Classical AI Planning: STRIPS Planning

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Remember: Problem-Solving Agent

```
function SIMPLE-PROBLEM-SOLVING-AGENT(p) returns an action
   inputs: p, a percept
   static: s, an action sequence, initially empty
           state, some description of the current world state
           g, a goal, initially null
           problem, a problem formulation

   state ← UPDATE-STATE(state, p)
   if s is empty then
      g ← FORMULATE-GOAL(state)
      problem ← FORMULATE-PROBLEM(state, g)
      s ← SEARCH(problem)
   action ← RECOMMENDATION(s, state)
   s ← REMAINDER(s, state)
   return action
```

Note: This is *offline* problem-solving. *Online* problem-solving involves acting w/o complete knowledge of the problem and environment

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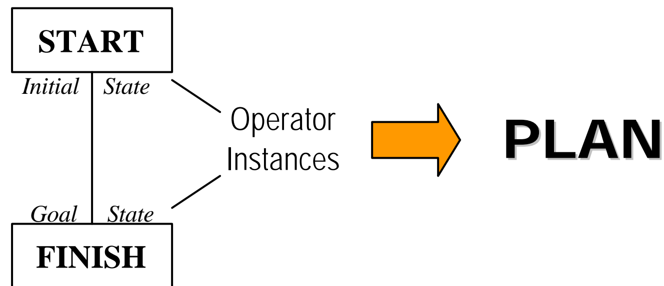
The Planning Problem

To find an executable sequence of actions that achieves a given goal when performed starting in a given state.



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Roots of Planning

- problem solving
- state-space search
- EXAMPLE: "Shakey" the Robot (SRI)
  - a robot that roamed the halls of SRI in the early 1970's
  - actions were based on STRIPS plans

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A Simple Planning Agent

```
function SIMPLE-PLANNING-AGENT(percept) returns an action
    static:      KB, a knowledge base (includes action descriptions)
                 p, a plan (initially, NoPlan)
                 t, a time counter (initially 0)
    local variables: G, a goal
                 current, a current state description
    TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
    current ← STATE-DESCRIPTION(KB, t)
    if p = NoPlan then
        G ← ASK(KB, MAKE-GOAL-QUERY(t))
        p ← IDEAL-PLANNER(current, G, KB)
    if p = NoPlan or p is empty then
        action ← NoOp
    else
        action ← FIRST(p)
        p ← REST(p)
    TELL(KB, MAKE-ACTION-SENTENCE(action, t))
    t ← t+1
    return action
```

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Algorithm: A Simple Planning Agent

1. Generate a goal to achieve
2. Construct a plan to achieve goal from the current state
3. Execute plan until finished
4. Begin again with new goal
    - Use percepts to build a model of the current world state
    - IDEAL-PLANNER: Given a goal, algorithm generates a plan of actions
    - STATE-DESCRIPTION: given percept, return initial state description in format required by planner
    - MAKE-GOAL-QUERY: used to ask KB what the next goal should be

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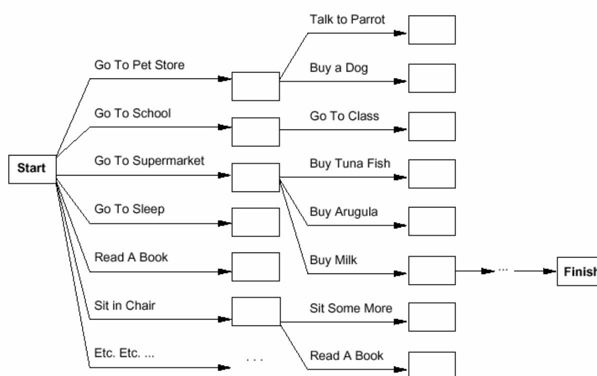
Search vs. planning

Consider the task *get milk, bananas, and a cordless drill*

Standard search algorithms seem to fail miserably:



After-the-fact heuristic/goal test inadequate

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Search vs. planning

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

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Basic Representation for Planning

- Most widely used approach: uses STRIPS language
- states: conjunctions of function-free ground literals (I.e., predicates applied to constant symbols, possibly negated); e.g.,

  At(Home) ∧ ¬Have(Milk) ∧ ¬Have(Bananas) ∧ ¬Have(Drill) …

- goals: also conjunctions of literals; e.g.,

  At(Home) ∧ Have(Milk) ∧ Have(Bananas) ∧ Have(Drill)

  but can also contain variables (implicitly universally quant.); e.g.,

  At(x) ∧ Sells(x, Milk)

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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

Planner vs. Theorem Prover

- Planner: ask for sequence of actions that makes goal true if executed
- Theorem prover: ask whether query sentence is true given KB

