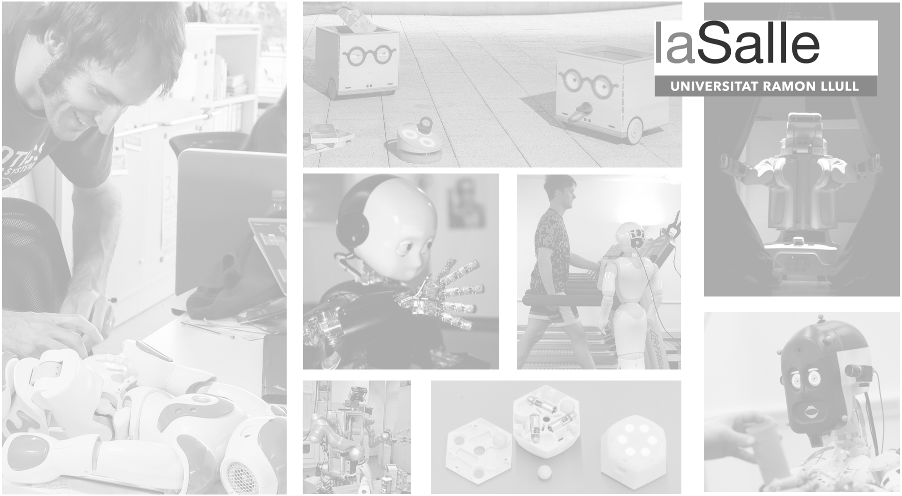


laSalle
UNIVERSITAT RAMON LLULL

Dr. Séverin Lemaignan

A strategic vision towards Socially-Driven Autonomous Robots for Real-World HRI

SHORT BIO

- **2008–2012** Joint French (LAAS-CNRS) German (TU Munich) PhD
  - AI & Cognitive Robotics
  - Prix GdR Meilleure thèse
- **2013–2015** Post-doc at EPFL
  - Creation of the HRI team
  - Two main projects: *CoWriter* & *Cellulo*
- **2015-2018** Post-doc at Plymouth University, UK
  - EU Marie Curie fellowship
  - Social Cognition in Robotics
- **2018–** Associate Prof. at Bristol Robotics Lab

symbolic grounding

situation assessment

symbolic reasoning

SYMBOLIC SOCIAL COGNITION FOR ROBOTS

ontologies

perspective taking

cognitive architectures

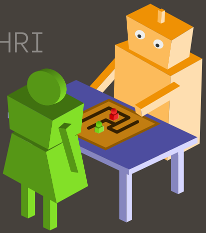
social situation assessment

joint action

ROS4HRI

natural language processing

REAL-WORLD SOCIAL AUTONOMY



DATA-DRIVEN HRI

learning of social policies

large datasets

theory of mind

group dynamics

social robotics

human-in-the-loop ML

responsible AI

trust

experimental robotics

HUMAN FACTORS

robotics for learning

child-robot interaction

engagement

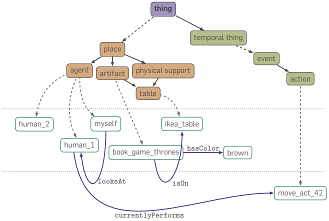
anthropomorphism

persuasion

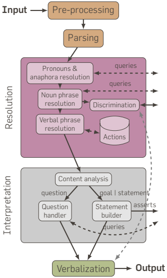
participatory design

SYMBOLIC SOCIAL COGNITION FOR ROBOTS

- real-time situation assessment
- geometric reasoning
- perspective-taking



- ontologies
- real-time symbolic reasoning
- theory of mind



- symbolic grounding
- natural language processing
- interactive disambiguation and concept learning

[Lemaignan et al. **Grounding the Interaction: Anchoring Situated Discourse in Everyday [...]** Intl. Journal of Social Rob. 2011],
[Lemaignan et al. **ORO, a Knowledge Management Module for Cognitive Architectures in Robotics** IROS 2010]

