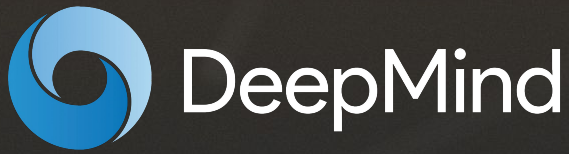
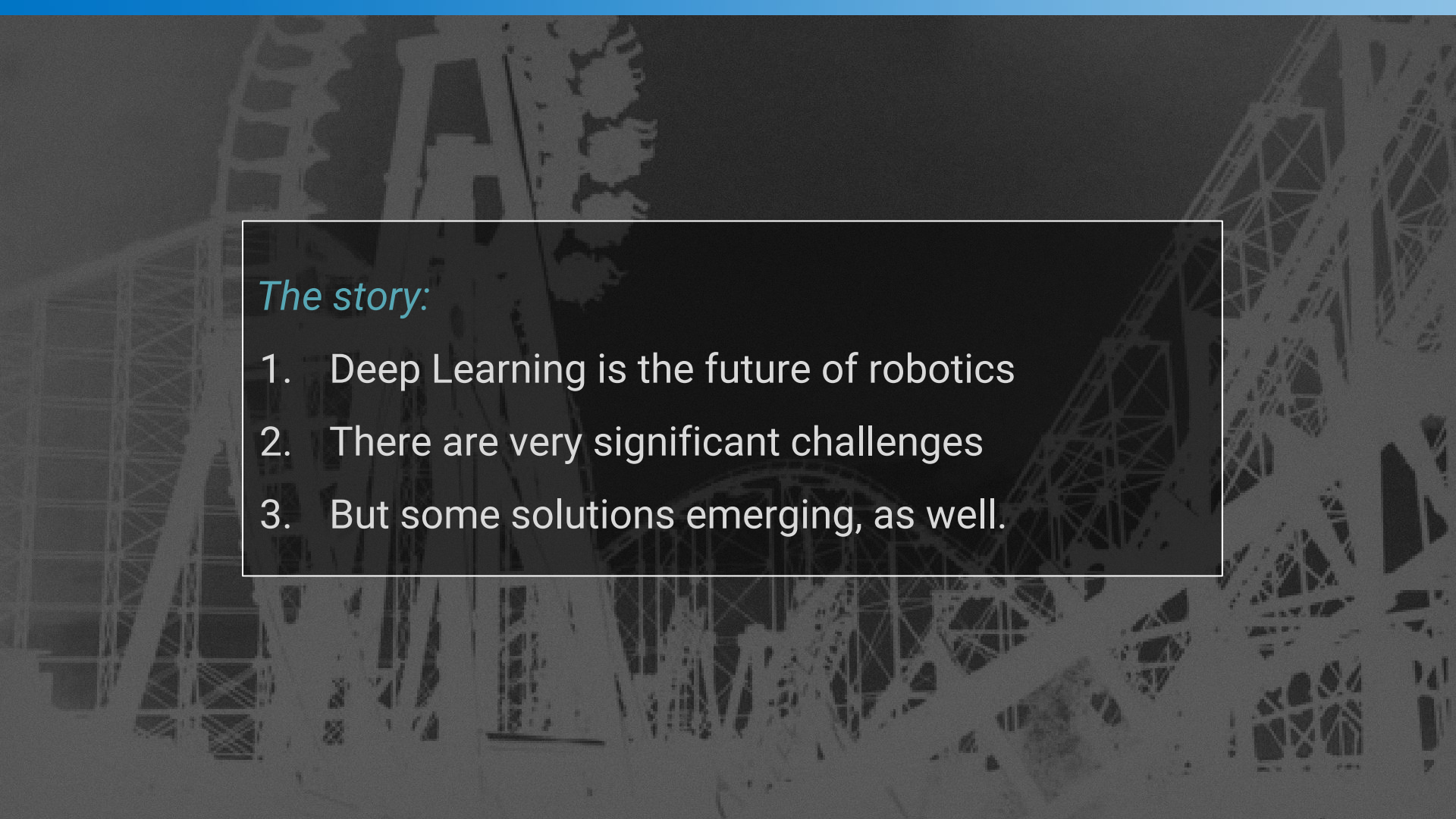
# Deep Learning for Robots

Raia Hadsell
www.raiahadsell.com




*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 → Acoustic Model → Phonetic Model → Language Model → Text

**2012:** Computer Vision

Pixels → Key Points → SIFT features → Deformable Part Model → Labels

**2014:** Machine Translation

Text → Reordering → Phrase Table/Dictionary → Language Model → Text

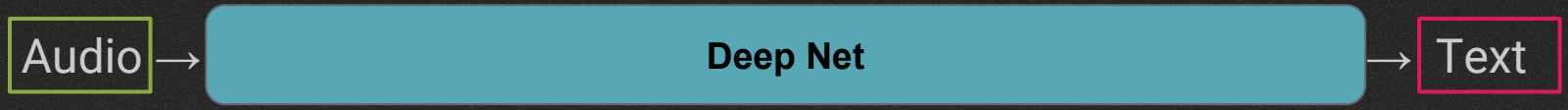
**2017: Robotics?**

Sensors → Perception → World Model → Planning → Control → Action

slide from V. Vanhoucke

# End-to-end Deep Learning for robots?

**2010**: Speech Recognition




**2012:** Computer Vision


**2014:** Machine Translation


**2017: Robotics?**


slide from V. Vanhoucke

# Robotics is different

# Robotics is different

SENSORS ⇄ ACTIONS

# Reinforcement Learning

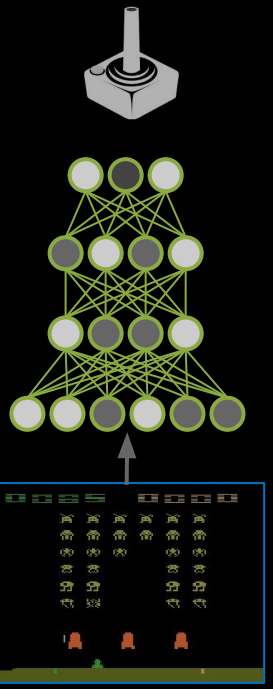
# Deep Reinforcement Learning

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

- Sensorimotor control ?

