Classical Planning

Chapter 10

Mausam

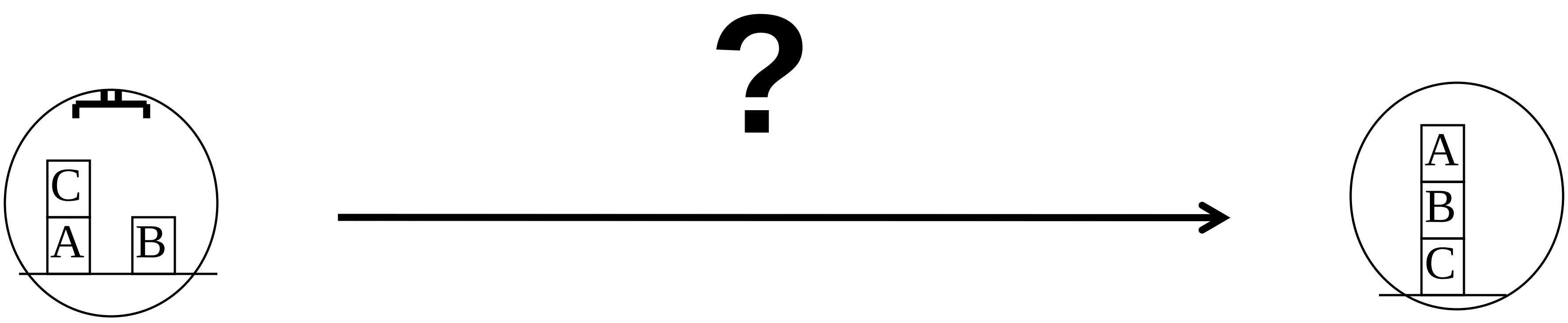
(Based on slides of Dan Weld, Marie desJardins)

Planning

- Given
  - a logical description of the **world states**,
  - a logical description of a set of **possible actions**,
  - a logical description of the **initial situation**, and
  - a logical description of the **goal conditions**,

- Find
  - a **sequence of actions** (a **plan of actions**) that brings us from the initial situation to a situation in which the goal conditions hold.

Example: BlocksWorld



Planning Input: State Variables/Propositions

- **(on-table a) (on-table b) (on-table c)**
- **(clear a) (clear b) (clear c)**
- **(arm-empty)**
- **(holding a) (holding b) (holding c)**
- **(on a b) (on a c) (on b a) (on b c) (on c a) (on c b)**

- **Typed constants:**
  - **block a, b, c**
- **Typed predicates:**
  - **(on-table ?b); (clear ?b)**
  - **(arm-empty); (holding ?b)**
  - **(on ?b1 ?b2)**

No. of state variables =16

No. of states = 2^{16}

No. of reachable states = ?

Planning Input: Actions

- **pickup a b, pickup a c, …**
- **place a b, place a c, …**
- **pickup-table a, pickup-table b, …**
- **place-table a, place-table b, …**

- **pickup ?b1 ?b2**
- **place ?b1 ?b2**
- **pickup-table ?b**
- **place-table ?b**

Total: 6 + 6 + 3 + 3 = 18 "ground" actions

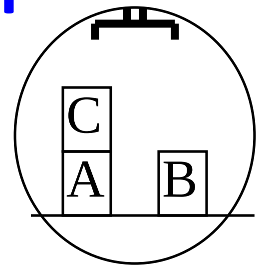
Total: 4 action schemata

Planning Input: Actions (contd)

- **:action pickup ?b1 ?b2**
  :precondition
  (on ?b1 ?b2)
  (clear ?b1)
  (arm-empty)
  :effect
  (holding ?b1)
  (not (on ?b1 ?b2))
  (clear ?b2)
  (not (arm-empty))

- **:action pickup-table ?b**
  :precondition
  (on-table ?b)
  (clear ?b)
  (arm-empty)
  :effect
  (holding ?b)
  (not (on-table ?b))
  (not (arm-empty))

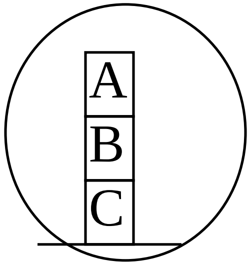
Planning Input: Initial State



- **(on-table a) (on-table b)**
- **(arm-empty)**
- **(clear c) (clear b)**
- **(on c a)**

- **All other propositions false**
  - **not mentioned → false**

Planning Input: Goal



- **(on-table c) AND (on b c) AND (on a b)**
- **Is this a state?**
- **In planning a goal is a set of states**

Planning Input Representation

- Description of world states
- Description of initial state of world
  - Set of propositions
- Description of goal: i.e. set of worlds
  - E.g., Logical conjunction
  - Any world satisfying conjunction is a goal
- Description of available actions

Classical Planning

- Simplifying assumptions
  - Atomic time
  - Agent is omniscient (no sensing necessary).
  - Agent is sole cause of change
  - Actions have deterministic effects

- STRIPS representation
  - World = set of true propositions (conjunction)
  - Actions:
    - Precondition: (conjunction of *positive* literals, no functions)
    - Effects (conjunction of literals, no functions)
  - Goal = conjunction of *positive* literals (e.g., Rich ^ Famous)