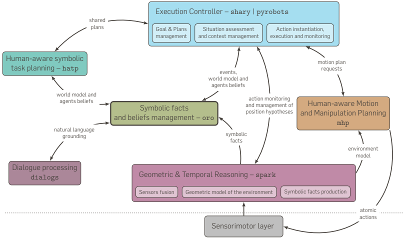
SYMBOLIC SOCIAL COGNITION — main contributions

1. **ontologies** to model the robot knowledge
2. **situation assessment** using real-time 3D models of the environment to generate symbolic facts
3. **perspective taking** and **theory of mind**: generate and maintain symbolic knowledge models for all the agents
4. Application: **perspective-aware situated dialogue** with real-time **symbolic grounding**

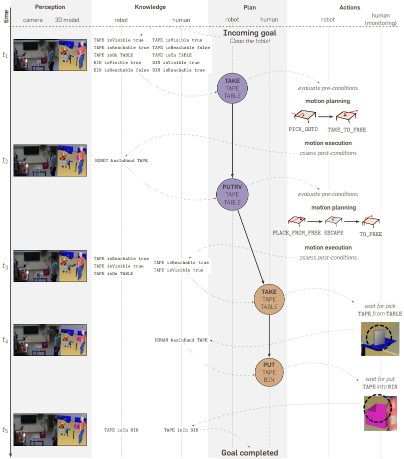
Impact:

- Prix GdR Meilleure thèse
- 10+ publications, incl. *Intl. Journal of Social Robotics*; *IROS*x2; *HRI*; *RoMAN*x2; 500+ citations

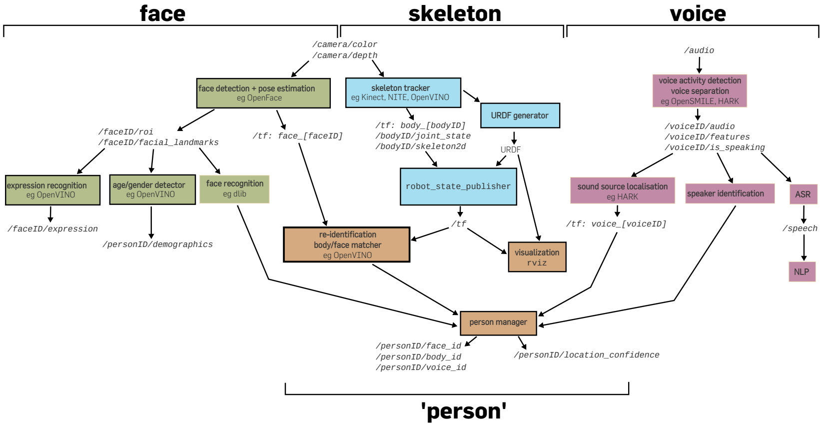
REAL-WORLD SOCIAL AUTONOMY — cognitive architectures



- full socio-cognitive architecture for robot autonomy
- semantic-driven via semantic blackboard
- full interaction loop: NLP, joint goals, joint actions, real-time monitoring



REAL-WORLD SOCIAL AUTONOMY — social signal processing



ROS4HRI: first integrated, multi-modal, ROS-based pipeline for social signal processing in robotics

[Mohamed, Lemaignan **ROS for Human-Robot Interaction** Arxiv 2021 (under review IROS)]

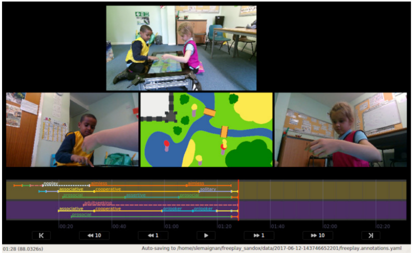
REAL-WORLD SOCIAL AUTONOMY — main contributions

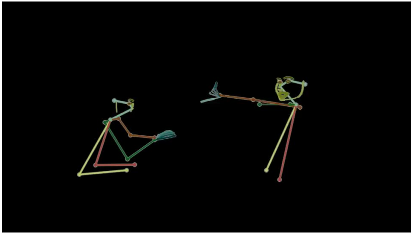
1. state-of-art **cognitive architecture for social interaction**
2. framing **semantic-aware robotic architectures**
3. large-scale, multi-modal, standard-compliant **social signal processing** for robots

