Vygotskian Autotelic Agents

Language as a Cognitive Tool to Imagine Goals in Curiosity-Driven Exploration

Tristan Karch
Flowers Lab
Inria - Univ. Bordeaux

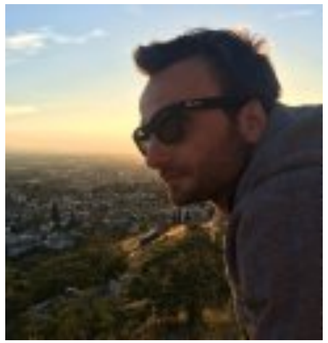
Special Thanks

Flowers Laboratory

FLOWing Epigenetic Robots and Systems

My Lab

Pierre-Yves Oudeyer



Clément Moulin-Frier

My PhD advisors

Peter Ford Dominey

Olivier Sigaud

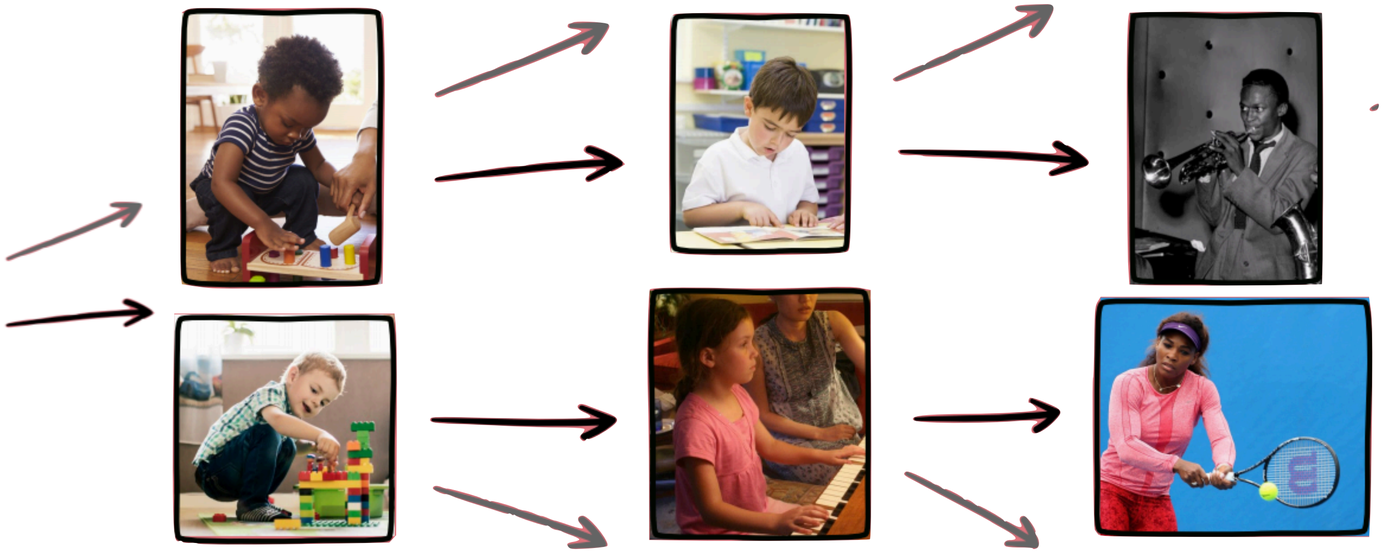
Nicolas Lair

Cédric Colas

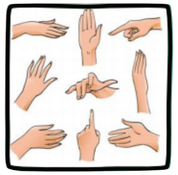
My co-authors

Humans are Intrinsically Motivated Learners

During exploratory play, children (learn to) invent and **pursue their own problems.** As they grow older they acquire an **open-ended repertoire of skills**

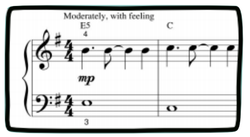


Various types of goals (modality and abstraction):



Proprioceptive

Visual



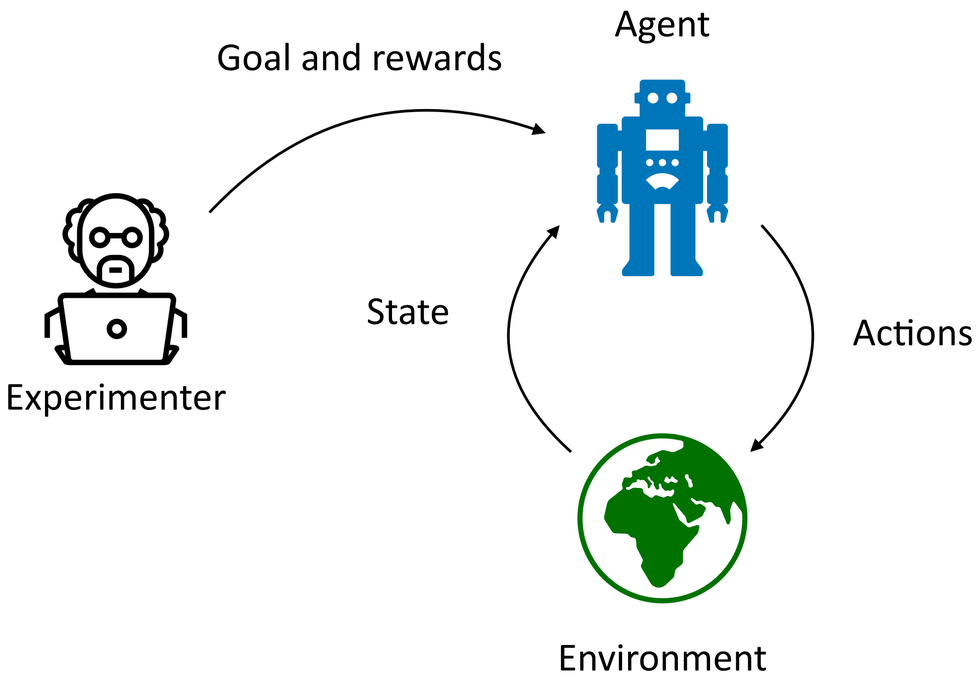
Auditory

Linguistic

Autotelic Agents and Reinforcement Learning

Autotelic Agents: Computational Implementation of Intrinsically Motivated Learners via Reinforcement Learning

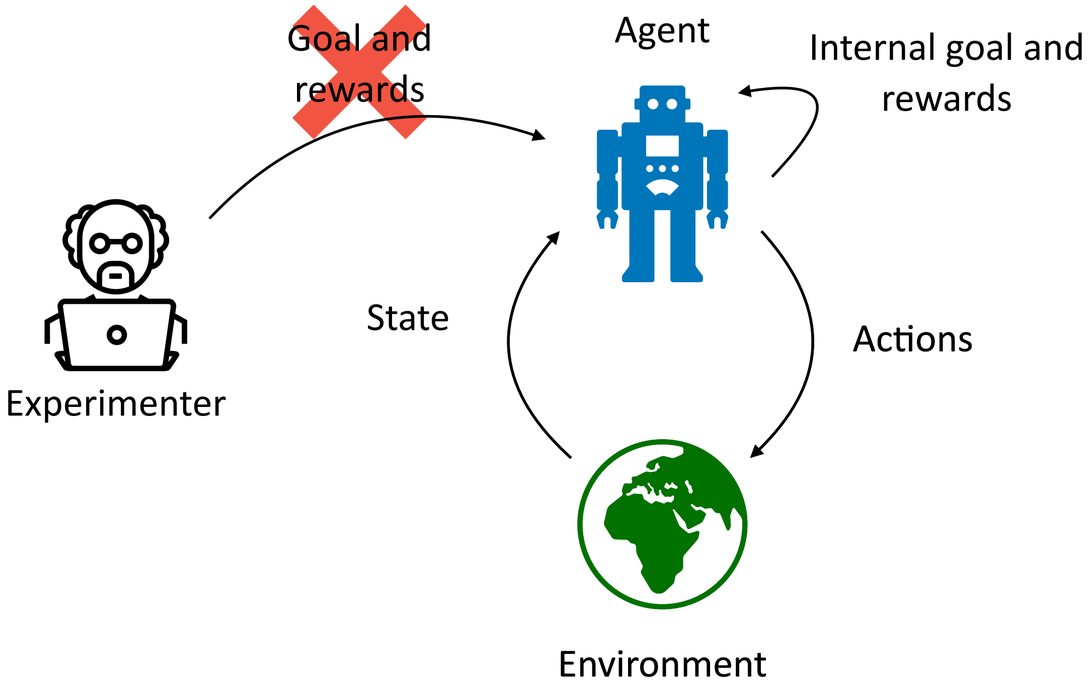
Classical Reinforcement Learning



Autotelic Agents and Reinforcement Learning

Autotelic Agents: Computational Implementation of Intrinsically Motivated Learners via Reinforcement Learning

Autotelic Reinforcement Learning or (Intrinsically Motivated Goal-Conditioned Reinforcement learning)



Autotelic Learning:
Autotelic agents are intrinsically motivated to learn to represent, generate, pursue and master their own goals.

"Autotelic" comes from the Greek auto (self) and telos (end, goal) (Steels, 2004).

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Autotelic Agents and Reinforcement Learning

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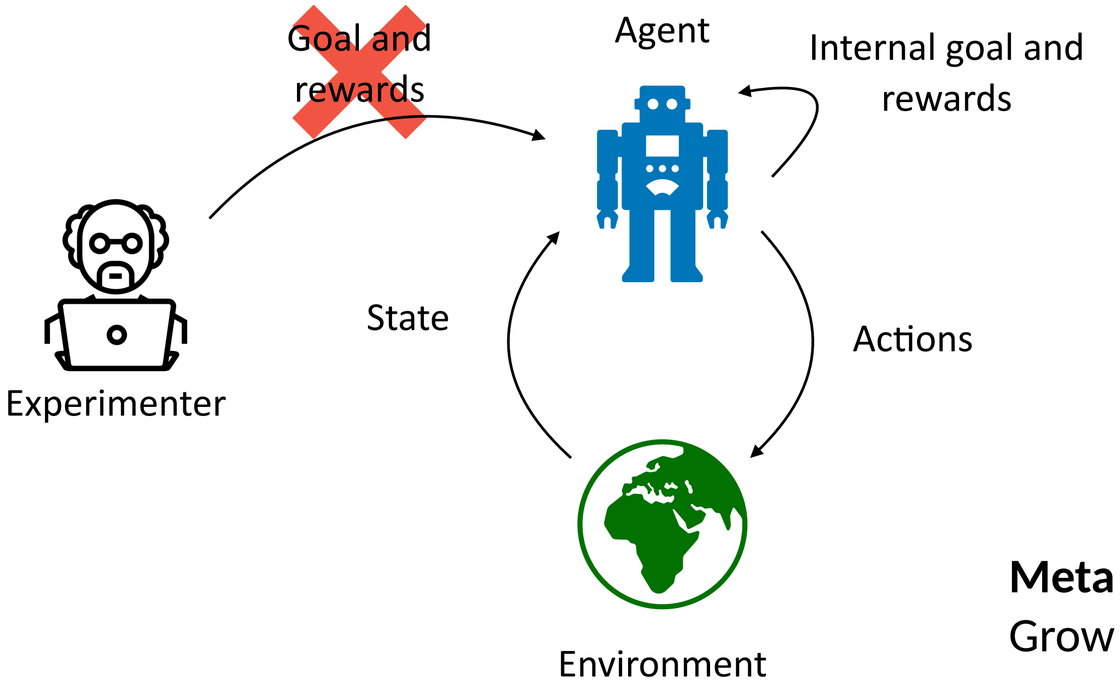

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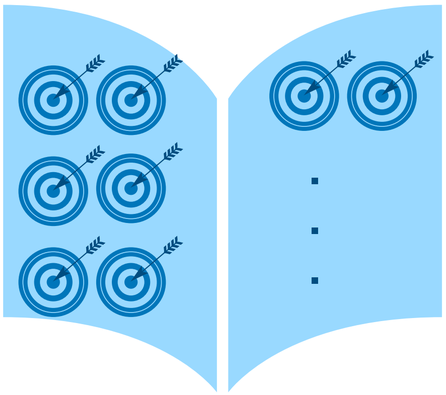
Meta Objective (open ended learning)
Grow a repertoire of skills



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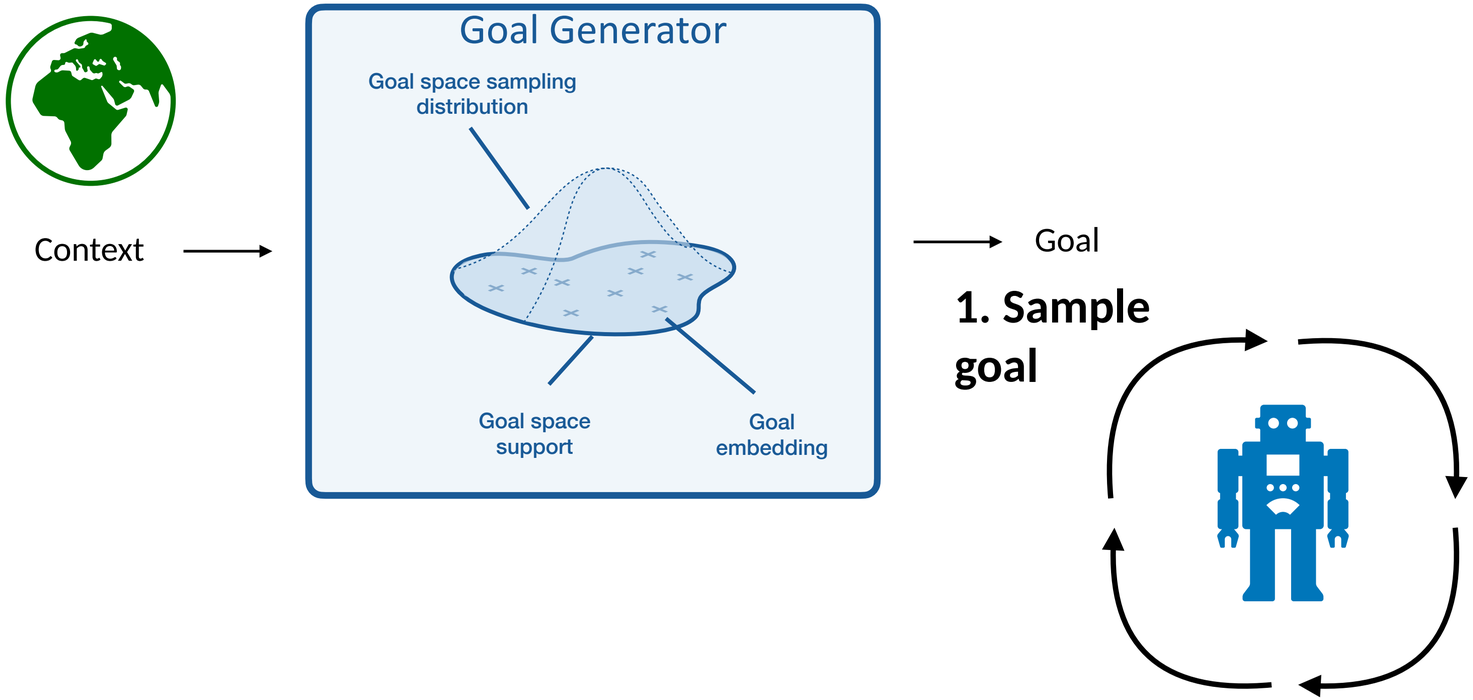
Autotelic Learning Loop



