Planning: Wrap up CSP Planning. Logic: Intro

CPSC 322 – Planning 3

Textbook §8.4, §5.1

March 2, 2011

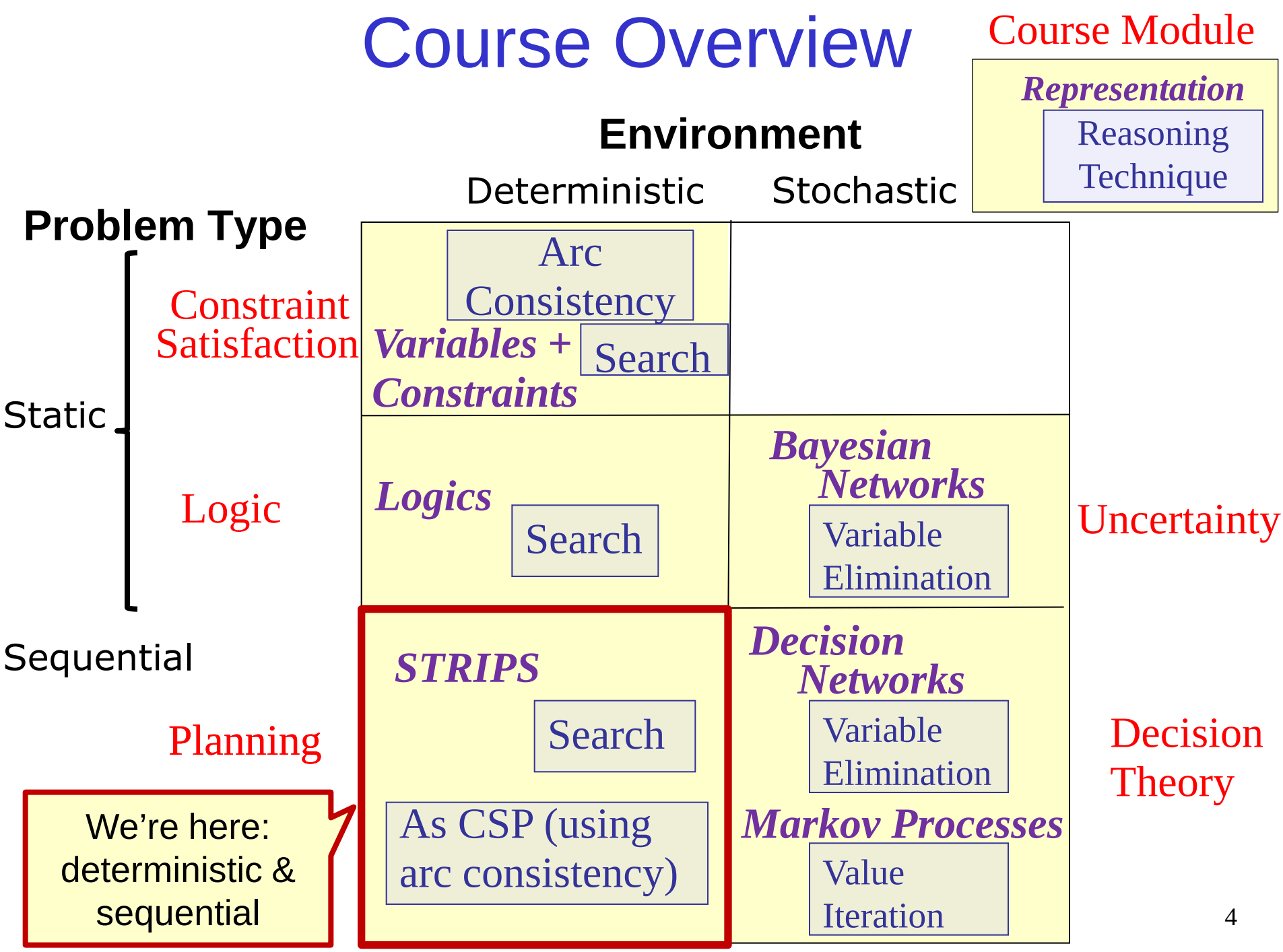
Announcements

- Assignment 2 & midterm will be marked by next Wednesday
- Assignment 3 is available on WebCT
  - Planning (2 questions) and Logic (2 questions)
  - Due in 2 weeks (March 16). Start the planning part early! (will know everything for planning part after today's lecture)
- Assignment 4 will be online March 16, due March 30
  - Only 2 late days allowed, so we can give out solutions
  - Final exam April 7
- Practice exercise 7 (STRIPS) available on course website & on WebCT
  - Useful to do before the assignment (should not take long)

Lecture Overview

- Recap: STRIPS, forward planning & heuristics
- Recap: CSP planning
- More CSP planning
  - Details on CSP representation
  - Solving the CSP planning problem
- Time-permitting: Intro to Logic

Course Overview



STRIPS

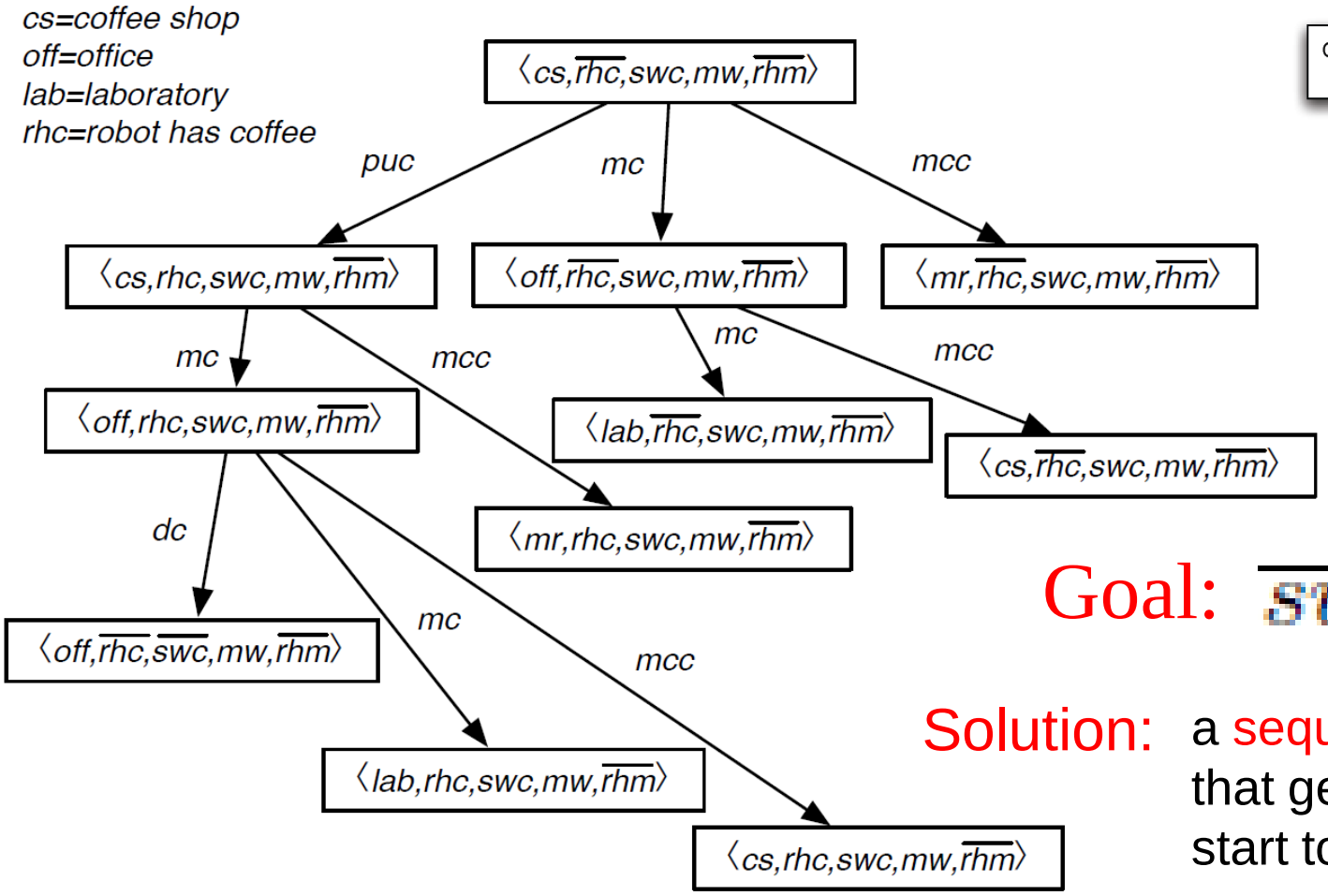
Definition:

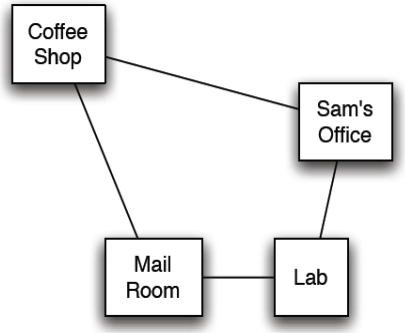
A STRIPS problem instance consists of:

- a set of variables (features) $\mathcal{V}$
- a domain dom(V) for each variable V $\in \mathcal{V}$
  - Let $\mathcal{X}$ be the space of partial assignments of a set of variables to values from their domains
- a set of actions $\mathcal{A}$
  - Each action a$\in \mathcal{A}$ has
    - A set of preconditions P(a)$\in \mathcal{X}$
    - A set of effects E(a)$\in \mathcal{X}$
- a start condition s $\in \mathcal{X}$
- a goal condition g $\in \mathcal{X}$

- Example for an action in robot example: pick up coffee
  - preconditions Loc = cs and RHC = $\overline{rhc}$
  - effects RHC = rhc

Forward planning: search in state space graph





Goal: $\overline{swc}$

Solution: a sequence of actions that gets us from the start to a goal

What is a solution to this planning problem?

(puc, mc, dc)

Planning as Standard Search

- Constraint Satisfaction (Problems):
  - State: assignments of values to a subset of the variables
  - Successor function: assign values to a “free” variable
  - Goal test: set of constraints
  - Solution: possible world that satisfies the constraints
  - Heuristic function: none (all solutions at the same distance from start)
- Planning :
  - State: full assignment of values to features
  - Successor function: states reachable by applying valid actions
  - Goal test: partial assignment of values to features
  - Solution: a sequence of actions
  - Heuristic function: relaxed problem! E.g. “ignore delete lists”
- Inference
  - State
  - Successor function
  - Goal test
  - Solution
  - Heuristic function

Example for domain-independent heuristics

- Let's stay in the robot domain
  - But say our robot has to bring coffee to Bob, Sue, and Steve:
  - G = {bob_has_coffee, sue_has_coffee, steve_has_coffee}
  - They all sit in different offices
- Admissible heuristic 1: ignore preconditions:
  - Basically counts how many subgoals are not achieved yet
  - Can simply apply "DeliverCoffee(person)" action for each person
- Admissible heuristic 2: ignore "delete lists"
  - Rewrite effects as add and delete lists, e.g.:
    - Add list for "pick-up coffee": rhc
    - Delete list for "deliver coffee": rhc
  - Here: "Ignore delete lists" $\Leftrightarrow$ once you have coffee you keep it
    - Problem gets easier: only need to pick up coffee once, navigate to the right locations, and deliver
    - Admissible, but typically more realistic than ignoring preconditions

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Planning as a CSP

- Idea: reformulate a STRIPS model as a set of variables and constraints
- What are variables in the CSP?
  (more than one answer is correct)

  The STRIPS variables

  The values of the STRIPS variables

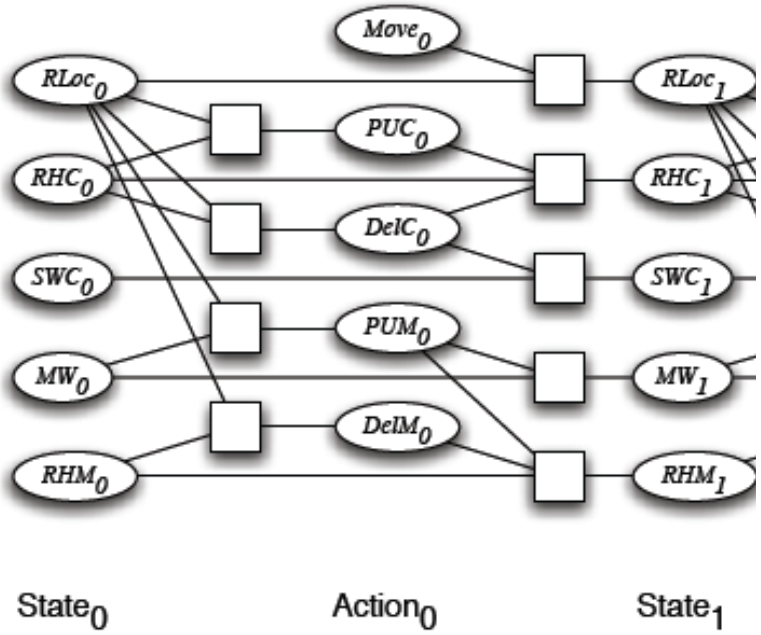
  The STRIPS actions

  The STRIPS preconditions

- We have CSP variables for both
  - STRIPS variables and
  - STRIPS actions

Planning as a CSP: General Idea

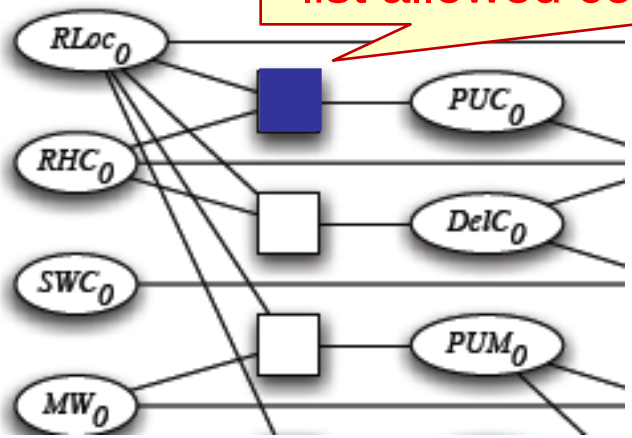
- Both features and actions are CSP variables
  - One CSP variable for each STRIPS feature for each time step
  - One (Boolean) CSP variable for each time step for each action
- Main Constraints:
  - Between actions at time t and previous state variables (time t)
    - When does an action apply? (precondition constraints)
  - Between actions at time t and following state variables (time t+1)
    - Hoes does an action change the variables? (effect constraints)