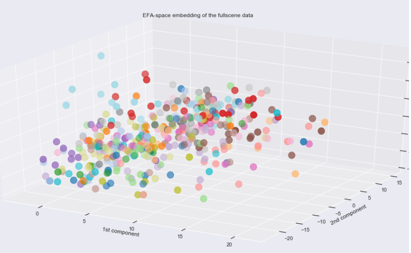
Impact:

- major publications, incl. *Artificial Intelligence*, *HRI*, *IROS*; 800+ citations
- 2nd most cited paper ever from *Artificial Intelligence*
- major contribution to open-source robotics; 150+ GitHub repos

DATA-DRIVEN HRI — dataset of natural interactions



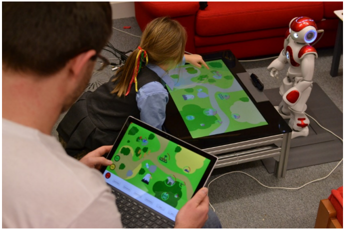


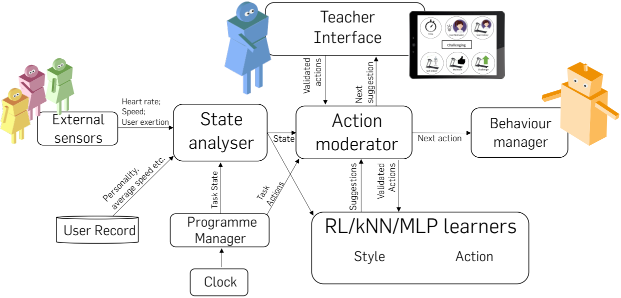


- PInSoRo dataset: 45h+ and 2M frames of annotated natural interactions
- new data analysis techniques to estimate internal state from body language
- first-in-kind dataset for data-driven study of social interactions in robotics

[Lemaignan et al. **The PInSoRo dataset: Supporting the data-driven study of child-child and child-robot [...]** PLOS One 2018]
[Bartlett et al. **What Can You See? Identifying Cues on Internal States from the Kinematics [...]** FrontiersIn 2019]

DATA-DRIVEN HRI — expert-in-the-loop machine learning





[Senft et al. **Teaching robots social autonomy from in situ human guidance** Science Robotics 2019]
[Winkle et al. **In-Situ Learning from a Domain Expert for Real World Socially Assistive Robot Deployment** RSS 2020]

DATA-DRIVEN HRI — summary of contributions

1. leading role in **shaping the emergent field of data-driven HRI**
2. pioneering work on methodology: **large datasets** and **data-driven behaviour analysis** for social robotics, drawing from both psychology and AI.
3. major advances towards **learning autonomous social policies** for service robots with **real-world robot deployments**

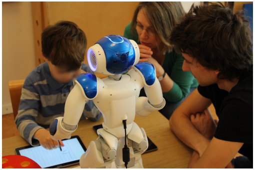
Impact:

- top publications incl. *Science Robotics*, *FrontiersIn Robotics and AI*, *PLOS One*, *RSS*, 300+ citations
- first large-scale and open dataset of natural social interactions

HUMAN FACTORS — experimental work

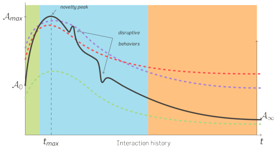
Extensive experimental work:

- over 25 field experiments over the past 10 years
- focus on real-world experiments (eg schools, gyms)
- child-robot interaction expertise: worked with 200+ children