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The Frame Problem

- Assumption: actions have local effects
- We need **frame axioms** for each action and each fluent that does not change as a result of the action
  - example: frame axioms for *move*:
  - If a block is on another block and *move* is not relevant, it will stay the same.
    - Positive:
      $$[On(x, y, s) \wedge (x \neq u)] \rightarrow On(x, y, do(move(u, v, z), s))$$
    - Negative
      $$(\neg On(x, y, s) \wedge [(x \neq u) \vee (y \neq z)]) \rightarrow \neg On(x, y, do(move(u, v, z), s)$$

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Other Problems in Planning

- **The qualification problem**: qualifying the antecedents for all possible exception. Needs (but *impossible*!) to enumerate all exceptions
  - ~heavy and ~glued and ~armbroken → can-move
  - ~bird and ~cast-in-concrete and ~dead… → flies
  - Solutions: default logics, nonmonotonic logics
- **The ramification problem:**
  - If a robot carries a package, the package will be where the robot is. But what about the frame axiom, when can we infer about the effects of the actions and when we cannot.
- Not everything true can be inferred On(C,F1) remains true but cannot be inferred

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Assumptions in Classical Planning

- Percepts
  - Perfect perception
  - Complete knowledge agent is omniscient
- Actions
  - Instantaneous actions
  - Atomic time
  - No concurrent actions allowed
  - Deterministic actions (effects are completely specified)
- Environment
  - Static environment
  - Completely observable environment
  - Agent is the sole cause of change in the world

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Assumptions

- Closed World Assumption
  - If ground terms cannot be proved to be true, they can be assumed to be false.
- Domain Closure Assumption
  - All objects in the domain are explicitly named.
- Unique Names Assumption
  - If ground terms cannot be proved to be equal, they can be assumed to be unequal.

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STRIPS Representation

- STRIPS is the simplest and the second oldest representation of operators in AI.
- When that the initial state is represented by a database of positive facts, STRIPS can be viewed as being simply a way of specifying an update to this database.

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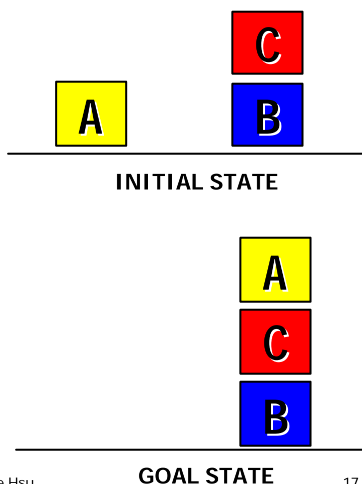
Example: "The Blocks World"

- Domain:
  - set of cubic blocks sitting on a table
- Actions:
  - blocks can be stacked
  - can pick up a block and move it to another position
  - can only pick up one block at a time
- Goal:
  - to build a specified stack of blocks



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Representing States & Goals

- STRIPS:
  - describes states & operators in a restricted language
- States:
  - a conjunction of "facts" (ground literals that do not contain variable symbols)
- Goals:
  - a conjunction of positive literals

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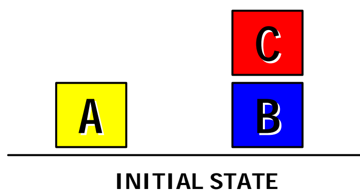
Representing States & Goals

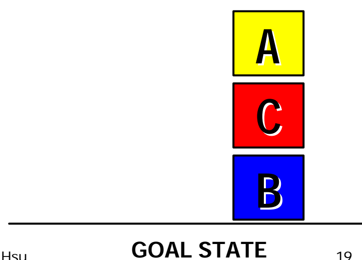
Initial State:

ontable(A) ∧
ontable(B) ∧
on(C, B) ∧
clear(A) ∧
clear(C) ∧
handempty



Goal:

ontable(B) ∧
on(C,B) ∧
on(A,C) ∧
clear(A) ∧
handempty



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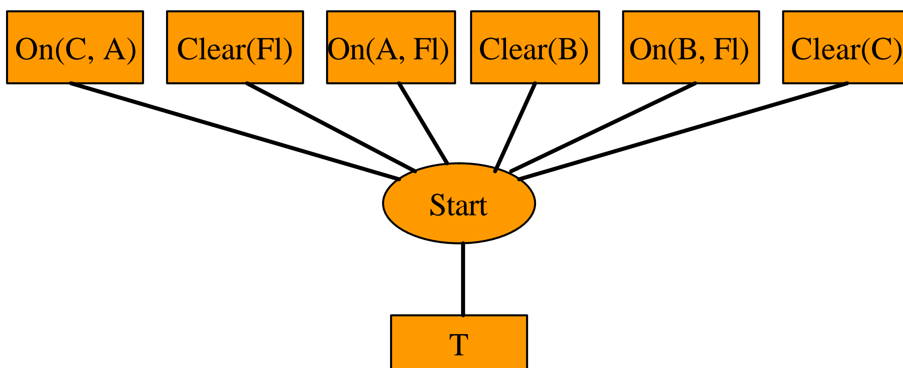
Graphical Representation: Initial State



