Reachability Heuristics for Handling State Uncertainty

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[ICAPS 2004; AAAI 2005; UAI 2005]
Belief Space Search

- Partially known initial state
- Actions with non-deterministic effects
- Need to search in Belief Space
  - Belief States are sets of world states ($2^S$)
    - Represented as formulas over fluents (implemented as BDDs)

Acute need for effective search control
Using Multiple Graphs

- Same-world Mutexes
- Memory Intensive
- Heuristic Computation Can be costly

Unioning these graphs a priori would give much savings …
Using a Single, Labeled Graph

Labels signify possible worlds under which a literal holds

Action Labels: Conjunction of Labels of Supporting Literals

Literal Labels: Disjunction of Labels of Supporting Actions

Label Key:
- True
- $\neg Q \& \neg R$
- $\neg P \& \neg R$
- $\neg P \& \neg R$
- $\neg P \& \neg Q$

Heuristic Value = 5

- Memory Efficient
- Cheap Heuristics
- Scalable
- Extensible

Benefits from BDD’s
Relaxed Plan on Labeled Graph

The gray subgraph is the relaxed plan supporting \( G \)

Notice that two actions \( A_4 \) and \( A_5 \) are needed to Support \( G \)

Literal Labels: Disjunction of Labels Of Supporting Actions

Heuristic Value = 5

Label Key:
- True
- \(~Q \& ~R\)
- \(~P \& ~R\)
- \(~P \& ~Q\)
State Agnostic Graphs

- Labelled graphs handle "state uncertainty" using labels on the PG elements
- But the same idea can be used to handle "search uncertainty"
  - We can compute a labelled graph that gives us reachability information from any set of states— including the set of all reachable states
- Such state agnostic graphs do "all pairs shortest path" analysis (as against single source shortest path analysis done by normal PG).
Empirical Evaluation

Figure 3: Reachable-SAG (using SLUG) vs. PG (using $PG_{LUG}$), Belief-Space Problems

Conformant

Figure 5: Comparison of planners on conformant (left) and conditional (right) domains. Four domains appear in each plot. The conformant domains are Rovers(Rv1-Rv6), Logistics(L1-L5), Cube Center(C5-C13), and Ring(R2-R10). The conditional domains are Rovers(Rv1-Rv6), Logistics(L1-L5), Medical(M2-M14), and BTCS(B10-B80).
- PG Variations
  - Serial
  - Parallel
  - Temporal
  - Labelled
  - State Agnostic

- Propagation Methods
  - Level
  - Mutex
  - Cost
  - Label

Versatility of PG Heuristics

- Planning Problems
  - Classical
  - Resource/Temporal
  - Conformant/Conditional
  - Partial Satisfaction

- Planners
  - Regression
  - Progression
  - Partial Order
  - Graphplan-style