Planning vs. General Search

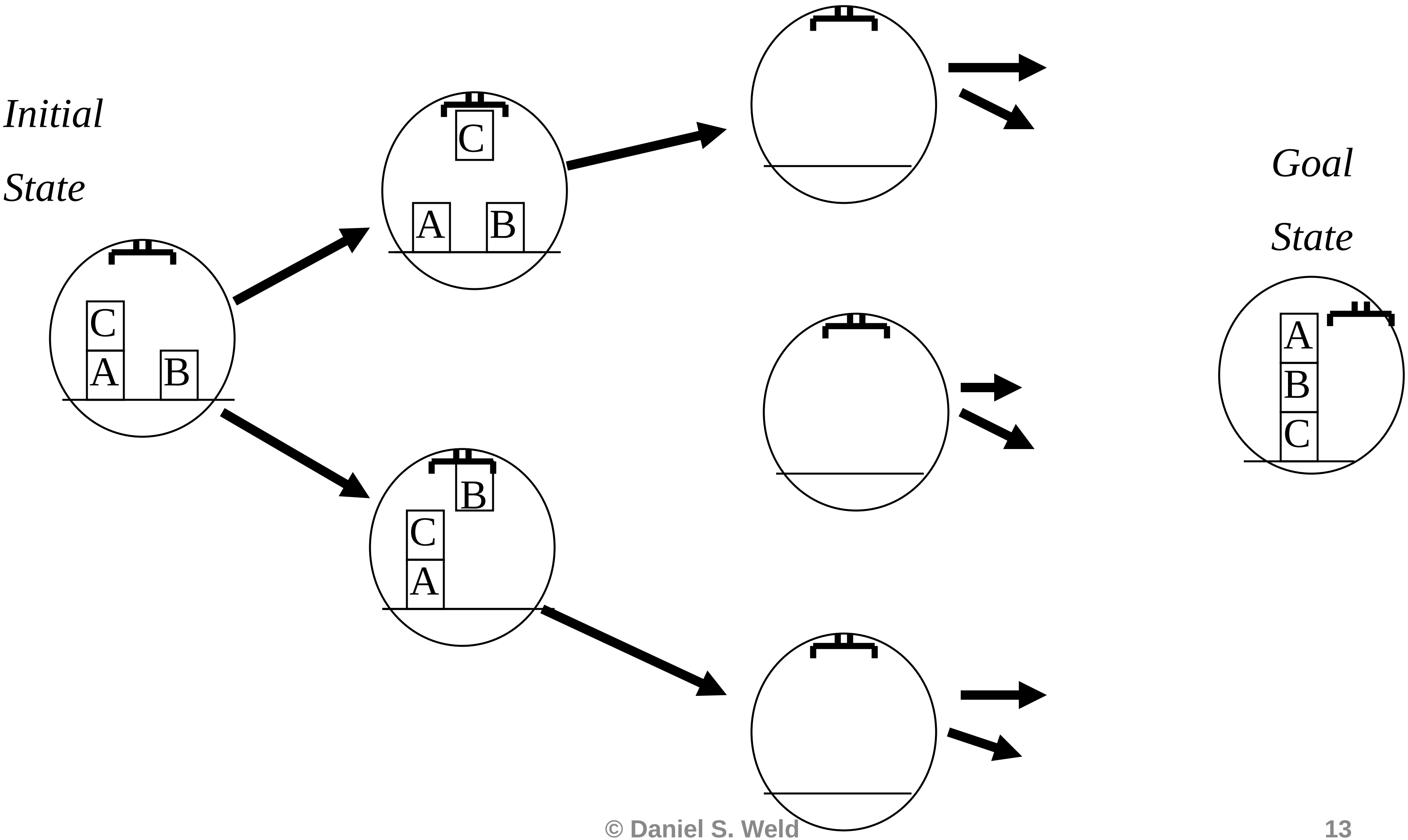
Basic difference: **Explicit, logic-based representation**

- States/Situations: descriptions of the world by logical formulae
  → agent can explicitly reason about and communicate with the world.
- Operators/Actions: Axioms or transformation on formulae in a logical form
  → agent can gain information about the effects of actions by inspecting the operators.
- Goal conditions as logical formulae vs. goal test (black box)
  → agent can reflect on its goals.

Planning as Search

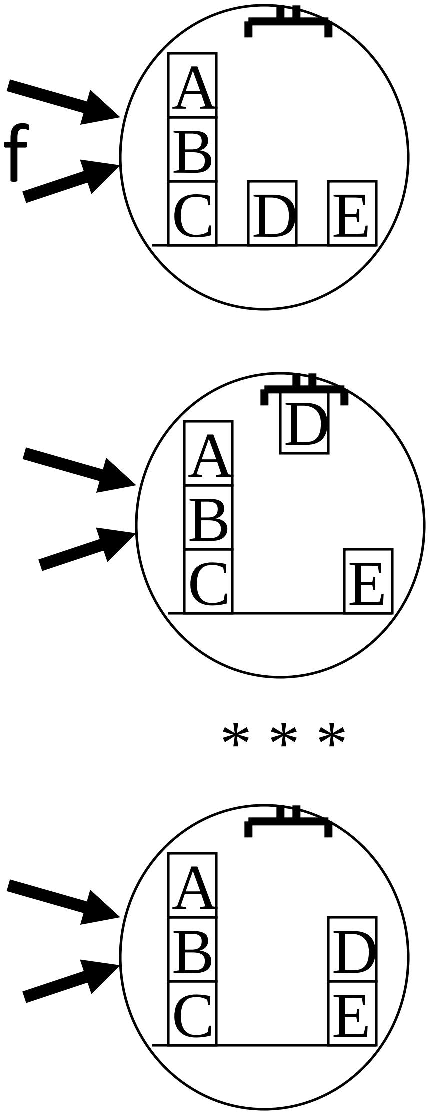
- Forward Search in ? Space
  - World State Space
  - start from start state; look for a state with goal property
    - dfs/bfs
    - A*
- Backward Search in ? Space
  - Subgoal Space
  - start from goal conjunction; look for subgoal that holds in initial state
    - dfs/bfs/A*
- Local Search in ? Space
  - Plan Space

Forward World-Space Search

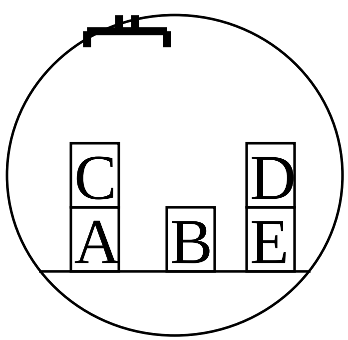


Backward Subgoal-Space Search

- Regression planning
- Problem: Need to find predecessors of state
- Problem: Many possible goal states are equally acceptable.
- From which one does one search?

