



**Scuola Superiore
Sant'Anna**
di Studi Universitari e di Perfezionamento

ISTITUTO
DI BIORBOTICA



Scuola Superiore
Sant'Anna

The BioRobotics Institute

Scuola Superiore Sant'Anna, Pisa

Reproducible Research in Robotics: the Road Ahead

Robotics is coming of age

Fabio Bonsignorio^{1,2,3,4,5}

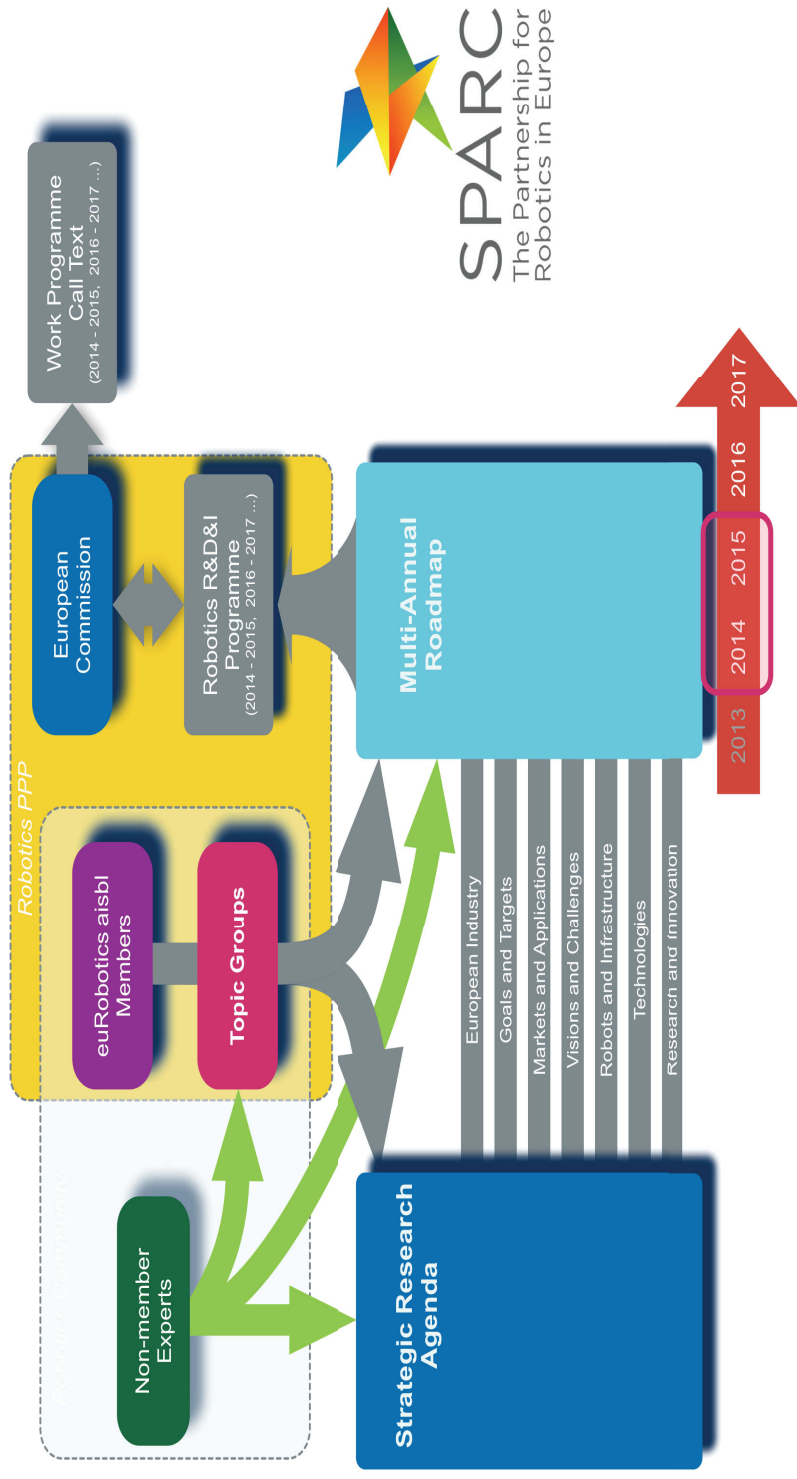
SPARC TG Benchmarking and Competitions¹

IEEE RAS TC-PEBRAS²

Member SPARC Board of Directors²

The BioRobotics Institute, SSSA⁴
and Heron Robots⁵





Older and newer attempts

Juanelo Torriano alias Gianello della Torre, (XVI century) a craftsman from Cremona, built for Emperor Charles V a mechanical young lady who was able to walk and play music by picking the strings of a real lute.



Hiroshi Ishiguro, early XXI century

Director of the Intelligent Robotics Laboratory, part of the Department of Adaptive Machine Systems at Osaka University. Japan



Scuola Superiore
Sant'Anna



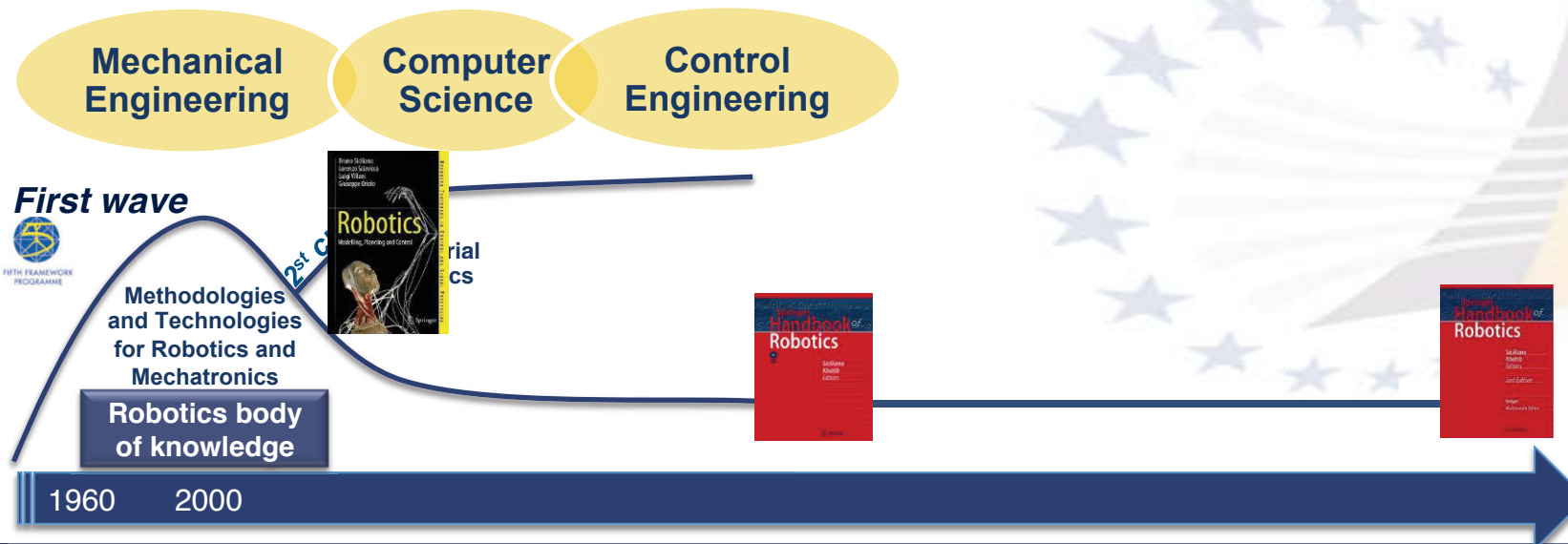
Old attempts



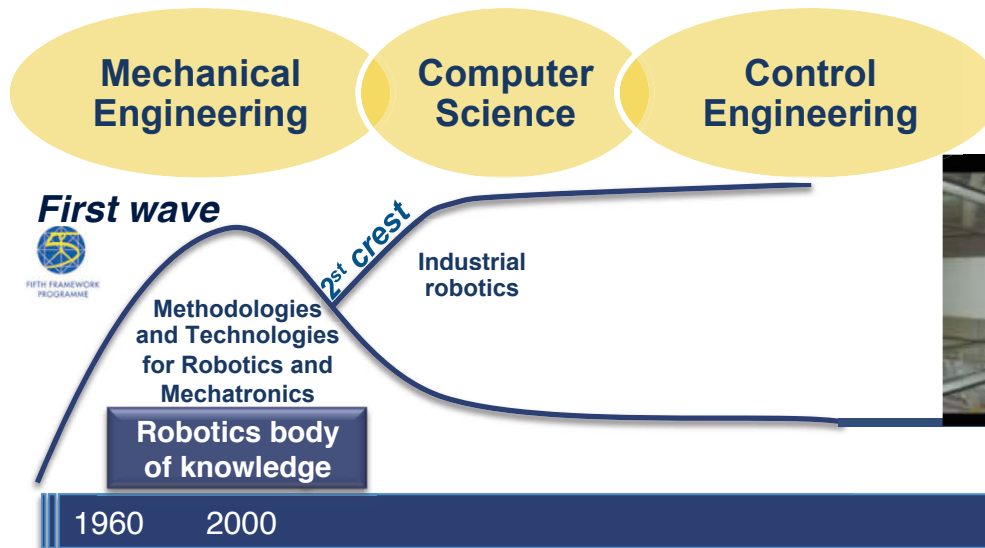
Karakuri Dolls
Chahakobi Ningyo (Tea Serving Doll) by SHOBEI Tamaya IX, and plan from 'Karakuri Zuii' ('Karakuri - An Illustrated Anthology') published in 1796.



