6.825 Techniques in Artificial Intelligence

Graph Plan

- Overview
  - PO Planning – “human-like” but very slow
- Graph Plan
  - Simplified planning model
  - Efficient algorithm

Graph Plan

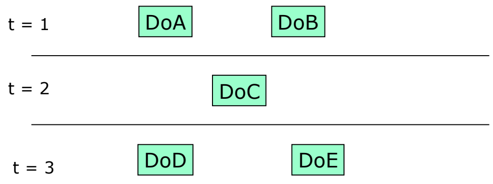
- A propositional planner, that is, there are no variables
  - Simpler – don’t have to worry about matching
  - Bigger – if you have six blocks, you need 36 propositions to represent all On(x,y) assertions

1. Make a plan graph of depth k
2. Search for a solution
3. If succeed, return a plan
4. Else k=k+1
5. Go to 1.

Plan Depth

A plan of depth k

- has k times steps
- may have multiple parallel actions per time step



Planning vs Scheduling

Scheduling: tasks are fixed

Planning vs Scheduling

Planning: find steps and schedule

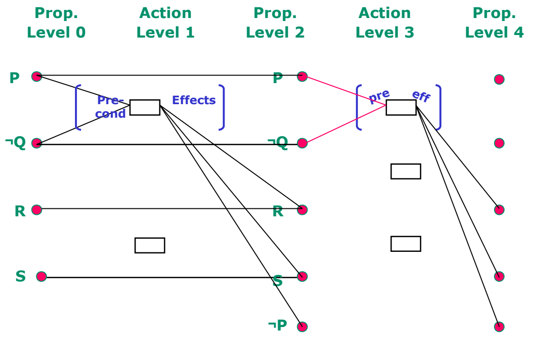
PSPACE-complete

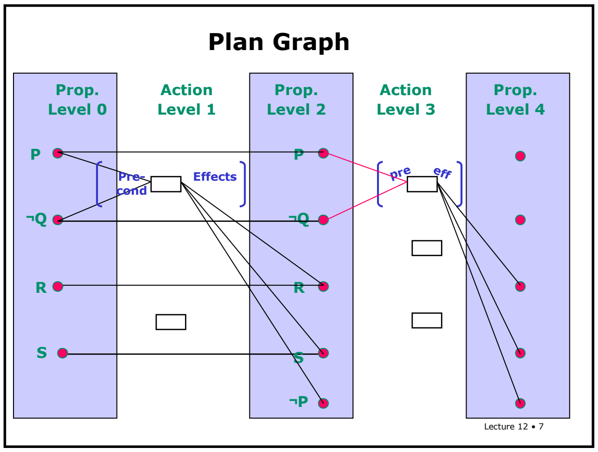
Graph Plan: find plans of a given depth

Scheduling: tasks are fixed

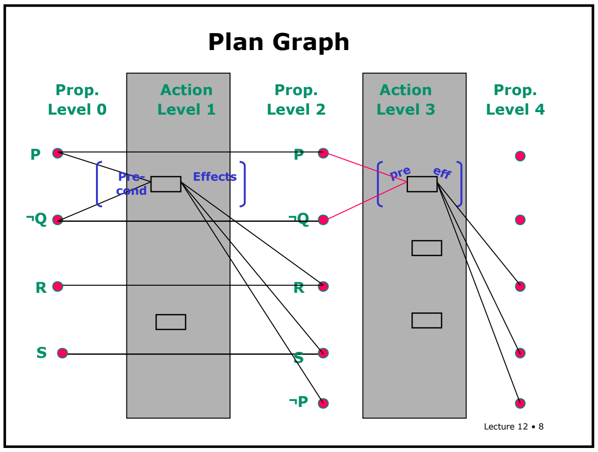
NP-Complete

Plan Graph





Plan Graph



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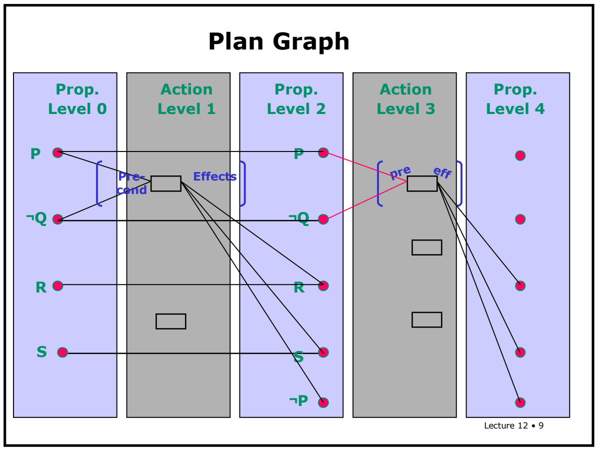

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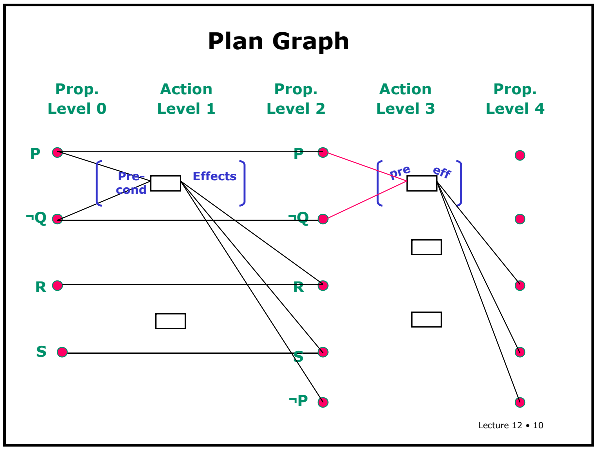

