Ethics of Interaction
classical framework
System engineering
Robot Behavior
Sensing and Interpretation

Artificial Intelligence: From the lab to the real world

Four decades of AI research at the VUB AI Lab

Prof. dr. Ann Nowé
Director AI Lab
ann.nowe@vub.be

Prof. dr. Bernard Manderick
Former Co-Director AI Lab
bernard.manderick@vub.be

30 March 2022

ai.vub.ac.be
@aibrussels

VUB
ARTIFICIAL INTELLIGENCE RESEARCH GROUP

1983
Year founded

87
Researchers

1000+
Publications

60+
Alumni

VUB Artificial Intelligence Lab

Interdisciplinary team, Strong heritage, Leading position

60
Collaborations with companies over last 3 years

5
Spin-offs

14
Active industry-funded projects

5
Active EU projects

2019
VUB AI Experience Center founded

VUB
ARTIFICIAL
INTELLIGENCE
RESEARCH GROUP

Adaptive Learning & Collaborative AI

Machine control

Autonomous machines

Resource management

Smart grids

VUB Artificial Intelligence Lab

Interdisciplinary team, Strong heritage, Leading position

Human-like AI

Emergent communication

Language and sound processing

Document layout analysis

AI Maturity & Safety

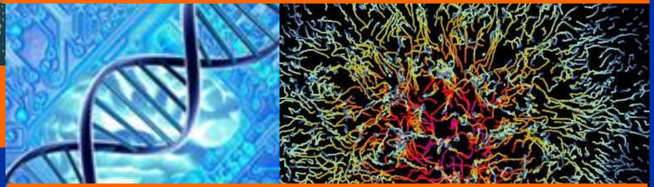
Explainable AI

Cybersecurity

Decision Intelligence

Data analytics & process optimization

Recommenders



Decision making in healthcare

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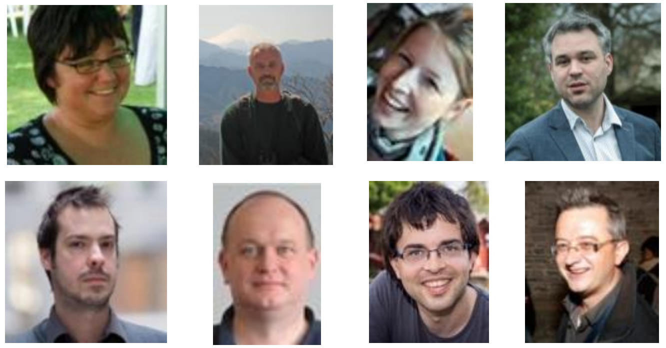
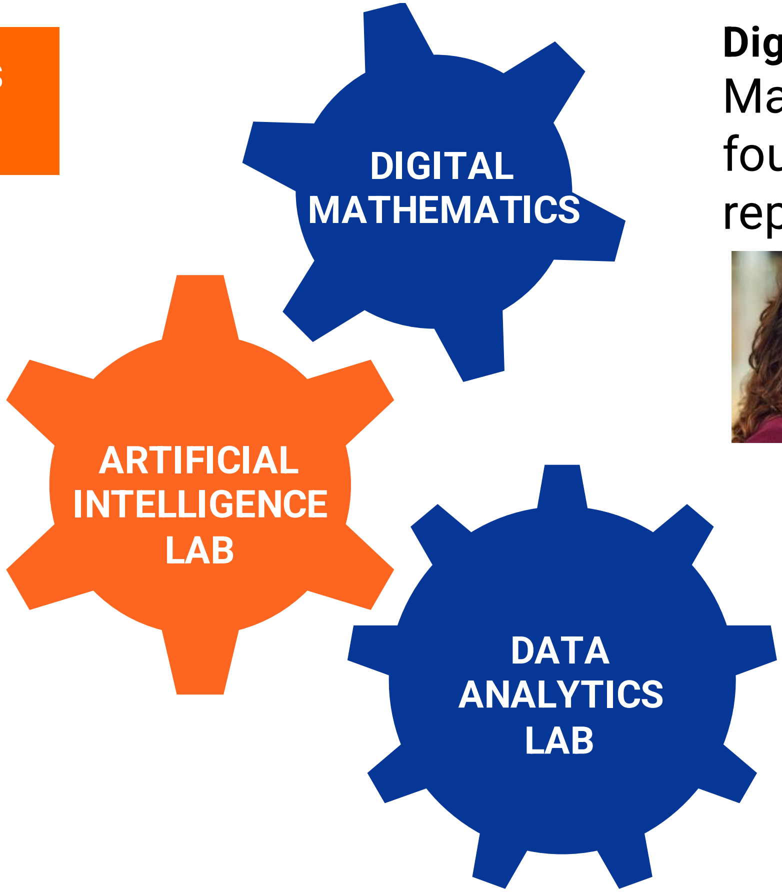
RESEARCH GROUP

Artificial Intelligence Lab *extended*: Consortium of three VUB research groups

Interdisciplinary team that performs **fundamental** and **applied** research

Artificial Intelligence Lab
Symbolic and subsymbolic AI,
Agnostic and cognitive AI




DIGITAL MATHEMATICS
ARTIFICIAL INTELLIGENCE LAB
DATA ANALYTICS LAB

Digital Mathematics
Mathematical aspects of data science foundations for data acquisition, representation and analysis

Data Analytics Lab
Applied data science, business-oriented

Presentation at 15.30

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INTELLIGENCE
RESEARCH GROUP

VUB Artificial Intelligence Lab

Guide enterprises through the AI revolution and help them become more innovative and increase their excellence through the potential of AI

Research

Collaborating intensively on fundamental, strategic and applied research

UZ Universitair Ziekenhuis Brussel

ULB

iB²

icity.brussels THE ICT HEART OF EUROPE

AI FLANDERS BUILDING OUR DIGITAL FUTURE

CLAIRE

AXILES BIONICS

SONY

collibra

telenet

SABCA

Education

Education programs for (under)graduate students…

Bachelor in AI starting 2022

… and professionals

Lifelong Learning Program

Services to society

Bringing researchers, industry and policymakers together

VUB AI XPERIENCE CENTRE

FARI AI FOR THE COMMON GOOD INSTITUTE BRUSSELS

Presentation at 11.10

VUB ARTIFICIAL INTELLIGENCE RESEARCH GROUP

More info on our website: ai.vub.ac.be

VUB AI Experience Centre (founded 2019)

- "One-stop shop" for everyone interested in AI
  - Meeting place for researchers, companies, policymakers and the general public
  - Offers training, consultancy, research projects
  - Showcases demonstrators/prototypes and test infrastructure
  - Used for seminars, company visits, events
- Partnership between multiple VUB research groups
  - Not only technological but also sociological and ethical aspects

BRUBOTICS
HUMAN ROBOTICS
RESEARCH CENTER

SMIT
STUDIES IN MEDIA,
INNOVATION & TECHNOLOGY

ETRO
ELECTRONICS &
INFORMATICS

ARTIFICIAL
INTELLIGENCE
RESEARCH GROUP

More info:
experience-centre.ai

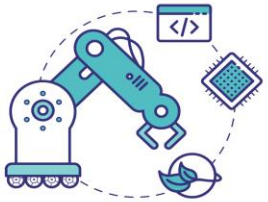
Hans De Canck
hans.de.canck@vub.be

Flanders AI Research Program
Challenge-based Research with Demand-driven Impact

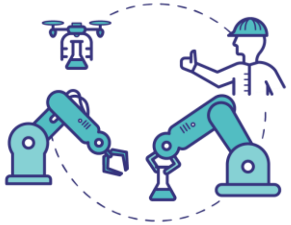
Generic research challenges

AI-driven data science

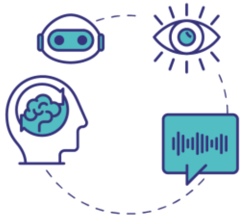
Edge AI



Collaborative AI



Human-like AI



Focus domains and use cases

HEALTH

INDUSTRY

ENERGY

GOVERNMENT & CITIZENS

DEMONSTRATORS
Inspire &
Steer research challenges

Ambition
Increase adoption of AI

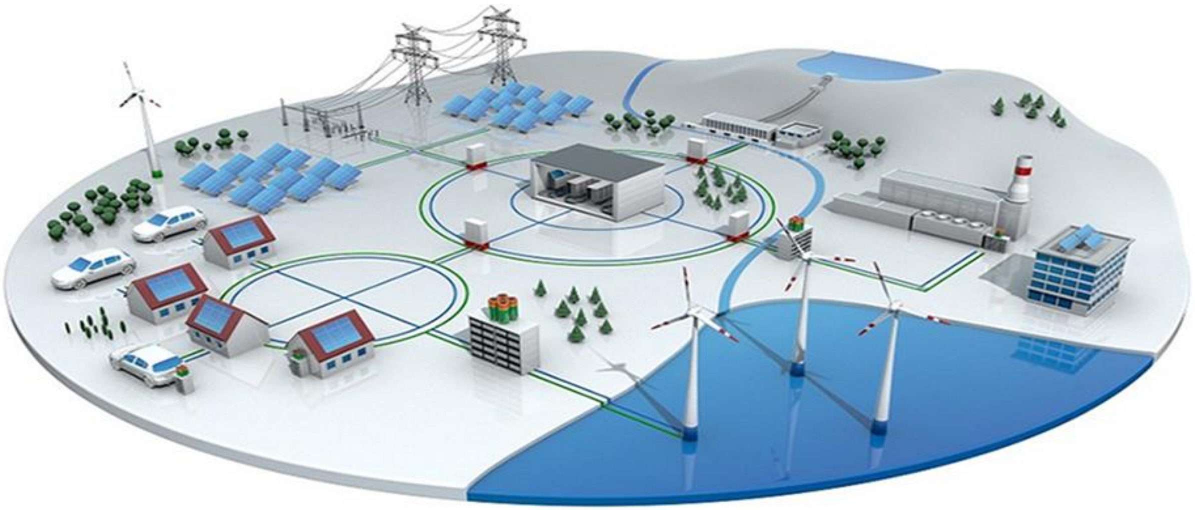
Uptake of research results in companies and organisations in ALL DOMAINS

1 AS ONE PROGRAM

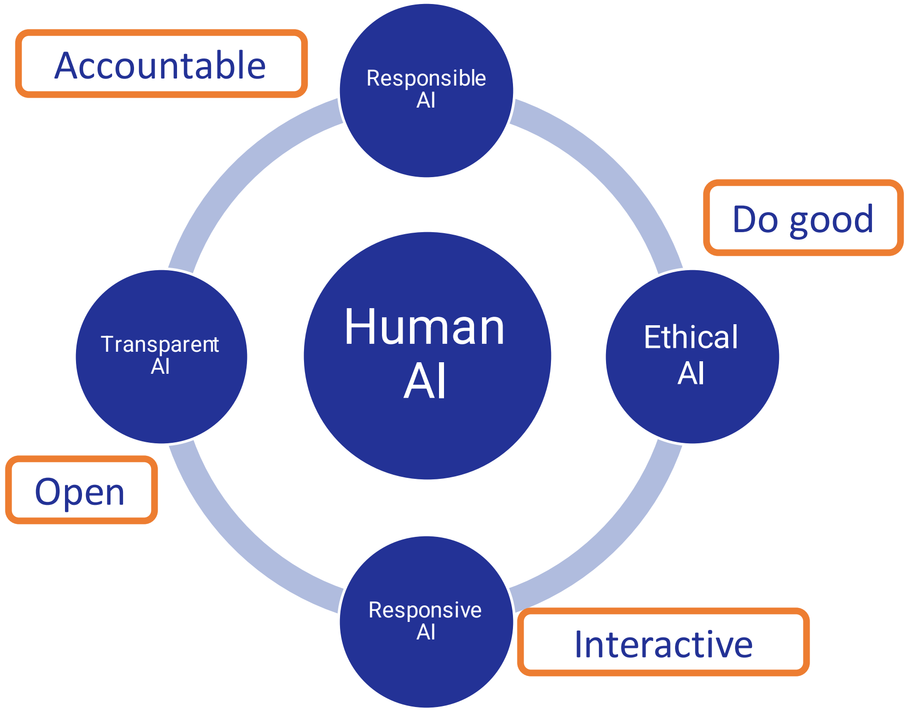
https://www.flandersairesearch.be/

Our research: multi-agent collaborative AI

- AI systems are not standalone
  - they act in an **environment**
  - they **interact** with **humans**