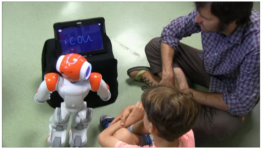


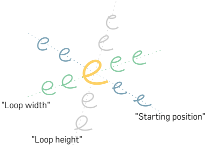
HUMAN FACTORS — expertise

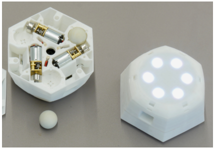
Understanding interaction



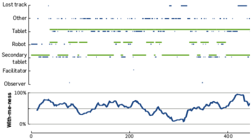
Robots for Learning

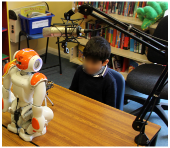


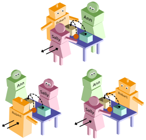




Methodology







HUMAN FACTORS — summary of contributions

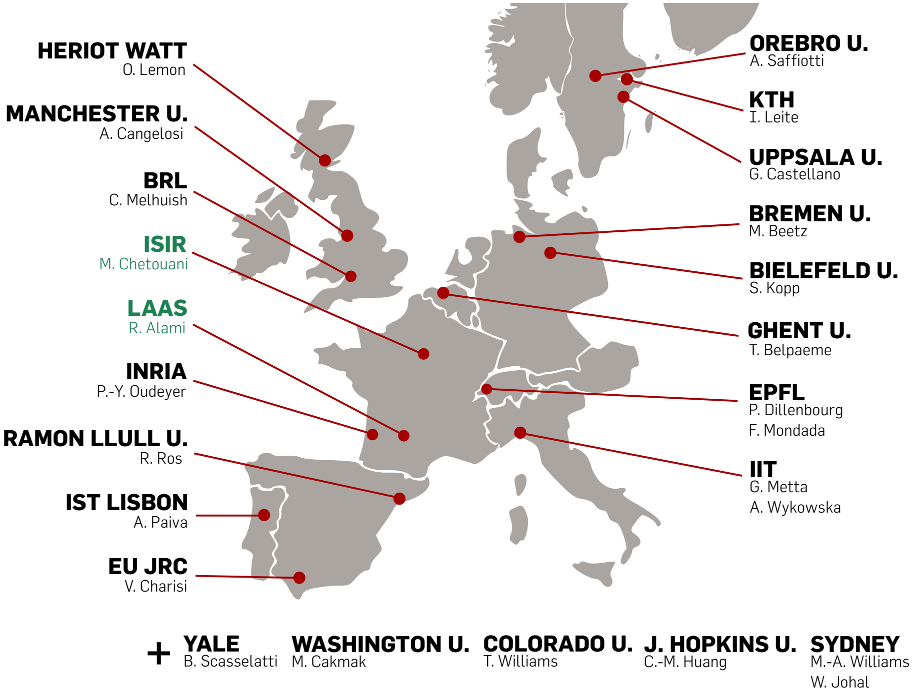
1. transdisciplinary expertise: key role in **bridging research in cognitive psychology with robotics**
2. number of **cross-disciplinary experimental work** and literature surveys
3. major contribution to **child-robot interaction**, in particular the **importance of social engagement** between children and robots

Impact:

- 20+ publications on human factors and experimental robotics, 1000+ citations
- EU H2020 Marie-Curie fellowship on Theory of Mind
- invited expert to EU & UNICEF on the Ethics of child-robot interactions

ASSOCIATE PROF IN SOCIAL ROBOTICS AND AI

- **Supervising 2 groups** at BRL (embodied cognition and autonomous vehicles), $\approx$**15 researchers**, $>$**€1M funding**
- Supervised or co-supervised **9 PhDs** to date
- **75+ publications** (incl. eg *Science Robotics*, *PLOS One*, *Artificial Intelligence*), mostly in HRI (2800+ citations, i-index=25 on Google Scholar)
- **Programme committee/editorial board** of FrontiersIn Robotics and AI; HRI; RSS; IROS; IJCAI
- First **ERC Consolidator submission** in 2019
- Significant **technical contributions** (ROS, large datasets, 150+ repos on Github)
- **Policy making**, eg expert on ethics of child-robot interaction to EU and UNICEF


HERIOT WATT
O. Lemon
MANCHESTER U.
A. Cangelosi
BRL
C. Melhuish
ISIR
M. Chetouani
LAAS
R. Alami
INRIA
P.-Y. Oudeyer
RAMON LLULL U.
R. Ros
IST LISBON
A. Paiva
EU JRC
V. Charisi
OREBRO U.
A. Saffiotti
KTH
I. Leite
UPPSALA U.
G. Castellano
BREMEN U.
M. Beetz
BIELEFELD U.
S. Kopp
GHENT U.
T. Belpaeme
EPFL
P. Dillenbourg
F. Mondada
IIT
G. Metta
A. Wykowska
+
YALE
B. Scasselatti
WASHINGTON U.
M. Cakmak
COLORADO U.
T. Williams
J. HOPKINS U.
C.-M. Huang
SYDNEY
M.-A. Williams
W. Johal