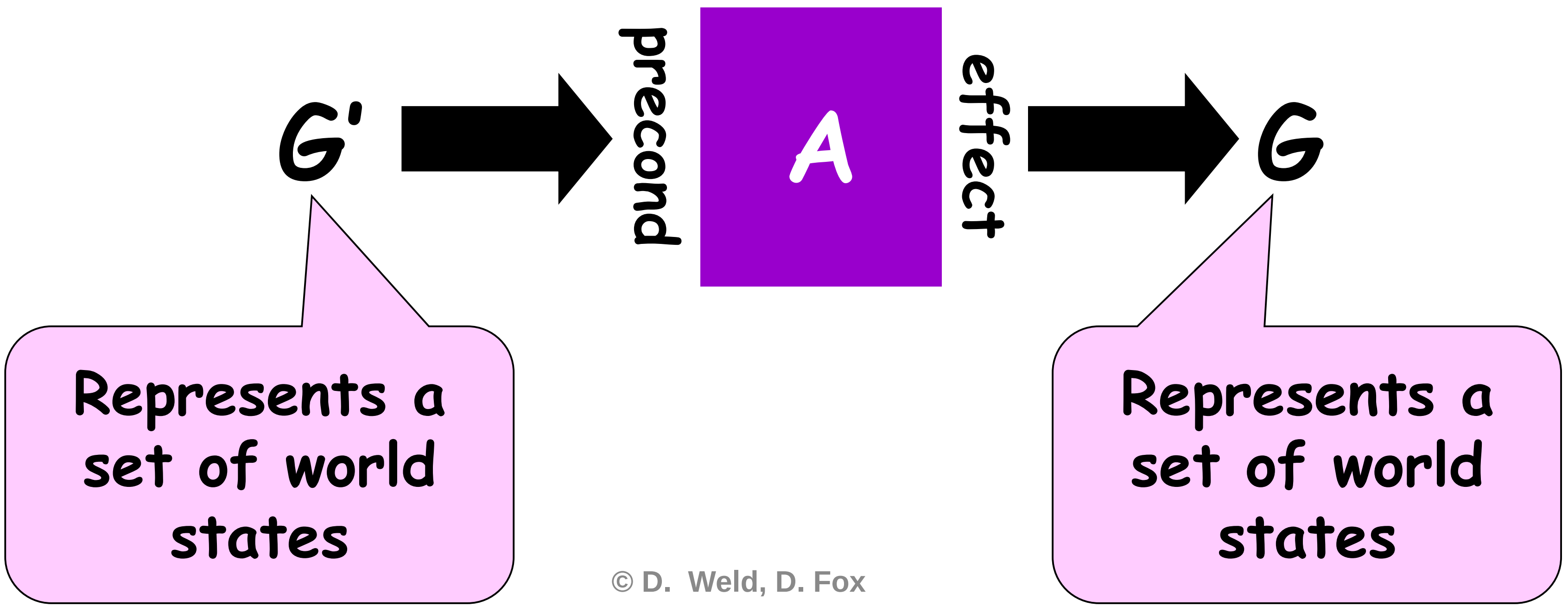


Initial State is completely defined

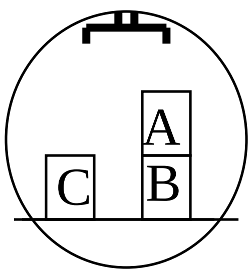


Regression

- Regressing a goal, G, thru an action, A yields the weakest precondition G'
  - Such that: if G' is true before A is executed
  - G is guaranteed to be true afterwards

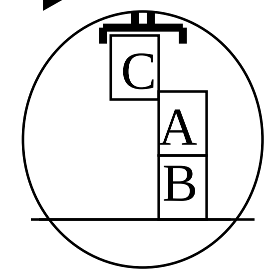


Regression Example



(and (clear C)
(on-table C)
(arm-empty)
(on A B))

- :action pickup-table ?b
  :precondition
  (on-table ?b)
  (clear ?b)
  (arm-empty)
  :effect
  (holding ?b)
  (not (on-table ?b))
  (not (arm-empty))



(and (holding C)
(on A B))

Remove positive effects
Add preconditions for A

Complexity of Planning

- Size of Search Space
  - Forward: size of world state space
  - Backward: size of subsets of partial state space!

- Size of World state space
  - exponential in problem representation

- What to do?
  - Informative heuristic that can be computed in polynomial time!

Heuristics for State-Space Search

- Count number of false goal propositions in current state

  Admissible?

  NO

- Subgoal independence assumption:
  – Cost of solving conjunction is sum of cost of solving each subgoal independently
  – Optimistic: ignores negative interactions
  – Pessimistic: ignores redundancy

  – Admissible? No

Heuristics for State Space Search (contd)

- Delete all preconditions from actions, solve easy relaxed problem, use length

  Admissible?

