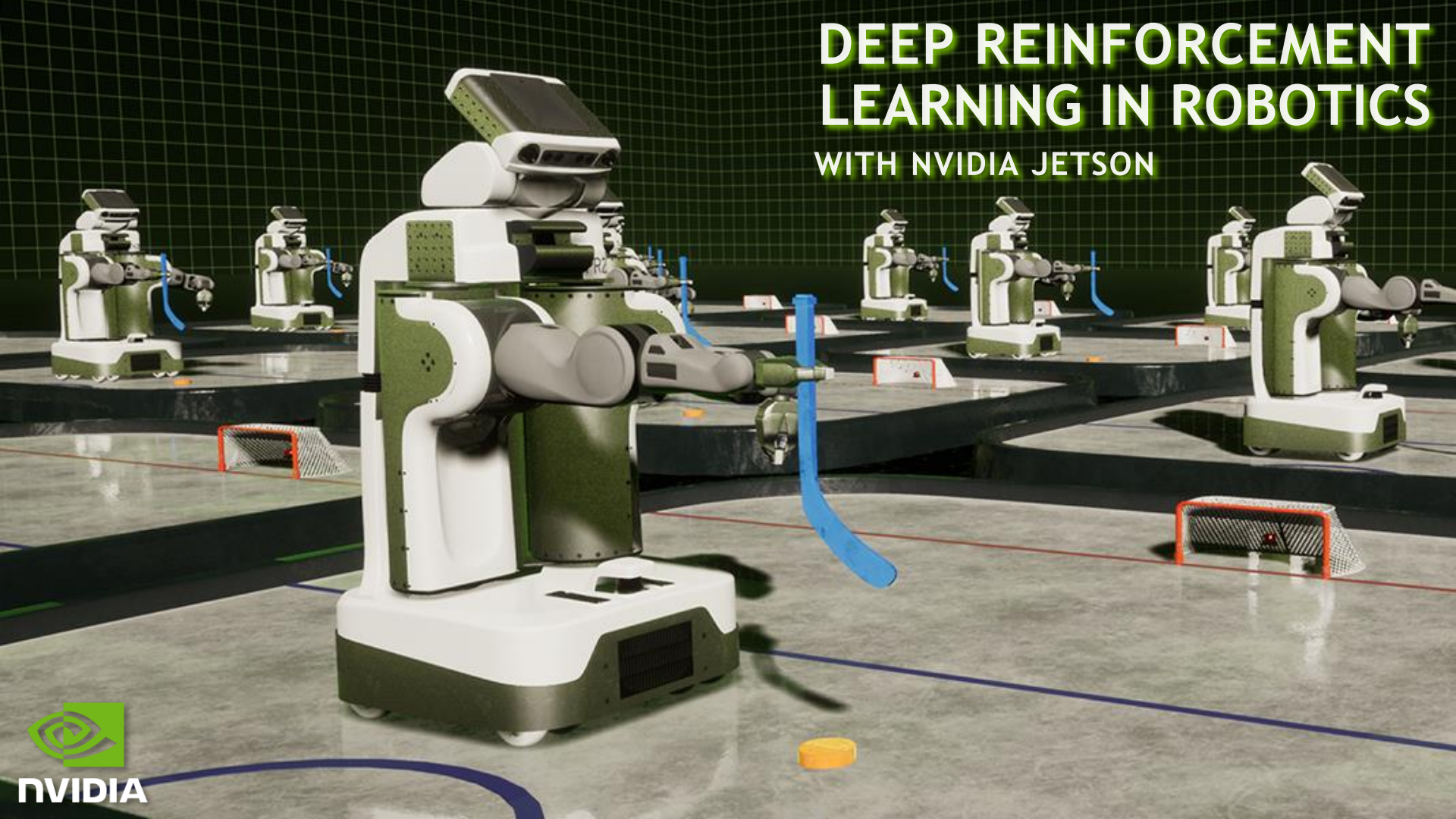
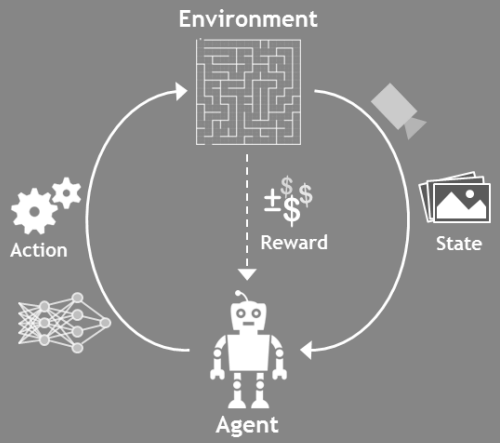
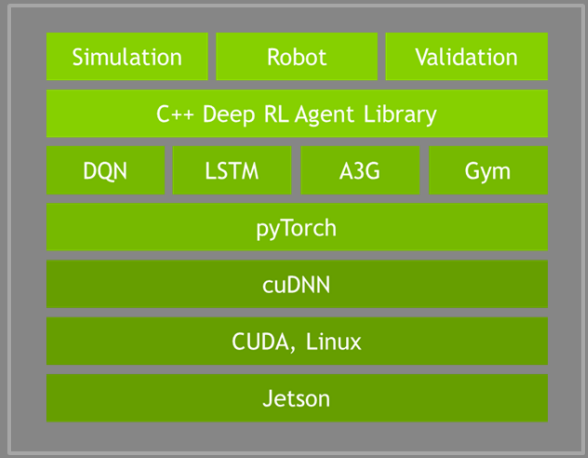

DEEP REINFORCEMENT LEARNING IN ROBOTICS
WITH NVIDIA JETSON
NVIDIA

WEBINAR AGENDA

Topics:

- Intro to Jetson & Deep RL
- PyTorch DQN & OpenAI Gym
- C++ Deep RL Agent Library API
- 3D Robotic Simulation with Gazebo
- Continuous Control - A3C/A3G/PPO
- Online Transfer Learning





