Integrated Planning and Acting: The Actor’s View

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What's a Godel? What's a planning system?
Invitation from Paul Bello

... We were especially impressed with your recent work on the Godel planning system, and would welcome a talk focused on those particular issues. ...


What's a Godel? What's a planning system?

The audience won't understand Godel unless I explain the "big picture"
What is Planning?

plan n.

1. A scheme, program, or method worked out beforehand for the accomplishment of an objective: a plan of attack.

2. A proposed or tentative project or course of action: had no plans for the evening.

Focus of AI planning research

3. A systematic arrangement of elements or important parts; a configuration or outline: a seating plan; the plan of a story.

4. A drawing or diagram made to scale showing the structure or arrangement of something.

5. A program or policy stipulating a service or benefit: a pension plan.

planning n. The process of making plans for something.

the reasoning side of acting.

AI Planning Research

- Focus of most (not all) AI planning research:
  - Finite world
    - finitely many states, finitely many actions
  - Static world
    - the plan executor is the only source of change
  - Implicit time:
    - Sequence of actions → sequence of instants
  - Planning problem
    - Initial state, set of goal conditions
  - Solution
    - sequence of actions or set of state-action pairs
    - takes world from initial state to a goal state
  - Offline planning
    - generate entire solution before performing it
Capabilities and Limitations

- **Huge** advances in planning in state-transition systems
  - Standard language (PDDL) for specifying states, actions and state-transition systems
  - Mature technology for finding plans in huge state spaces

- But less practical impact than one might hope
  - Why?

- Consider some of AI planning’s successes
  - What the environment is like
  - How the planning is done
Example Planning Applications

- Robotics
  - Mars Rovers
  - Specialized manufacturing applications

- Management of services and operations
  - “City in your pocket” app, Trento, Italy

- Computer games
  - Bridge Baron
  - Killzone 2

- Very different environments, but several common characteristics
Environment

- World is dynamic
  - Exogenous events that aren’t under the actor’s control
  - Multiple agents, some may be human

- World is not fully known
  - Don’t always know in advance when exogenous events will happen
  - Don’t always know in advance what all the possible events are
  - Models of actions and states may not be fully accurate

- Usually not feasible to produce the final complete plan beforehand
  - Restrictions on how much time is available for planning
  - Planning for all possible contingencies may take too much time
  - We might not even know what the possible contingencies are
Planning in a Dynamic and Open World

- Planning is continual and online
  - Monitor, refine, extend, update, change, and repair plans *throughout the acting process*
  - Generate activities dynamically at run-time
    - to carry out other higher-level activities that one is currently performing
    - to respond to unexpected developments
  - Plans remain *partial* as long as the cost of possible mistakes is lower than the cost of modeling, information gathering, thorough planning
Planning in Acting

- Planner is part of a larger system: the actor
- Deliberation is organized hierarchically
  - View, prepare, and carry out actions hierarchically
  - An action may be a task that needs further refinement and planning
- This goes beyond HTN planning
  - Refinement usually needs to be done online
  - High-level state and action models are abstract approximations
  - Refining may require different representations, tools, and techniques at other levels of the hierarchy
# Comparison

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<th>typical applications</th>
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Most planning research has ignored many of those requirements
   » How have the existing successes been accomplished?

Approximate some part of the overall problem as a planning problem
   » Develop a special-purpose planner for that problem
   » Use the planner are part of a larger system

I’ll discuss some examples that involve Hierarchical Task Network (HTN) planning
   » First, I’ll explain what HTN planning is
For some planning problems
  » The available knowledge may be about tasks rather than states
  » The natural problem statement may be not a goal, but a task to perform
  » We may already have some ideas for how to perform the task

Example: travel to a destination $D$ that's far away:
  » Brute-force search for a state in which one is at $D$:
    • Many ways to combine vehicles and routes
  » Experienced human: small number of “recipes” for carrying out various tasks
    • e.g., flying:
      1. buy ticket from local airport to remote airport
      2. travel to local airport
      3. fly to remote airport
      4. travel to final destination
  » HTN planners use such recipes to generate the search space

Ingredients
  » states, tasks, operators, methods, planning algorithm
States and Tasks

- **State**: description of the current situation
  - I’m at home, I have $20, there’s a park 8 miles away

- **Task**: description of an activity to perform
  - Travel to the park

- Two kinds of tasks
  - *Primitive* task: a task that corresponds to a basic action
  - *Compound* task: a task that is composed of other simpler tasks
Operators

- **Operators**: parameterized descriptions of what the basic actions do

  - **walk** from location $x$ to location $y$
    - Precond: agent is at $x$
    - Effects: agent is at $y$
  
  - **call taxi** to location $x$
    - Precond: (none)
    - Effects: taxi is at $x$
  
  - **ride taxi** from location $x$ to location $y$
    - Precond: agent and taxi are at $x$
    - Effects: agent and taxi at $y$, agent owes $1.50 + \frac{1}{2} \text{distance}(x,y)$
  
  - **pay driver**
    - Precond: agent owes amount of money $r$, agent has money $m \geq r$
    - Effects: agent owes nothing, agent has money $m - r$