CSP Planning: Precondition Constraints

- precondition constraints
  - between state variables at time t and action variables at time t
  - specify when actions may be taken
    - E.g. robot can only pick up coffee when Loc=cs (coffee shop) and RHC = false (don't have coffee already)

Truth table for this constraint:
list allowed combinations of values



Rob Location

Rob has coffee

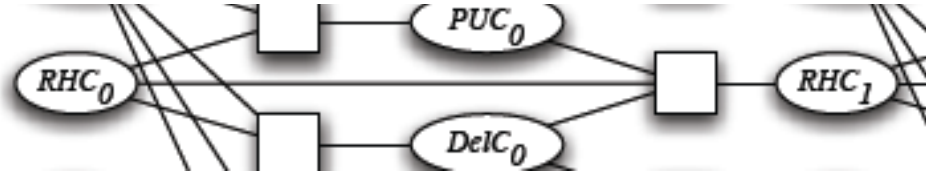
$RLoc_0$	RHC_0	PUC_0
cs	T	F
cs	F	T
cs	F	F
mr	*	F
lab	*	F
off	*	F

Need to allow for the option of *not* taking an action even when it is valid

CSP Planning: Effect Constraints

- Effect constraints
  - Between action variables at time t and state variables at time t+1
  - Specify the effects of an action
  - Also depends on state variables at time t (frame rule!)
    - E.g. let's consider RHC at time t and t+1
      Let's fill in a few rows in this table

RHC_t	$DelC_i$	PUC_i	RHC_{t+1}
T	T	T	
T	T	F	
T	F	T	
T	F	F	
F	T	T	F
F	T	F	F
F	F	T	T
F	F	F	F



Planning as a CSP

- What gives rise to constraints in the CSP? (more than one answer is correct)

The STRIPS preconditions

The STRIPS effects

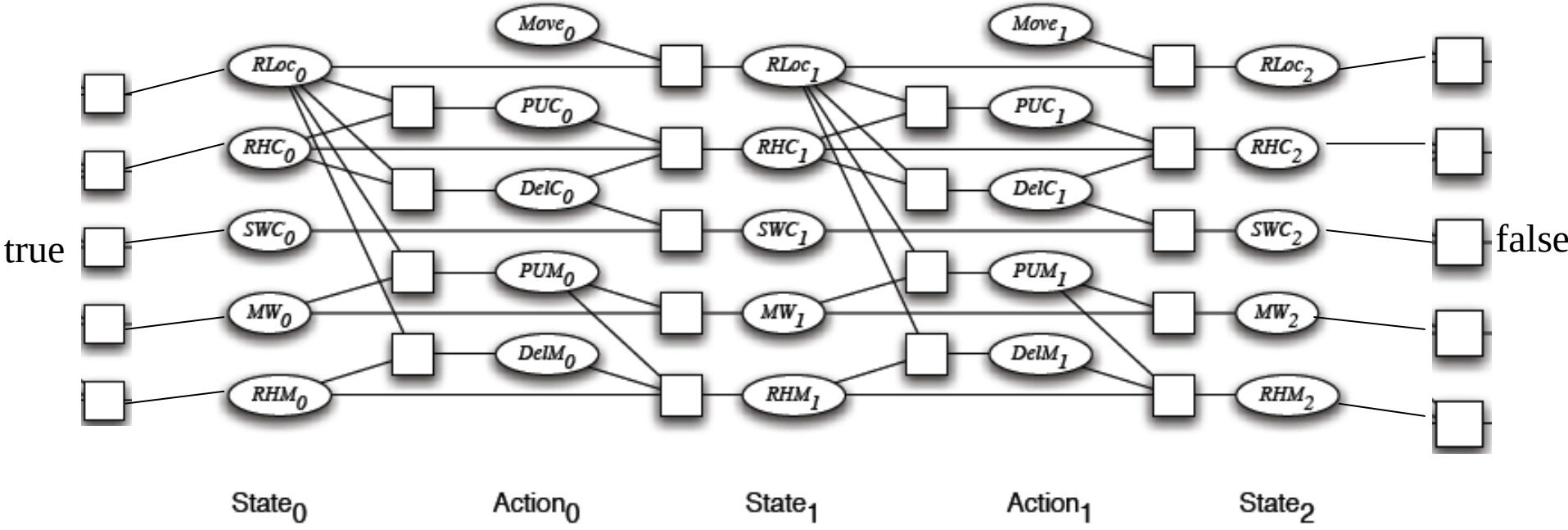
The STRIPS start state

The STRIPS goal condition

- All of them!
- Plus, constraints between each variable V at time t and t+1:
  - If no action changes V, it stays the same
  - Called a frame constraint

Initial and Goal Constraints

- initial state constraints: **unary** constraints on the values of the state variables at time 0
- goal constraints: **unary** constraints on the values of the state variables at time *k*
- *E.g. start condition: Sam wants coffee*
  E.g. goal condition: Sam doesn't want coffee



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Additional constraints in CSP Planning

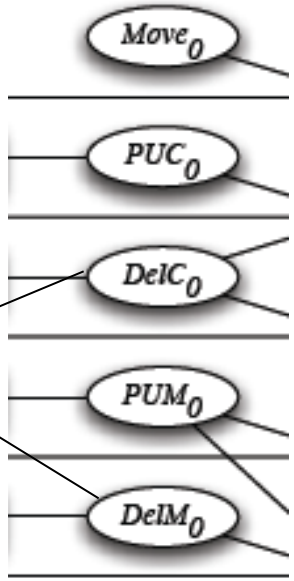
- Other constraints we may want are action constraints:
  - specify which actions cannot occur simultaneously
  - these are often called mutual exclusion (mutex) constraints

E.g., in the Robot domain

DelM and *DelC* can occur in any sequence (or simultaneously)

But we can enforce that they do not happen simultaneously

$DelM_i$	$DelC_i$
T	F
F	T
F	F

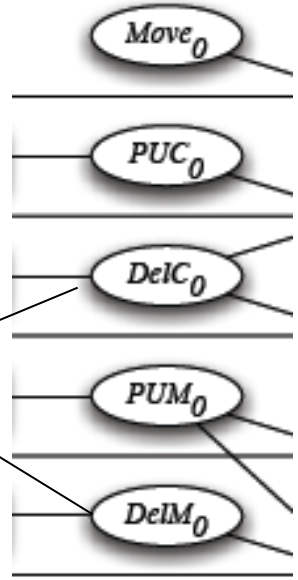


Handling mutex constraints in Forward Planning

E.g., let's say we don't want *DelM* and *DelC* to occur simultaneously

How would we encode this into STRIPS for forward planning?

