Graphplan

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[* based in part on slides by Jim Blythe and Dan Weld]

Basic idea

- Construct a graph that encodes constraints on possible plans
- Use this “planning graph” to constrain search for a valid plan:
  - If valid plan exists, it’s a subgraph of the planning graph
- Planning graph can be built for each problem in polynomial time

Problem handled by GraphPlan*

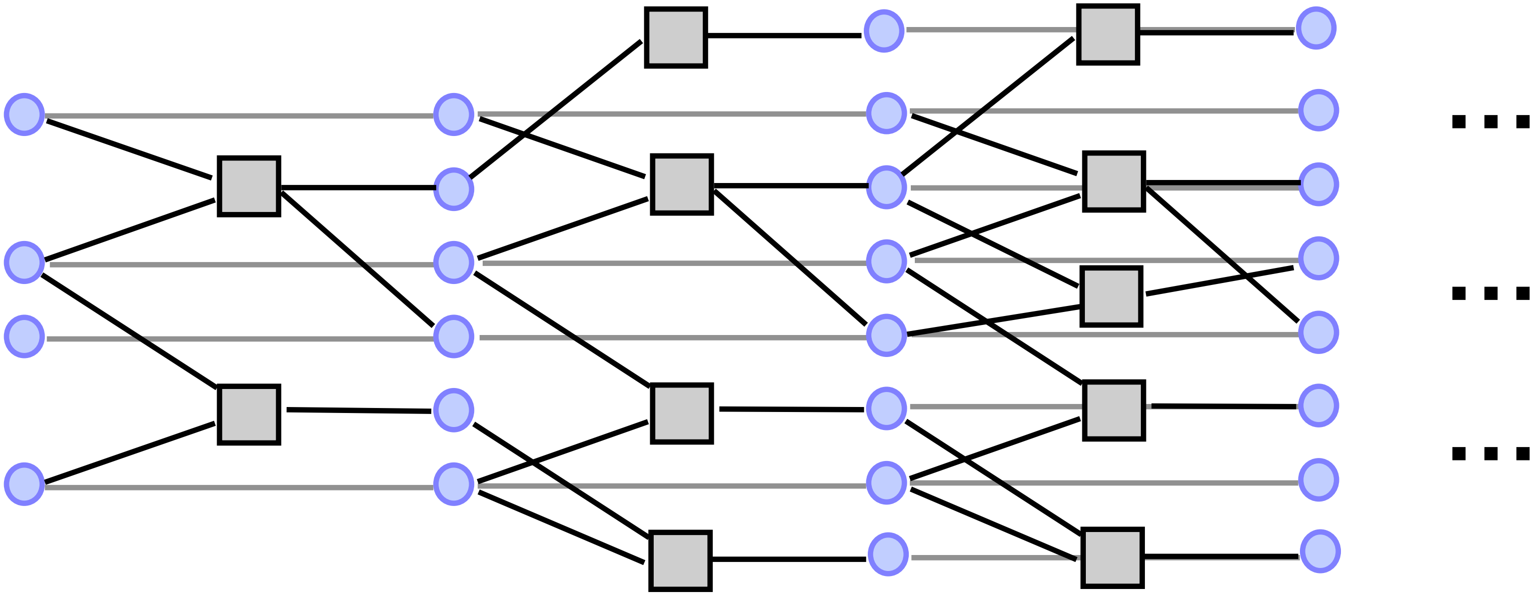
- Pure STRIPS operators:
  - conjunctive preconditions
  - no negated preconditions
  - no conditional effects
  - no universal effects
- Finds “shortest parallel plan”
- Sound, complete and will terminate with failure if there is no plan.

***Version in [Blum& Furst IJCAI 95, AIJ 97],**
later extended to handle all these restrictions [Koehler et al 97]

Planning graph

- Directed, leveled graph
  - 2 types of nodes:
    - Proposition: P
    - Action: A
  - 3 types of edges (between levels)
    - Precondition: P -> A
    - Add: A -> P
    - Delete: A -> P
- Proposition and action levels alternate
- Action level includes actions whose preconditions are satisfied in previous level plus no-op actions (to solve frame problem).

Planning graph



Constructing the planning graph

- Level P_1: all literals from the initial state
- Add an action in level A_i if all its preconditions are present in level P_i
- Add a precondition in level P_i if it is the effect of some action in level A_{i-1} (including no-ops)
- Maintain a set of exclusion relations to eliminate incompatible propositions and actions (thus reducing the graph size)

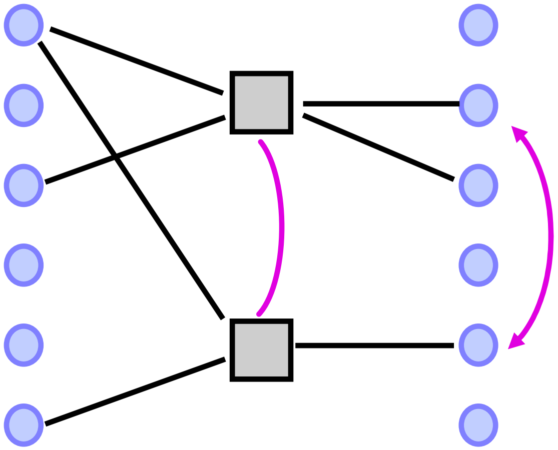
$$\mathbf{P_1\ A_1\ P_2\ A_2\ \ldots\ P_{n-1}\ A_{n-1}\ P_n}$$

