By Newell, Shaw, and Simon  
Presented by Stephen G. Ware



# Context

- Dartmouth Conference: 1956
- This paper: 1959
- Authors all become important names in early AI
- First AI Winter: ~1970



# “General” Problem Solver

- GPS is one of the first computer programs to separate the problem from the method of solving.
- Early mention of heuristics
- Authors acknowledge it is not fast enough to work for real world problems.
- Designed based on observations of human problem solving.

# Recursive Solving

The principle of subgoal reduction: Make progress by substituting for the achievement of a goal the achievement of a set of easier goals.

Some differences will prove more difficult to affect than others. It is profitable, therefore, to try to eliminate "difficult" differences, even at the cost of introducing new differences of lesser difficulty. This process can be repeated as long as progress is being made toward eliminating the more difficult differences.

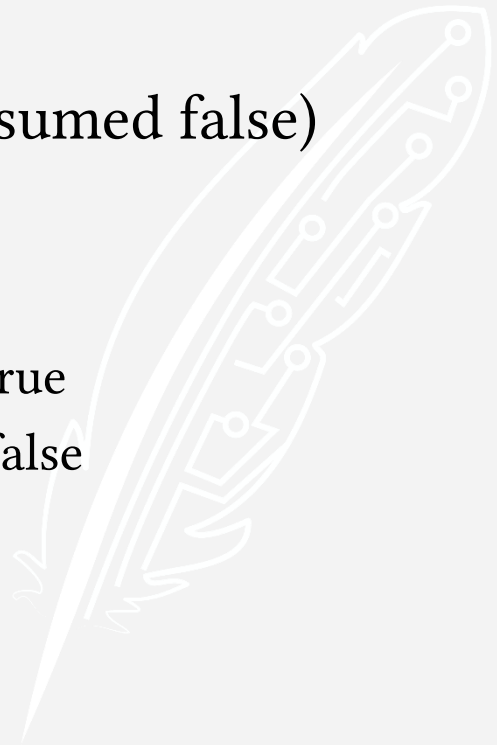
# Operators

|     | <u>Operators</u>  | <u>Abstract Operators</u>        |
|-----|---|----------------------------------|
| R1  | $A \vee B \rightarrow B \vee A, A \cdot B \rightarrow B \cdot A$  | Identity                         |
| R2  | $A \supset B \rightarrow \neg B \supset \neg A$   | Identity                         |
| R3  | $A \vee A \leftrightarrow A, A \cdot A \leftrightarrow A$   | $(AA) \leftrightarrow A$         |
| R4  | $A \vee (B \vee C) \leftrightarrow (A \vee B) \vee C, A \cdot (B \cdot C) \leftrightarrow (A \cdot B) \cdot C$                    | $A(BC) \leftrightarrow (AB)C$    |
| R5  | $A \vee B \leftrightarrow \neg(\neg A \cdot \neg B)$  | Identity                         |
| R6  | $A \supset B \leftrightarrow \neg A \vee B$   | Identity                         |
| R7  | $A \vee (B \cdot C) \leftrightarrow (A \vee B) \cdot (A \vee C), A \cdot (B \vee C) \leftrightarrow (A \cdot B) \vee (A \cdot C)$ | $A(BC) \leftrightarrow (AB)(AC)$ |
| R8  | $A \cdot B \rightarrow A, A \cdot B \rightarrow B$  | $(AB) \rightarrow A$             |
| R9  | $A \rightarrow A \vee X$ (X is any expression.)   | $A \rightarrow (AX)$             |
| R10 | $[A, B] \rightarrow A \cdot B$ (Two expressions input.)   | $[A, B] \rightarrow (AB)$        |
| R11 | $[A \supset B, A] \rightarrow B$ (Two expressions input.)   | $[(AB), A] \rightarrow B$        |
| R12 | $[A \supset B, B \supset C] \rightarrow A \supset C$ (Two expressions input.)   | $[(AB), (BC)] \rightarrow (AC)$  |