$DelM_i$	$DelC_i$
T	F
F	T
F	F



Via the actions' preconditions (how?)

Via the actions' effects (how?)

No need to enforce this constraint in Forward Planning

None of the above

Handling mutex constraints in Forward Planning

E.g., let's say we don't want *DelM* and *DelC* to occur simultaneously

How would we encode this into STRIPS for forward planning?

$DelM_i$	$DelC_i$
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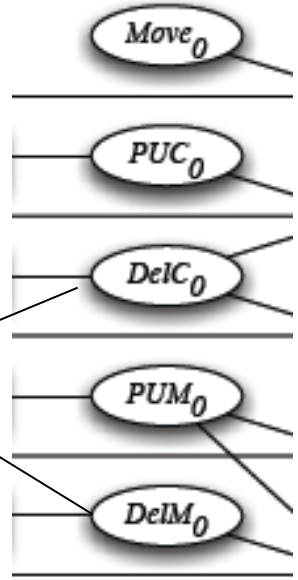


Action$_0$

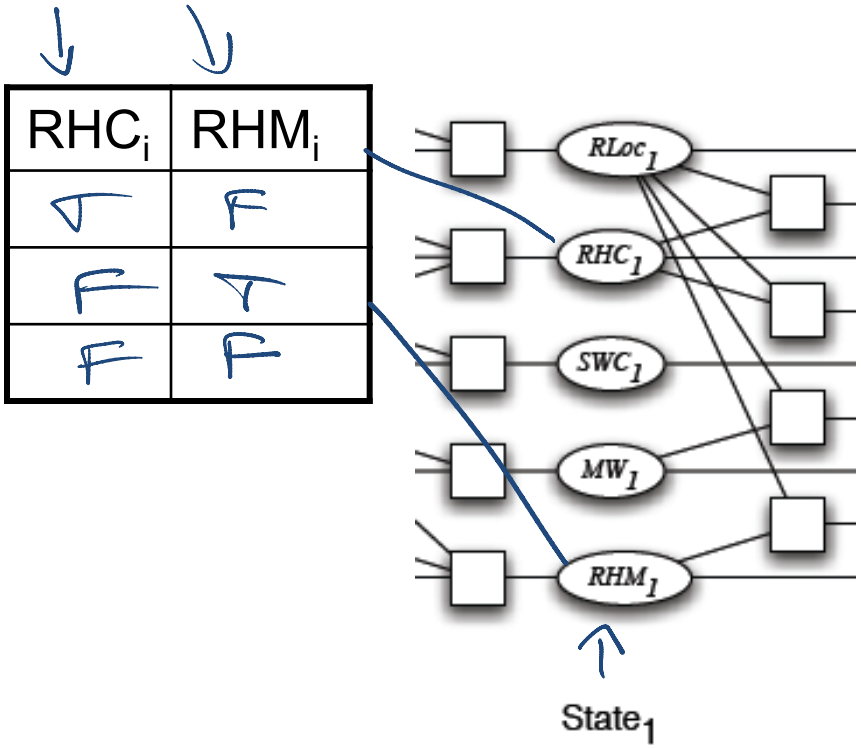
No need to enforce this constraint in Forward Planning

Because forward planning gives us a sequence of actions: only one action is carried out at a time anyways

Additional constraints in CSP Planning

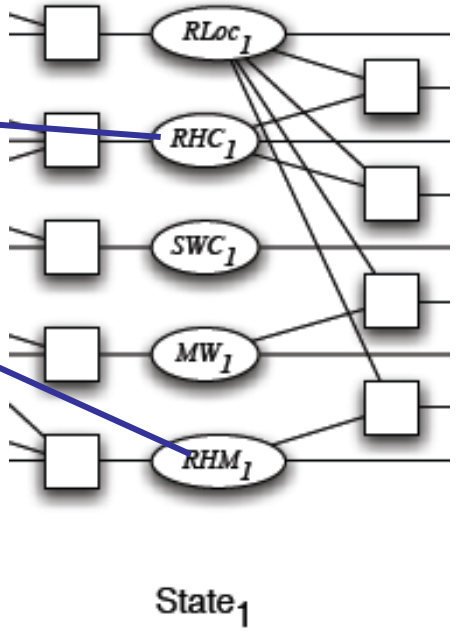
Other constraints we may want are state constraints

- hold between variables at the same time step
- they can capture physical constraints of the system (e.g., robot cannot hold coffee and mail)



Handling state constraints in Forward Planning

RHC_i	RHM_i
T	F
F	T
F	F



How could we handle these constraints in STRIPS for forward planning?

Via the actions' preconditions (how?)

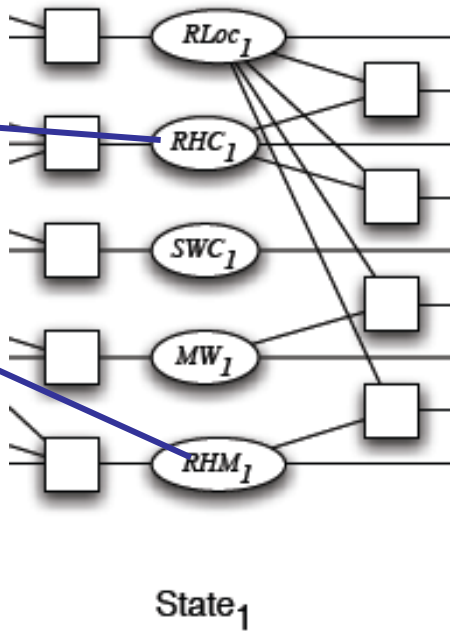
Via the actions' effects (how?)

No need to enforce this constraint in Forward Planning (why?)

None of the above

Handling state constraints in Forward Planning

RHC_i	RHM_i
T	F
F	T
F	F



How could we handle these constraints in STRIPS for forward planning?

We need to use preconditions

- Robot can pick up coffee only if
  it does not have coffee and it does not have mail
- Robot can pick up mail only if
  it does not have mail and it does not have coffee

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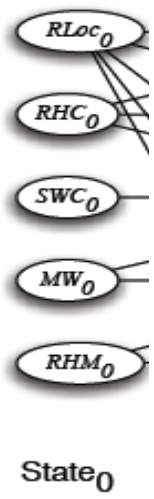
CSP Planning: Solving the problem

Map STRIPS Representation into CSP for horizon 0,1, 2, 3, …

Solve CSP for horizon 0, 1, 2, 3, … until solution found at the lowest possible horizon



K = 0

Is there a solution for this horizon?