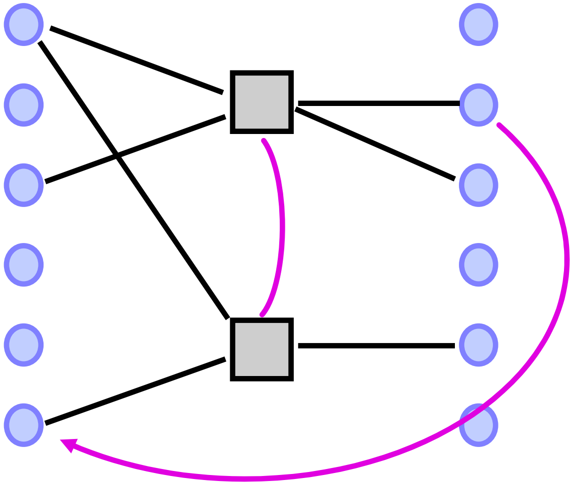
Mutual Exclusion relations

- Two actions (or literals) are mutually exclusive (mutex) at some stage if no valid plan could contain both.
- Two actions are mutex if:
  - Interference: one clobbers others' effect or precondition
  - Competing needs: mutex preconditions
- Two propositions are mutex if:
  - All ways of achieving them are mutex

Mutual Exclusion relations

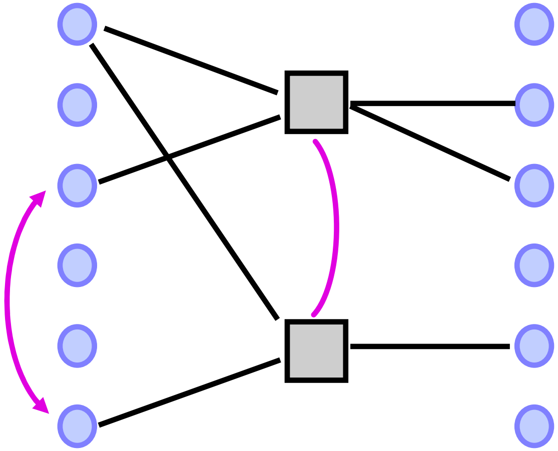
Inconsistent Effects

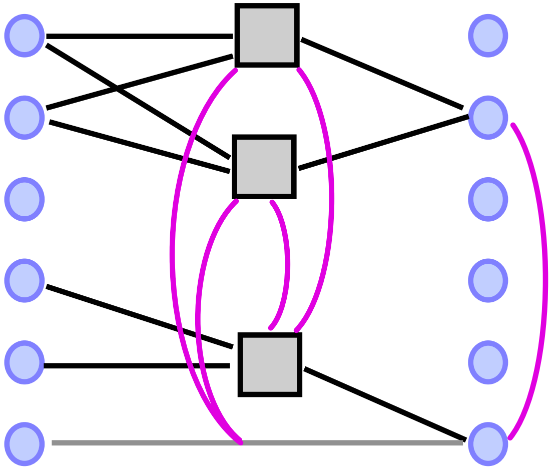




Interference (prec-effect)

