Summary of Three Developments in AI Planning Research

	STRIPS [1]	GRAPHPLAN [2]	HSP [3]
General Approach	Analysis and transformation of world models	Constructing and analyzing a Planning Graph	Transformation of planning problems into problems of heuristic search
Planning Problem	Finding a sequence of operators that transforms a given initial world model into a model that satisfies the stated goal condition	Finding a shortest-possible, valid partial-order plan that makes all the problem goals true at the final time step	Finding a sequence of actions that generates a state trajectory such that the final state is a goal state, where an optimal solution being the one with minimum total cost
Problem/State Space Representation	(A) Initial world model (a set of first-order predicate calculus formulas) (B) Set of operators, including description of their effects and preconditions (C) Goal condition	(A) Set of operators (B) Set of objects (C) Initial Conditions (set of propositions) (D) Problem Goals (set of propositions required to be true at final time step)	(A) Set of states S (B) Set of actions A (C) State transition function f (D) Cost function c (E) Initial state s_0 (F) Set of goal states S_G
Planning Strategies	Separation between theorem proving (for deciding operator applicability and goal satisfaction within a model, via theorem prover) and search (through the space of world models, via means-ends analysis)	Combination of aspects of total-order planning (in considering an action at a specific point in time) and partial-order planning (in generating partially-ordered plans)	Extraction of heuristic function h for solving problem P by considering a relaxed problem P', by setting h as an approximation of value function h' that estimates the cost of achieving the goal
Planning/Search Structure/Process Representation	Tree, where each node is represented as a tuple of world model and goal list, and generation of each successive	Directed, leveled graph with two kinds of alternating nodes (proposition nodes and action nodes) and three	

	node is based on the determination of sub-goal satisfaction and application of the corresponding operator	kinds of edges (precondition-edges, add-edges, and delete-edges, encoding relations between actions and propositions)	
Search Strategy	Combination of the advantages of both forward search and backward search	Recursive search using backward chaining plus forward checking to make sure that no goal ahead has been cut off due to exclusion relations	* Forward state planning using hill-climbing and best-first heuristics * Regression planning using additive, max, and greedy best-first heuristics
Search Algorithm	(1) Extract differences between the current world model and the goal (2) Identify an operator that can reduce differences (3) Find a world model where the operator can apply (4) If found, apply the operator (5) Reconsider the original goal in the resulting model	(1) At time step t, take Planning Graph at t-1 and expand it one more step (2) Given a set of goals at time t, try to find a set of actions at time t-1 having the goals as effects (3) If the goal set at time t-1 turns out not to be solvable, find a different set of actions (4) Continue until it succeeds or has proven that the set of goals is not solvable at time t	
Mechanisms/Heuristics for Search Space Reduction and Search Efficiency Improvement	Selection of nodes with uncompleted successors to work on next based on heuristic evaluation of (i) number of remaining goals on the goal list, (ii) number and types of predicates in the	* Identification and propagation of mutual exclusion relations among nodes * Memoization of goal sets explored and proven to be unsolvable, used to reduce unnecessary	* Additive heuristic to guide a hill-climbing search * Best-first search heuristic * Additive heuristic and mutex set to guide a regression search

	remaining goal formulas, (iii) complexity of the difference attached to a node	re-visit and search	
Impact	Foundational setting of the definition, representation, and solution approach to planning problems	Casting of planning problems as graph search problems	Re-casting of planning problems as heuristic search problems

References

[1] Fikes, R. E. and Nilsson, N. J. STRIPS: A new approach to the application of theorem proving to problem solving. *Artificial Intelligence* 2 (1971), 189-208.

[2] Blum, A. L. and Furst, M. Fast planning through planning graph analysis. *Artificial Intelligence* 90 (1997), 281–300.

[3] Bonet, B. and Geffner, H. Planning as heuristic search. *Artificial Intelligence* 129 (2001), 5-33.