Deep Reinforcement Learning (DRL)

An introduction to using DRL in robotics

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Arts et Métiers Institute of Technology

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An introduction to using DRL in Robotics

An introduction to get familiarised with...

- Unsupervised / Supervised / Reinforcement learning.
- DRL Training & operating of Artificial Neural Networks
- PyTorch module for DRL training.
- Applications of DRL to robotics.

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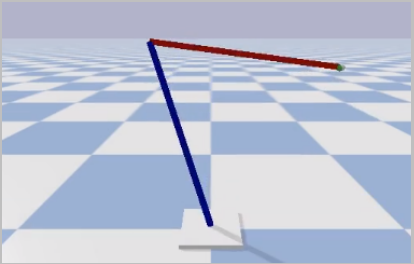
Ressources

- 2 hours of lecture and 1 $\times$ practical work Python session (4h) on **your laptop**
- Dedicated github repository with all the course material (PDF, notebooks...)

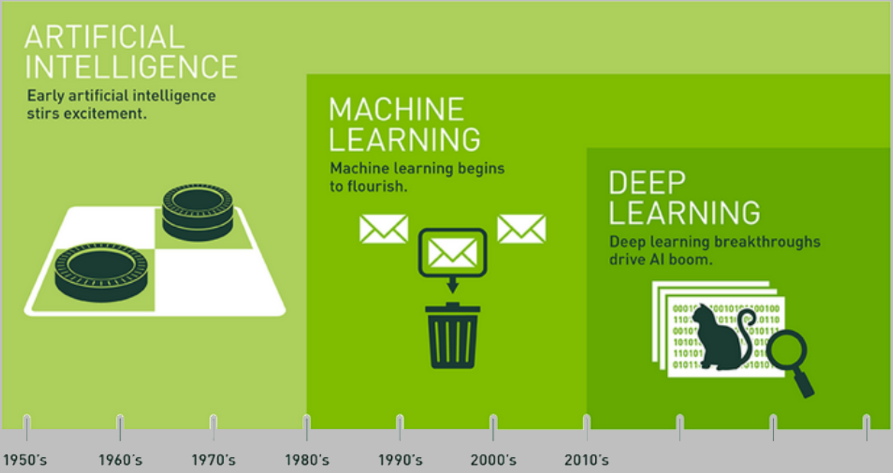
Practical Work: 1 $\times$ 4h

DRL pactical work:

- Build the PyBullet simulation of a 2 DOF robot arm based on its URDF description.
- train a PPO network to drive the displacement of the end effector of a 2 DOF robot arm.



The historical way...



(from : developer.nvidia.com/deep-learning)

Artificial Intelligence ?

Artificial Intelligence [1]: remains an ambiguous term with multiple definitions varying with time:

- *"...the science of making computers do things that require intelligence when done by humans."* Alan Turing, 1940
- *"the field of study that gives computers the ability to learn without being explicitly programmed."* Arthur Samuel, 1960
- *"A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E."* Tom Mitchell, 1997
- Notion of *intelligent agent* or *rational agent*
  "...agent that acts in such a way as to reach the best solution or, in an uncertain environment, the best predictable solution." Stuart Russel, Peter Norvig, "Intelligence Artificielle" 2015

[1] first used in 1956 by John McCarthy, researcher at Stanford during the Dartmouth conference

Artificial Intelligences ?

Qualifiers often encountered:

Strong AI

Weak AI

General AI

Narrow AI

Artificial Intelligences ?

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Strong AI

- Build systems that think exactly the same way that people do.
- Try also to explain how humans think... Whe are not yet here.

Weak AI

- Build systems that can behave like humans.
- The results will tell us nothing about how humans think.
- We already are there... We use it every day!
  (anti-spam, facial/voice recognition, language translation...)

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General AI

- AI systems designed for the ability to reason in general.

Narrow AI

- AI systems designed for specific tasks.