Competing Needs



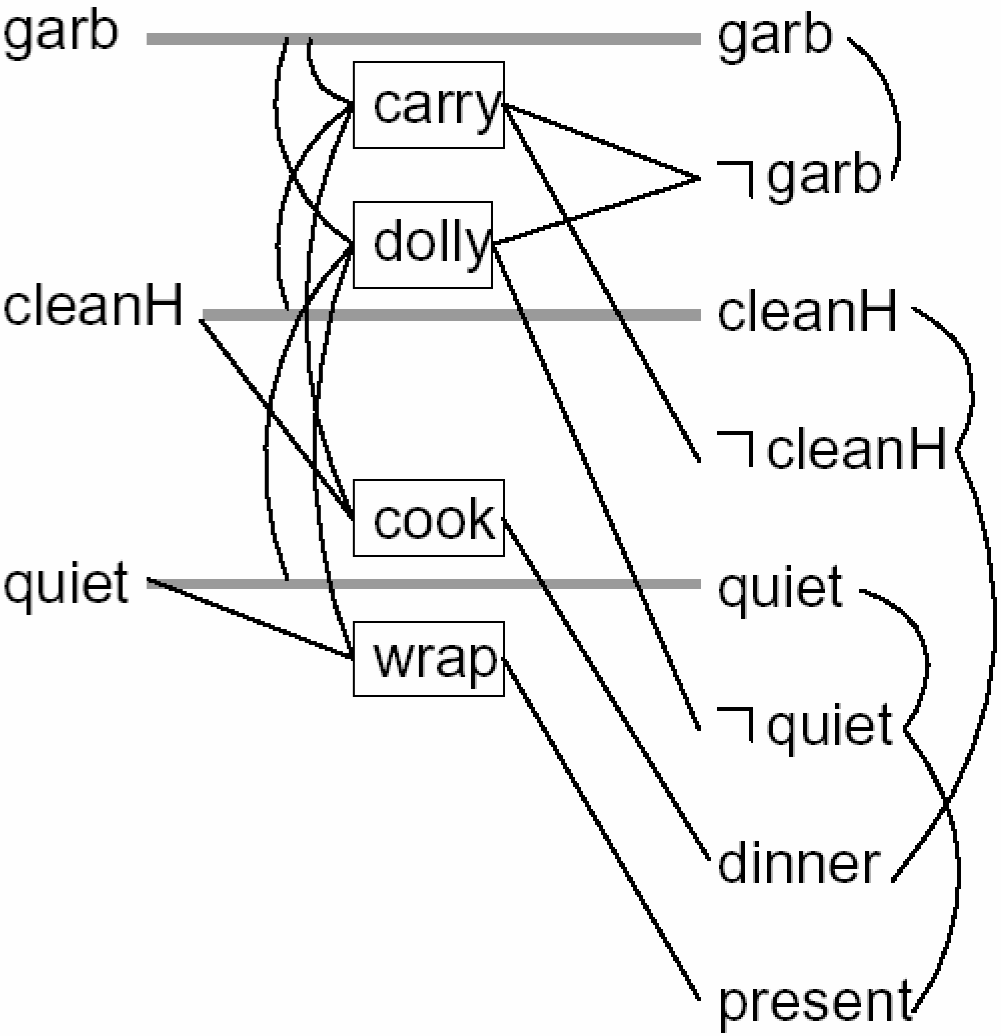


Inconsistent Support

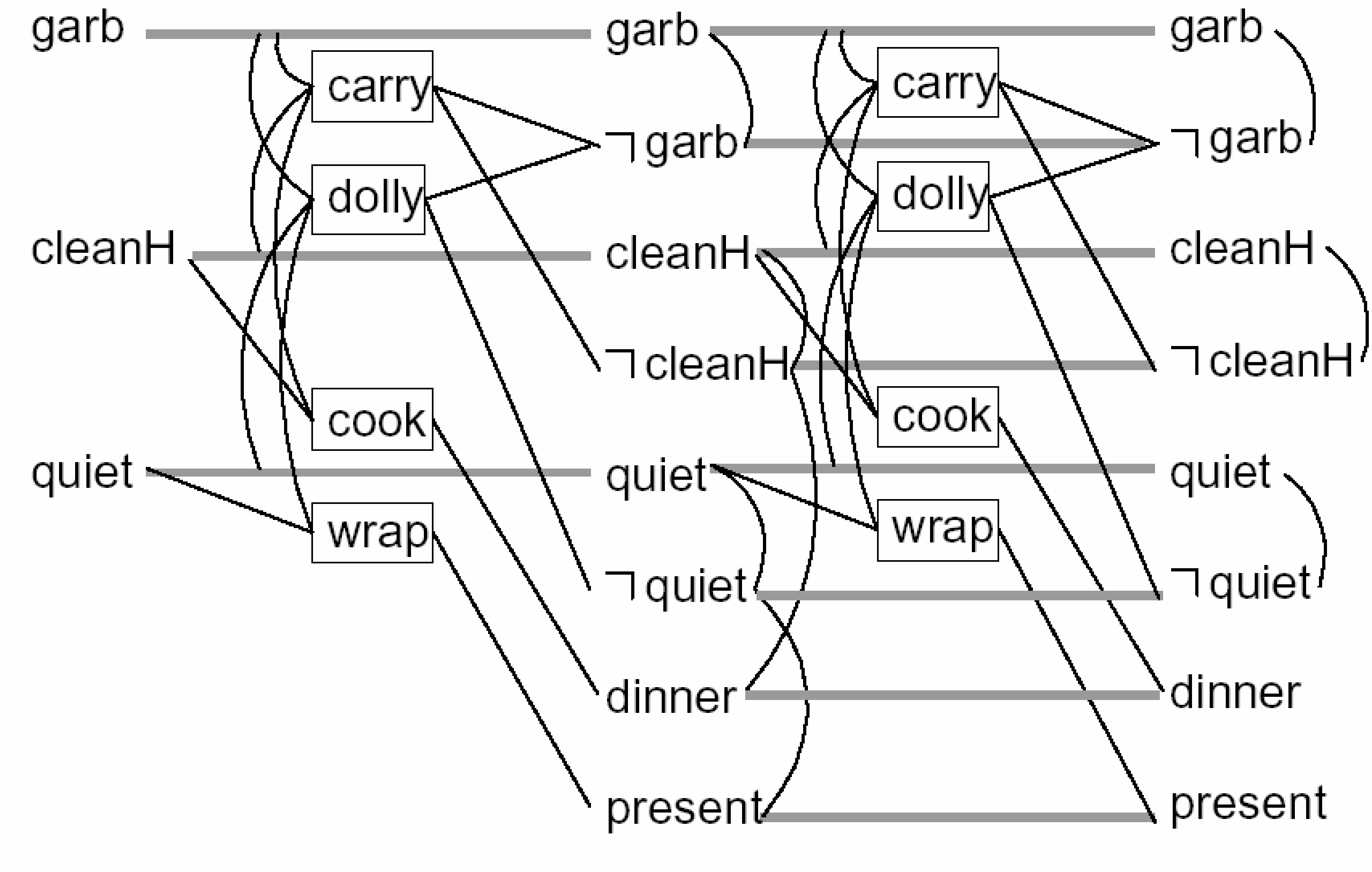
Dinner Date example

- Initial Conditions: (and (garbage) (cleanHands) (quiet))
- Goal: (and (dinner) (present) (not (garbage))
- Actions:
  - Cook :precondition (cleanHands)
:effect (dinner)
  - Wrap :precondition (quiet)
:effect (present)
  - Carry :precondition
:effect (and (not (garbage)) (not (cleanHands))
  - Dolly :precondition
:effect (and (not (garbage)) (not (quiet)))