Agents in a smart grid model


Accountable
Responsible AI
Do good
Transparent AI
Human AI
Ethical AI
Open
Responsive AI
Interactive

- Focus on **online**, **adaptive** and **dynamic** learning algorithms
- Not only **learning**, but **acting** from knowledge

AI Lab research

Reinforcement learning and **multi-agent systems**

Language processing & *interaction*

Emergent communication

: smart grid demo

Hybrid AI

RL 101

Robot communication

Data science and **business** analytics

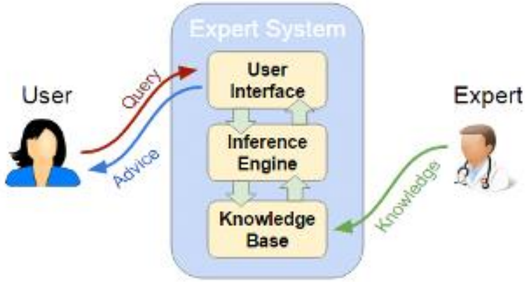
Knowledge **representation** and **reasoning**

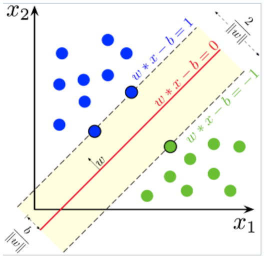
Luc Steels' opera Fausto
@ Monnaie, Brussels

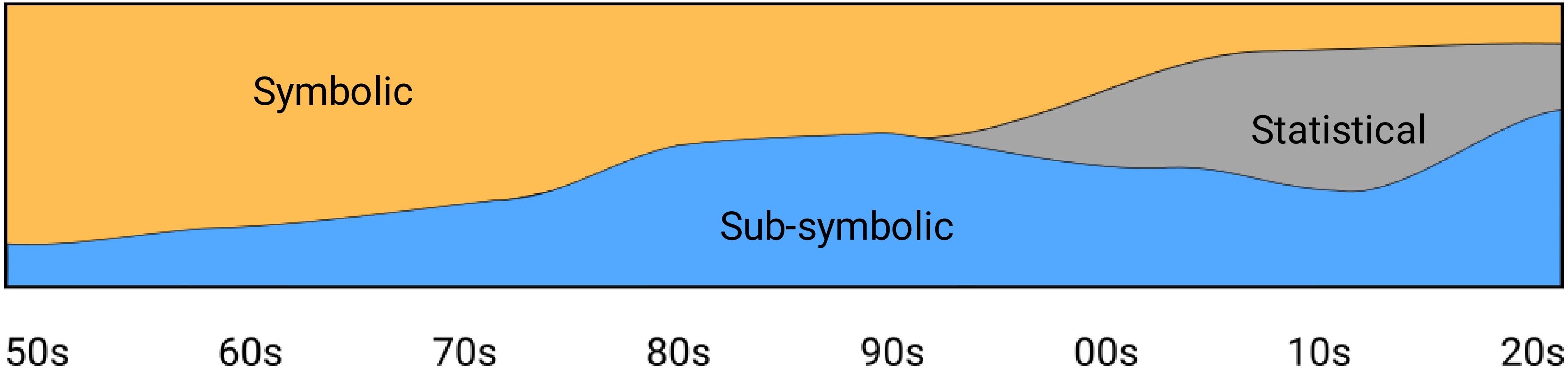
Computational **creativity**

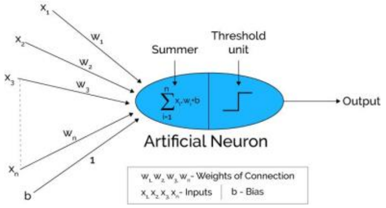
ARTIFICIAL
INTELLIGENCE
RESEARCH GROUP

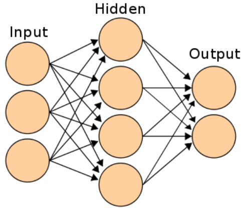
Brief history of AI: the different movements


Expert System
User
Query
Advice
User Interface
Inference Engine
Knowledge Base
Expert
Knowledge


x_2
x_1
$w * x - b = 1$
$w * x - b = 0$
$w * x - b = -1$
$\frac{2}{\|w\|}$
$\frac{b}{\|w\|}$
w

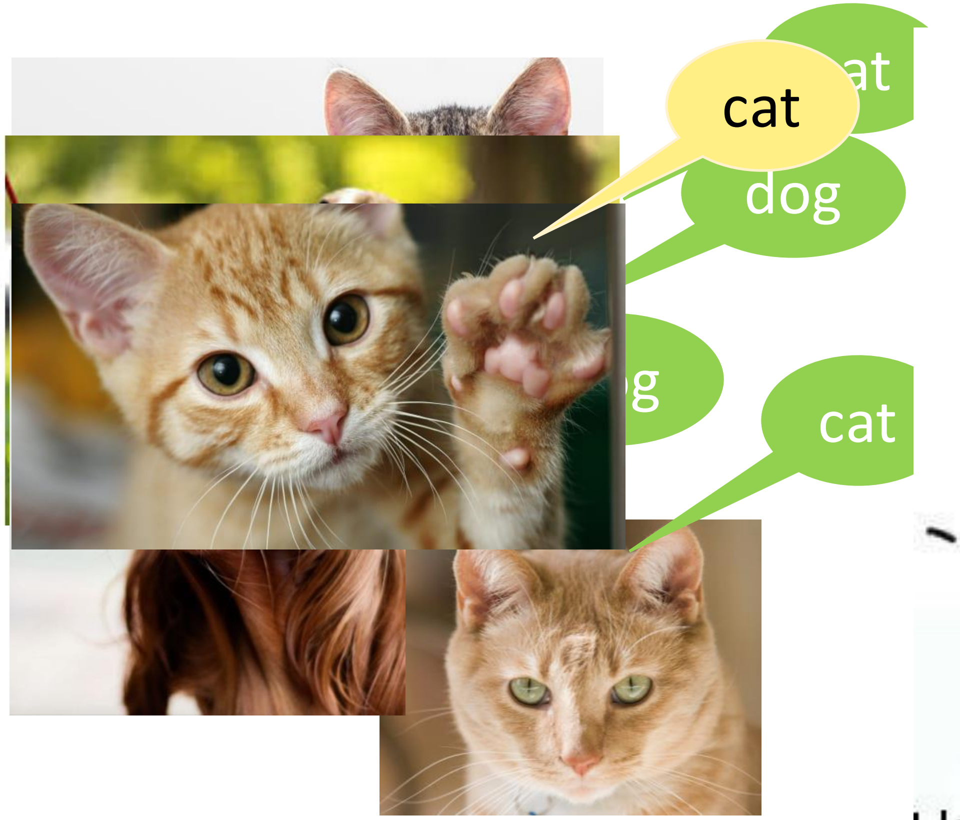



x_1
x_2
x_3
x_n
b
w_1
w_2
w_3
w_n
1
Summer
Threshold unit
$\sum_{i=1}^{n} x_i w_i + b$
Output
Artificial Neuron
$w_1\ w_2\ w_3\ w_n$ - Weights of Connection
$x_1\ x_2\ x_3\ x_n$ - Inputs
b - Bias