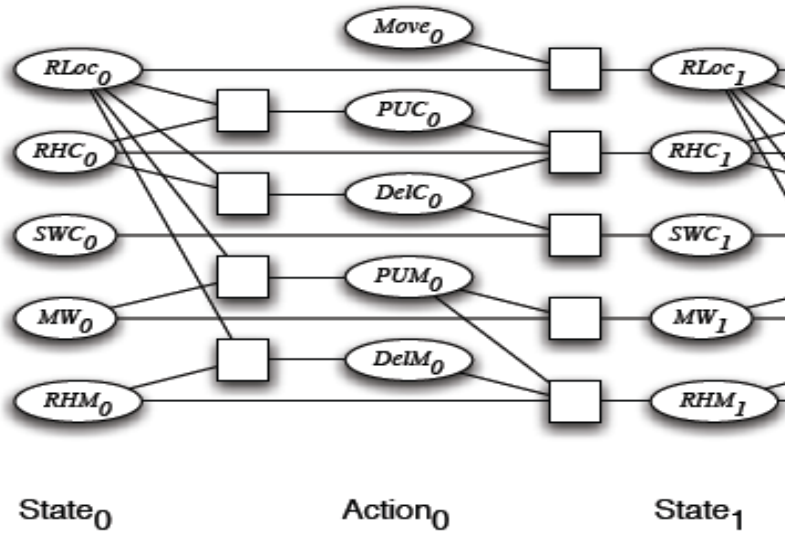
If yes, DONE!

If no, continue …

CSP Planning: Solving the problem

Map STRIPS Representation into CSP for horizon 0,1, 2, 3, …

Solve CSP for horizon 0, 1, 2, 3, … until solution found at the lowest possible horizon



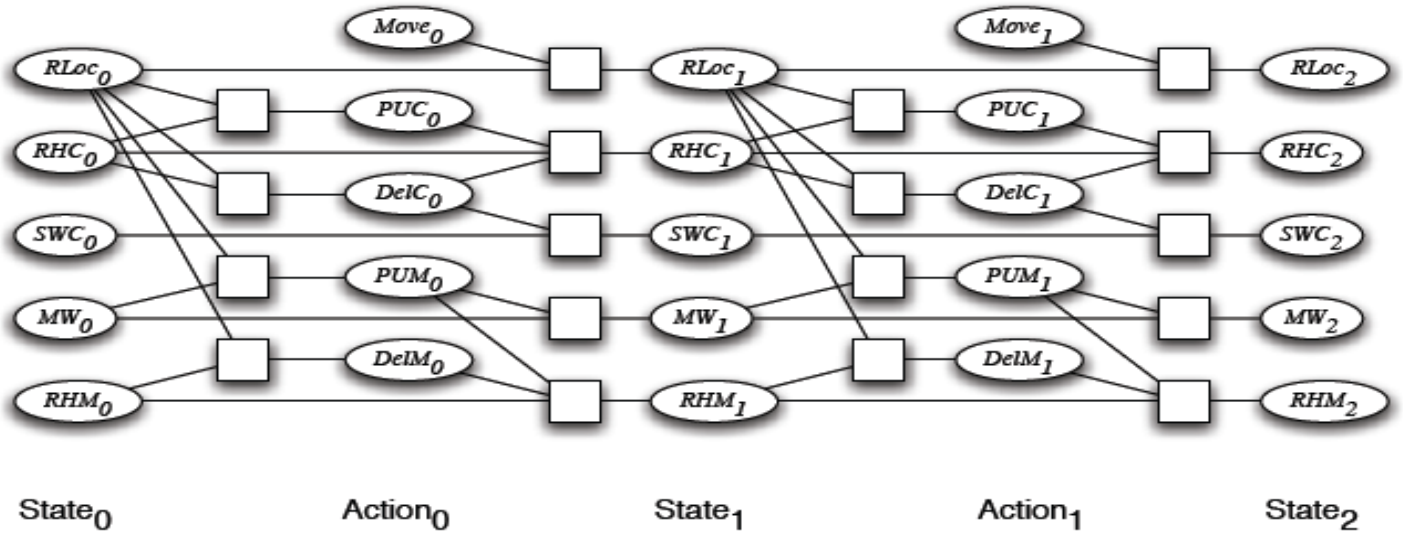
K = 1
Is there a solution for this horizon?

If yes, DONE!
If no, continue …

CSP Planning: Solving the problem

Map STRIPS Representation into CSP for horizon 0,1, 2, 3, …

Solve CSP for horizon 0, 1, 2, 3, … until solution found at the lowest possible horizon



K = 2: Is there a solution for this horizon?

If yes, DONE!

If no….continue

Solving Planning as CSP: pseudo code

```
solved = false
for horizon h=0,1,2,…
    map STRIPS into a CSP csp with horizon h
    solve that csp
    if solution exists then
        return solution
    else
        horizon = horizon + 1
end
```

Which method would you use to solve each of these CSPs?

Stochastic Local Search

Arc consistency + domain splitting

Not SLS! SLS cannot determine that no solution exists!

STRIPS to CSP applet

Allows you:

- to specify a planning problem in STRIPS
- to map it into a CSP for a given horizon
- the CSP translation is automatically loaded into the CSP applet where it can be solved

