Skill Machines: Temporal Logic Skill Composition in Reinforcement Learning

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Solving temporal logic tasks specified by regular languages without further learning by composing skill primitives

PAPER

What we want

We want agents (e.g robots) that can **solve multiple complex tasks** in an environment (e.g real world) **without further learning**

Defining tasks is hard!
Reward design requires expert knowledge

Learning is slow!
Sample efficiency in RL is terrible

Curses of dimensionality

In general (for P environment propositions/sub-goals):

- *Spatial curse*: ***Eventually*** 2^{2^P}
- *Temporal curse*: ***Always*** 2^{2^P}

Task: "Navigate to a button ***and then*** to a cylinder ***while never*** entering blue regions"

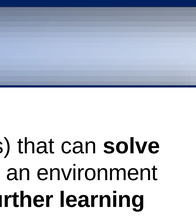
LTL: $(F(\bullet \wedge X(F\,\bullet))) \wedge (G\,\neg\bullet)$

Agent needs to:

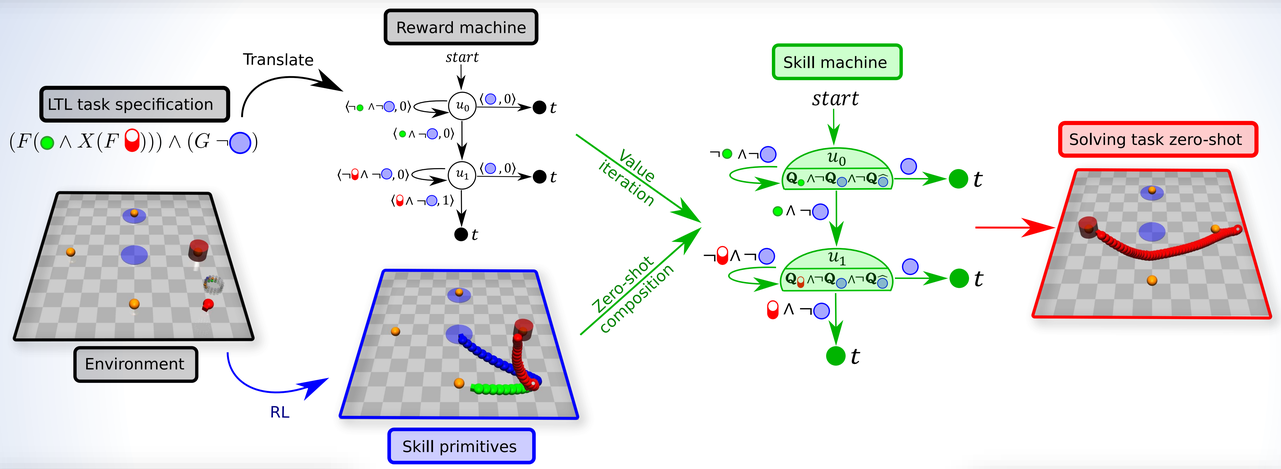
1. ***Eventually*** $\bullet \wedge \neg\bullet$
2. *Then* ***eventually*** $\bullet \wedge \neg\bullet$
3. *while* ***always*** $\neg\bullet$

Learned skills (Options)

- *"Go to a button"* $F\ \bullet$
- *"Go to a blue region"* $F\ \bullet$
- *"Go to the cylinder"* $F\ \bullet$



[1] R. T. Icarte et al., "Using reward machines for high-level task specification and decomposition in reinforcement learning," ICML, 2018
[2] G. Nangue Tasse et al., "World value functions: Knowledge representation for multitask reinforcement learning," RLDM, 2022.
[3] G. Nangue Tasse et al., "A Boolean task algebra for reinforcement learning" NeurIPS, 2020.