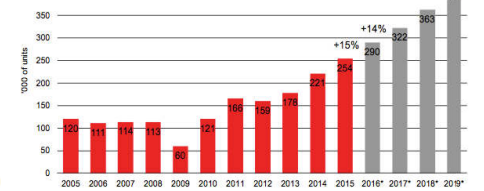
The first wave



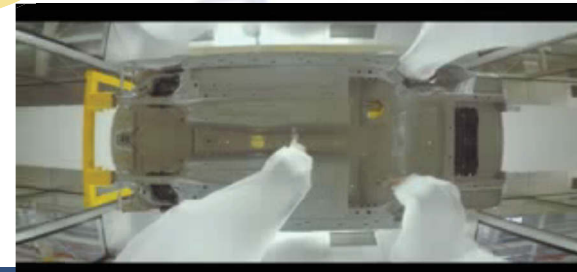
The first wave



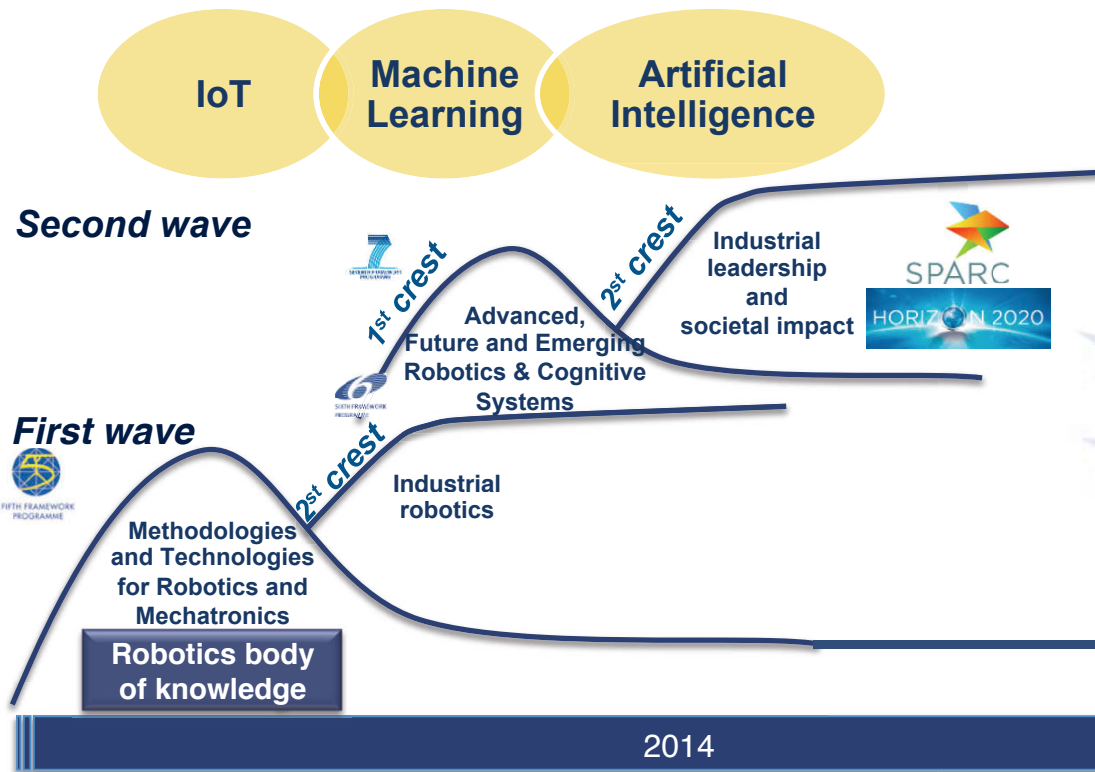
Worldwide annual supply of industrial robots 2001 – 2019*



Source: IFR (International Federation of Robotics) World Robotics

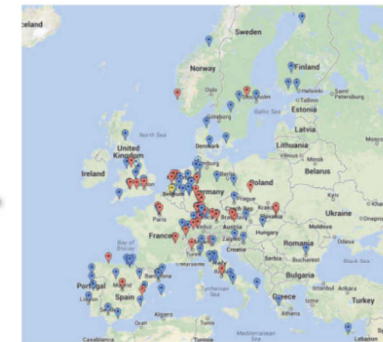


The second wave



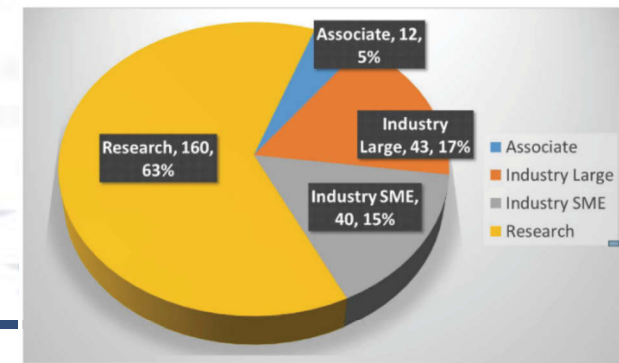
Membership development

280 member organisations



Legend:

- Industry
- Research
- Associate
- euRobotics AISBL

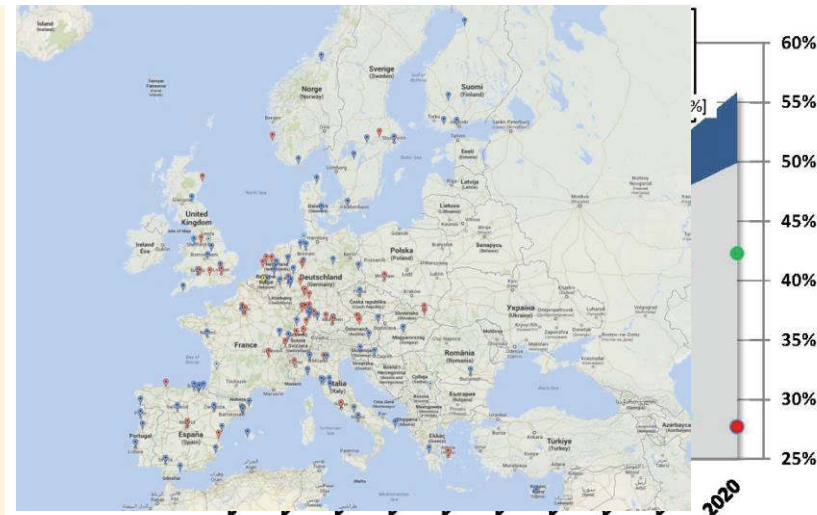


The second wave

Data are very important, but they are not all in a digital economy. ACTIONS, MOBILITY and STRENGTH are also needed! **Robotics**: a great opportunity to **innovate, connect and transform. Robotics is technology and business, but it is also creativity and fun!**

“[...] The size of the robotics market is projected to grow substantially to 2020s. This is a global market and Europe’s traditional competitors are fully engaged in exploiting it. Europe has a 32% share of the industrial market. Growth in this market alone is estimated at 8%-9% per annum. Predictions of up to 25% annual growth are made for the service sector where Europe holds a 63% share of the non-military market. [...]”

“[...] From today’s €22bn worldwide revenues, robotics industries are set to achieve annual sales of between €50bn and €62bn by 2020. [...]”

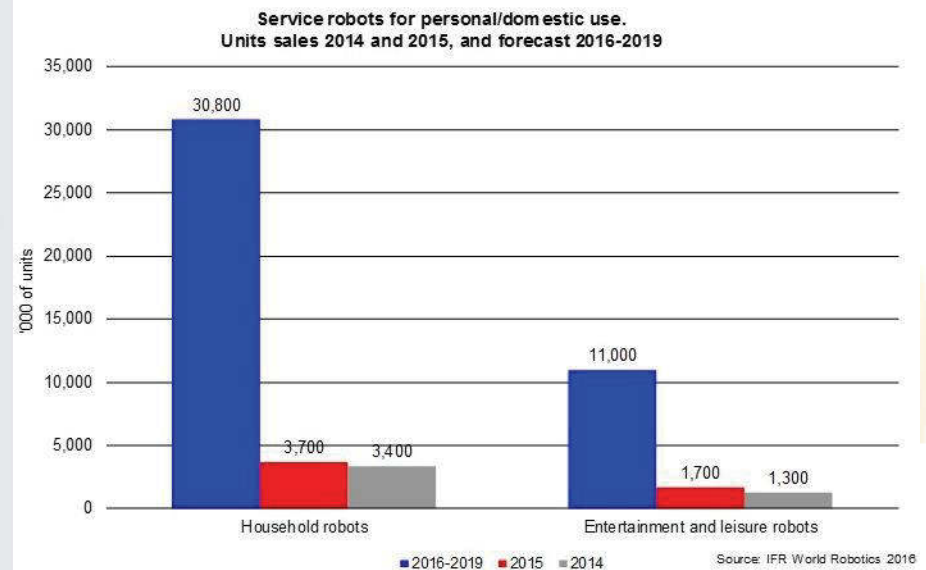
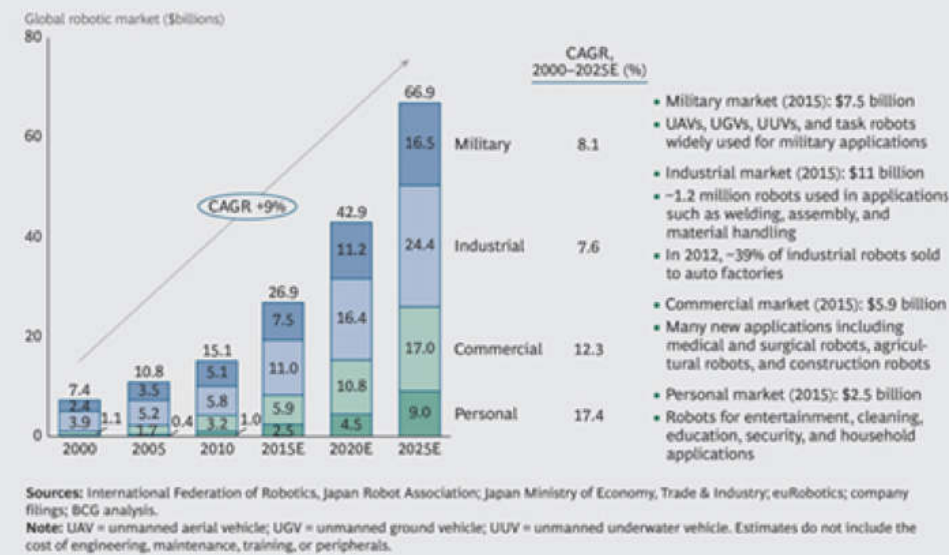