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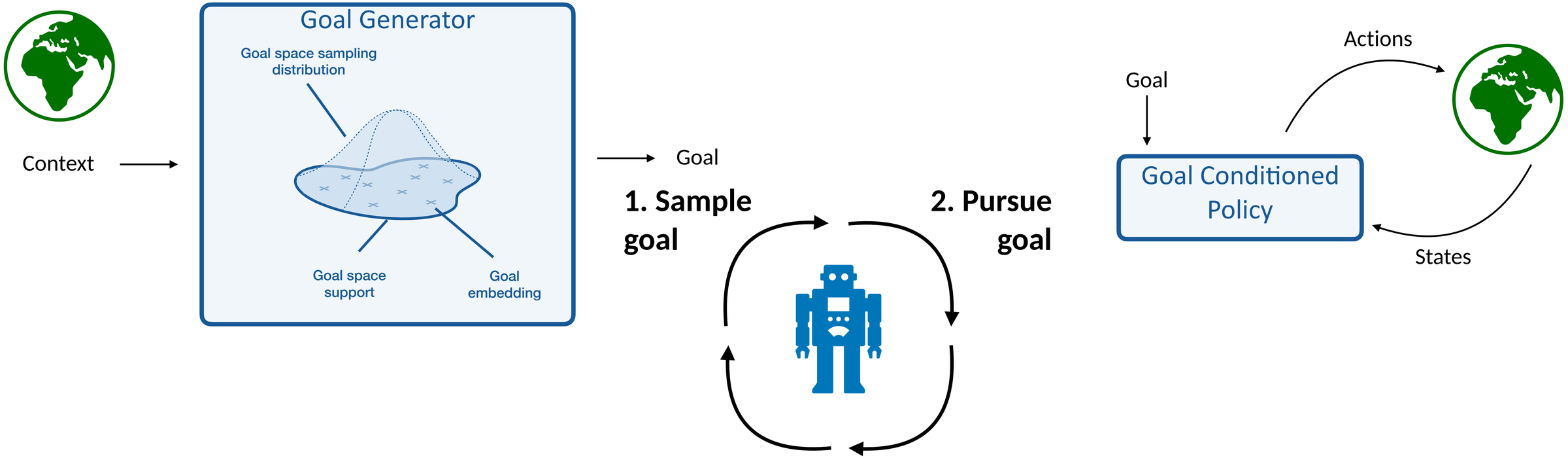

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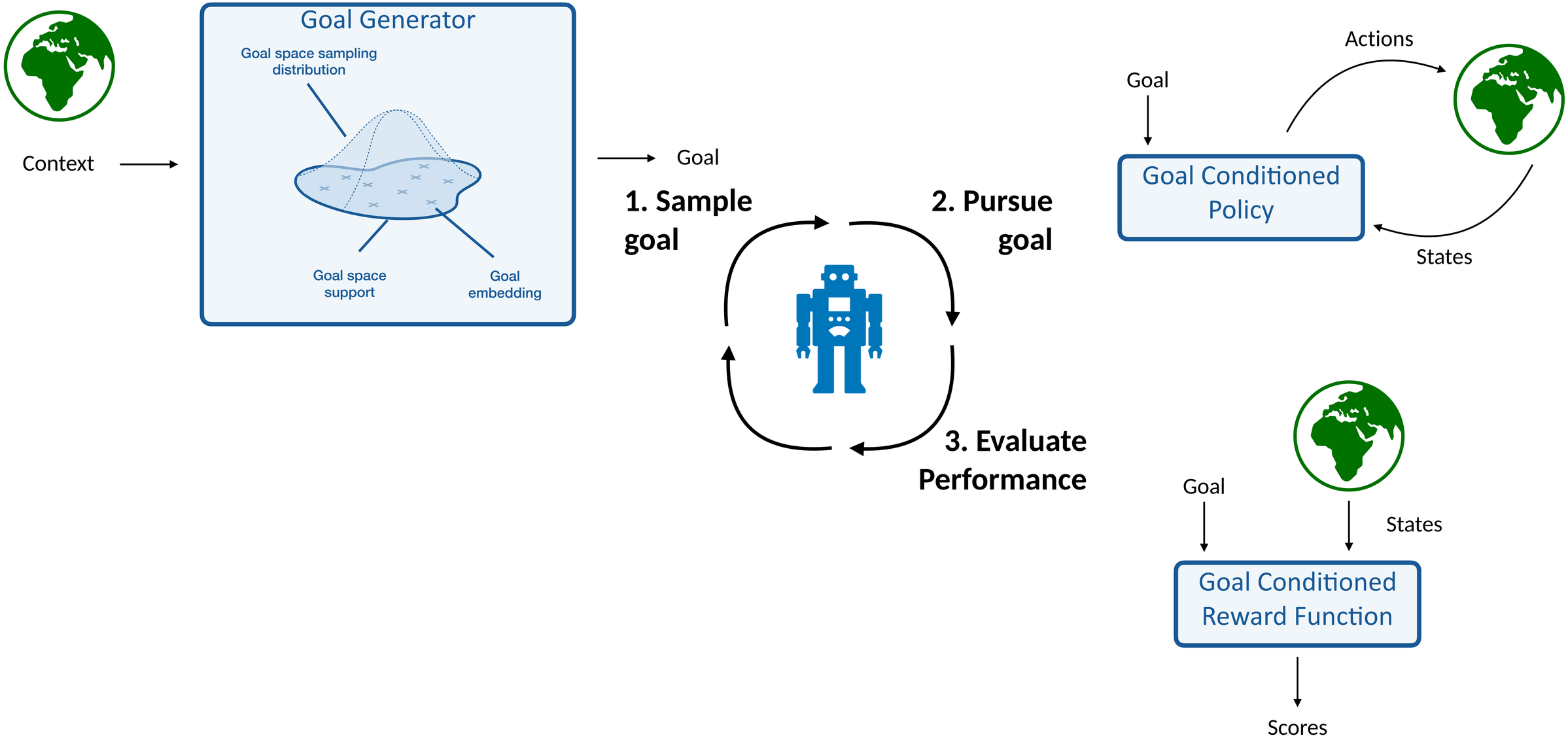

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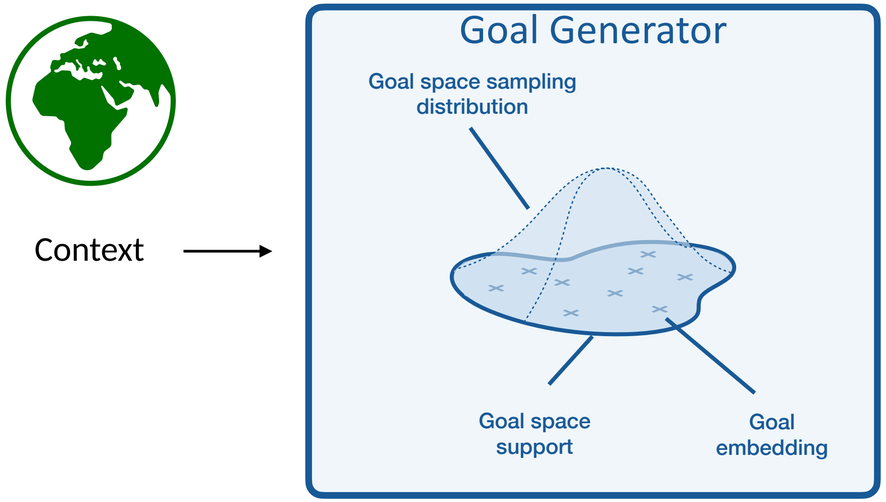

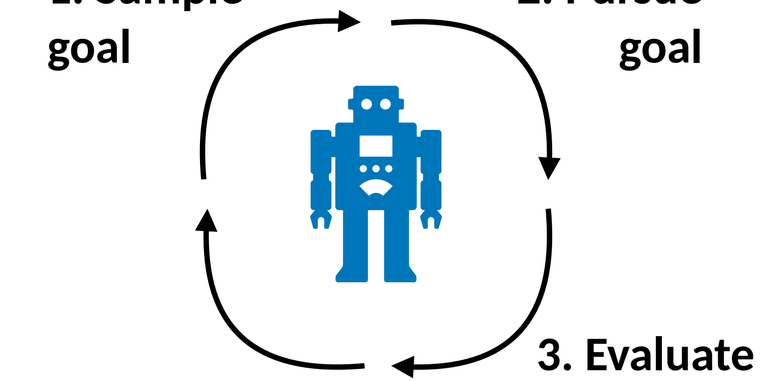

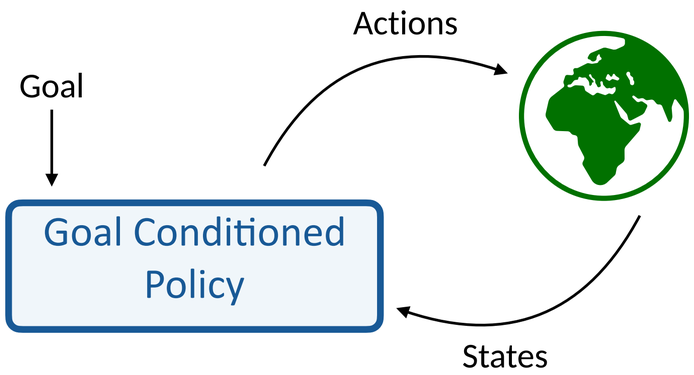

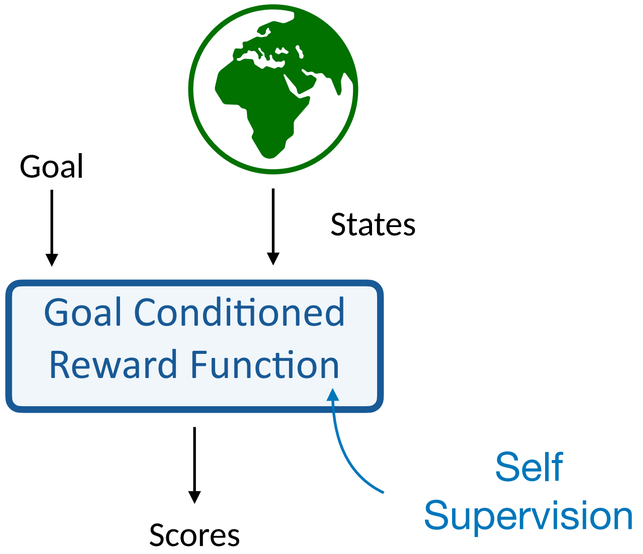

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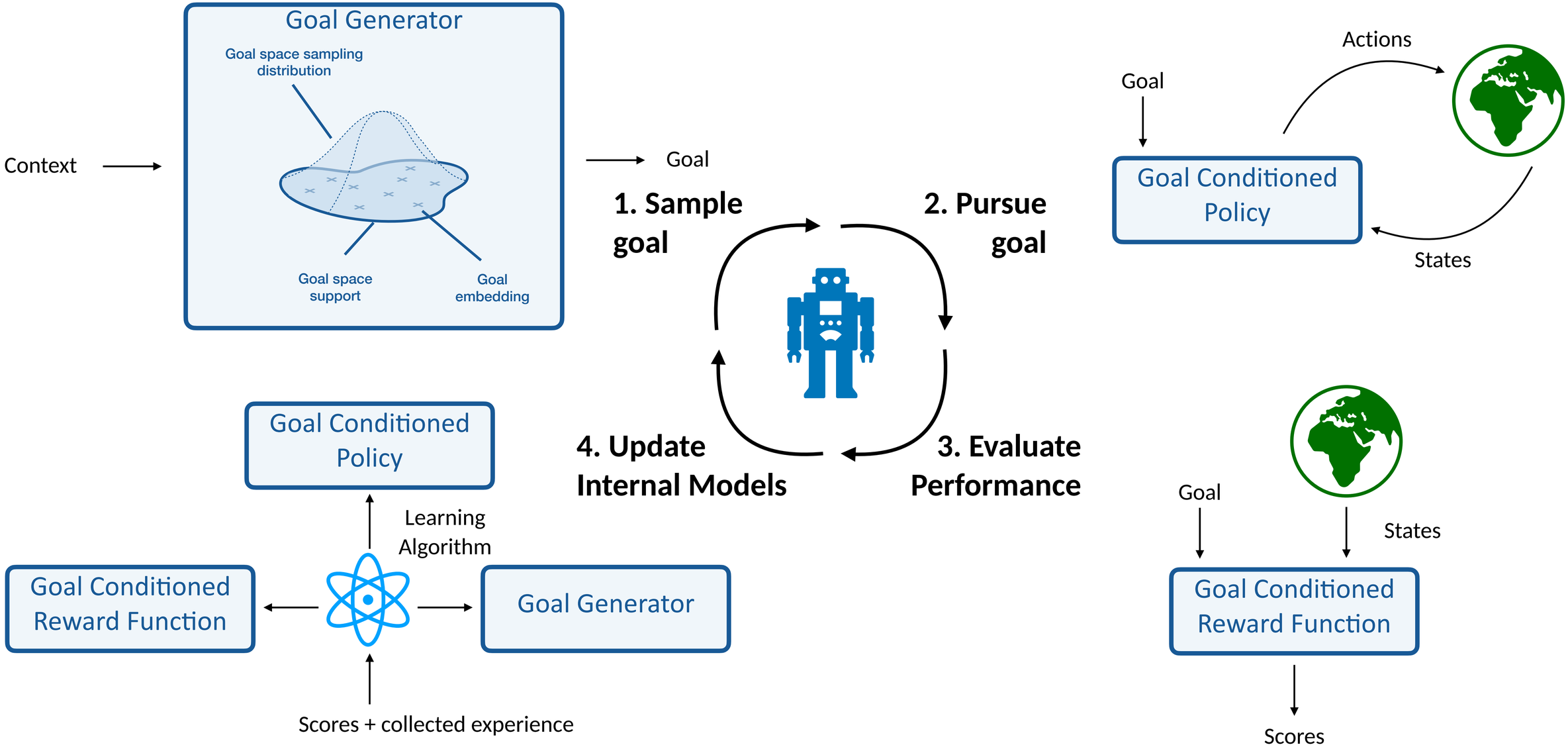

