The BioRobotics Institute

Scuola Superiore Sant'Anna, Pisa

Lecture 8
Grab Bag, Summary and topics to discuss

Fabio Bonsignorio[1,2,3,4,5,6]

RoboCom++ Embodied Intelligence in Natural and Artificial Agents WG Leader[1]
SPARC TG Benchmarking and Competitions[2]
IEEE RAS TC-PEBRAS[3]
Member SPARC Board of Directors[4]

The BioRobotics Institute, SSSA[5]
and Heron Robots[6]

Prologue

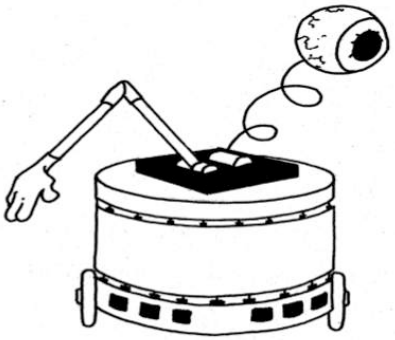
The “frame problem” (1)

From: Dennett*, D.C. 1987. “Cognitive Wheels: The Frame Problem in AI”, in Pylyshyn, Z.W., ed., The Robot’s Dilemma: The Frame Problem in Artificial Intelligence. Norwood, NJ: Ablex, pp. 41–64.

R1: (naive ☺) robot

INSIDE(R1,ROOM)
ON(BATTERY,WAGON)
PULLOUT(WAGON, ROOM)

*Daniel Dennett,
American philosopher
(philosophy of mind)



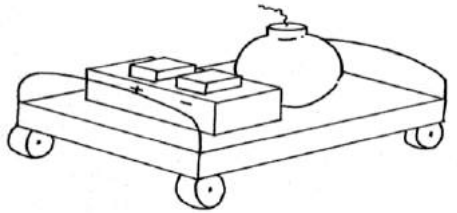


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Illustration: (adapted from) **Isabelle Follath**

Not as expected

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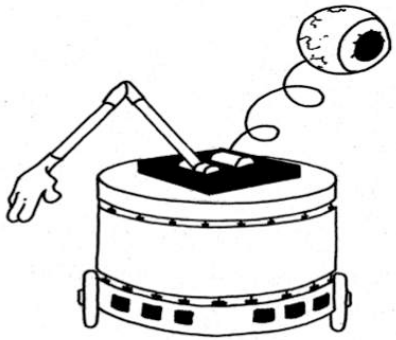
The “frame problem” (2)

From: Dennett*, D.C. 1987. “Cognitive Wheels: The Frame Problem in AI”, in Pylyshyn, Z.W., ed., The Robot’s Dilemma: The Frame Problem in Artificial Intelligence. Norwood, NJ: Ablex, pp. 41–64.

R1D1:
Robot Deducer
(it deduces the implications of its own acts)

*Daniel Dennett, American philosopher (philosophy of mind)



INSIDE(R1D1,ROOM)
ON(BATTERY,WAGON)
COLOUR(PULLOUT(WAGON, ROOM))
=UNCHANGED
…
…
WHEELS(REVOLUTIONS, PULLOUT(.))=..

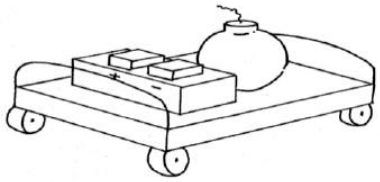


Illustration: (adapted from) **Isabelle Follath**

In the meantime…

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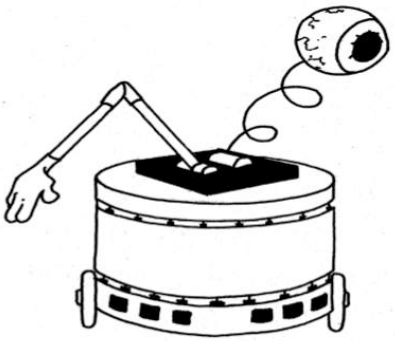
The “frame problem” (3)

From: Dennett*, D.C. 1987. “Cognitive Wheels: The Frame Problem in AI”, in Pylyshyn, Z.W., ed., The Robot’s Dilemma: The Frame Problem in Artificial Intelligence. Norwood, NJ: Ablex, pp. 41–64.