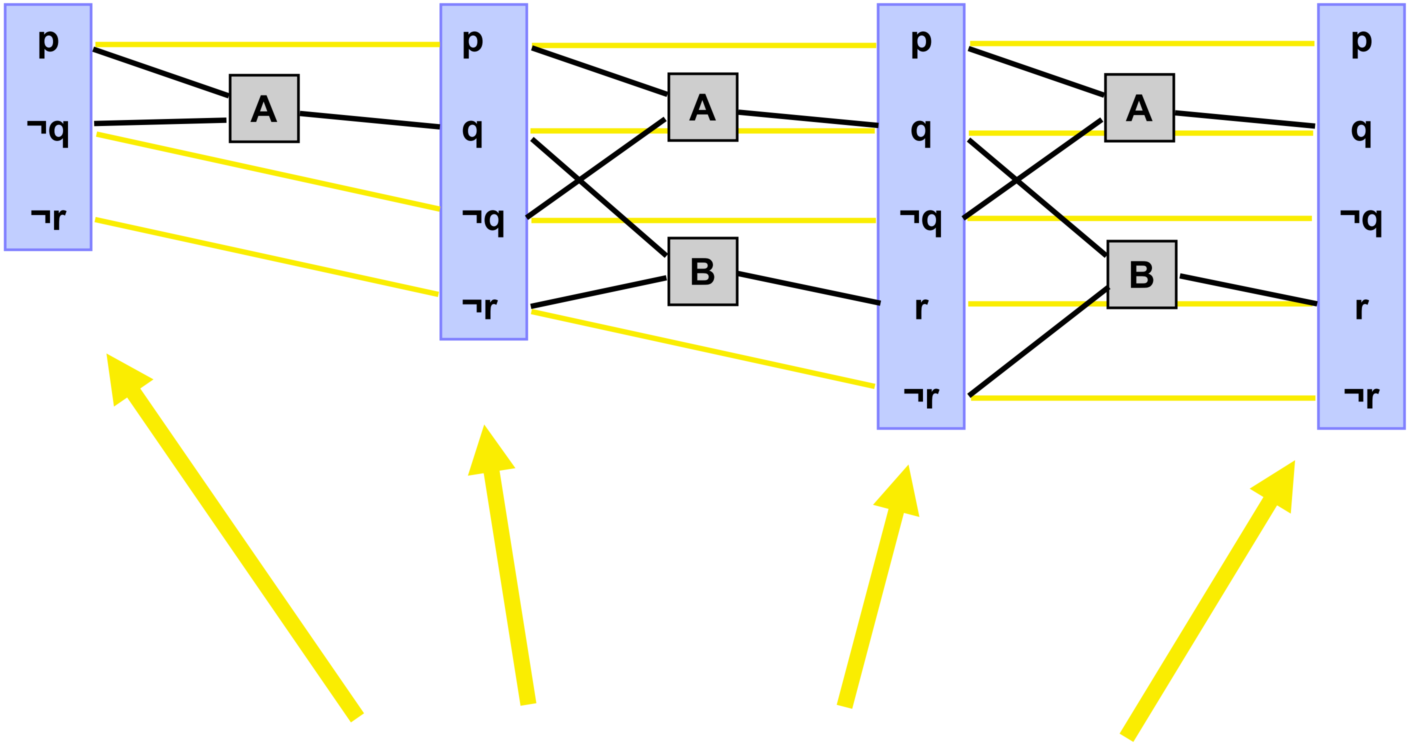
Dinner Date example



Dinner Date example



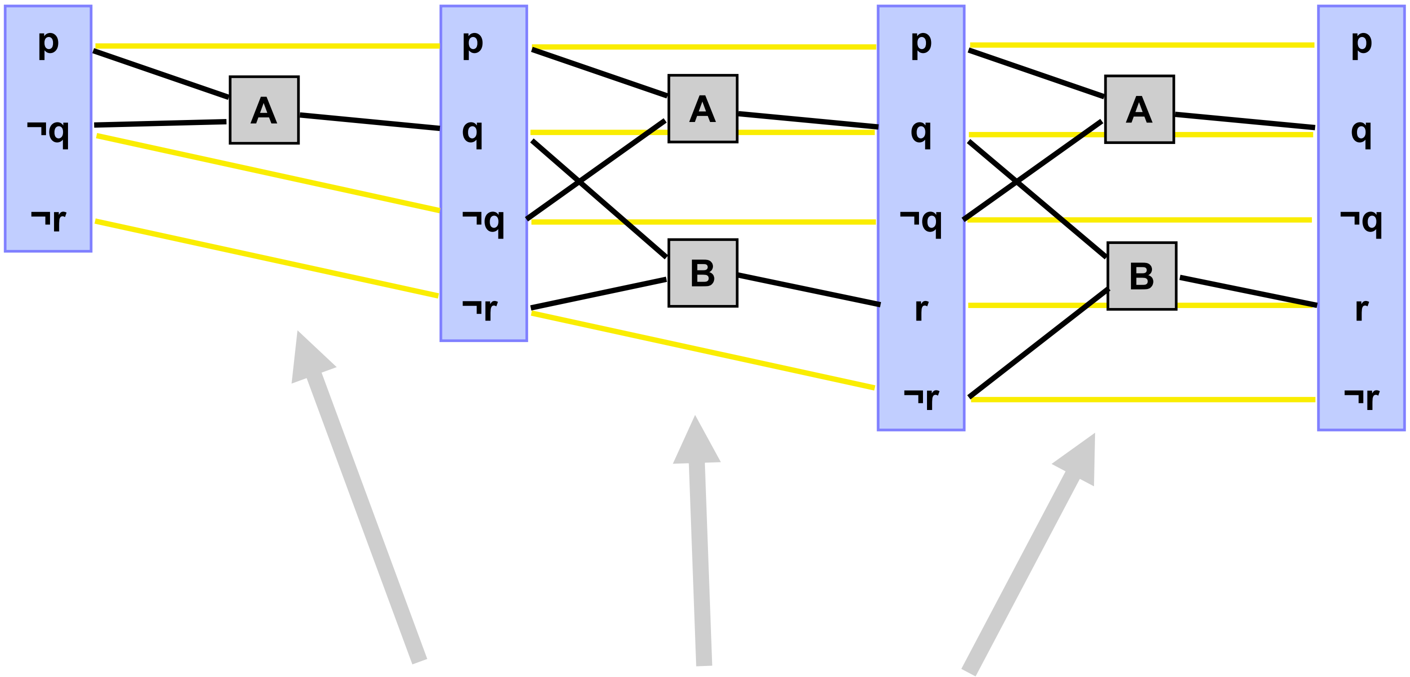
