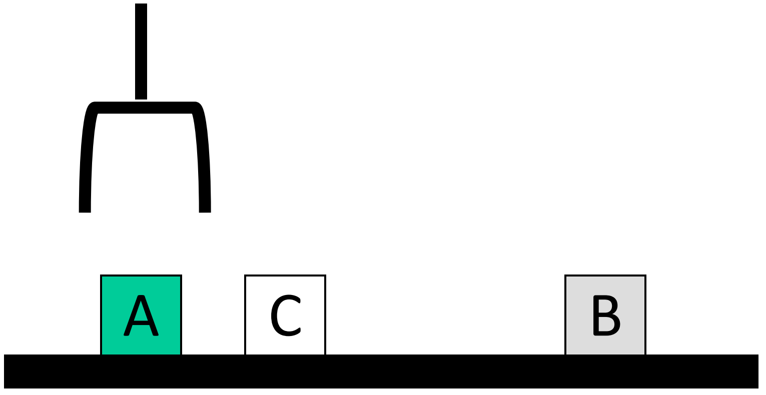
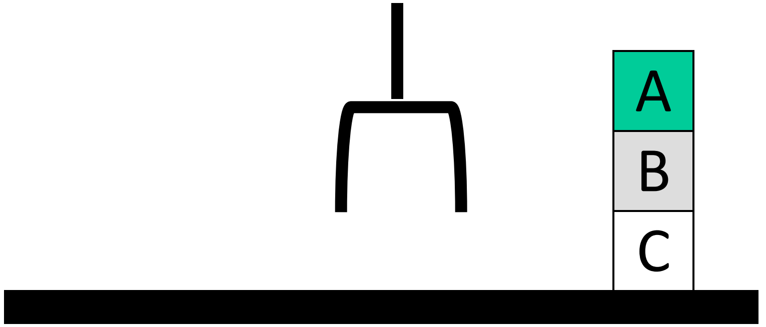
Planning 1

Chapter 11.1-11.3

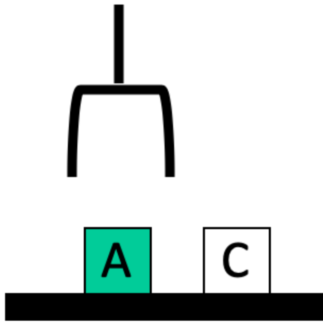
Some material adopted from notes
by Andreas Geyer-Schulz
and Chuck Dyer

Blocks World Planning





Blocks world



The blocks world is a micro-world with a table, a set of blocks, and a robot hand

Some constraints for a simple model:

- Only one block can be on another block
- Any number of blocks can be on the table
- The hand can only hold one block

Typical representation uses a logic notation:

ontable(b) ontable(d)

on(c,d)   holding(a)

clear(b)   clear(c)

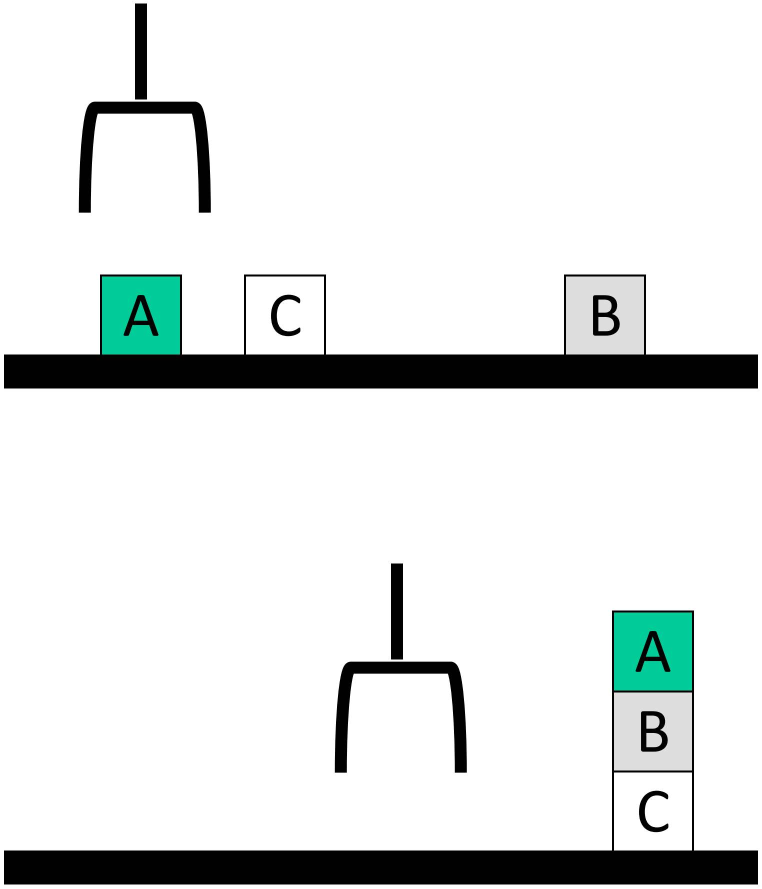
Typical BW planning problem

Initial state:

clear(a)
clear(b)
clear(c)
ontable(a)
ontable(b)
ontable(c)
handempty

Goal:

on(b,c)
on(a,b)
ontable(c)