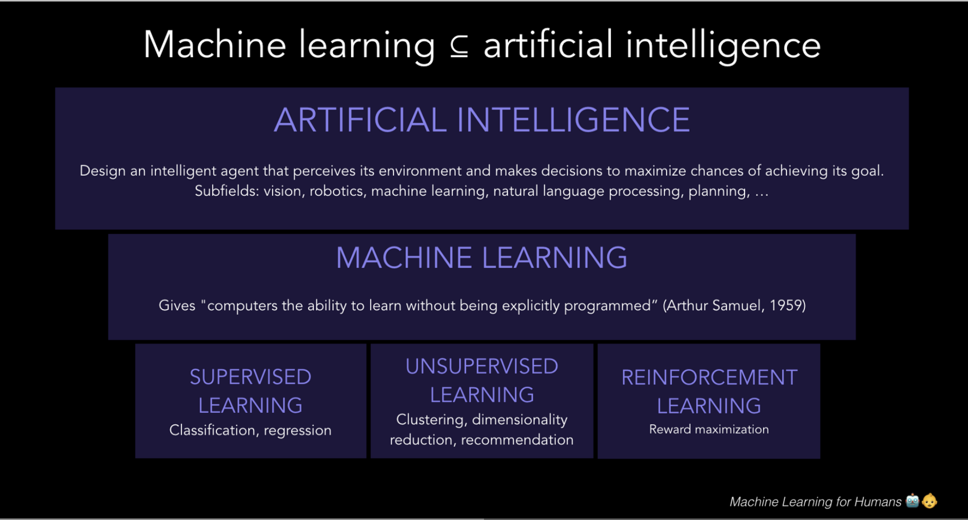
Artificial Intelligence

already a reality:

- Runs in much of our present technology (smartphone apps...)
- Powered by rapid advances in data storage, computer processing power.
- Powered by **free dataset acces via Internet** and **code publishing as open source** environments.
- Rate of acceleration is already astounding.
- Will likeky shape our future more powerfully than any other innovation this century.

Machine Learning and AI

Page from medium.com/machine-learning-for-humans/...



Branches of Machine Learning

Supervised learning applications

labeled dataset is used to train algorithms to classify data:

- **Classification**
  - Images classification
  - Objects detection
  - Speech recognition...
- **Regression**
  - Predict a value...
- **Anomaly detection**
  - Spam detection
  - Manufacturing: finding known (learned) defects
  - Weather prediction
  - Diseases classification...

Branches of Machine Learning

Unsupervised learning application

Analyze and cluster **unlabeled datasets**:

- **Clustering** & **Grouping**
  - Data mining, web data grouping, news grouping...
  - Market segmentation
  - DNA grouping
  - Astronomical data analysis...
- **Anomaly Detection**
  - Fraud detecion
  - Manufacturing: finding defects even new ones
  - Monitoring abnormal activity: failure, hacker, fraud...
  - Fake account on Internet...
- **Dimensionality reduction**
  - Compress data using fewer numbers...

Branches of Machine Learning

Reinforcement learning

An agent learns how to drive an environment by maximising a **reward**:

- **Control/command**
  - Controlling robots, drones...
  - Factory optimization
  - Financial (stock) trading...
- **Decision making**
  - games (video games)
  - financial analysis...

Various approaches for ML algorithms

Supervised learning:

- Neural Networks
- Bayesian inference
- Random forest
- Decision Tree
- Support Vector Machine
- K-Nearest Neighbor
- Linear regression
- Logistic regression...

Unsupervised learning:

- Neural Networks
- Principal Composant Analysis
- Singular Value Decomposition
- K-mean & Probabilistic clustering

Reinforcement learning:

- Monte Carlo
- SARSA
- Neural Networks (Q-learning, Actor-Critic...)

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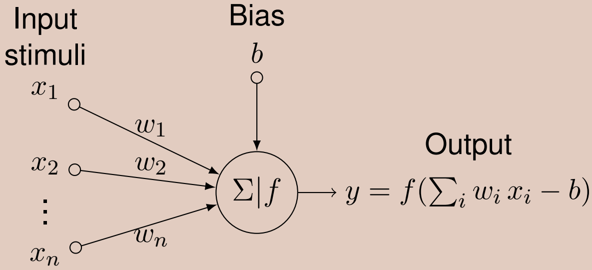
The following deals only with **Artificial Neural Networks**.