R2D1(aka ‘Hamlet’)
Robot Relevant
- Deducer

(it discards not relevant implications
of its own acts)



INSIDE(R2D1,ROOM)
ON(BATTERY,WAGON)
COLOUR(PULLOUT(WAGON, ROOM))
=NotRelevant
…
…
WHEELS(REVOLUTIONS, PULLOUT(.))=
NotRelevant
…
Not Relevant…Not Relevant…
Not Relevant….

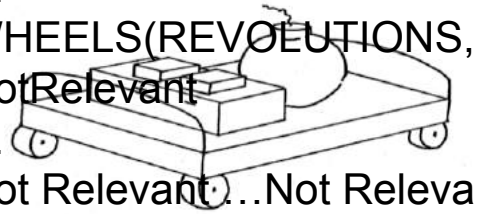


Illustration: (adapted from) **Isabelle Follath**

You know the story…

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Summary of Dennett's points

- obvious to humans, not obvious to (GOFAI) robots (robot only has symbolic model/representation of world)
- vast number of potential side effects, mostly irrelevant

distinction between relevant and irrelevant inferences
must test all

Also spracht 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."

Also spracht Rodney Brooks ☺

- What to do in a blocked road
- Maps don't tell the whole story
- The Police (and…), in general interacting with humans..(reading human intentions)
- Getting Towed
- Other tricky situations
- …

The real world is surprising

Columbus discovering America while looking for a short route to Asia (wikipedia)

Traders looking at screens during the global market crash of 2008 (seekingalpha.com)

There are unexpected events that change the F-O-R (at many levels)

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Outline of the talk

- Robotics ‘waves’
- Industry 4.0
- I4.0 impact on the Circular Economy
- Another I4.0 side effect: impact on Construction Industry
- Open issues with current ‘paradigms’ and approaches, and the road ahead
- Societal impacts
- Last but not least: the Koans!

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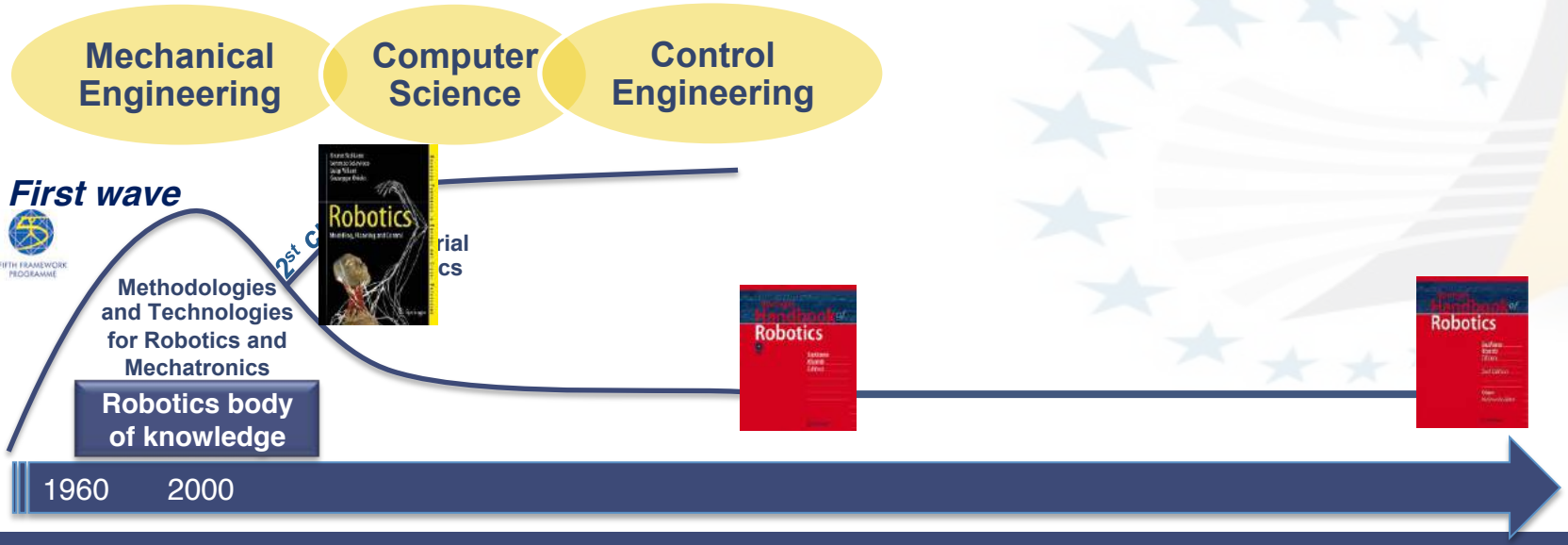
Older and newer attempts