Observation 1



Propositions monotonically increase

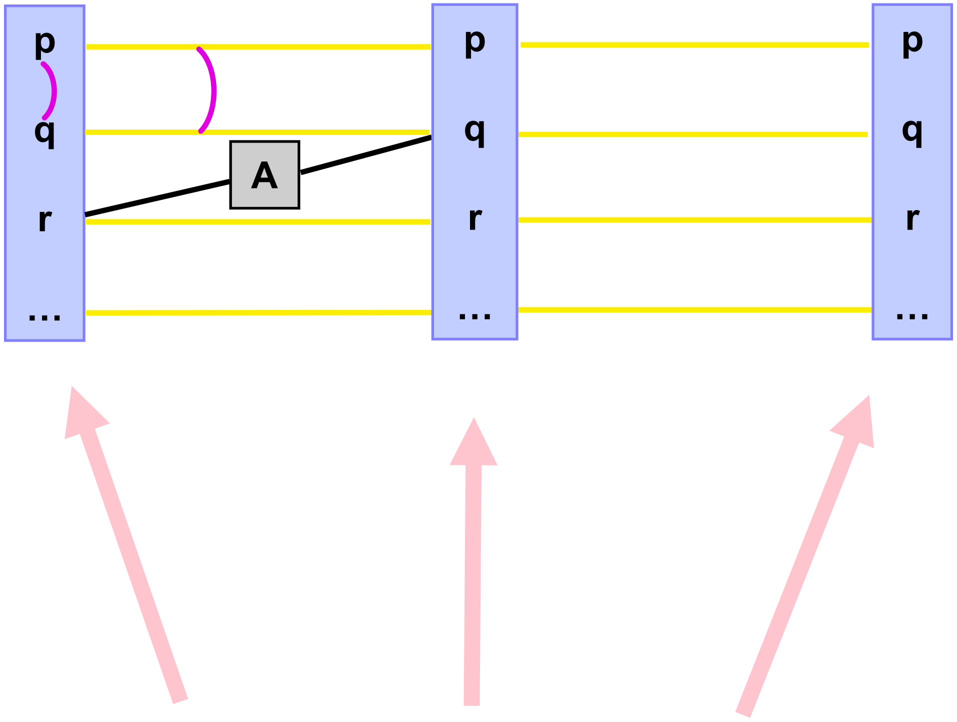
(always carried forward by no-ops)