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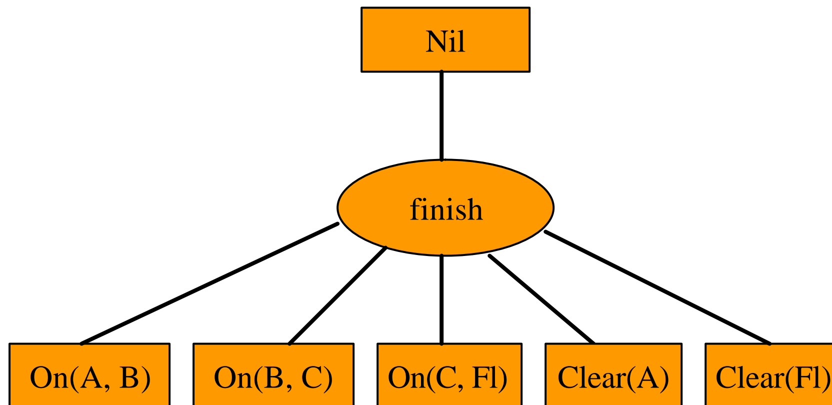
Graphical Representation: Goal State



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Representing Actions

1. Action description

   Name: pickup(x)

2. Precondition

   Preconditions: ontable(x), clear(x), handempty

3. Effect

   Effect: holding(x), ~ontable(x), ~clear(x), ~handempty

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Actions in "Blocks World"

- **pickup(x)**
  - picks up block '*x*' from table
- **putdown(x)**
  - if holding block '*x*', puts it down on table
- **stack(x,y)**
  - if holding block '*x*', puts it on top of block '*y*'
- **unstack(x,y)**
  - picks up block '*x*' that is currently on block '*y*'

An operator is APPLICABLE if all preconditions are satisfied.

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Blocks World - Operator

- Move(x, y, z)
  - Move block x that is above y to above z
  - ***PC***: On(x,y), Clear(x), Clear(z)
  - ***D***: Clear(z), On(x, y)
  - ***A***: On(x,z), Clear(y), Clear(Fl)

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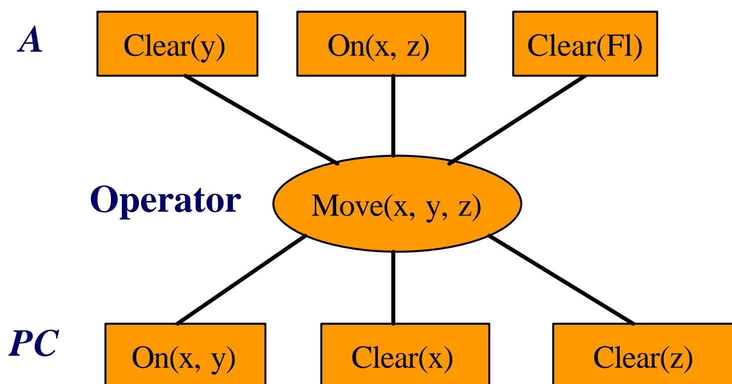
Graphical Representation: Operator



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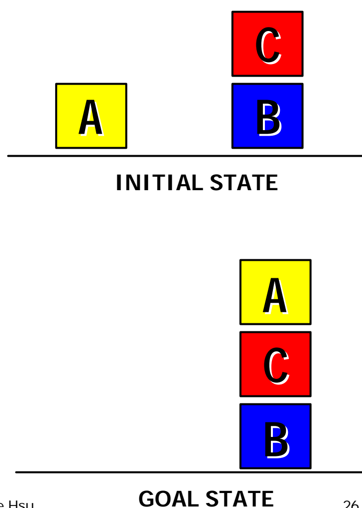
Progression Situation-Space

Algorithm:

1. Start from initial state
2. Find all operators whose preconditions are true in the initial state
3. Compute effects of operators to generate successor states
4. Repeat steps 2-3, until a new state satisfies the goal conditions



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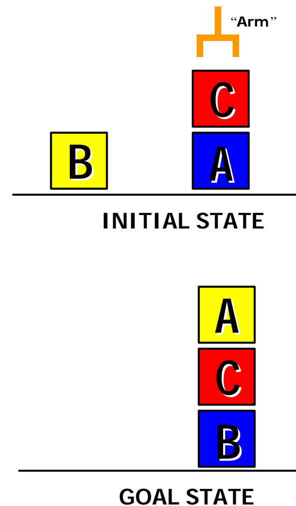
Regression Situation-Space

Algorithm:

1. Start with goal node corresponding to goal to be achieved
2. Choose an operator that will *add* one of the goals
3. Replace that goal with the operator's preconditions
4. Repeat steps 2-3 until you have reached the initial state



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STRIPS: Goal-Stack Planning

Given a goal stack:

1. Initialize: Push the goal to the stack.
2. If the top of the stack is satisfied in the current state, pop.
3. Otherwise, if the top is a conjunction, push the individual conjuncts to the stack.
4. Otherwise, check if the add-list of any operator can be unified with the top, push the operator and its preconditions to the stack.
5. If the top is an action, pop and execute it.
6. Loop 2-5 till stack is empty.