Under “Prototype Tools” in the AISpace Home Page

Learning Goals for Planning

- STRIPS
  - Represent a planning problem with the STRIPS representation
  - Explain the STRIPS assumption
- Forward planning
  - Solve a planning problem by search (forward planning). Specify states, successor function, goal test and solution.
  - Construct and justify a heuristic function for forward planning
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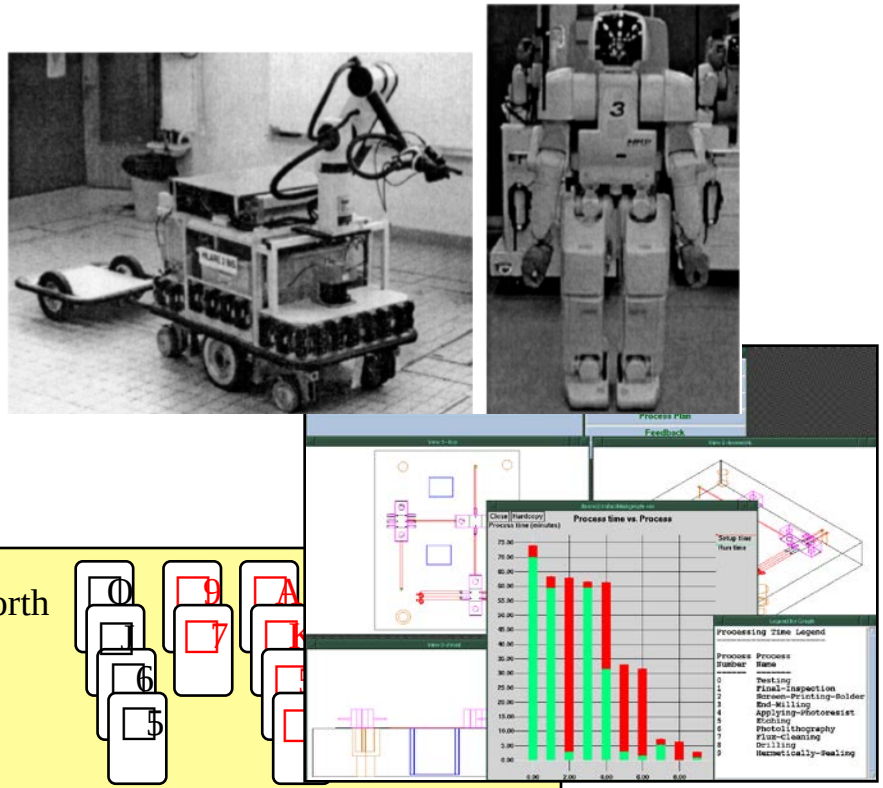
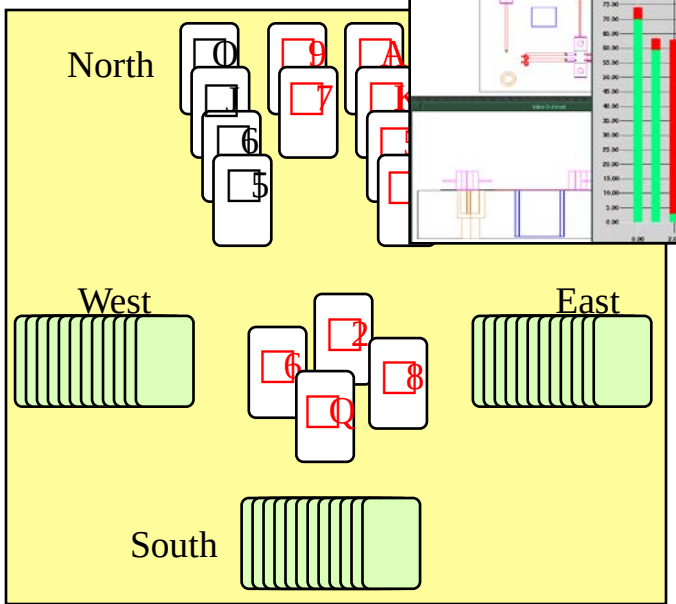
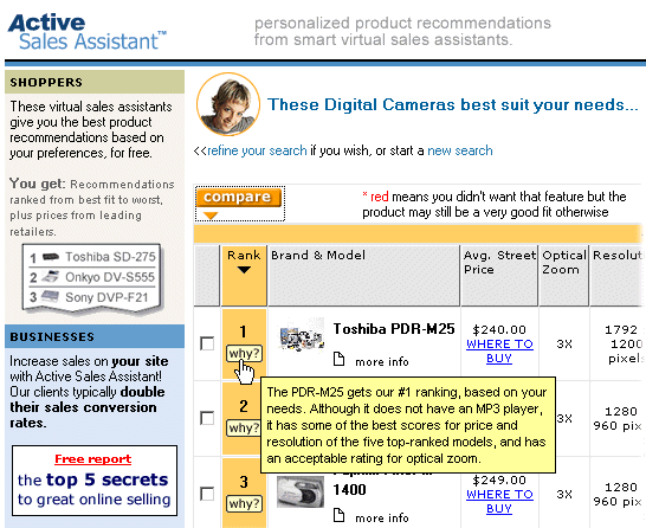
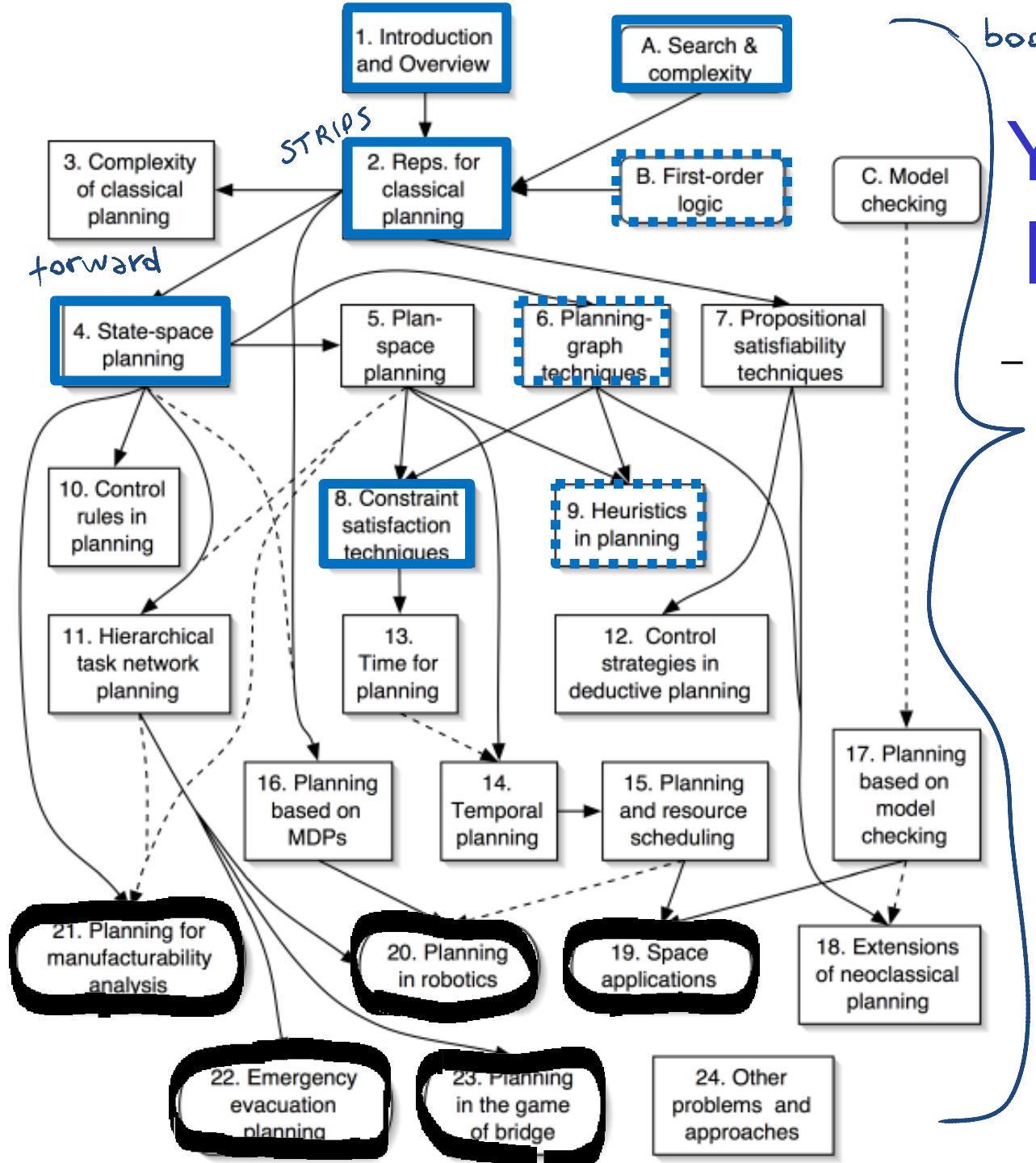
Some applications of planning