NVIDIA

AI REDEFINES ROBOTICS

Delivery

Consumer

Healthcare

Agriculture

Retail

Logistics

Manufacturing

Inspection

NVIDIA

AI AT THE EDGE

BANDWIDTH

1 billion cameras WW (2020)
10’s of petabytes per day

LATENCY

Safety-critical services
Realtime decisions

PRIVACY

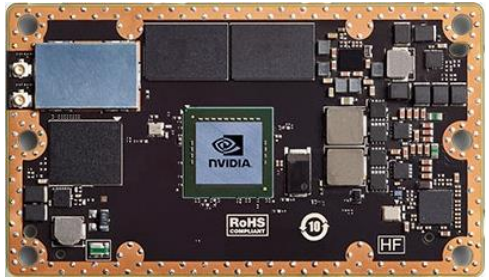
Confidentiality
Private cloud or on-premise storage

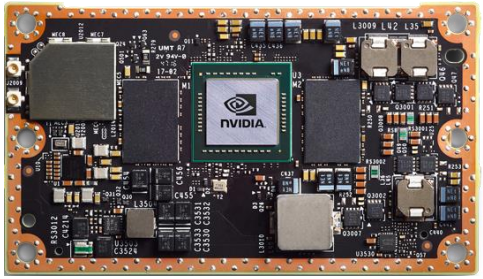
CONNECTIVITY

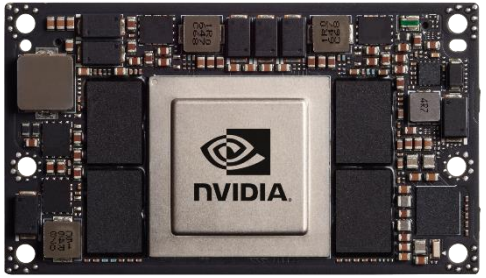
50% of populated world < 8mbps
Bulk of uninhabited world no 3G+

NVIDIA

NVIDIA





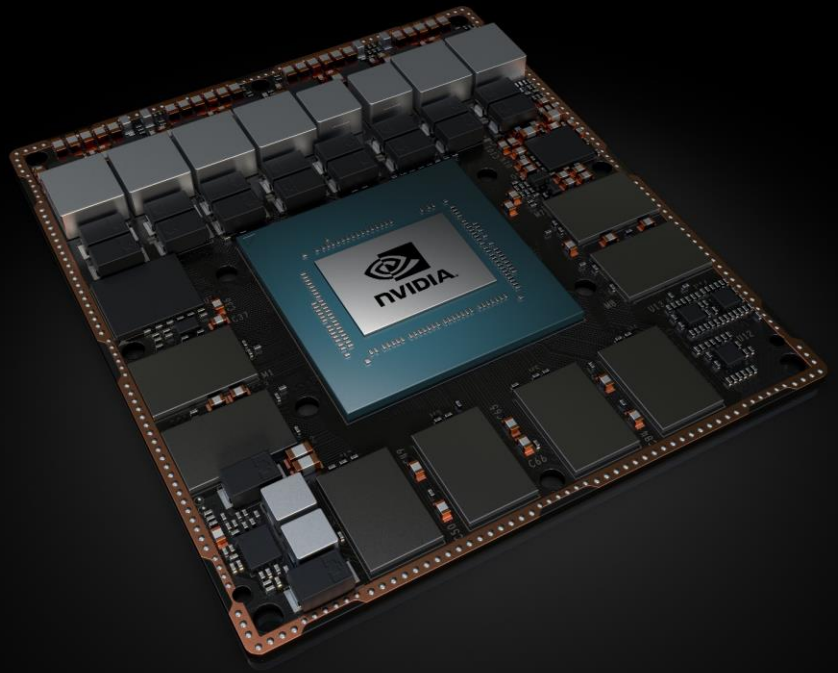


	JETSON TX1	JETSON TX2	JETSON TX2i
GPU	256-core Maxwell @ 996 MHz	256-core Pascal @ 1134 MHz	
CPU	64-bit quad-core ARM A57 CPU	64-bit Denver 2 and quad-core A57 CPU	
Memory	4GB 64 bit LPDDR4 @ 25.6 GB/s	8GB 128-bit LPDDR4 @ 58.2 GB/s	8GB 128-bit LPDDR4 (ECC) @ 51.9 GB/s
Storage	16GB eMMC	32GB eMMC	
Wireless	802.11 2x2 ac WLAN | BT4.0 Ready	802.11 2x2 ac WLAN | BT4.1 Ready	Wireless not on-module
Video Encode	4Kp30 | (2x) 1080p60	4Kp60 | (3x) 4Kp30 | (8x) 1080p60	
Video Decode	4Kp60 | (4x) 1080p60	(2x) 4Kp60 | (4x) 4Kp30 | (7x) 1080p60	
Camera	12 lanes MIPI CSI-2 | 1.5Gbps per lane	12 lanes MIPI CSI-2 | 2.5Gbps per lane	
Peripherals	USB3, GigE, PCIe, SATA, HDMI, GPIO, I2C, SPI, UART	USB3, GigE, PCIe, SATA, HDMI, GPIO, I2C, SPI, UART, dual CAN bus	
Power	6.5W – 15W	7.5W (Max-Q) | 15W (Max-P)	10W (Max-Q) | 20W (Max-P)
Operating Temp	-25°C to 80°C		-40°C to 85°C
Operating Life	5 years | MTBF: 1,711,180 Hours @ 35°C	5 years | MTBF: 1,747,520 Hours @ 35°C	10 years | MTBF: 2,505,155 Hours @ 45°C
Mechanical	50mm x 87mm, 400-pin backwards-compatible Board to Board Connector		