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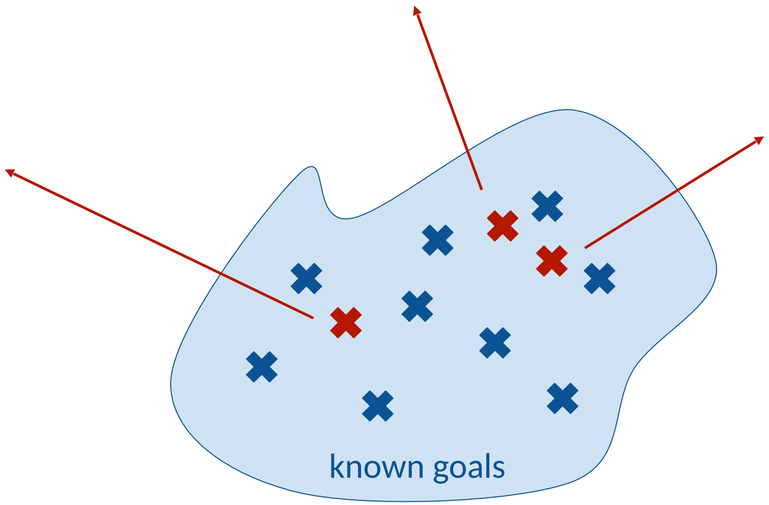
Towards Out of Distribution Goal Generation



Towards Out of Distribution Goal Generation

known goals

Goal generation:

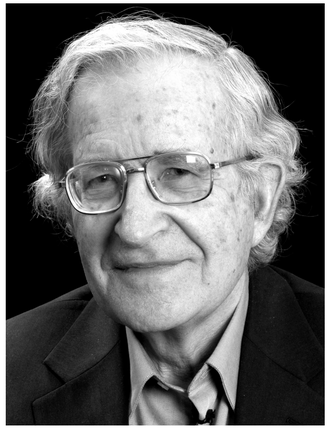
in-distribution

out-of-distribution

Language as a Cognitive Tool

Jean Piaget

Lev Vygotsky



Noam Chomsky

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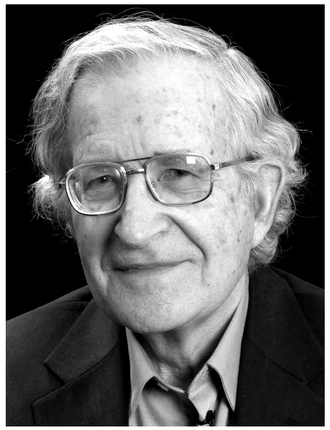
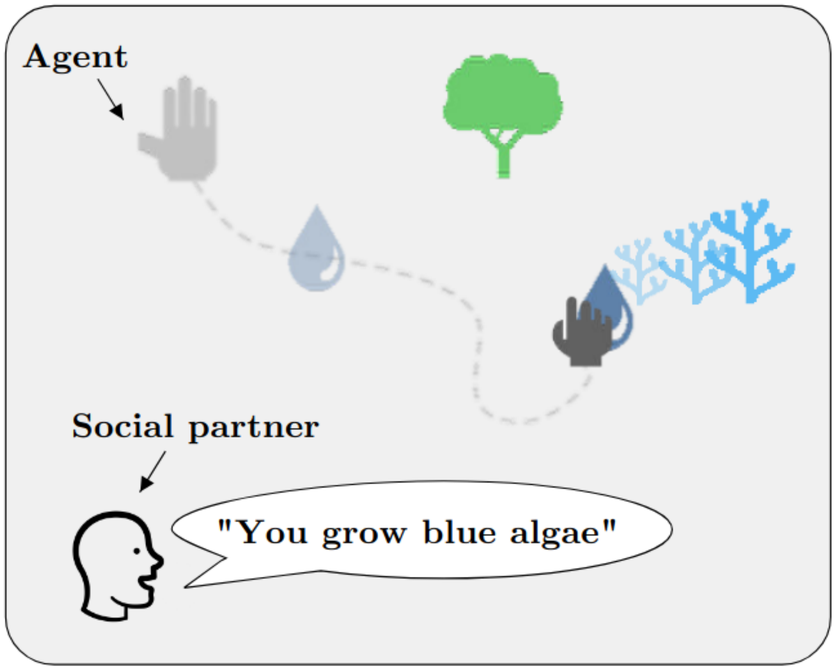


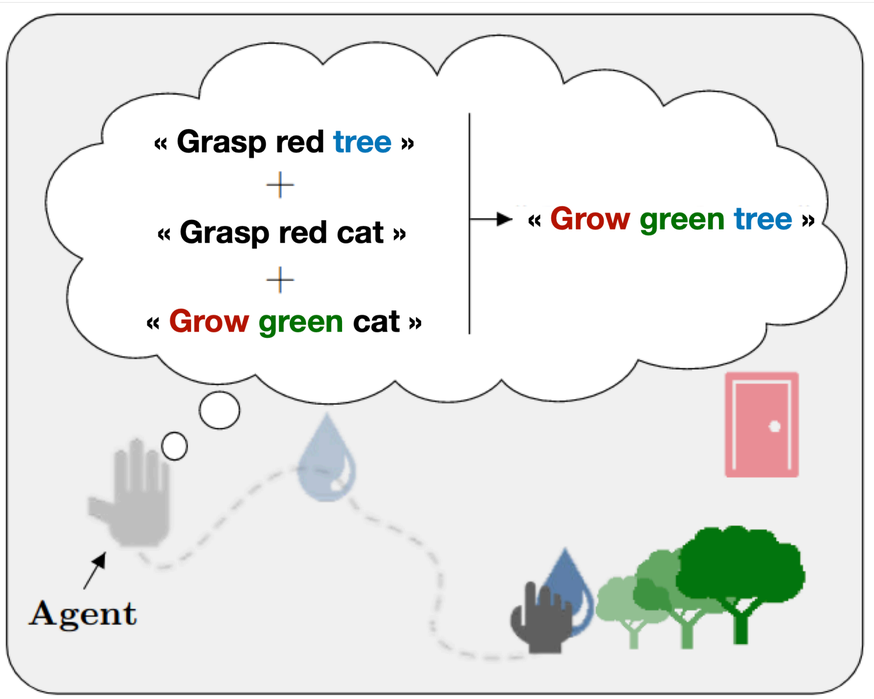
Noam Chomsky

“Colorless green ideas sleep furiously”

Imagine - Language goal imagination for RL agents



1. **Guided Exploration with a Social Partner:**
Learning the meaning of new sentences through interaction with a Social Partner



2. **Creative Autonomous Exploration:**
Imagining new goals by composing known sentences

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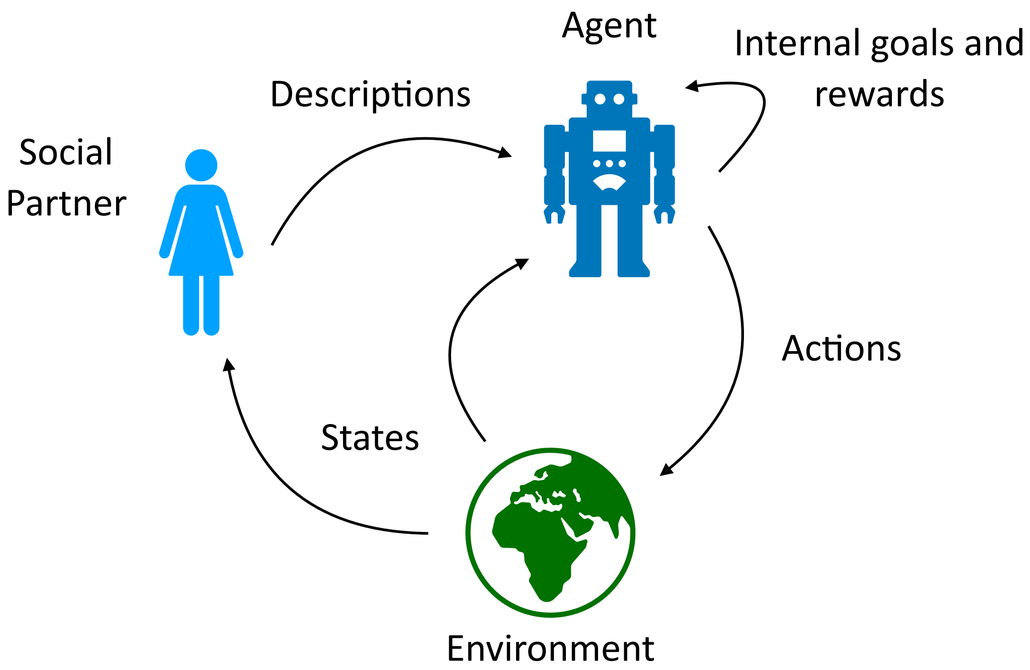
Imagine

1. Guided Exploration with a Social Partner

Social Autotelic Reinforcement Learning



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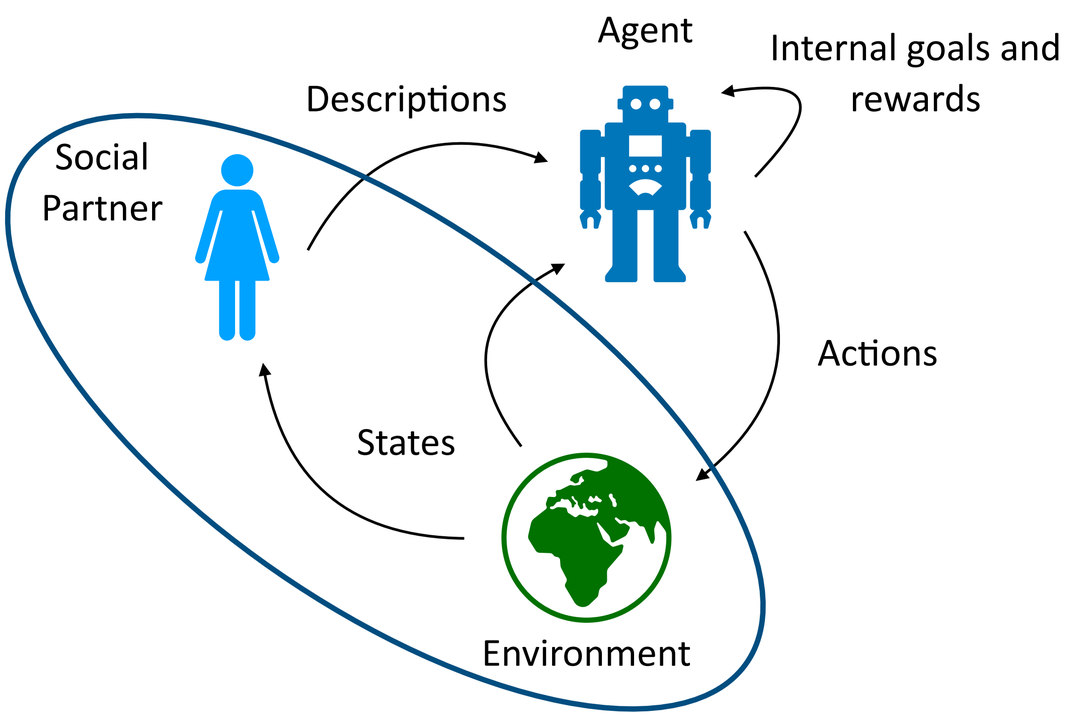
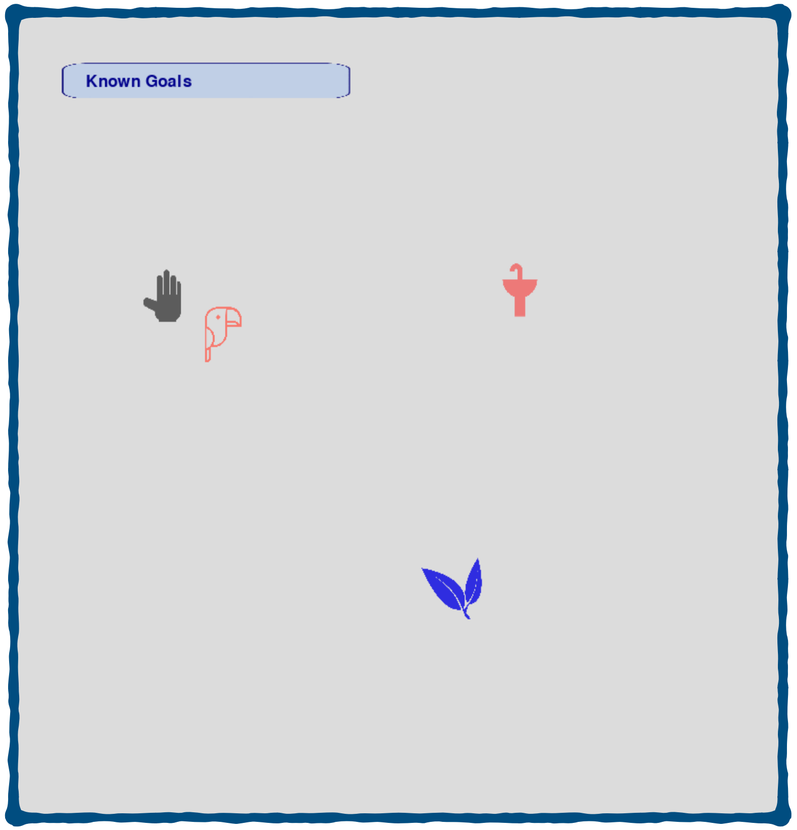