- Emergency Evacuation
- Robotics
- Space Exploration
- Manufacturing Analysis
- Games (e.g., Bridge)
- Product Recommendations
- …









book chapters

You know the key ideas! ☺

– Ghallab, Nau, and Traverso
Automated Planning: Theory and Practice
Web site:

- http://www.laas.fr/planning
- Also has lecture notes

you know

you know a little

Applications

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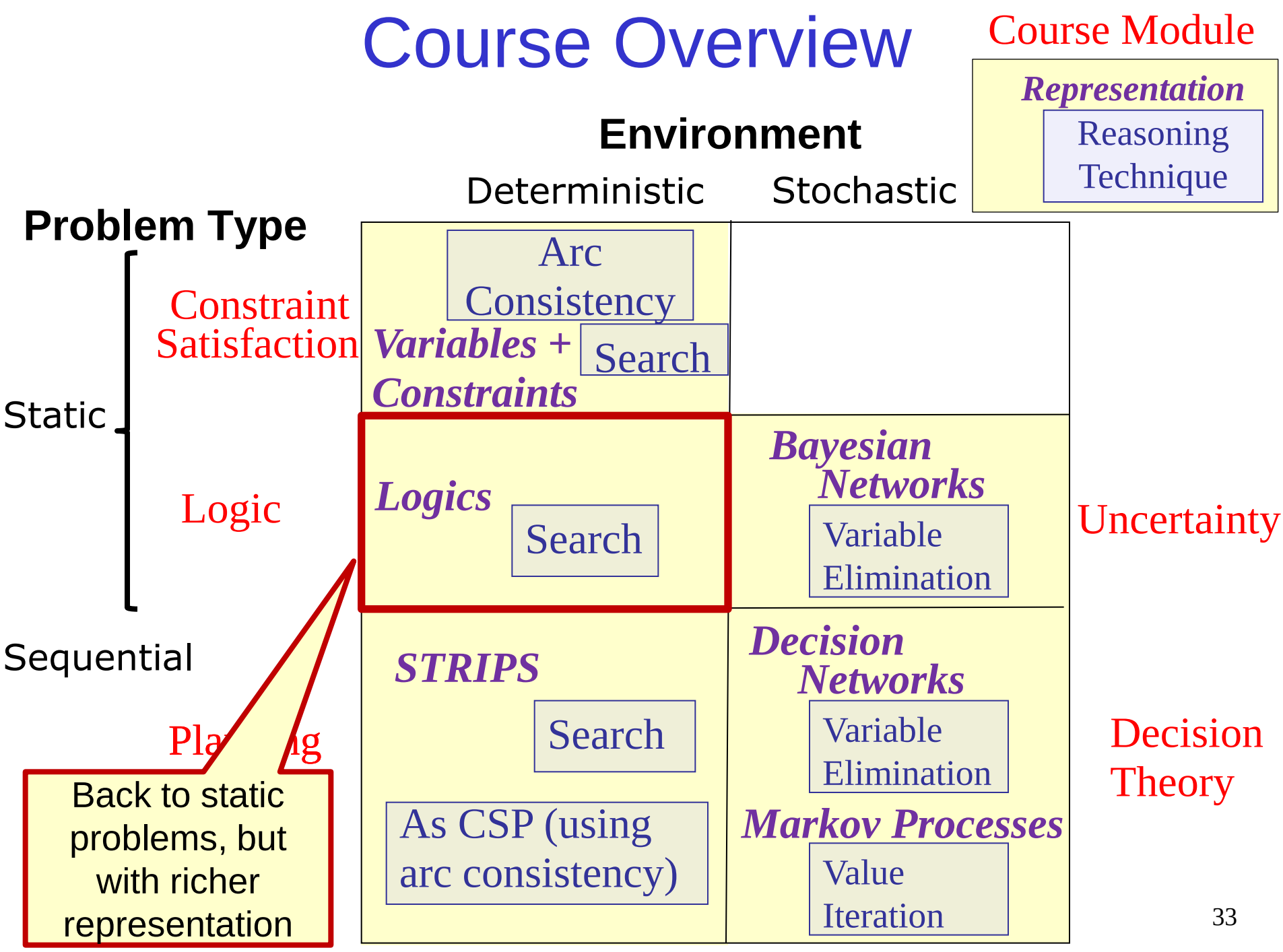
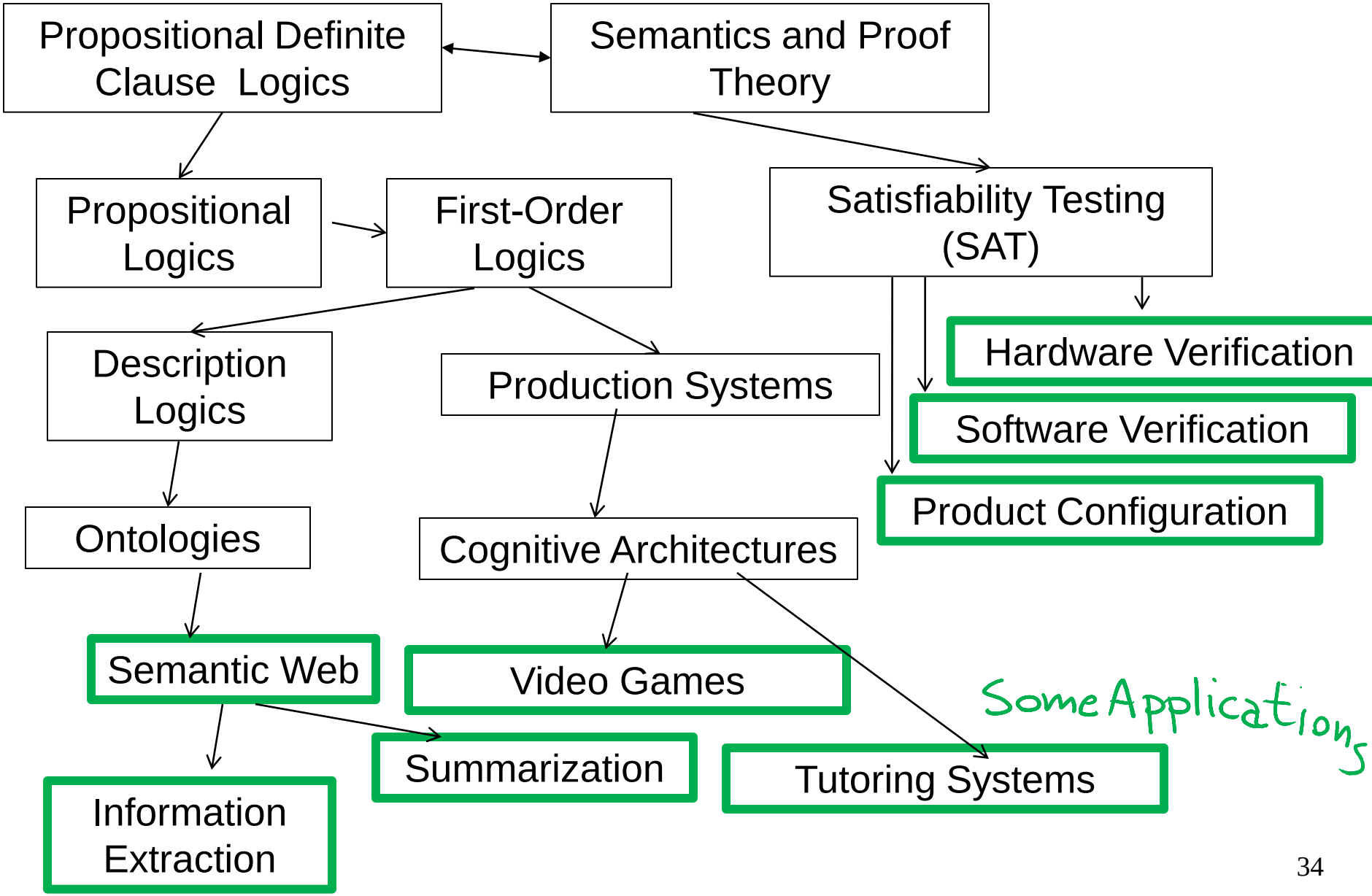