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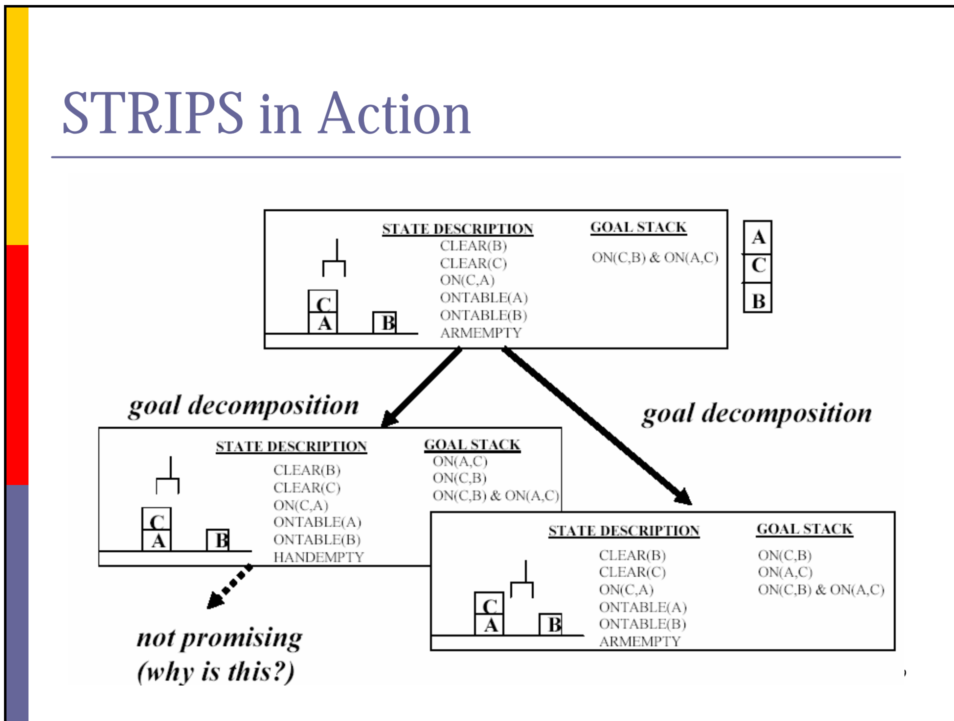
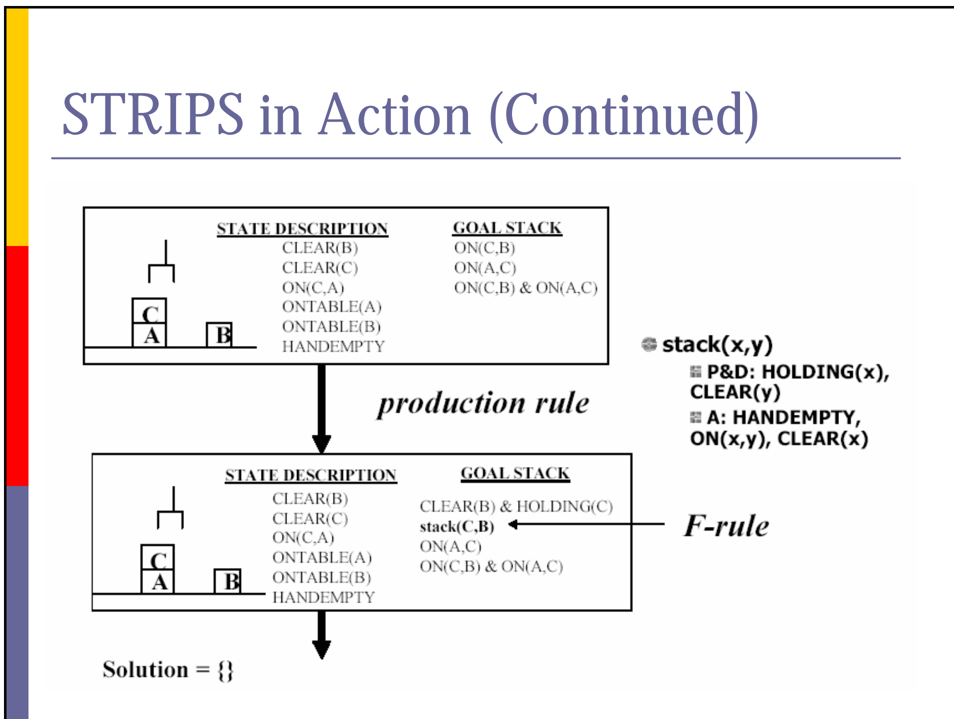
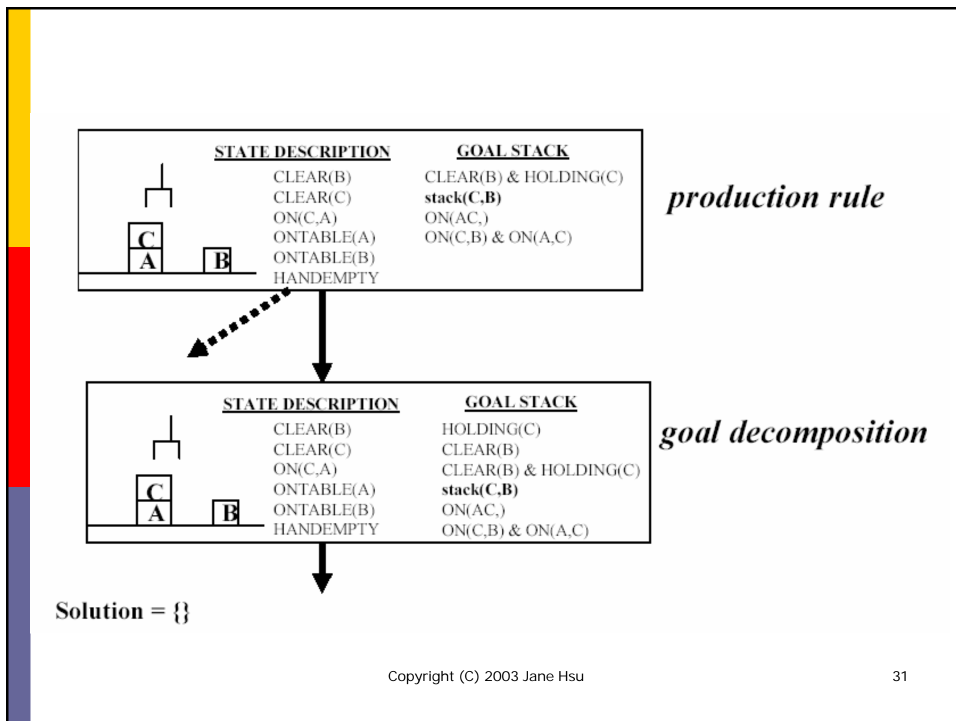