Environment and Social Partner



Playground Env:

- Procedurally generated
- Animals, plants, furniture, water, food

Compositional Dynamic:

- Animal + (food or water) —> Grow!
- Plant + water —> grow

Social Partner

Notifies the agent when a something interesting is happening (at the end of the episode)

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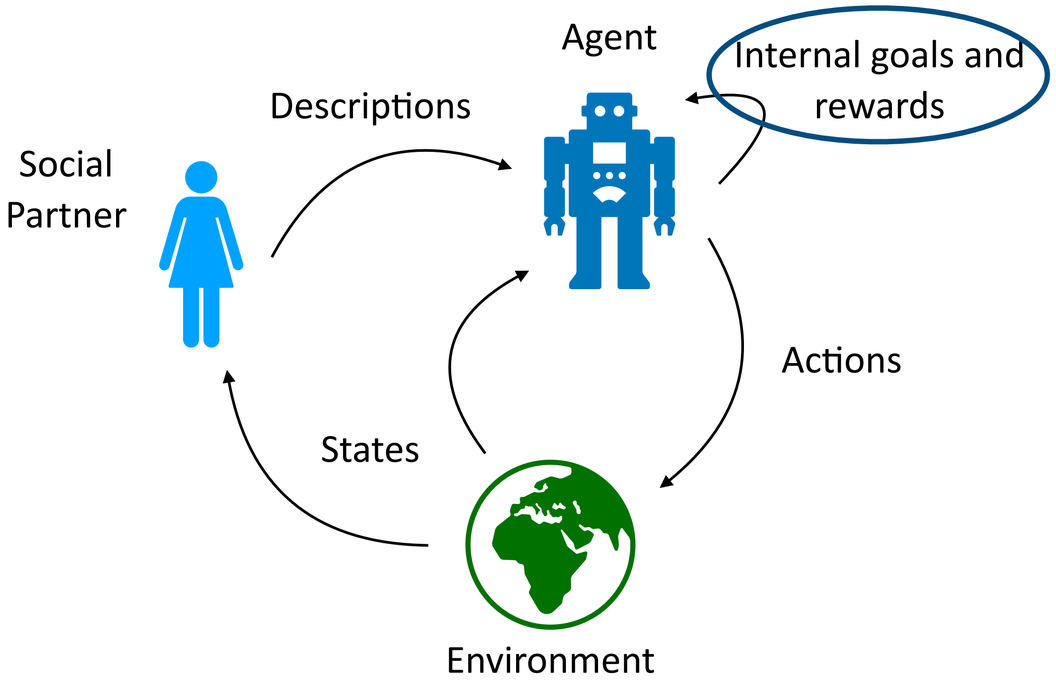
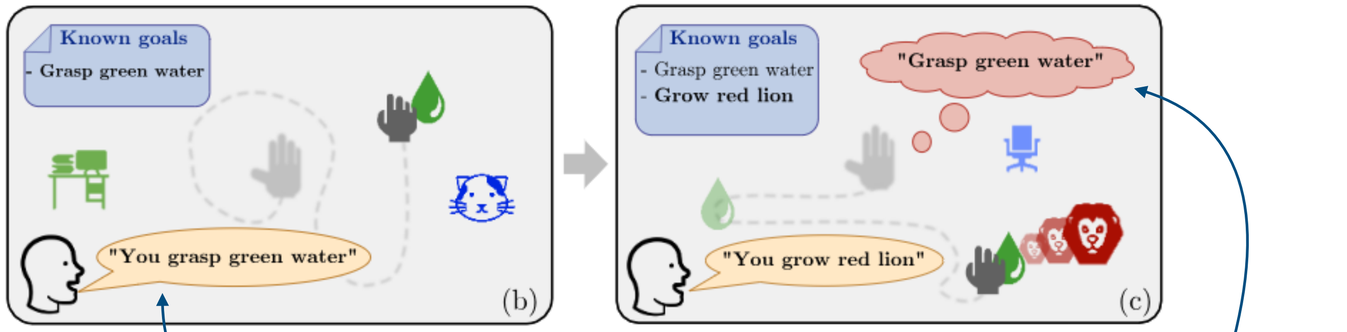


Internal goals and rewards

The agent converts the description it receives into targetable goals



1. Discovering a goal

2. Targeting it later on

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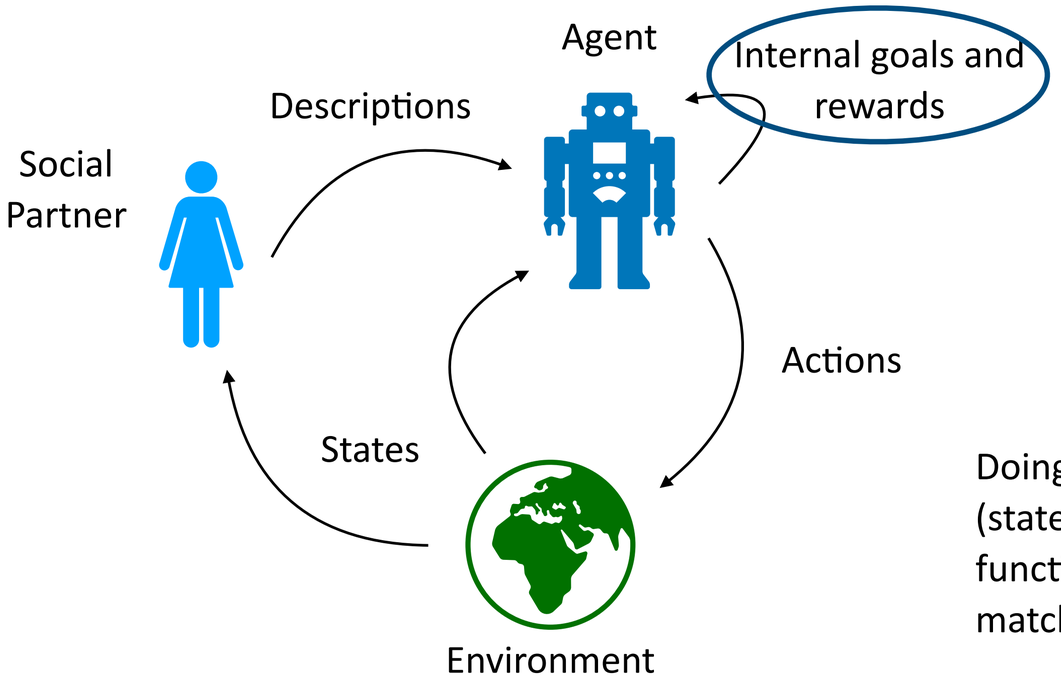

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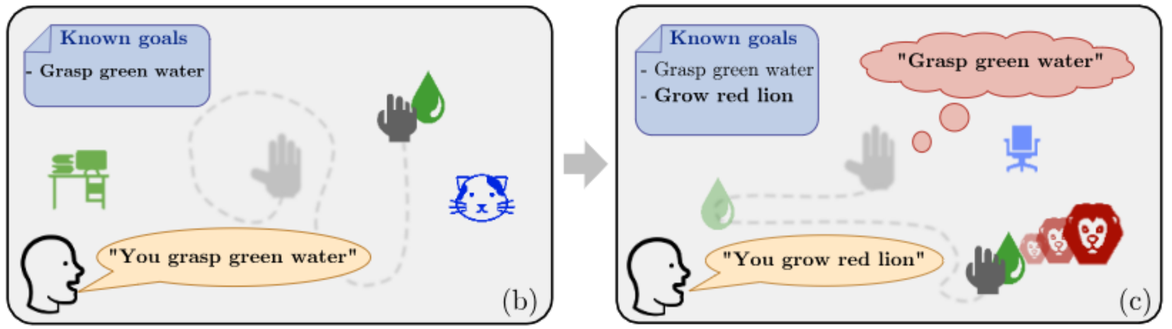
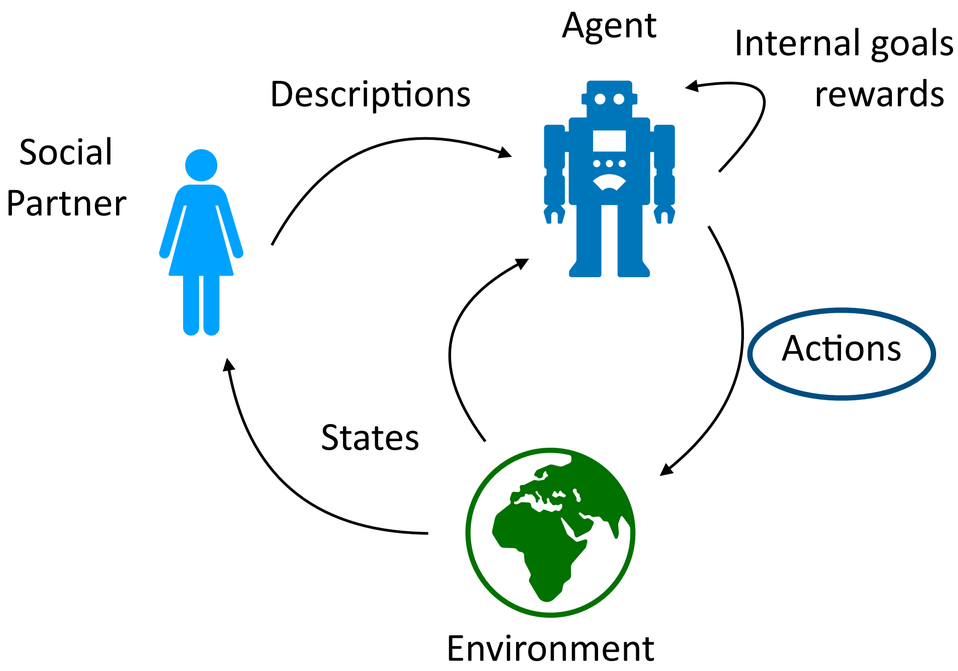


Doing so, it collects a dataset of pairs (state, description) to learn a reward function that detects when a state match with a description

Imagine

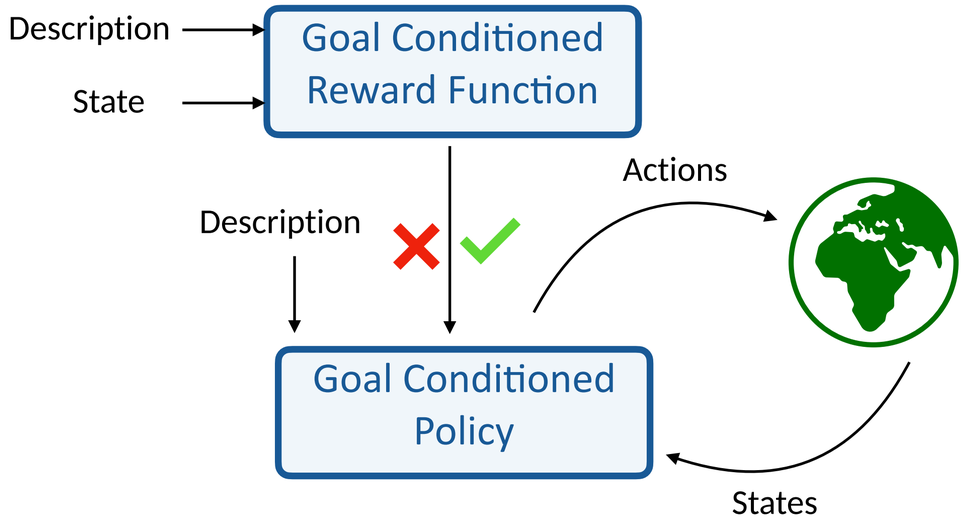
1. Guided Exploration with a Social Partner

Social Autotelic Reinforcement Learning



Goal conditioned policy

The agent then use the learned reward function to train a goal-conditioned policy via standard Reinforcement Learning



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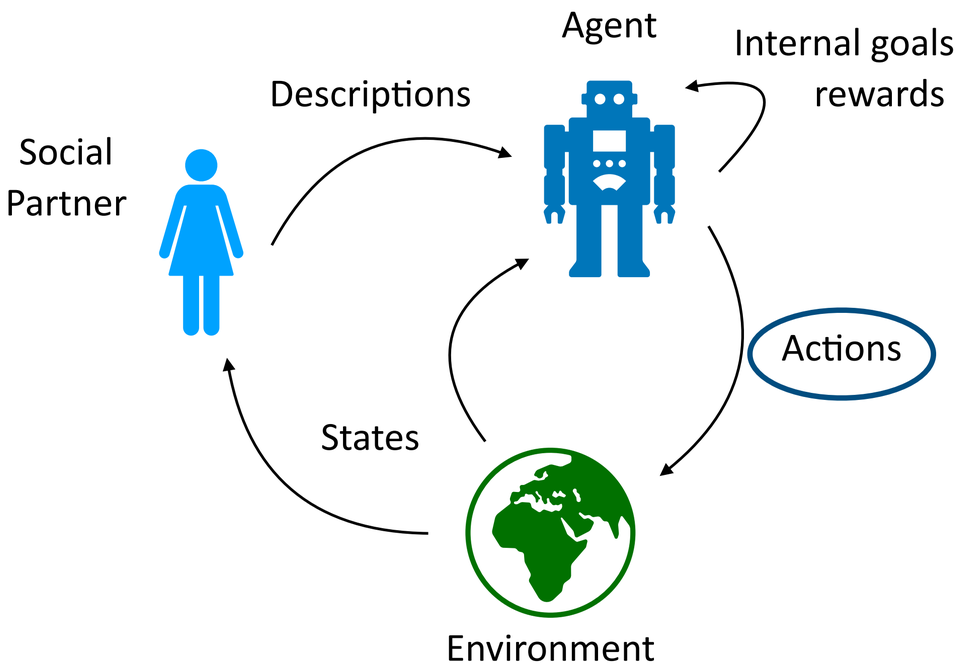