Typical BW planning problem

Logical assertions describing initial & final states

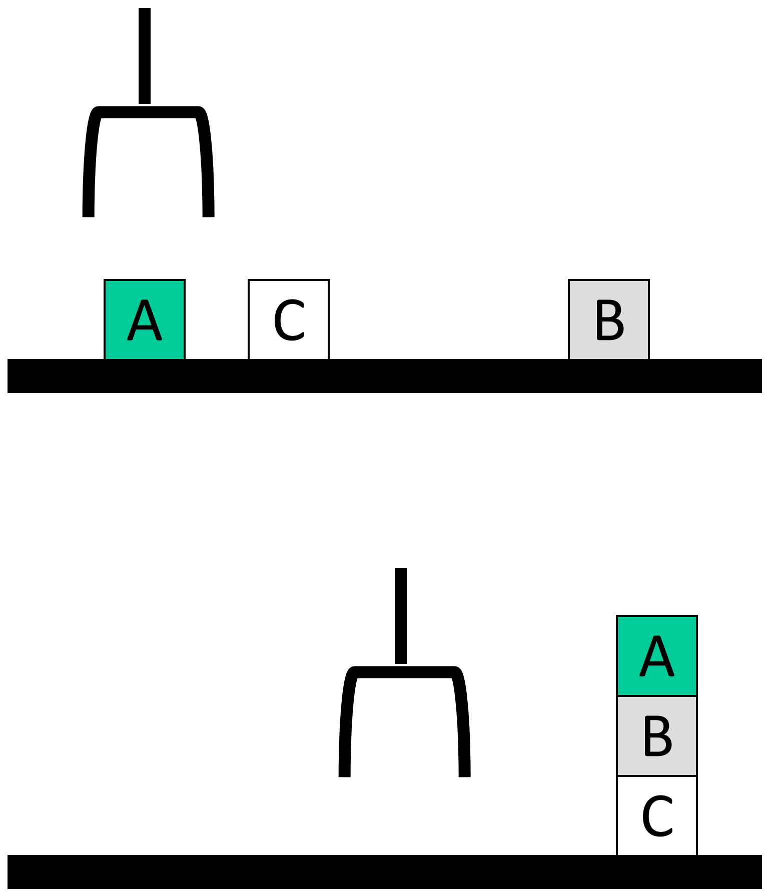
Sequence of robot actions

Initial state:

- clear(a)
- clear(b)
- clear(c)
- ontable(a)
- ontable(b)
- ontable(c)
- handempty

Goal state:

- on(b,c)
- on(a,b)
- ontable(c)



Plan:

- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

Planning problem

- Find sequence of actions to achieve goal state when executed from initial state given
  - set of possible primitive actions, including their *preconditions* and *effects*
  - initial state description
  - goal state description
- Compute plan as a sequence of actions that, when executed in initial state, achieves goal state
- States specified as a KB , i.e. conjunction of conditions
  - e.g., $ontable(a) \wedge on(b, a)$

Planning vs. problem solving

- Problem solving methods can solve similar problems
- Planning is more powerful and efficient because of the representations and methods used
- States, goals, and actions are decomposed into sets of sentences (usually in first-order logic)
- Search often proceeds through *plan space* rather than *state space* (though there are also state-space planners)
- Sub-goals can be planned independently, reducing the complexity of the planning problem

Typical simplifying assumptions

- Atomic time: Each action is indivisible
- No concurrent actions: but actions need not be ordered w.r.t. each other in the plan
- Deterministic actions: action results completely determined — no uncertainty in their effects
- Agent is the sole cause of change in the world
- Agent is omniscient with complete knowledge of the state of the world
- Closed world assumption: everything known to be true in world is included in state description and anything not listed is false

Blocks world

The blocks world consists of a table, a set of blocks and a robot hand

Some domain constraints:

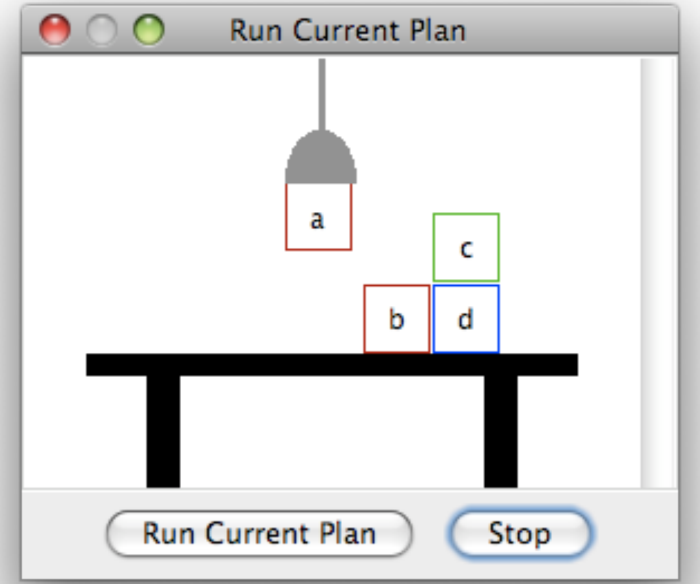
- Only one block can be on another block
- Any number of blocks can be on the table
- The hand can only hold one block

Typical representation:

ontable(b) ontable(d)

on(c,d) holding(a)

clear(b) clear(c)



Meant to be a simple model!

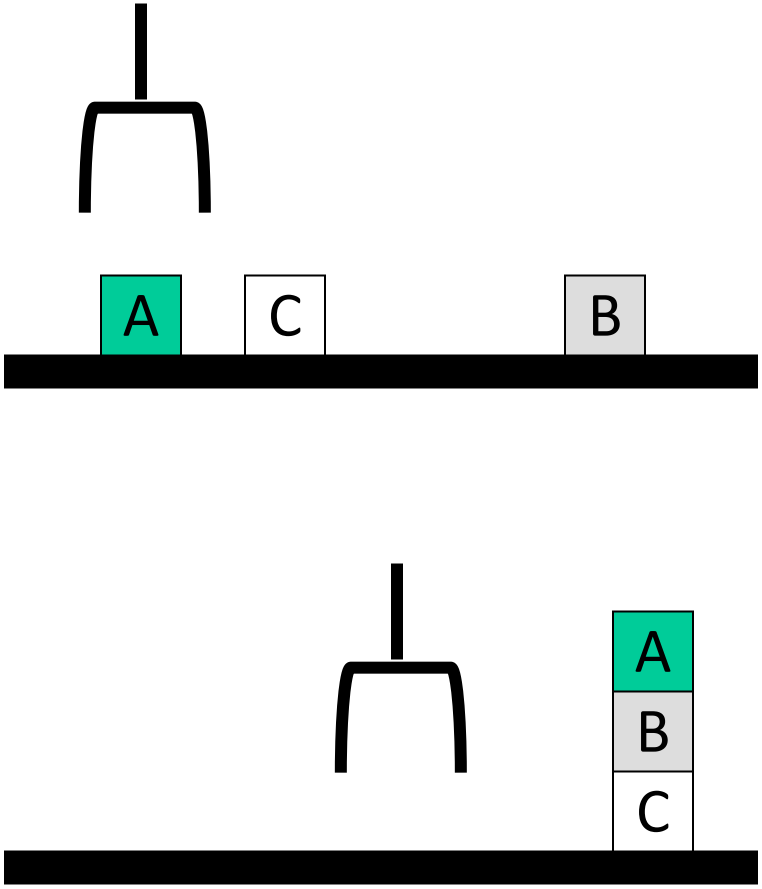
Typical BW planning problem

Initial state:

- clear(a)
- clear(b)
- clear(c)
- ontable(a)
- ontable(b)
- ontable(c)
- handempty

Goal:

- on(b,c)
- on(a,b)
- ontable(c)



A plan:

- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

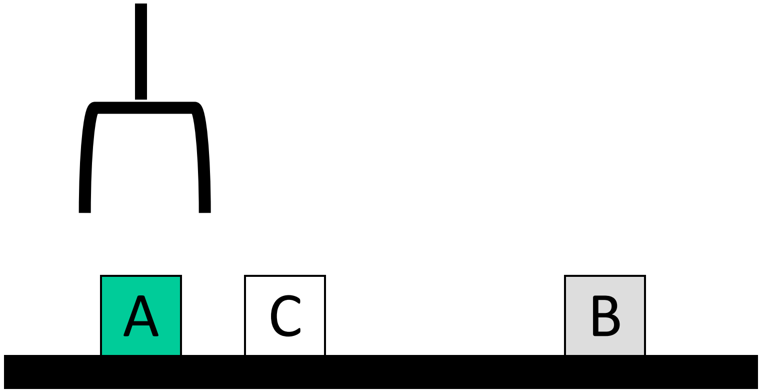
Another BW planning problem

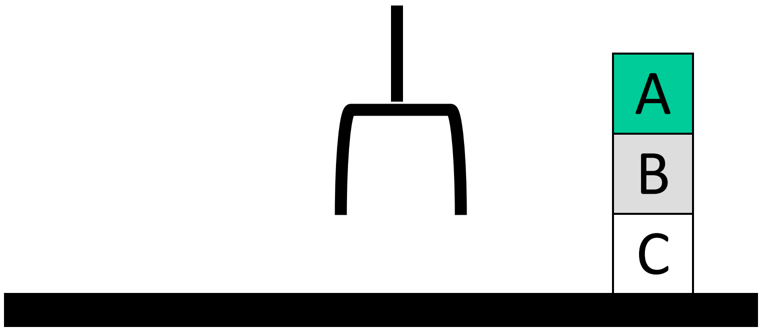
Initial state:

- clear(a)
- clear(b)
- clear(c)
- ontable(a)
- ontable(b)
- ontable(c)
- handempty

Goal:

- on(a,b)
- on(b,c)
- ontable(c)





A plan:

- pickup(a)
- stack(a,b)
- unstack(a,b)
- putdown(a)
- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

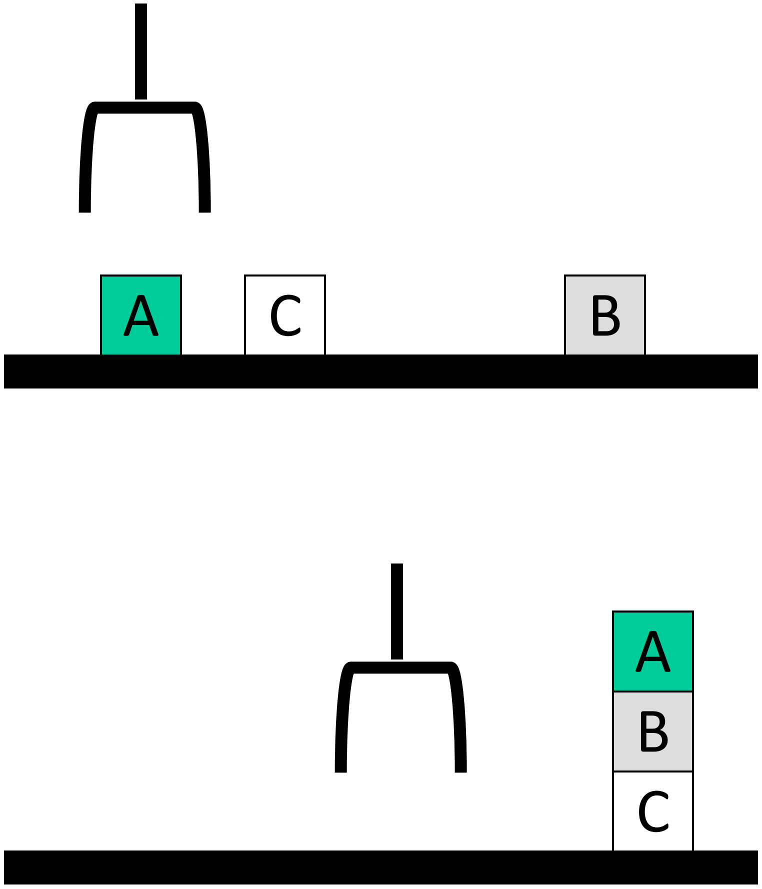
Another BW planning problem

Initial state:

- clear(a)
- clear(b)
- clear(c)
- ontable(a)
- ontable(b)
- ontable(c)
- handempty

Goal:

- on(a,b)
- on(b,c)
- ontable(c)



A plan:

- pickup(a)
- stack(a,b)
- unstack(a,b)
- putdown(a)
- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

Note: Goals in a different order!

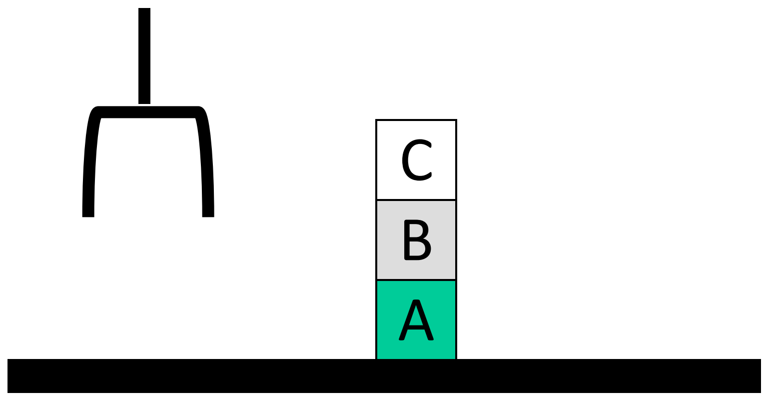
Yet Another BW planning problem

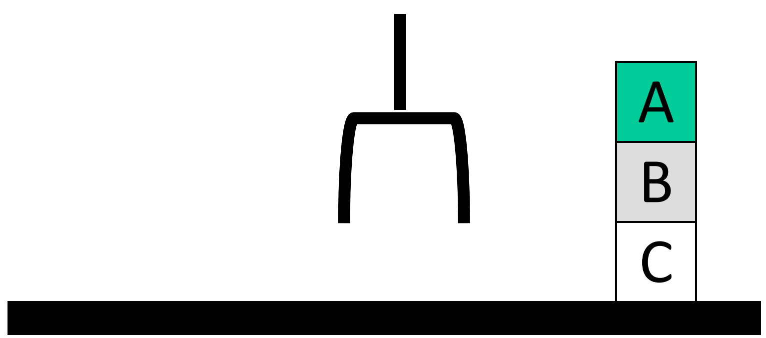
Initial state:

- clear(c)
- ontable(a)
- on(b,a)
- on(c,b)
- handempty

Goal:

- on(a,b)
- on(b,c)
- ontable(c)





Plan:

- unstack(c,b)
- putdown(c)
- unstack(b,a)
- putdown(b)
- pickup(a)
- stack(a,b)
- unstack(a,b)
- putdown(a)
- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

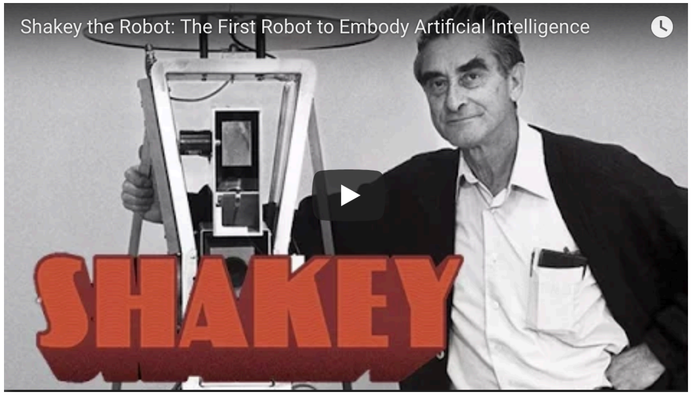
Note: not very efficient!

Major approaches

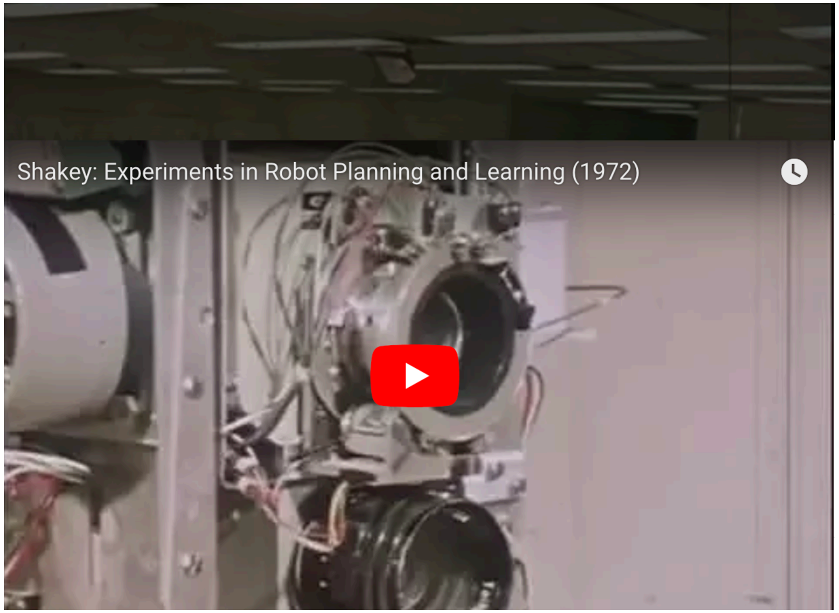
- Planning as search
- GPS / STRIPS
- Situation calculus
- Partial order planning
- Hierarchical decomposition (HTN planning)
- Planning with constraints (SATplan, Graphplan)
- Reactive planning

Shakey the robot

First general-purpose mobile robot to be able to reason about its own actions



[Shakey the Robot: 1st Robot to Embody Artificial Intelligence](2017, 6 min.)



Shakey: Experiments in Robot Planning and Learning (1972, 24 min)

Strips planning representation

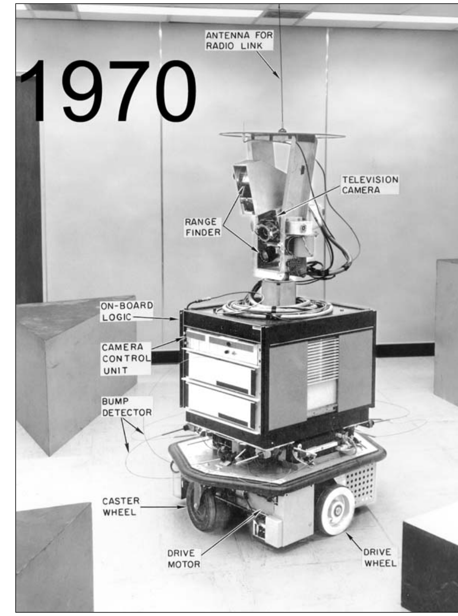
- Classic approach first used in the STRIPS (Stanford Research Institute Problem Solver) planner
- A State is a conjunction of ground literals

  at(Home) $\wedge$ $\neg$have(Milk) $\wedge$ $\neg$have(bananas) ...