STRIPS in Action
STATE DESCRIPTION
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
ARMEMPTY
GOAL STACK
ON(C,B) & ON(A,C)
A
C
B
goal decomposition
STATE DESCRIPTION
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
GOAL STACK
ON(A,C)
ON(C,B)
ON(C,B) & ON(A,C)
goal decomposition
STATE DESCRIPTION
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
ARMEMPTY
GOAL STACK
ON(C,B)
ON(A,C)
ON(C,B) & ON(A,C)
not promising
(why is this?)


STRIPS in Action (Continued)
STATE DESCRIPTION
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
GOAL STACK
ON(C,B)
ON(A,C)
ON(C,B) & ON(A,C)
stack(x,y)
P&D: HOLDING(x), CLEAR(y)
A: HANDEMPTY, ON(x,y), CLEAR(x)
production rule
STATE DESCRIPTION
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
GOAL STACK
CLEAR(B) & HOLDING(C)
stack(C,B)
ON(A,C)
ON(C,B) & ON(A,C)
F-rule
Solution = {}


STATE DESCRIPTION
GOAL STACK
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
CLEAR(B) & HOLDING(C)
stack(C,B)
ON(AC,)
ON(C,B) & ON(A,C)
production rule
STATE DESCRIPTION
GOAL STACK
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