Observation 2



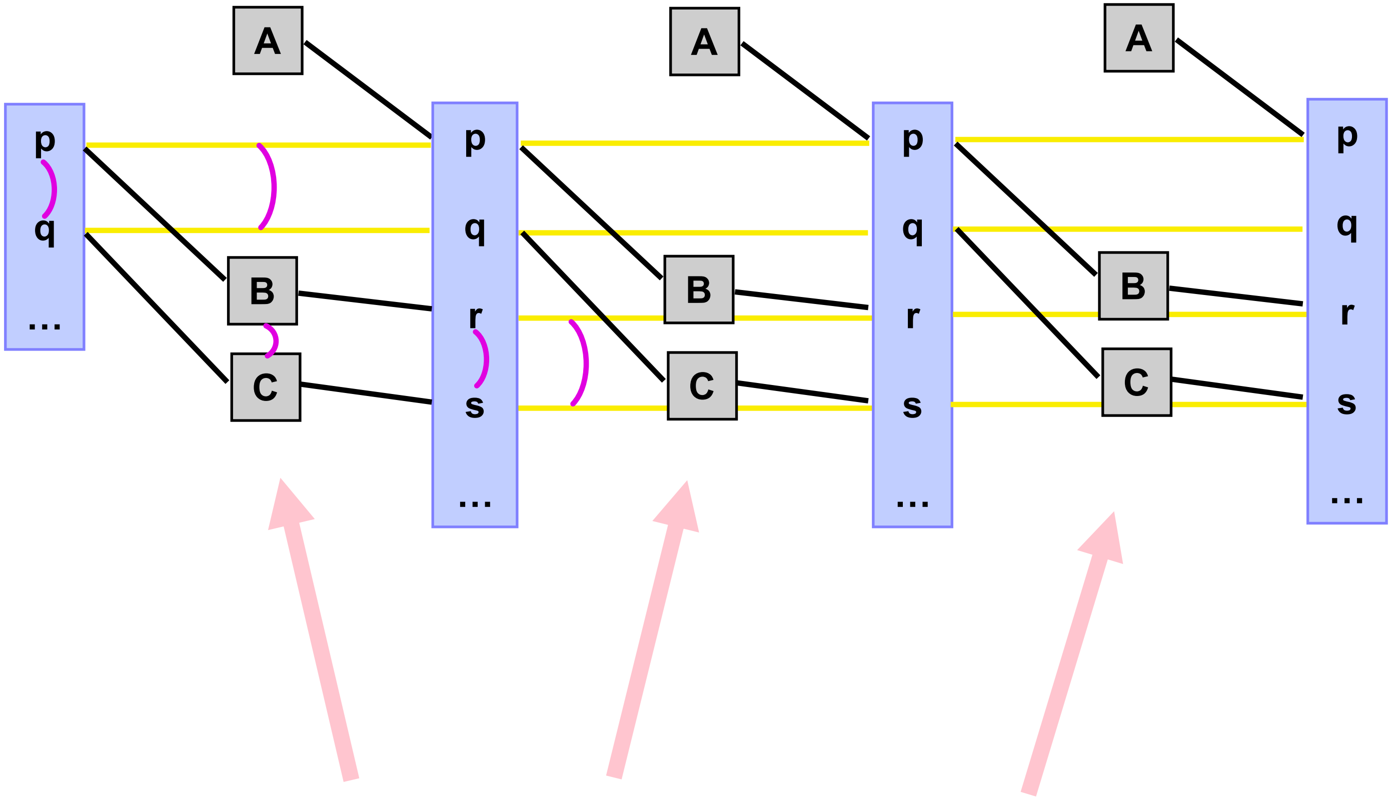
Actions monotonically increase

Observation 3



Proposition mutex relationships monotonically decrease

Observation 4



Action mutex relationships monotonically decrease

Observation 5

Planning Graph ‘levels off’.

- After some time k all levels are identical
- Because it’s a finite space, the set of literals never decreases and mutexes don’t reappear.

Valid plan

A valid plan is a planning graph where:

- Actions at the same level don’t interfere
- Each action’s preconditions are made true by the plan
- Goals are satisfied

GraphPlan algorithm

- Grow the planning graph (PG) until all goals are reachable and not mutex. (If PG levels off first, fail)
- Search the PG for a valid plan
- If non found, add a level to the PG and try again

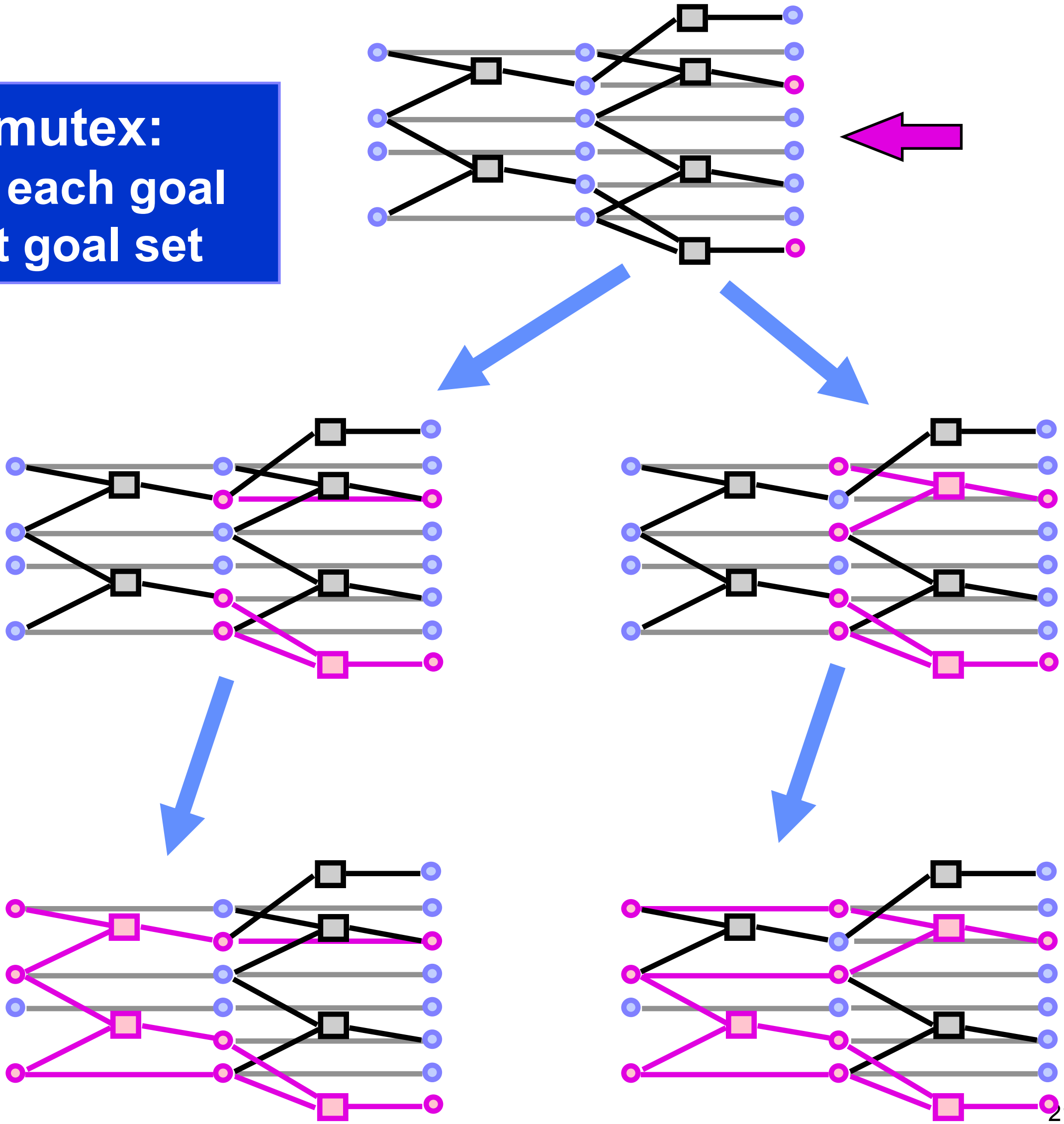
Searching for a solution plan

- Backward chain on the planning graph
- Achieve goals level by level
- At level k, pick a subset of non-mutex actions to achieve current goals. Their preconditions become the goals for k-1 level.
- Build goal subset by picking each goal and choosing an action to add. Use one already selected if possible. Do forward checking on remaining goals (backtrack if can't pick non-mutex action)