  YES

- Delete negative effects from actions, solve easier relaxed problem, use length

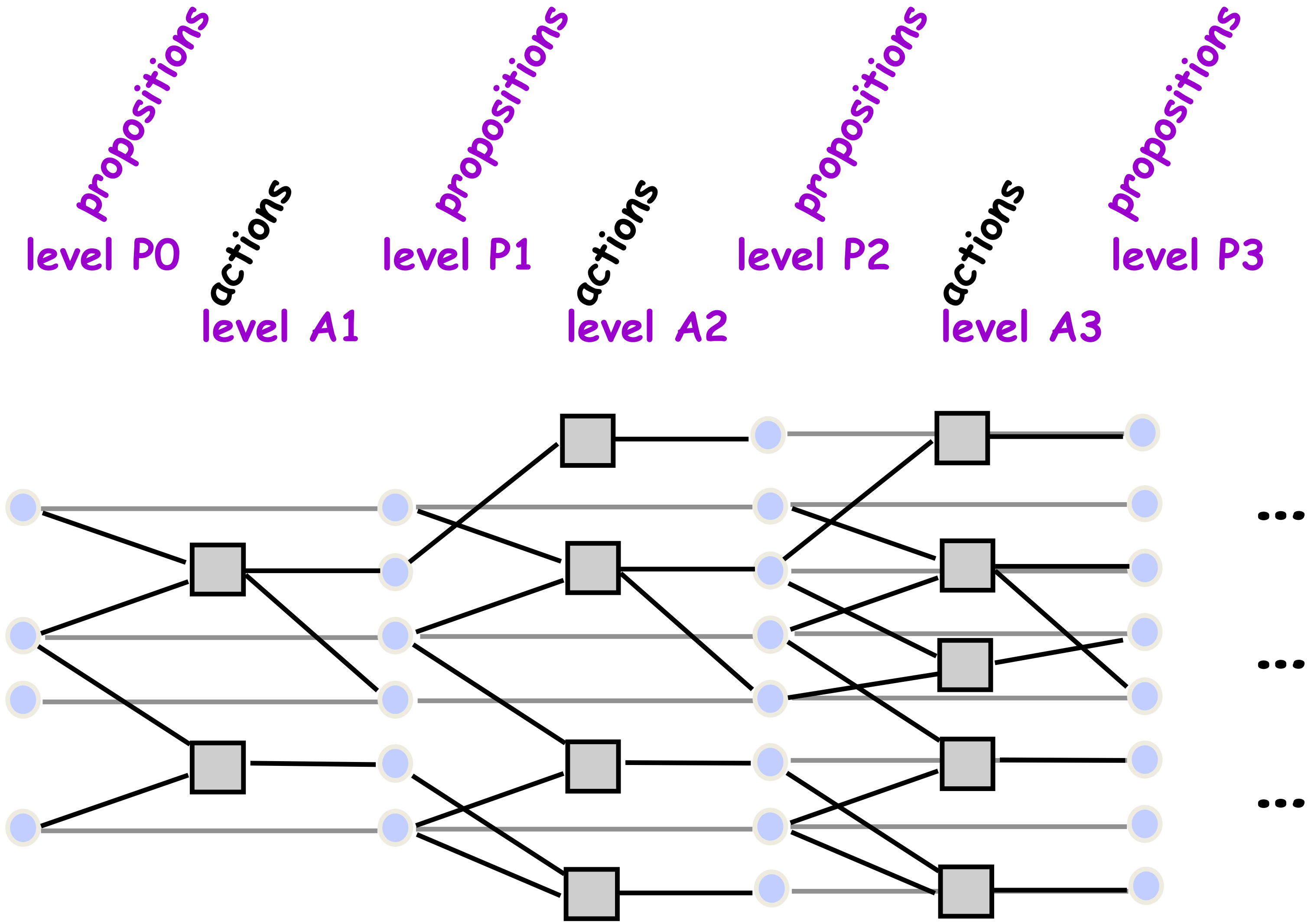
  Admissible?

  YES (if Goal has only positive literals, true in STRIPS)

Planning Graph: Basic idea

- Construct a planning graph: encodes constraints on possible plans
- Use this planning graph to compute an informative heuristic (Forward A*)
- Planning graph can be built for each problem in polynomial time

The Planning Graph



Note: a few noops missing for clarity

Graph Expansion

Proposition level 0

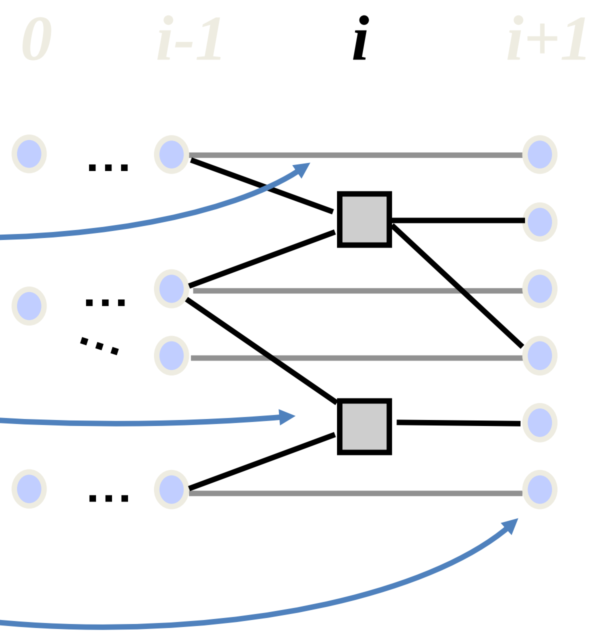
- initial conditions

Action level i

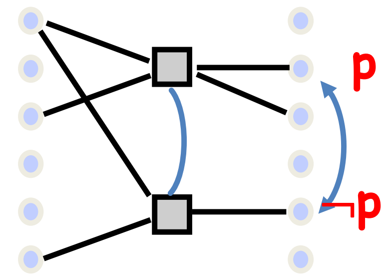
- no-op for each proposition at level i-1
- action for each operator instance whose
  - preconditions exist at level i-1