Artificial Neural Networks

The Artificial neuron model



Artificial Neural Networks

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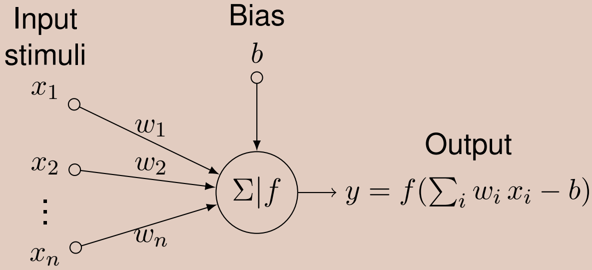

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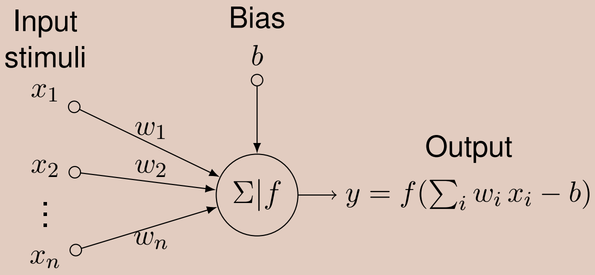

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Artificial Neural Networks

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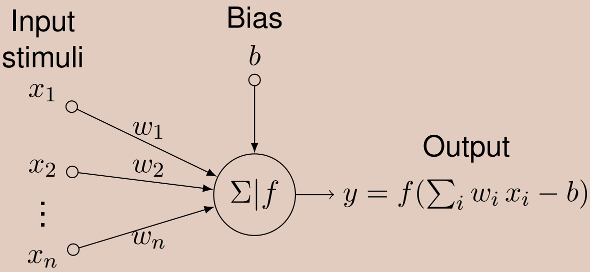

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Artificial Neural Networks

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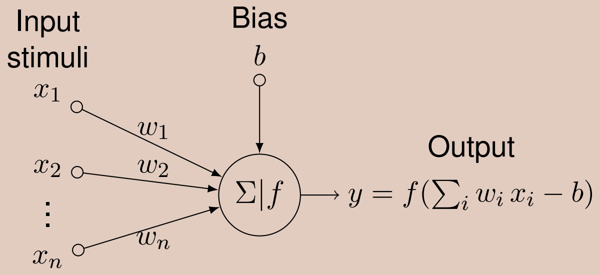
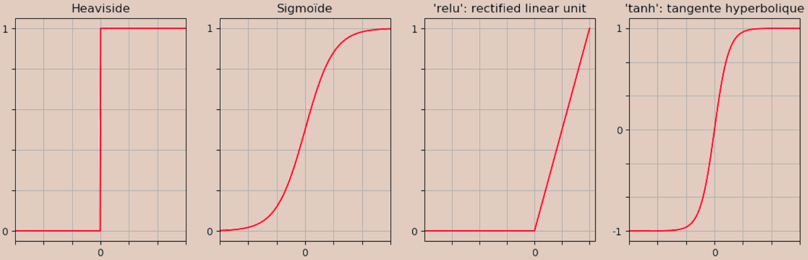


An **artificial neuron**:

- receives the input stimuli $(x_i)_{i=1..n}$ with **weights** (w_i)
- computes the **weighted sum** of the input $\sum_i w_i\, x_i - b$
- outputs its activation $f(\sum_i w_i\, x_i - b)$, computed with a non-linear **activation function** f .

Artificial Neural Networks

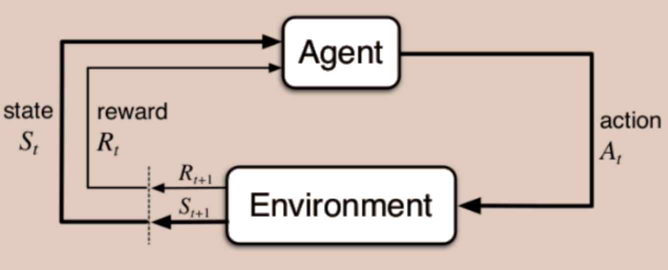
Common activation functions



- Introduces a non-linear behavior.
- Sets the range of the neuron output: $[-1,1]$, $[0,1]$, $[0,\infty[$...
- The bias b sets the activation threshold of the neuron.