Plan Graph Search

If goals are present & non-mutex:

- Choose action to achieve each goal
- Add preconditions to next goal set



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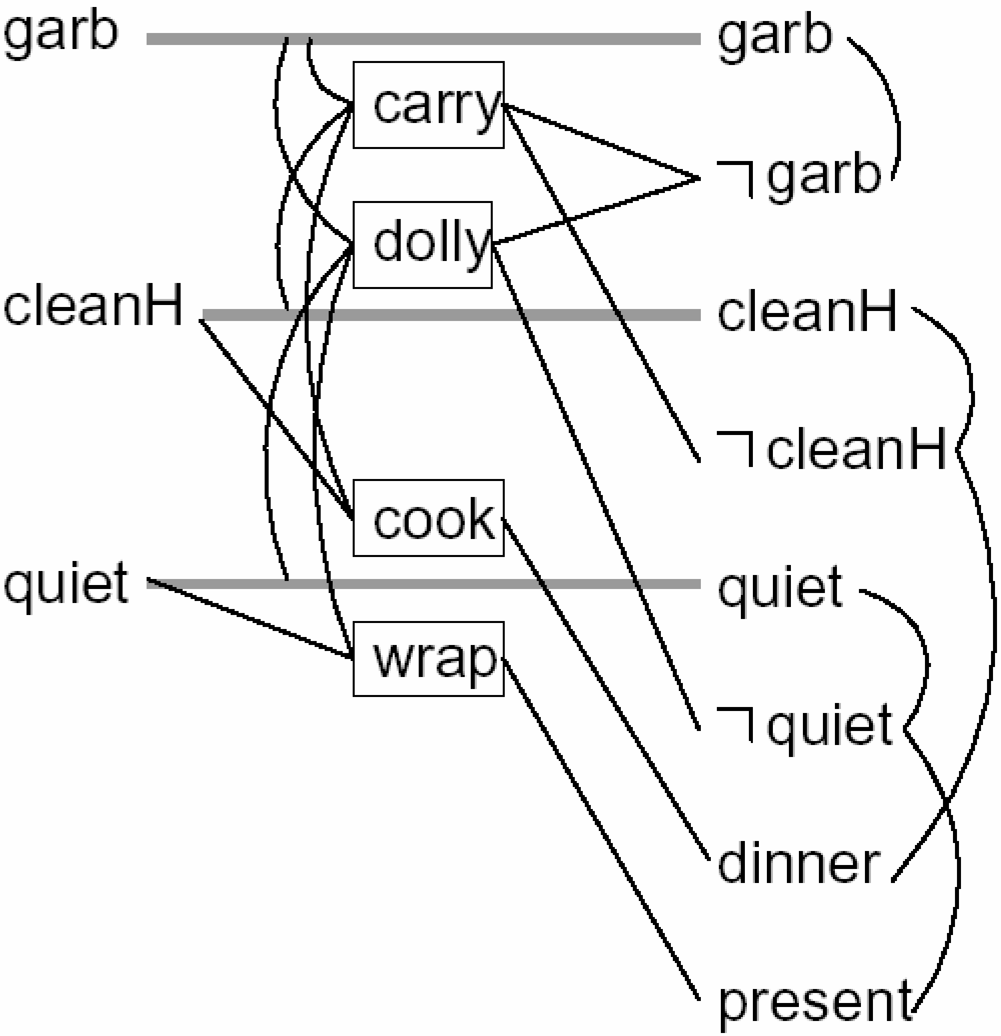

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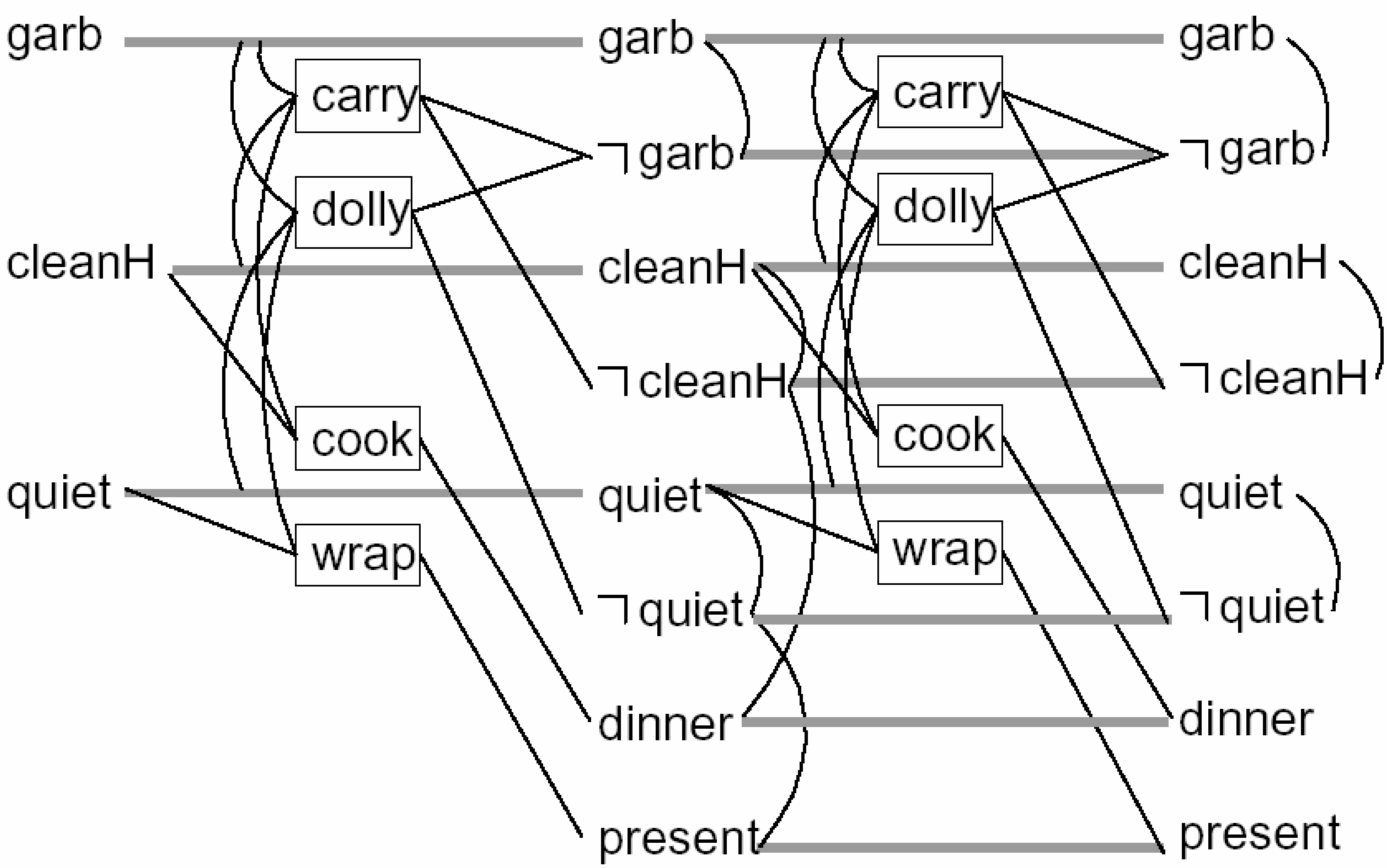

