Research review: Three key historical developments in AI planning and search

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This short overview summarizes three key historical developments in AI planning and search.

1. *Graphplan system*
   The Graphplan system was first introduced by Blum and Furst [Blum and Furst 1997]. This approach to solving planning problems was to first build a "compact structure" known as a "planning graph" which maps all the necessary constraints into a graph structure. This structure then facilitates downstream search. Unlike a state-space graph, a plan is represented like a "flow" in a planning graph. The valid plan is then identified using a "backward-chaining strategy". If all independent actions can occur simultaneously, the Graphplan search algorithm is optimal: the shortest path is guaranteed to be found (even if this path is more difficult than a longer but more natural/methodical one).

   Based on experiments on different planners, Blum and Furst identified four key factors that affect efficiency: (i) mutual exclusion, (ii) consideration of parallel plans, (iii) memoizing, (iv) low-level costs. Collectively, these factors help to minimize the search space for Graphplan, while reducing the number of instantiations required during search.

2. *Exploiting symmetry equivalence*
   Exploiting symmetry in a search problem readily reduces the search phase space. In 1997, Joslin and Roy introduced an algorithm to automatically identify symmetry in search problems, and also then to generate propositional logic encodings from them. In their paper, Joslin and Roy [Joslin and Roy, 1997] implemented their algorithm on constraint satisfaction problems (CSPs) with "lifted" descriptions, which is a more compact description of CSPs than propositional logic.

   A lifted CSP is simplified as "a tuple $\{D, S, L\}$, where D is a finite, colored set of atoms representing the necessary domains, with a distinct 'color' assigned to each type of element, S is a set of ground literals, and L is a restricted first-order theory in which quantification is allowed only over the finite domains". With this representation, the algorithm searches for symmetries in the space of S, rather than over the full propositional theory space, which is much larger and hence less tractable. Then, D is used to map the symmetries from S to the propositional space. The identified symmetries can then be broken by adding constraints to the CSPs.

   There are other symmetry-exploitation methods that are more dynamic, but require coupling to specific search methods, and hence are less general [Joslin and Roy, 1997].

3. Heuristic Search Planner (HSP)
   Unlike Graphplan, HSPs do not require a planning graph to be built prior to search. Instead, planning problems are converted into heuristic search problems automatically, by "extracting heuristics from STRIPS encodings" [Bonet and Geffner, 2001]. (STRIPS is a form of planning representation [Fikes and Nilsson, 1971].)

   Bonet and Geffner discussed two versions of HSP:

(i) Forward state planning: An additive heuristic was used to guide a hill-climbing search, with children of nodes selected to minimize the additive heuristic. However, the hill-climbing planner is not complete, and instead the best-first search approach leads to better performance.

(ii) Heuristic regression planning: A backward search helps to alleviate the bottleneck of "the computation of the heuristic from scratch in every state". Instead, with the initial state, all costs are computed and used in the heuristic without any further updates. These leads to a 6-7 times faster node generation.

References:

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