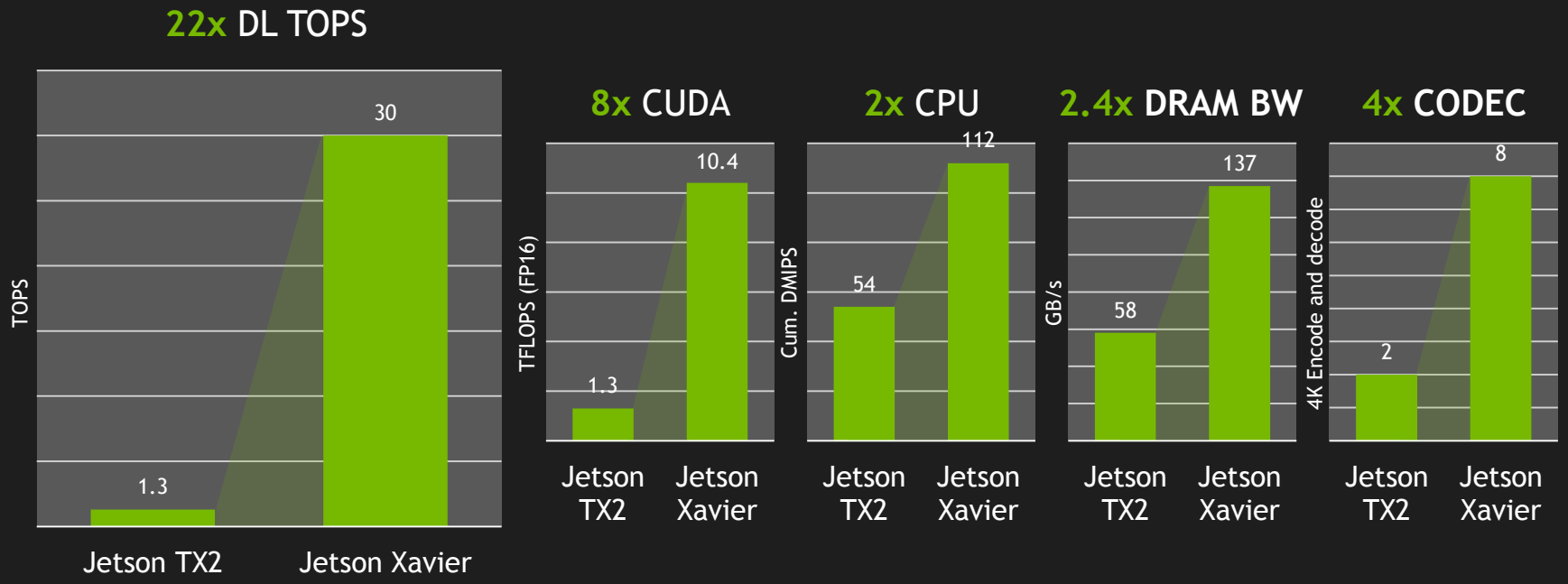
JETSON XAVIER

Computer for Autonomous Machines

AI Server Performance in 30W • 15W • 10W
512 Volta CUDA Cores • 2x NVDLA
8 core CPU • 16GB 256-bit LPDDR4x
30 DL TOPS



JETSON XAVIER
20X PERFORMANCE IN 2 YEARS



MOST COMPREHENSIVE HIGH PERFORMANCE I/O SUBSYSTEM

PCIE
5 16GT/s gen4 controllers
1 x8, 1x4, 1x2, 2x1
3x Root port + Endpoint
2x Root port