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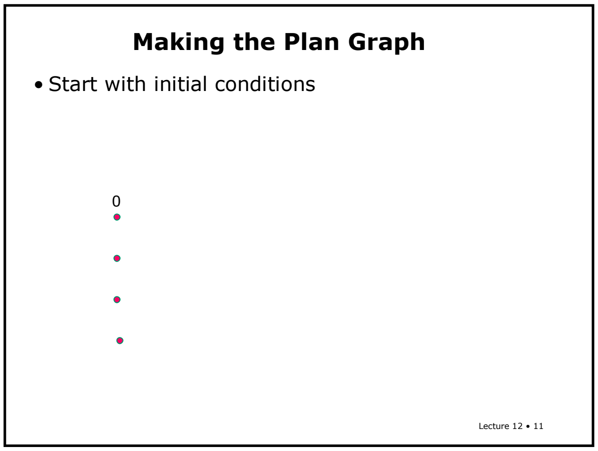
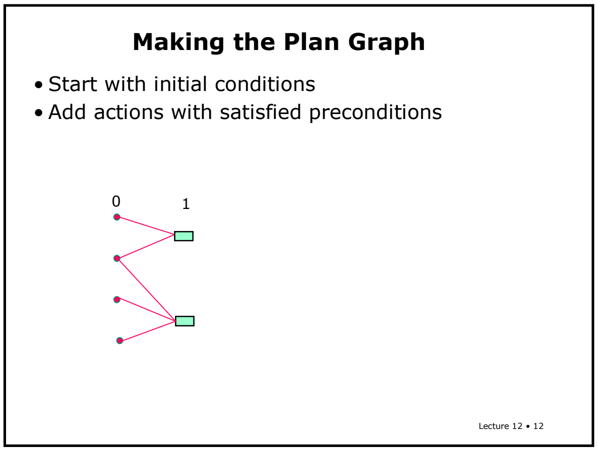


Making the Plan Graph

- Start with initial conditions

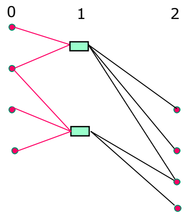


Making the Plan Graph

- Start with initial conditions
- Add actions with satisfied preconditions

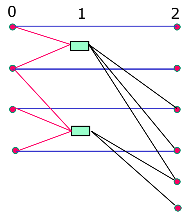
Making the Plan Graph

- Start with initial conditions
- Add actions with satisfied preconditions
- Add all effects of actions at previous levels



Making the Plan Graph

- Start with initial conditions
- Add actions with satisfied preconditions
- Add all effects of actions at previous levels
- Add maintenance actions



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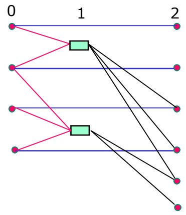

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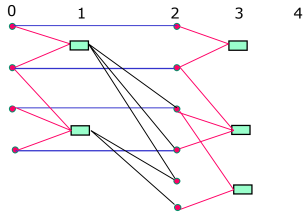

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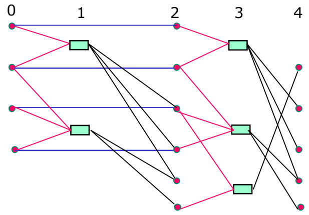

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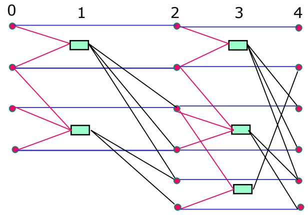
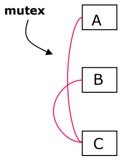


Mutually Exclusive Actions

Two action instances at level i are mutex if:

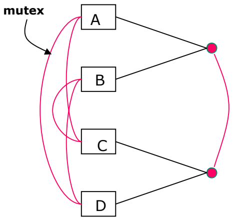
- Inconsistent effects: effect of one action is negation of effect of another
- Interference: one action deletes the precondition of the other
- Competing needs: the actions have preconditions that are mutex at level i-1



Mutually Exclusive Propositions

Two propositions at level i are mutex if:

- Negation: they are negations of one another
- Inconsistent support: all ways of achieving the propositions at level i-1 are pairwise mutex.