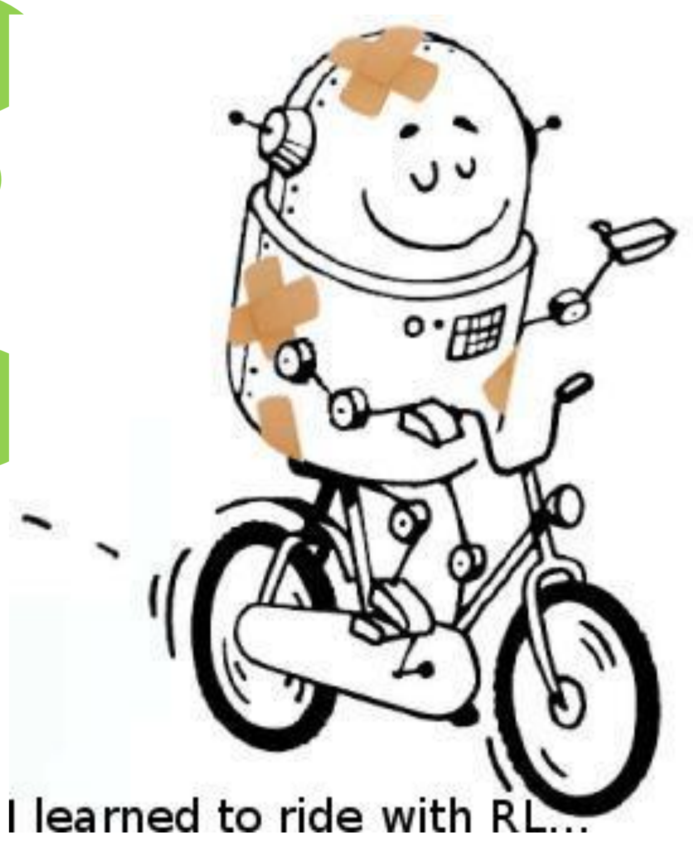

Input
Hidden
Output

Subfields of Machine Learning

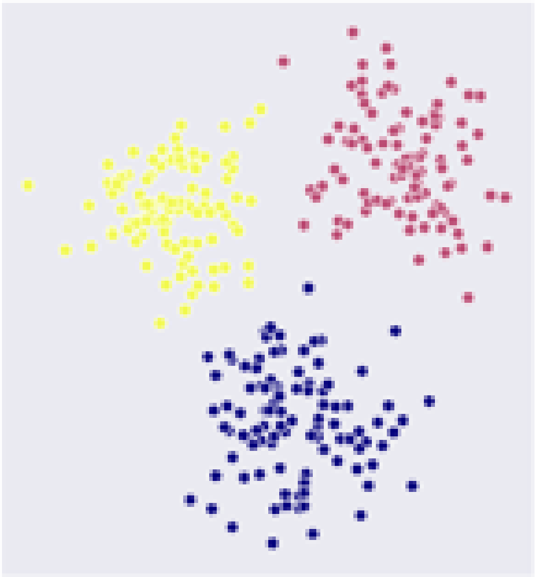
Supervised


at
cat
dog
g
cat

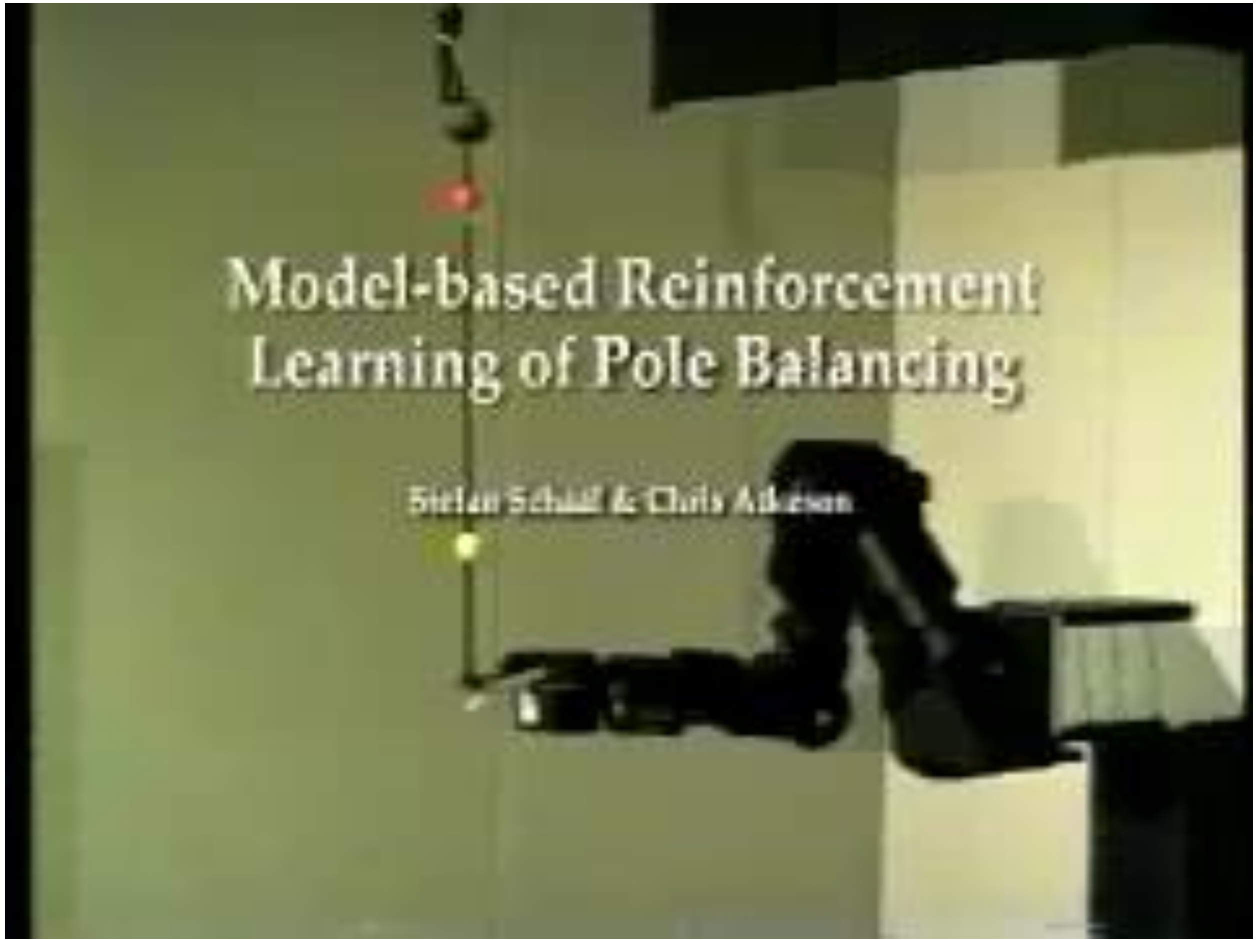
Reinforcement


I learned to ride with RL...

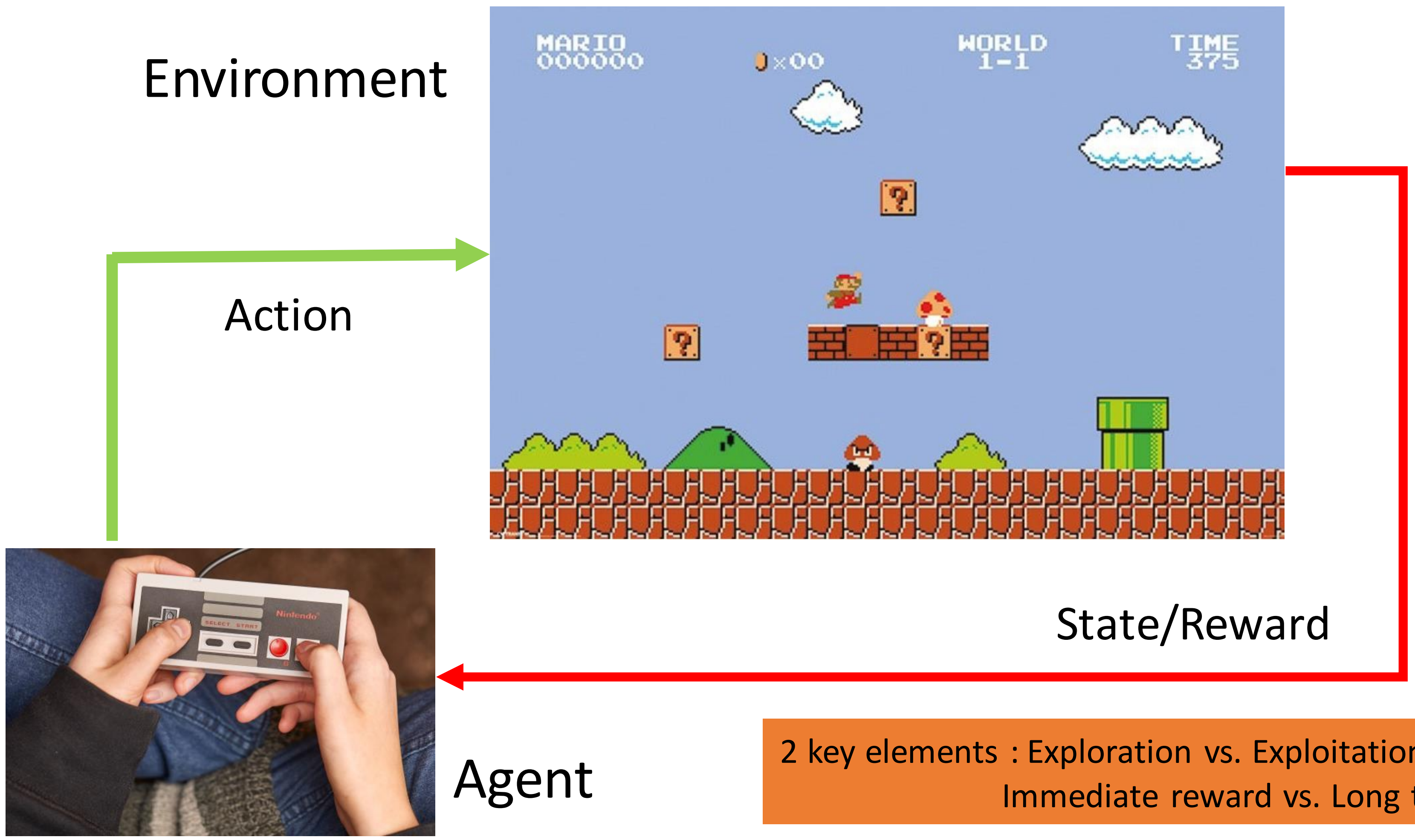
Unsupervised



Reinforcement Learning


Model-based Reinforcement Learning of Pole Balancing
Stefan Schaal & Chris Atkeson

Learning from interactions


MARIO
000000
×00
WORLD
1-1
TIME
375

Environment

Action

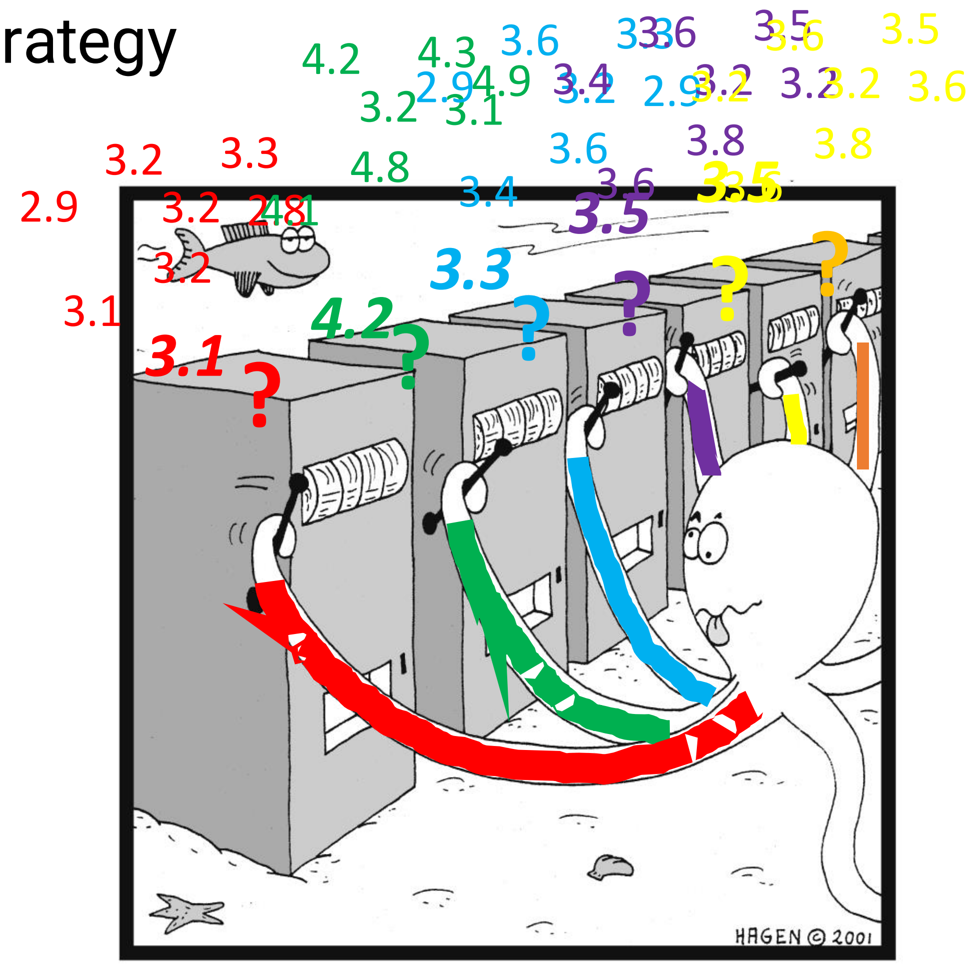
State/Reward

Agent

2 key elements : Exploration vs. Exploitation
Immediate reward vs. Long term reward

Exploration versus exploitation: bandits

Finding the best epidemic mitigation strategy



3.1
4.2
3.3
3.5
3.5
?
?
?
?
?
?
2.9
3.2
3.3
3.2
3.2
3.1
4.2
4.3
3.6
3.2
2.9
4.9
3.1
4.8
3.4
3.6
3.6
3.4
3.2
2.9
3.2
3.8
3.5
3.6
3.2
3.2
3.8
3.5
3.6
HAGEN © 2001

Close school

Close restaurants

Close non-essential shops

Close shops & restaurants

Exploration versus exploitation: bandits

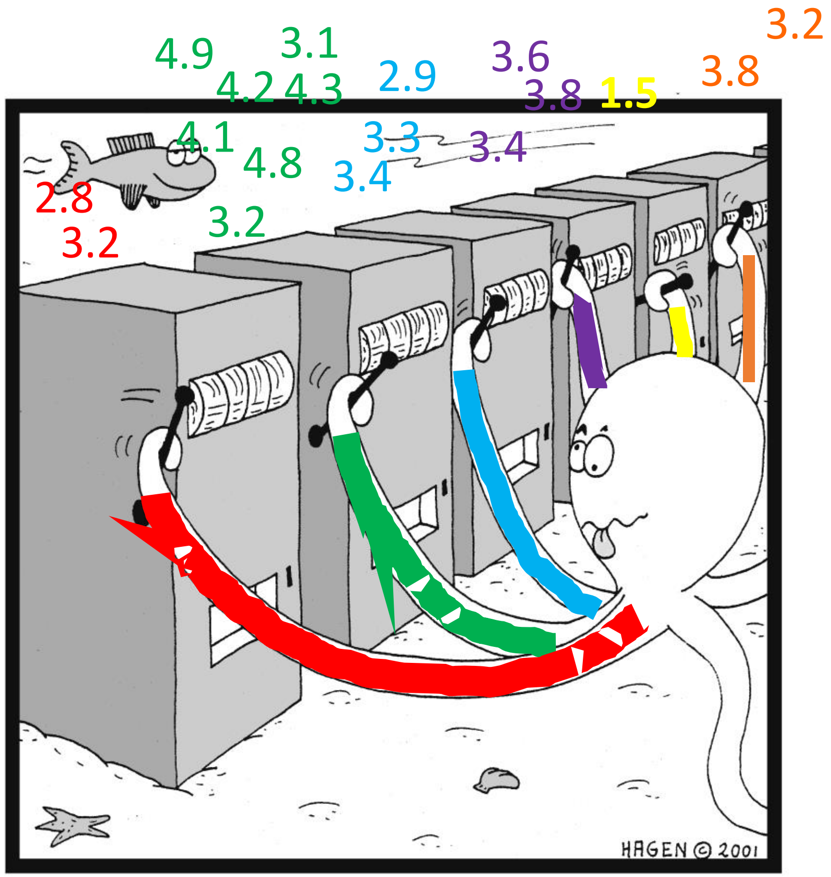
Finding the best epidemic mitigation strategy