USB
3x USB3.1 (10 GT/s) ports
4x USB2.0 ports

ETHERNET
1x Ethernet-AVB over RGMII
PTP, WoL

DISPLAY
3x DP/HDMI/eDP
4K @ 60 Hz
DP HBR3
HDMI 2.0

CAMERA
16 MIPI CSI-2 lanes
40 Gbps in DPHY 1.2 Mode
109 Gbps in CPHY 1.1 Mode

OTHER I/Os
I2C I2S UFS
CAN SPI SD
UART GPIO

JETSON XAVIER DEVELOPER KIT

2x USB-C+DP, HDMI, USB3+eSATA, 8x CSI x2

M.2 key E, M.2 key M, micro-SD, 40-pin GPIO

$1299 (US), early access August 2018

JETSON XAVIER DEVELOPER KIT

2x USB-C+DP, HDMI, USB3+eSATA, 8x CSI x2

M.2 key E, M.2 key M, micro-SD, 40-pin GPIO

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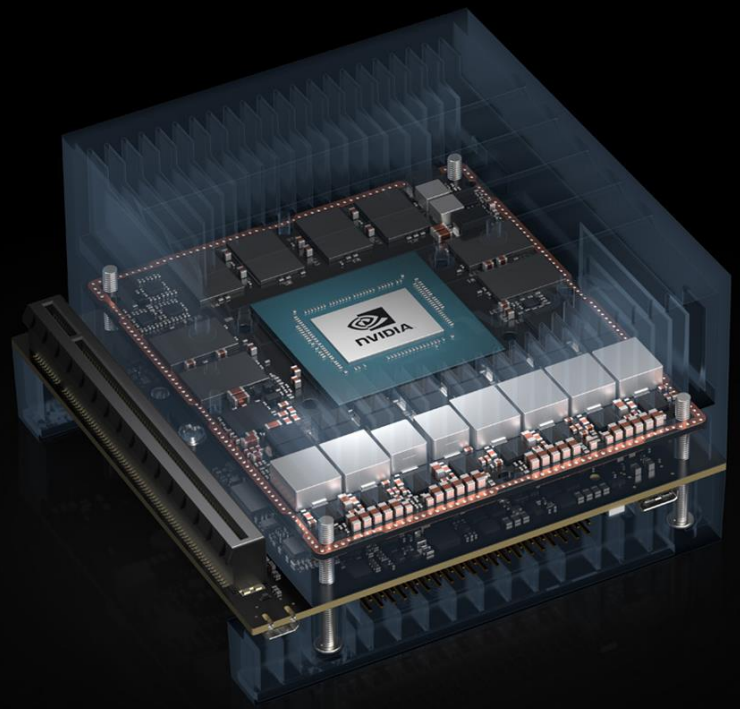
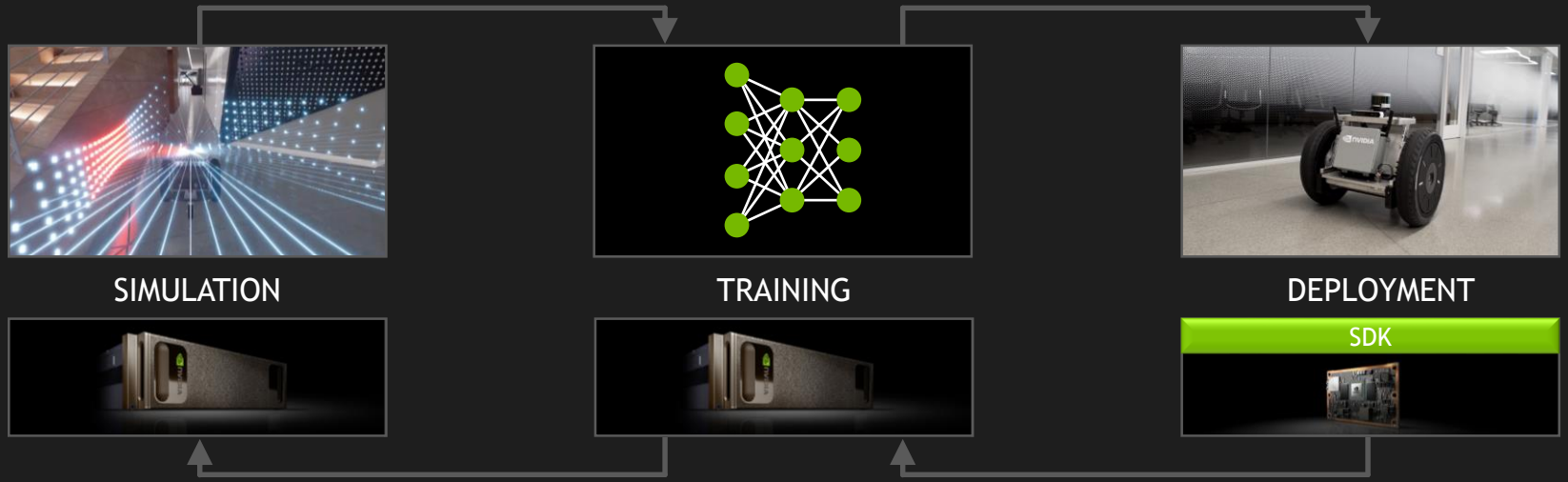
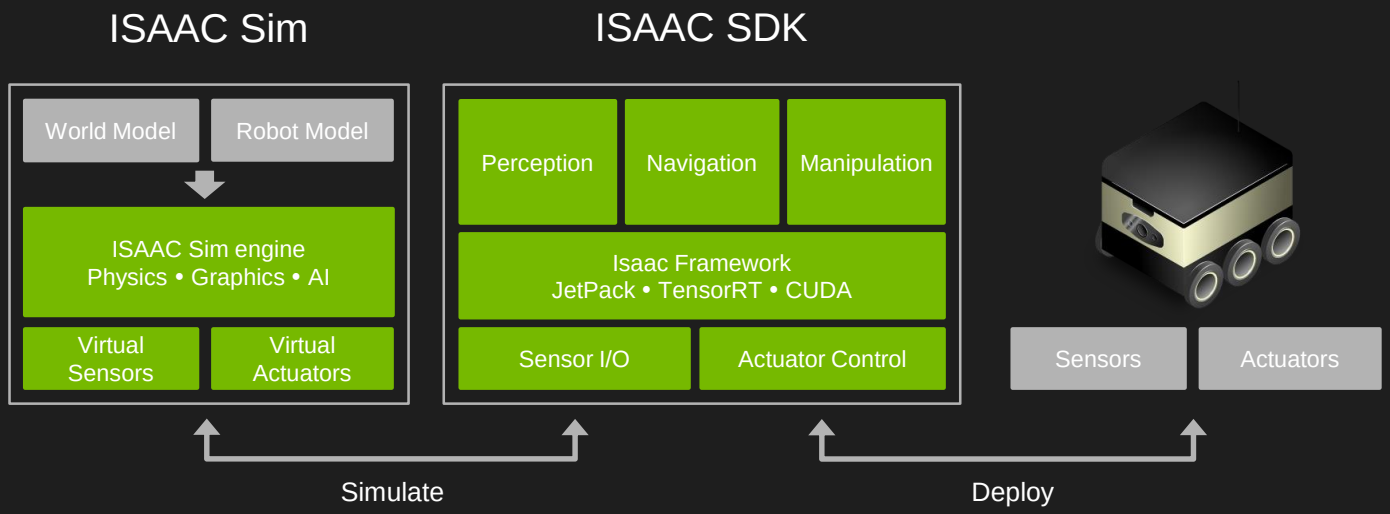


NVIDIA ISAAC ROBOTICS PLATFORM



https://developer.nvidia.com/isaac-sdk

ISAAC WORKFLOW



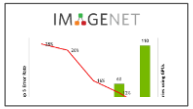
POWERING THE DEEP LEARNING ECOSYSTEM

NVIDIA accelerates every major framework

COMPUTER VISION

OBJECT DETECTION

IMAGE CLASSIFICATION



SPEECH & AUDIO

VOICE RECOGNITION

LANGUAGE TRANSLATION

NATURAL LANGUAGE PROCESSING

RECOMMENDATION ENGINES

SENTIMENT ANALYSIS

DEEP LEARNING FRAMEWORKS

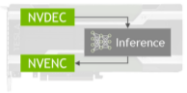
Caffe · Caffe2 · DIGITS · KERAS · Microsoft CNTK · mxnet · Purine · TensorFlow · torch · Chainer · DL4J Deeplearning4j · MatConvNet · MINERVA · OpenDeep · PYTORCH · theano