PLYMOUTH UNIVERSITY
ROCO318
Mobile and Humanoid Robots
Part 1 – Introduction
Séverin Lemaignan
Centre for Neural Systems and Robotics
Plymouth University

EVENT-ORIENTED PROGRAMMING

Event-oriented programming is a possible way of implementing a behavioural control paradigm:

```
def on_dummy(robot):
    robot.look_at_dummy()
    robot.blink()
    sleep = robot.fall_asleep()
    robot.lightbar(RAINBOW).wait()
    sleep.wait()

def on_dummy_removed(robot):
    robot.light_bar(colors.rand())
    robot.wakeup().wait()
    robot.move(0.4, v = 0.8).wait()
    robot.idle().wait()
```

```
def on_bumper(robot):
    pulse = robot.pulse_row(0)
    while abs(robot.state.v) > 0.01:
        robot.sleep(0.2)
    pulse.cancel()

def on_toy(robot):
    robot.playsound(SOUNDS["toy_in"])
    robot.lightbar(RAINBOW).wait()
```


GRASSFIRE ALGORITHM

	A	B	C	D	E	F	G	H	I	J	K	L
1	13	12	11	10	9	8	7	8	9	10	11	10
2	12	11	10	9	8	7	6					9
3	11	10	9	8	7	6	5	4	5	6	7	8
4	10	9	8	7	6	5	4	3	4	5	6	7
5	11	S	9			4	3	2	3	4	5	6
6	12	11	10	11		3	2	1	2		6	7
7	11	10	11	12		2	1	G	1		7	8
8	10	9				3	2	1	2		8	9
9	9	8	7	6	5	4	3	2	3		9	10
10	10	9	8	7	6	5	4	3	4		10	11

RoboMaze

RoboMaze REST API documentation.

View the Project on GitHub

Move a robot

To move your robot in the map, use the action **move**, with two option of your robot, and the direction of the move: North **N**, South **S**, East **E** or West **W**.

> *If your robot does not exist yet (or has been killed), calling* **move** *will first create it at the coordinate* `(1,1)`

Returns: a JSON object

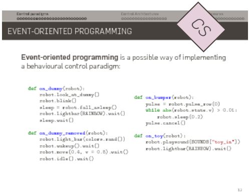
```
[<move successful?>, [<obstacle at N?>, <S?>, <E?>, <W?>]]
```

Examples:

```
# from a terminal
curl 'https://robomaze.skadge.org/move/Wall-E/E'
```

```
# in python
import json
import requests

REST_ENDPOINT = "https://robomaze.skadge.org/"
requests.get(REST_ENDPOINT + "move/Wall-E/N")
```


CS
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robot.wakeup().wait()
robot.move(0.4, v = 0.8).wait()
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robot.sleep(0.2)
pulse.cancel()
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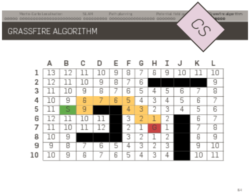
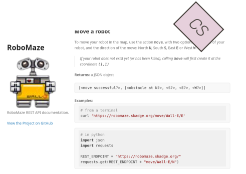
robot.lightbar(RAINBOW).wait()
12