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

Recent successes: the first wave



The first wave

Mechanical Engineering | **Computer Science** | **Control Engineering**

First wave

2st crest

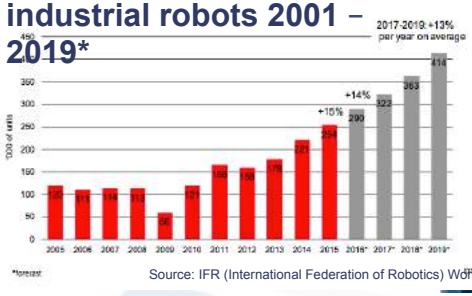
Industrial robotics

Methodologies and Technologies for Robotics and Mechatronics

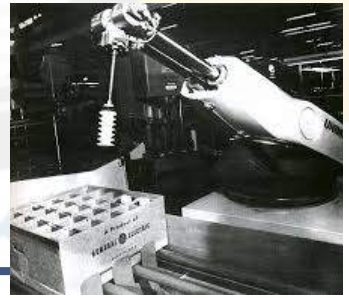
Robotics body of knowledge

1960 2000

Worldwide annual supply of industrial robots 2001 – 2019*



Source: IFR (International Federation of Robotics) World Robotics 20



The second wave

IoT

Machine Learning

Artificial Intelligence

Second wave

1st crest

2st crest

Advanced, Future and Emerging Robotics & Cognitive Systems

Industrial leadership and societal impact

SPARC

HORIZON 2020

First wave

2st crest

Industrial robotics

Methodologies and Technologies for Robotics and Mechatronics

Robotics body of knowledge

2014

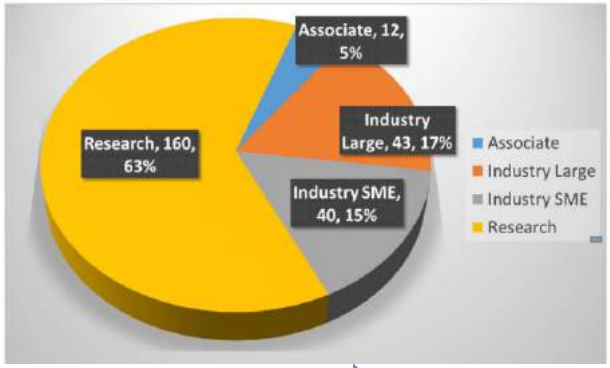
2020

Membership development

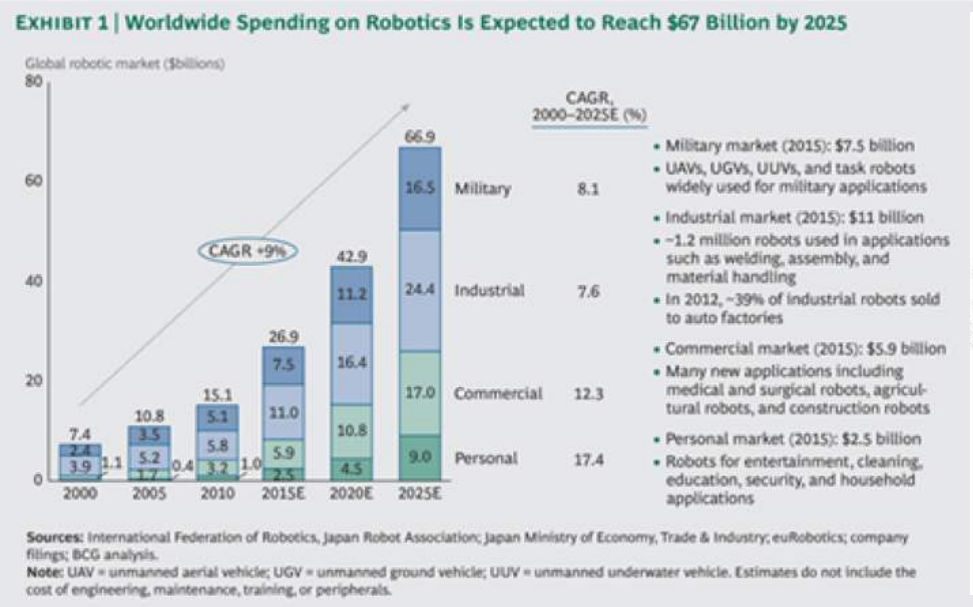
280 member organisations

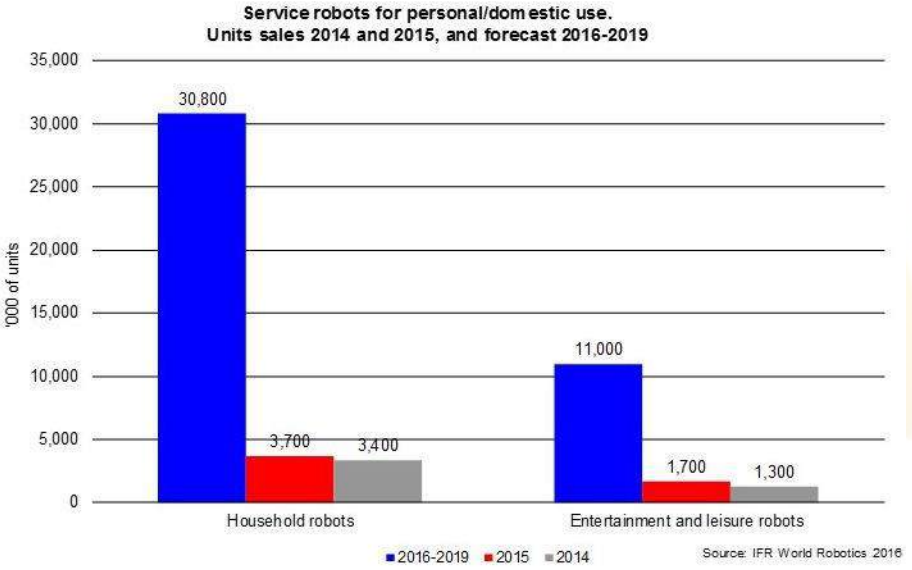
Legend:

- Industry
- Research
- Associate
- euRobotics AISBL



The second wave





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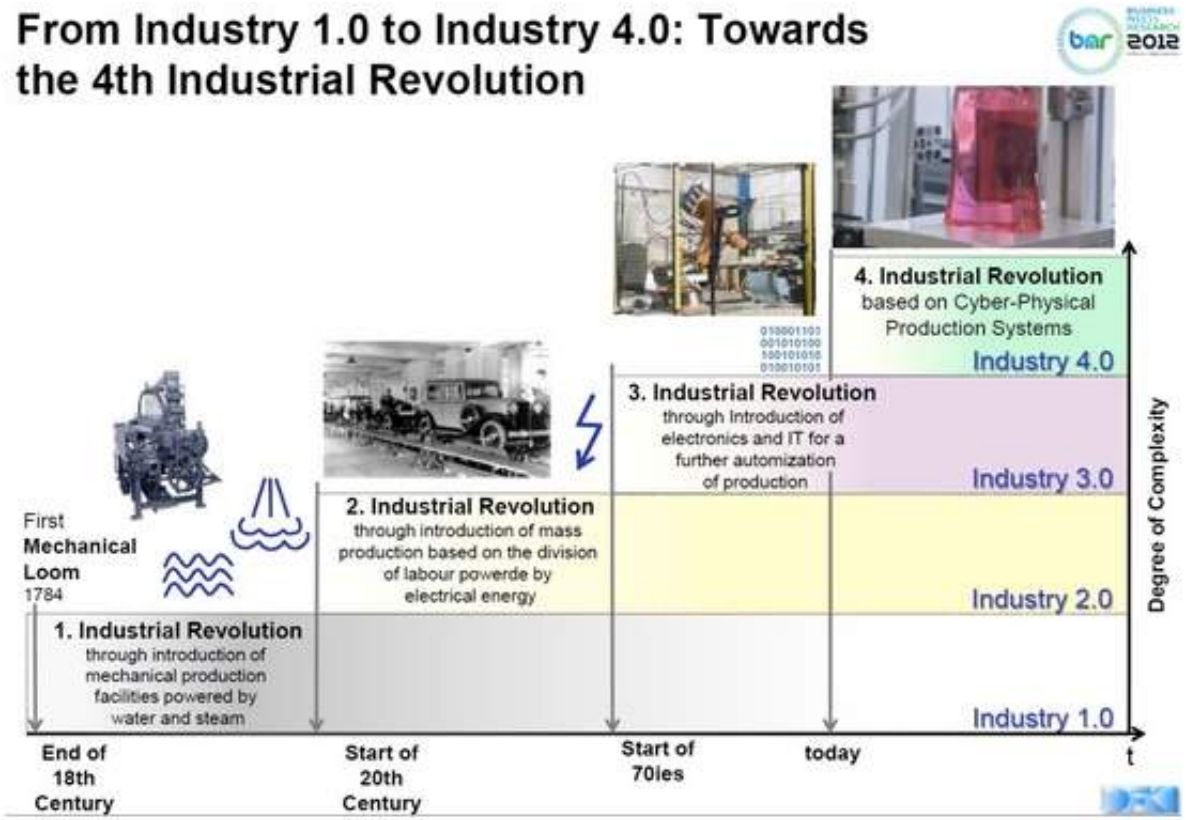
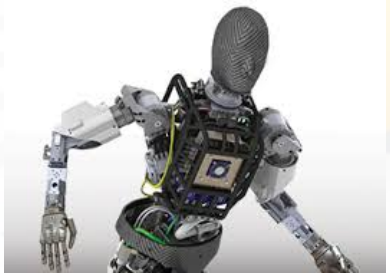
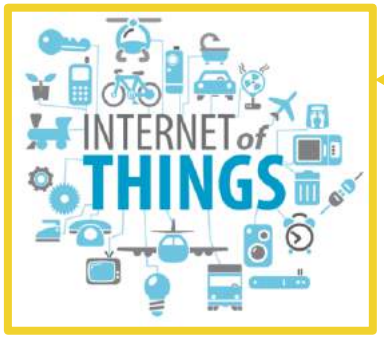
The second wave

