

CS 730/730W/830: Intro AI

Heuristics

Regression

POP

Beyond STRIPS

1 handout: slides
730W blog entries were due

Heuristics

- Planning Graphs
- Cake World
- Relaxed Plan
- Heuristics

Regression

POP

Beyond STRIPS

Planning Heuristics

The 'Planning Graph'

Heuristics

■ Planning Graphs

■ Cake World

■ Relaxed Plan

■ Heuristics

Regression

POP

Beyond STRIPS

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

Cake World

Heuristics

■ Planning Graphs

■ **Cake World**

■ Relaxed Plan

■ Heuristics

Regression

POP

Beyond STRIPS

Initial: Have(Cake)

Eat: Pre: Have(Cake)

Post: \neg Have(Cake), Eaten(Cake)

Bake: Pre: \neg Have(Cake)

Post: Have(Cake)

Goal: Have(Cake), Eaten(Cake)

Relaxed Plan

Heuristics

■ Planning Graphs

■ Cake World

■ Relaxed Plan

■ Heuristics

Regression

POP

Beyond STRIPS

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)

Heuristics

Heuristics

■ Planning Graphs

■ Cake World

■ Relaxed Plan

■ Heuristics

Regression

POP

Beyond STRIPS

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

Heuristics

Regression

- Aristotle
- Regression
- Comparison
- Break

POP

Beyond STRIPS

Regression

Aristotle's Means-ends Analysis

Heuristics

Regression

■ Aristotle

■ Regression

■ Comparison

■ Break

POP

Beyond STRIPS

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*

Regression

Heuristics

Regression

■ Aristotle

■ Regression

■ Comparison

■ Break

POP

Beyond STRIPS

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

Heuristics

Regression

- Aristotle
- Regression

■ Comparison

- Break

POP

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

Break

Heuristics

Regression

■ Aristotle

■ Regression

■ Comparison

■ Break

POP

Beyond STRIPS

- asst 3 milestone
- final projects: must see me before turning in
- office hours

Heuristics

Regression

POP

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

Beyond STRIPS

Partial-order Planning

Partial-order Planning

Heuristics

Regression

POP

■ POP

■ Search

■ Main Loop

■ Finding Threats

■ Principles

■ Comparison

Beyond STRIPS

Initial node: empty plan

Branch on all achievers of selected precondition

Branch on all threat resolutions

Goal node: plan without open preconditions

Searching Plan-space

Heuristics

Regression

POP

■ POP

■ Search

■ Main Loop

■ Finding Threats

■ Principles

■ Comparison

Beyond STRIPS

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

Partial-order Planning

Heuristics

Regression

POP

■ POP

■ Search

■ Main Loop

■ Finding Threats

■ Principles

■ Comparison

Beyond STRIPS

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

Finding Threats

Heuristics

Regression

POP

■ POP

■ Search

■ Main Loop

■ Finding Threats

■ Principles

■ Comparison

Beyond STRIPS

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

Heuristics

Regression

POP

■ POP

■ Search

■ Main Loop

■ Finding Threats

■ Principles

■ Comparison

Beyond STRIPS

- 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

Heuristics

Regression

POP

Beyond STRIPS

- Comparison
- Extensions
- Setting
- EOLQs

Beyond STRIPS

Comparison

Heuristics

Regression

POP

Beyond STRIPS

■ Comparison

■ Extensions

■ Setting

■ EOLQs

Forward: states

- + state known: strong heuristic, expressivity
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Partial-order: plans

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STRIPS Extensions

Heuristics

Regression

POP

Beyond STRIPS

■ Comparison

■ Extensions

■ Setting

■ EOLQs

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

Heuristics

Regression

POP

Beyond STRIPS

■ Comparison

■ Extensions

■ **Setting**

■ EOLQs

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

Heuristics

Regression

POP

Beyond STRIPS

■ Comparison

■ Extensions

■ Setting

■ EOLQs

- 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!