NVIDIA DEEP LEARNING SDK

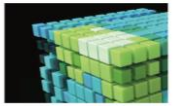
cuDNN

TensorRT

DeepStream SDK



cuBLAS



cuSPARSE

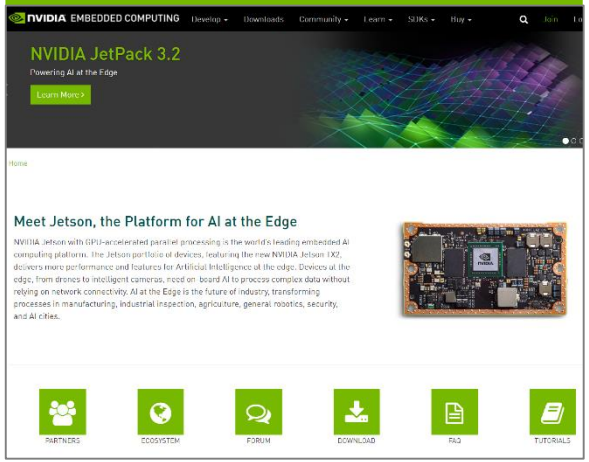
NCCL

developer.nvidia.com/deep-learning-software

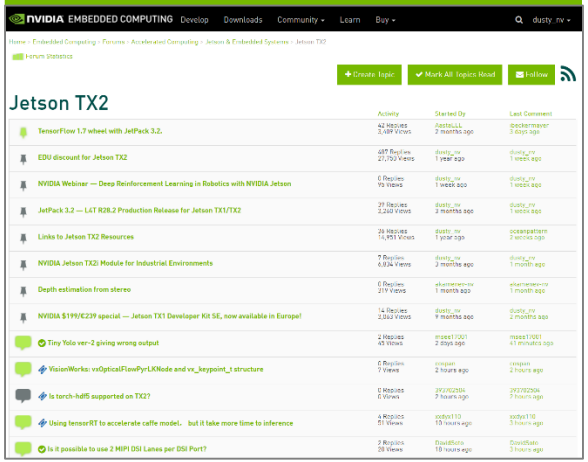
GETTING STARTED

JETSON COMMUNITY

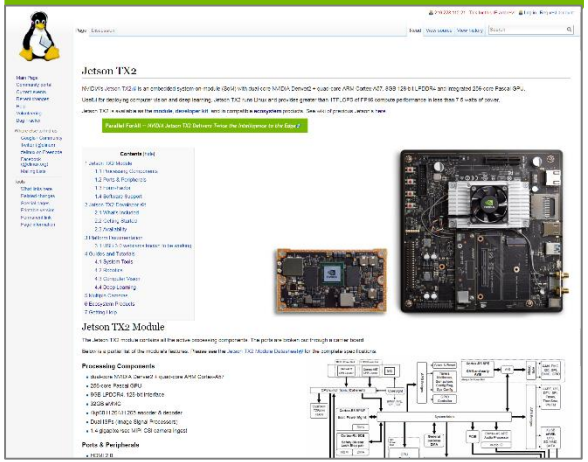
Developer Portal developer.nvidia.com



Developer Forums devtalk.nvidia.com



eLinux Wiki eLinux.org/Jetson

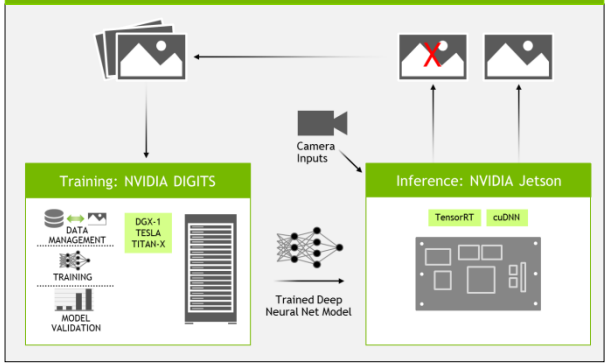


developer.nvidia.com/embedded

TWO DAYS TO A DEMO

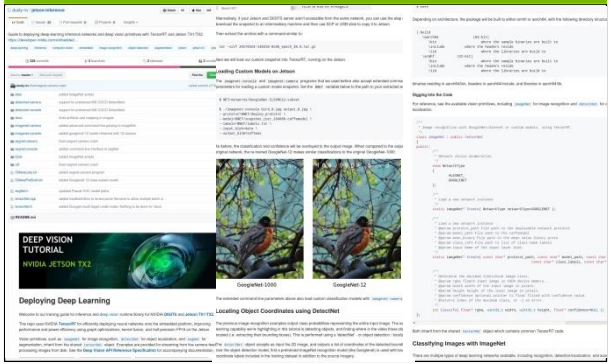
Get Started with Deep Learning

AI WORKFLOW



Train using DIGITS and cloud/PC
Deploy to the field with Jetson

TRAINING GUIDES



All the steps required to follow to train
your own models, including the datasets.

DEEP VISION PRIMITIVES

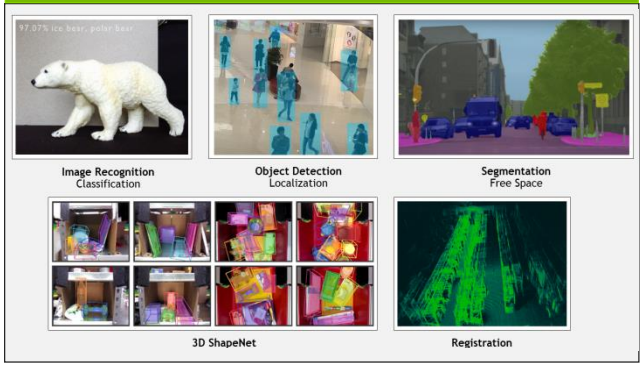
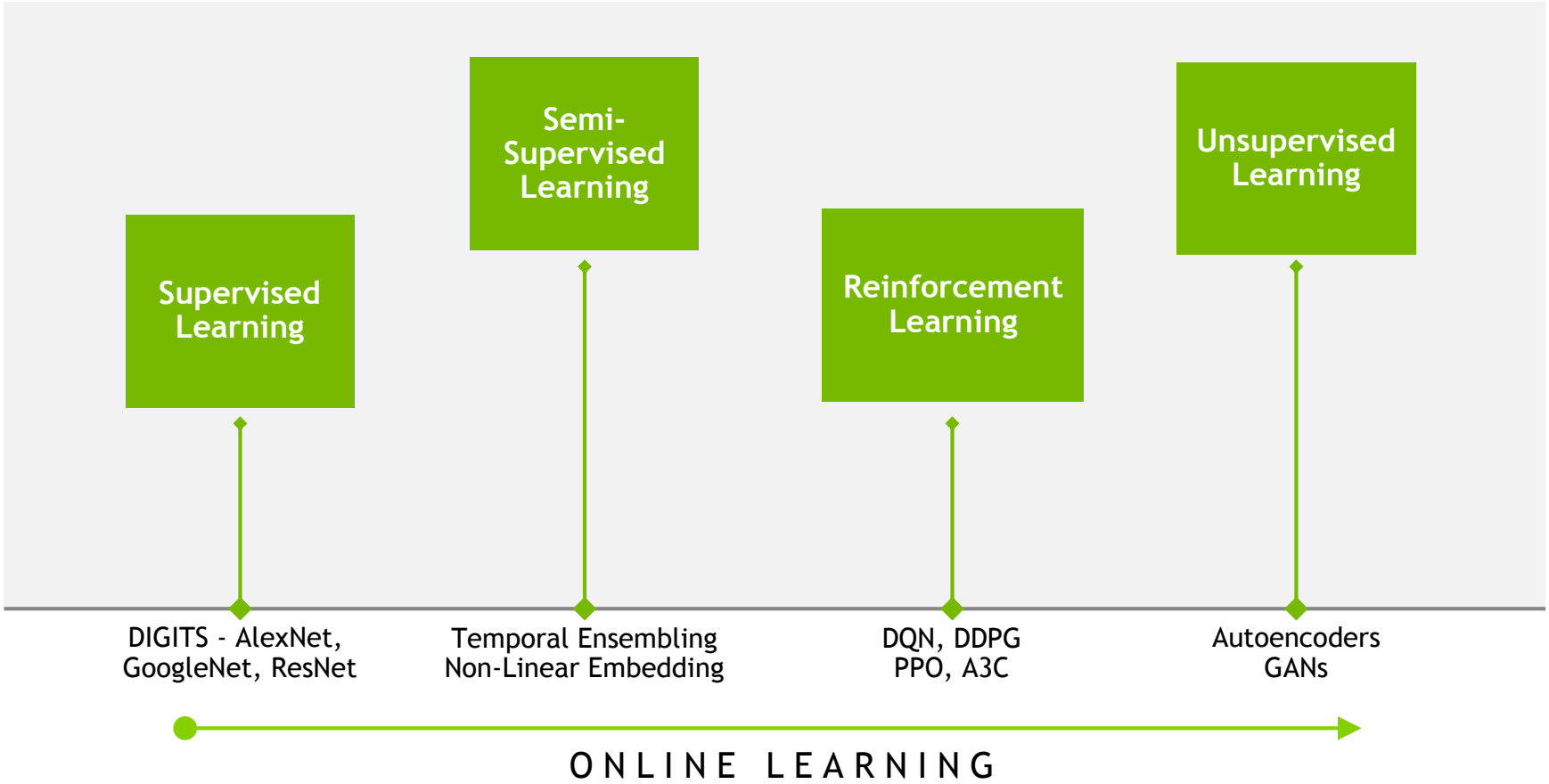