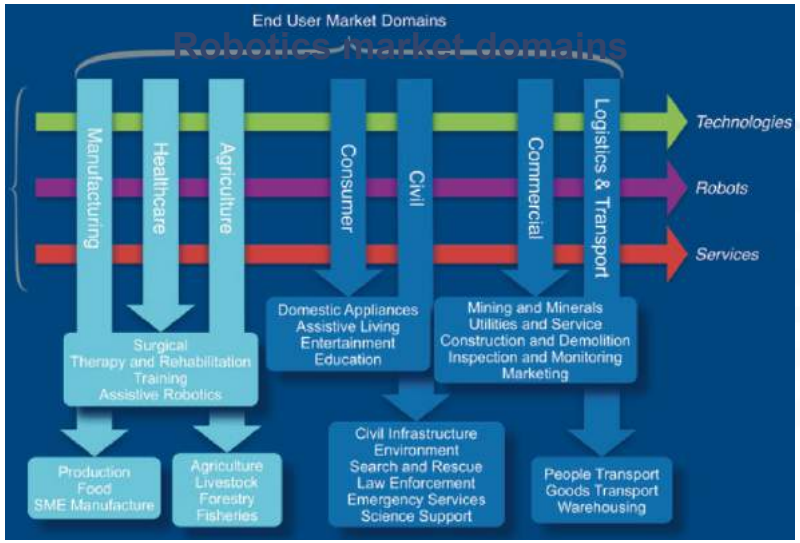


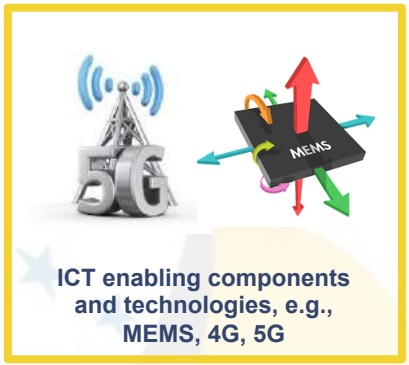


The second wave: Robotics: a great opportunity to innovate, connect and transform



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





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

Robots and Jobs

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

PIAGGIO

Regione Toscana

FAS
Fondo Aree
Sottoutilizzate
2007-2013

REPUBBLICA ITALIANA

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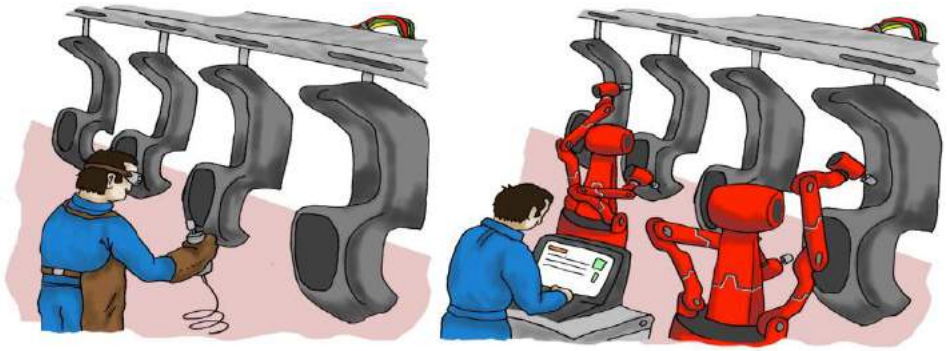
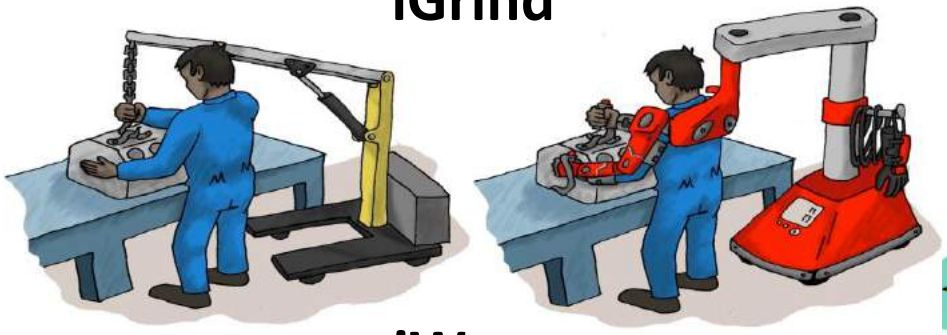
FACTORY 4.0: 'CENTAURO' Project