Proposition level i

- effects of each no-op and action at level i

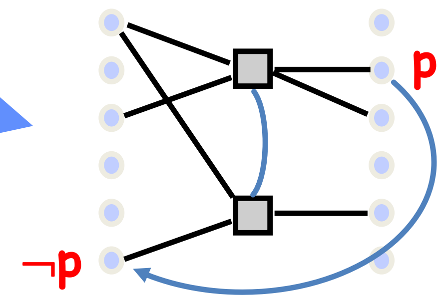


Mutual Exclusion



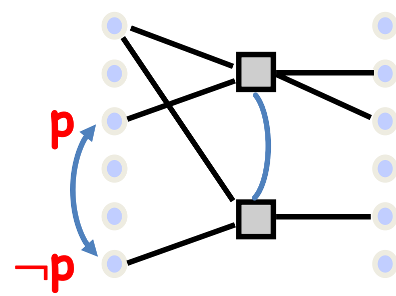
Two actions are mutex if

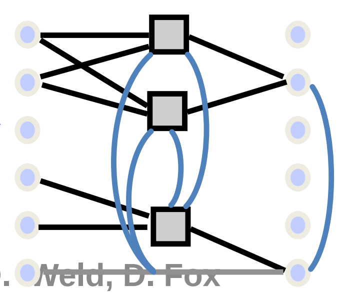
- **one clobbers the other's effects or preconditions**
- **they have mutex preconditions**



Two proposition are mutex if

- **one is the negation of the other**
- **all ways of achieving them are mutex**





Dinner Date

Initial Conditions: (:and (cleanHands) (quiet))

Goal: (:and (noGarbage) (dinner) (present))

Actions:

(:operator **carry** :*precondition*
:*effect* (:and (noGarbage) (:not (cleanHands)))
(:operator **dolly** :*precondition*
:*effect* (:and (noGarbage) (:not (quiet)))
(:operator **cook** :*precondition* (cleanHands)
:*effect* (dinner))
(:operator **wrap** :*precondition* (quiet)
:*effect* (present))