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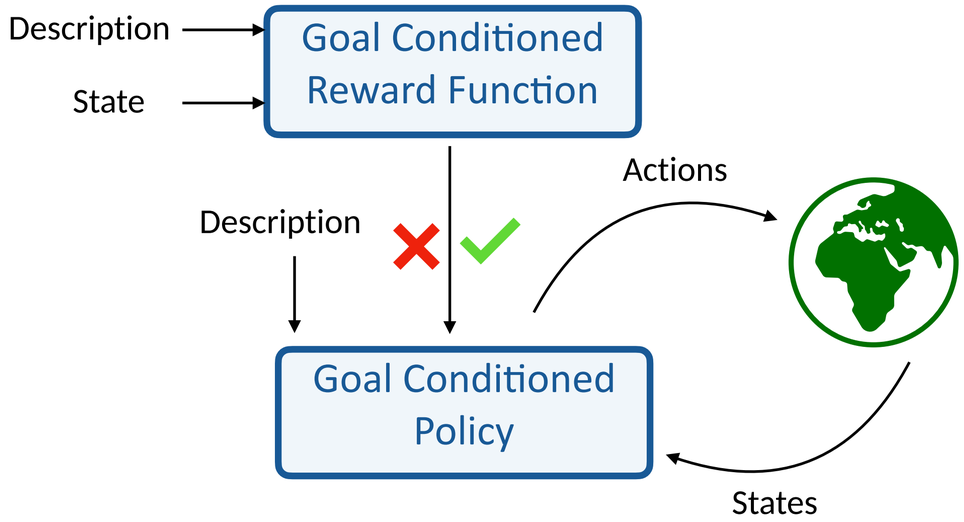

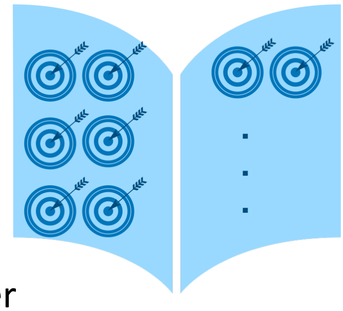

Following this procedure the agent learns a repertoire of skills containing the descriptions/goals communicated by the Social partner

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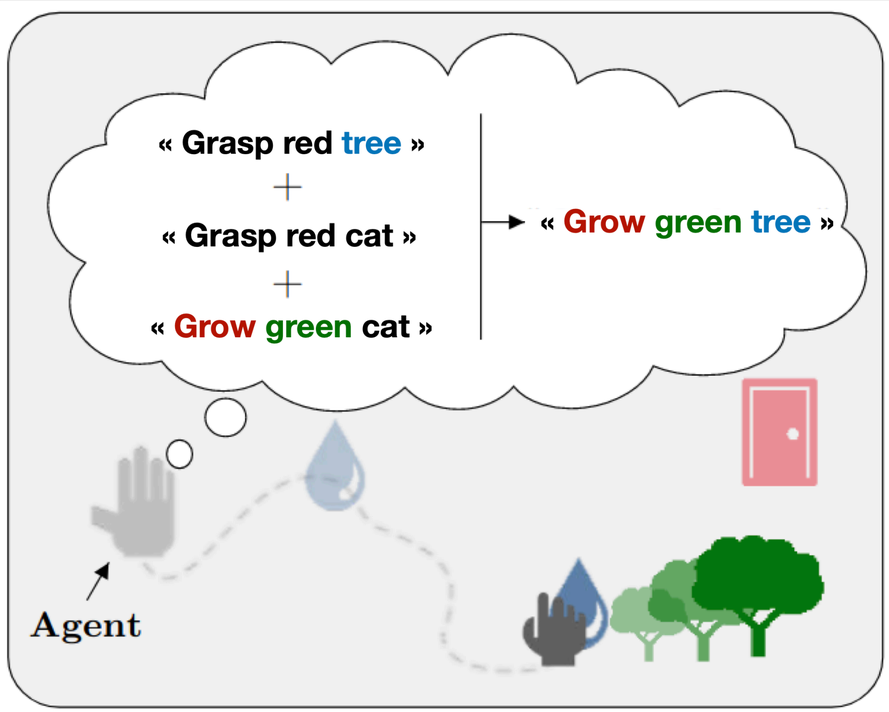
Imagine

2. Creative Autonomous Exploration

Goal Imagination



Details

- The social partner does not speak anymore
- The agent continues to sample known goals and learn to reach them
- In addition the agent performs **goal imagination:**
  It invents new goals by leveraging the compositionality of language

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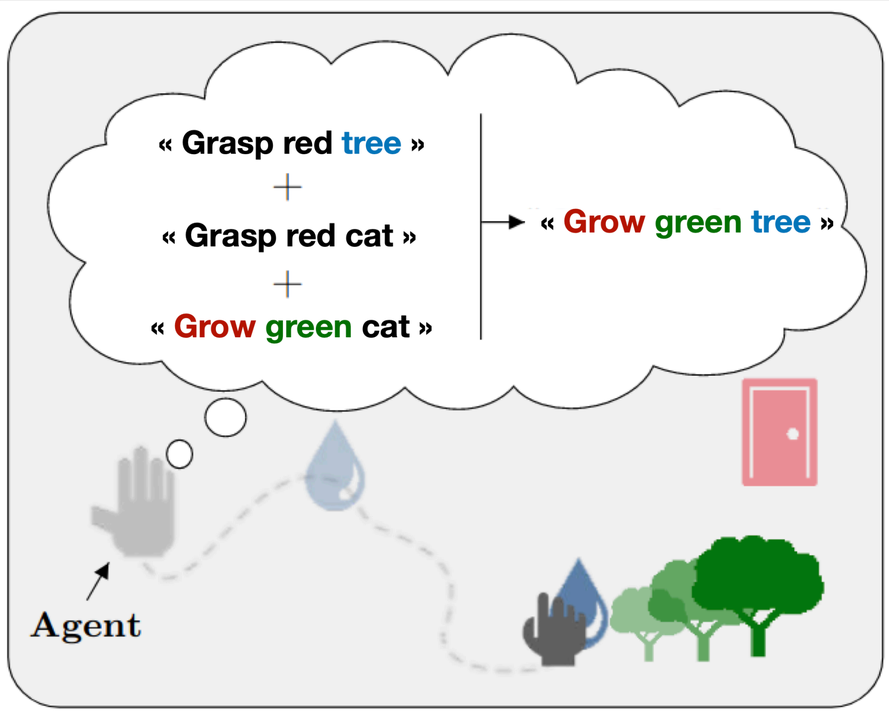


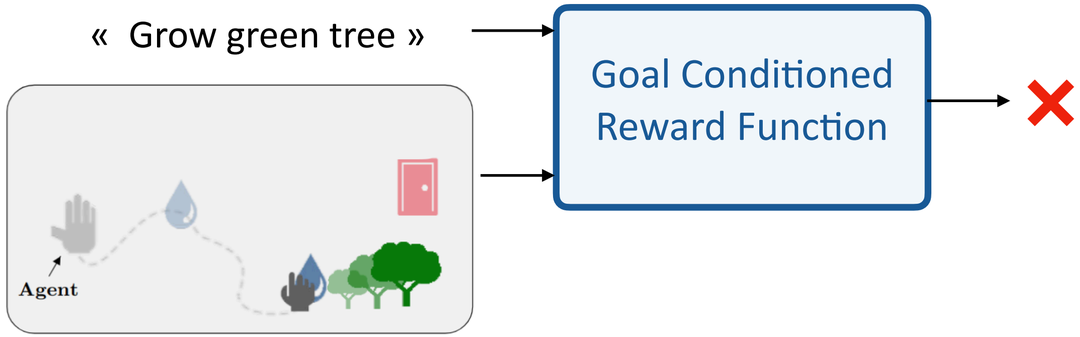
Two Important Challenges

1. Imagined goal descriptions must have a sufficient probability to be meaningful in the environment

—> Meaningless sentence: « Algae dog dog » or « red grasp tree »

2. Reward function needs to generalise on meaningful imagined goals

—> Reward function that does not generalise:



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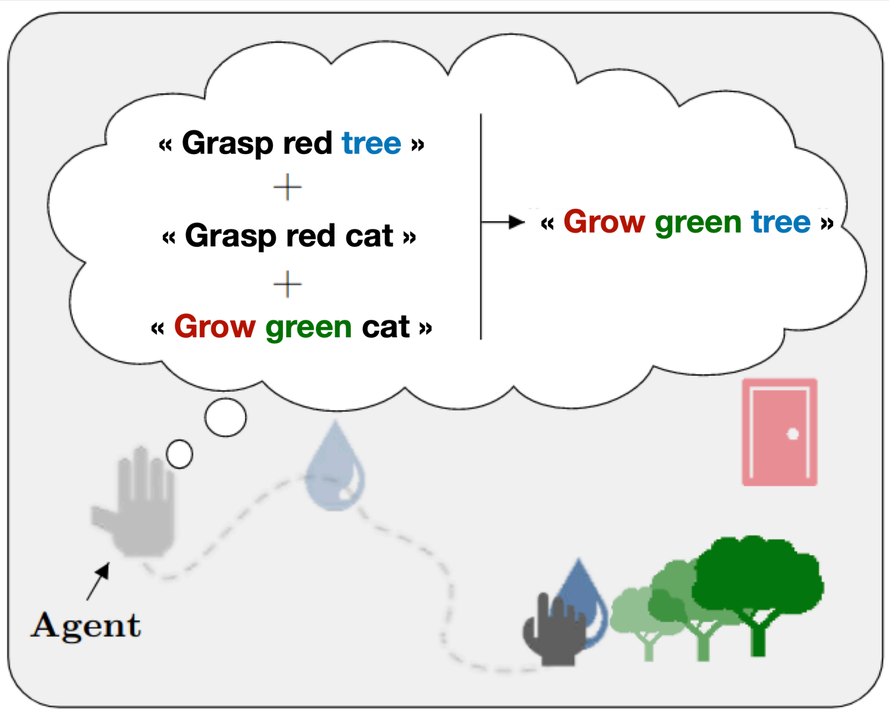

Two Important Challenges

1. Imagined goal descriptions must have a sufficient probability to be meaningful in the environment

—> Leverage the **construction grammar** framework used to model child language acquisition (Golderg, 2003; Tomasello, 2000) with pattern imitation and discovery of word equivalence classes

Creativity = Novelty x Appropriateness (Simonton, 2012)
Linguistic creativity: Generate new utterances (novelty) from a known grammar/known constructions (appropriateness)

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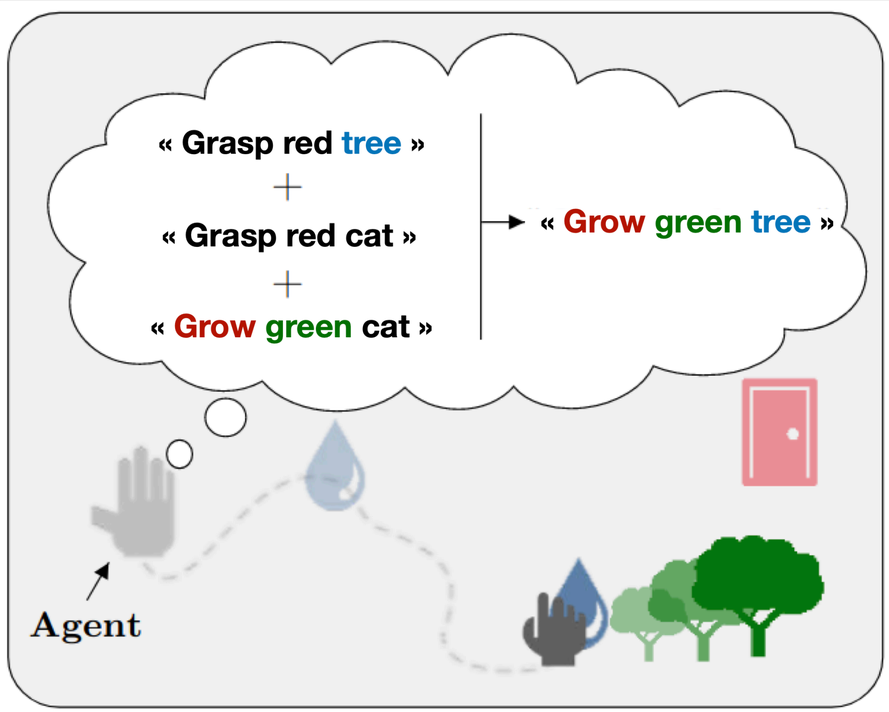

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2. Reward function needs to generalise on meaningful imagined goals

—> Use **object-factored architecture** for the architecture of the model couple with an attention mechanism

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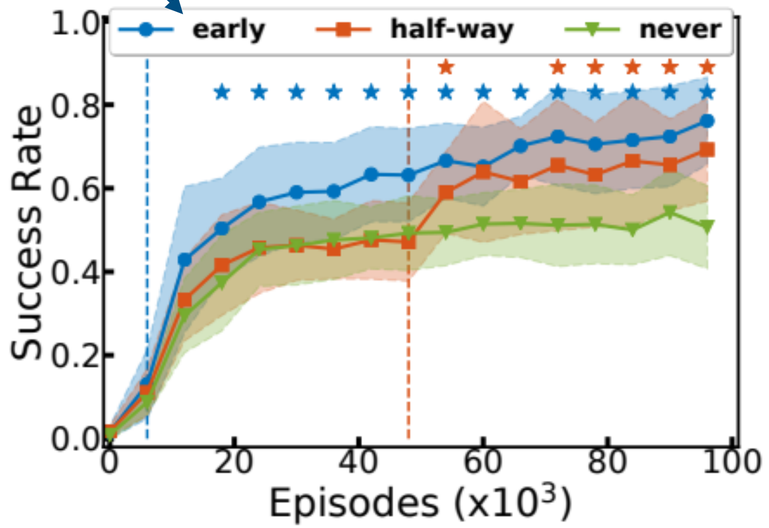
Imagine

2. Creative Autonomous Exploration

Results: Generalization and Exploration Boost

Measures of success rate on a **set of testing goals never communicated by the SP**

Indicates when goal imagination starts

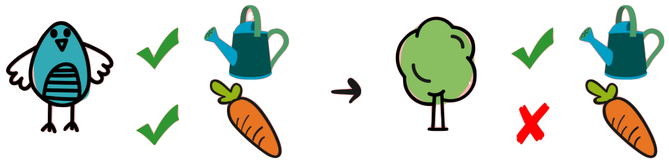


HOW BIG IS MY REPERTOIRE OF SKILLS?