Reinforcement Learning

RL main ingredients



(Source: Reinforcement Learning: An Introduction by Richard S. Sutton and Andrew G. Barto)

The **agent** (the neural network) learns how to take the right **action** on the **environment** (the system to be controlled) in order to maximize its long-term **reward**.

RL ingredients: **Agent**

The **Agent** is the **algorithm**:

RL ingredients: **Agent**

The **Agent** is the **algorithm**:

- Monitors the **Environment**
- Decides wich **action** to be taken
- Action can be
  discrete: on/off, left/right...
  continuous: force/velocity applied....
- Goal: maximize the total reward it receives in the long run.

Discrete versus continuous action involves different algorithms for the learning stage

RL ingredients: **Environment**

The **Environment** is what the Agent wants to monitor:

RL ingredients: **reward** funtion

RL ingredients: **Environment**

The **Environment** is what the Agent wants to monitor:

- Receives **actions** from the Agent.
- Takes a new **state** under the Agent's action.
- Gives back its new **state** and computed **reward** to the Agent.
- Modelized as a **Partially Observable Markov Process**.

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RL ingredients: **reward** funtion

- Maps each (state, action) pair of the environment to a number indicating the intrinsic desirability of that state.
- The environment sends a **scalar value** as a **reward** in response to the agents's action.

Model-free versus Model-based DRL algorithms

Model-free

- No explicit representation of the environment
- Learning rely only on experiences using **trial and error**.
- Examples : Monte Carlo, SARSA, Q-learning, and Actor-Critic algorithms.
- Applies to car driving, robot control...

Model-based algorithms

- The agent has access to (or learns) a **model** of the environment.
- Applies to environment like Chess, Go...

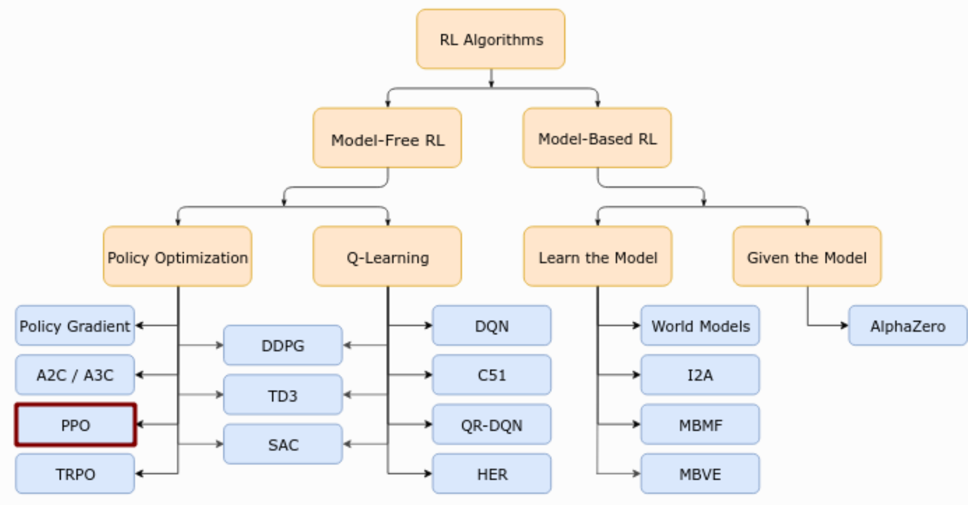
RL reference sites

Stable-baseline3

A set of reliable implementations of reinforcement learning algorithms in **PyTorch**.

- github.com/DLR-RM/stable-baselines3
- docs: stable-baselines3.readthedocs.io spinningup.openai.com
- install: `pip install stable-baselines3`

A Taxonomy of RL Algorithms (Source: spinningup.openai.com)



The DRL practical work

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- The robot is described in the simulator thanks to its URDF file.
- The PyTorch Python module provides classes to instanciate and train the PPO neural network.
- To ensure the robustness and maintainability of Python developments, the work is done in a **Python Virtual Environment** (PVE).

The DRL practical work

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