HOLDING(C)
CLEAR(B)
CLEAR(B) & HOLDING(C)
stack(C,B)
ON(AC,)
ON(C,B) & ON(A,C)
goal decomposition
Solution = {}
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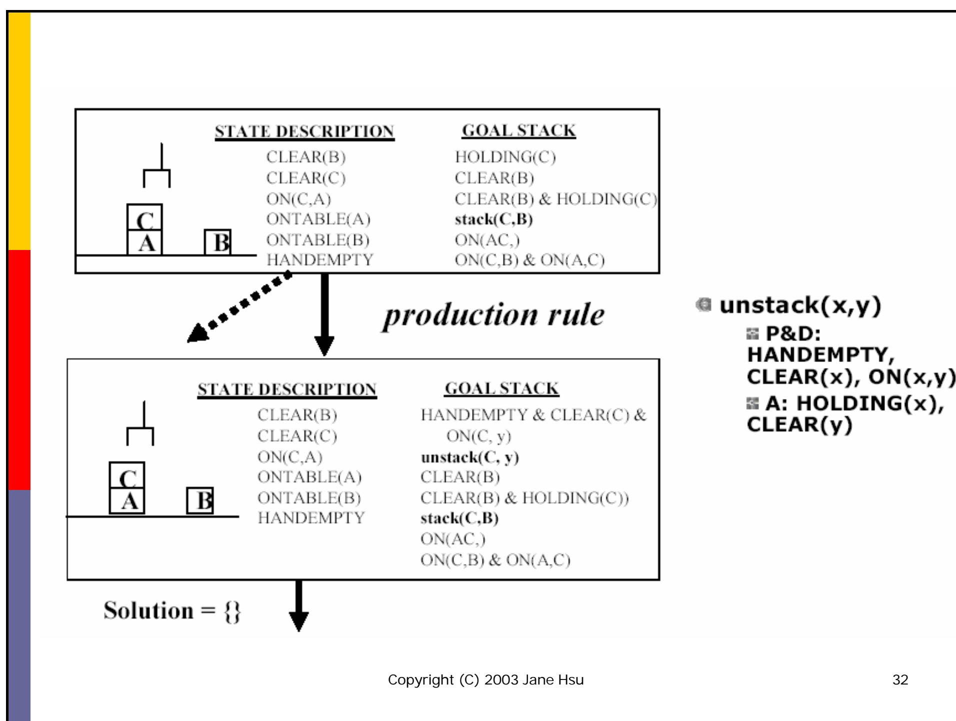
STATE DESCRIPTION
GOAL STACK
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
HOLDING(C)
CLEAR(B)
CLEAR(B) & HOLDING(C)
stack(C,B)
ON(AC,)
ON(C,B) & ON(A,C)
production rule
STATE DESCRIPTION
GOAL STACK
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
HANDEMPTY & CLEAR(C) &
ON(C, y)
unstack(C, y)
CLEAR(B)
CLEAR(B) & HOLDING(C))
stack(C,B)
ON(AC,)
ON(C,B) & ON(A,C)
Solution = {}
unstack(x,y)
P&D: HANDEMPTY, CLEAR(x), ON(x,y)
A: HOLDING(x), CLEAR(y)
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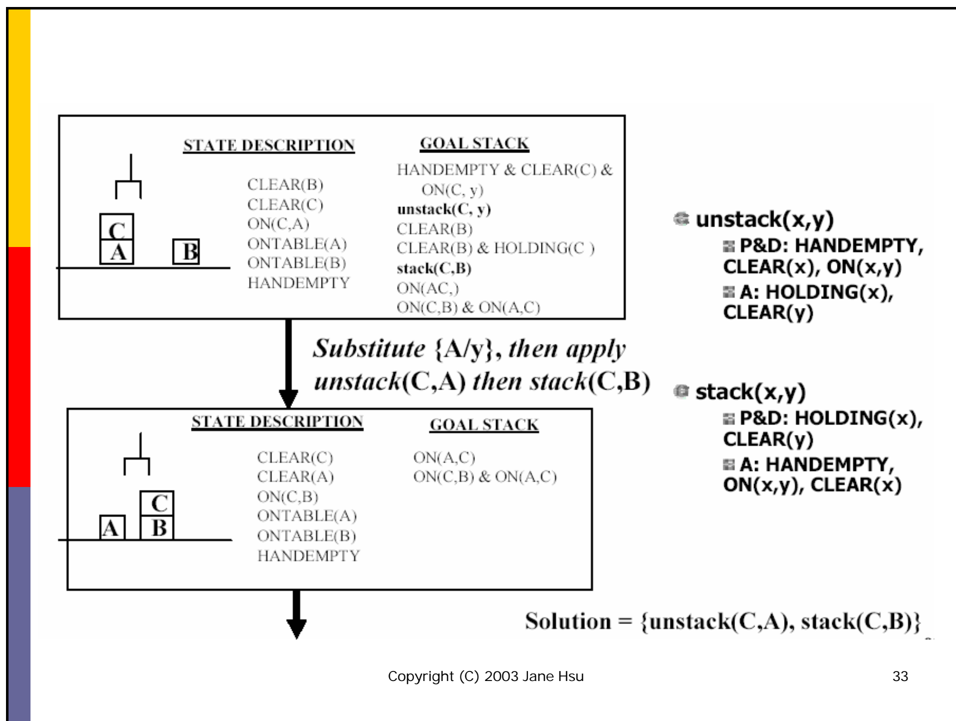
STATE DESCRIPTION
GOAL STACK
CLEAR(B)
CLEAR(C)
ON(C,A)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
HANDEMPTY & CLEAR(C) & ON(C, y)
unstack(C, y)
CLEAR(B)
CLEAR(B) & HOLDING(C)
stack(C,B)
ON(AC,)
ON(C,B) & ON(A,C)
C
A
B
Substitute {A/y}, then apply unstack(C,A) then stack(C,B)