Imagine

2. Creative Autonomous Exploration

Results: Generalization and Exploration Boost



Growing plant descriptions are never communicated by the Social Partner

Measures of success rate on a **set of testing goals never communicated by the SP**

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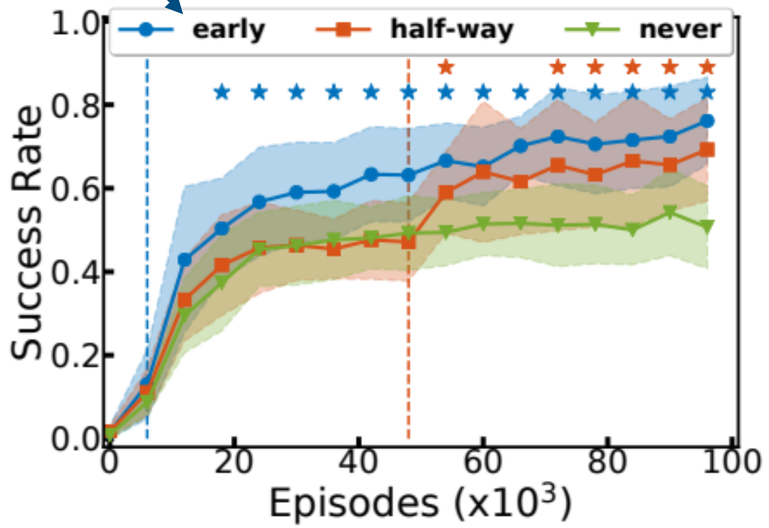

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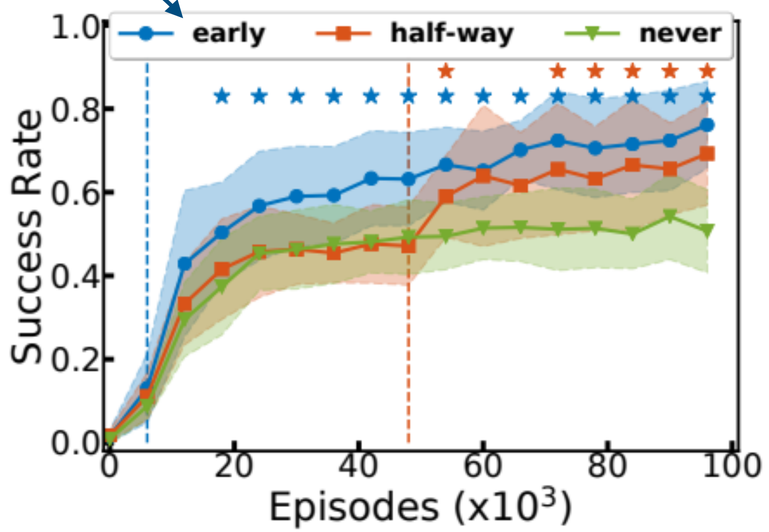
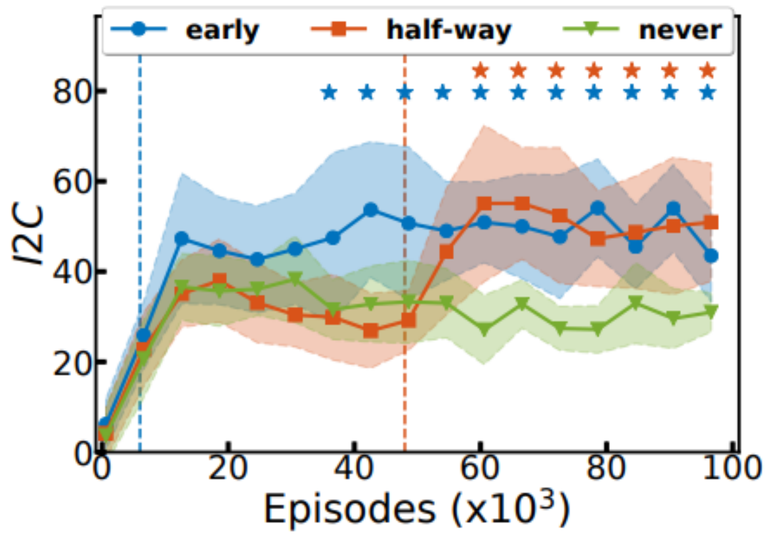


HOW BIG IS MY REPERTOIRE OF SKILLS?

Count of Interesting Interactions in the environment as a proxy to measure exploration



HOW GOOD AM I AT EXPLORING NEW INTERACTIONS

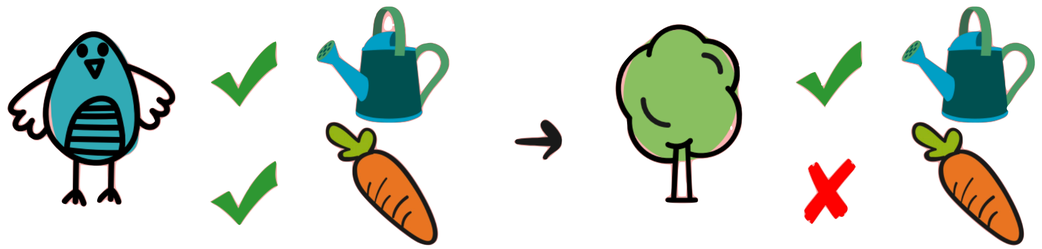
Ref: C Colas, T Karch, N Lair, JM Dussoux, C Moulin-Frier, PF Dominey, PY Oudeyer - NeurIPS 2020 - Language as a Cognitive Tool to Imagine Goals in Curiosity-Driven Exploration

Imagine

2. Creative Autonomous Exploration

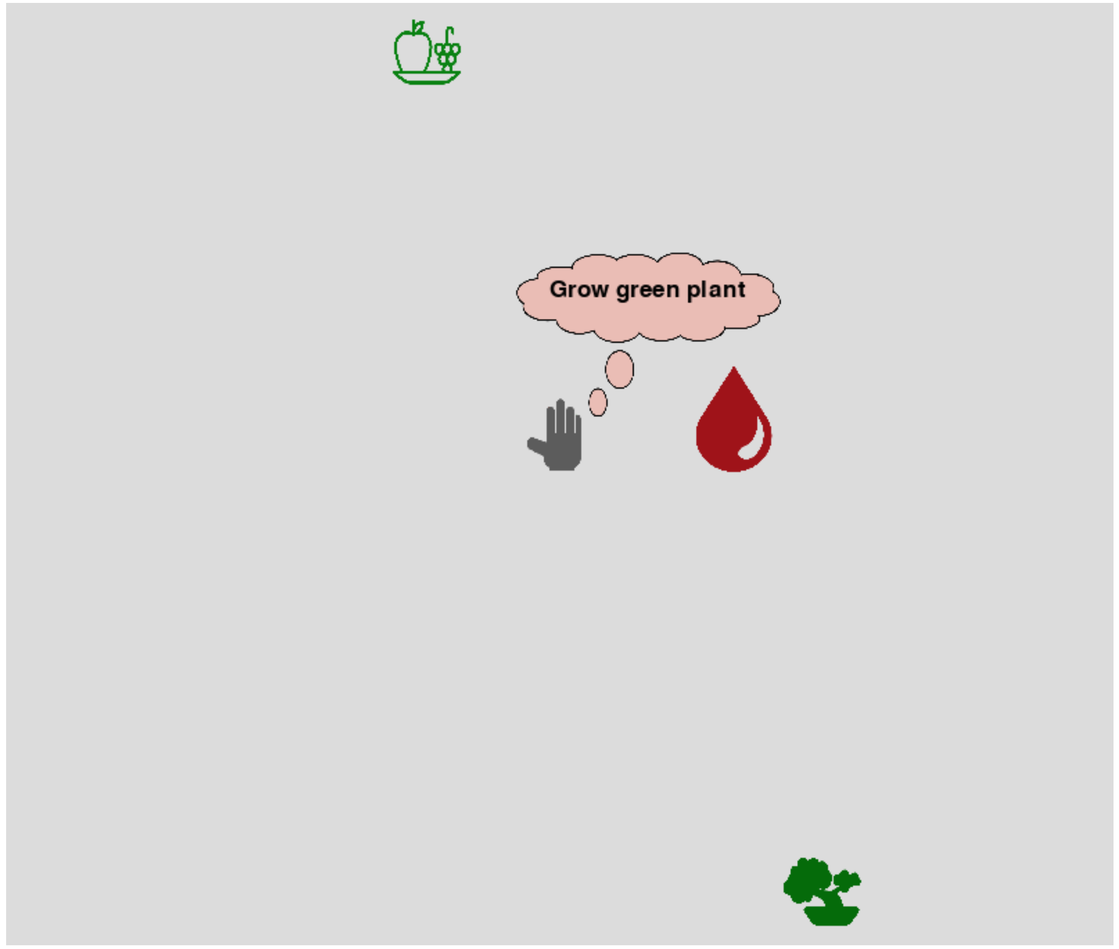
Results: Behavioral Adaptation

Objects have different interaction dynamics and the Social Partner never communicates descriptions of growing plants



Train Set Test Set

But agents correctly learn that they should not bring food to plants —> They correct overgeneralizations of their policy thanks to their reward function



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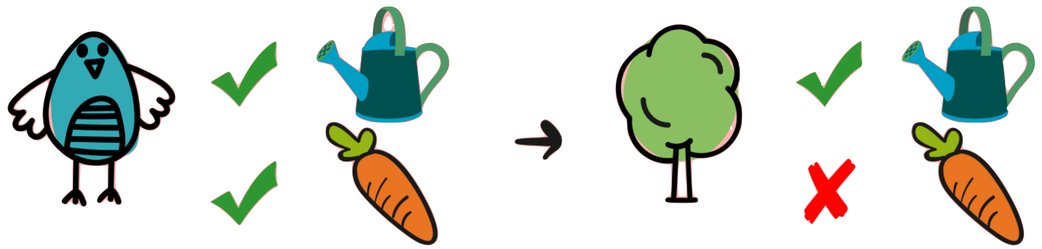

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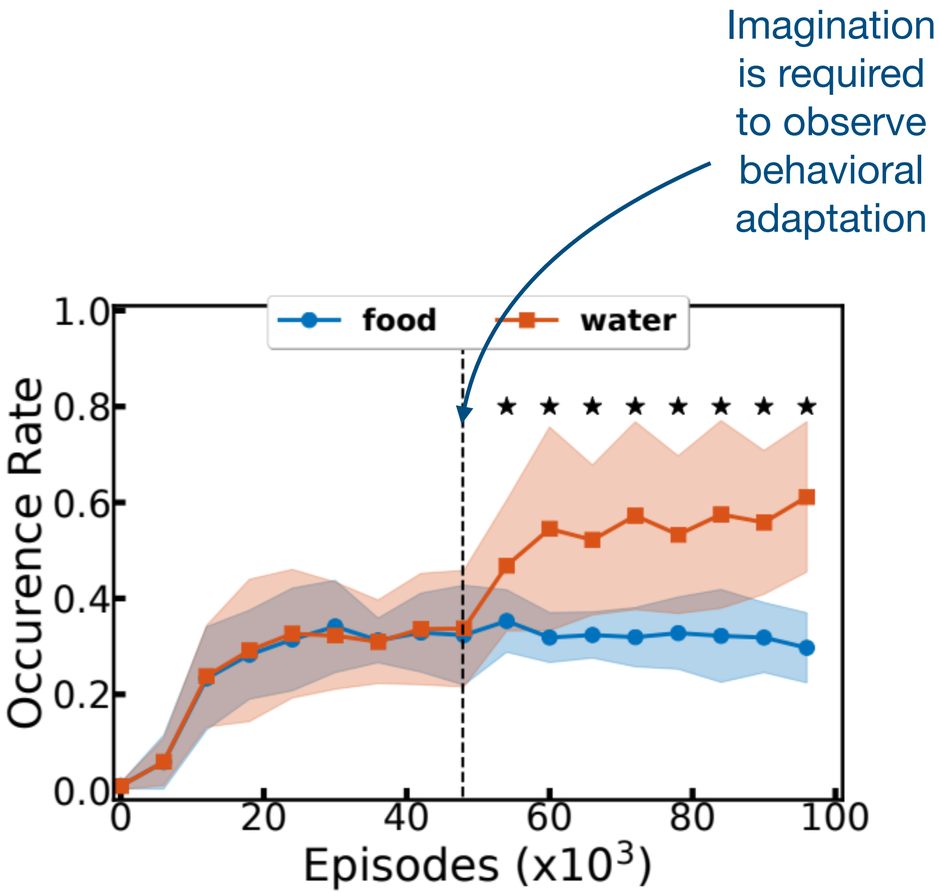

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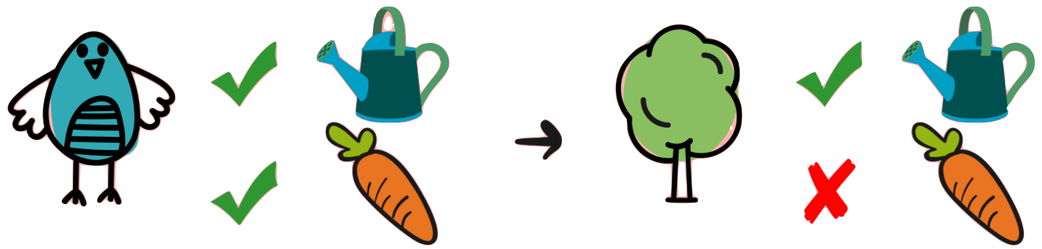


Train Set

Test Set

But agents correctly learn that they should not bring food to plants —> They correct overgeneralization of their policy thanks to their reward function

Without goal imagination

« Grow green tree » → Inference of goal conditioned policy → Agent brings food or water by transferring what it has learned on animals

With goal imagination

« Grow green tree » → Inference of reward function → Self training of goal conditioned policy → Agent brings water to plants

