Generalizable Task Planning

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Abstract

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Introduction

The ability to plan for multi-step tasks is essential for home robots. The planning for everyday tasks is challenging. Some of the issues faced when doing task planning are the search in high-dimensional, non-convex spaces over long time horizons. Another issue is the amount of data needed to train a model capable of planning for a vast amount of home tasks. Most of the task-planning approaches rely on a carefully chosen abstract geometric representation of objects in the scene and analytically defined transition models, which are usually task-specific.

Recent developments in Machine Learning have shown that extracting generalizable features of objects in the training set is possible. This can help create higher-level policies capable of generalizing different tasks. However, there are some challenges when trying to apply skills with a higher-level policy. Planning with manipulation skills (higher-level policies) requires modeling the effect the skill has on the environment. Scene representation derived from learning abstract concepts such as `on-top` or `on-hand` may not be sufficient for accurate task planning.

The objective of this paper is to create a learning-to-plan method that is able to generalize task planning with unseen objects. This method has two stages. The first stage extracts the object-level embedding from a raw RGB-D observation of the scene. This first module of the method generates a set of high-level semantic attributes (Predicates) of the objects in the scene. The second stage is a planning framework that uses the high-level semantic attributes of the first stage to generate a sequence of skills that will achieve a goal task. We evaluate the method with one manipulation task, stacking cubes of blocks.

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Methodology

We propose a two-stage framework to achieve generalizable task planning. The first stage is trained as a segmentation encoder used to extract object-level features and produce a set of predicates that represent the state of the objects in the scene. The second stage consists of a task planner that uses a search-based method for long-horizon tasks.

Problem Setup

Consider a planning problem in a partially observable setting. The goal of the framework is to take an observation $o \in O$ as input and plan a sequence of parameterized skills to reach a task goal $g \in G$. The goal is a set of known symbolic predicates $g = \{p_1, p_2, \dots\}$ that represent the object-level state of the environment. For example, the goal of stacking a block on top of another block: $p_1 = \texttt{OnTop(Blue Block, Red Block)}$. The observation will be in the form of segmentation-masked images derived from a point-cloud image of the scene.

Parameterized Skills

A parameterized skill is represented as a set of four functions: $s = (L_P, L_E, \pi, f_T)$, where L_p is the set of logical preconditions necessary to execute the skill, L_E is the set of expected logical effects, π is a visuomotor policy (Reinforcement learning algorithm) and f_T is the termination condition of the policy. The skills are parameterized by an optional number of objects. Each policy π is either learned or manually designed. The learned policies are learned from the generated expert policy using imitation learning. During execution the trained policies operate on the object-level predicates derived from a point cloud.

Search Based Planning

The task planning problem consists to find list of parameterized skills that will achieve the goal. The list of parameterized skills is defined as follows: $\{(\pi, \theta)_t\}_{t=1}^{T}$ such that the goal condition is satisfied at the end of the sequence. A task is considered succesful if and only if all the all conditions have been met. A breadth-first search is used to find the optimal sequence of skills. The objective of the search algoritm is to take a pair of start and goal state and generate a sequence of skills that will transform the start state into the goal state.

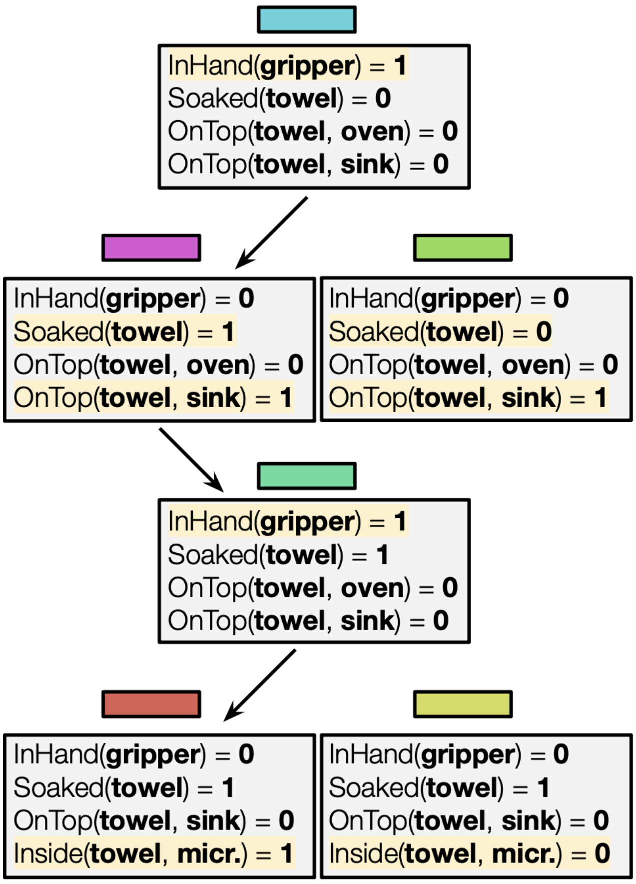

Figure 1: *Caption describing your figure.*

Skills and Predicate Learning

Consider the robot's joint states as $q \in Q$ and the camera observation as $o \in O$. Each of the actions in the task planning corresponds to a skill $s \in S$. Each skill has a corresponding visuomotor policy π that is learned from expert demonstrations. The policy predicts the next state q for the robot given an observation o. Given a sequence of states and observations in an expert trajectory $\{(q_t, o_t)\}_{t=0}^{T}$,the skill is trained to predict a state q_{t+1} for an observation o_t. Each skill also has a termination policiy that outputs a binary value indicating if the skill has been completed. The termination policy is trained to predict the termination condition of the skill.