STATE DESCRIPTION
GOAL STACK
CLEAR(C)
CLEAR(A)
ON(C,B)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
ON(A,C)
ON(C,B) & ON(A,C)
unstack(x,y)
P&D: HANDEMPTY, CLEAR(x), ON(x,y)
A: HOLDING(x), CLEAR(y)
stack(x,y)
P&D: HOLDING(x), CLEAR(y)
A: HANDEMPTY, ON(x,y), CLEAR(x)
Solution = {unstack(C,A), stack(C,B)}
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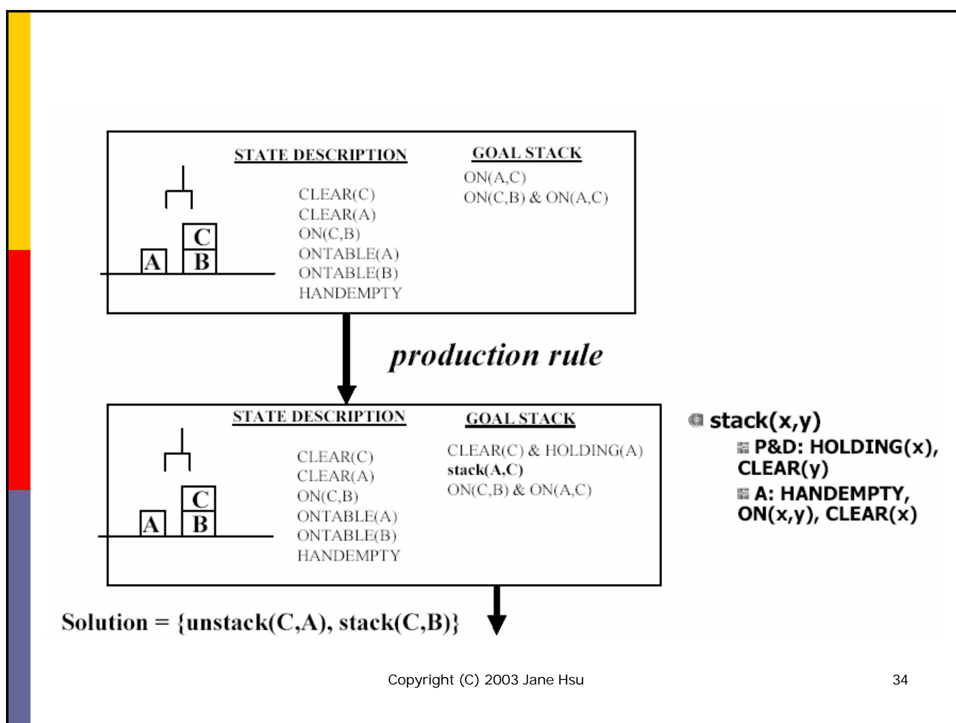
STATE DESCRIPTION
GOAL STACK
CLEAR(C)
CLEAR(A)
ON(C,B)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
ON(A,C)
ON(C,B) & ON(A,C)
production rule
STATE DESCRIPTION
GOAL STACK
CLEAR(C)
CLEAR(A)
ON(C,B)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
CLEAR(C) & HOLDING(A)
stack(A,C)
ON(C,B) & ON(A,C)
stack(x,y)
P&D: HOLDING(x), CLEAR(y)
A: HANDEMPTY, ON(x,y), CLEAR(x)
Solution = {unstack(C,A), stack(C,B)}
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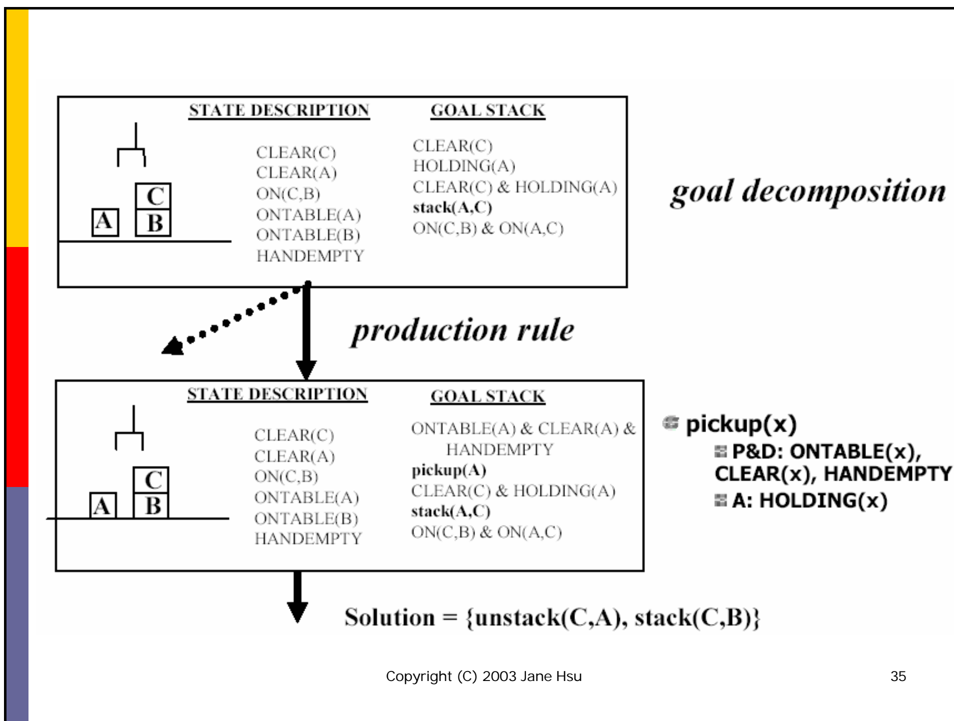
STATE DESCRIPTION
GOAL STACK
C
A B
CLEAR(C)
CLEAR(A)
ON(C,B)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
CLEAR(C)