CS
GRASSFIRE ALGORITHM
A B C D E F G H I J K L
1 13 12 11 10 9 8 7 8 9 10 11 10
2 12 11 10 9 8 7 6 9
3 11 10 9 8 7 6 5 4 5 6 7 8
4 10 9 8 7 6 5 4 3 4 5 6 7
5 11 S 9 4 3 2 3 4 5 6
6 12 11 10 11 3 2 1 2 6 7
7 11 10 11 12 2 1 G 1 7 8
8 10 9 3 2 1 2 8 9
9 9 8 7 6 5 4 3 2 3 9 10
10 10 9 8 7 6 5 4 3 4 10 11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If your robot does not exist yet (or has been killed), calling move will first create it at the coordinate (1,1)
Returns: a JSON object
[<move successful?>, [<obstacle at N?>, <S?>, <E?>, <W?>]]
Examples:
from a terminal
curl 'https://robomaze.skadge.org/move/Wall-E/E'
# in python
import json
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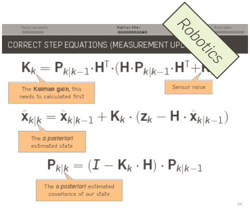
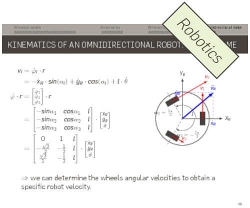
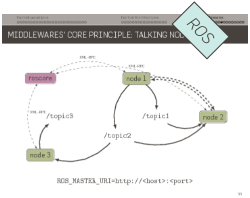
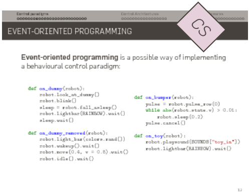
REST_ENDPOINT = "https://robomaze.skadge.org/"
requests.get(REST_ENDPOINT + "move/Wall-E/N")


Robotics
CORRECT STEP EQUATIONS (MEASUREMENT UP
$K_k = P_{k|k-1} \cdot H^T \cdot (H \cdot P_{k|k-1} \cdot H^T + R$
The Kalman gain, this needs to calculated first
Sensor noise
$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k \cdot (z_k - H \cdot \hat{x}_{k|k-1})$
The a posteriori estimated state
$P_{k|k} = (I - K_k \cdot H) \cdot P_{k|k-1}$
The a posteriori estimated covariance of our state
24


Robotics
KINEMATICS OF AN OMNIDIRECTIONAL ROBOT: ME
$v_i = \dot{\varphi}_i \cdot r$
$= -\dot{x}_R \cdot sin(\alpha_i) + \dot{y}_R \cdot cos(\alpha_i) + l \cdot \dot{\theta}$
$\dot{\varphi} \cdot r = \begin{bmatrix} \dot{\varphi}_1 \\ \dot{\varphi}_2 \\ \dot{\varphi}_3 \end{bmatrix} \cdot r$
$= \begin{bmatrix} -sin\alpha_1 & cos\alpha_1 & l \\ -sin\alpha_2 & cos\alpha_2 & l \\ -sin\alpha_3 & cos\alpha_3 & l \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \dot{\theta} \end{bmatrix}$
$= \begin{bmatrix} 0 & 1 & l \\ -\frac{\sqrt{3}}{2} & -\frac{1}{2} & l \\ \frac{\sqrt{3}}{2} & -\frac{1}{2} & l \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \dot{\theta} \end{bmatrix}$
Y_R
X_R
v_1
v_2
v_3
$\vec{v}_R$
$\dot{x}_R$
$\dot{y}_R$
l
$\alpha_2 = \frac{2\pi}{3}$
$\alpha_3 = -\frac{2\pi}{3}$
⇒ we can determine the wheels angular velocities to obtain a specific robot velocity.
46