Table 1: *Learned Skills and Predicates.*

Name	Description	Type
ReachOnTable	Reach object	Skill
ReachOnTower	Reach object	Skill
Stack	Stack object	Skill
On	On Top	Predicate
InHand	In Hand	Predicate

Learning Transition Model

Another challenge of task planning is to predict the effects of skills so that the robot could determine the best skill plan to reach a goal. For simplicity purposes the Transition Model (Effects on the environment for a given skill) gave been hardcoded, however transition models could also be learned. Generalizable transition models are subject to further research, as creating a model that can predict the effects of a skill on the environment is a challenging task given the specific effect of skills under certain environments.

Results

Proposed Architecture

For learned skills, termination conditions and the predicated the model architecture will take as an input a point cloud image of the scene. The point cloud is processed to generate a segmentation mask of the scene that will highlight objects of interest to a particular task. For example for the skill `ReachOnTable` the model will generate a segmentation mask that highlights the object that the robot needs to reach. Then a PointNet++ architecture is used to extract the object-level features from the segmentation mask. The point cloud features are appended with the features extracted from the joint states of the arm to predict either the joint targets, in the case of the skills, or the probability of a given skill being terminated. The skills are trained with a linear combination of joint-space and operations loss, meanwhile the termination policies are trained with a binary cross-entropy loss.

Joint-space loss The joint-space loss is the mean squared error between the predicted joint targets and the ground truth joint targets. The joint targets are the joint angles that the robot needs to reach in order to execute a skill. The joint-space loss is defined as follows:

$$L = \frac{1}{n}\sum_{i=1}^{n}(y_{\text{true},i} - y_{\text{pred},i})^2 \tag{1}$$

Operation loss The operation loss is used to minimize the loss to the final Cartesian end-effector position. The end-effector is represented with two points, one on the x and y axis. These two points determine the robots end-effector position. Using forward kinematics, the joint state q is mapped for the prediction and the ground truth. The operation loss is defined as follows:

$$p_{\text{true},i} = f(q_{\text{true},i}) \tag{2}$$

$$p_{\text{pred},i} = f(q_{\text{pred},i}) \tag{3}$$

$$L_{\text{op}} = \frac{1}{n}\sum_{i=1}^{n}(p_{\text{true},i} - p_{\text{pred},i})^2 \tag{4}$$

Task Planning and Execution

The goal is defined by a list of predicates L_g. A set of predicates $p \in P$ is used to generate a logical state of the environment. The task planner finds a sequence of skills from the set of Skills S that will satisfy the goal. The task planner uses a breadth-first search to find the optimal sequence of skills. The search algorithm takes a pair of start and goal state and generates a sequence of skills that will transform the start state into the goal state. The logical effects of skills are updated after each skill is executed. The preconditions of the next skill are updated based on the logical effects of the previous skill. The search algorithm continues until the goal is satisfied. The following algorithm describes the task planning algorithm:

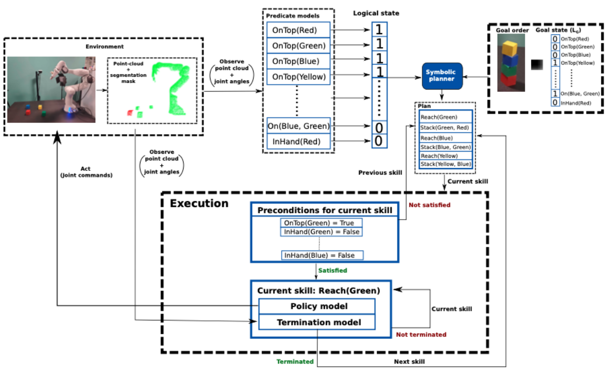

Figure 2: *Overview of model architecture.*

An example of the execution of the algorithm is shown in the following figure.

Algorithm 1 Execution

```
procedure EXECUTE(L_G)
    replan_counter ← 0
    while replan_counter < MAX_REPLANS do
        o ← OBSERVE()
        P ← PLAN(o, L_G)
        replan_counter ← replan_counter + 1
        if EXECUTEPLAN(o, L_G, P) = Success then
            return Success
        end if
    end while
    return Failure
end procedure
procedure EXECUTEPLAN(o, L_G, P)
    i ← 0
    while i < |P| do
        s ← P_i
        while not ∀p ∈ L_P, p(o) = True do
            i ← i − 1
            if i < 0 then
                return Failure
            end if
            s ← P_i
        end while
        retrial_counter[s] ← retrial_counter[s] + 1
        if retrial_counter[s] > MAX_RETRIALS then
            return Failure
        end if
        EXECUTESKILL(s)
        o ← OBSERVE()
        if ∀p ∈ L_G, p(o) = True then
            return Success
        end if
        i ← i + 1
    end while
    return Failure
end procedure
```

Initial predicates:

$$\begin{aligned}
\text{on-table}(red) &: \text{False} \\
\text{in-hand}(red) &: \text{False} \\
\text{on-top}(red, blue) &: \text{False} \\
\text{on-top}(red, green) &: \text{False} \\
\text{on-table}(blue) &: \text{False} \\
\text{in-hand}(blue) &: \text{False} \\
\text{on-top}(blue, red) &: \text{False} \\
\text{on-top}(blue, green) &: \text{False} \\
\text{on-table}(green) &: \text{False} \\
\text{in-hand}(green) &: \text{False} \\
\text{on-top}(green, red) &: \text{False} \\
\text{on-top}(green, blue) &: \text{False}
\end{aligned}$$

Goal predicates:

$$\text{on-top}(red, blue) : \text{True}$$

Plan:

1. reach-on-table(red)
2. stack(red, blue)

Github repository: `https://github.com/miguel-merlin/generalizable_task_planning`