Close school

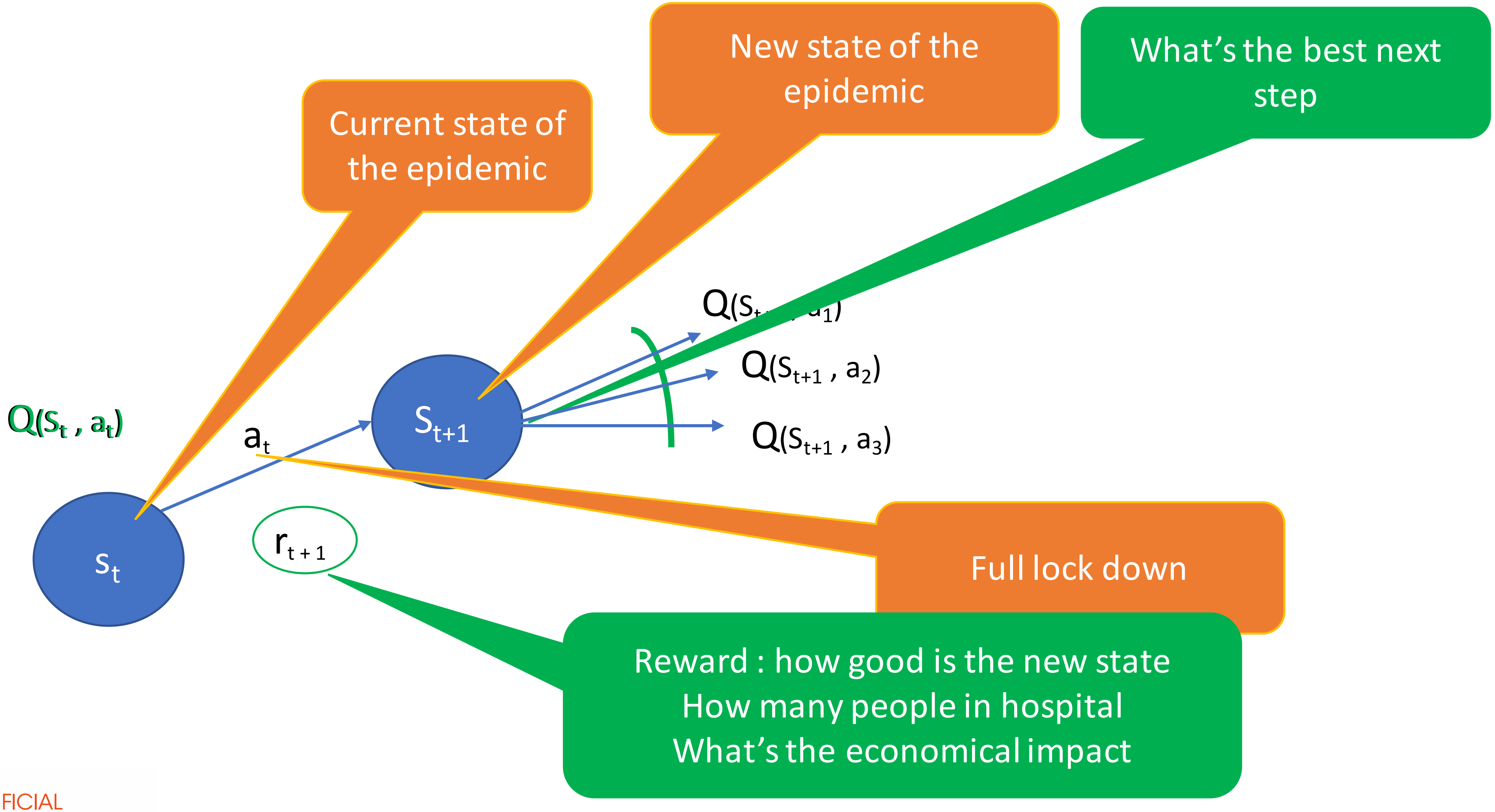
Close restaurants

Close non-essential shops

Close shops & restaurants


4.9
3.1
4.2
4.3
2.9
3.6
3.8
1.5
3.2
3.8
4.1
4.8
3.3
3.4
3.4
2.8
3.2
3.2
HAGEN © 2001

Immediate and long-term reward


Current state of the epidemic
New state of the epidemic
What's the best next step
$Q(S_{t+1}, a_1)$
$Q(S_{t+1}, a_2)$
$Q(S_{t+1}, a_3)$
$Q(S_t, a_t)$
a_t
S_{t+1}
S_t
r_{t+1}
Full lock down

Reward : how good is the new state
How many people in hospital
What's the economical impact

Applications of reinforcement learning

AlphaGo

LEE SEDOL
00:01:00

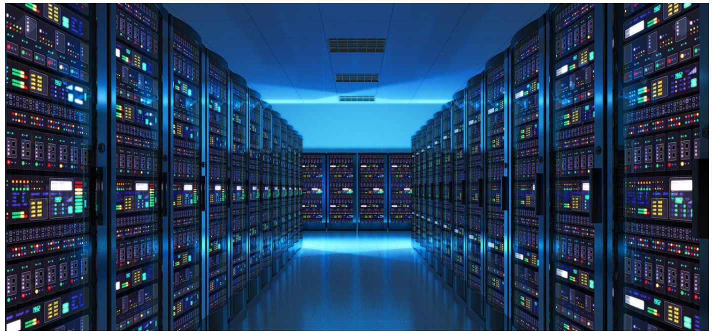
Exploration of 5.12×10^{20} possible configurations of the game

Space Shuttle Attitude Control

United States

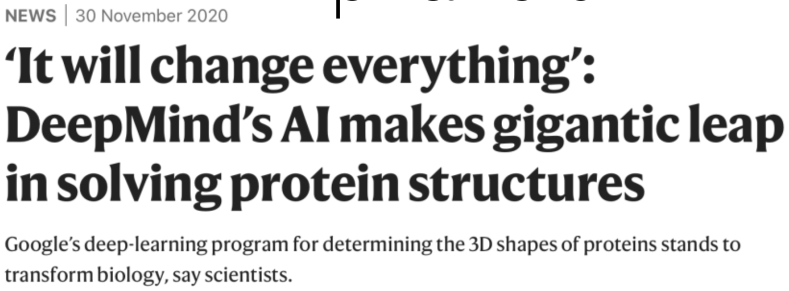
Difficult non-linear controller, higher optimality with RL than classical control

Datacenter cooling



Exploration of the impact of decisions on long time-scales

AlphaFold

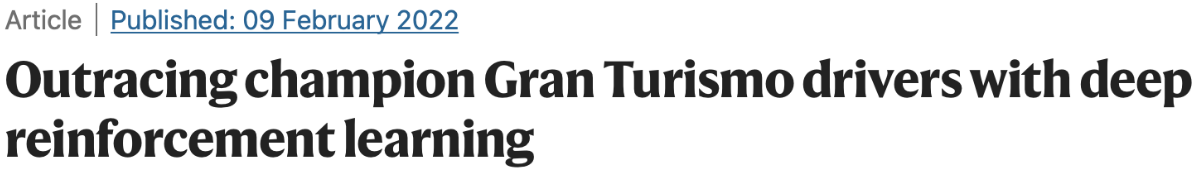


NEWS | 30 November 2020

‘It will change everything’: DeepMind’s AI makes gigantic leap in solving protein structures

Google’s deep-learning program for determining the 3D shapes of proteins stands to transform biology, say scientists.