Inconsistent support

Solution Extraction

- If all the literals in the goal appear at the deepest level and not mutex, then search for a solution for each subgoal at level i
  - For each subgoal at level i
    - Choose an action to achieve it
    - If it's mutex with another action, Fail
  - Repeat for preconditions at level i-2

Birthday Dinner Example

- Goal: : garb Æ dinner Æ present
- Init: garb Æ clean Æ quiet
- Actions:
  - Cook
    - Pre: clean
    - Effect:dinner
  - Wrap
    - Pre: quiet
    - Effect: present
  - Carry
    - Pre: garb
    - Effect: : garb Æ : clean
  - Dolly
    - Pre: garb
    - Effect: : garb Æ : quiet

clean
garb
quiet

Goal	¬ garb ^ dinner ^ present	
Init	garb ^ clean ^ quiet	
Action	Pre	Post
Cook	clean	dinner
Wrap	quiet	present
Carry	garb	¬ garb ^ ¬ clean
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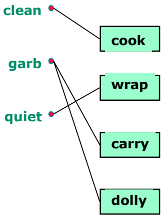

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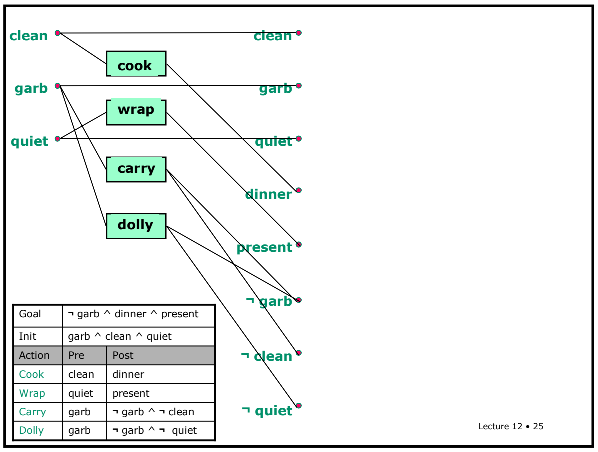

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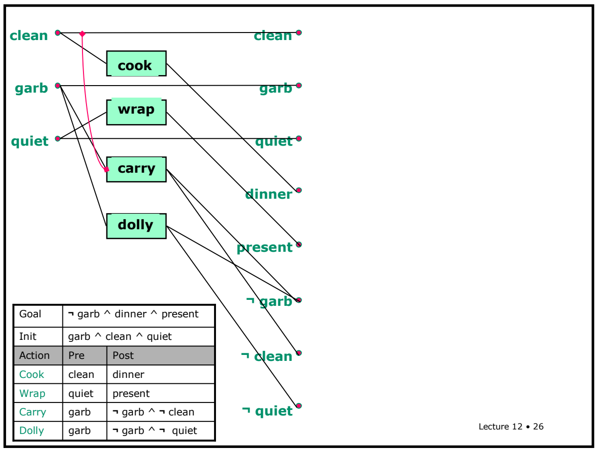
Lecture 12 • 25



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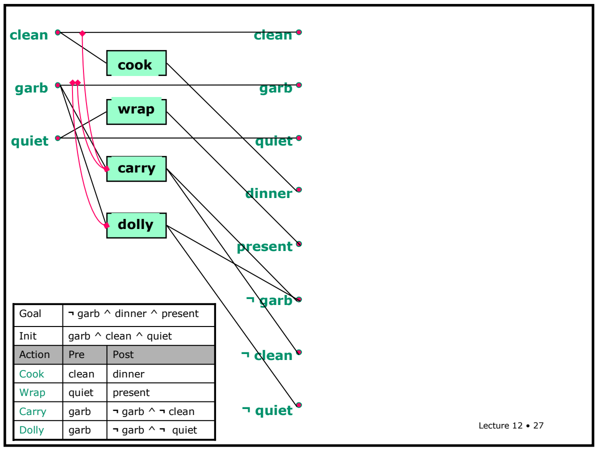
Lecture 12 • 26



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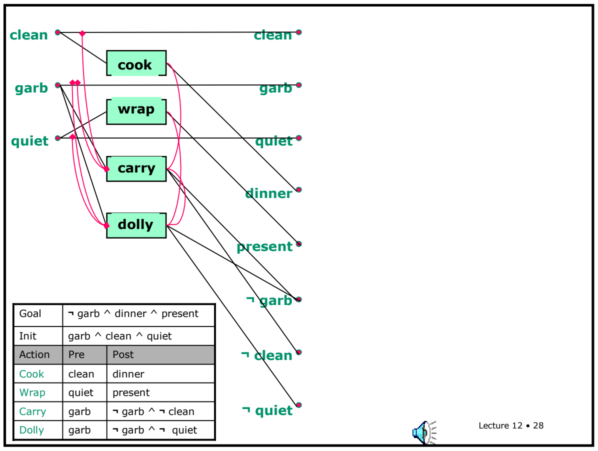
Lecture 12 • 27



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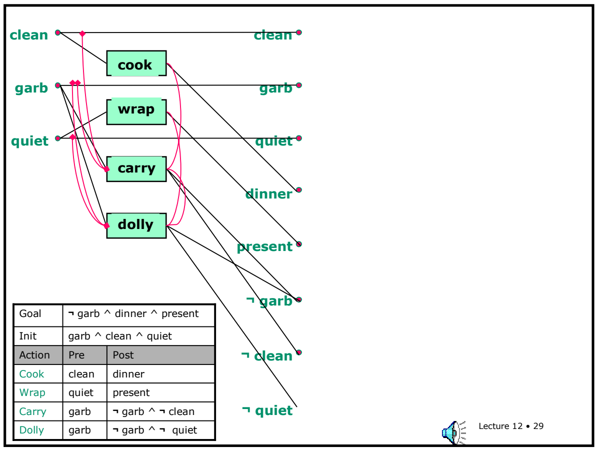
Lecture 12 • 28