Imagine

Limitations

Natural Language

- Our goal imagination heuristic based on pattern matching and construction grammar is not likely to scale to the high combinatoriality of natural language

Imagination is not grounded

- In IMAGINE, goal imagination is not ‘grounded’: Imagined goals are not conditioned by the procedurally generated scene

  —> In real life, children are likely to imagine possible interactions based on the affordance they have in their environment

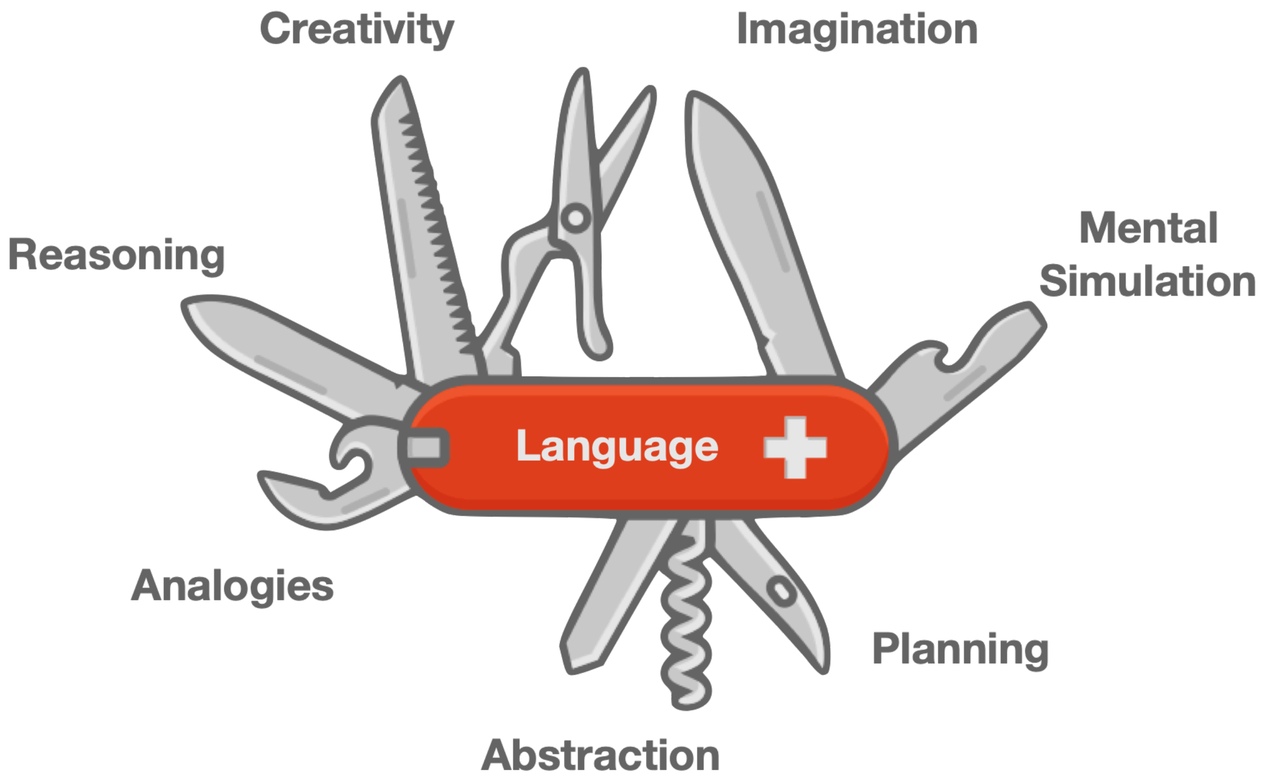
Imagination is limited to achievable goals

- In IMAGINE, new interactions can only be discovered if the reward functions **generalises** i.e. detects configurations that match imagined goals

  —> During pretend play, children discover interactions by making plans that are not necessarily achievable

Perspective: Towards Vygotskian Autotelic Agents

Language plays an important role for many of our cognitive functions



Blog Post: https://developmentalsystems.org/language_as_cognitive_tool_vygotskian_rl

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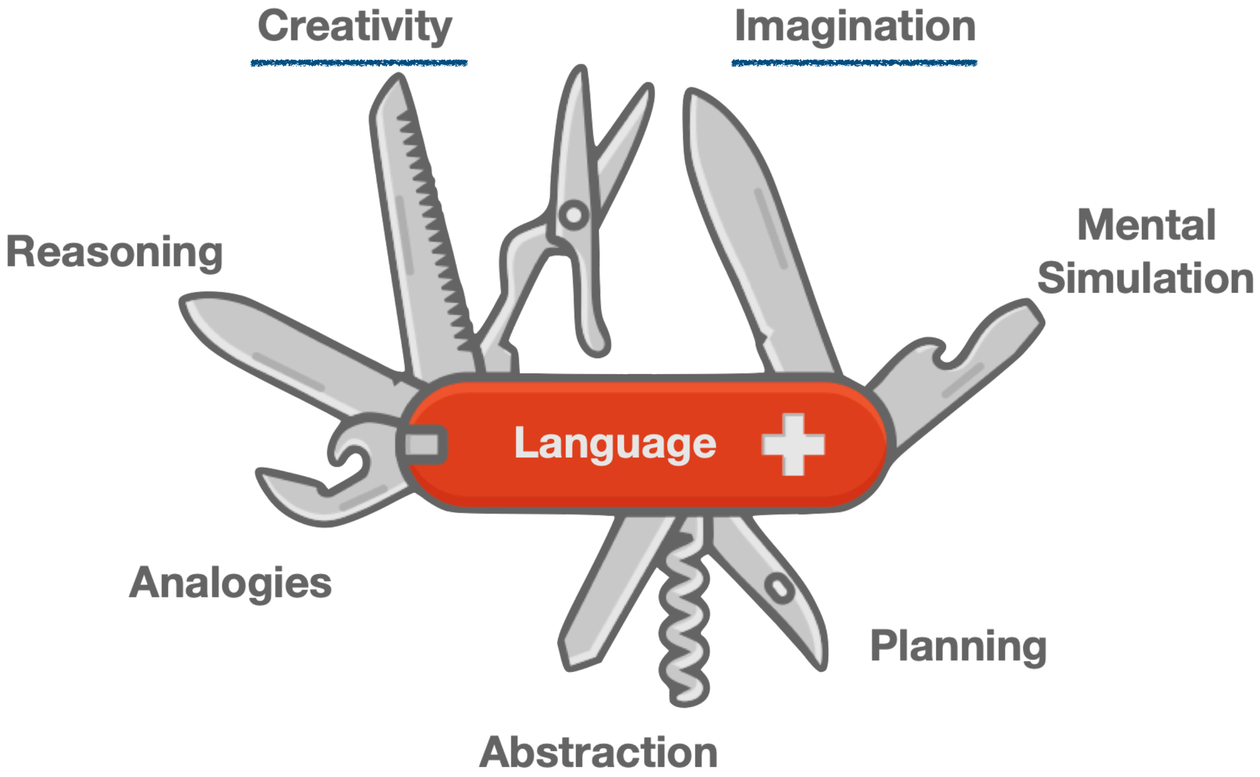

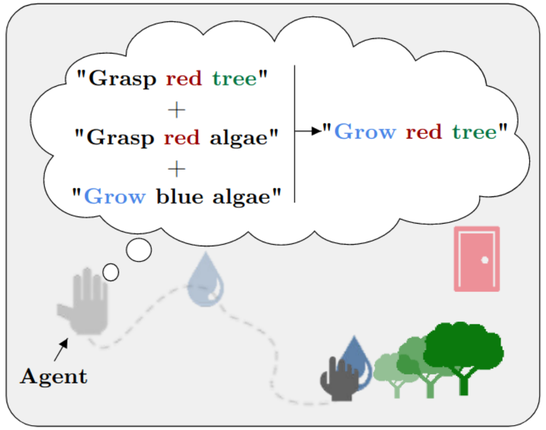

IMAGINE

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Take Aways

Three messages

1. **A Framework - Autotelic Deep RL agents:** Agents that (learn to) invent and sample their own goals, and (learn to) generate their own feedback for achieving these goals

2. Towards Out-of-Distribution Goal Generation:

Problem: Most implementations of Autotelic Agents often consider goal-as state (images or specific configurations). Moreover their goal sampler is limited to the generation of plans that are within the distribution of known goals.

—> **Language as a Cognitive Tool** enables creative exploration

3. Towards Vygotskian Autotelic Agents: Autonomous agent, like us, should have a rich linguistic mental life that help structure learning.

References

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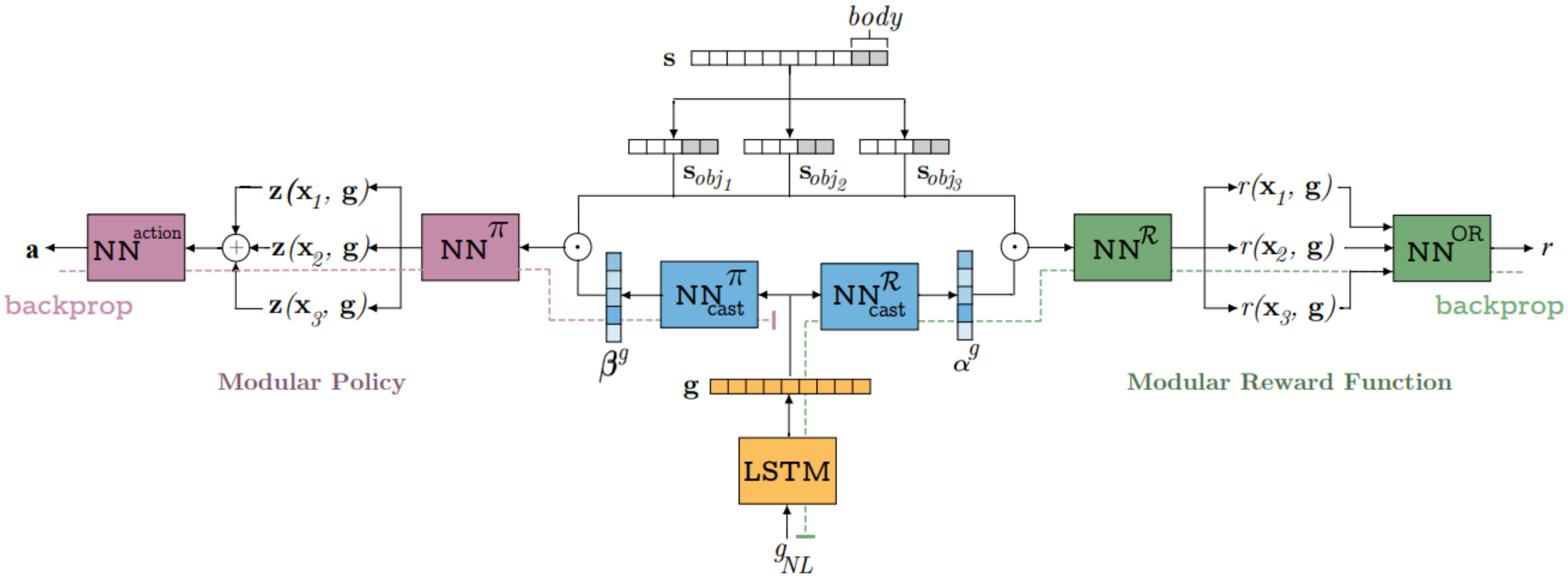
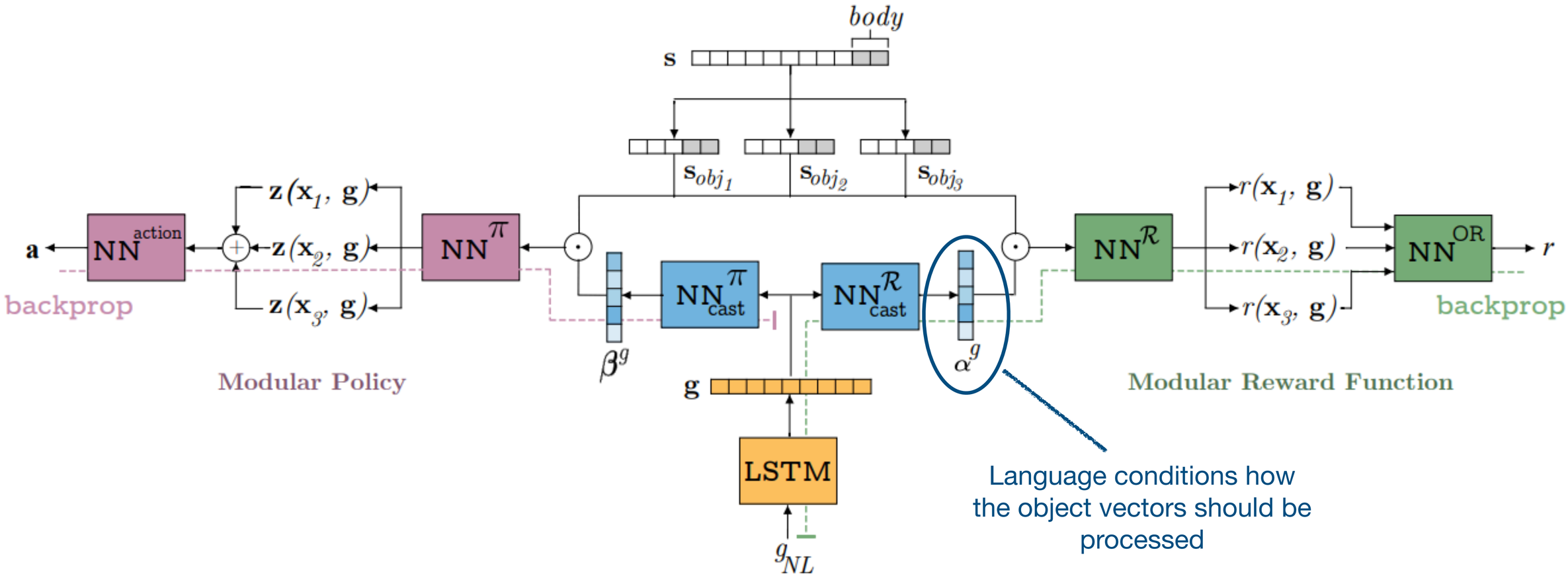
Object-factored architecture and Attention