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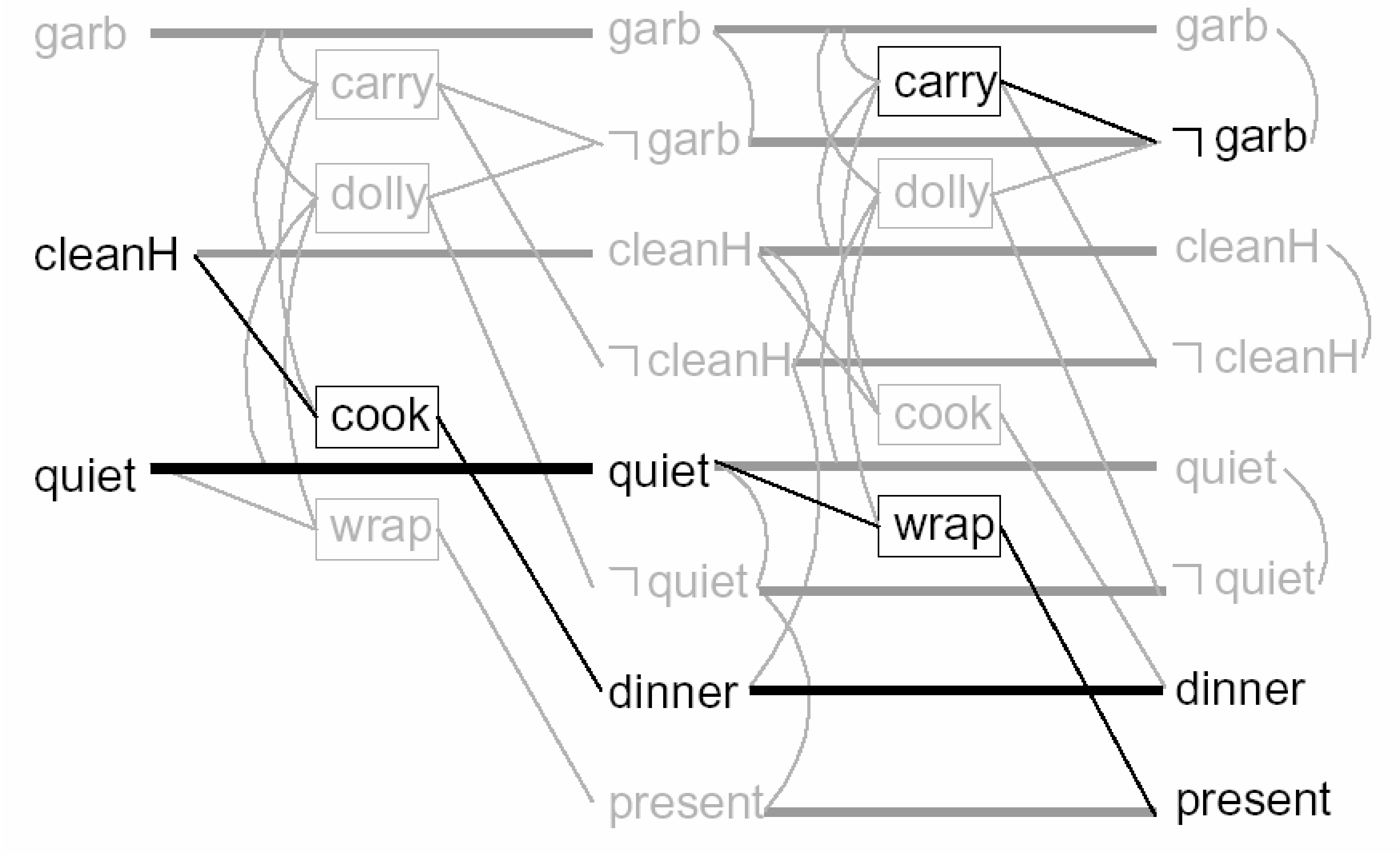
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