ROS
MIDDLEWARES' CORE PRINCIPLE: TALKING NOD
XML-RPC
XML-RPC
roscore
node 1
node 2
node 3
XML-RPC
/topic3
/topic1
/topic2
ROS_MASTER_URI=http://<host>:<port>
33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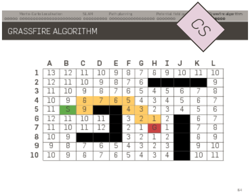
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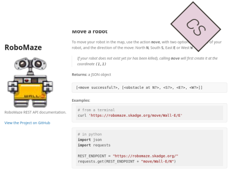
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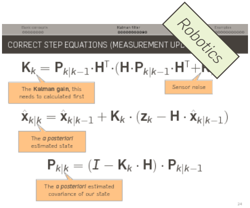
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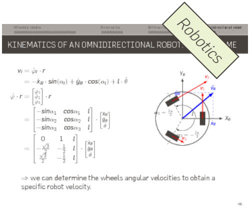
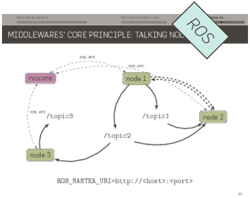
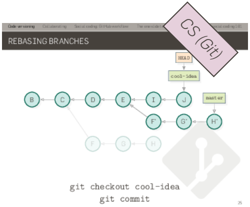
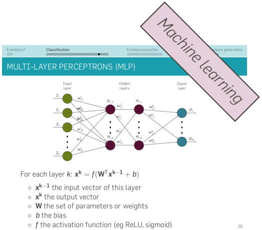
The Kalman gain, this needs to calculated first
Sensor noise
$\hat{\mathbf{x}}_{k|k} = \hat{\mathbf{x}}_{k|k-1} + \mathbf{K}_k \cdot (\mathbf{z}_k - \mathbf{H} \cdot \hat{\mathbf{x}}_{k|k-1})$
The a posteriori estimated state
$\mathbf{P}_{k|k} = (I - \mathbf{K}_k \cdot \mathbf{H}) \cdot \mathbf{P}_{k|k-1}$
The a posteriori estimated covariance of our state


Robotics
KINEMATICS OF AN OMNIDIRECTIONAL ROBOT
⇒ we can determine the wheels angular velocities to obtain a specific robot velocity.


ROS
MIDDLEWARES' CORE PRINCIPLE: TALKING NO
roscore
node 1
node 2
node 3
/topic1
/topic2
/topic3
XML-RPC
ROS_MASTER_URI=http://<host>:<port>


CS (Git)
REBASING BRANCHES
HEAD
cool-idea
master
B C D E I J
F' G' H'
F G H
git checkout cool-idea
git commit


Machine learning


Machine learning
MULTI-LAYER PERCEPTRONS (MLP)
Input layer
Hidden layers
Ouput layer
For each layer k: $\mathbf{x}^k = f(\mathbf{W}^T\mathbf{x}^{k-1} + b)$
$\mathbf{x}^{k-1}$ the input vector of this layer
$\mathbf{x}^k$ the output vector
$\mathbf{W}$ the set of parameters or weights
b the bias
f the activation function (eg ReLU, sigmoid)

situation assessment

symbolic grounding

symbolic reasoning

SYMBOLIC SOCIAL COGNITION FOR ROBOTS

ontologies

perspective taking

cognitive architectures

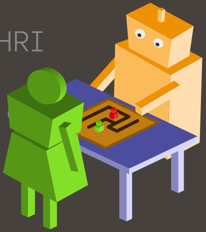
social situation assessment

joint action

ROS4HRI

natural language processing

REAL-WORLD SOCIAL AUTONOMY



DATA-DRIVEN HRI

learning of social policies

large datasets

theory of mind

group dynamics

social robotics

human-in-the-loop ML

responsible AI

trust

experimental robotics

HUMAN FACTORS

robotics for learning

child-robot interaction

engagement

anthropomorphism

persuasion

participatory design

RESEARCH PROJECT: SOCIAL ROBOTICS

Creating interactive robots that are **embedded and understand their (human) social context**; **generate and adopt appropriate social behaviours**; have a **positive impact on human society**.

⇒ designing and implementing the **assistant and companion robots** for tomorrow. Direct impact on ageing society, education, customer service.

