Means-ends Analysis

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0. Introduction

Means-ends analysis is a problem-solving technique used commonly in Artificial Intelligence (AI) for limiting search space in AI applications. It involves strategies that can reason in both forward and backward directions and is appropriate for solving large, complicated problems. It functions to solve small problems that arise during combination of the parts of the larger problem. It is centered around the evaluation of differences between the current state and the goal state and the reduction of those differences.

An important aspect of intelligence is the ability to find the solution of a problem by finding a sequence of actions that lead to a desirable goal. A solving system is supposed to be connected to its environment by virtue of afferent (inward) sensors and efferent (outward) actions. A MEA system also contains memory storing information about the state of the environment, sensors, and actions.

1. Theoretical Foundations

1.1 Goal Stack Planning

Goal Stack Planning involves organizing goals and subgoals in a hierarchical manner. We start at the goal state and try fulfilling the preconditions required to be satisfied first. We keep solving these goals and sub-goals until we finally arrive at the Initial State. A stack is used to hold these goals and the actions that we need to perform.

Algorithm

1. Push Original Goal on Stack.

2. Repeat following until stack is empty

a. If stack-top is compound goal, push its sub-goals

b. if stack-top is single unsatisfied goal, replace it with action and its preconditions.

c. If stack-top is action, pop and extend knowledge-base with action effects

d. if stack-top is a satisfying goal, pop it from stack.

1.2 Heuristic Guidance

Heuristics in MEA serve as problem-solving strategies that guide the selection and application of means to achieve goals. Heuristics are rules of thumb or guiding principles that expedite the decision-making process, helping to navigate through the solution space more efficiently.

a. Subgoal Ordering

Subgoal ordering involves prioritizing or ordering the resolution of subgoals based on certain criteria. This can include factors such as dependencies between subgoals, the ease of resolution, or the significance of a subgoal in achieving the overall objective.

b. Difference Reduction

Difference reduction focuses on identifying the differences between the current state and the desired goal state. The heuristic strategy involves selecting means that reduce these differences incrementally, guiding the system towards the goal.

c. Means Refinement

Means refinement involves continuously improving and optimizing the selected means during the problem-solving process. This heuristic ensures that the chosen means are not only effective in achieving the subgoals but are refined iteratively to enhance efficiency.

2. Algorithmic Implementation

2.1 Initialization

The algorithm begins with the input of the problem description, including the initial state and the desired goal state.

Create an empty goal stack to present the hierarchy of goals and subgoals. Push the top-level goal into the goal stack.

Initialize the current state to the initial state of the problem.

2.2 Means Identification

At each iteration, pop the top goal from the goal stack.

Identify potential means (actions or subgoals) that can be applied to achieve the current goal.

Apply heuristics, as given in Section 1.2, to guide the selection of most suitable means. Evaluate the effectiveness of each potential means based on the heuristics.

If means refinement is part of the strategy, adjust the chosen means to optimize the solution path.

2.3 Iteration

a. Check if the current state satisfies the goal at the top of the stack. If yes, mark the goal as achieved and proceed to the next iteration.

b. If the goal is not achieved, apply the selected means to transition the system to a new state. Update the current state based on the side effects of the chosen means.

c. If sub-goals were generated in the process, push them onto the goal stack, maintaining the hierarchical structure.

d. Repeat the process from b. until the top level goal is marked as achieved.

The algorithm terminates once the top level goal is achieved. The sequence of means and sub-goals that lead from the initial state to the goal state represent the solution path.

3. Extensions and Enhancements to MEA

3.1 Backward Chaining

Backward chaining is an extension of MEA that reverses the problem-solving direction. Instead of starting with the initial state and progressing toward the goal, backward chaining starts with the goal and works backward to identify the means necessary to achieve it.

Backward chaining is particularly useful in scenarios where the final goal is known, and the challenge lies in determining the prerequisite conditions or subgoals to reach that goal.

3.2 Forward Chaining

In contrast to backward chaining, forward chaining starts with the initial state and progresses toward the goal. It iteratively applies means to achieve subgoals, gradually building toward the top-level goal.

Forward chaining is effective when the initial state is known, and the challenge is to determine the sequence of actions or subgoals that lead to the desired outcome.

3.3 Domain Knowledge

The basic MEA algorithm can be enhanced by incorporating domain-specific knowledge. This involves leveraging information about the problem domain to guide the selection of means and improve the efficiency of problem-solving.

Incorporating domain-specific knowledge enhances the adaptability of MEA by tailoring the problem-solving approach to the intricacies of a particular domain. This is especially valuable when dealing with complex and specialized problem spaces.

4. Applications in Computer Science

In the context of expert systems, MEA is employed as a problem-solving technique that utilizes knowledge-based reasoning. Expert systems are designed to emulate the decision-making capabilities of a human expert in a specific domain.

MEA aids in decision-making by breaking down complex problems within the expert system into subproblems. This hierarchical approach facilitates problem resolution, allowing the system to navigate through the knowledge base and apply MEA iteratively until a solution is reached.

In the domain of automated planning, MEA plays a pivotal role in goal decomposition. High-level goals are decomposed into actionable steps, forming a hierarchical structure that guides the planning process.

MEA facilitates the generation of plans by systematically identifying the means necessary to achieve each subgoal. This process continues iteratively until the entire plan is constructed.

5. Real-life Implementations.

The MEA technique as a problem-solving strategy was first introduced in 1961 by *Allen Newell* and *Herbert A. Simon* in their computer problem-solving program **General Problem Solver (GPS).** In that implementation, the correspondence between differences and actions, also called operators, is provided beforehand as knowledge in the system.

Prodigy, a problem solver developed in a larger learning-assisted automated planning project started at Carnegie Mellon University by *Jaime Carbonell, Steven Minton* and *Craig Knoblock*, is another system that used MEA.