Robotics is one of the 12 disruptive technologies identified by McKinsey

The second wave

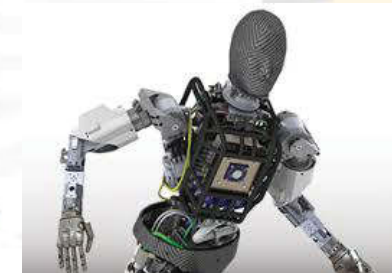
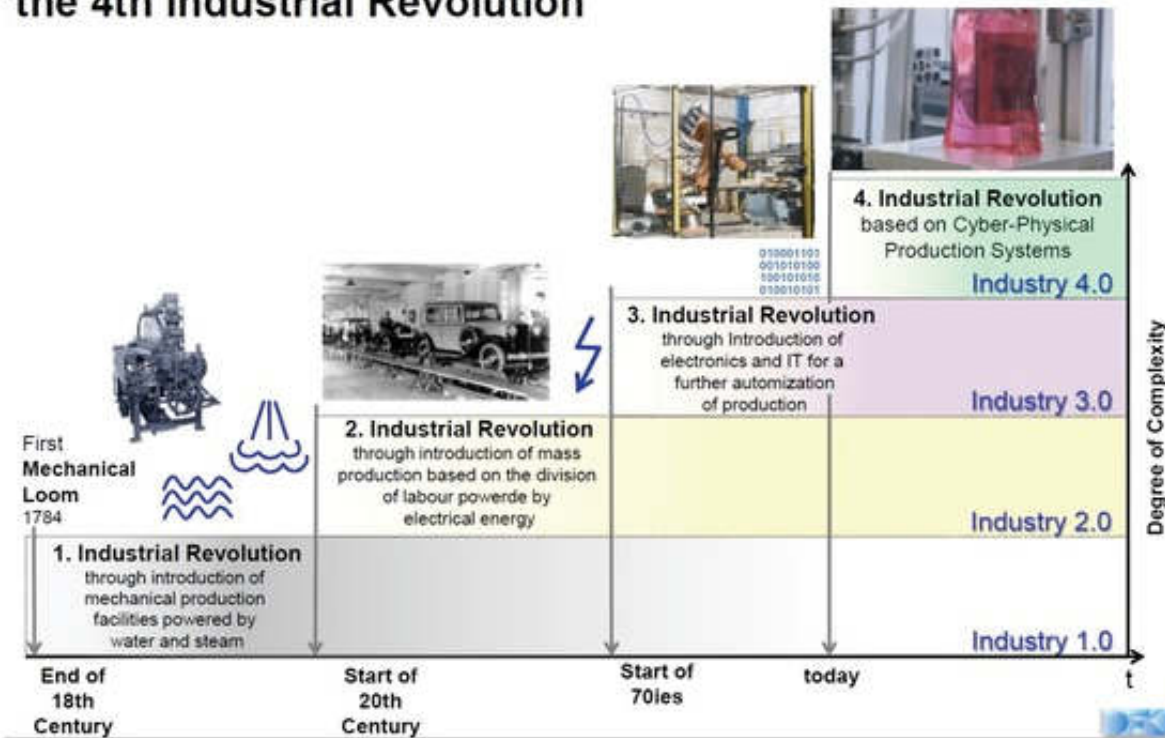


EXHIBIT 1 | Worldwide Spending on Robotics Is Expected to Reach \$67 Billion by 2025



The second wave

From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution



The second wave: Robotics: a great opportunity to innovate, connect and transform

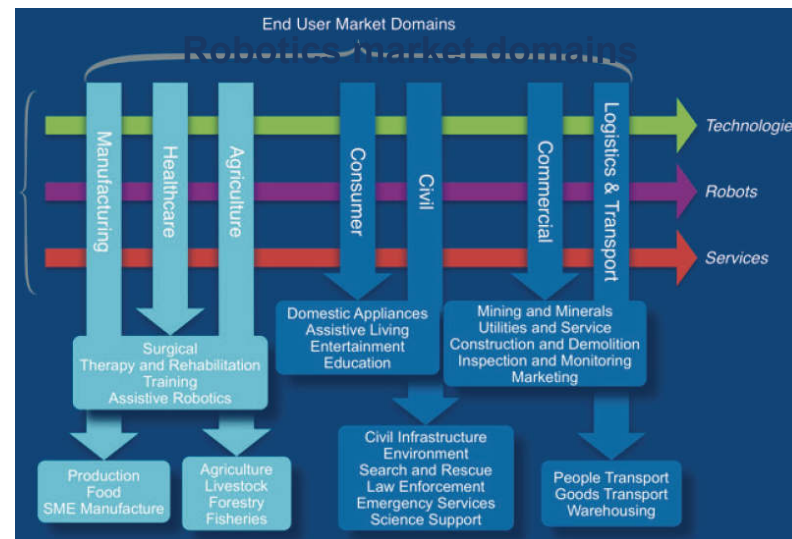


- The web and IoT pull new robotic applications
- Robotics expands the boundaries of the Web and of IoT
- The Web is an 'infrastructure' of future robotics



Robots and Jobs

- Creating **new jobs** in robotics
- Creating new industrial opportunities (and **jobs**)
- Taking advantage of robotics and automation to enable GDP growth



- Robotics integrates enabling ICT components
- Robotics will drive the development of new ICT components
- Robotics pulls the development of next generation communication networks

The second wave: the success stories

DARPA (American Defense Advanced Research Projects Agency) challenges have demonstrated how current robots are becoming **more accurate, fast and dexterous in structured and unstructured environments.**

According to H.Yanco a minimum of 9 people were needed to teleoperate latest DRC's robots!!! And...



Not everything worked as expected!

The second wave: the current approach shows some limitations

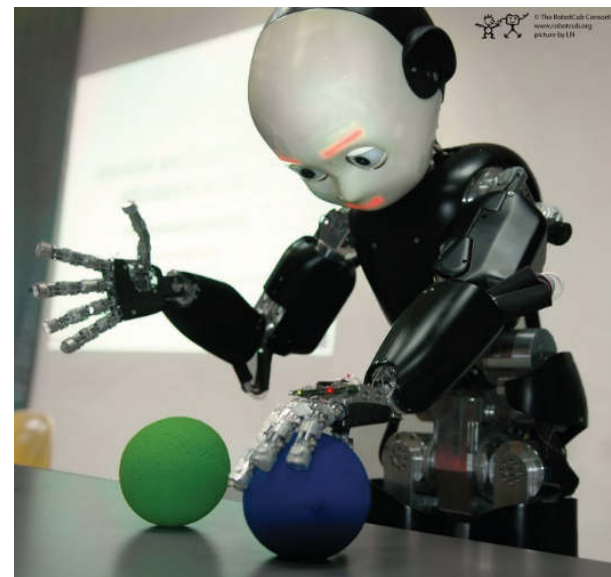
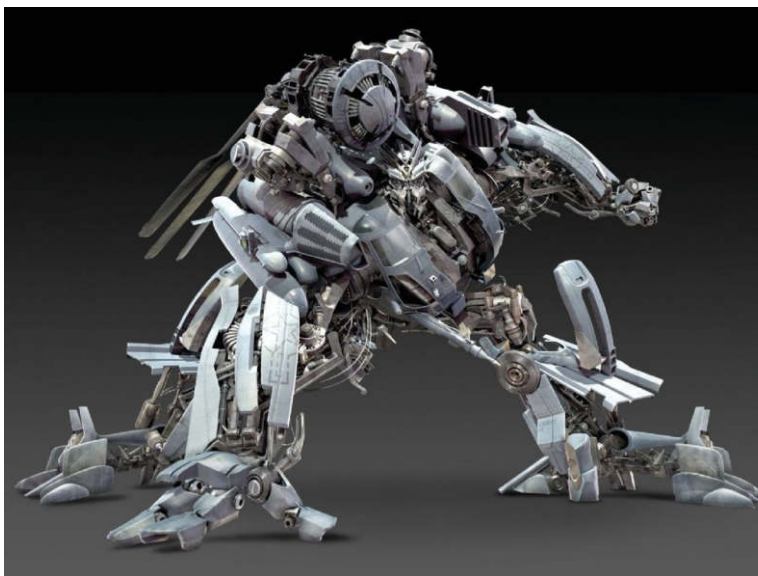
On the other hand the debriefing of DARPA DRC shows clearly that humanoid robots are **still far from the required level of capabilities** in fact many metrics, such as time-to-completion, are highly application or task specific.



