Planning over MDPs through Probabilistic HTNs

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Motivations

- Planning when
  - The environment is non-deterministic — Markov Decision Processes (MDPs)
  - The applicability of the how-to knowledge on tasks is uncertain — probabilistic hierarchical task networks (HTNs)
- Earley graphs (borrowed from natural language processing [Stolcke, 1995]) to integrate probabilistic HTNs and MDPs
Markov Decision Processes

- Probabilistic state transitions: $Pr : S \times S \times A \rightarrow [0, 1]$
  - Markov Property: The resulting state is independent of previous history
- Rewards: $R : S \rightarrow [0, 1]$
Probabilistic Hierarchical Task Networks (HTNs)

- Human experts abstract how-to-act knowledge into HTNs
- HTNs
  - Primitive tasks: Directly executable tasks (actions)
  - Non-primitive tasks: Symbolic abstraction about what to do
  - Methods: Recipes about how to decompose tasks into smaller tasks
    - Decomposition probability: \([0, 1]\)
  - Task networks: A set of tasks that are (partially) ordered or constrained
Probabilistic Earley Graph for HTNs

- **Prediction links:**
  Non-primitive task to method decomposition

- **Scanning links:**
  Primitive task executions

- **Completing links:**
  Completing methods preceding to next tasks

- **#Nodes:**
  $\sum_{m \in \mathcal{M}} |\text{network}(m)|$

- **#Edges:**
  $O\left(\sum_{m \in \mathcal{M}} |\text{network}(m)| + 2\sum_{t \in \mathcal{N_T}} (|\text{Appearances}(t)| \cdot |\text{Methods}(t)|)\right)$
Computing Probabilities and Rewards with Earley Graph

The probability of a decomposition-execution path \( de \)

\[
Pr(de) = \prod_{EN_i \in de} Pr(EN_{i+1}|EN_i) \cdot \prod_{s_j, a_j, s_{j+1} \in de} Pr(s_{j+1}|s_j, a_j)
\]

- Compute probabilities of the decomposition-execution paths
- Compute expected rewards of decomposition-execution paths
- Learn decomposition probabilities from past experiences
Solution Concepts with Earley Graph

- **Simple solution:** A decomposition-execution path with maximum expected reward
- **Generalized solution:**
  - Given a sequence of encountered states and executed actions, compute the probability for each predictive nodes that the system can be in
  - Associate with each prediction node (non-primitive task) a table of rewards \( \{ \langle s, \text{method, method-parameters, expected reward} \rangle \} \) to select the method that can lead to MEU
  - Associate with each scanning node (primitive task) a table of \( \{ \langle s, \text{action-parameters, expected reward} \rangle \} \) to select the action parameters that can lead to MEU
Summary and Future Directions

- Earley graphs (borrowed from natural language processing [Stolcke, 1995]) to integrate probabilistic HTNs and MDPs
  - Compute probabilities and rewards of the decomposition-execution paths
  - MEU planning

Future directions

- Experiment with the generalized solution concepts
- Learn decomposition probabilities
- Bridge to plan recognition systems
- Bridge to multiagent systems
  - Agents observe other agents’ behaviors and run plan recognition algorithms to obtain probabilistic HTNs
  - Agents communicate to incrementally share the how-to knowledge (represented in HTNs) with a potential to converge into a same set of task networks
  - Agents adapt to the environment and revise their task decomposition probabilities
  - Agents converge to a set of cooperative behaviors regulated by the HTNs authorized by individual agents in an uncertain environment

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Earley-HTN-MDPs
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