GPU TECHNOLOGY CONFERENCE

NVIDIA

Deep Learning for Complexity and Capability in Humanoid Robots

the robot studio

Powered by

maxon motor

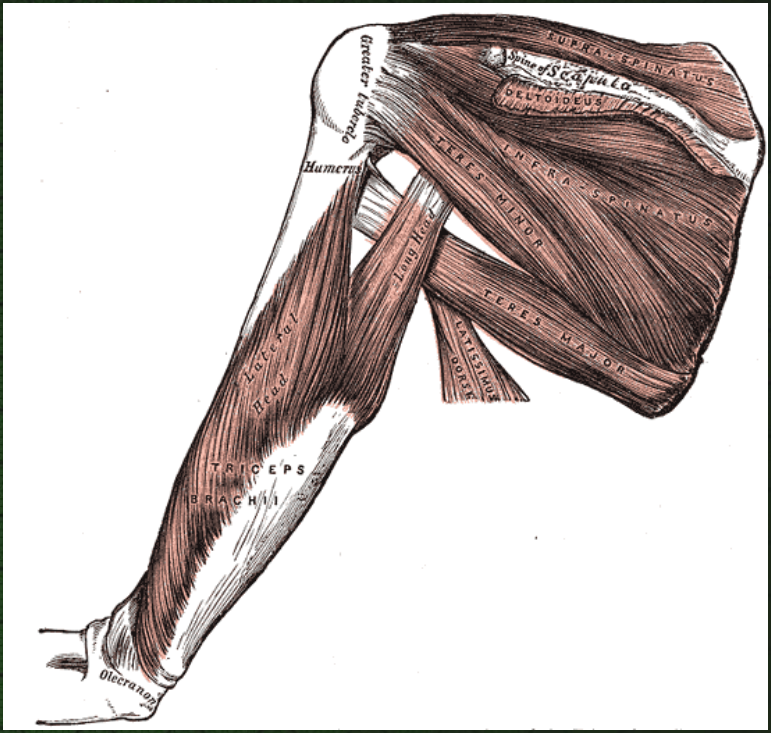
driven by precision

Welcome

- Overview of the particular type of robot we manufacture
  - An “Anthropomimetic” robot
- Place it within the range of humanoid robot technologies
  - Challenges and opportunities abound
- Make some predictions as to how robots may develop
  - The rise of smart robots
- Present our thoughts on embedded AI systems
- Q&A

Open Source Android

- Our robot is the humanoid with a single green eye
- Aims to copy the anatomy of the real human body
  - The “anthropomimetic” approach
- Developed a series of robot prototypes over the last 10 years
- Anatomical input from medical, sports training and plastinations


SUPRA-SPINATUS
Spine of Scapula
DELTOIDEUS
Greater tubercle
Humerus
INFRA-SPINATUS
TERES MINOR
Long Head
TERES MAJOR
LATISSIMUS DORSI
Lateral Head
TRICEPS BRACHII
Olecranon

CRONOS – a conscious robot

- Original reason to create these robots was to investigate consciousness
  - Funded by the EPSRC Adventure Fund
  - Theory is to shape the sensation of existence with the form of the body
    - Make a robot as much like the human body as possible
    - Synthetic Methodology
  - Embedded Intelligence
    - HAL is impossible

The Anthropomimetic Approach

- Endoskeleton actuated by tendons
  - Electric motors spool tendons
- 3D joints are true ball and socket
- Attachment points match the real muscles
  - Muscle does a lot more than just contract
- Compliant structure
  - Tendons are elastic
- Antagonistic set-up

Unexpectedly likeable robot

- Despite looking like a skinned body people loved the robot

Control

- We were not constrained by having to actually make the robot do any particular task
  - The point of ECCE was to address “Emerging Cognition”
    - Had to build a structure that can be controlled
    - All complex animals solve this problem
- Doesn’t seem like a good idea to an engineer
  - Appropriate for copying the human body
    - “Not an engineered system!”
- Needs a self-learning control system

Robots with real capability

- Lots of robots have come and gone
  - End up abandoned in the corner
- World's most popular robot is R2-D2
  - Not C3-PO – function is more important than form
- General Purpose Power Tool
  - From the POV of the user the task is completed in its entirety
  - Not an appliance
- Extremely high expectations – oldest anticipated invention

Technologies in humanoid robots

- A spectrum defined by how hard they are to control
  - Depends on mechanical design approach
- Classical
  - Familiar and well understood – factory robots
- Compliant
  - Series-elastic actuation – factory robots with suspension
- Bio-inspired
  - Compliant, tendon-driven, antagonistic

Classical robots – Common in industry

- Mechanical design maximises stiffness
- Very precise control
- Continuous maximum power
- Usually fixed base
- Highly dangerous
  - Contact with people heavily restricted by safety legislation
- Ultimate example ASIMO
  - Requires precise conditions to operate