Logics in AI: Similar slide to the one for planning



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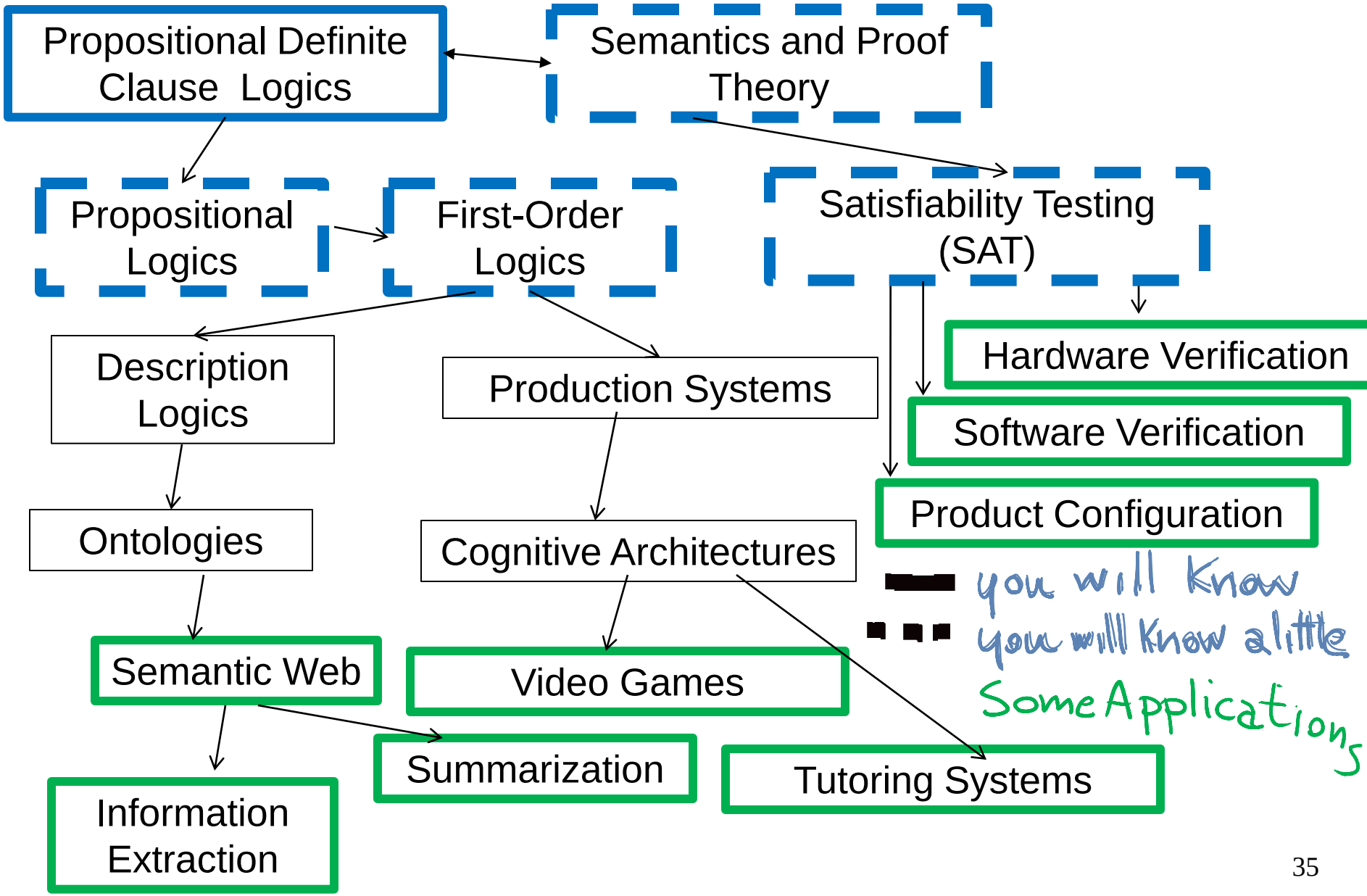


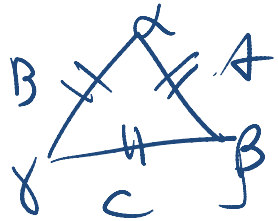
What you already know about logic...

- **From programming: Some logical operators**

- `If ((amount > 0) && (amount < 1000)) || !(age < 30)`
- `...`

You know what they mean in a "procedural" way

Logic is the language of Mathematics. To define formal structures (e.g., sets, graphs) and to prove statements about those



$\forall(x)\ \text{TRIANGLE}(x)\ A = B = C \iff \alpha = \beta = \gamma$

We use logic as a Representation and Reasoning System that can be used to formalize a domain and to reason about it

Logic: a framework for representation & reasoning

- When we represent a domain about which we have only partial (but certain) information, what are some of the things we need to represent?

Logic: a framework for representation & reasoning

- When we represent a domain about which we have only partial (but certain) information, we need to represent….
  - Objects, properties, sets, groups, actions, events, time, space, …
- All these can be represented as
  - Objects
  - Relationships between objects
- Logics is the language to express the world this way

Why Logics?

- **"Natural"** to express **knowledge** about the world
- (more natural than a "flat" set of variables & constraints)

- *e.g. "Every 101 student will pass the course"*
- *Course (c1)*
- *Name-of (c1, 101)* $\forall z,\ student(z) \wedge registered(z, c1) \Leftrightarrow will\text{-}pass(z, c1)$

- It is easy to incrementally add knowledge
- It is easy to check and debug knowledge
- Provides language for asking complex queries
- Well understood formal properties

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- Coming up: assignment 3 is available
  - Due in 2 weeks. Do the planning part early
- Useful to do practice exercise 7 before the assignment