# Space Invaders

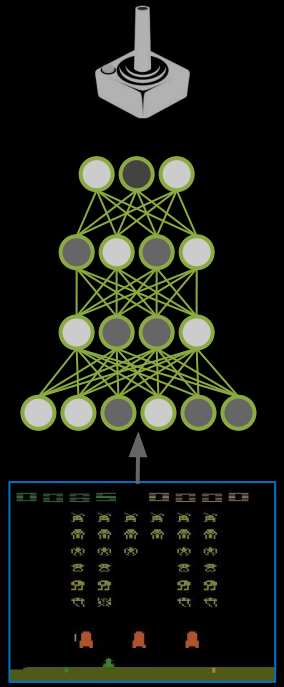
https://www.youtube.com/watch?v=wHDxF5N700Q



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

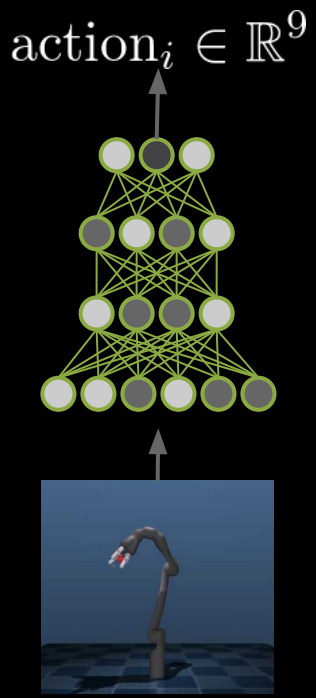
# General Atari Player

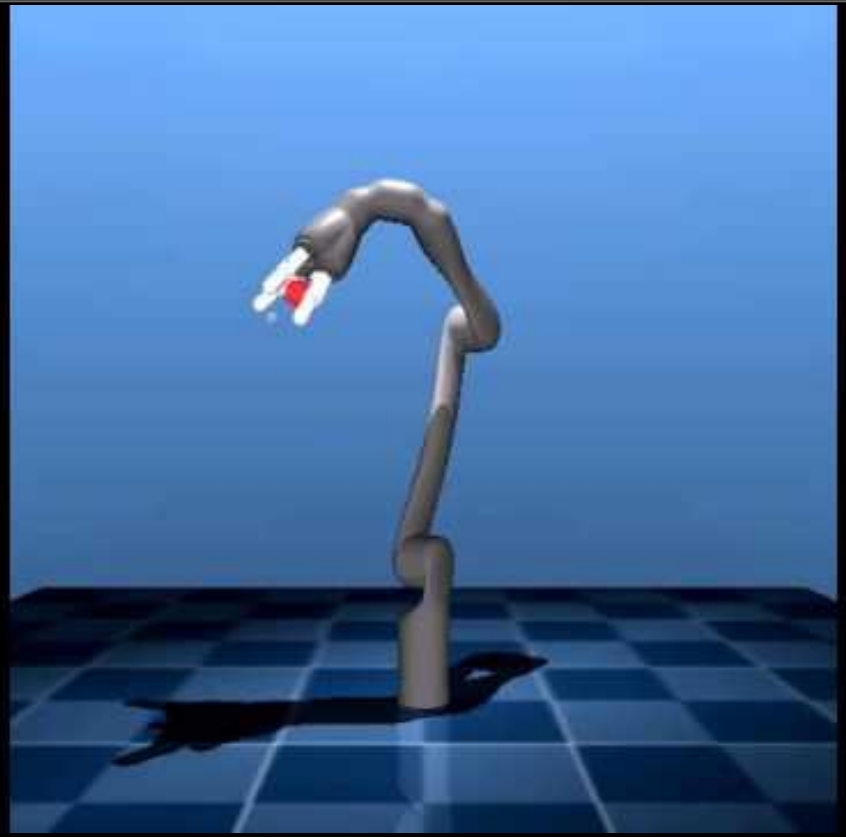
https://www.youtube.com/watch?v=Erkt7HelEco