Planning Graph

noGarb

carry

cleanH   cleanH

dolly

quiet   quiet

cook

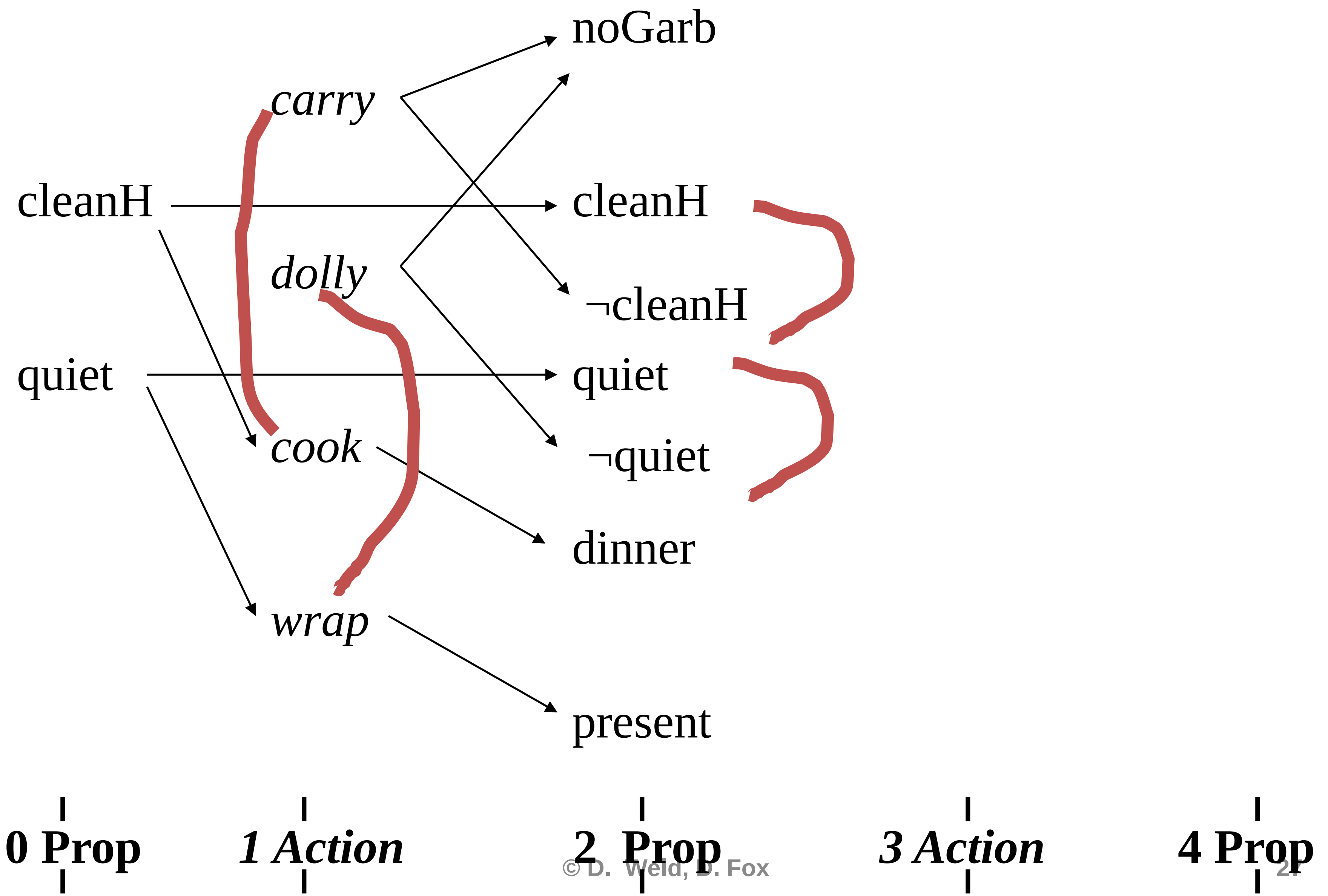
dinner

wrap

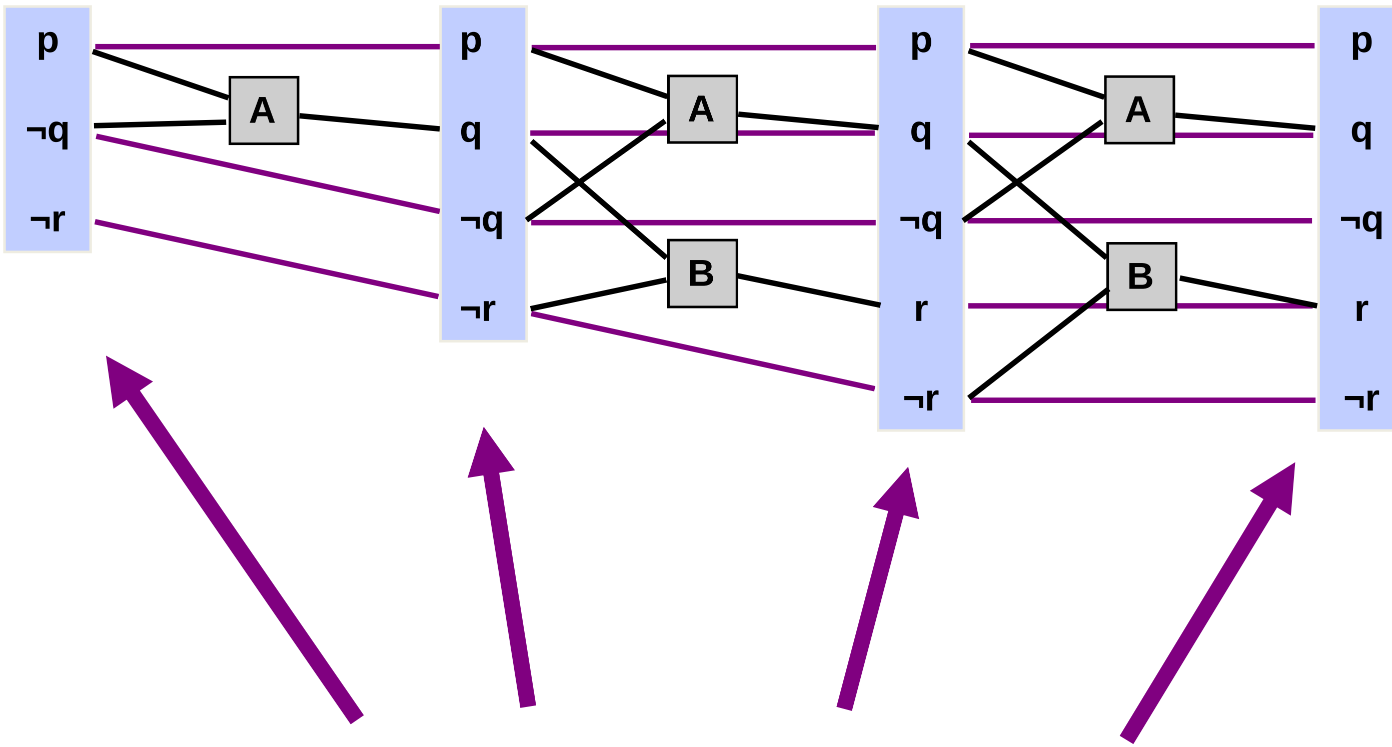
present

0 Prop | ***1 Action*** | **2 Prop** | ***3 Action*** | **4 Prop**

Are there any exclusions?