Figure 3a. Symbolic logic task environment

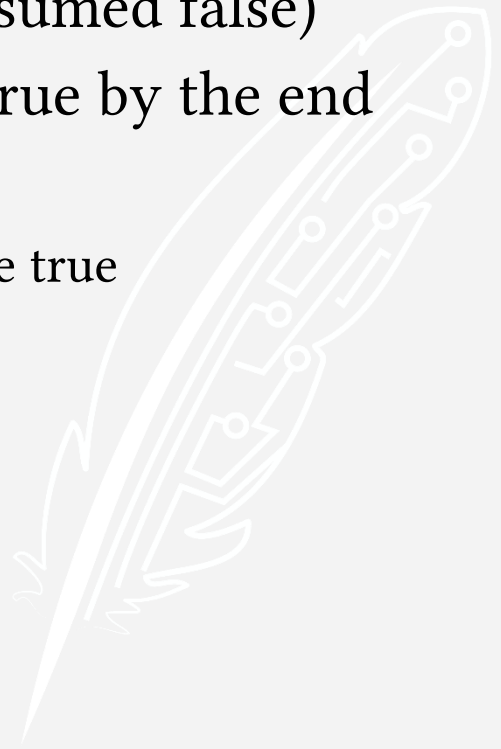
# STRIPS

- STanford Research Institute Problem Solver
- A problem is composed of:
  - Initial State: list of true facts (all others assumed false)
  - Goal: facts that should be true by the end
  - Operators:
    - True Preconditions: list of facts that must be true
    - False Preconditions: list of facts that must be false
    - Add Effects: list of facts that become true
    - Delete Effects: list of facts that become false



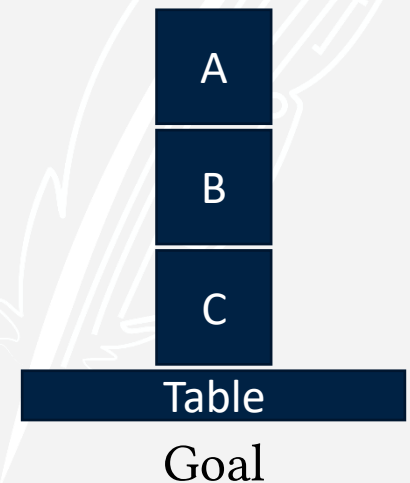
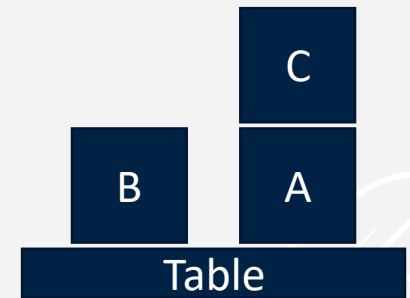
# STRIPS-like

- A problem is composed of:
  - Initial State: list of true facts (all others assumed false)
  - Goal: a logical expression that should be true by the end
  - Operators:
    - Precondition: logical expression that should be true
    - Effect: conjunction of literals



# Blocks World

- Some number of labeled blocks on an infinite table.
- Blocks can be stacked on top of one another.
- A block can only be moved when nothing is stacked on it.
- The goal describes a particular arrangement.

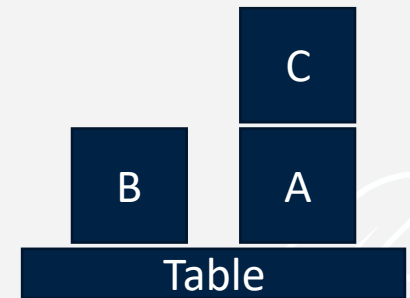




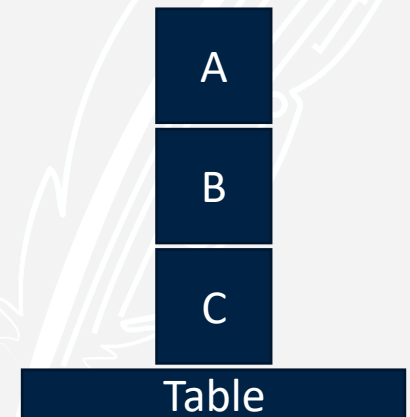
# Blocks World: Language

The constant *Table* represents the table.

The predicate  $on(b, i)$  means that block  $b$  is stacked on top of thing  $i$ , where a thing is another block or the table.