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

# 9DOF Random reacher



https://youtu.be/u0M3PvTgTcE

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

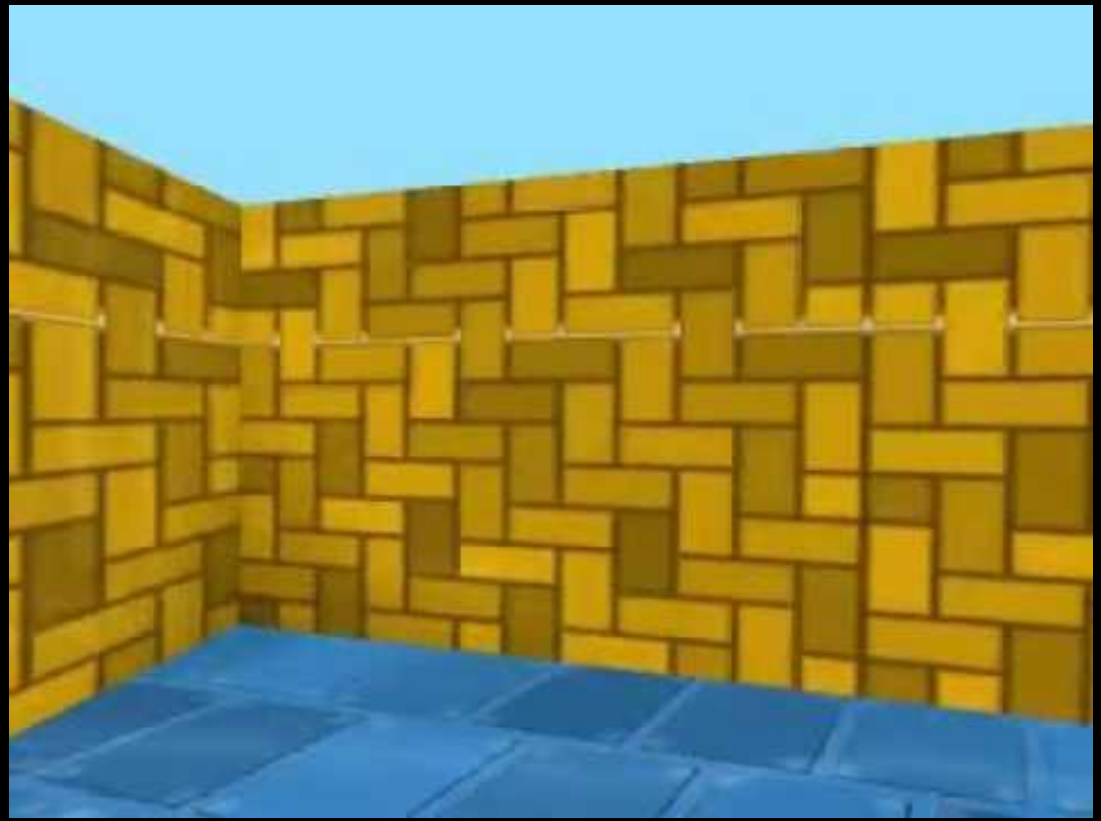
- Sensorimotor control

# 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?

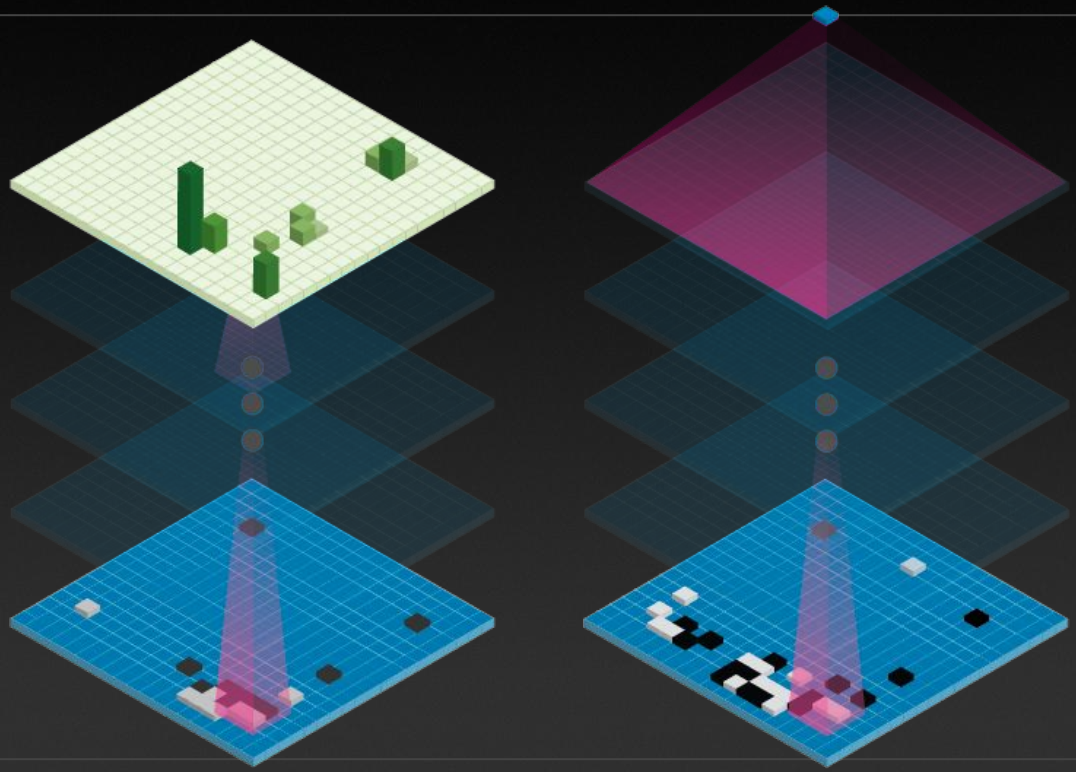
- Sensorimotor control
- Exploration of complex spaces

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

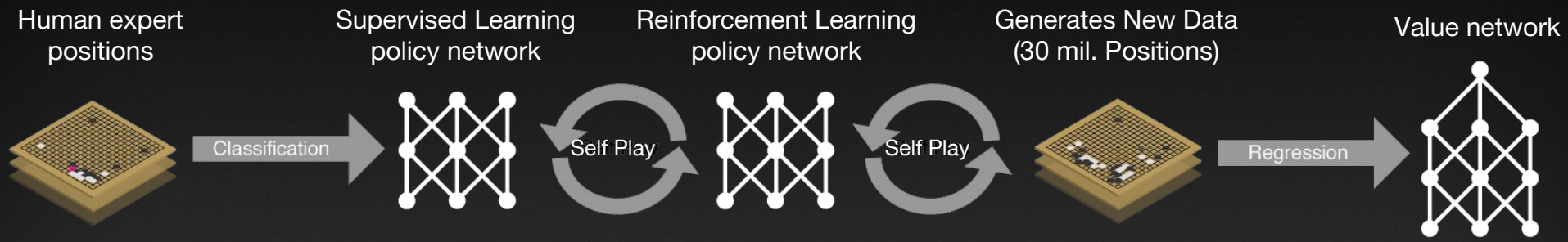
- Sensorimotor control
- Exploration of complex spaces
- Strategy and decision making ?