Pursuing new frontiers: The robotics bottleneck

Today, more functionality means:

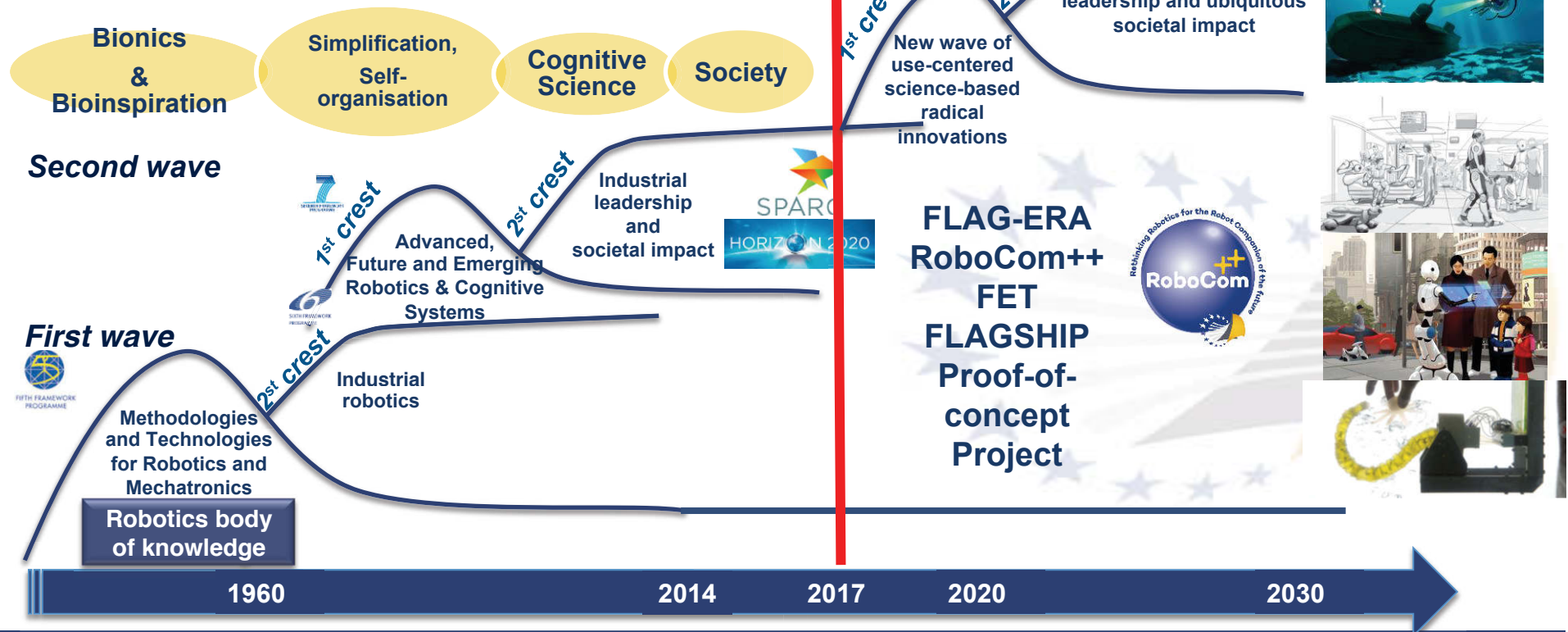
- **more** complexity, energy, computation, cost
- **less** controllability, efficiency, robustness, safety



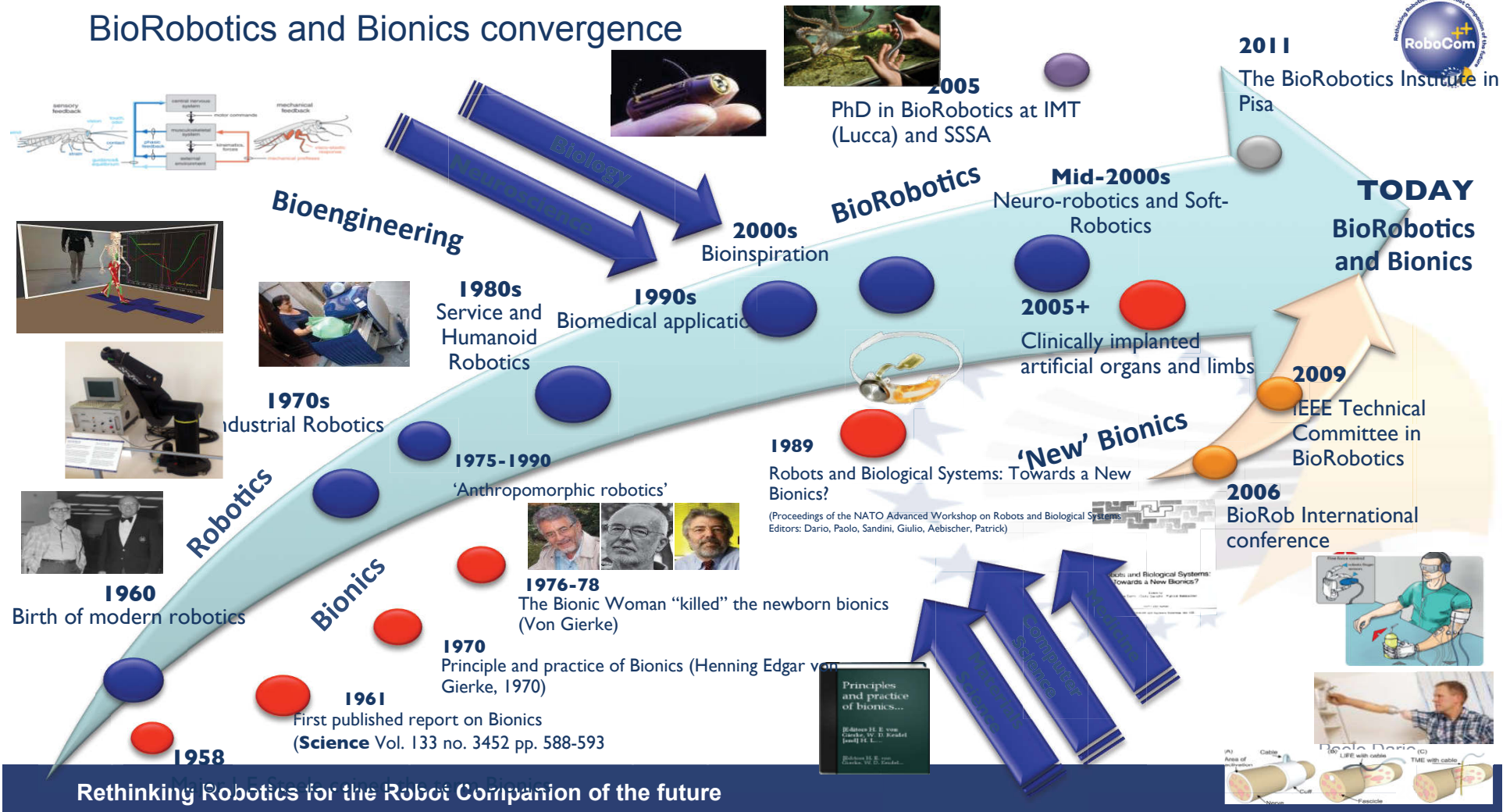
The Robotics waves



Third wave



BioRobotics and Bionics convergence



SCIENCE ROBOTICS



Science Robotics AAAS

Home News Journals Topics Careers

Science Science Advances Science Immunology Science Robotics Science Signaling Science Translational Medicine

Search

Softness is a strength
Soft robotics expand the boundaries of robot abilities
Massimo Brega/Kepach Production

The marvellous progress of Robotics and AI... 'Look Ma, No Hands' syndrome?



'Look Ma, No Hands' syndrome?



Also sprach Rodney Brooks 😊

JUNE 17, 2017 — ESSAYS

Edge Cases For Self Driving Cars

rodneybrooks.com/edge-cases-for-self-driving-cars/



“Perhaps through this essay I will get the bee out of my bonnet that fully driverless cars are a lot further off than many techies, much of the press, and even many auto executives seem to think. They will get here and human driving will probably disappear in the lifetimes of many people reading this, but it is not going to all happen in the blink of an eye as many expect. There are lots of details to be worked out.”



- 'Look Ma, No Hands' syndrome?
- Replication of experiments
- Performance benchmarks, challenges and competitions to allow comparisons of results
- Needed to foster research advancement and enable practical application of research achievements

Much Needed to define 'How good' is a robot at performing tasks



A bit of History

Early stages
2008-2010

- 2008 Euron establishes the GEM SIG (coordinated by me, John Hallam, Angel P. del Pobil as a small funded networking project)
- Reproducibility issues in Robotics exposed at Euron General Meeting in Prague.
- Many meetings help define the issues related to Benchmarking and Good Experimental methodology in Robotics
- 2009: The IEEE RAS TC on Performance Evaluation and Benchmarking of Robotics and Autonomous Systems (PEBRAS) is established

2010-2016

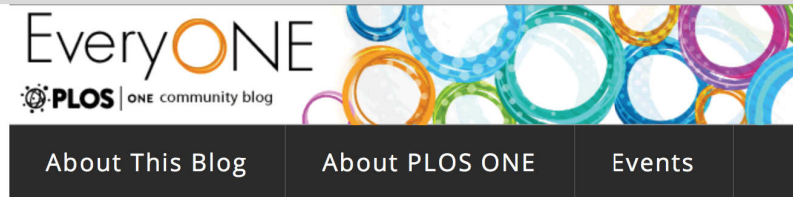
- More than 20 workshops at ICRA, IROS, RSS, ERF discuss the issues and propose solutions
- 2015: the very first Special issues made of Reproducible paper on an high profile venue on IEEE R&A Magazine
- 2015: the first IEEE RAS Summer School on Reproducible Research in Robotics

Today

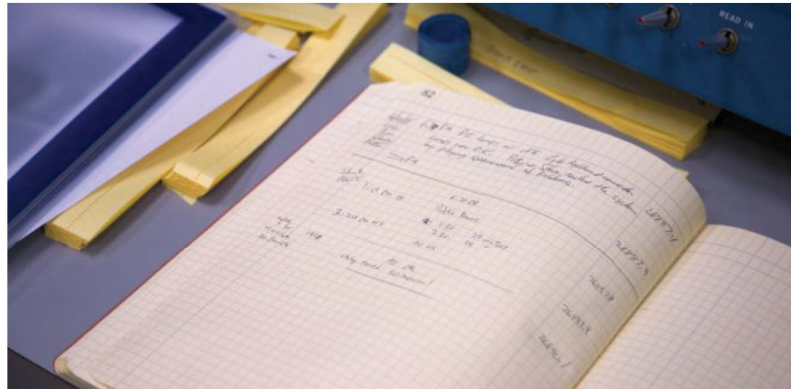
- Still more workshops (the latest at ICRA 2017 in Singapore)
- New cool upcoming initiatives on IEEE RAM
- The best is yet to come!