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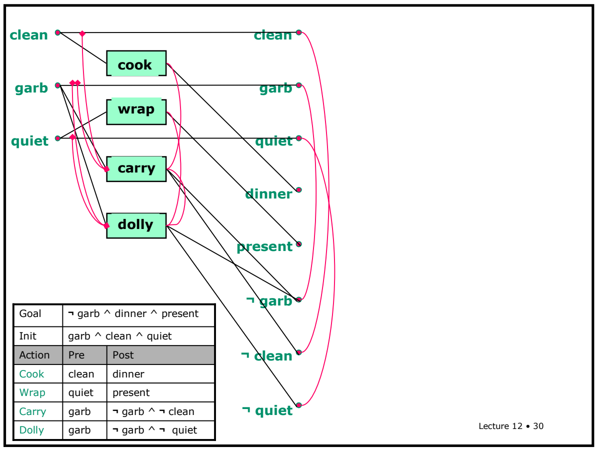
Lecture 12 • 29



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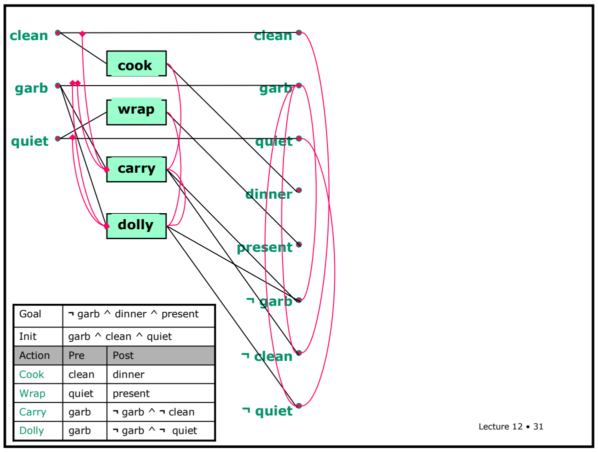
Lecture 12 • 30



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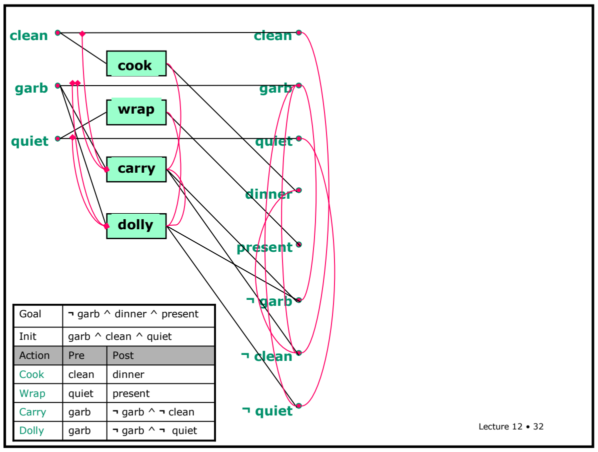
Lecture 12 • 31



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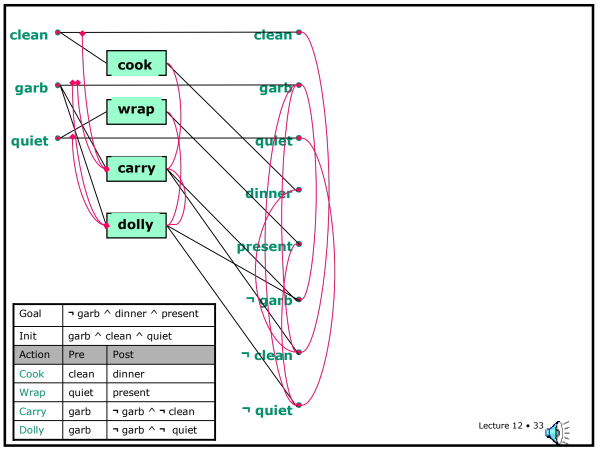
Lecture 12 • 32



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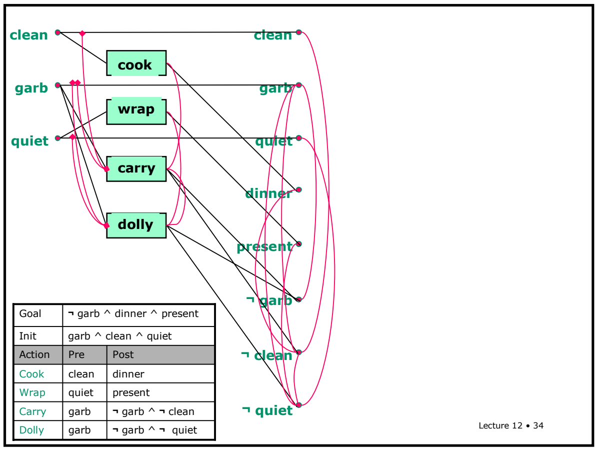
Lecture 12 • 33



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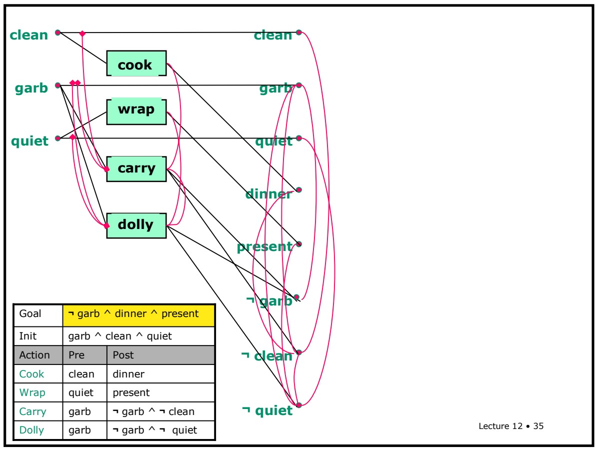
Lecture 12 • 34



