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STUDY NOTES

ARTIFICIAL INTELLIGENCE

Unit V — Planning and Industrial Applications of AI

Topics Covered (09 Hours)

Overview of Classical AI Planning
The Blocks World Domain Model & Predicates
Actions schemas & Components of Planning Systems
Goal Stack Planning (STRIPS Algorithm)
The Sussman Anomaly & Linear Planning Limits
Nonlinear Planning using Constraint Posting (POP)
Hierarchical Planning & Hierarchical Task Networks (HTN)
Industrial Applications of AI (Healthcare, Finance, Retail)
AI in Agriculture, Education, Transportation & Research

Compiled in a simple, easy-to-understand, book style format for students of Computer Science and Engineering

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5.1 Planning: Overview

In previous units, we saw search agents find action paths using state space search, and logic agents derive actions using theorem proving. However, both have drawbacks: search agents treat states as 'black boxes' and cannot easily prioritize subgoals, while logic agents face computational scaling issues. AI Planning solves this by using a factored representation of states and actions. Planning is the process of generating a structured sequence of actions (a plan) to move an agent from an initial state to a goal state.

Planning systems break states down into collections of logical properties (predicates). This allows the planner to understand the relationship between different parts of the world, solving separate parts of a problem independently and then combining them.

5.2 An Example Domain: The Blocks World

The Blocks World is the most famous toy domain in AI planning history. It consists of a set of square blocks resting on a table, and a single robotic arm that can manipulate the blocks. The goal is to stack the blocks in a specific configuration.

Blocks World Predicates (States)

- **On(x, y):** Block x is resting on top of block y.
- **OnTable(x):** Block x is resting directly on the flat table.
- **Clear(x):** There are no blocks resting on top of block x.
- **Holding(x):** The robotic arm is currently grasping block x.
- **ArmEmpty:** The robotic arm is not holding any block.

Blocks World Operators (Actions)

We define four operators to describe the robot's physical movements. Each operator has Preconditions (what must be true to execute the action) and Effects (what changes after execution, split into an Add List of new truths and a Delete List of things that are no longer true).

Action Schema	Preconditions	Effects (Add List)	Effects (Delete List)
Pickup(x)	Clear(x), OnTable(x), ArmEmpty	Holding(x)	Clear(x), OnTable(x), ArmEmpty
Putdown(x)	Holding(x)	Clear(x), OnTable(x), ArmEmpty	Holding(x)
Stack(x, y)	Holding(x), Clear(y)	On(x, y), Clear(x), ArmEmpty	Holding(x), Clear(y)
Unstack(x, y)	On(x, y), Clear(x), ArmEmpty	Holding(x), Clear(y)	On(x, y), Clear(x), ArmEmpty

5.3 The Components of a Planning System

A standard planning system consists of several core components:

- **Planning Language:** A formal syntax (like STRIPS or PDDL - Planning Domain Definition Language) to define states, actions, goals, and transitions.
- **State Database:** Tracks the current world configuration as a conjunction of ground, function-free literals.
- **Search Engine:** The algorithm that navigates the space of states or plans to find a solution.

Planning Search Directions

- **Progression Planning (Forward Search):** Starts at the initial state and applies applicable actions forward to reach the goal state.
- **Regression Planning (Backward Search):** Starts at the goal state and applies actions backward to find a path to the initial state, matching goal schemas.
- **Plan-Space Planning:** Starts with an empty plan and adds actions and ordering constraints directly to resolve flaws in the plan (non-linear planning).

5.4 Goal Stack Planning

Goal Stack Planning is one of the earliest planning algorithms, famously used by the STRIPS planner. It utilizes a stack to hold subgoals and actions. The planner pops the top item from the stack; if it is a subgoal that is not currently satisfied, it pushes the operators that can achieve it onto the stack, along with their preconditions.

Sussman Anomaly

The Sussman Anomaly is a classic problem in the Blocks World that demonstrates the failure of linear planners (like simple Goal Stack Planning).

If we have three blocks arranged as: A on the table, B on the table, and C on top of A. The goal is to stack them in the order: A on B, and B on C.

