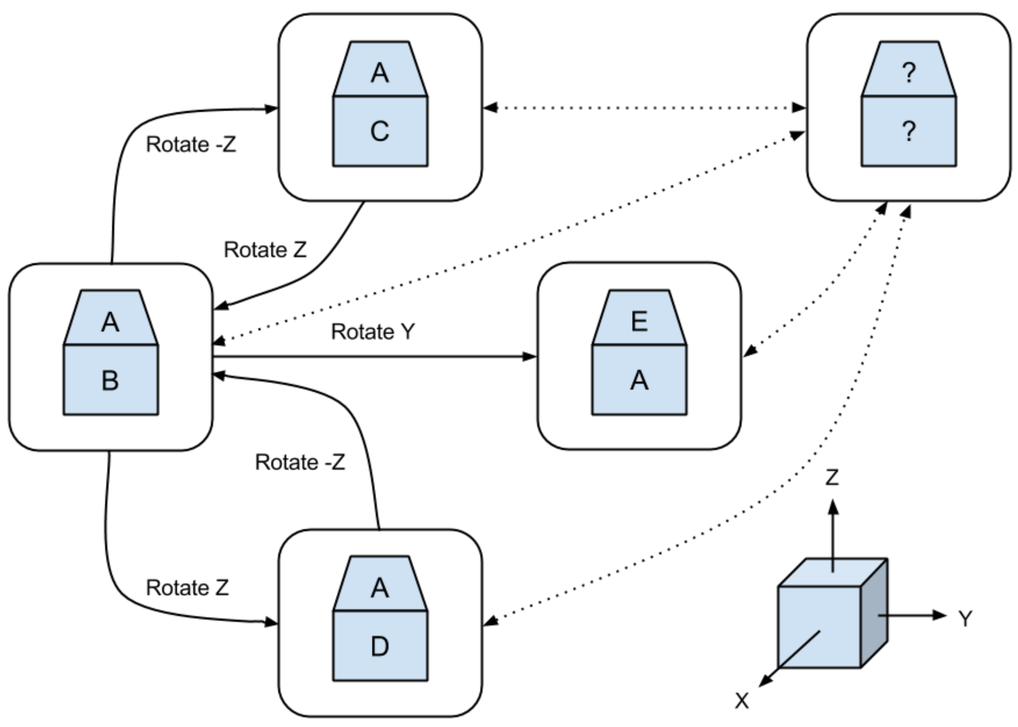
Action-Based Models for Belief Space Planning

Li Yang Ku, Shiraj Sen, Erik G. Learned-Miller, and Roderic A. Grupen
University of Massachusetts Amherst

Goal - Address the dual problems of modeling and reasoning by employing an action-based model grounded in the robot's own actions and perceptions.

Aspect Transition Graph (ATG)

- An ATG is a directed graph $G = (\mathcal{X},\mathcal{U})$, composed of a set of aspect nodes $\mathcal{X}$ connected by a set of action edges $\mathcal{U}$.
- Each aspect node $x \in \mathcal{X}$ represents the properties of an object that are measurable given a set of sensor parameters.



Learning Models

- An ATG is added to the robot memory $\mathcal{M}$ only if the presented object has not been presented to the robot in the past.
- Given a sequence of observations $z_{1:t}$ and actions $a_{1:t}$ during trial T, the probability that the presented object O_T during trial T is novel can be calculated;

