Deep Learning for Robots

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The story:

1. Deep Learning is the future of robotics
2. There are very significant challenges
3. But some solutions emerging, as well.
End-to-end Deep Learning for robots?

2010: Speech Recognition

Audio $\rightarrow$ Acoustic Model $\rightarrow$ Phonetic Model $\rightarrow$ Language Model $\rightarrow$ Text

2012: Computer Vision

Pixels $\rightarrow$ Key Points $\rightarrow$ SIFT features $\rightarrow$ Deformable Part Model $\rightarrow$ Labels

2014: Machine Translation

Text $\rightarrow$ Reordering $\rightarrow$ Phrase Table/Dictionary $\rightarrow$ Language Model $\rightarrow$ Text

2017: Robotics?

Sensors $\rightarrow$ Perception $\rightarrow$ World Model $\rightarrow$ Planning $\rightarrow$ Control $\rightarrow$ Action

slide from V. Vanhoucke
End-to-end Deep Learning for robots?

2010: Speech Recognition
Audio → Audio → Deep Net → Text

2012: Computer Vision
Pixels → Pixels → Deep Net → Labels

2014: Machine Translation
Text → Text → Deep Net → Text

2017: Robotics?
Sensors → Sensors → Deep Net → Action

slide from V. Vanhoucke
Robotics is different

![Image with a red 'X' and 'LABELS' text]
Robotics is different

SENSORS \leftrightarrow ACTIONS
Reinforcement Learning

GOAL

OBSERVATIONS

REWARD?

Agent

Environment

ACTIONS
Deep Reinforcement Learning

GOAL

OBSERVATIONS

REWARD?

ACTIONS

neural network

Agent

Environment
Could deep RL allow robots to learn end-to-end?

- Sensorimotor control?
Space Invaders

https://www.youtube.com/watch?v=wHDxF5N700Q

[Mnih et al, Playing Atari with Deep Reinforcement Learning, 2014]
General Atari Player

https://www.youtube.com/watch?v=Erkt7HelEco

9DOF Random reacher

\[ \text{action}_i \in \mathbb{R}^9 \]

https://youtu.be/u0M3PvTgTcE
Could deep RL allow robots to learn end-to-end?

- Sensorimotor control
Could deep RL allow robots to learn end-to-end?

- Sensorimotor control
- Exploration of complex spaces?
Maze navigation

https://youtu.be/zHhbypmKaj0
Could deep RL allow robots to learn end-to-end?

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Could deep RL allow robots to learn end-to-end?

- Sensorimotor control
- Exploration of complex spaces
- Strategy and decision making?
Lesson: use supervised learning when possible
Could deep RL allow robots to learn end-to-end?

- Sensorimotor control
- Exploration of complex spaces
- Strategy and decision making
So, where are the superhuman robots?

*Not so fast …*

- Deep RL is very data inefficient - how can it learn on real robots?

24 hours in simulation with 16 threads …
… 55 days on the real Jaco arm
Two methods to speed up Deep RL for robots

1. Train in simulation, then transfer to real robot
   - Benefit is obvious
   - Hard to do in practice
Progressive Neural Networks
Progressive Neural Networks
Progressive Neural Networks
Progressive Neural Networks
Sim-to-Real
Sim-to-Real

Task A                   Task A             Task B
Sim-to-Real: 3d reacher

https://www.youtube.com/watch?v=YZz5Io_ipi8
Sim-to-Real: 2d reacher with moving target

www.youtube.com/watch?v=e78J1K5LKCi
Two methods to speed up Deep RL for robots

2. Learn with auxiliary tasks
   ● Accelerate and stabilise reinforcement learning
Navigation mazes

Game episode:
1. Random start
2. Find the goal (+10)
3. Teleport randomly
4. Re-find the goal (+10)
5. Repeat (limited time)
**NAV agent ingredients:**

1. Convolutional encoder and RGB inputs
2. Stacked LSTM
3. Additional inputs (reward, action, and velocity)
4. RL: Asynchronous advantage actor critic (A3C)
5. Auxiliary task 1: Depth predictor
6. Auxiliary task 2: Loop closure predictor

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![Diagram](image-url)

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Variations in architecture

a. FF A3C
b. LSTM A3C
c. Nav A3C
d. Nav A3C +D₁D₂L
Results: Auxiliary tasks speed up RL ten-fold!
Large static maze

https://youtu.be/lNoaTyMZsWI
Learning to navigate in complex environments

arxiv.org/abs/1611.03673
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Thank you!

We are hiring! joinus@deepmind.com, raia@google.com