ASIMO

- ASIMO Cart bot video
- Mobile phone catch

Compliant robots – Series Elastic

- Mechanical design maximises efficiency
- Precise control is difficult
- Peak power output considerably higher than average
- Well suited to legged robots
- Generally safer
  - Governed by difference legislation
- Best examples produced by Boston Dynamics
  - SPOT Mini is the most important

Compliant robots

- Spot video
- Flip video

Bio-inspired robots – ballistic tendons

- Mechanical design reproduces organic system
- Any control is difficult
- Ballistic speeds and power are possible
- Best design for legged robots
- Accidental high impacts rare but possible
  - Governed by compliant legislation
- Most complete examples ourselves and Kijiro

Ballistic robots

- Video ball throw
- Video jumping robot

Future direction

- Must be compliant
  - Real compliance, not active
- Tendons as appropriate
  - Hybrid design to save cost and complexity
- Tremendous amount of work to do in control
  - High level – vision, navigation, decision making, etc
  - Low level – , basic co-ordination, physics modelling, etc
- Are GPU's the answer?

Complexity and capability

- By definition a general purpose robot cannot be simplified
  - Complexity at three levels: Mechanics, Electrical and Computational
- Dependency Principle
  - The interaction of three domains makes debugging very challenging
  - Lack of abstraction makes it hard to divide work
- Gestalt entity
  - Really don't know what you have until it's finished
  - When initial assumptions revisited you know you're getting close
- Useful also means powerful enough to be dangerous

Practical solutions

- Convergence of culture and technology inevitable
- Two approaches evident:
  - 1. End-to-end development – Centralised resources e.g. Softbank
  - 2. Open Source movement – Distributed effort, worked for drones
- Parallels to iPhone and android, Mac and PC
  - Component level manufacturing remains black-box
- We're looking for collaborators to move up to the next step
  - Enough reliable robots to generate the data for control

Problem

- We want the robots to **perform tasks well** in our environment, be **safe** and **robust**.
- Complexity of the robot: **non-linearity**, **elasticity**, compliance.
- **Unpredictable** environment, always changing.
- => **not possible to program by hand**
- The robot has to **learn skills** by itself
- Tools available for that : **Reinforcement Learning**

Applying RL on hardware directly

- Takes a **long time** to get results
- Requires **many robots** to learn faster
- In many cases, it would **damage itself** or the **environment**
- Needs of **maintenance** and **human supervision**

➢

➔ Cost a lot of **money**

➔ **Not efficient!**

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- We need to **simulate** the robot and apply RL in a simulation, then **transfer the skill** to the robot.

Procedure and progress

- ✓ **Build** the robot
- ✓ Getting **actuators** and **sensors** working
- ➢ **Simulation** of the robot
- ✗ **Training** of DRL in the cloud in a parallel simulators, on a server with **GPUs**
- ✗ **Knowledge transfer** to the real robot.
- ✗ Running inferences locally on a **Jetson TX2**

Jetson TX2 – a game changer

- Credit card size **footprint**

- 1TFLOPS with GPU
  - Run inferences in embedded systems
- 2 CAN bus
  - Direct connexion with motor controllers, no need of extra micro-controller hardware.

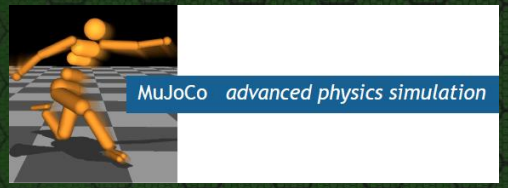
Technology convergence

the robot studio

ROS

OpenCV

BULLET PHYSICS LIBRARY



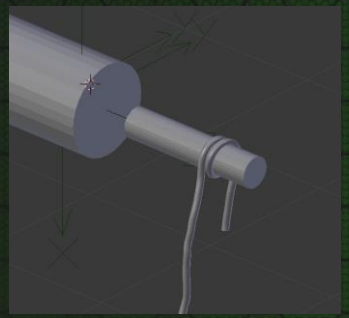
UNREAL ENGINE

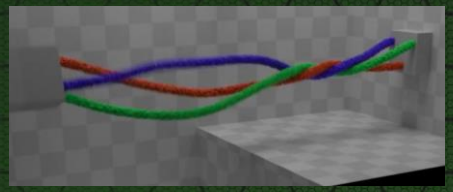
OpenSim

PhysX by NVIDIA

Reinforcement Learning

- Blender + molecular add-on + python scripting + tensorflow





Deep Reinforcement Learning

- Combining DL and RL
- Example: The agent input observation from the environment is camera images on which DL with CNN can be applied.

Challenge

- Model the physics of series-elastic actuators
  - Blender + python scripting
  - Bullet API
  - OpenSim
- Simulators
  - ROS rviz – too limited in terms of physics
  - Gazebo – too limited in terms of graphics
- Model photo-realistic environment
  - Unreal Engine 4

- ISSAC Initiative

Thank you! Any questions ?

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