## Policy Network

## Value Network



# Lesson: use supervised learning when possible




AlphaGo

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

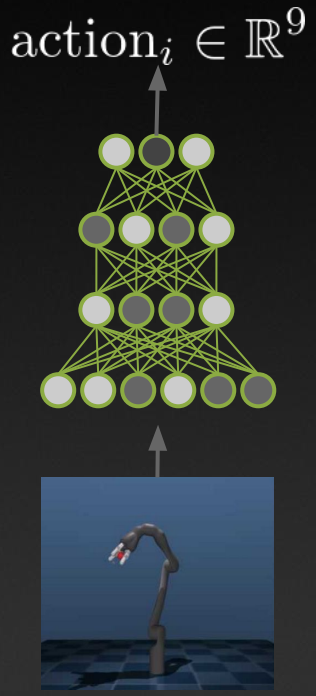
- Sensorimotor control
- Exploration of complex spaces
- Strategy and decision making

# So, where are the superhuman robots?

*Not so fast …*

- Deep RL is very data inefficient -

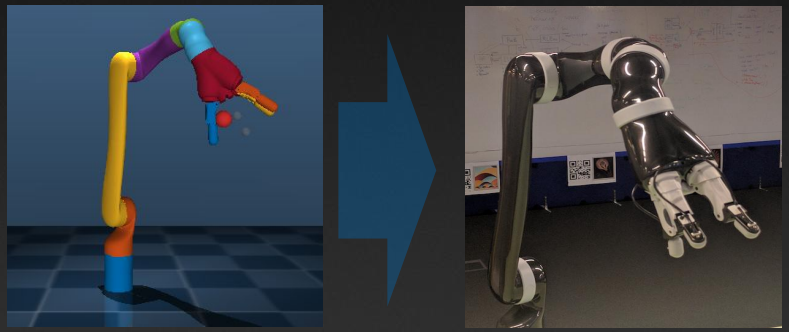
  how can it learn on real robots?




24 hours in simulation with 16 threads …
… 55 days on the real Jaco arm

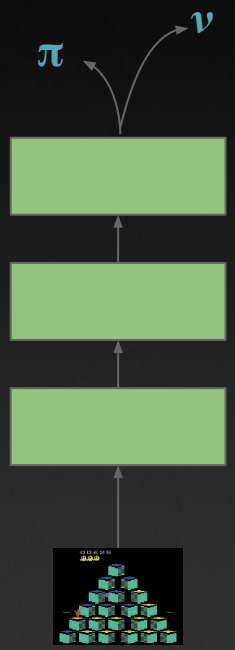
# Two methods to speed up Deep RL for robots