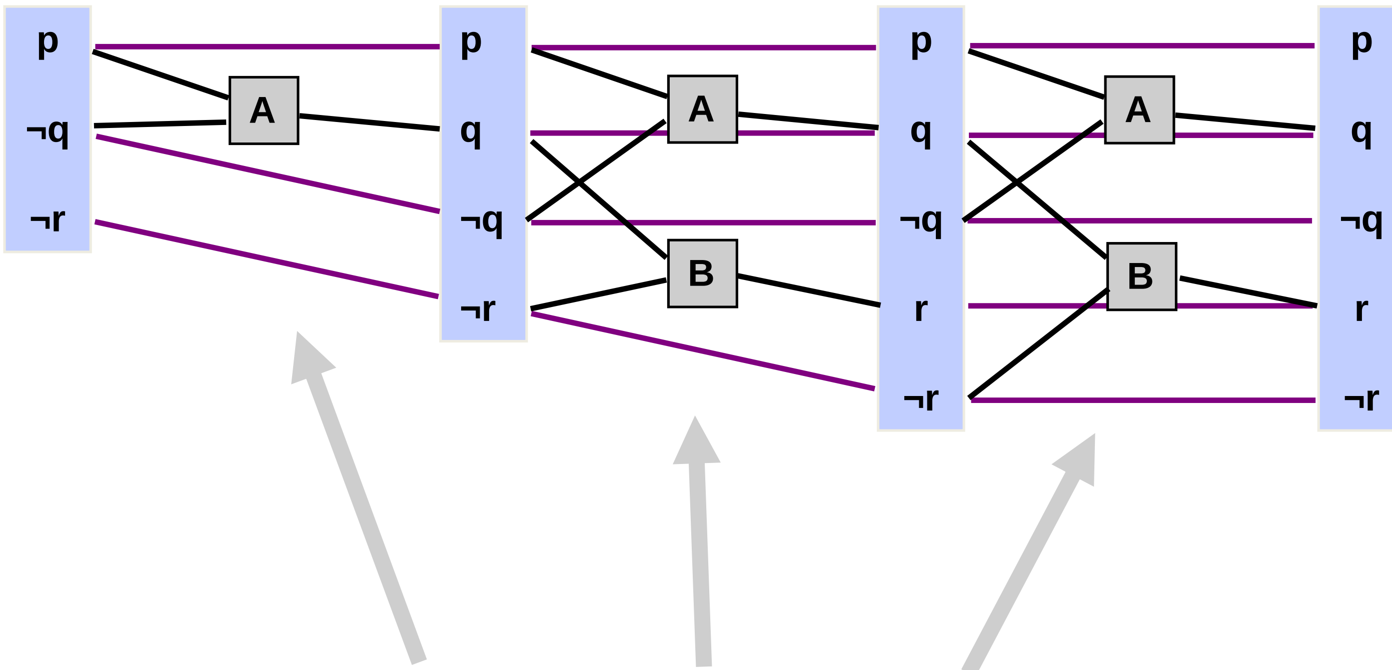
Observation 1



Propositions monotonically increase

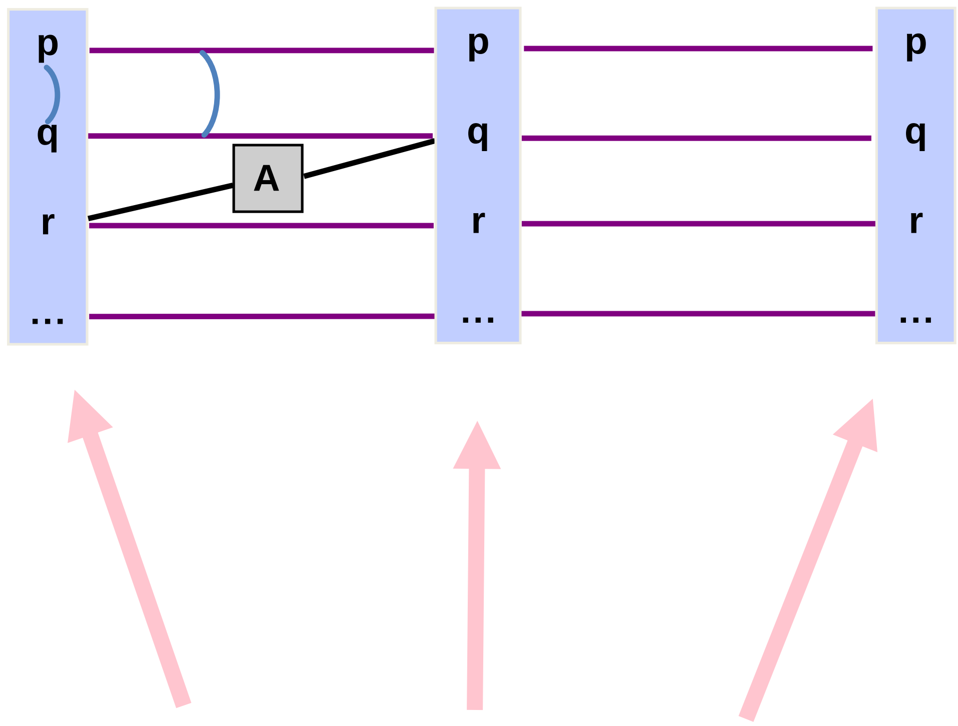
(always carried forward by no-ops)

Observation 2



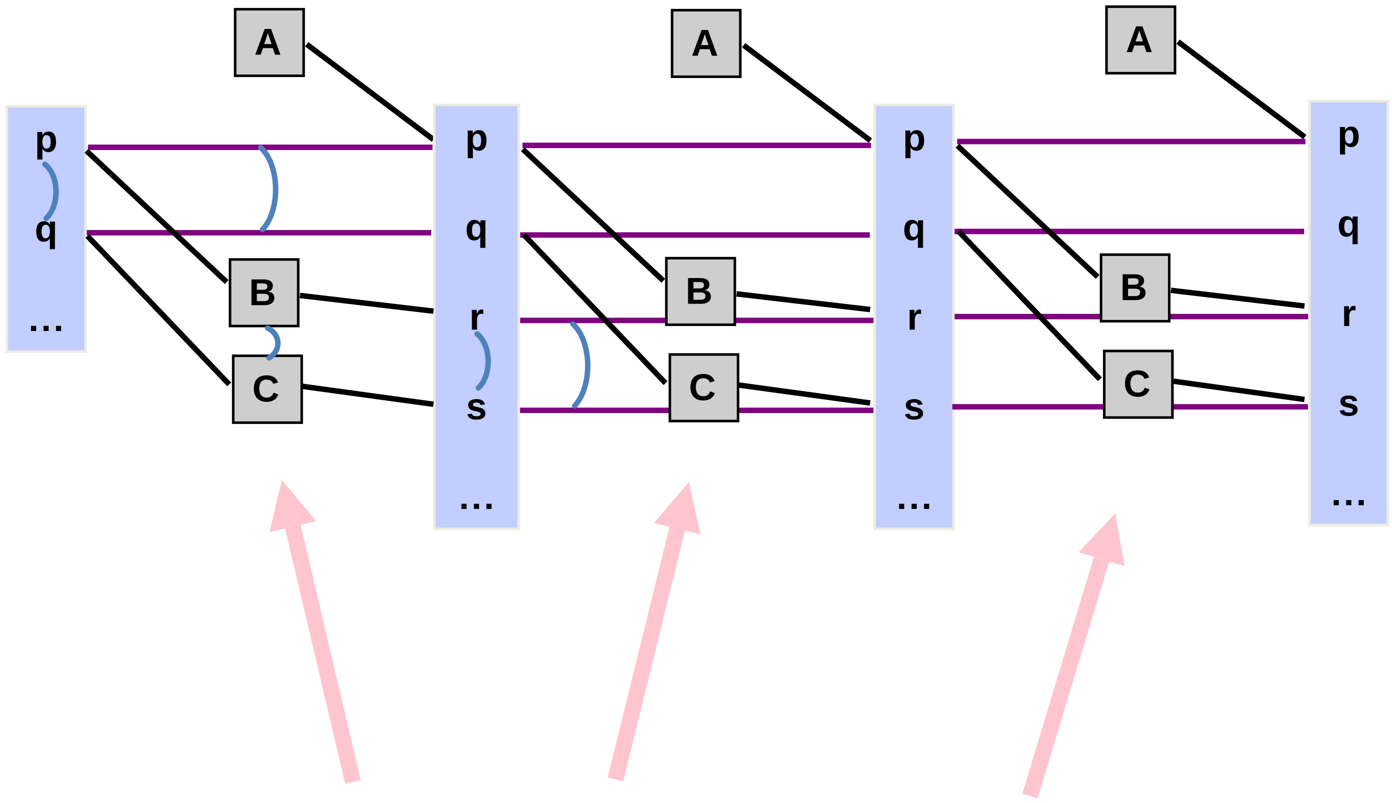
Actions monotonically increase

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.