and other variants

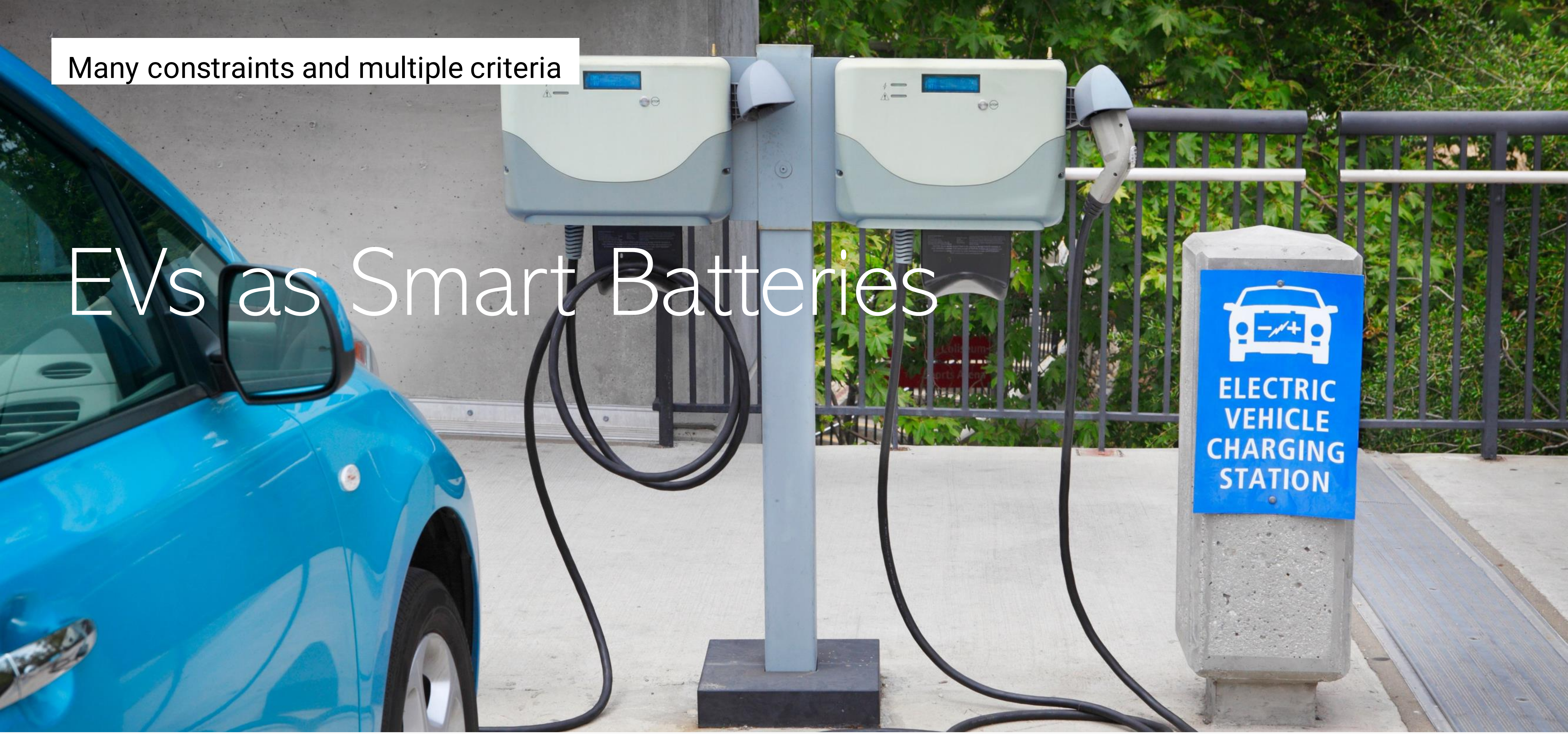


Article | Published: 09 February 2022

Outracing champion Gran Turismo drivers with deep reinforcement learning

Many constraints and multiple criteria

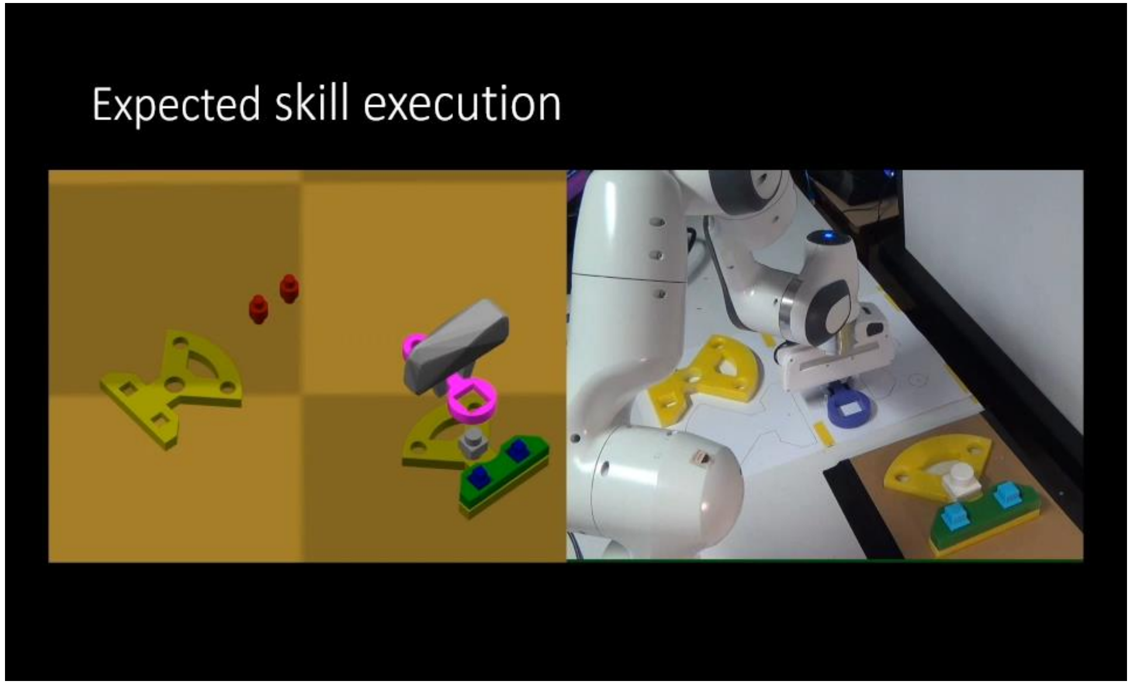
EVs as Smart Batteries


ELECTRIC
VEHICLE
CHARGING
STATION

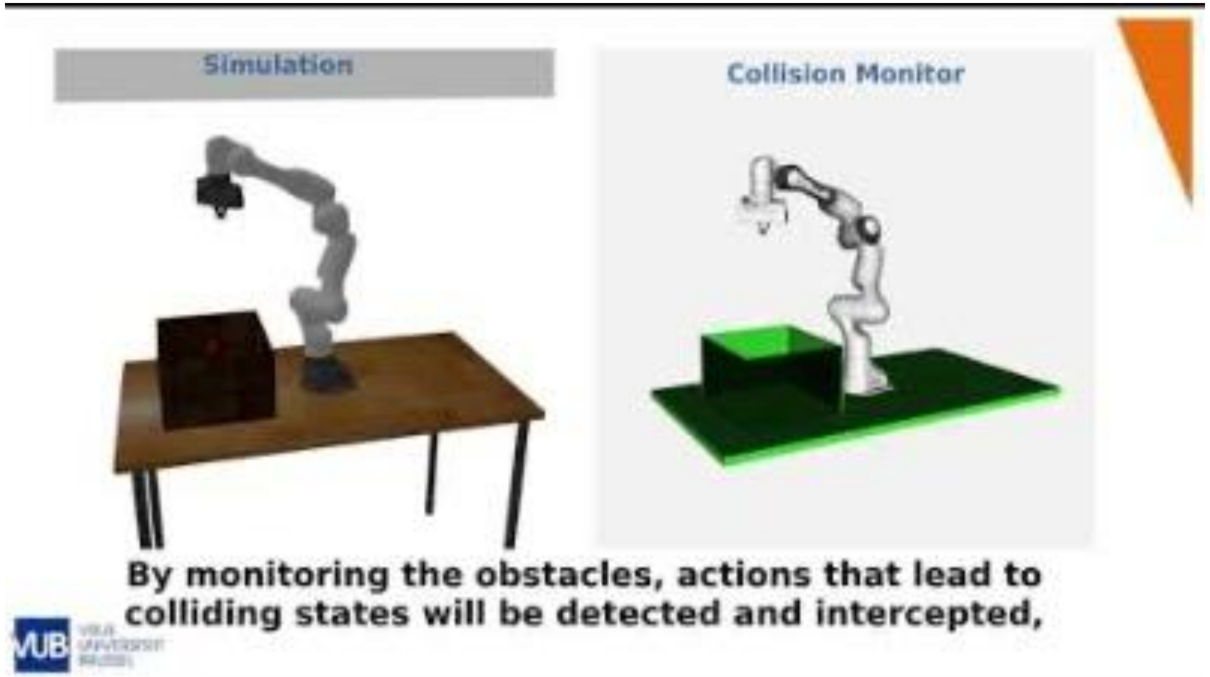
Non-stationary dynamic system, unexpected events

Wind Turbines

RL and digital twins



Expected skill execution


Simulation
Collision Monitor

By monitoring the obstacles, actions that lead to colliding states will be detected and intercepted,

Ann Nowé (VUB AI Lab), Bram Vanderborght (VUB R&MM)

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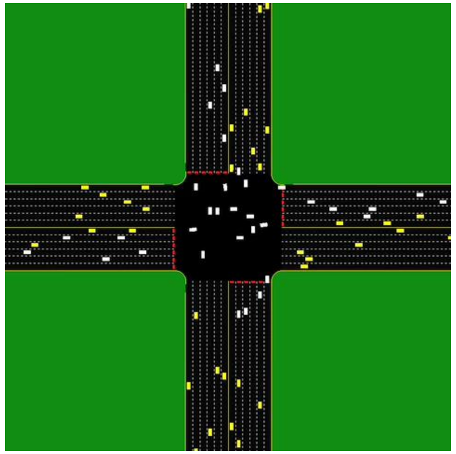
RESEARCH GROUP

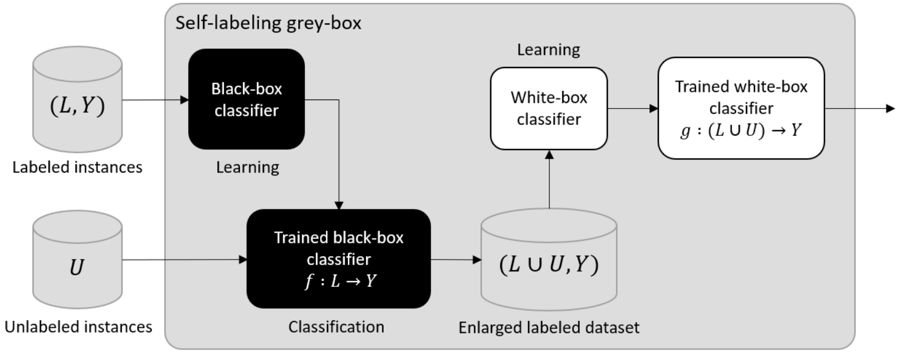
Multiple agents

AI systems are not standalone and have to coordinate between each other



Other research lines

Explainable AI



Self-labeling grey-box

(L, Y)

Labeled instances

Black-box classifier

Learning

U

Unlabeled instances

Trained black-box classifier $f : L \rightarrow Y$

Classification

$(L \cup U, Y)$

Enlarged labeled dataset

Learning

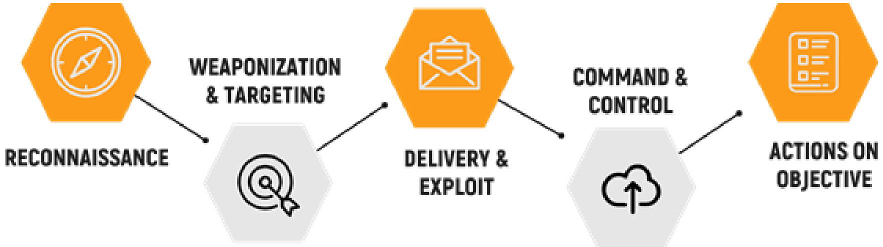
White-box classifier

Trained white-box classifier $g : (L \cup U) \rightarrow Y$

Document Layout Analysis

Visual Query Answering

AI & Cybersecurity



RECONNAISSANCE

WEAPONIZATION & TARGETING

DELIVERY & EXPLOIT

COMMAND & CONTROL

ACTIONS ON OBJECTIVE

And many more…

Interested in collaborating? Contact us!

Ann Nowé

Director

ann.nowe@vub.be

Hans De Canck

Manager AI Experience Centre & FARI

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Leander Schietgat

Research & Innovation Manager

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Gill Balcaen

Business developer

gill.balcaen@vub.be

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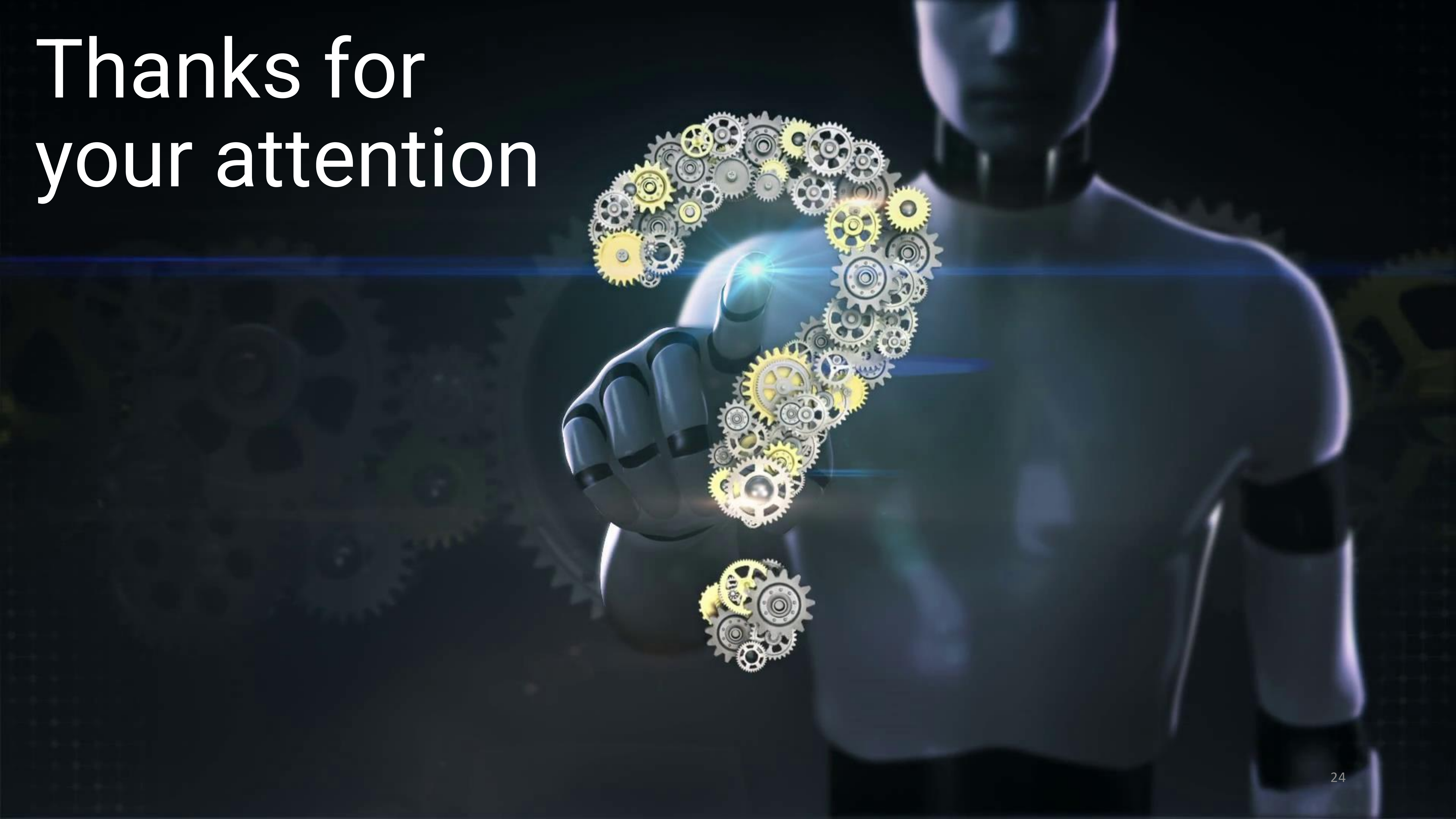
Thanks for your attention



AI Lab Expertise

Innovation Tracks

Human-Like AI

- Document Layout Analysis
- Language Processing
- Reasoning with ‘concepts’
- Signal compression & decompression (sound, EEG, …)

Adaptive Learning & Collaborative AI

- Control for Industrial Machines
- Planning and coordination of UAVs and AGVs
- Resource Optimization (smart grids, logistics, mobility, …)

Sub-tracks

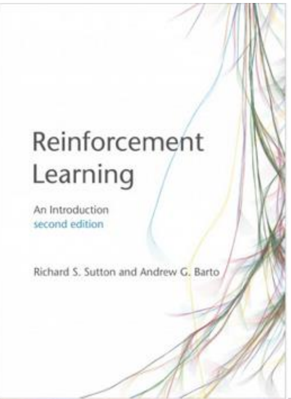
AI Maturity & Safety

- Explainability, transparency, fairness, Bias, Safety, … in AI
- Cybersecurity
- Fraud analytics
- Digital Forensics
- AI Coaching, trainings, Audits, testing, consultancy, …

Decision Intelligence

- Data Analytics
- Process optimization
- Inverse Design (Molecules)
- Recommender Systems
- Decision Making
- Define strategies based on models

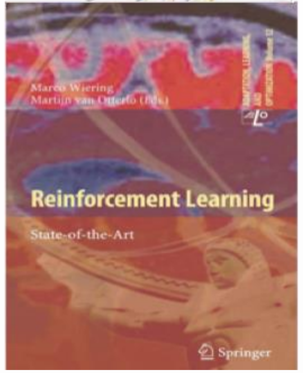
More on RL?