1. Train in simulation, then transfer to real robot
   - Benefit is obvious
   - Hard to do in practice

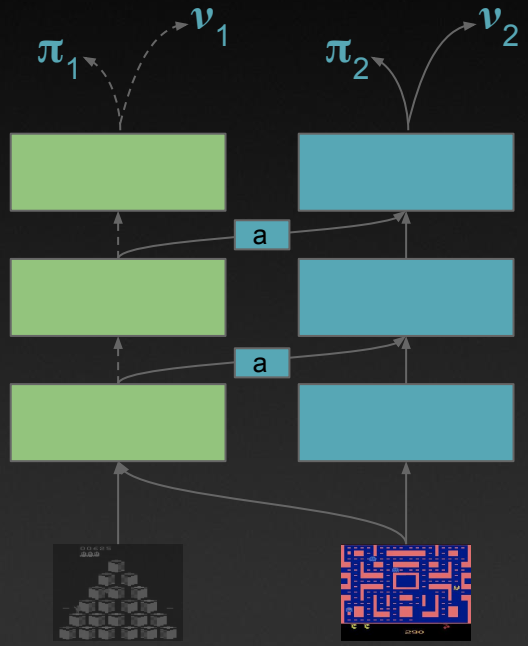


# Progressive Neural Networks

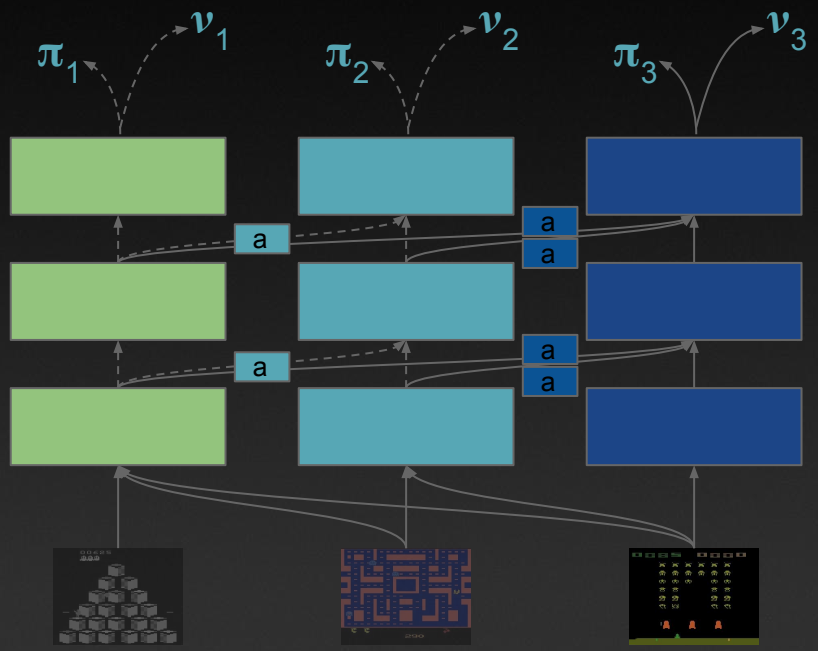
# Progressive Neural Networks



# Progressive Neural Networks



# Progressive Neural Networks



# Sim-to-Real

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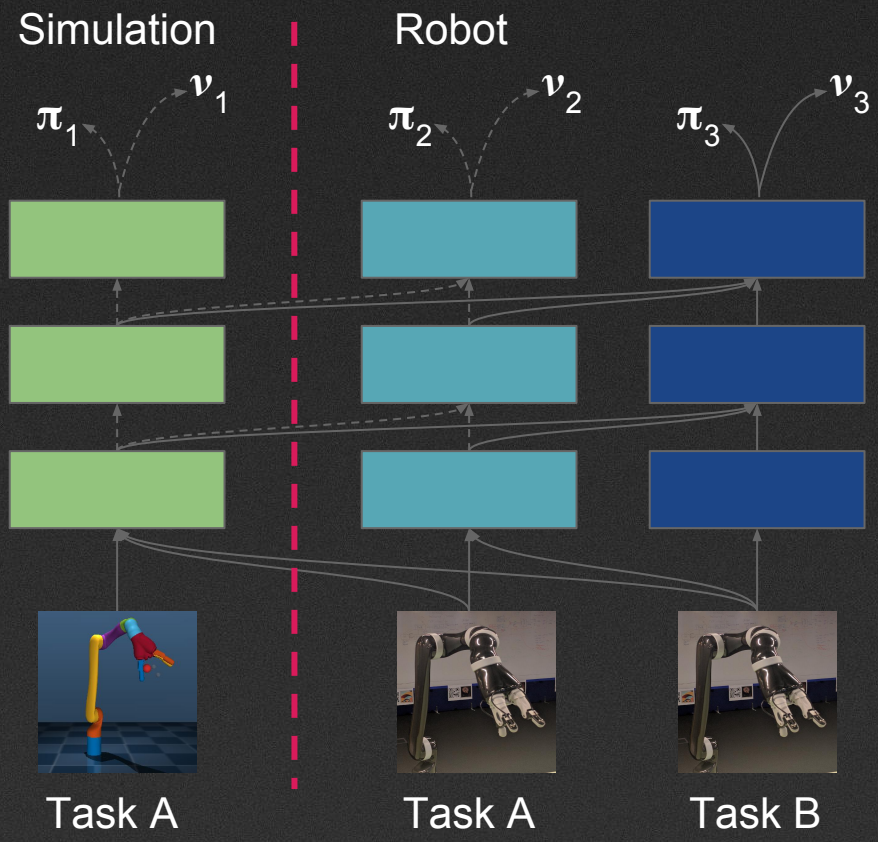
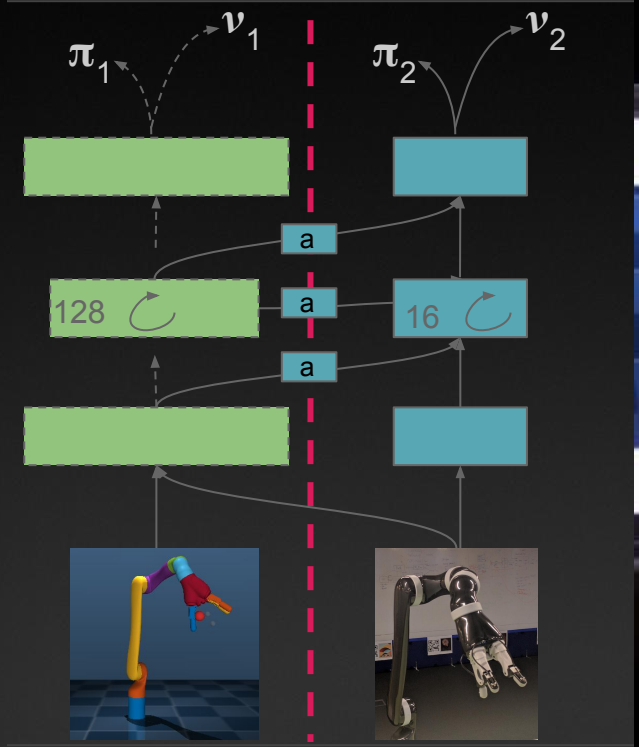
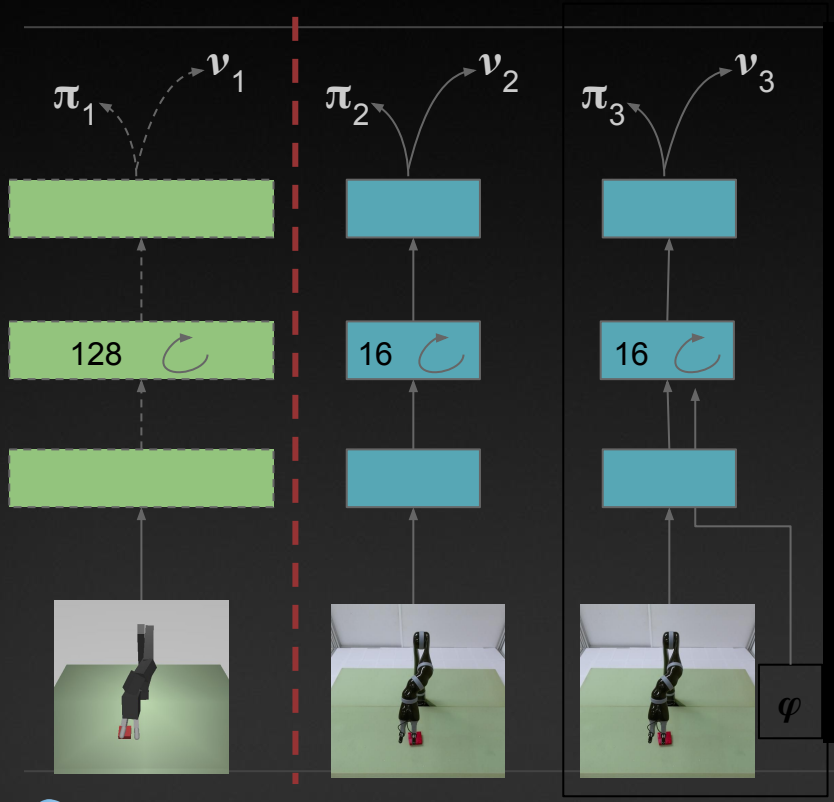