- **Actions**: operators with arguments
Methods

- Method: parameterized description of a possible way to perform a compound task by performing a collection of subtasks
- There may be more than one method for the same task

» **travel by foot** from $x$ to $y$
  - Task: travel from $x$ to $y$
  - Precond: agent is at $x$, distance to $y$ is $\leq 2$ miles
  - Subtasks: walk from $x$ to $y$

» **travel by taxi** from $x$ to $y$
  - Task: travel from $x$ to $y$
  - Precond: agent is at $x$, agent has money $\geq 1.5 + \frac{1}{2} \text{distance}(x,y)$
  - Subtasks: call taxi to $x$, ride taxi from $x$ to $y$, pay driver
Planning Algorithm

- Planning problem:
  - Initial state
  - Initial task or sequence of tasks

- Solution:
  - Recursively decompose tasks into subtasks until every leaf node contains an action
  - If the sequence of actions is executable then it is a solution

- Planning algorithm
  - Left-to-right backtracking search
Example

- Simple travel-planning problem

Travel by foot

Precond:
- ✓ I’m at home
- ❌ home to park ≤ 2 mi

Travel by taxi

Precond:
- ✓ I’m at home
- ✓ I have ≥ $5.50

Initial state

I’m at home
I have $20
home to park is 8 mi
Taxi is at home

Precond: ...
Effects: ...

Precond: ...
Effects: ...

Precond: ...
Effects: ...

Final state

I’m at the park
I have $14.50
home to park is 8 mi
I owe nothing
Taxi is at the park

Backtrack

s₀

s₁

s₂

s₃
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Implementations

- SHOP and SHOP2
  - Written around 2000; Lisp and Java versions available
  - SHOP2 received an award in the AIPS-2002 Planning Competition
  - Open source: http://www.cs.umd.edu/projects/shop
  - Used in hundreds of projects worldwide

- Pyhop
  - Written in Python, released summer 2013
  - Objective: something easy to integrate into ordinary computer programs
  - Easy to understand – less than 150 lines of code
  - Representation of states, actions, methods are closer to what you’d use in ordinary computer programming
    - Manipulate computer variables rather than logical predicates
  - Open-source: http://bitbucket.org/dananau/pyhop
Bridge Baron

- Won the 1997 world championship of computer bridge
- Used a special-purpose HTN planner that generated game trees
  - Only generated branches corresponding to known bridge strategies
    - finesse, ruff, cash out, …
    - About $10^5$ leaf nodes
    - A conventional game tree would have had about $10^{24}$ leaf nodes
  - Less time needed to search the tree and compute expected utility values

- Why it worked:
  - Special-purpose HTN planner
    - multiple agents
    - generate game trees, not linear plans
  - Lots of human effort to make the HTN methods as complete as possible
  - Can run it repeatedly during the game
Developed by Guerrilla Games, released in early 2009

- Incorporates a special-purpose HTN planner for planning at the squad level
  - Method and operator syntax similar to SHOP and SHOP2
  - Quickly generates a linear plan that would work if nothing interferes
    - Replan several times per second as the world changes

**Why it worked:**
- Very different objective from a bridge tournament
- Don’t *want* to look for the best possible play
- Need actions that appear believable and consistent to human users
- Need them very quickly
Planning

- Planning problem:
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A human must write a complete set of HTN methods
Godel

- Instead of decomposing tasks into subtasks, Godel’s methods decompose goals into subgoals
- Planning problem:
  - initial state and goal (as in classical planning)
- For each subgoal
  - If a subgoal matches an action
    - then the subgoal is solved
  - Otherwise if there’s an applicable method
    - use it to produce subgoals
  - Otherwise
    - generate landmarks
      - Classical planning algorithm
    - use the landmarks as subgoals
  - Repeat until all subgoals are solved
Properties

- Properties of Godel
  - With a complete set of methods, Godel behaves like an HTN planner
  - With no methods, Godel behaves like a classical planner
  - With an incomplete set of methods, Godel uses a combination of HTN-style decomposition and classical planning

- This reduces the “method writing” bottleneck
  - Don’t need to write all the methods
    - write methods for high-level strategy, let Godel fill in the detail
    - write methods for details, let Godel figure out the high-level strategy

- Potential foundation for integration with goal-reasoning algorithms
  - Quick replanning in response to unexpected events or new goals
  - Vikas Shivashankar will talk about this in the Goal Reasoning workshop this afternoon
Summary

- **Acting** is a key capability of integrated systems
  - Neglected, needs more attention
- Some requirements
  - Continual online planning during acting
  - Hierarchical organized deliberation
- How AI planning algorithms have been used effectively
  - Find a subproblem that approximates AI planning
  - Special-purpose planner, plan multiple times as the world changes
- Hierarchical requirements go beyond HTN planning
  - Heterogeneous representations
- Extensions of HTN planning
  - Pyhop: state variable representation
  - Godel: goal reasoning
References

- **Planning:**

- **Planning and acting:**

- **Pyhop:**

- **Godel:**