- Goals are conjunctions of literals, but may have variables, assumed to be existentially quantified

  at(?x) $\wedge$ have(Milk) $\wedge$ have(bananas) ...

- Need not fully specify state
  - Non-specified conditions either don't-care or assumed false
  - Represent many cases in small storage
  - May only represent changes in state rather than entire situation
- Unlike theorem prover, not seeking whether goal is true, but is there a sequence of actions to attain it



Shakey the robot

Blocks world operators

- Classic basic operations for the blocks world
  - stack(X,Y): put block X on block Y
  - unstack(X,Y): remove block X from block Y
  - pickup(X): pickup block X
  - putdown(X): put block X on the table
- Each represented by
  - list of preconditions
  - list of new facts to be added (add-effects)
  - list of facts to be removed (delete-effects)
  - optionally, set of (simple) variable constraints
- For example stack(X,Y):

preconditions(stack(X,Y), [holding(X), clear(Y)])

deletes(stack(X,Y), [holding(X), clear(Y)]).

adds(stack(X,Y), [handempty, on(X,Y), clear(X)])

constraints(stack(X,Y), [X≠Y, Y≠table, X≠table])

STRIPS planning

- STRIPS maintains two additional data structures:
  - State List - all currently true predicates.
  - Goal Stack - push down stack of goals to be solved, with current goal on top
- If current goal not satisfied by present state, find operator that adds it and push operator and its preconditions (subgoals) on stack
- When a current goal is satisfied, POP from stack
- When an operator is on top stack, record application of that operator on plan sequence and use operator’s add and delete lists to update current state

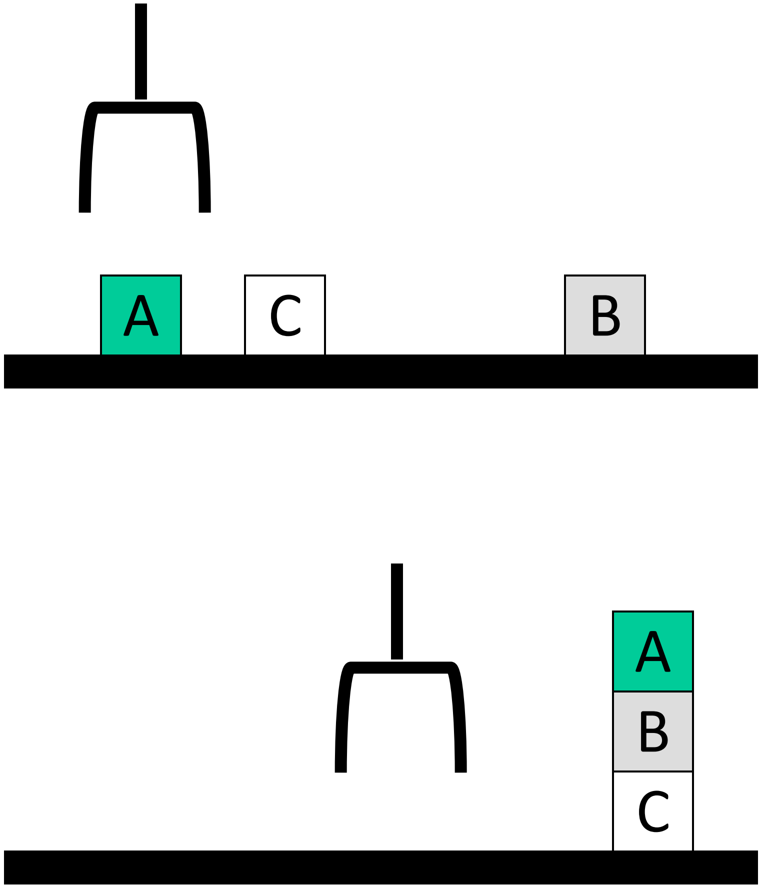
Typical BW planning problem

Initial state:

- clear(a)
- clear(b)
- clear(c)
- ontable(a)
- ontable(b)
- ontable(c)
- handempty

Goal:

- on(b,c)
- on(a,b)
- ontable(c)



A plan:

- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

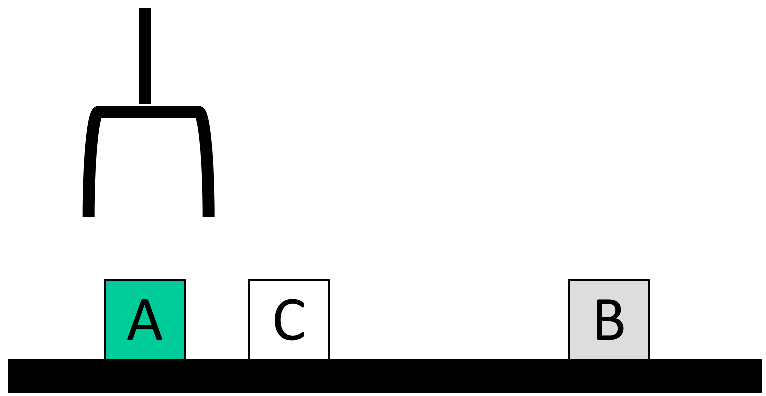
Another BW planning problem

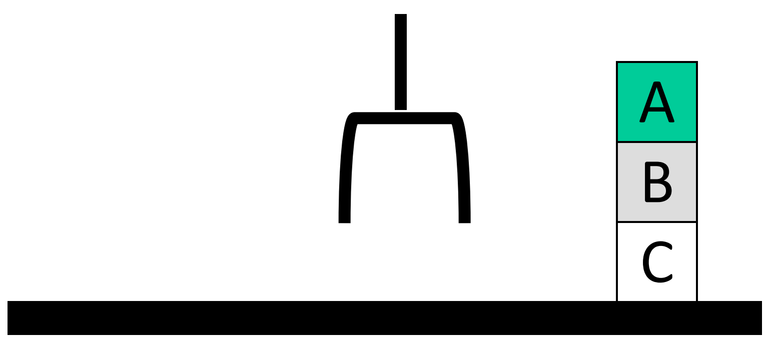
Initial state:

- clear(a)
- clear(b)
- clear(c)
- ontable(a)
- ontable(b)
- ontable(c)
- handempty

Goal:

- on(a,b)
- on(b,c)
- ontable(c)





A plan:

- pickup(a)
- stack(a,b)
- unstack(a,b)
- putdown(a)
- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

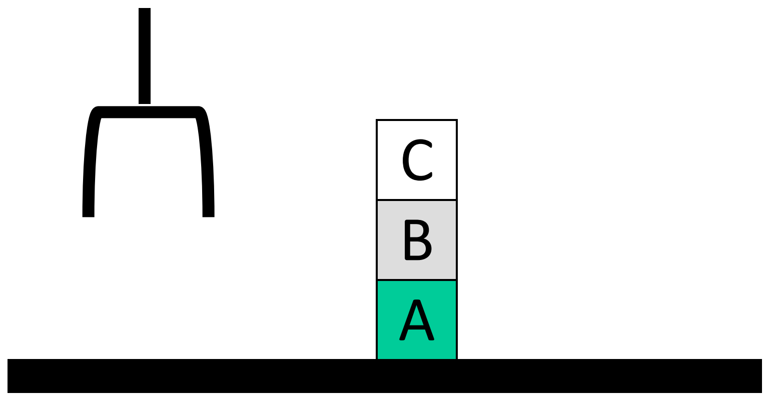
Yet Another BW planning problem

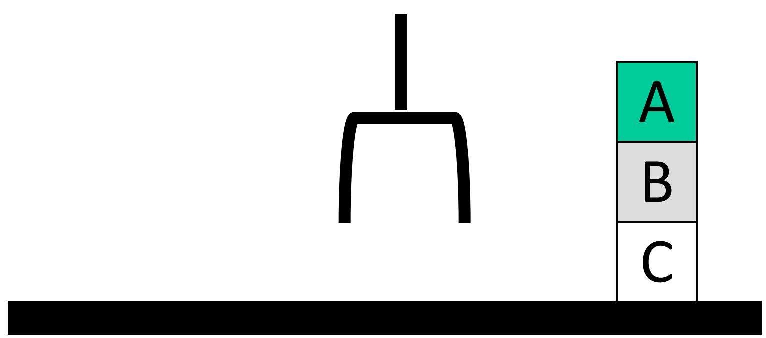
Initial state:

- clear(c)
- ontable(a)
- on(b,a)
- on(c,b)
- handempty

Goal:

- on(a,b)
- on(b,c)
- ontable(c)





Plan:

- unstack(c,b)
- putdown(c)
- unstack(b,a)
- putdown(b)
- pickup(b)
- stack(b,a)
- unstack(b,a)
- putdown(b)
- pickup(a)
- stack(a,b)
- unstack(a,b)
- putdown(a)
- pickup(b)
- stack(b,c)
- pickup(a)
- stack(a,b)