Object-factored architecture and Attention



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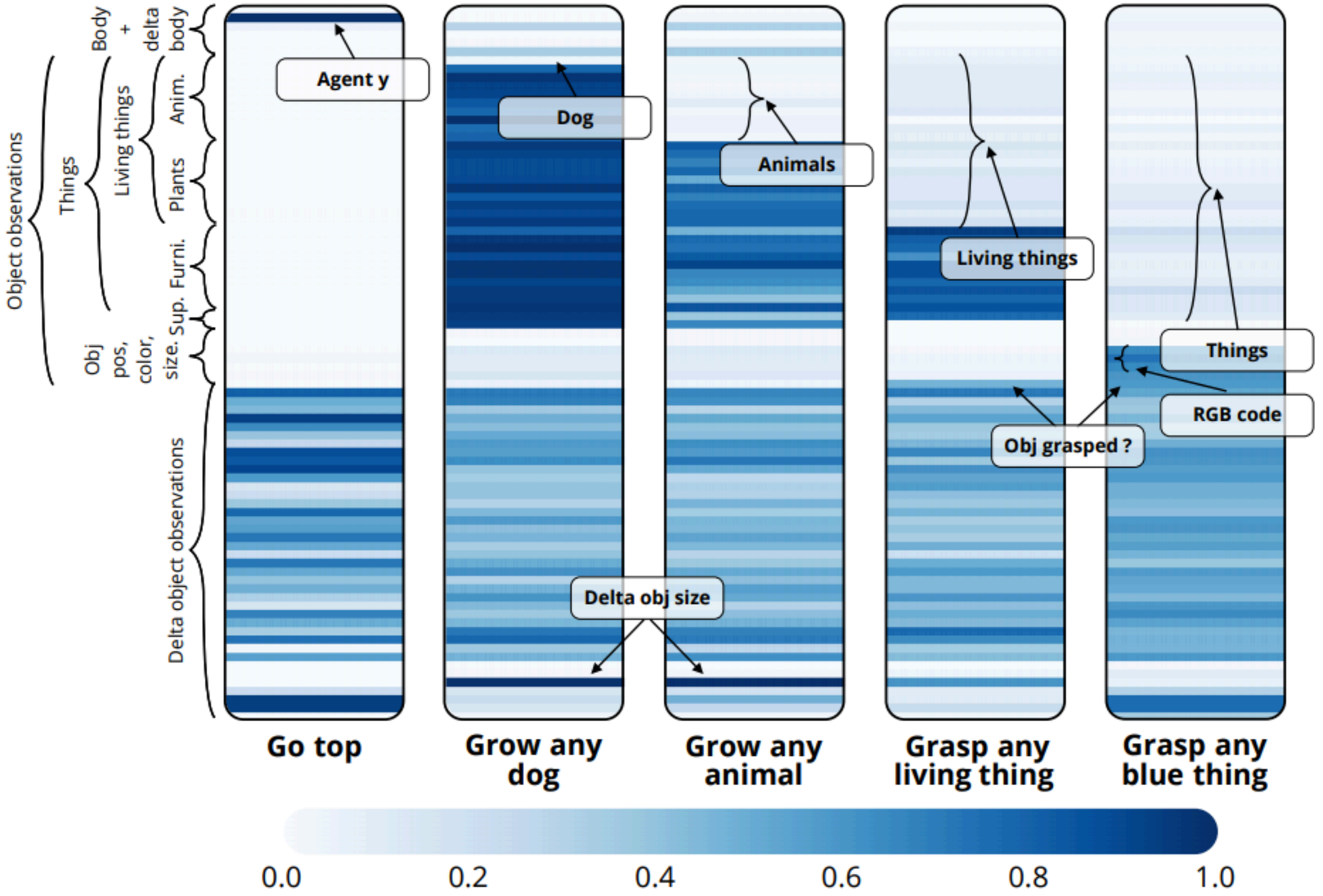

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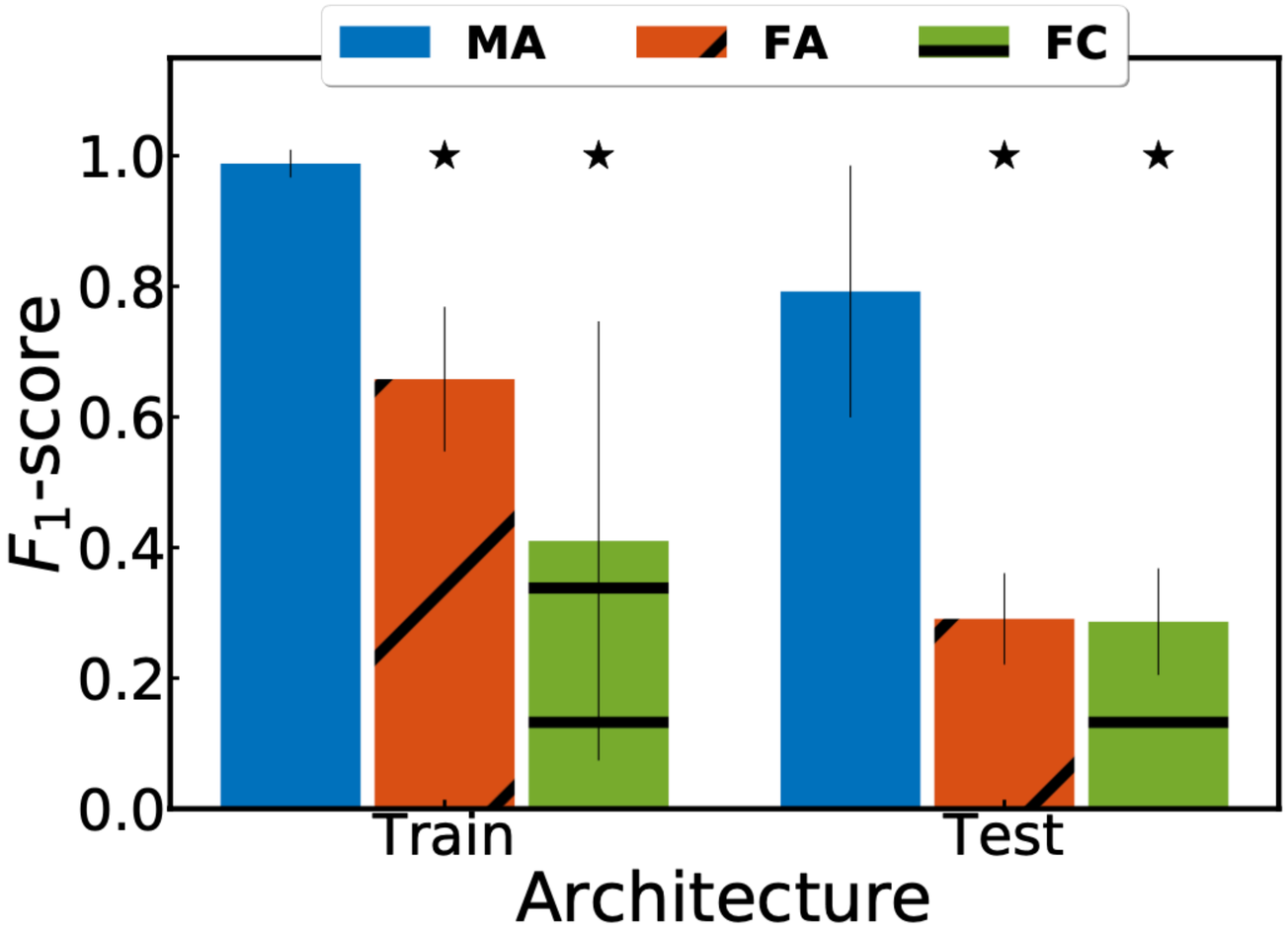

Perspective: Towards Vygotskian Autotelic Agents

Vygostkian Autotelic Agents must be **social**, autotelic and vygotskian

Social

Smart eve versus the iCub. iCub learns from how children play. Sandy Spence, CC BY-NC

Agents must align language with their behaviour to extract the meaning of sentences:
They need to project linguistic structures onto their sensorimotor experience and learn to recognize the building blocks that will help them plan, compose, generalize and create

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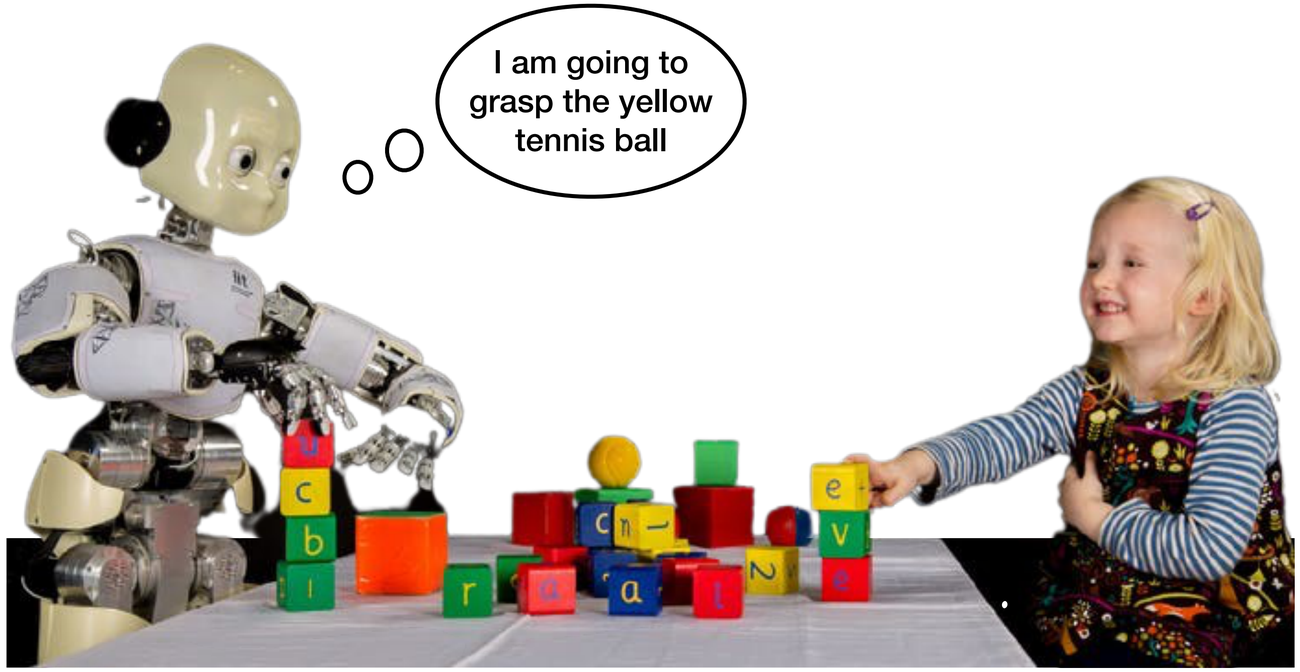
Perspective: Towards Vygotskian Autotelic Agents

Vygostkian Autotelic Agents must be social, **autotelic** and vygotskian

Autotelic



Smart eve versus the iCub. iCub learns from how children play. Sandy Spence, CC BY-NC

They need to be autotelic and organise their exploration so as to generate linguistic goals and learn to achieve them.

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Perspective: Towards Vygotskian Autotelic Agents

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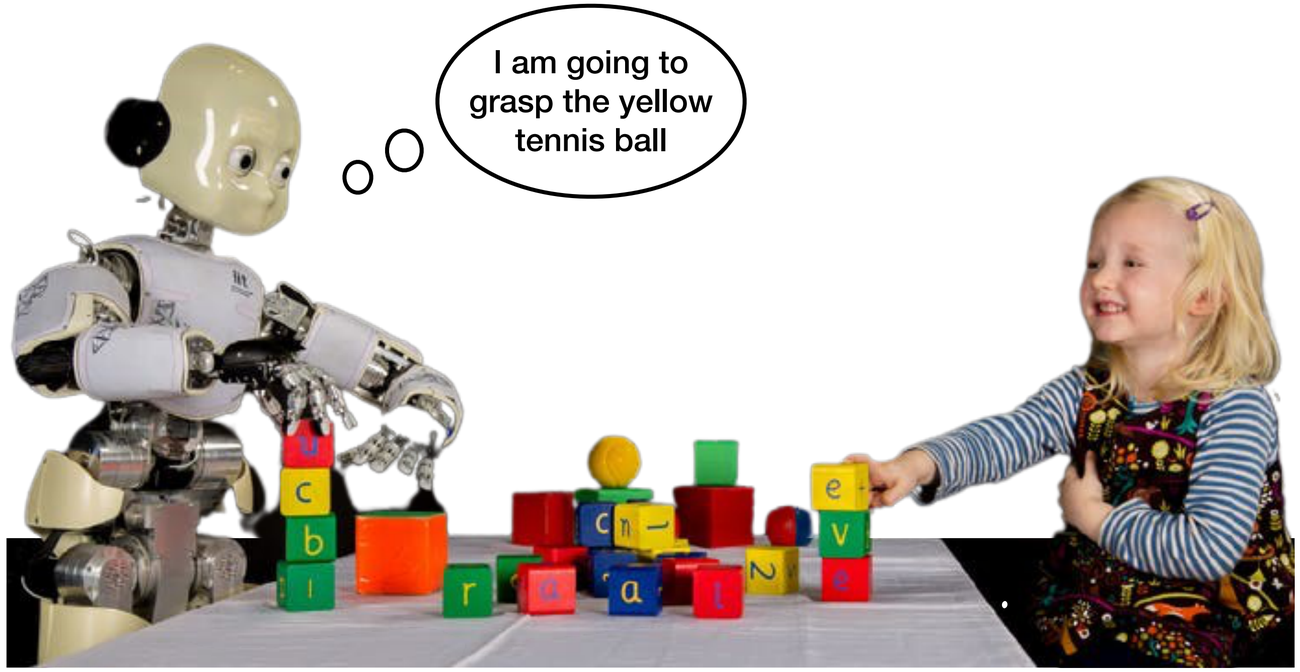
Vygostkian



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They need to be Vygostkian and use language as a cognitive tool

Language

↓

Internal Model Mimicking a cognitive function

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