We are not alone: the ‘reproducibility crisis’



[< Previous](#)



Promoting reproducibility by emphasizing reporting: PLOS ONE's approach

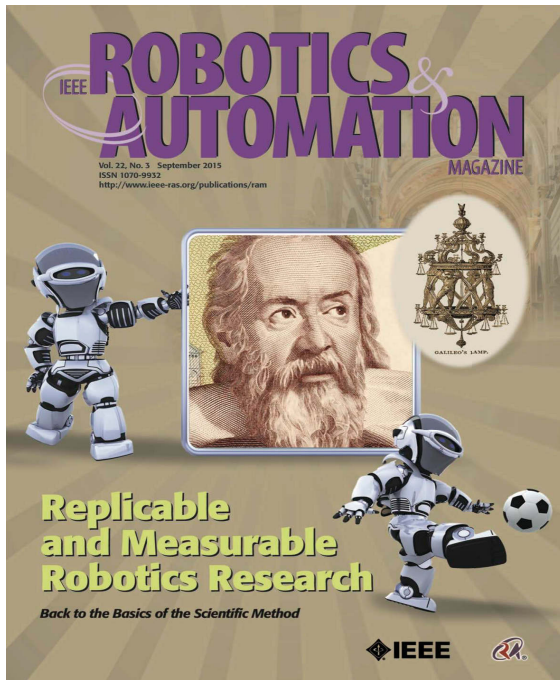


The September '15 RAM's issue leads the way to RR
(Reproducible Research) in Robotics and AI.

A lot has been done, A lot has still to be done.

What exactly is missing?





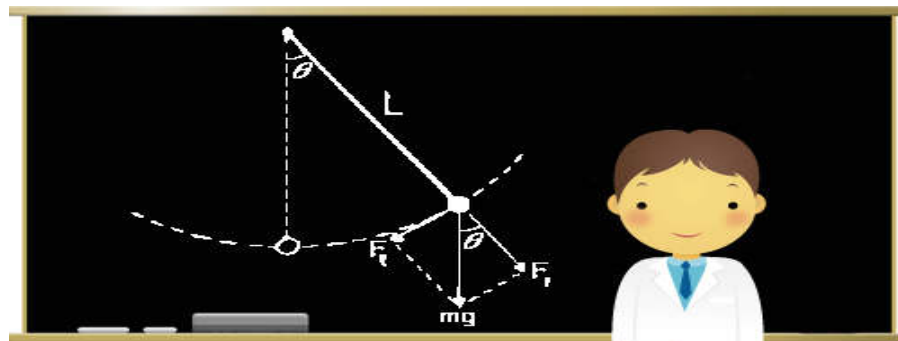
The September '15 RAM's issue leads the way to RR (Reproducible Research) in Robotics and AI.

A lot has been done, A lot has still to be done.

What exactly is (still) missing?



Reminder: the pendulum experiment by Galileo



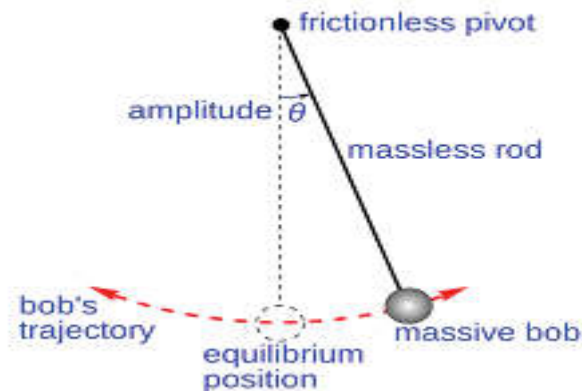
$$\frac{d^2\theta}{dt^2} + \frac{g}{\ell} \sin \theta = 0$$

$$T \approx 2\pi \sqrt{\frac{L}{g}}$$

What is an 'experiment' in robotics?



Replication of experiments



If robotics aims to be serious science, serious attention must be paid to experimental method.

Again, what is an 'experiment' in robotics?



An experiment in Robotics is a well defined (stochastically) repeatable set of (stochastically) reproducible behaviors in well defined set of (stochastically) similar set of environments (see clinical studies in Medicine, Biology, Psychology, etc.)



Performance evaluation



Dyson's robot vacuum cleaner should be considered more intelligent than the Roomba? (it costs 3 times as much....)

How to compare, classify and rank complex adaptive behaviors (Intelligent/Cognitive)?



Number 1 Issue: Reproducibility of experiments

A new kind of papers?

We may think of theoretical/concept papers, proof of concept papers, and experimental papers , as we have started to define here, as steps in a research idea 'life-cycle'. We believe that more paper of the 'experimental' kind would greatly help the research activities in robotics and the industrial exploitation of the results.



A new kind of papers?

- ‘description’ : a journal paper text+figures+ multimedia
....according to GEM Guidelines (or similar)
- Data sets (attachments, not just ‘multimedia’)
- Complete ‘code’ identifiers and or downloadable code
(executables may be enough)
- ‘HW’ description or HW identifier (if it is identifiable)
- ...



A new kind of papers?

EXAMPLE:

throughput.sourceforge.net

A reproducible HRI experiment published in RAM
Dec. 15 issue



A new kind of papers?

The Euron Good Experimental Methodology Guidelines

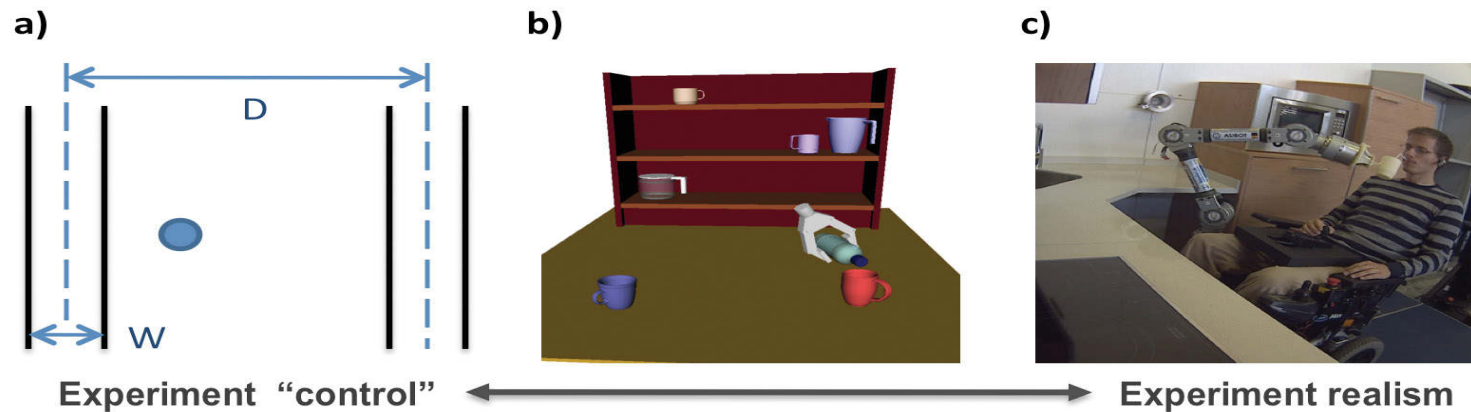
1. Is it an experimental paper?
2. Are the system assumptions/hypotheses clear?
3. Are the evaluation criteria spelled out explicitly?
4. What is being measured and how?
5. Do the methods and measurements match the criteria?
6. Is there enough information to reproduce the work?
7. Do the results obtained give a fair and realistic picture of the system being studied?
8. Are the drawn conclusions precise and valid?

<http://www.heronrobots.com/EuronGEMSig/downloads/GemSigGuidelinesBeta.pdf>



A new kind of papers?

Replicable experiments for human-robot systems?



(a few) Critical Points

Robot requirements:

- *Simulated* robot on commercially available simulator available (commercially or open source) *real* robot platform

Human experiment requirements :

- Sufficient data: Participant statistics, participant instructions, experiment protocol
- Sufficient “control”: Sufficient repetitions, clear success/failure criteria, confidentiality ++
- Informed consent, ethical issues (including forms ☺), boundary with clinical protocols)



What should be ‘Opensource’?

Should ALL experiment software be open?

- Not necessarily: for hypothesis confirmation/refutation
- Sourceforge: Open source “experimentware” ok?

Minimum software requirements:

- All executables and configuration files
- All shared libraries or instructions for install

Licensing:

- Code: LGPL-3.0
- All other content: Creative Commons Attribution 3.0



Example (from RAM December 15's issue)

What metrics can be applied to evaluating shared control?

- Mean Time (MT)
- Errors
- MT and errors (one metric)?
- Information metrics?

Case study:

- Online adaptation of collision limitation behavior
- 5 participants @ 1 hour each



Description

Abstract

Assistive robots are increasingly being envisioned as an aid to the elderly and disabled. However controlling a robotic system with a potentially large amount of Degrees of Freedom (DOF) in a safe and reliable way is not an easy task, even without limitations in the mobility of the upper extremities. Shared control has been proposed as a way of aiding disabled users in controlling mobility aids such as assistive wheelchairs, by using the sensors of the robotic platform to predict the user's intent and assist in navigation. Assistive manipulators, that aim to perform physical Daily Life Activities (DLA), is a more complex problem however. The problem arise from the exponential increase in the size of the state-space with DOF and the increased level of accuracy required for manipulation. Another complication is the potential need for adapting the system to each user's abilities and disabilities. This calls for good experimental practices to ensure repeatability, reproducibility, and steady progress. The work presented here attempts to model the complete system for assistive manipulators, and in the context of this model define metrics and good practices for benchmarking shared control for such robots. An adaptive shared control approach for limiting collisions during teleoperation is used as a case study.

Link

Coming soon...

Citation

```
@article{Maintainer,
author = {Stoelen, M.F. and Tejada, V.F. and Jardon, A.H. and Bonsignorio, F. and Balaguer, C.},
journal = {to be presented at the 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems},
title = {Benchmarking Shared Control for Assistive Manipulators: From Controllability to the Speed-Accuracy Trade-Off},
year = {2012}
}
```

Data sets

All Cartesian trajectories. All trial-level results. Development of neural network weight matrices over time. Matlab examples for loading trajectories, plotting the trial-level results and visualizing the development of the neural network weights. See [\[AdaptiveCollisionHand-DataSets\]](#).

