Subgoal Ordering and Granularity Control for Incremental Planning

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Outline

- Introduction
- Approach
  - Incremental planning by subgoals
- Issues addressed
  - Initial ordering of subgoals
  - Recovery from failed subgoals in basic planners
  - Granularity control
  - Trade-offs between solution quality and search time
- Demonstration of improvements over basic planners
- Conclusions

Motivations

- In planning under uncertainty in dynamic domains, a planner needs to
  - React to new uncertain events
  - Maintain valid prefixes of short-term goals that have been achieved
- Decompose a large planning problem into a sequence of smaller subproblems
  - Much easier to satisfy a subset of requirements
  - Important to maintain high solution quality

Problems Addressed

- Solve planning problems in STRIPS representation
  - P = (F, O, I, G):
    - F: set of facts
    - O: set of operators
    - I: set of facts in the initial state
    - G: set of facts in the goal state
  - Generate a sequence of actions from I to G
- Goals
  - Solve more instances than existing (basic) planners
  - Improve run time and quality

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Incremental Planning by Subgoals

- Solve a planning problem in a multi-step fashion
  - Decompose goal facts into several subproblems
  - Achieve in each step all the goal facts in this and previous stages
- Issues
  - Order and group goal facts for best performance
  - Integrate with basic planner

Diagram: Incremental Planning by Subgoals

Diagram: Incremental Planning by Subgoals
Assumptions

- Achieve a set of goal facts in each stage with
  - Ordering constraints among subgoals
  - Durative actions (in addition to duration of one)
- But without
  - General state trajectory constraints such as deadlines
  - Optimization metric

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Initial Ordering of Subgoals

- Crucial for runtime efficiency and solution quality
  - For an order that causes no subgoal invalidations
    - A small number of new subgoals solved in each step
  - For an order that causes subgoal invalidations
    - Extra actions and search time to re-achieve invalidated subgoals
    - Backtracking to a different order if the order leads to an infeasible plan
- Evaluation metric
  - Number of invalidations

Previous Reasonable-Ordering Algorithm

- Detect partial order between subgoals $i$ and $j$ (Koehler'00)
  - Order $i$ after $j$ if any plan that reaches $j$ must invalidate $i$
- Resolve loops and unordered pairs to produce a total ordering
  - May group all subgoals involved in unresolved partial-order relations together
- Deficiencies of reasonable ordering
  - Only analyze subgoal interactions without considering initial state
  - Invariant order for any initial state is rare in practice
  - Little ordering information found in IPC-4 domains
    - Some partial orders in 42 out of 50 instances in Airport, 42 out of 100 instances in Pipesworld, and none in the other domains

Proposed Relaxed-Plan Ordering

- Use the order of subgoals achieved in relaxed plan
  - Consider the initial state of relaxed plan
  - Use the original order for subgoals at the same level
  - Total ordering
  - Little overhead since relaxed plans are widely used for guidance in planning
- Detect a superset of partial-order information than reasonable ordering
  - Relaxed-plan ordering is specific to the initial state and the current planning graph
  - Reasonable ordering is independent of initial state and is stronger
- No constraints on grain size

Relaxed-Plan Ordering Algorithm

1. procedure Relaxed-Plan-Ordering ($P = (F, O, I, G)$)
2. construct planning graph $G$ from $I$ to $G$ without computing mutual exclusions;
3. extract a relaxed plan from $G$;
4. for each pair of subgoals $g_i$ and $g_j$
5.   set PREC $\leftarrow$ true;
6.   for each action $o$ in $P$ that has $g_j$ as an add effect
7.     if $(o, G \subseteq \text{del}(o))$ and $(\text{pre}(o) \cap \text{F}(g_i) \equiv \emptyset)$
8.       then PREC $\leftarrow$ false;
9. endfor
10. if PREC = true
11. then order $g_j$ before $g_i$;
12. else if $g_j$ is reached before $g_i$ in the relaxed plan
13. then order $g_j$ before $g_i$;
14. else order $g_i$ before $g_j$;
15. endif
16. endprocedure
Comparison of Three Orders

Airport Domain

- Original ordering
- Reasonable ordering
- Relaxed-plan ordering

Comparison of search time (number of actions) and solution quality

- Normalize performance measures with respect to those of non-incremental version
- Also compare with SGPlan

Dynamic Reordering

- Embedded planner may take too long to complete one stage
- Alternative orders may alleviate this problem
- Reorder subgoals to achieve easy ones first
- Estimate difficulty and search-time limit based on the length of the relaxed plan for unsatisfied subgoals
- Invoke dynamic reordering if the number of states evaluated exceeds a threshold

Granularity Control

- Trade-offs between grain size and total time to solve overall problem
- Initially partition all goal facts into ten equal-sized subsets
- Double the grain size if number of states evaluated is less than a predefined threshold (4)
- Additive increases may not find a good grain size quickly
- Insignificant improvements when the number of stages is small

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Experiment Results

- Evaluation of all IPC4 STRIPS domains and some domains with a lot of goal interactions
- 3 basic planners: Metric-FF, YAHSP, LPG-TD-speed
- Comparison of search time (number of actions) and solution quality
  - Normalize performance measures with respect to those of non-incremental version
  - Also compare with SGPlan

Normalized Performance

- Airport Domain
Observations

- Generally solve more instances and use less time than the original planners: Metric-FF, LPG, YAHSP
- Incremental planning benefits the most from domains with little goal interactions
  - Airport domain: impossible to invalidate previously achieved “Take-off” subgoals
  - Produce longer plans on domains when using improper subgoal order
    - Extra actions due to lots of goal invalidations
    - Likely to occur in domains with intensive goal interactions, e.g., Satellite and Logistics
    - Incremental planning with optimal order can improve run time without sacrificing quality

Redundant-Execution Scheme

- Evaluate two alternative subgoal orders
  - First relaxed-plan order and then original order
    - Restrict the total time spent to 30 minutes
    - Significant improvement in quality over the non-incremental version
      - One of the orders may lead to shorter plans
      - Better solution quality even in domains with intensive goal interactions
      - More run time than evaluating one subgoal order but still less than non-incremental version
Conclusions

- Incremental planning framework for any basic planner
- Relaxed-plan ordering to reduce number of invalidations
- Dynamic reordering to avoid dead ends in search
- Dynamic grain size to achieve good performance
- More instances solved and significant reductions on run time when compared with original planner
- Improvements on both solution quality and run time when using a redundant-execution scheme