1 handout: slides
730W blog entries were due
Planning Heuristics
The ‘Planning Graph’

2 types of layers: fact and action
track both positive and negative grounded literals
‘no-op’ frame actions

actions $a$ and $b$ mutex iff:

- **inconsistency**: $a$ deletes add of $b$
- **interference**: $a$ deletes precondition of $b$
- **competing needs**: inconsistent preconditions

literals $a$ and $b$ mutex iff:

- **inconsistent**: $a$ is $\neg b$
- **inconsistent support**: all ways of achieving them are mutex
Initial: Have(Cake)

**Eat:** Pre: Have(Cake)  
Post: ¬ Have(Cake), Eaten(Cake)

**Bake:** Pre: ¬ Have(Cake)  
Post: Have(Cake)

Goal: Have(Cake), Eaten(Cake)
Relaxed Plan

$H_1$ max too small, sum too large

Basic graph assumes parallelism: serial planning graph

building a plan:

- choose no-op when possible
- re-use previously chosen action when possible

optimal relaxed plan is admissible but NP-hard

need actions if optimizing costs (not makespan)
1. 0
2. number of unachieved goals
3. $H_1$ max
4. $H_1$ sum
5. planning graph max
6. planning graph sum
7. relaxed plan
Regression
We deliberate not about ends, but about means. For a doctor does not deliberate whether he shall heal, nor an orator whether he shall persuade, nor a statesman whether he shall produce law and order, nor does any one else deliberate about his end. They assume the end and consider how and by what means it is attained, and if it seems easily and best produced hereby; while if it is achieved by one means only they consider how it will be achieved by this and by what means this will be achieved, till they come to the first cause, which in the order of discovery is last... and what is last in the order of analysis seems to be first in the order of becoming. And if we come on an impossibility, we give up the search, for example, if we need money and this cannot be got; but if a thing appears possible we try to do it.

— Aristotle, *Nicomachean Ethics*
Note that STRIPS has full initial state, partial goal state (= set). Search over sets of states!

**Initial node:** set of states in which goal is true

**Applicable:** at least one effect present, deletes not present, non-deleted preconditions present

**Child node:** remove adds, add preconditions

**Goal node:** subset of initial state

Doesn’t assume reversible actions

Lower branching factor

Larger space ($3^n$ vs $2^n$)
Comparison

Forward: states
- + state known: strong heuristic, expressivity
- - branching factor
- - irrelevant states

Backward: sets of states
- + relevant states
- - partial states: larger space, weaker heuristic, expressivity
asst 3 milestone
final projects: must see me before turning in
office hours
Partial-order Planning
Initial node: empty plan
Branch on all achievers of selected precondition
Branch on all threat resolutions
Goal node: plan without open preconditions
Principle of least commitment

**plan**: bindings, temporal links, causal links

**complete**: every precondition achieved, all vars instantiated

**consistent**: no temporal or binding contradictions

**threat**: potential clobber

**refinement** = adding actions and links
initialize plan to empty loop

- **pick** unachieved precondition
- **find** or **add** action to establish it
  - if no such, backtrack
- add causal and temporal link for every threat
  - put threat before achiever **or** after dependent
  - if inconsistent, backtrack
- for possible threats
  - add inequality constraint
For each new effect and each causal link check if effect unifies with \( \neg \) (condition of link)

For each new causal link and each step check if effect of step unifies with \( \neg \) (condition of link)

- refinement = adding actions and links
- achieve, establish, produce
- promote, demote, protect
- inequality, separation, non-codesignation
Principles

- **Causal links**
  - Limits search to relevant actions
  - Easy plan modification and explanation

- **Least commitment**
  - Flexibility in choosing what to branch on
  - Limits backtracking
  - Smaller search space
  - Allows more pruning of implicit plans
  - Hard to find a good heuristic
Comparison

Heuristics

Regression

POP
- POP
- Search
- Main Loop
- Finding Threats
- Principles

Comparison

Beyond STRIPS

forward: states

+ state known: strong heuristic, expressivity

- branching factor

- irrelevant states

backward: sets of states

+ relevant states

- partial states: larger space, weaker heuristic, expressivity

Partial-order: plans

+ small space

+/− least commitment

- poor heuristics
Beyond STRIPS

Heuristics
Regression
POP

Beyond STRIPS
- Comparison
- Extensions
- Setting
- EOLQs

Beyond STRIPS
Forward: states

- + state known: strong heuristic, expressivity
- - branching factor
- - irrelevant states

Backward: sets of states

- + relevant states
- - partial states: larger space, weaker heuristic, expressivity

Partial-order: plans

- + small space
- +/- least commitment
- - poor heuristics
negated goals: no problem with CWA

disjunctive precondition: for regression, just branch

conditional effects: for regression, if we need the effect, plan for the condition

universal preconditions and effects: just ground goals and preconditions
STRIPS assumes static, deterministic world, discrete time, single discrete actions.

1. time, resources
2. concurrent actions
3. abstraction: hierarchical planning
4. uncertainty: eg, disjunctive effects
5. execution monitoring, replanning
6. continuous state
7. multiple (self-interested) agents
What question didn’t you get to ask today?

What’s still confusing?

What would you like to hear more about?

Please write down your most pressing question about AI and put it in the box on your way out.

Thanks!