Code

Complete set of executables, Linux 32 and 64 bit. Tested on Ubuntu 10.04 for 32 bit and 11.04 for 64 bit. See



Archive content

Code

- 7 executables, Linux 32 and 64 bit
- Shared libraries
- Models and configuration files

data_sets

- 184 MB of raw data (csv text files)
- Trajectories, MT, errors, NN weights
- method
- Example video
- Questionnaires
- Consent form w/ participant instructions



Replication

Hardware requirements:

- Modern multicore desktop computer
- 3DConexion SpaceNavigator: 99 \$ (US)

Full instructions for installation and setup

- All experiment executables provided
- Freely available shared libraries used: (OpenRAVE, YARP, C++)



Reference results

Trial-level data

- MT (medium time), errors and number of attempts

Cartesian trajectories

- User velocity input
- Noise input
- Shared control output

Neural network data

- Weight matrix stored every 3 seconds



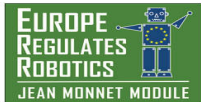
A new kind of papers?

Total effort to replicate: 1-2 hours (on clean Ubuntu machine) but...

Time needed for the setup: a few days (under pressure, but first time)→ a very small fraction of the overall effort to set up the experiments and get the results....

→ Conclusions?😊





THE REGULATION OF ROBOTICS IN
EUROPE: LEGAL, ETHICAL AND ECONOMIC
IMPLICATIONS
INTERNATIONAL SUMMER SCHOOL | 11-16 JULY 2016, PISA, ITALY

Reproducible Research now an IEEE priority

FROM THE EDITOR'S DESK

Research Reproducibility and Performance Evaluation for Dependable Robots

By Eugenio Guglielmelli

This issue of *IEEE Robotics & Automation Magazine (RAM)* focuses on reproducibility and measurability of robotics re-



search. In this issue, the IEEE Robotics and Automation Society demonstrates that we are well aware of and perfectly in line with

Stay tuned, big news soon from IEEE R&A Magazine



Comparison and ranking



We will need shared testing facilities and shared protocols.....to calculate insurance fees (like LHC and Nardò's VW autodrome)





THE REGULATION OF ROBOTICS IN
EUROPE: LEGAL, ETHICAL AND ECONOMIC
IMPLICATIONS
INTERNATIONAL SUMMER SCHOOL | 11-16 JULY 2016, PISA, ITALY

ECHORD⁺⁺: PECCIOLI RIFs



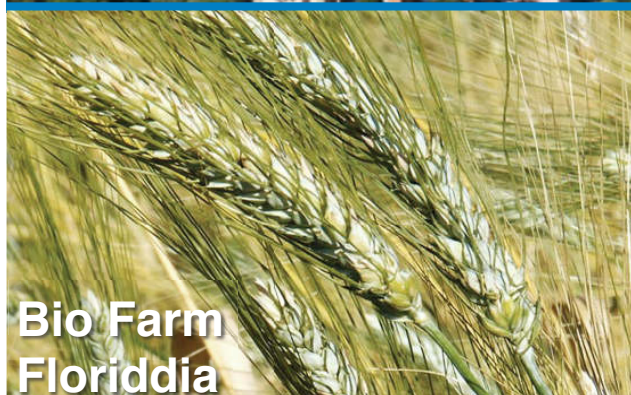
Peccioli Town



Nursing Home
Ghizzano



Bio Farm
FredeCrecchi



Bio Farm
Floriddia



Farm of Stassano



DomoCasaLab



*Comparison and ranking: **typical tasks***



It's complicated!



It's complicated:

Reminder: Type I and Type II errors (in statistics)

- **'null hypothesis'**: An example of a null hypothesis is the statement "Smoke has no effect on the probability to suffer with bronchitis" The purpose is to prove that actually smoke influences your probability to develop a bronchitis.
- **type I error** (aka "error of the first kind") 'Cry wolf' you believe something when it is actually false
- **type II error** (aka "error of the second kind") you believe it is not true something that it is true



It's complicated: Reminder: Statistical significance

An experiment is statistically significant if the ' p -value' is equal to or smaller than the significance level (α), a threshold value is chosen, called the significance level of the test, traditionally 5% or 1%.

The p -value can be calculated as the probability of obtaining the observed measured values (sample results), or "more extreme" ones, when the "null hypothesis" is true. It depends on the probability distribution (customary a Gaussian)

An 'high' p -value means that it is unlikely that the "null hypothesis" is true and thus that hypothesis must be rejected (*this does not mean that the NOT("null hypothesis") should be accepted as true for this reason only*). *This test guarantees that the probability of a Type I error is minor or equal to α . (that you don't 'cry wolf')*



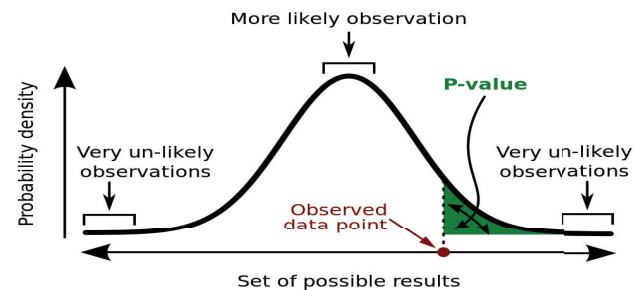
It's complicated: Statistical significance

Important:

$\Pr(\text{observation} \mid \text{hypothesis}) \neq \Pr(\text{hypothesis} \mid \text{observation})$

The probability of observing a result given that some hypothesis is true is *not equivalent* to the probability that a hypothesis is true given that some result has been observed.

Using the p-value as a “score” is committing an egregious logical error:
the transposed conditional fallacy.



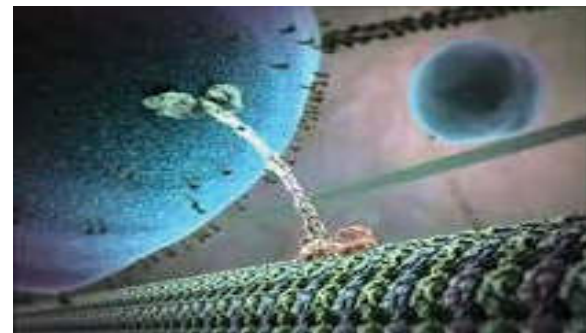
A **p-value** (shaded green area) is the probability of an observed (or more extreme) result assuming that the null hypothesis is true.

Picture source:
wikipedia



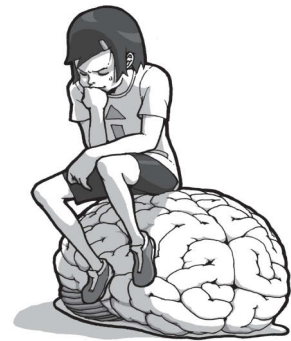
Is It Alive?

Big Questions lie in front of us!



Two views of intelligence

classical:
cognition as computation



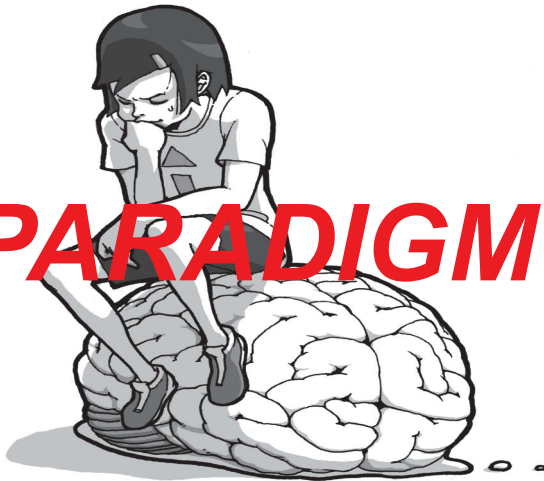
embodiment:
**cognition emergent from sensory-
motor and interaction processes**



Embodied Intelligence or Morphological Computation: the modern view of Artificial Intelligence

Classical approach

The focus is on the brain and central processing



Modern approach

The focus is on interaction with the environment. Cognition is emergent from system-environment interaction



PARADIGM CLASHES

Soft Robotics: a working definition

Variable impedance actuators and stiffness control

- * Actuators with variable impedance
- * Compliance/impedance control
- * Highly flexible (hyper-redundant or continuum) robots



THE BIROBOTICS
INSTITUTE



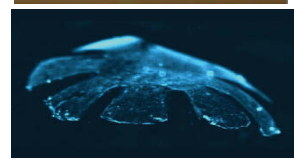
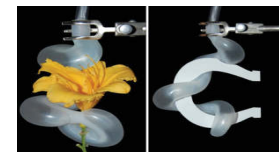
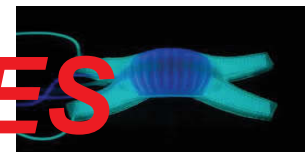
Scuola Superiore
Sant'Anna

IEEE Robotics and Automation Magazine,
Special Issue on Soft Robotics, 2008
A. Albu-Schaffer et al. (Ed.s)



Use of soft materials in robotics

- * Robots made of soft materials that undergo high deformations in interaction
- * Soft actuators and soft components
- * Control partially embedded in the robot morphology and mechanical properties



Kim S., Laschi C., and Trimmer B. (2013) Soft robotics: a bioinspired evolution in robotics, *Trends in Biotechnology*, April 2013.
Laschi C. and Cianchetti M. (2014) "Soft Robotics: new perspectives for robot bodyware and control" *Frontiers in Bioengineering and Biotechnology*, 2(3)

Discussion

‘mature enough areas’?

- SLAM
- Mobile Robots’ Motion Control
- Robot Obstacle Avoidance
- Grasping
- Visual Servoing
- Autonomy/Cognitive tasks (e.g. Turing Test!, “the imitation game”)
- Last but not least: Object Recognition and Manipulation



Performance evaluation

How to compare, classify and rank complex adaptive behaviors (Intelligent/Cognitive)?

A few examples from other various '*mature enough*' application domains

1. Robot mobility
2. Robot manipulation and grasping
3. HRI and Social Robotics
4. General novel approaches
5. Last but not least....Cleaning!

Object recognition and manipulation are an excellent starting point!