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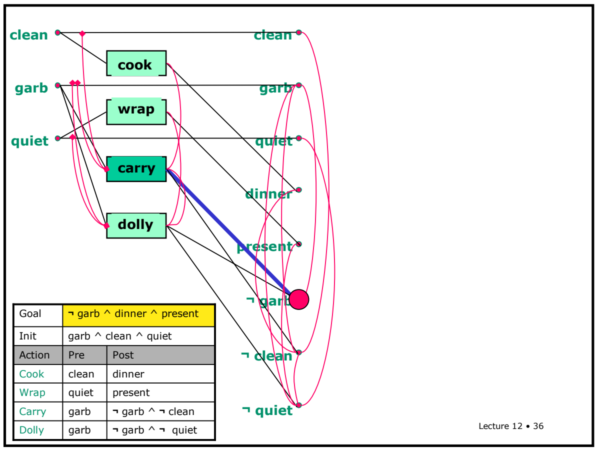
Lecture 12 • 35



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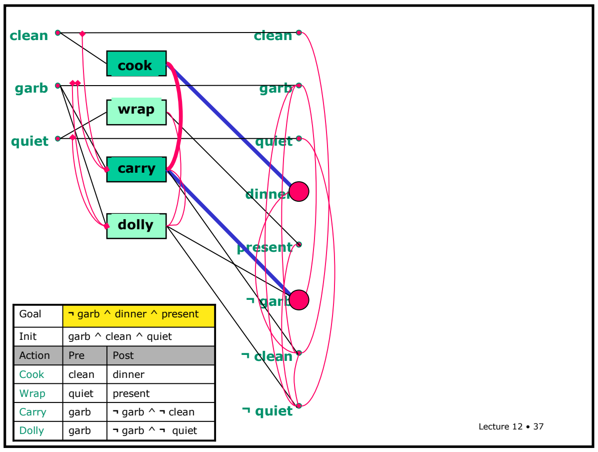
Lecture 12 • 36



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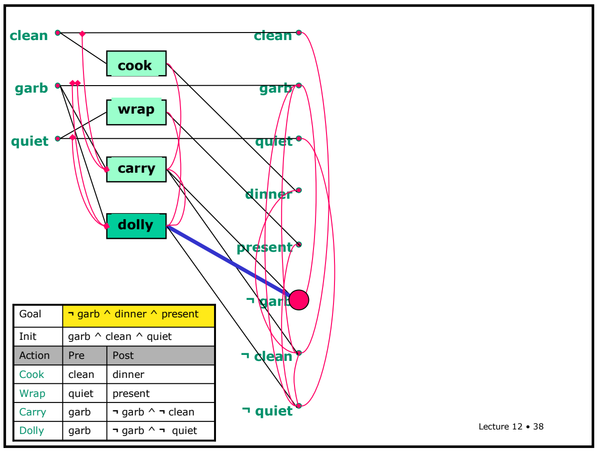
Lecture 12 • 37



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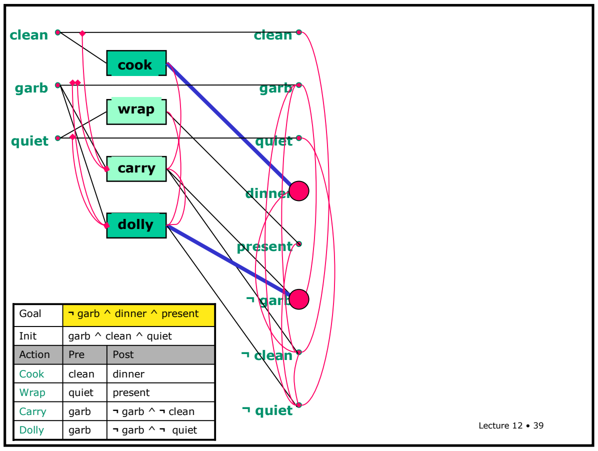
Lecture 12 • 38



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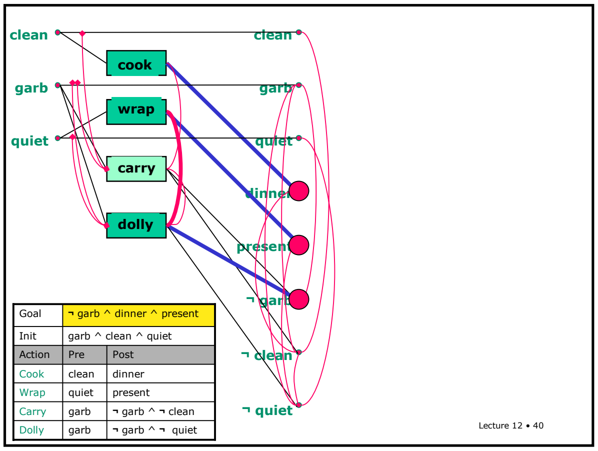
Lecture 12 • 39