A linear planner tries to solve one subgoal completely before starting the other. If it stacks A on B first, it must later undo this work (unstack A) to put B on C. If it puts B on C first, it blocks the path to put A on B. This shows that subgoals cannot always be solved independently; they must be interleaved.

5.5 Nonlinear Planning using Constraint Posting

To solve anomalies like Sussman's, modern planners use Nonlinear Planning (also called Partially Ordered Planning). Instead of committing to a strict linear sequence of actions immediately, a partially ordered planner leaves actions unordered unless there is a constraint that forces a specific order. This is known as the Principle of Least Commitment.

Types of Constraints (Constraint Posting)

- **Temporal Ordering Constraints:** Specifies that action A must happen before action B (written as A < B).
- **Binding Constraints:** Specifies variable assignments. For example, x = A (equality) or x != B (inequality).
- **Causal Links:** Indicates that action A achieves a specific precondition for action B. Causal links are used to detect and protect preconditions from being undone by other actions (called threats or demotions).

5.6 Hierarchical Planning

In large, complex domains, planning at the level of primitive actions (like individual robot steps) is computationally impossible. Hierarchical Planning solves this by organizing planning tasks into Hierarchical Task Networks (HTN).

HTN planners use High-Level Actions (HLAs) that can be decomposed into smaller sub-tasks, eventually reaching primitive actions that the agent can execute directly. For example, the HLA 'Travel from New York to London' can be refined into 'Buy plane ticket', 'Go to airport', 'Fly to London', and 'Go to hotel'. This hierarchical structure reduces search space and makes planning highly scalable.

5.7 Industrial Applications of AI

AI has evolved from a laboratory science into the primary driver of digital transformation across global industries. Below is a detailed analysis of how AI is applied in key sectors.

Core Industrial Applications of AI

Industry Sector	Primary AI Technologies Used	Key Real-World Applications
Healthcare	Computer vision, deep learning, NLP, generative models.	Medical image analysis (tumor detection), automated drug discovery, robotic surgery, patient risk scoring.
Finance	Predictive modeling, reinforcement learning, anomaly detection.	Algorithmic trading, real-time credit scoring, automated fraud prevention, robo-advisors.
Retail	Recommendation algorithms, reinforcement learning, demand forecasting.	Personalized shopping feeds, automated checkout stores, dynamic pricing engines, supply chain optimization.
Agriculture	Computer vision (drones), IoT sensor fusion, robotics.	Precision farming (weed detection), automated crop harvesting, soil health monitoring, crop yield prediction.
Education	Intelligent tutoring systems, NLP, adaptive learning pathways.	Personalized curriculum generation, automated grading assistants, early student dropout prediction, learning difficulty analysis.
Transportation	Deep reinforcement learning, computer vision, sensor fusion.	Autonomous driving (self-driving cars), dynamic traffic routing, predictive vehicle maintenance, drone delivery logistics.
Experimentation & Research	AI-guided search, machine learning, physics-informed neural networks.	Automating scientific discovery, material science synthesis, genomic sequence alignment, climate modeling.

Unit Summary

This unit explored classical planning systems, domain modeling, and industrial applications of AI. The key takeaways are summarized below.

- AI Planning uses factored representation of states and actions (STRIPS/PDDL) to solve complex tasks more efficiently than raw search.
- The Blocks World uses predicates like On, Clear, and ArmEmpty, and actions with Preconditions and Add/Delete lists.
- Planning systems can search forward (progression), backward (regression), or in plan-space.
- Goal Stack Planning is a linear method. It fails on the Sussman Anomaly because it cannot interleave subgoals.
- Nonlinear planning (Partially Ordered Planning) follows the Principle of Least Commitment, leaving actions unordered using constraint posting.
- Hierarchical planning uses High-Level Actions (HLAs) and Hierarchical Task Networks (HTN) to scale to complex, real-world problems.
- AI is revolutionizing industries, including diagnostics in healthcare, fraud detection in finance, demand forecasting in retail, and automated driving in transportation.