Image Recognition, Object Detection
and Segmentation

github.com/dusty-nv/jetson-inference

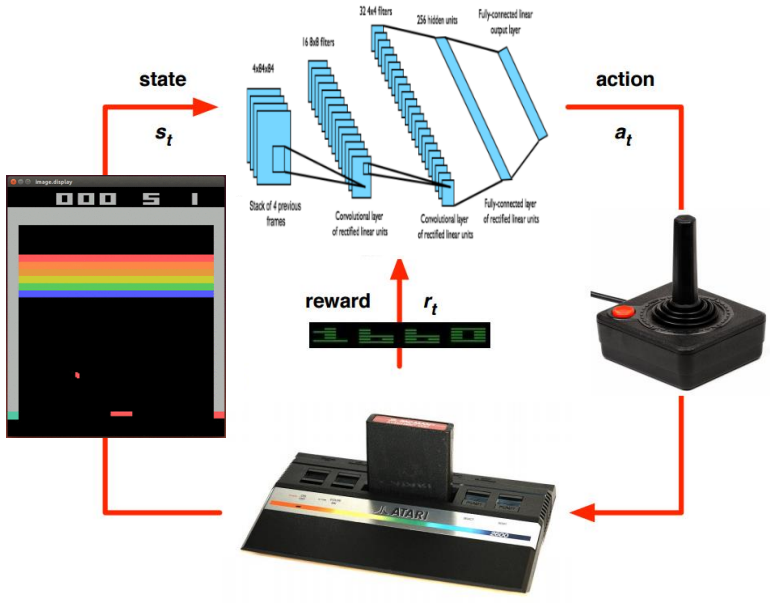
SPECTRUM *of* LEARNING



REINFORCEMENT LEARNING

How's it work?

- A reinforcement learning agent includes:
  - **state** (environment)
  - **actions** (policy)
  - **reward** (feedback)
- A **value function** predicts the future reward of performing actions in the current state
  - Given the recent state, action with the maximum estimated future reward is chosen for execution
- For complex state spaces, deep neural networks are used as **value approximators**
  - Numerical solver (**gradient descent**) optimizes the network in-situ based on reward feedback



TWO DAYS TO A DEMO

Deep Reinforcement Learning

OpenAI Gym

Test environments and games for research and verification

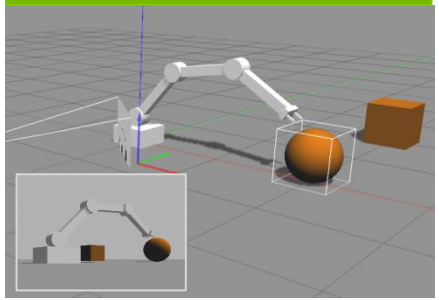
RL Algorithms

```
Do you want to continue [Y/n]? y
Get:1 http://archive.ubuntu.com/ubuntu/ lucid/universe python-keybinde
[12.2kB]
Get:2 http://archive.ubuntu.com/ubuntu/ lucid/universe terminator 0.93
[190kB]
Fetched 202kB in 5s (37.2kB/s)
Selecting previously deselected package python-keybinder.
(Reading database ... 129972 files and directories currently installed
Unpacking python-keybinder (from .../python-keybinder_0.0.4-1_i386.deb
Selecting previously deselected package terminator.
Unpacking terminator (from .../terminator_0.93-0ubuntu1_all.deb) ...
Processing triggers for desktop-file-utils ...
Processing triggers for python-gmenu ...
Rebuilding /usr/share/applications/desktop.en_US.utf8.cache...
Processing triggers for man-db ...
Processing triggers for hicolor-icon-theme ...
Processing triggers for python-support ...
Setting up python-keybinder (0.0.4-1) ...

Setting up terminator (0.93-0ubuntu1) ...
update-alternatives: using /usr/bin/terminator to provide /usr/bin/x-t
ulator (x-terminal-emulator) in auto mode.
```