HOLDING(A)
CLEAR(C) & HOLDING(A)
stack(A,C)
ON(C,B) & ON(A,C)
goal decomposition
production rule
STATE DESCRIPTION
GOAL STACK
C
A B
CLEAR(C)
CLEAR(A)
ON(C,B)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
ONTABLE(A) & CLEAR(A) & HANDEMPTY
pickup(A)
CLEAR(C) & HOLDING(A)
stack(A,C)
ON(C,B) & ON(A,C)
pickup(x)
P&D: ONTABLE(x), CLEAR(x), HANDEMPTY
A: HOLDING(x)
Solution = {unstack(C,A), stack(C,B)}
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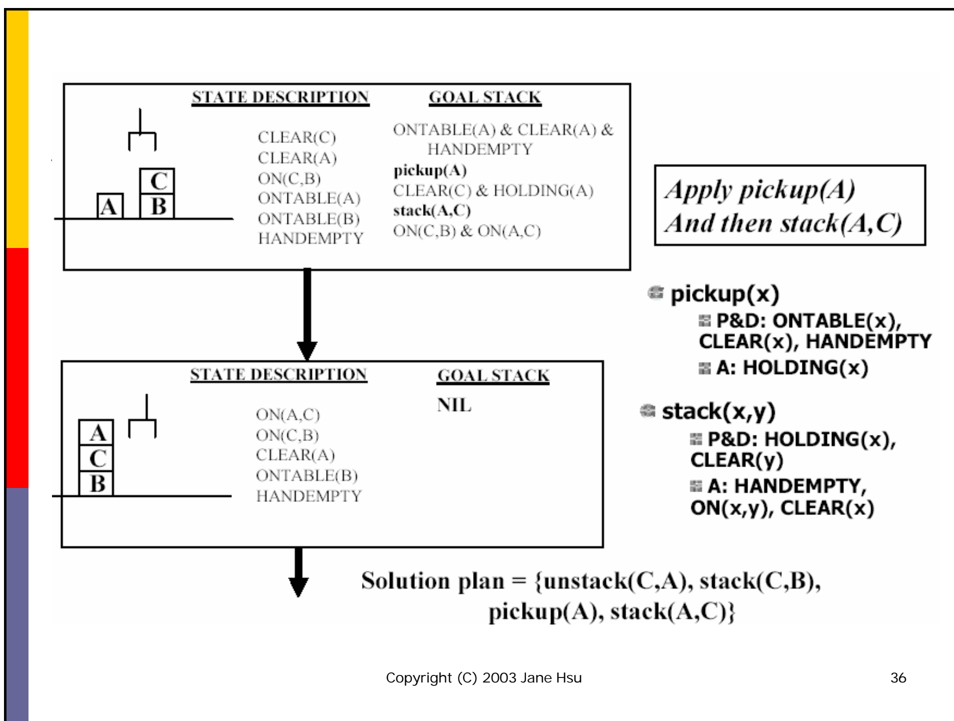
STATE DESCRIPTION
GOAL STACK
C
A B
CLEAR(C)
CLEAR(A)
ON(C,B)
ONTABLE(A)
ONTABLE(B)
HANDEMPTY
ONTABLE(A) & CLEAR(A) & HANDEMPTY
pickup(A)
CLEAR(C) & HOLDING(A)
stack(A,C)
ON(C,B) & ON(A,C)
Apply pickup(A)
And then stack(A,C)
pickup(x)
P&D: ONTABLE(x), CLEAR(x), HANDEMPTY
A: HOLDING(x)
STATE DESCRIPTION
GOAL STACK
A
C
B
ON(A,C)
ON(C,B)
CLEAR(A)
ONTABLE(B)
HANDEMPTY
NIL
stack(x,y)
P&D: HOLDING(x), CLEAR(y)
A: HANDEMPTY, ON(x,y), CLEAR(x)
Solution plan = {unstack(C,A), stack(C,B), pickup(A), stack(A,C)}
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