Visual servoing example

Visual servoing control the movement of robots (video assisted mobile robots or manipulators) on the basis of feedback coming from a video device, like a video camera.

This example is relevant because formal proof are very difficult if not impossible in many if not most cases, as a consequence experimental work is necessary to assess the potential of different approaches to control.



Visual servoing example

Assumptions

For a visual servoing systems there typical which must be detailed. A non exhaustive list is given here:

- the visual features
- scene 3D model
- the kinematics model of the robot.
- dynamics model of the robot.



Visual servoing example

Assumptions

Plus the list related to image processing:

- background characteristics (homogeneous or if not color and luminance distributions)
- lighting conditions
- robustness to outliers in feature detection
- others inherent to real life experimentation.



Visual servoing example

Performance criteria

Generally speaking these criteria measure the convergence of the system to a predefined goal.

Non exhaustive list:

- the time of convergence
- the trajectories of the visual features in the image plane
- the 3D trajectory of the robot computation time
- positioning error after convergence.

A special attention must be paid to stability and robustness against image noise, the errors in the models (object, camera, robot), and the control parameters.



Visual servoing example

Measured characteristics

An unequivocal procedure to derive the quantitative aspects of the system must be given. For example visual features can be directly obtained from the video camera. For manipulators what is directly measurable are the generalized joint angles while the end effector 3D trajectory must be estimated by the (direct) kinematic model. Calibration procedures for the robot relevant characteristics and camera must be described.

In experiments the visual features (at least) must be varied and the variation policy documented.



Visual servoing example Implementation Information

The information given above don't allow by themselves the replication of results.

There more data needs than in other kind of papers:

- Visual servoing system configuration environment (either real or simulation) should be described in detail: in-hand vs. external camera, etc.
- model and control parameters
- ground truth for robot positioning and the environment



Visual servoing example

Implementation Information

- Technical specification of the hardware platform
- Technical specifications of the camera (model, frame rate, resolution, etc.).
- Computer specifications (at least, processor and amount of memory, o.s., relevant configuration details)
- sw libraries (they should be available at least as linkable components) list and configuration

Probably the adoption of widely known sw libraries like ViSP, VXL, OpenCV may ease replication.



Visual servoing example

Parameter and variable distribution

Statistical distributions of all relevant parameter must be given (as in an open ended stochastic environment results will have a probabilistic formulation). This is by the way quite common in clinical research (as noticed before)



Visual servoing example

Parameter and variable distribution

The list of findings in the discussion/conclusion section should be against a detailed list of criteria within a detailed list of conditions as recalled above.

For example better convergence speed, robustness /weakness against certain parameters, behavior with respect to current technology visual servoing systems:

- visual features moving of the field of view
- workspace and singularity issues

The findings listed in a paper might be negative: the given algorithm in our test conditions fail under the listed set of conditions with respect to the listed series of criteria.



Legal and Insurance Issues



Activity Summary (all metrics are as of August 31, 2015)

Vehicles

- 23 Lexus RX450h SUVs – currently self-driving on public streets in Mountain View, CA, & Austin, TX
- 25 prototypes – 5 are currently self-driving on public streets in Mountain View, CA

Miles driven since start of project in 2009

“Autonomous mode” means the software is driving the vehicle, and test drivers are not touching the manual

controls. “Manual mode” means the test drivers are driving the car.

- **Autonomous mode: 1,158,818 miles**
- Manual mode: 877,477 miles
- We’re currently averaging ~10,000 autonomous miles per week on public streets

Source: Google Self-Driving Car Project, Monthly Report August 2015



Activity Summary

Over the 6 years since we started the project, we've been involved in 11 minor accidents (light damage, no injuries) during those 1.7 million miles of autonomous and manual driving with our safety drivers behind the wheel, *and not once was the self-driving car the cause of the accident.*

Chris Urmson (Google/Alphabet), blog post on Medium, May 2015



Standards (an example)

ISO 13482 applies to manufacturers of “personal care robots” which allow close robot-human interaction and even robot-human contact.

“The single most important thing required for the widespread expansion of the [personal robotics] market is the development of standards,” says Gurvinder Virk, convenor of ISO TC184/SC2/WG7, the group responsible for ISO 13482 project.

“The lack of safety standards has prevented small companies from innovating and taking the risk that an accident may occur with their new robotic product. If such an accident did happen, it’s up to the company to prove to a court of law that they have carried out the risk assessment for their product in a sufficiently logical and thorough way. For a small company with limited resources, that’s quite difficult to prove without an ISO standard,” says Virk.

The economic effect of ISO 13482 will be felt most in the E.U., where it will be deemed to comply with the E.U.’s Machinery Directive.



Performance evaluation



Dyson's new robot vacuum cleaner should be considered more intelligent than the Roomba? (it costs 3 times as much....)

Standard drafting and commercial benchmarking definition will require a huge amount of knowledge...much still in the making



Not 'academic issues'



The crashed Tesla S car involved in the first fatal self driving car accident on May 7th 2016. Source: Reuters



Not ‘academic issues’

“... This is the first known fatality in just **over 130 million miles** where Autopilot was activated. Among **all vehicles in the US**, there is a fatality **every 94 million miles**. **Worldwide**, there is a fatality approximately **every 60 million miles....**”

Tesla Motors Blog, June 30th 2016

According to Tesla: the Autopilot... "does not turn a Tesla into an autonomous vehicle and **does not allow the driver to abdicate responsibility.**"

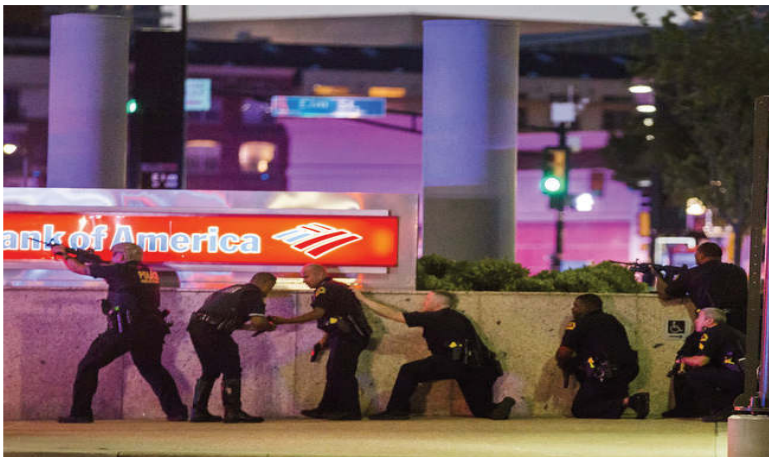


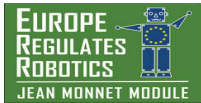
Two different approaches: Liability and insurance models are different!

- **Google:** not even has a steering wheel → Extensive dedicated testing
- **Tesla motors:** cumulative deployment of 'ready' functionalities **under user responsibility** (many others do that with parking assistance)→ data logging from real usage



Not 'academic issues': Dallas shooting





THE REGULATION OF ROBOTICS IN
EUROPE: LEGAL, ETHICAL AND ECONOMIC
IMPLICATIONS
INTERNATIONAL SUMMER SCHOOL | 11-16 JULY 2016, PISA, ITALY

Not 'academic issues': yesterday in Palo Alto



Lilian Kim
@liliankim7

Segui

16 mo old has injuries to leg, foot after
[@StanfordShop](#) security robot knocks him down
and runs him over. [#paloalto](#)



RETWEET
106

MI PIACE
57



22:49 - 11 lug 2016

Palo Alto, CA



Other more mundane questions waiting to be answered

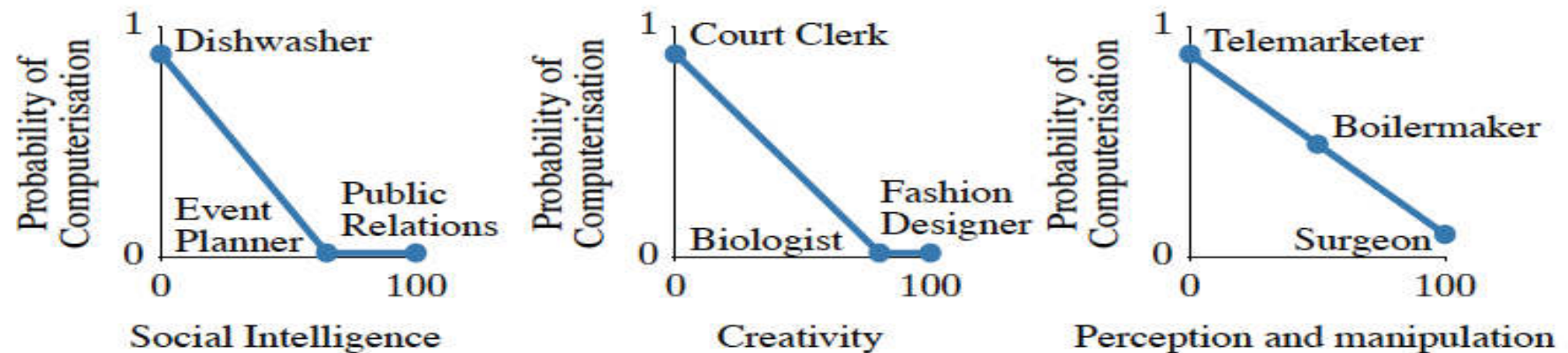


FIGURE I. A sketch of how the probability of computerisation might vary as a function of bottleneck variables.