Initial State

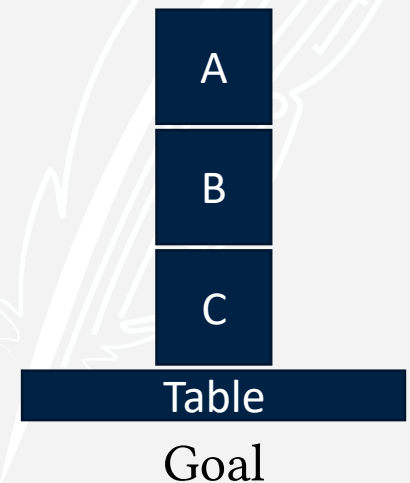
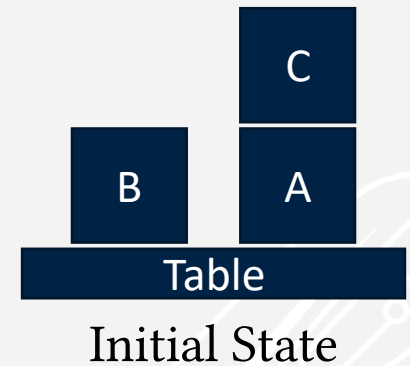


Goal

# Blocks World: Initial State

Initial State:  $\text{block}(A) \wedge$   
 $\text{block}(B) \wedge \text{block}(C) \wedge$   
 $\text{on}(B, \text{Table}) \wedge \text{on}(C, A) \wedge$   
 $\text{on}(A, \text{Table})$

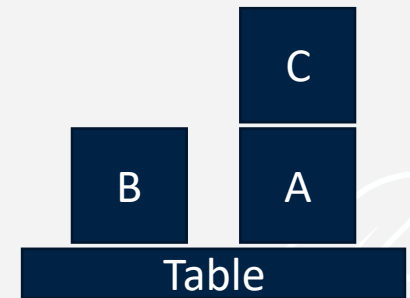
Planning uses the **closed world assumption**, meaning that facts not explicitly stated to be true are false. Thus, if we need to, we can assume things like  $\neg \text{on}(B, A)$ .



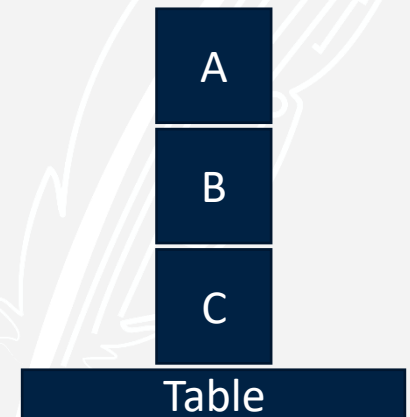
# Blocks World: Goal

Goal:  $on(A, B) \wedge on(B, C)$

A goal is a conjunction of things which must be true, but it is *not* a complete description of the goal state (note how it does not specify the position of  $C$ ). This means there are potentially many **goal states**.



Initial State



Goal

# Action Template Using FOL

Name:  $move(b, from, to)$ :

Precondition:  $block(b) \wedge on(b, from) \wedge$   
 $\neg \exists x on(x, b) \wedge \neg \exists y on(y, to)$

Effect:  $on(b, to)$



# Action Template Using FOL

Name:  $move(b, from, to)$ :

Precondition:  $block(b) \wedge on(b, from) \wedge \neg \exists x on(x, b) \wedge \neg \exists y on(y, to)$

Effect:  $on(b, to) \wedge \neg on(b, from)$



Note that we need to state which things are no longer true.



# Action Template w/o FOL

Name:  $move(b, from, to)$ :

Precondition:  $block(b) \wedge on(b, from) \wedge clear(b) \wedge clear(to)$

Effect:  $on(b, to) \wedge \neg on(b, from) \wedge clear(from) \wedge \neg clear(to)$

# Action Template STRIPS

Name: *move(b, from, to)*:

Preconditions:

- *block(b)*
- *on(b, from)*
- *clear(b)*
- *clear(to)*

Add:

- *on(b, to)*
- *clear(from)*

Delete:

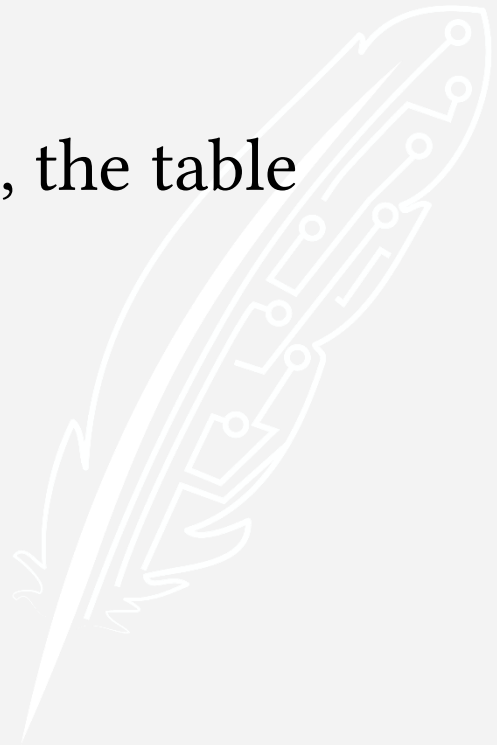
- *on(b, from)*
- *clear(to)*



# Bug in the Problem

What happens when you move a block onto the table?

When you move anything onto the table, the table will no longer be clear.





# Move to Table Action

Name:  $moveToTable(b, from)$ :

Precondition:  $block(b) \wedge on(b, from) \wedge clear(b)$

Effect:  $on(b, Table) \wedge \neg on(b, from) \wedge clear(from)$



# Bug in the Problem

Has the *moveToTable* action fixed the problem when it is still possible to using the regular move action to put things on the table?

- Yes, because some plans will be invalid, but valid plans now exist for any legal configuration.
- We could also constrain the *move* action to not allow the table as the destination. Then all plans will reflect the scenario we are trying to model.

# GPS: General Problem Solver

Let the initial state be the current state.

To satisfy some goal  $G$ :

For each conjunct  $C$  of  $G$ :

If  $C$  is true in the current state, do nothing.

Else:

Choose an action  $A$  which achieves  $C$ .

For each precondition  $P$  of  $A$ , satisfy  $P$ .

If all preconditions were satisfied:

Add the action to the plan.

Update the current state.

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$on(A, B) \wedge on(B, C)$



$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$



$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$



$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(C, Table) \wedge clear(C) \wedge on(A, Table) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(C, Table) \wedge clear(C) \wedge on(A, Table) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(C, Table) \wedge clear(C) \wedge on(A, Table) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

$on(A, B) \wedge on(B, C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(B) \wedge on(B, Table) \wedge clear(B) \wedge clear(C)$

$move(B, Table, C)$

$on(B, C) \wedge \neg on(B, Table) \wedge clear(Table) \wedge \neg clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, C) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A)$

$block(B) \wedge on(B, C) \wedge clear(B)$

$moveToTable(B, C)$

$on(B, Table) \wedge \neg on(B, C) \wedge clear(C)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(A, Table) \wedge on(C, A) \wedge clear(C)$

$block(C) \wedge on(C, A) \wedge clear(C)$

$moveToTable(C, A)$

$on(C, Table) \wedge \neg on(C, A) \wedge clear(A)$

$block(A) \wedge block(B) \wedge block(C) \wedge on(B, Table) \wedge clear(B) \wedge on(C, Table) \wedge clear(C) \wedge on(A, Table) \wedge clear(A)$

$block(A) \wedge on(A, Table) \wedge clear(A) \wedge clear(B)$

$move(A, Table, B)$

$on(A, B) \wedge \neg on(A, Table) \wedge clear(Table) \wedge \neg clear(B)$

This goal was undone!



$on(A, B) \wedge on(B, C)$



# Why Planning is Hard

Planning problems can be broken down into individual goals, but these goals can't be solved independently.

Solving one affects how others are solved:

- Sometimes goals interfere with one another
- Sometimes goals synergize with one another

# Designing Planners

A good planner needs to:

- Cope with goal interference
- Leverage goal synergy
- Aggressively prune the search space
  - Abstraction
  - Heuristics



# Designing Planners

A planner is **sound** if it produces only valid plans (i.e. plan guaranteed to work).

A planner is **complete** if it is guaranteed to find a solution when one exists.