Learning Communication Protocols

with Deep Reinforcement Learning

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Emergence of Communication and Language

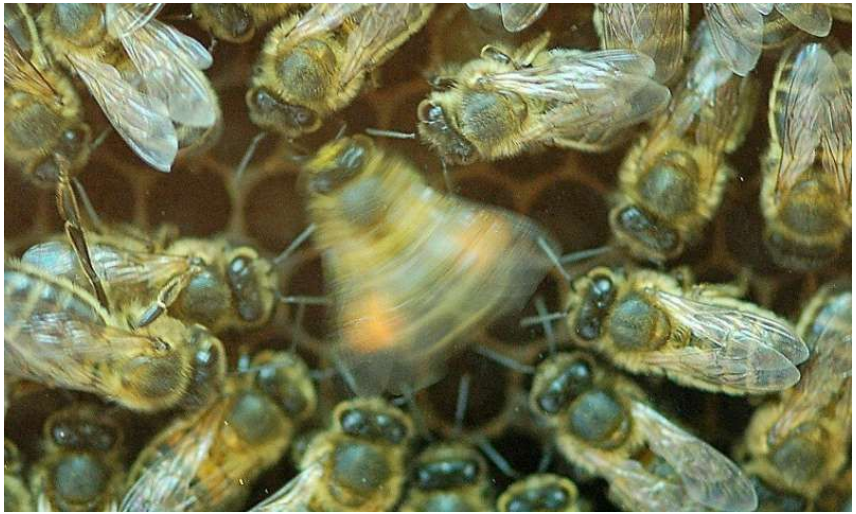
Does language learning need grounding in the world?

What is the origin of language?

How did intelligent agents in the real world learn a common communication protocol?

Can a population of agents learn to communicate to fulfill an objective?

Simple forms of communication in neural networks found in nature



Multi-Agent Environment

XXX			
	XX		
	X		
			XXX

- Grid with patches of “food”
- Objective: gather food on the grid in collaboration
- Agents can broadcast messages to other agents & select cells to explore

Deep Reinforcement Learning

- Task as partially observable Markov decision process (POMDP)
- Agents receive positive/negative reward by choosing actions
- Parameterized policy (neural network) maps states to action
- Actions consist of location in the grid and a message with a given length and vocabulary

Agent architecture

- Single policy:
  - state of agent *i* consists of previous messages and last observation *i*
  - action consists both of message to send and location to explore

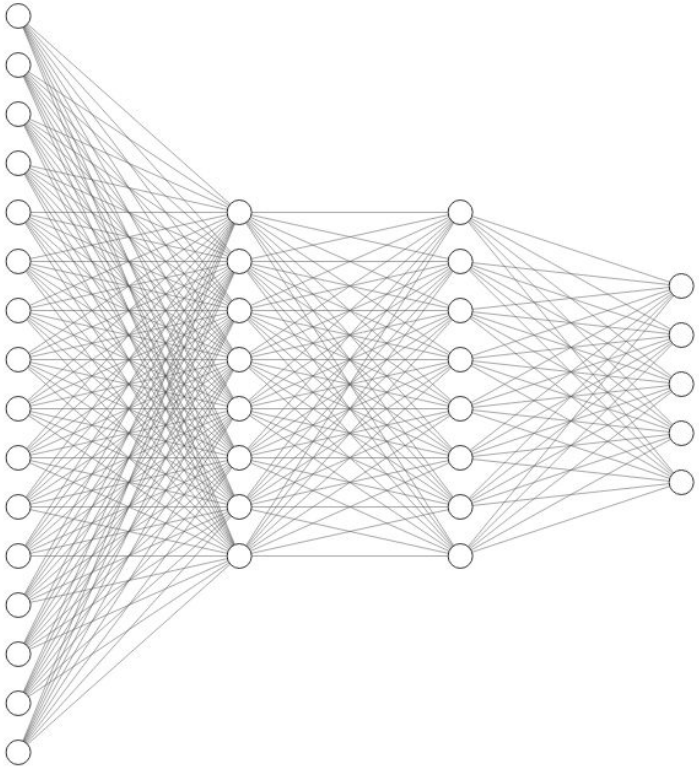
- Dual policy:
  - separate policies for sending messages and selecting location
  - message policy: observation *i* → message *i*
  - exploring policy: messages → location *i*

Proximal Policy Optimization

- State-of-the-art deep RL algorithm, used f.e. for OpenAI Five Dota
- Objective: $J(\theta) = E(R)$
- Standard Actor-Critic gradient: $\nabla_\theta J(\theta) = E[\nabla_\theta log(\pi_\theta(a|s))A^\pi(a|s)]$
- Advantage instead of reward: $A^\pi(a|s) = r - V^\pi$
- PPO gradient:

$$L(s, a, \theta_k, \theta) = min[\frac{\pi_\theta(a|s)}{\pi_k\theta(a|s)}A^\pi(s, a), clip(\frac{\pi_\theta(a|s)}{\pi_k\theta(a|s)}, 1 - \epsilon, 1 + \epsilon)A^\pi(s, a)]$$

messages +
observation



message +
location +
value estimate

N input units → 8 hidden units → 8 hidden units → M output units

Single Policy

sparsity:	popul.:	msg-len:	avg rew:
High	Small	3	~0.31
High	Big	3	~2.52
Low	Small	3	~10.11
Low	Big	3	~55.12
High	Small	0	~0.32
High	Big	0	~2.55
Low	Small	0	~10.09
Low	Big	0	~55.01

Dual Policy

sparsity:	popul.:	msg-len:	avg rew:
High	Small	3	~0.28
High	Big	3	~2.52
Low	Small	3	~10.01
Low	Big	3	~56.01
High	Small	0	~0.31
High	Big	0	~2.51
Low	Small	0	~10.22
Low	Big	0	~55.02

Result is that messages do not improve objective

→ *clearly no meaningful communication*

Conclusion & Further Research

- are RL algorithms fitted to learn policies that happen extremely rarely through random actions?
- would it help to use explicit gradient information of message impact on other agents?
- which exploration strategy does nature use to come up with communication?
- can new individuals learn from already trained agents?