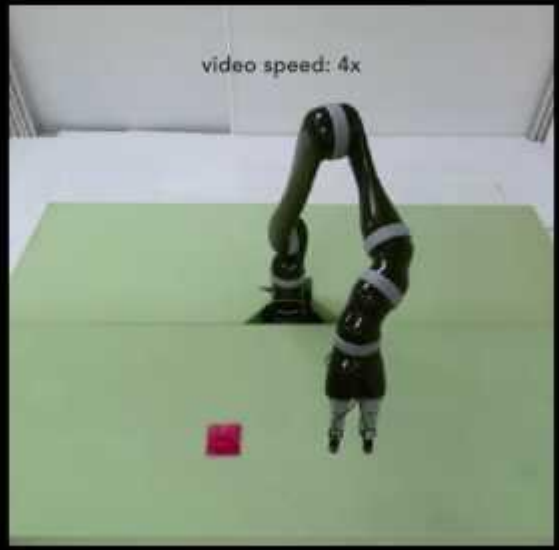
# Sim-to-Real: 3d reacher




https://www.youtube.com/watch?v=YZz5lo_ipi8

# Sim-to-Real: 2d reacher with moving target




www.youtube.com/watch?v=e78J1K5LKCI

# Progressive Neural Networks

# Sim-To-Real Robot Learning From Pixels

arxiv.org/abs/1606.04671
arxiv.org/abs/1610.04286v1

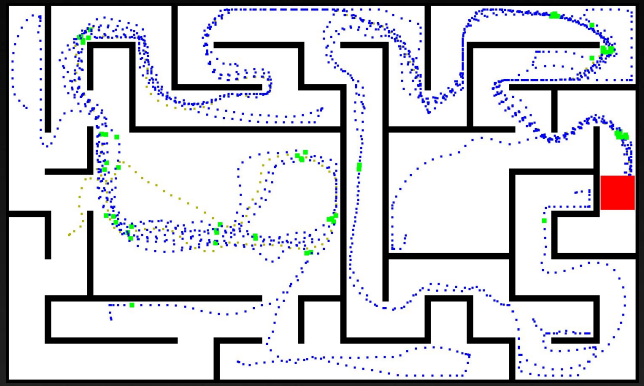
Andrei Rusu, Neil C. Rabinowitz, Guillaume Desjardins, Hubert Soyer, James Kirkpatrick, Koray Kavukcuoglu, Razvan Pascanu, Nicolas Heess, Raia Hadsell

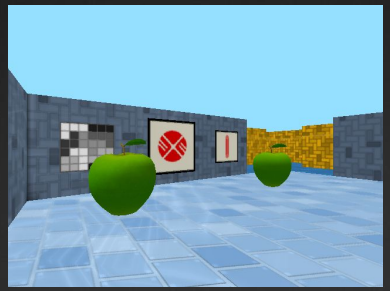
# Two methods to speed up Deep RL for robots

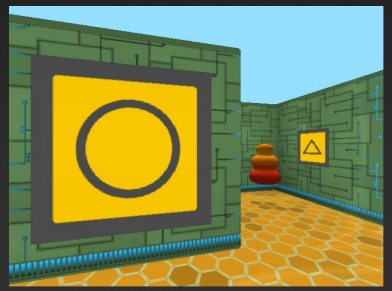
## 2. Learn with auxiliary tasks

- 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)