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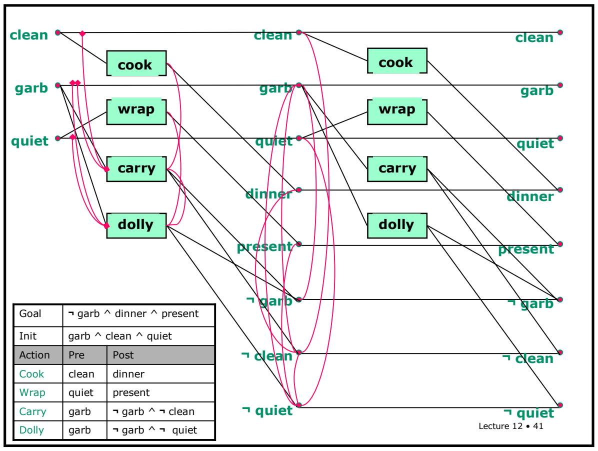
Lecture 12 • 40



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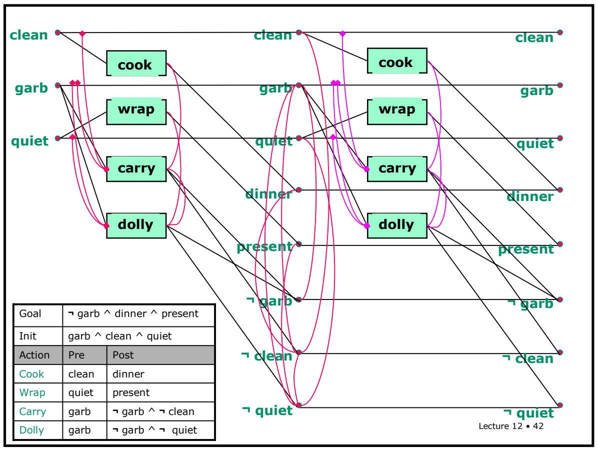

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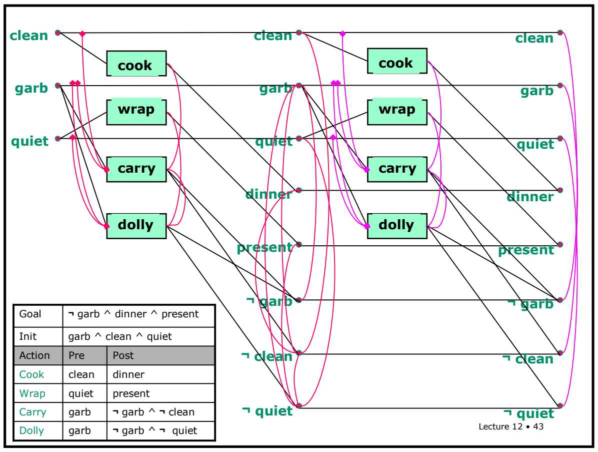
Lecture 12 • 42



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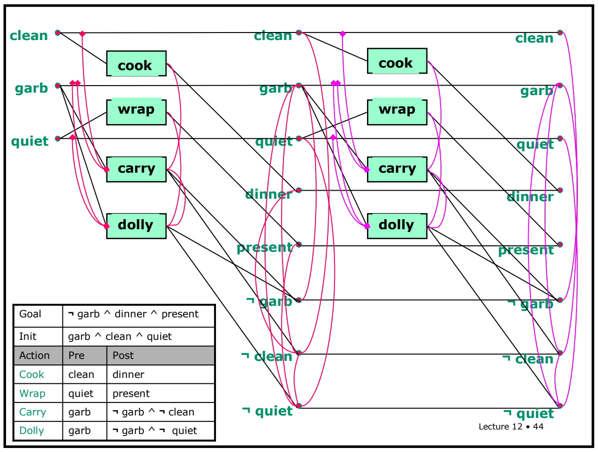
Lecture 12 • 43



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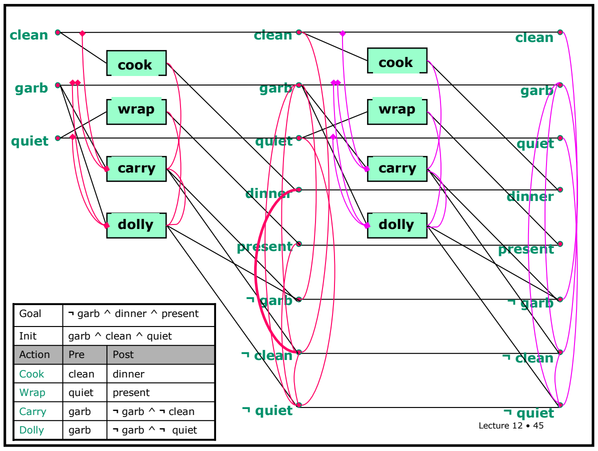
Lecture 12 • 44