Reinforcement Learning
An Introduction
second edition
Richard S. Sutton and Andrew G. Barto

Reinforcement Learning: an introduction

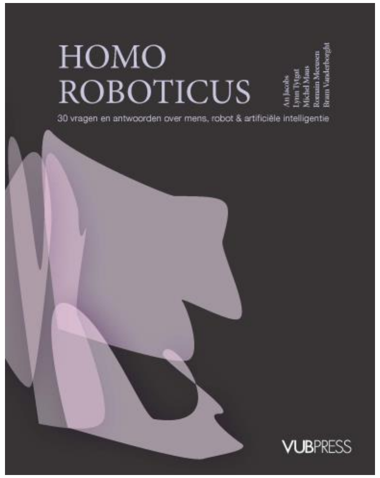
R.S. Sutton and A.G. Barto

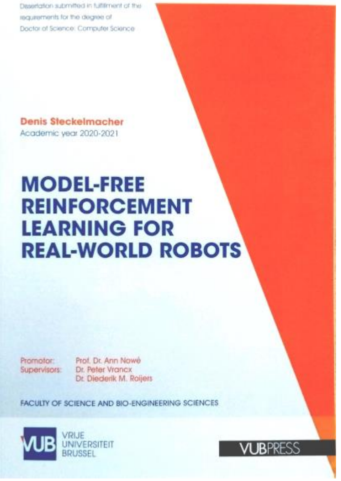
Available for free online


Marco Wiering
Martijn van Otterlo (Eds.)
Reinforcement Learning
State-of-the-Art
Springer

Reinforcement Learning: State-of-the-Art,
M. Wiering and M. van Otterlo

Covers more advanced topics


HOMO
ROBOTICUS
An Jacobs
Lynn Tytgat
Michel Maus
Romain Meeusen
Bram Vanderborght
30 vragen en antwoorden over mens, robot & artificiële intelligentie
VUBPRESS



Dissertation submitted in fulfillment of the requirements for the degree of Doctor of Science: Computer Science

Denis Steckelmacher
Academic year 2020-2021

MODEL-FREE REINFORCEMENT LEARNING FOR REAL-WORLD ROBOTS

Promotor: Prof. Dr. Ann Nowé
Supervisors: Dr. Peter Vrancx
Dr. Diederik M. Roijers

FACULTY OF SCIENCE AND BIO-ENGINEERING SCIENCES

VUB VRIJE UNIVERSITEIT BRUSSEL

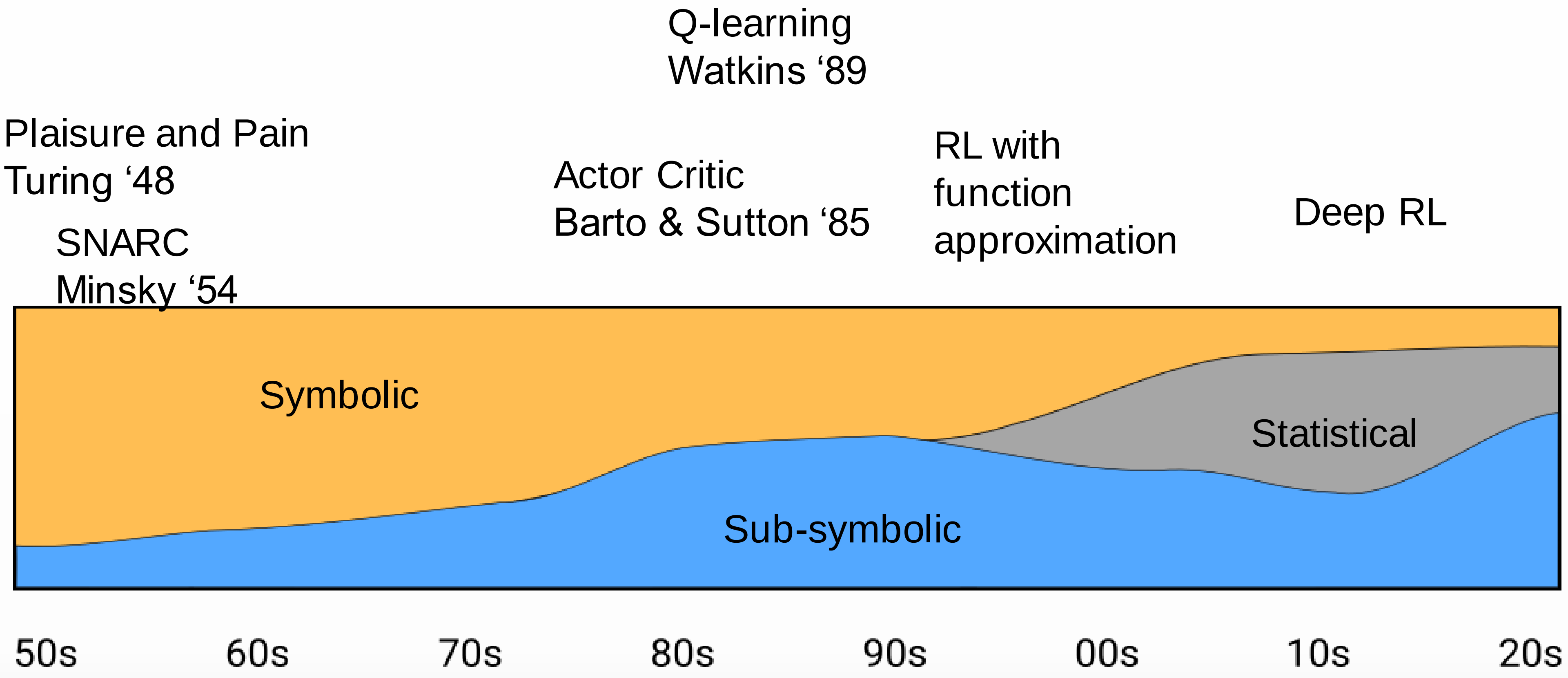
VUBPRESS

steckdenis.be/phd_thesis.pdf

A Gentle introduction to Reinforcement Learning

Ann Nowé & Tim Brys

Reinforcement Learning



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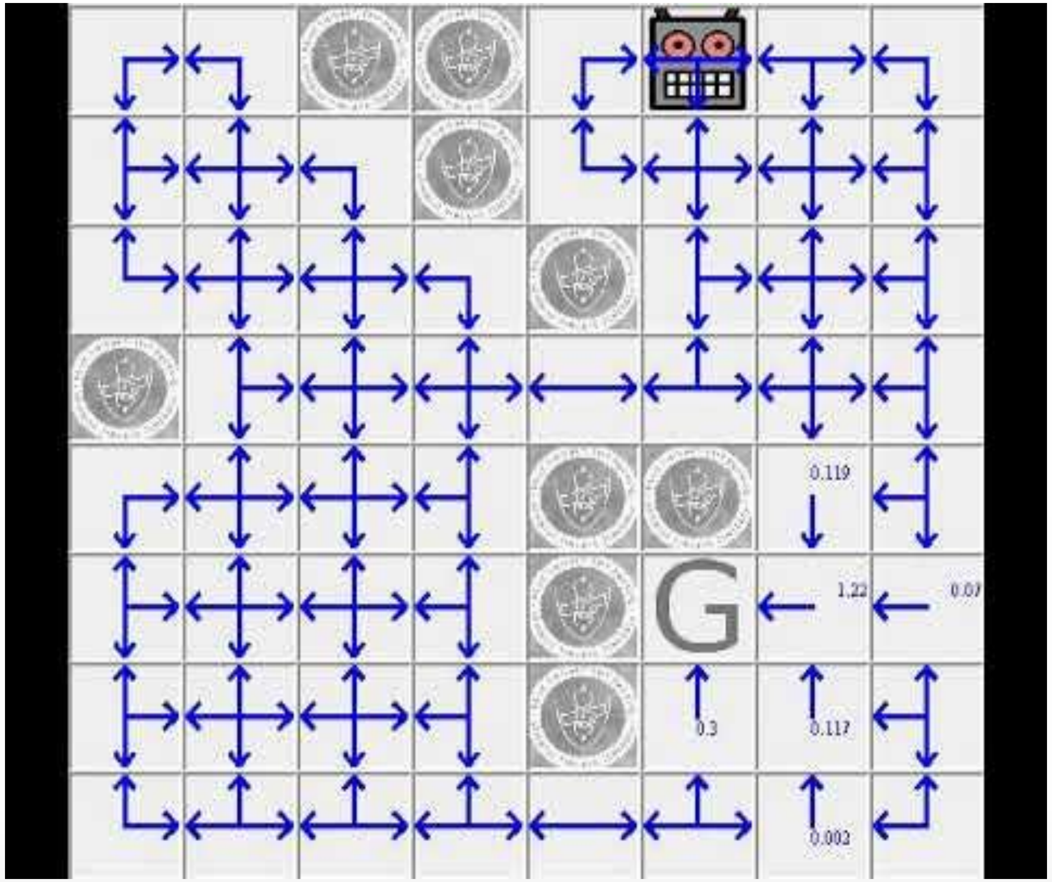
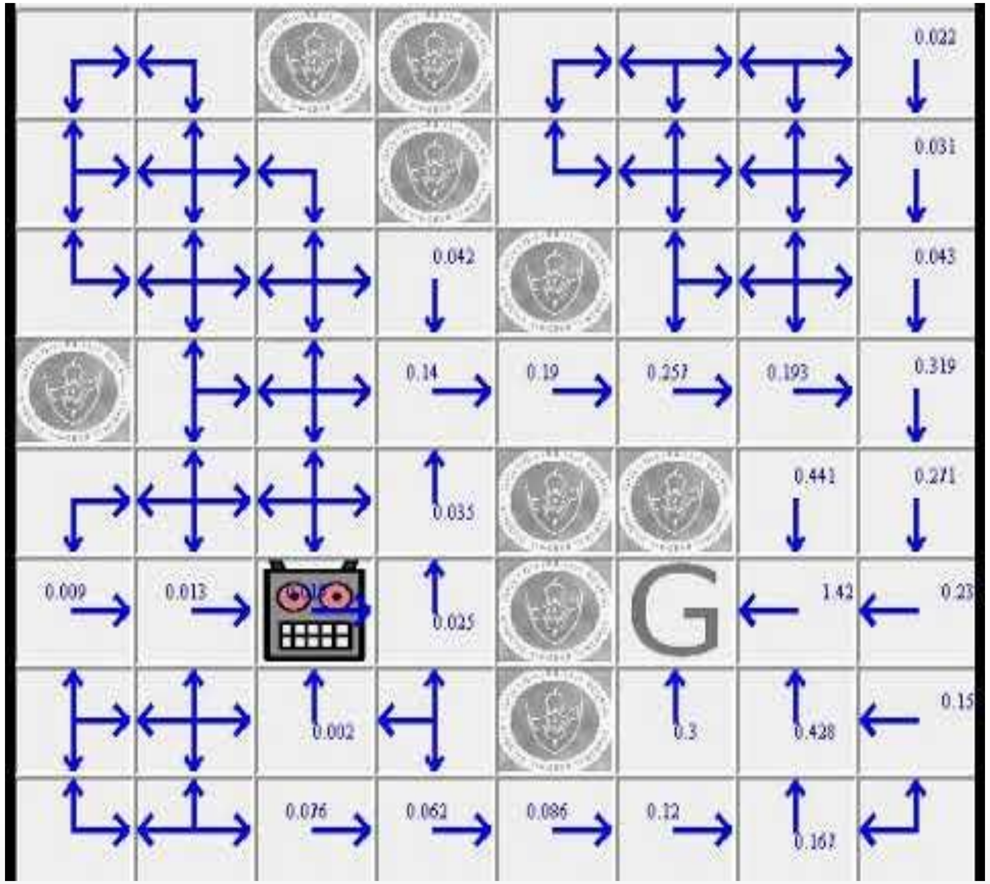
How does RL work?