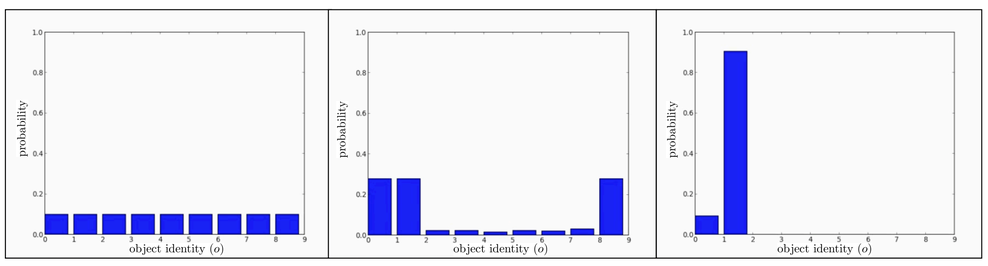
$$
\begin{aligned}
& p(O_T \notin \mathcal{S}_{T-1} | z_{1:t}, a_{1:t}, \mathcal{M}) \\
&= \sum_{o_i \notin \mathcal{S}_{T-1}} p(O_T = o_i | z_{1:t}, a_{1:t}, \mathcal{M}) \\
&= \sum_{o_i \notin \mathcal{S}_{T-1}} \sum_{x_t \in \mathcal{X}_i} p(x_t | z_{1:t}, a_{1:t}).
\end{aligned}
$$

Notation	Definition
x_t	the aspect at time t
z_t	the measurement data at time t
a_t	the control data at time t
$\mathcal{M}$	the current robot memory
O_T	the object given to the robot at the Tth trial
o_j	the object labeled id j
$\mathcal{S}_T$	the set of objects given to the robot up to the Tth trial, $O_i \in \mathcal{S}_T \quad i = 1 \ldots T$

Minimum Entropy Planner

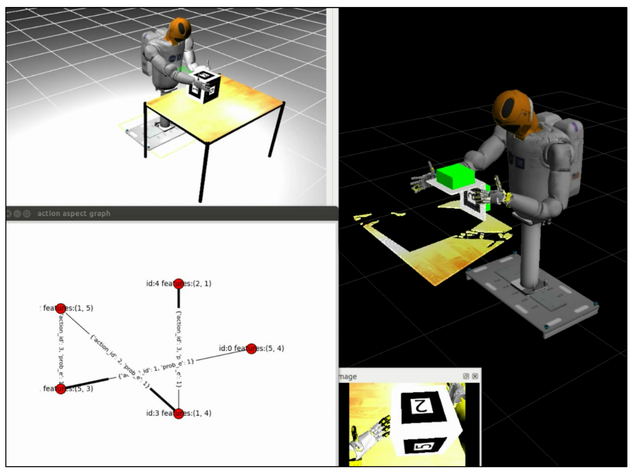
- The action a_t that minimizes the expected entropy over the random variable O_T representing the object identity is selected.
- Future observation is estimated through object models created from past observation.

$$
\begin{aligned}
& \underset{a_t}{\operatorname{argmin}}\ E(H(O_T | z_{t+1}, a_t, z_{1:t}, a_{1:t-1})) \\
&= \underset{a_t}{\operatorname{argmin}} \sum_{z_{t+1}} H(O_T | z_{t+1}, a_t, z_{1:t}, a_{1:t-1}) \times \\
& \quad p(z_{t+1} | a_t, z_{1:t}, a_{1:t-1}).
\end{aligned}
$$



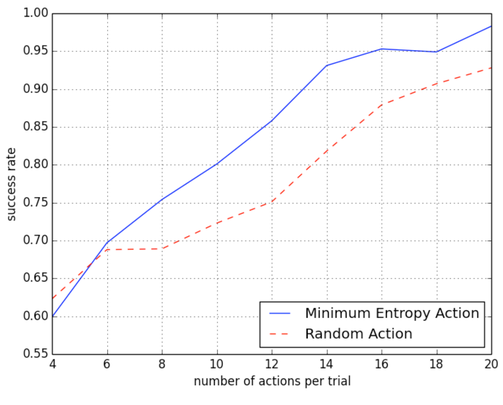
Simultaneous Object Modeling and Recognition

- The robot builds up a set of object models through interacting with random objects one at a time.
- Evaluated based on whether the robot can identify novel objects or recognize which object it corresponds to in memory.



Experiment Results

- Each test involves 100 trials and starts with an empty robot memory $\mathcal{M}$.
- The efficiency of the planner is tested against a random policy.



Test	Correct Identification	Correct Recognition	Success Rate
1	100/100	34/34	100%
2	98/100	32/32	98%
3	98/100	40/40	98%
4	99/100	37/37	99%
5	99/100	32/32	99%
average	98.8%	100%	98.8%

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