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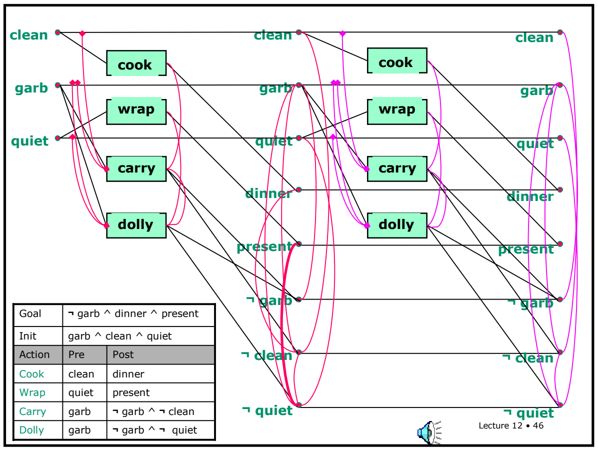
Lecture 12 • 45



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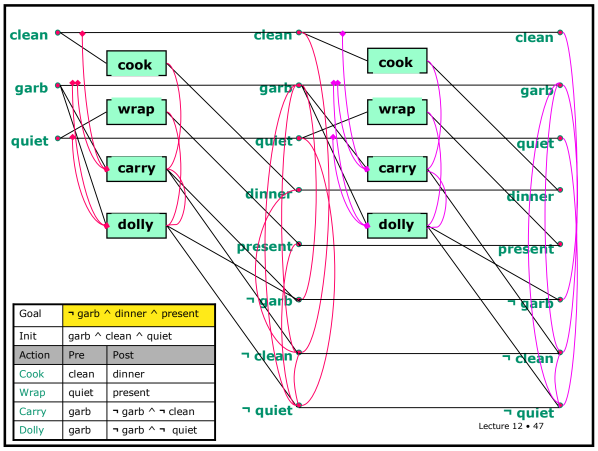
Lecture 12 • 46



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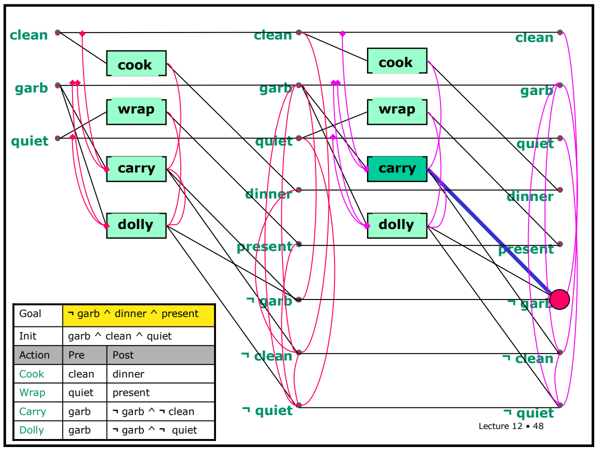
Lecture 12 • 47



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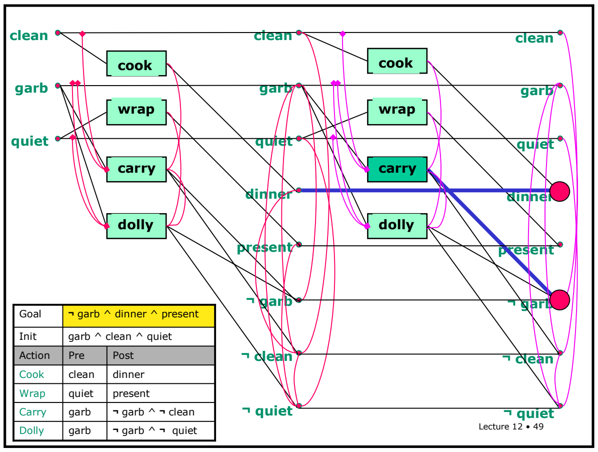
Lecture 12 • 48



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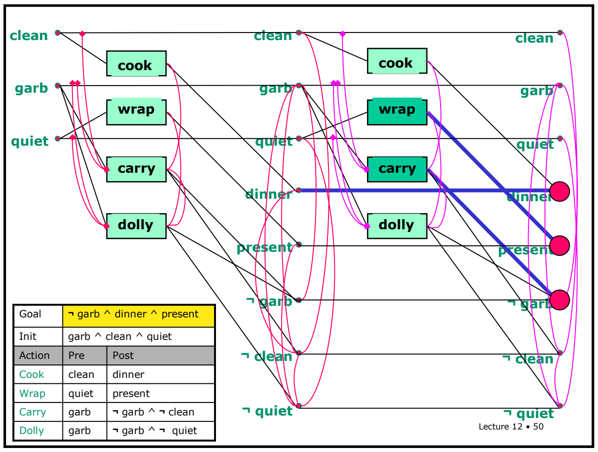

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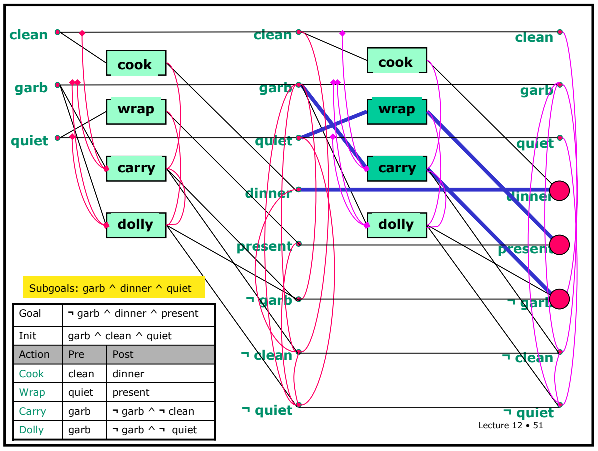
Lecture 12 • 50