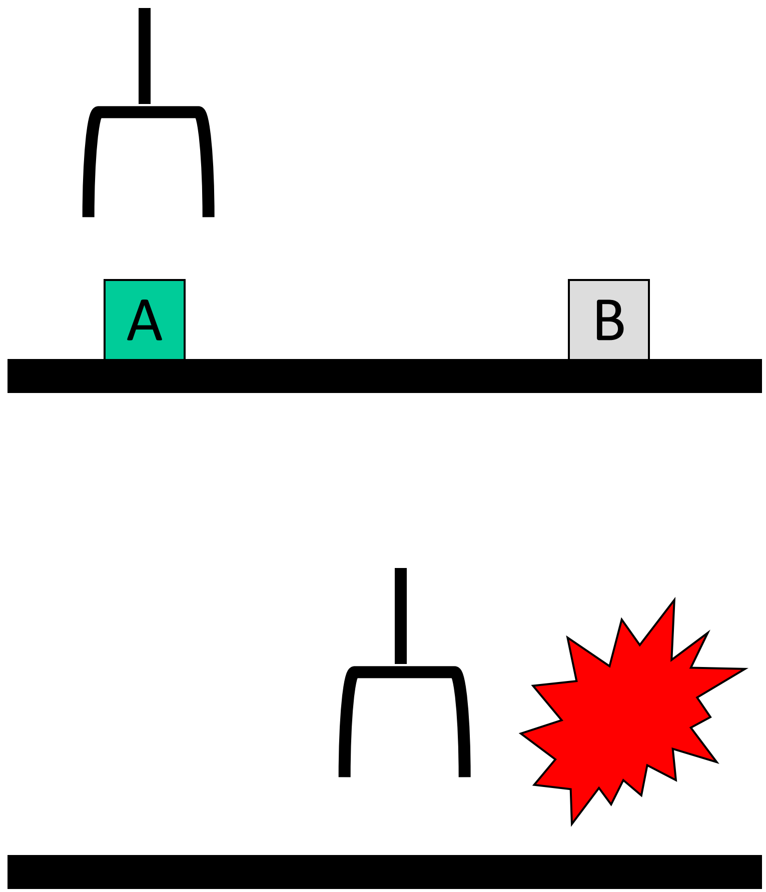
Yet Another BW planning problem

Initial state:

- ontable(a)
- ontable(b)
- clear(a)
- clear(b)
- handempty

Goal:

- on(a,b)
- on(b,a)



Plan:

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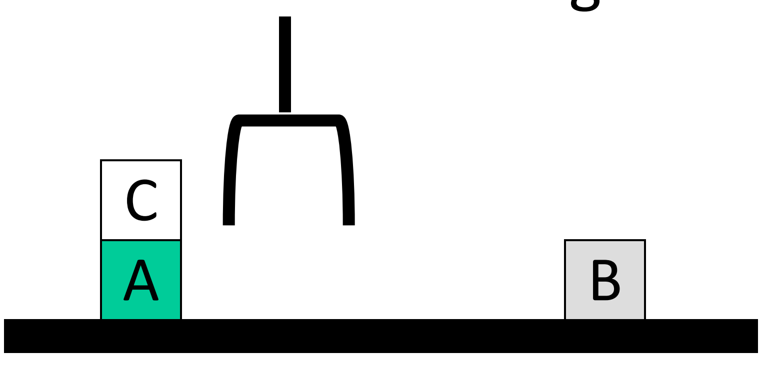
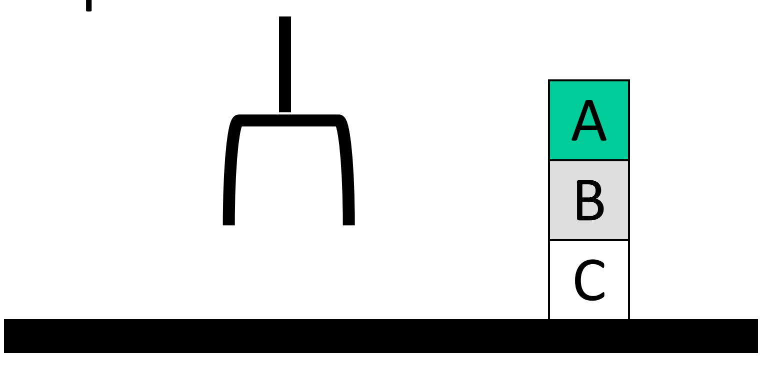
Goal interaction

- Simple planning algorithms assume independent sub-goals
  - Solve each separately and concatenate the solutions
- The "Sussman Anomaly" is the classic example of the goal interaction problem:
  - Solving on(A,B) first (via unstack(C,A), stack(A,B)) is undone when solving 2nd goal on(B,C) (via unstack(A,B), stack(B,C))
  - Solving on(B,C) first will be undone when solving on(A,B)
- Classic STRIPS couldn't handle this, although minor modifications can get it to do simple cases



Initial state



Goal state

Fin