Q-Learning

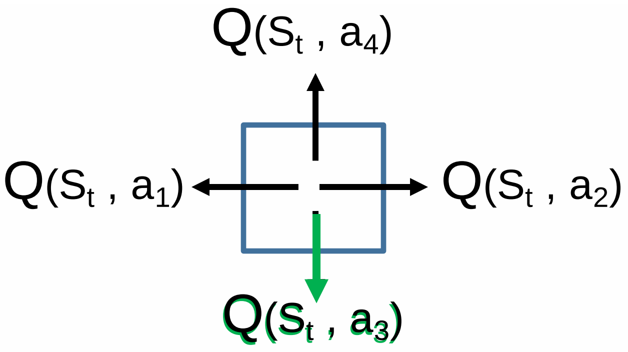

0.119
G
1.22
0.07
0.3
0.117
0.002

Q(lambda)


0.022
0.031
0.042
0.043
0.14
0.19
0.257
0.193
0.319
0.035
0.441
0.271
0.009
0.013
0.025
G
1.42
0.23
0.002
0.3
0.428
0.15
0.076
0.062
0.086
0.12
0.167

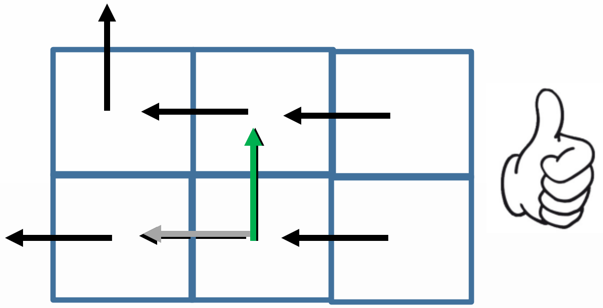
Two main approaches

- Learn how good it is to apply a certain action in a given state **(value-based approaches)**



Q-learning → DQN, Rainbow

- Evaluate a given policy, and try to improve the policy **(actor critic methods)**



Policy Gradient → Soft Actor-Critic

BDPI

Applications of Reinforcement Learning

Exploration of 5.12×10^{20} possible configurations of the game

LEE SEDOL
00:01:00

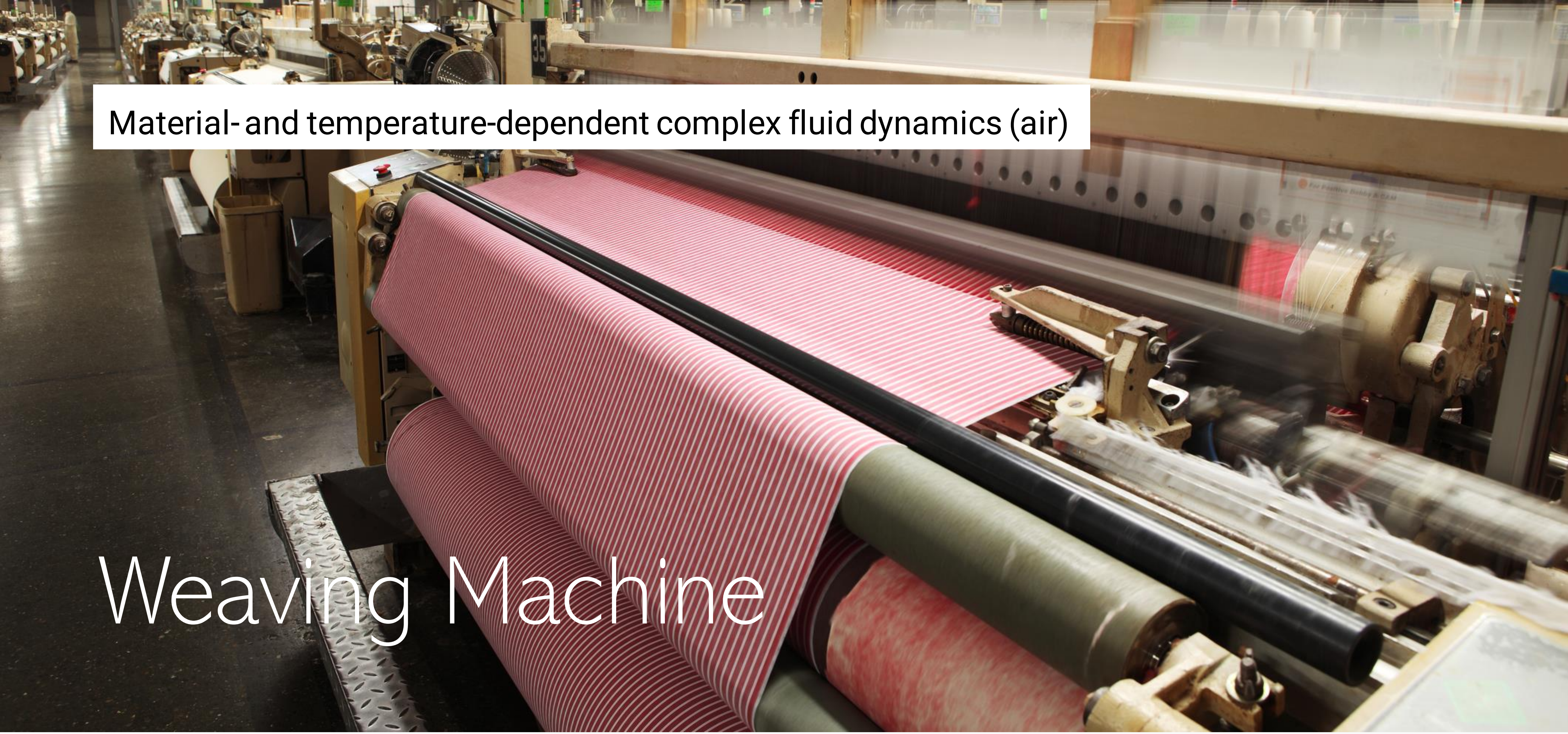
AlphaGo

Difficult non-linear controller, higher optimality with RL than classical control

Space Shuttle attitude control (1993)

Exploration of the impact of decisions on long time-scales

Datacenter cooling



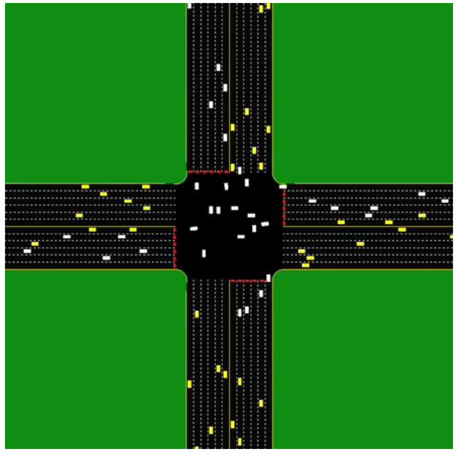
Material- and temperature-dependent complex fluid dynamics (air)

Weaving Machine

Multi-agent collaborative AI

- **Multi-agent learning:** AI systems are not standalone and have to coordinate between each other
- **Reinforcement learning:** AI systems are embedded in an environment and can learn from interacting with that environment

real-life traffic interactions



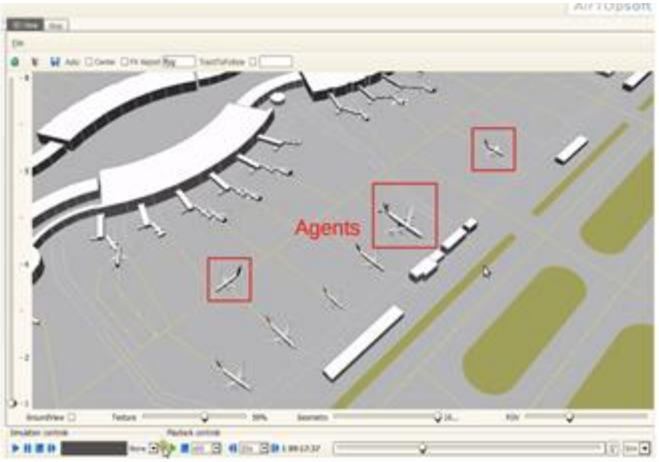
AI agents interactions

Departure management of planes in airports using multi-agent reinforcement learning

300
290
280
270
260
250
240
230
060
070
080
090
100
110
120
130

- Goal: learn **optimal scheduling** of departing planes
- Optimizing different constraints
  - Maximizing on-time departures
  - Minimizing fuel consumption
  - Minimizing noise emissions
- Particularly difficult for **complex airport layouts** with many different runways
- On a simulator of CDG and JFK airports, the algorithm was able to significantly **improve the number of on-site departures**, compared to a human controller using traditional heuristics
- The multi-agent algorithms can also be used for on-route and arrival scheduling of planes

Paris Charles de Gaulle Airport (CDG)



New York John F. Kennedy Airport (JFK)

Reinforcement learning to optimize charging of electric vehicles

Scheduling algorithm for charging of EVs (electric vehicles)

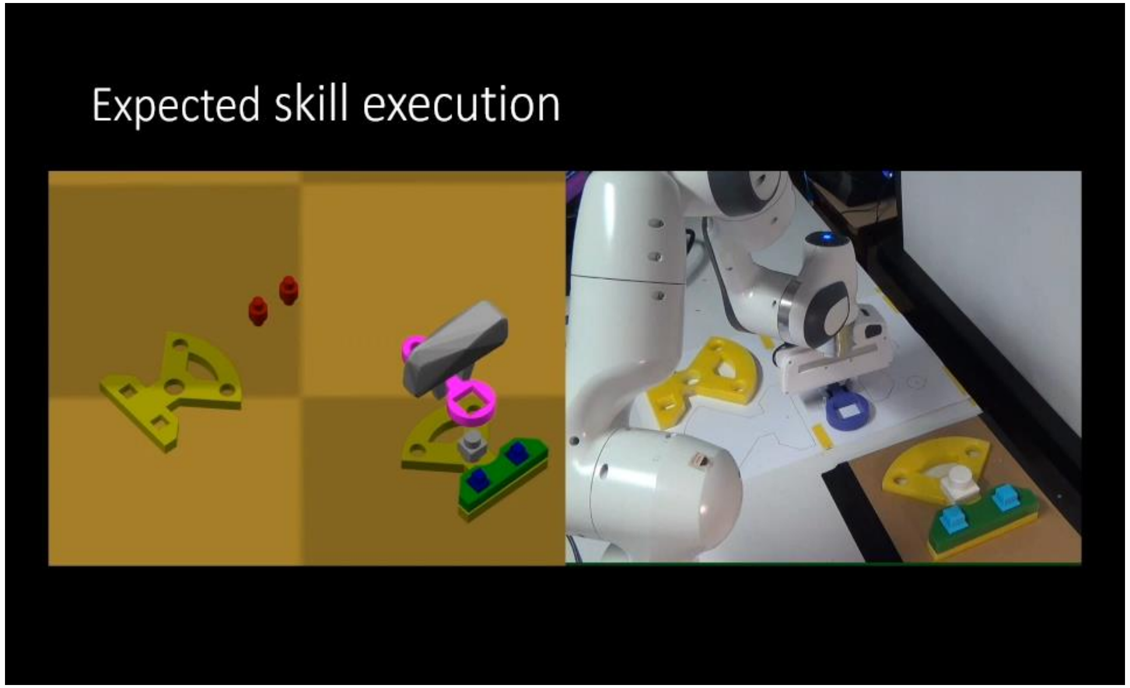
Challenges

- **Constraints** (# charging connectors, maximum load of the grid, minimize charging time, maximize battery lifetime, minimize charging cost, etc.)
- **Uncertainties** (arrival and departure of EV, amount of energy needed to charge battery, available green energy, etc.)