Subgoals: garb ^ dinner ^ quiet

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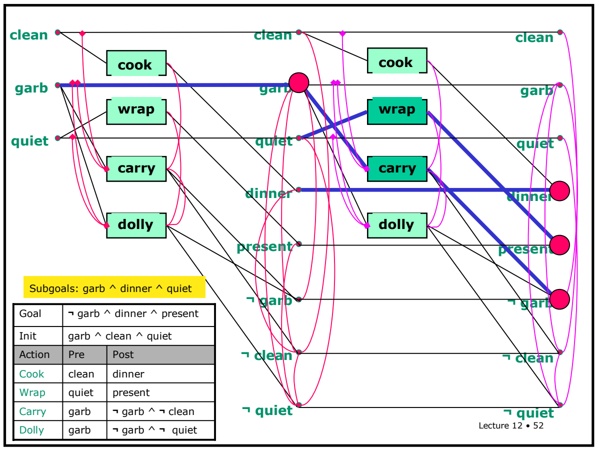
Lecture 12 • 51



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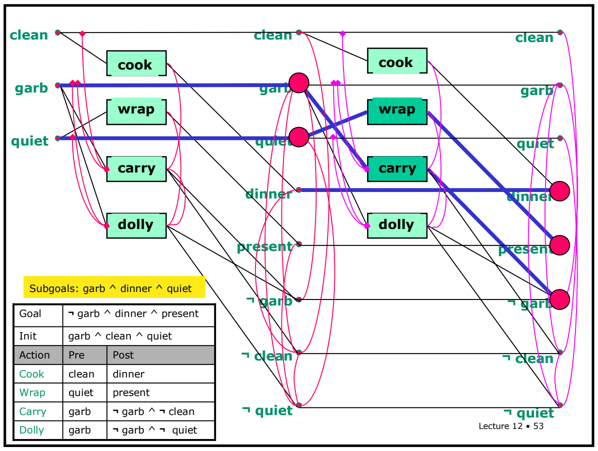
Dolly	garb	¬ garb ^ ¬ quiet

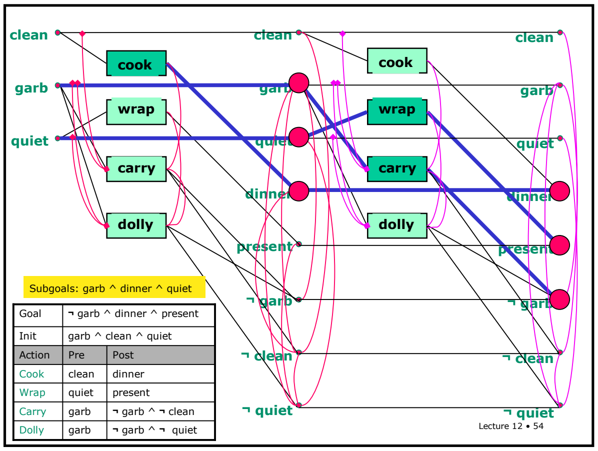
Lecture 12 • 52



Subgoals: garb ^ dinner ^ quiet

Goal	¬ garb ^ dinner ^ present	
Init	garb ^ clean ^ quiet	
Action	Pre	Post
Cook	clean	dinner
Wrap	quiet	present
Carry	garb	¬ garb ^ ¬ clean
Dolly	garb	¬ garb ^ ¬ quiet

Lecture 12 • 53



Subgoals: garb ^ dinner ^ quiet

Goal	¬ garb ^ dinner ^ present	
Init	garb ^ clean ^ quiet	
Action	Pre	Post
Cook	clean	dinner
Wrap	quiet	present
Carry	garb	¬ garb ^ ¬ clean
Dolly	garb	¬ garb ^ ¬ quiet

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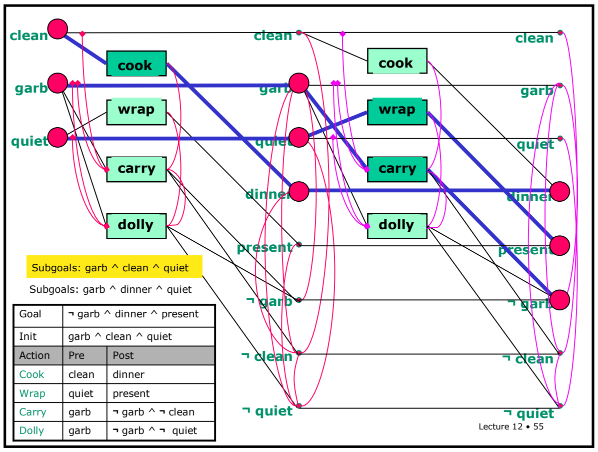

Subgoals: garb ^ clean ^ quiet

Subgoals: garb ^ dinner ^ quiet

Goal	¬ garb ^ dinner ^ present	
Init	garb ^ clean ^ quiet	
Action	Pre	Post
Cook	clean	dinner
Wrap	quiet	present
Carry	garb	¬ garb ^ ¬ clean
Dolly	garb	¬ garb ^ ¬ quiet

Extensions

- Lots of time optimizations
- Disjunctive preconditions
- Universally quantified (sort of) preconditions and effects
- Conditional planning