TABLE I. O*NET variables that serve as indicators of bottlenecks to computerisation.

| Computerisation bottleneck | O*NET Variable | O*NET Description |
|-----------------------------------|------------------------------------|--|
| Perception and Manipulation | Finger Dexterity | The ability to make precisely coordinated movements of the fingers of one or both hands to grasp, manipulate, or assemble very small objects. |
| | Manual Dexterity | The ability to quickly move your hand, your hand together with your arm, or your two hands to grasp, manipulate, or assemble objects. |
| | Cramped Awkward Positions | How often does this job require working in cramped work spaces that requires getting into awkward positions? |
| | Work Space. | |
| Creative Intelligence | Originality | The ability to come up with unusual or clever ideas about a given topic or situation, or to develop creative ways to solve a problem. |
| | Fine Arts | Knowledge of theory and techniques required to compose, produce, and perform works of music, dance, visual arts, drama, and sculpture. |
| Social Intelligence | Social Perceptiveness | Being aware of others' reactions and understanding why they react as they do. |
| | Negotiation | Bringing others together and trying to reconcile differences. |
| | Persuasion | Persuading others to change their minds or behavior. |
| | Assisting and Caring for Others | Providing personal assistance, medical attention, emotional support, or other personal care to others such as coworkers, customers, or patients. |

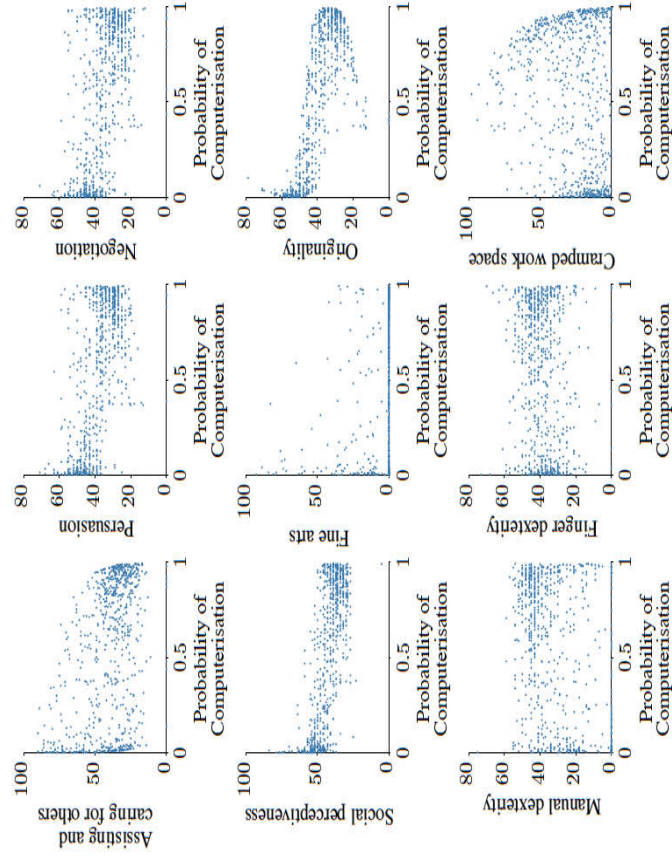


FIGURE II. The distribution of occupational variables as a function of probability of computerisation; each occupation is a unique point.

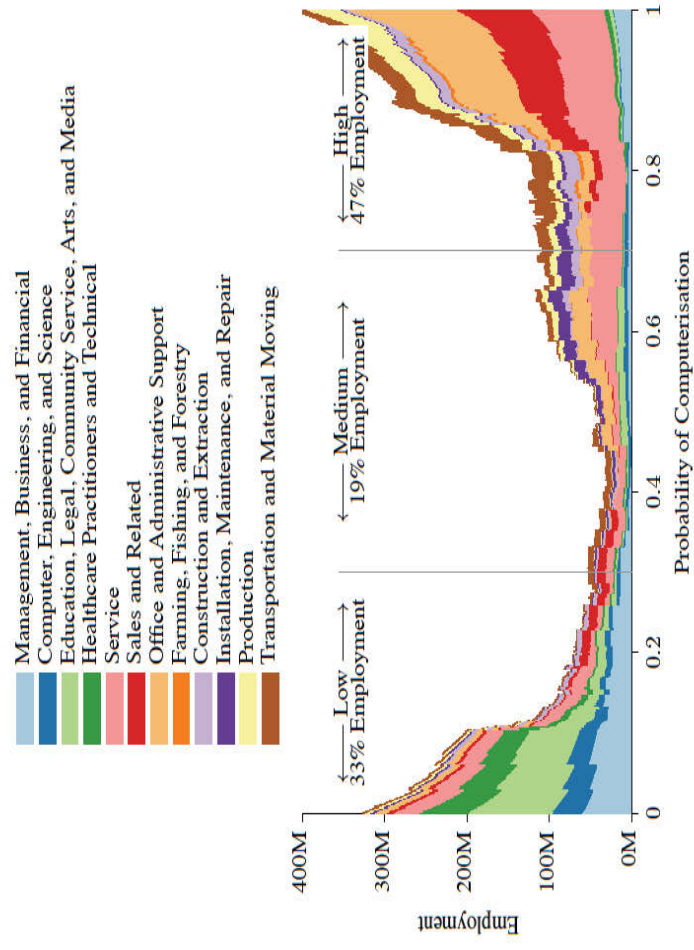


FIGURE III. The distribution of BLS 2010 occupational employment over the probability of computerisation, along with the share in low, medium and high probability categories. Note that the total area under all curves is equal to total US employment.

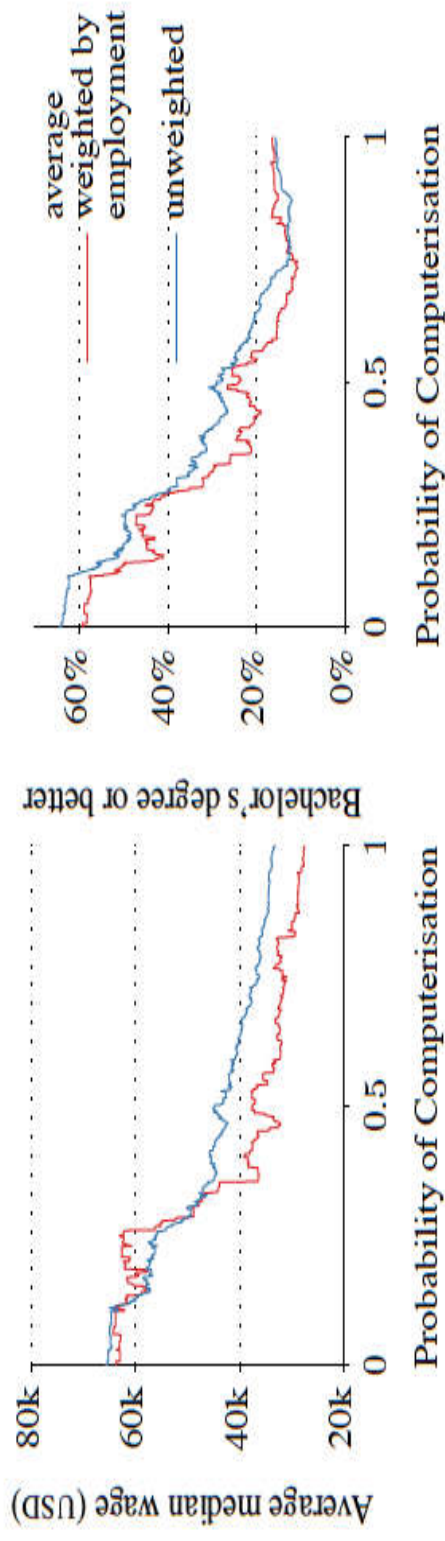


FIGURE IV. Wage and education level as a function of the probability of computerisation;
note that both plots share a legend.

What we need to be able to evaluate robots(including risks)?

- Models (with probabilistic elements) based on robots' and environments' 'physics'
- Extensive test campaigns for model fine tuning, but first of all to get statistically significant data



What we need to be able to evaluate robots?

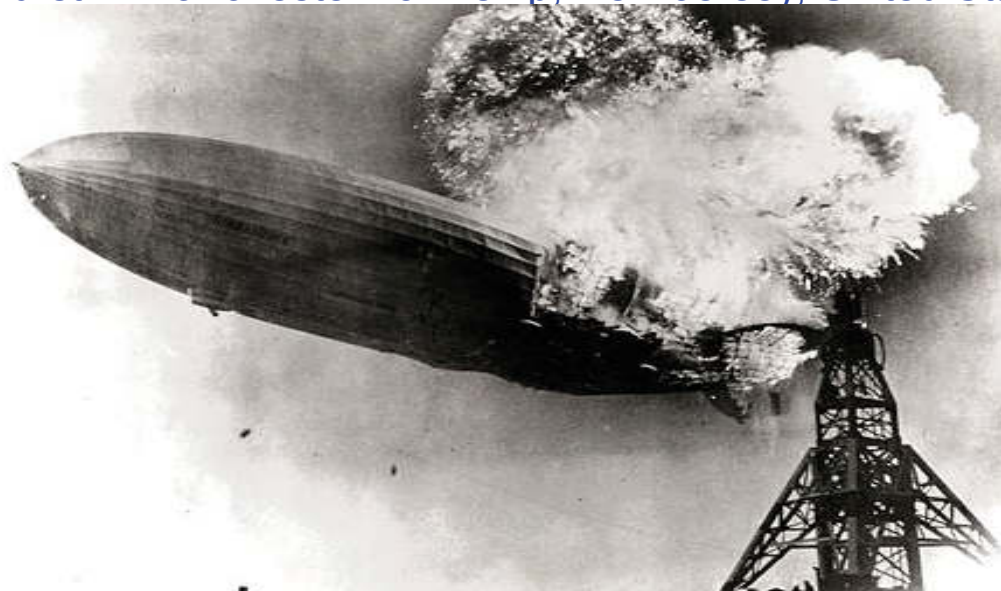
- **Testing and evaluation Infrastructures**
(‘Nardò’++!!!)
- ‘Special sites’ – for example small towns – where it is possible to assess the convivence of humans and intelligent robots and systems
- **DATA, DATA, DATA!!!**



The fears...

May 6, 1937

Naval Air Station Lakehurst in Manchester Township, New Jersey, United States



and the promise of robotics....





THE REGULATION OF ROBOTICS IN
EUROPE: LEGAL, ETHICAL AND ECONOMIC
IMPLICATIONS
INTERNATIONAL SUMMER SCHOOL | 11-16 JULY 2016, PISA, ITALY



Co-funded by the
Erasmus+ Programme
of the European Union

Thank you!