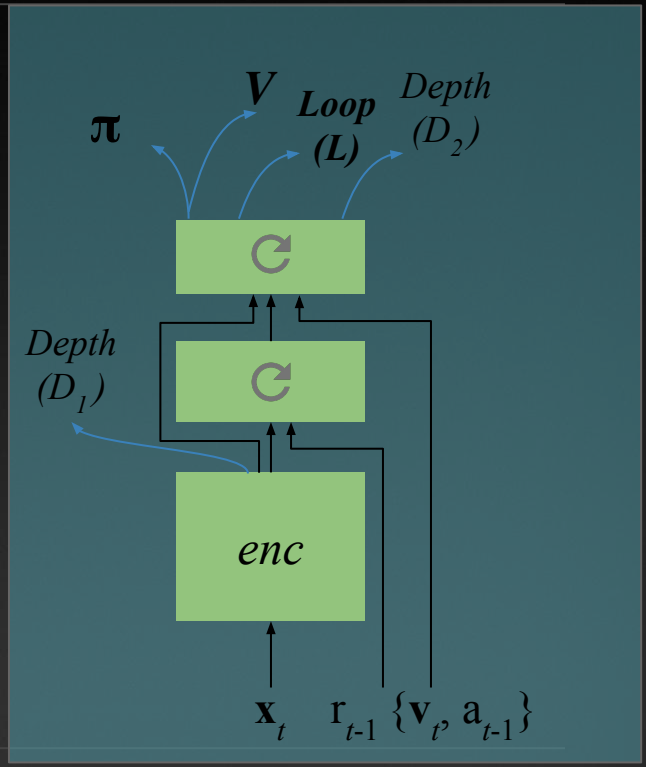
+10

+1

DeepMind Lab

# nav agent ingredients:

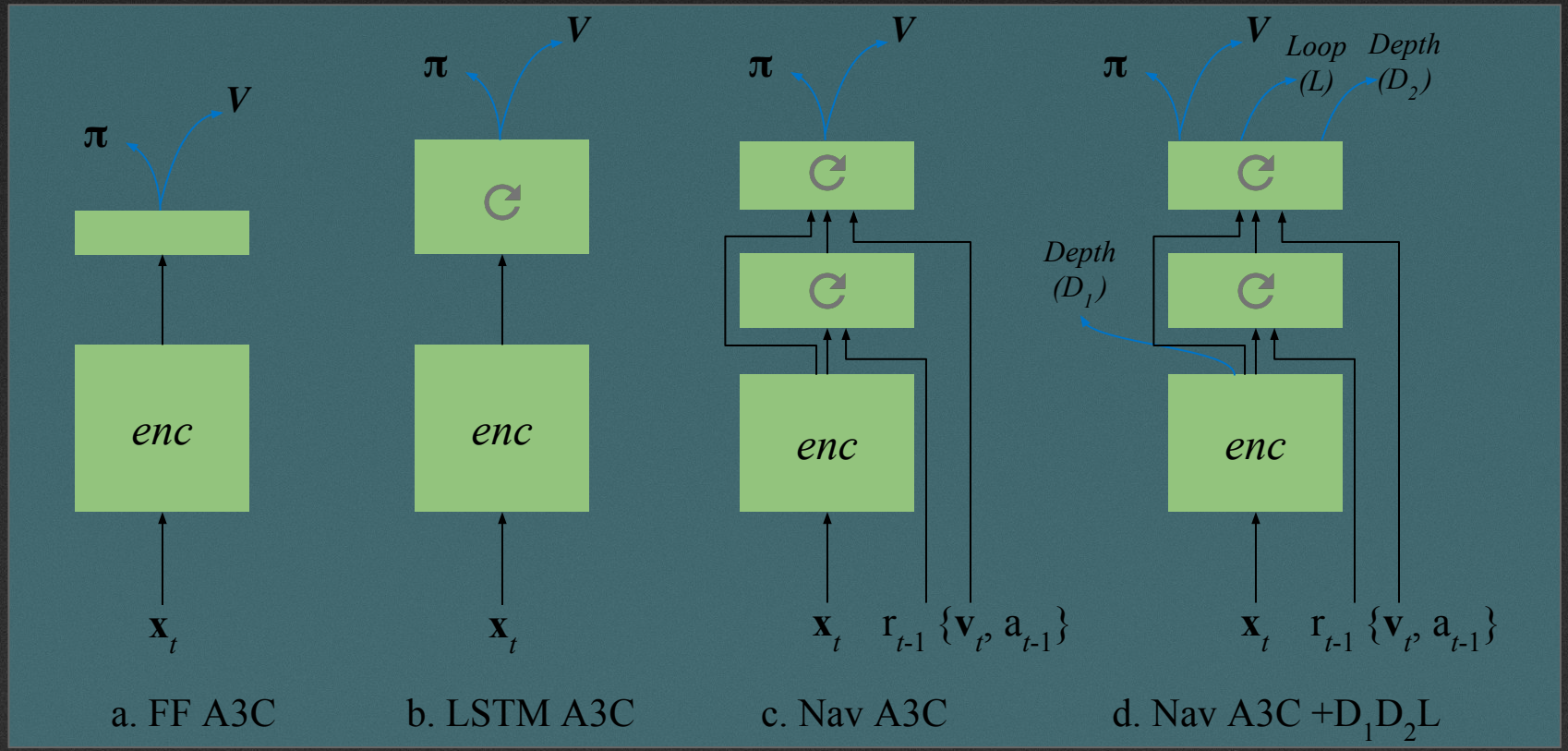
1. Convolutional encoder and RGB inputs
2. Stacked LSTM
3. Additional inputs (reward, action, and velocity)
4. RL: Asynchronous advantage actor critic (A3C)
5. Auxiliary task 1: Depth predictor
6. Auxiliary task 2: Loop closure predictor