Properties of Planning Graph

- If goal is absent from last level
  – Goal cannot be achieved!
- If there exists a path to goal
  – Goal is present in the last level
- If goal is present in last level
  – There may not exist any path still

Heuristics based on Planning Graph

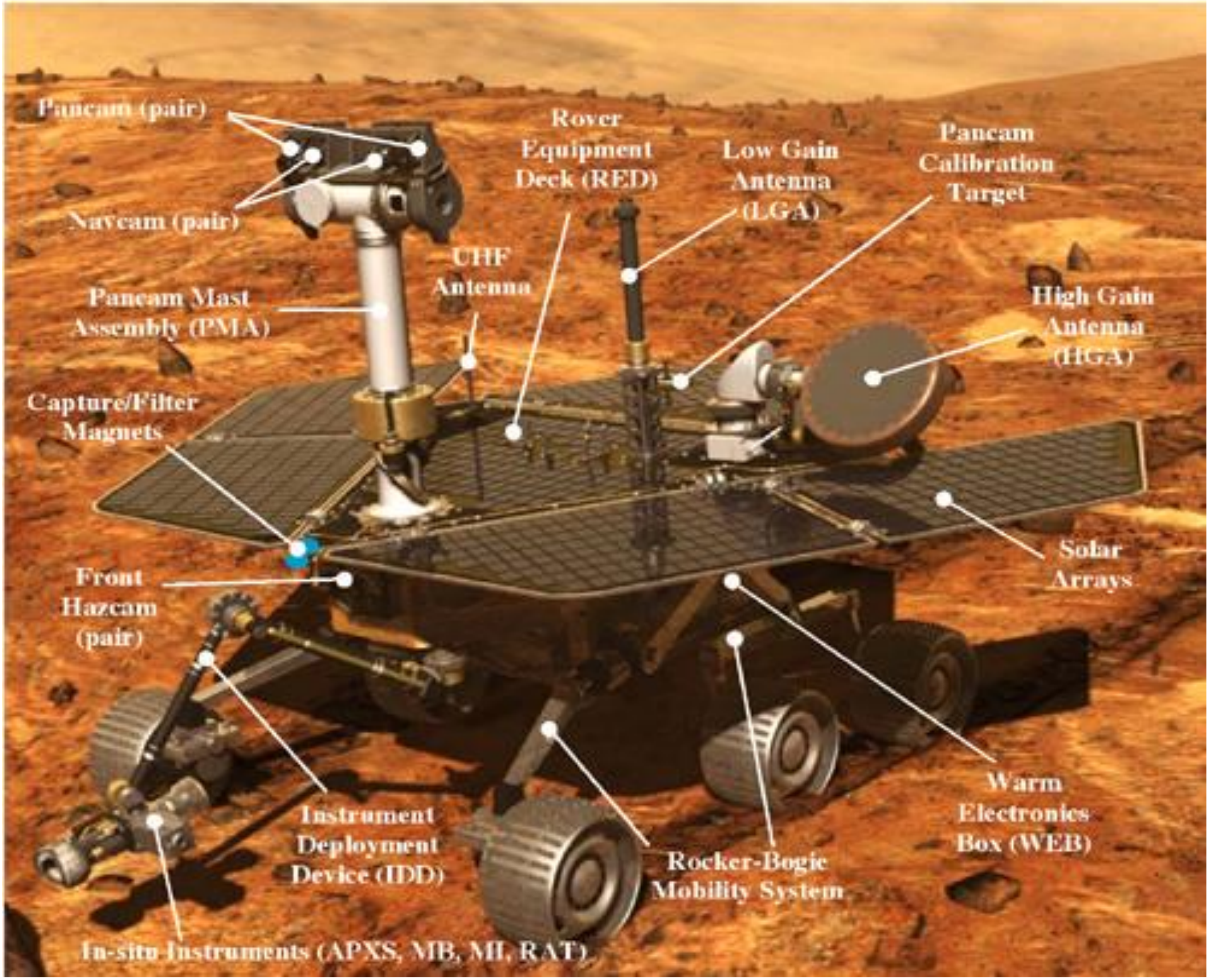
- Construct planning graph starting from s
- h(s) = level at which goal appears non-mutex
  - Admissible?
  - YES

- Relaxed Planning Graph Heuristic
  - Remove negative preconditions build plan. graph
  - Use heuristic as above
  - Admissible? YES
  - More informative? NO
  - Speed: FASTER

FF

- Topmost classical planner until 2009
- State space local search
  - Guided by relaxed planning graph
  - Full bfs to escape plateaus – enforced hill climbing
  - A few other bells and whistles…

Application: Mars Rover



Application: Network Security Analysis

Planning Summary

- Problem solving algorithms that operate on explicit propositional representations of states and actions.
- Make use of specific heuristics.
- STRIPS: restrictive propositional language
- State-space search: forward (progression) / backward (regression) search
- Local search FF

- Local search using compilation into SAT
- Partial order planners search space of plans from goal to start, adding actions to achieve goals (did not cover)