Solution: primitives

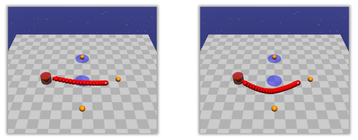
For spatial curse

- *Task primitives (M_p): Composable MDPs for **eventually** satisfying each proposition*
- *Skill primitives ($\boldsymbol{Q}_p$): WVFs for each task primitive*

For temporal curse

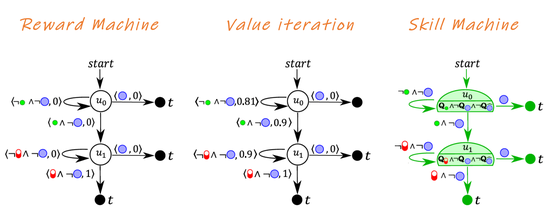
- *Constraints (C): Propositions to **always** keep True or False in an episode*
- *Augments the state space of task primitives*

E.g. $M_{\bullet}$ *where* $C = \{\bullet\}$



Reward machine to skill machine

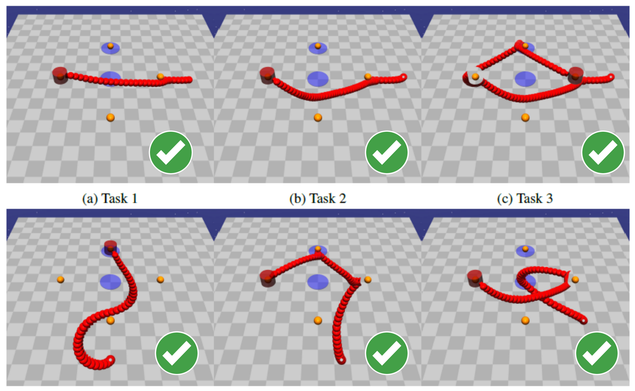
Plan over RM (e.g value iteration) then pick skills greedily



Zero-shot transfer

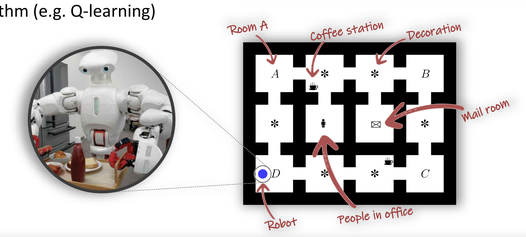
Task	Description — LTL
1	Navigate to a button and then to a cylinder. — $(F(\bullet \wedge X(F\,\bullet)))$
2	Navigate to a button and then to a cylinder while never entering blue regions — $(F(\bullet \wedge X(F\,\bullet))) \wedge (G\,\neg\bullet)$
3	Navigate to a button, then to a cylinder without entering blue regions, then to a button inside a blue region, and finally to a cylinder again. — $F(\bullet \wedge X(F((\bullet \wedge \neg\bullet) \wedge X(F((\bullet \wedge \bullet) \wedge X(F\bullet))))))$
4	Navigate to a button and then to a cylinder in a blue region. — $(F(\bullet \wedge X(F\,\bullet \wedge \bullet)))$
5	Navigate to a cylinder, then to a button in a blue region, and finally to a cylinder again. — $(F(\bullet \wedge X(F((\bullet \wedge \bullet) \wedge X(F\bullet)))))$
6	Navigate to a blue region, then to a button with a cylinder, and finally to a cylinder while avoiding blue regions. — $(F(\bullet \wedge X(F((\bullet \wedge \bullet) \wedge X((F\bullet) \wedge (G\neg\bullet))))))$

Table A4: Tasks in the Safety Gym domains. The RMs are generated from the LTL expressions.



Few-shot transfer

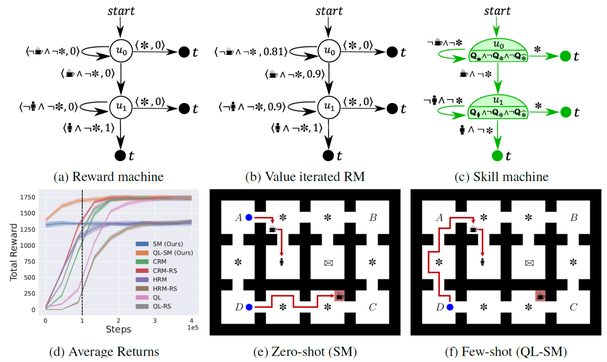
We can improve the zero-shot policy to **optimality** by using any off-policy algorithm (e.g. Q-learning)



When reachability doesn't hold

"Deliver coffee to the office and never break a decoration"

$(F(\bullet \wedge X(F\,\bullet))) \wedge (G\,\neg\bullet)$



When choosing skills greedily is bad

"Go to the office but not until you have coffee"

$(F\,\bullet) \wedge (\neg\bullet\, U\,\bullet)$