DQN, DDPG, A3C, Actor Critic
PyTorch and TensorFlow

Robotic Simulation



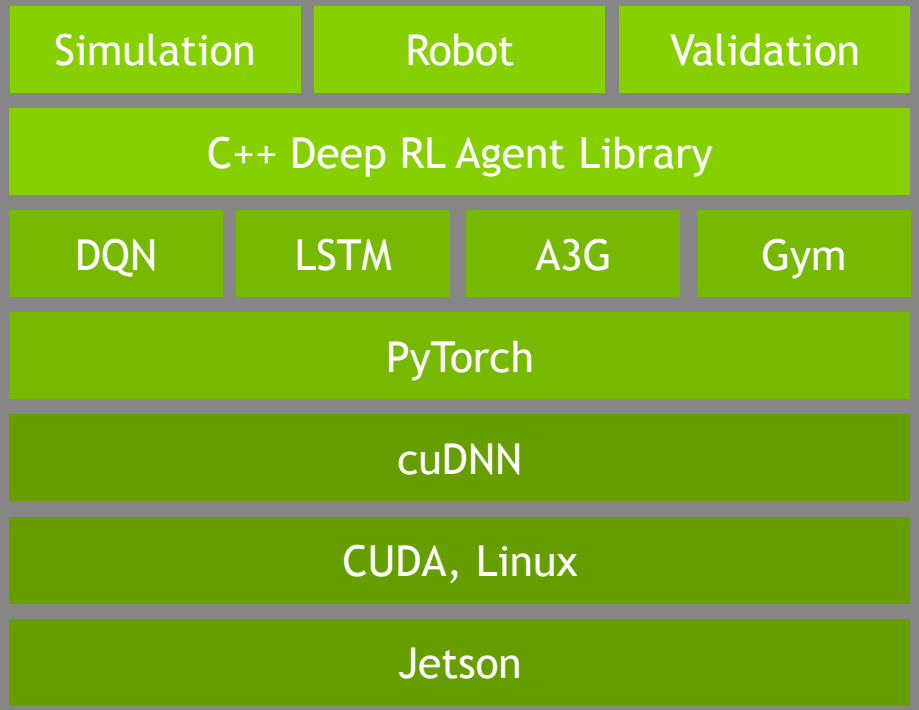
Observation from Vision
Pixels-to-Actions

Transfer Learning

Adapt network to real robot
Online learning in the field

github.com/dusty-nv/jetson-reinforcement

DEEP REINFORCEMENT LEARNING STACK

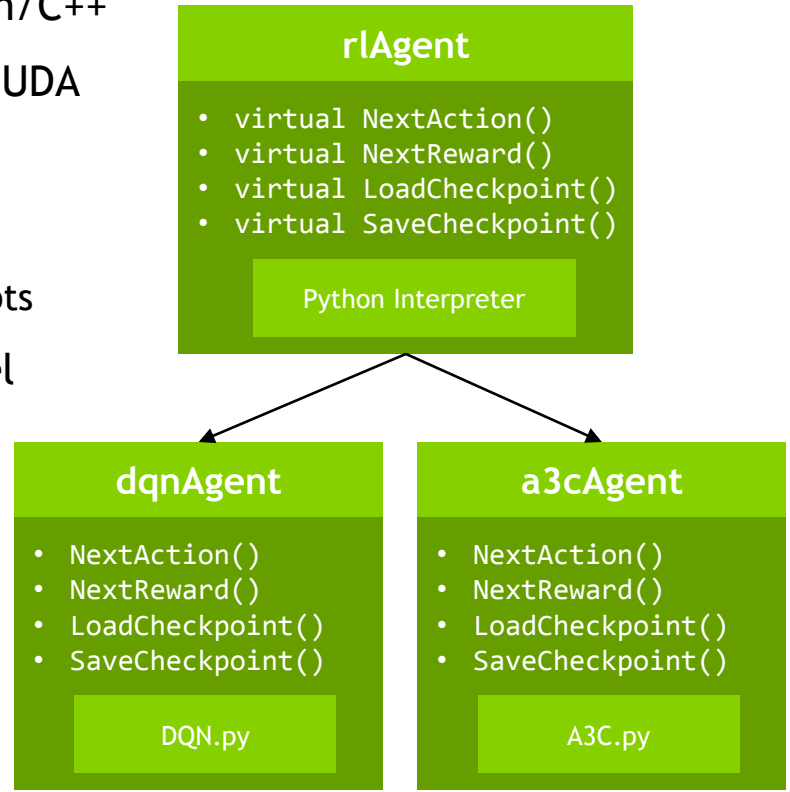


WHY PYTORCH?

- Natively runs and builds smoothly/efficiently on Jetson
- Low-overhead tensor ops in C++/CUDA backends
- Portable to ARM64 architecture and others
- First-class CUDA + cuDNN integration
- Full cuDNN layers (inc. RNN/LSTM)
- Tensor allocation API from C/C++
- Version 0.3/0.4 relatively stable
- Lots of RL code on GitHub (area of active research)

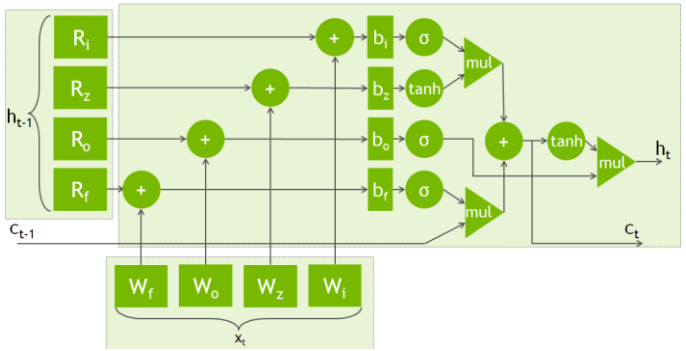
RL AGENT LIBRARY API

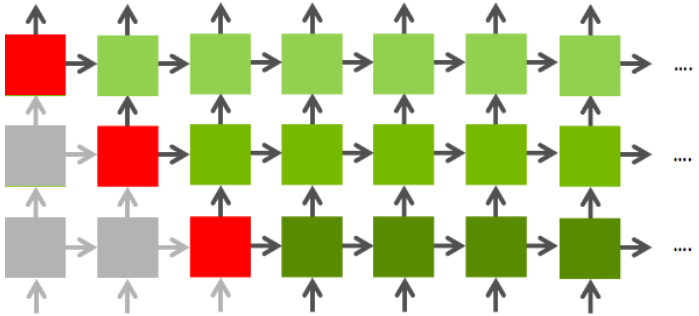
- Low-overhead interoperability layer between Python/C++
- Zero-Copy tensor transport Python↔C++, supports CUDA
- Modular event-driven agent model
  - Defines Python stub functions to be called from C++
  - Extensible for new agents implemented in Python scripts
- Able to run & synchronize multiple agents in parallel
- Shared API between virtual & physical robot
  - Plus C++ samples for agent debugging/verification
  - Common codebase reduces porting to platforms
  - Supports Jetson (ARM64) & Linux x86_64 (dGPU)