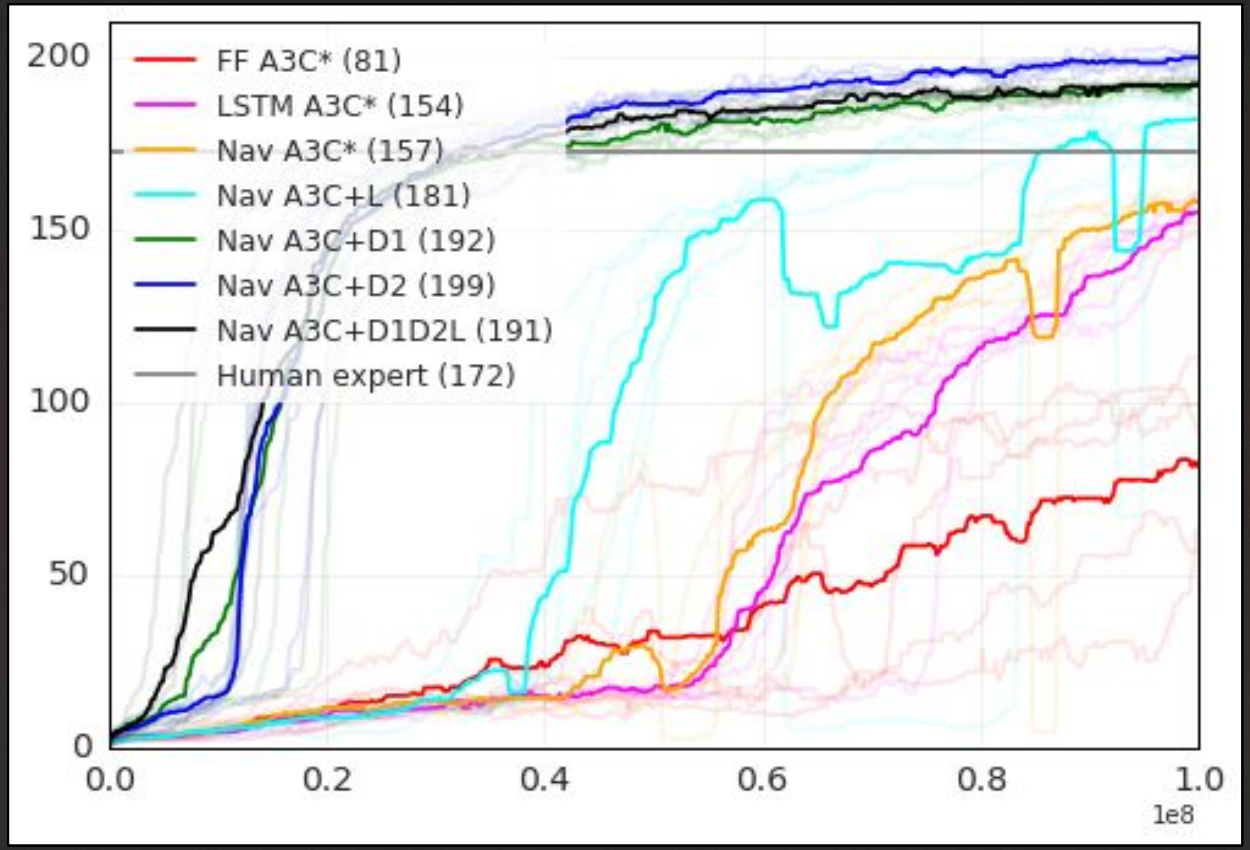



[Mnih et al, *Asynchonous Methods for Deep Reinforcement Learning*, 2016]

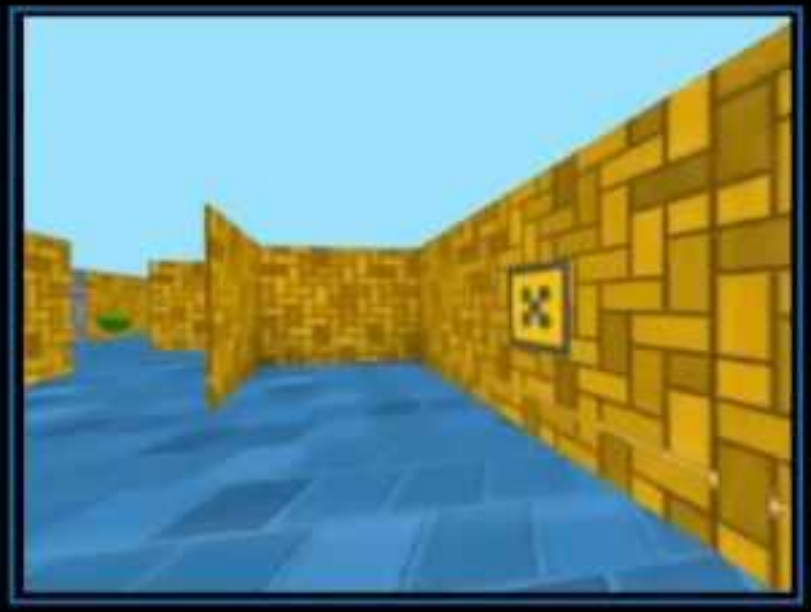
# Variations in architecture



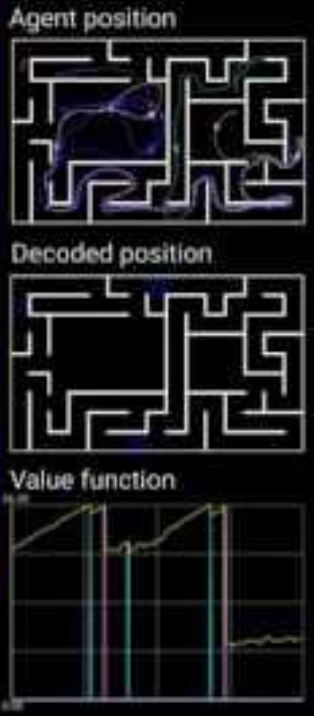
# Results: Auxiliary tasks speed up RL ten-fold!




DeepMind



Large static maze




https://youtu.be/lNoaTyMZsWI

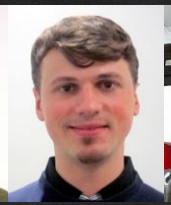
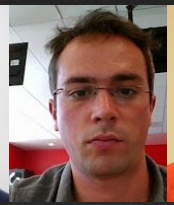
# Learning to navigate in complex environments

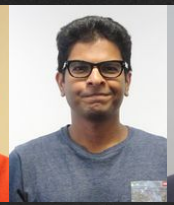
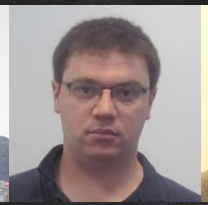
arxiv.org/abs/1611.03673



Piotr Mirowski, Razvan Pascanu, Raia Hadsell




Fabio Ross Andy Hubert Laurent Koray Dharsh Misha Andrea

*The story:*

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# Thank you!

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