Major socio-economic challenge + **European priority** ⇒ need to **develop capacity** and assert **leadership**

RESEARCH PROJECT: SOCIAL ROBOTICS

Major scientific challenges:

- Understand and sustain long-term autonomous social interactions;
- Real-world algorithmic robustness;
- Complex ethical landscape;
- $\Rightarrow$ cross-disciplinary & holistic approach required

RESEARCH PROJECT: SOCIAL ROBOTICS

Major scientific challenges:

- Understand and sustain long-term autonomous social interactions;
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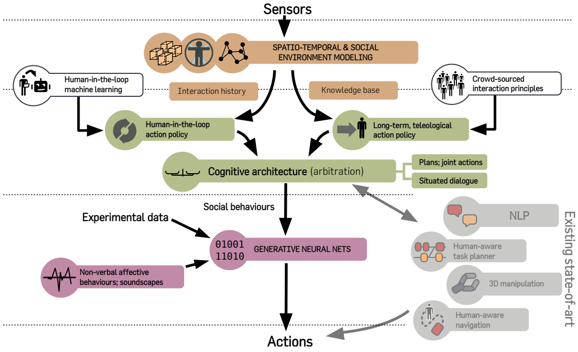
- $\Rightarrow$ cross-disciplinary & holistic approach required

My research proposal:

Socially-Driven Autonomous Robots for Real-world Human-Robot Interactions

KEY SCIENTIFIC AIMS

1. beyond state-of-art **robust real-world social modelling**; **social embeddings**
2. **public-in-the-loop** approach to design of **intrinsic social motivation**
3. **generative social behaviours** for robots
4. **cognitive architecture** for **long-term interaction**



MIXED METHODS

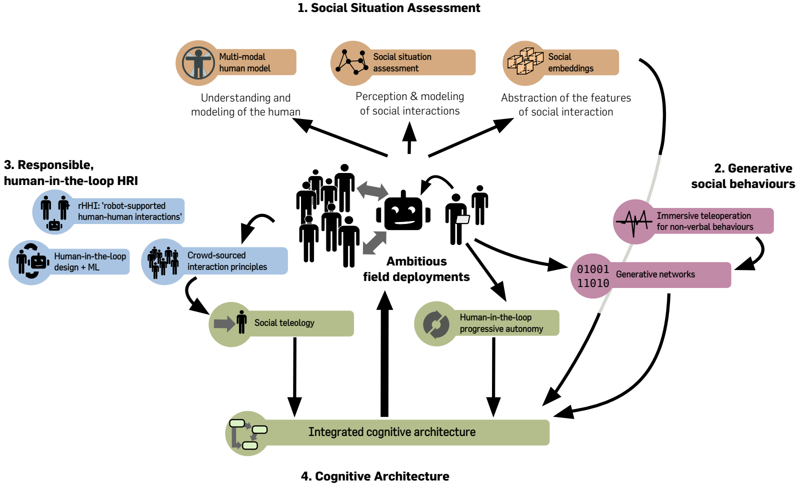
Standard methods:

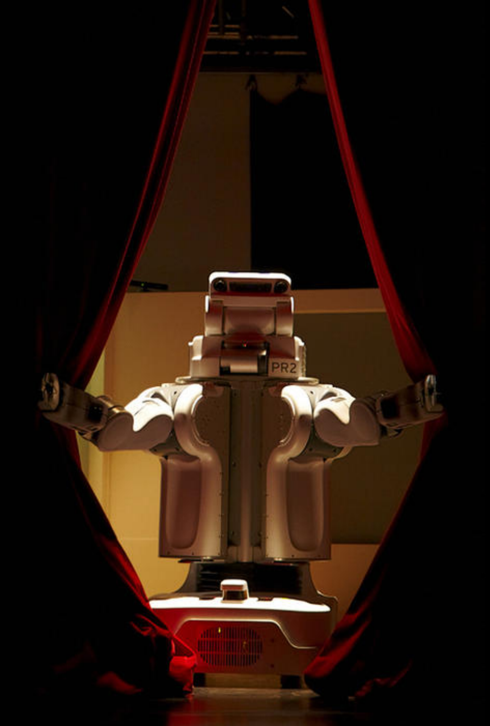
- Exploratory field work/case studies
- Participatory design; co-design
- Ecologically-valid controlled studies
- Longitudinal studies
- Large-scale online crowd-sourcing

Novel methods that I introduce in my project:

- **Public-in-the-loop machine learning**
- **Immersive teleoperation and generative behaviours** with artists

4 AXES TO SCAFFOLD AN AMBITIOUS RESEARCH GROUP





Thank you!

(photo of roboscopie*, a theatre play I created with director Nicolas Darrot in 2012)*