LSTM ACCELERATION

- cuDNN - GPU-accelerated RNNs/LSTM
- Forms internal working memory cells
- **Partially-observable inputs/environments**
- Launch a 2D grid of RNN cells
- PyTorch layer integration
- Supports:
  - Uni/Bidirectional RNNs
  - Non-uniform length minibatches
  - Dropout between layers





REWARD SHAPING

- Receive large reward on episode success/failure [-100 100]
- Intermediary & Micro-rewards
  - Trail of breadcrumbs — game of hot & cold
  - Distance Δ to goal (i.e. getting closer or farther away)
  - Clipped to [-1 +1]
- Cap episode max length to slightly more than the minimum time to complete task
  - Otherwise agent may “park” itself or hover to collect extra intermediary reward
  - If agent exceeds the max episode timeout, count it as a loss and reset
  - In some scenarios, the agent should run as long as possible (e.g. CartPole, obstacle avoidance)
- Recent research applies sparse rewards (Hindsight Experience Replay)

RL MOTION CONTROL

- Discrete action/delta mappings
  - Each action adjusts (increases or decreases) a DoF by a set amount
  - Num actions = DoF * 2 (or DoF * 2 + 1 if you want a NULL idle action)
  - Agents are limited by DoF, increases training and difficulty converging
- 1st order — adjust joint positions or motor PWMs
  - Only able to move one DoF at a time (can lead to jerkiness)
- 2nd order — adjust joint velocities
  - Allows all DoF to operate simultaneously
  - Smoother but slower to react than 1st order
- 3rd order — adjust joint accelerations
  - Similar benefits/drawbacks to 2nd order, slower to learn

TRANSFER LEARNING

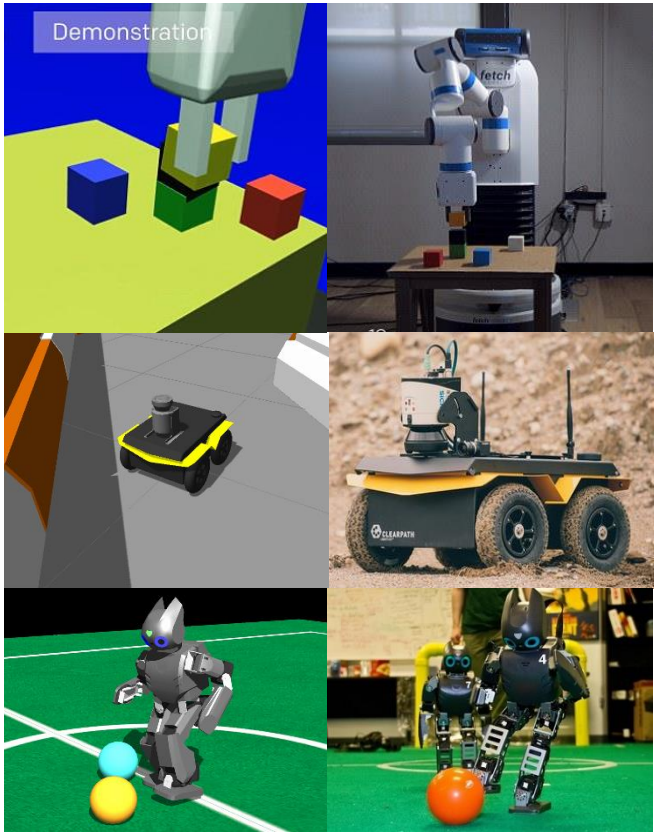
- Adapt learning between similar tasks/environments
- Transition from virtual to physical robot
  - Save model at end of simulation

    ```
    agent->SaveCheckpoint("my_agent.model");
    ```

  - Load model at robot start-up

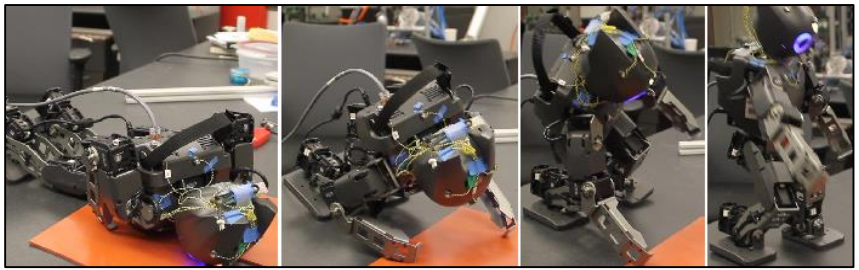
    ```
    agent->LoadCheckpoint("my_agent.model");
    ```

- Some degree of model fine-tuning required based on:
  - Fidelity of simulation
  - Sensor calibration
  - Break-in period
  - Dynamic environment



ONLINE LEARNING

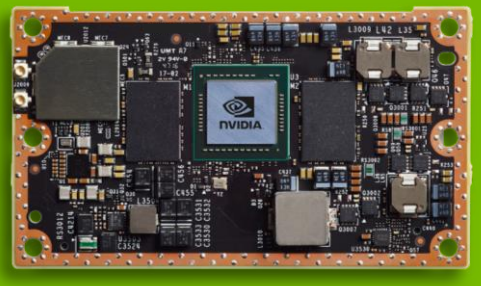
- In-situ training & exploration
  - Realtime interaction with environment and feedback loop needed for agent's convergence, can't just store or record experiences for later
- Self-reinforcing rewards
  - Using higher-end sensors to train simpler sensors (e.g. LIDAR vs. camera)
  - Pre-trained supervisor network (image recognition, object detection)
- Episodic automation
  - "Endless" roaming or self-resetting



WHAT'S NEXT?

- Recent research in Policy Gradient & Actor Critic
  - PPO, ACKTR, A2C/A3C, DDPG/D4PG
- Sparse Rewards - Hindsight Experience Replay
- Multitasking / Hierarchical Subtasks
- Genetic Pruning
- Imitation Learning
  - Supervised seeding of RL models
- NVIDIA Isaac https://developer.nvidia.com/isaac-sdk
- Jetson Xavier https://developer.nvidia.com/jetson-xavier

Thank you!



Developer Portal	developer.nvidia.com/embedded
Download JetPack	developer.nvidia.com/jetpack
2 Days To a Demo	github.com/dusty-nv
Jetson Forums	devtalk.nvidia.com
Visit the Wiki	eLinux.org/Jetson
EDU Discount	bit.ly/2veKN1X

Q&A: What can I help you build?

NVIDIA