Solution

- **Dynamic** algorithm needed
- Reinforcement learning learns the optimal scheduling through a simulator, taking into account **changing and implicit behavior** and **external factors** such as weather, traffic, etc.

RL and digital twins


Expected skill execution

Learning
Quadrupedal
Locomotion
over
Challenging
Terrain

PhD Joris De Winter
Ann Nowé (VUB AI Lab), Bram Vanderborght (VUB R&MM)

Multiple agents

To find the MOST CHALLENGING problems to solve

To EXTEND the reach of what is KNOWN and FEASIBLE in the field of AI

- ➔ Our RESPONSIBILITY to society
- ➔ What DRIVES our people

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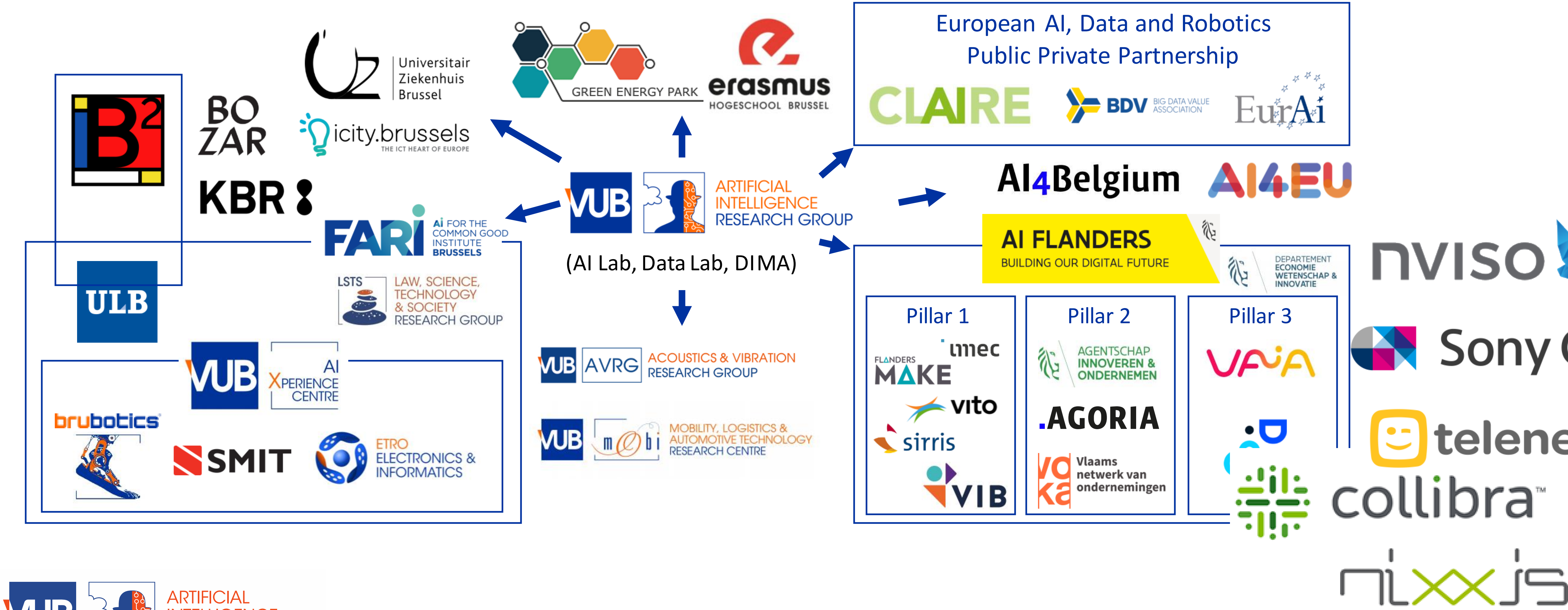
Networks and partners



VUB ARTIFICIAL INTELLIGENCE RESEARCH GROUP

(AI Lab, Data Lab, DIMA)

Universitair Ziekenhuis Brussel

icity.brussels THE ICT HEART OF EUROPE

GREEN ENERGY PARK

erasmus HOGESCHOOL BRUSSEL

iB²

BOZAR

KBR

FARI AI FOR THE COMMON GOOD INSTITUTE BRUSSELS

ULB

LSTS LAW, SCIENCE, TECHNOLOGY & SOCIETY RESEARCH GROUP

VUB AI XPERIENCE CENTRE

brubotics

SMIT

ETRO ELECTRONICS & INFORMATICS

VUB AVRG ACOUSTICS & VIBRATION RESEARCH GROUP

VUB mobi MOBILITY, LOGISTICS & AUTOMOTIVE TECHNOLOGY RESEARCH CENTRE

European AI, Data and Robotics
Public Private Partnership

CLAIRE

BDV BIG DATA VALUE ASSOCIATION

EurAi

AI4Belgium

AI4EU

AI FLANDERS
BUILDING OUR DIGITAL FUTURE

DEPARTEMENT ECONOMIE WETENSCHAP & INNOVATIE

Pillar 1	Pillar 2	Pillar 3
imec FLANDERS MAKE vito sirris VIB	AGENTSCHAP INNOVEREN & ONDERNEMEN .AGORIA voka Vlaams netwerk van ondernemingen	VAIA

nviso

Sony

telene

collibra™

nixxis
the ultimate customer experience

VUB ARTIFICIAL INTELLIGENCE RESEARCH GROUP

How we do this?

1. Attract great people
2. Focus on our expertise fields within AI
3. The right interdisciplinary network
4. Collaboration with private sector

IOF GEAR Proposal 2022-2026: Consolidator (200K / year)

Context

- Interdisciplinary team
- Long-standing expertise & heritage
- Strong reputation

Rationale

Overwhelmed with AI
➔ Joint Research of high-qualty AI technologies
➔ Provide guidance

Vision & Mission

- Initiate and mature **high quality AI technologies** (through research)
- **Interact and collaborate** with decision takers at different steps to ensure relevancy

GOALS		OBJECTIVES
Stay at Forefront in Fundamental Research on AI	➔	**Increase P4 (EU projects) by 30%**
More & Stronger Collaborations with Industry & Government	➔	**Increase P3 by 100% (min. 25% P3C)**
Create Awareness & Provide Support	➔	**+60% revenue from counseling and opportunity workshops**
Nourish AI Ecosystem	➔	**Build relations with an extra 50 companies / organisations**

VUB Artificial Intelligence Lab

Interdisciplinary team, Strong heritage, Leading position

- Academic network

brubotics

ETRO ELECTRONICS & INFORMATICS

SMIT

VUB mobi

VUB AVRG

GREEN ENERGY PARK

UZ Universitair Ziekenhuis Brussel

AI FLANDERS
BUILDING OUR DIGITAL FUTURE

CLAIRE

VUB ARTIFICIAL INTELLIGENCE RESEARCH GROUP

DATA ANALYTICS LAB

ARTIFICIAL INTELLIGENCE LAB

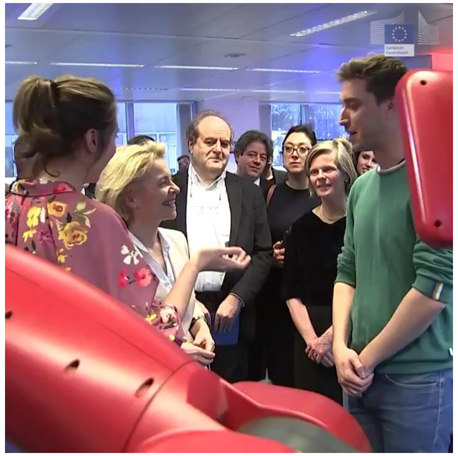
AI LAB GEAR
MANAGEMENT TEAM

DIGITAL MATHEMATICS

- Outreach to industry and policymakers

VUB AI XPERIENCE CENTRE

FARI AI FOR THE COMMON GOOD INSTITUTE BRUSSELS



telenet

AXILES BIONICS

SONY

collibra

SABCA

- Unique interdisciplinary team
  - With complementary AI expertise
  - Collaborating intensively on fundamental, strategic and applied research
  - Bringing researchers, industry and policymakers together

AI Experience Center

- **One-stop-shop** for all AI research & training needs
  - Legal, ethical aspects of AI (LSTS)
  - Sociological, ethical side of AI (AI Lab, Data Lab, SMIT)
  - Smart city, mobility (SMIT, MOBI, Data Lab, AI Lab)
  - Industry 4.0 & Robotics (Brubotics, MFYS, AI Lab)
  - Health (AI Lab, ETRO, Brubotics)
  - Broader VUB Network

- **Broker** for innovation & implementation
  - **AI Opportunity** Workshops, Deep Dive sessions, ...

AI Lab Mission

Guide enterprises through the AI revolution and help them become **more innovative** and **increase their excellence** through the potential of AI

- Types of collaborations:
  - internships, bachelor and master theses, training, consultancy, applied PhDs, R&D projects, etc.

Demos Showcase

- 20 Demos from AI Lab, SMIT, Brubotics & Etro
  - NRGCoin: Smart Energy Grid
  - Autonomous Wheelchair
  - VR Maze: Reinforcement Learning Navigation
  - Robotic Hand & Foot
  - Baxter Robot: Collaborative Robot
  - Exoskeletons
  - Pepper Robot: Care / Diabetic cases
  - SARA: Augmented Reality Neuro Chirurgy
  - Virtual Reality Brussels City Map
  - And many more ...

Adaptive Learning & Collaborative AI

Machine control

Autonomous machines

Resource management

Smart grids

VUB Artificial Intelligence Lab

Interdisciplinary team, Strong heritage, Leading position

Human-like AI

Emergent communication

Language and sound processing

Document layout analysis

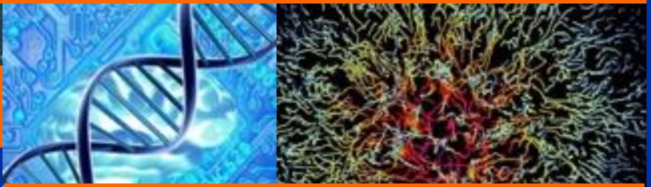
Explainable AI

Cybersecurity

AI Maturity & Safety

Recommenders

Data analytics & process optimization



Decision making in healthcare

Decision Intelligence

VUB ARTIFICIAL INTELLIGENCE RESEARCH GROUP

Networks and partners

VUB AI XPERIENCE CENTRE ARTIFICIAL INTELLIGENCE TEST & EXPERIENCE CENTRE

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APICBASE.COM

VASCO THE AUTHENTICATION COMPANY

AirTOpsoft Air Traffic Optimization

Postbuzz

knowliah

fifthplay

nviso

Smals ICT for society

edebex

FLANDERS MAKE MANUFACTURING INNOVATION NETWORK

B²

movilitas

attentia

OMINA TECHNOLOGIES artificial intelligence insights

trema

P&G

Energis

AI4EU Advancing Europe through collaboration in AI

OMPARTNERS

Enervalis

nixxis the ultimate customer experience

k

ONTOFORCE EVERYBODY A DATASCIENTIST

JUYO HOTEL ANALYTICS

brubotics®

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We continuously investigate how we can help companies become **more innovative** and **increase their excellence** through the potential of AI.