SCENARIOS

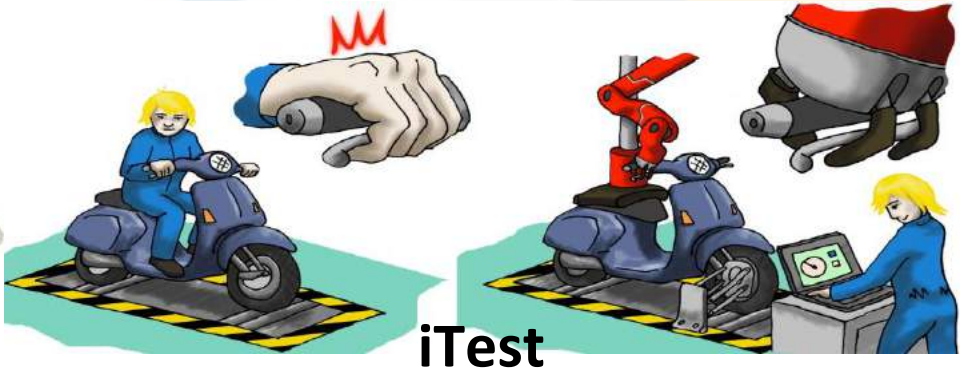


iGrind

iSort



iWear



iTest

This is a dismantling scenario!

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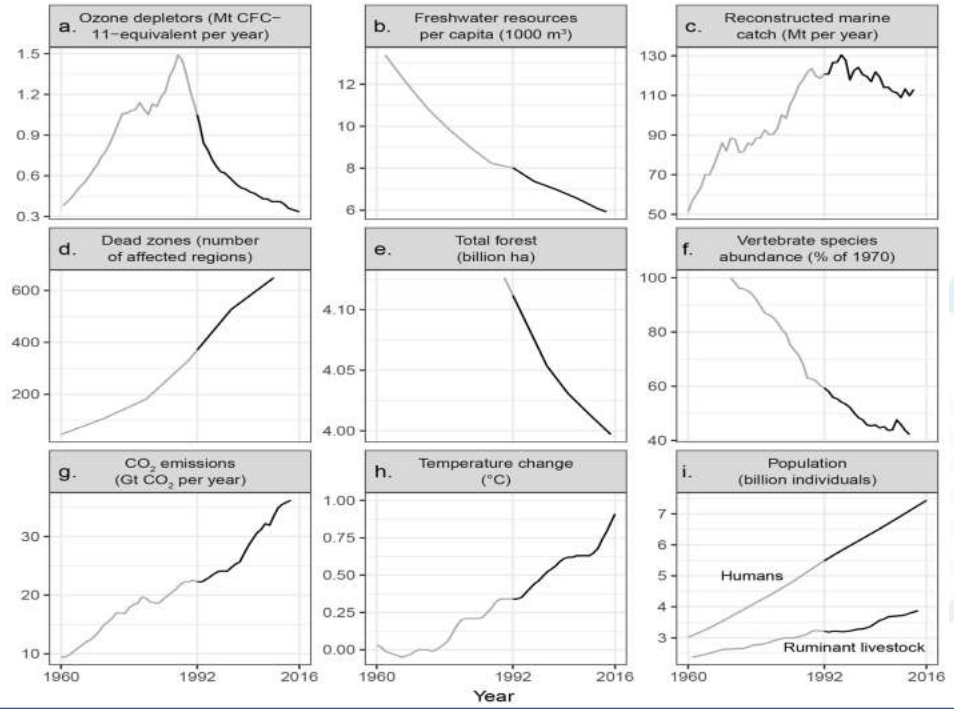
Why we do need a Circular Economy?



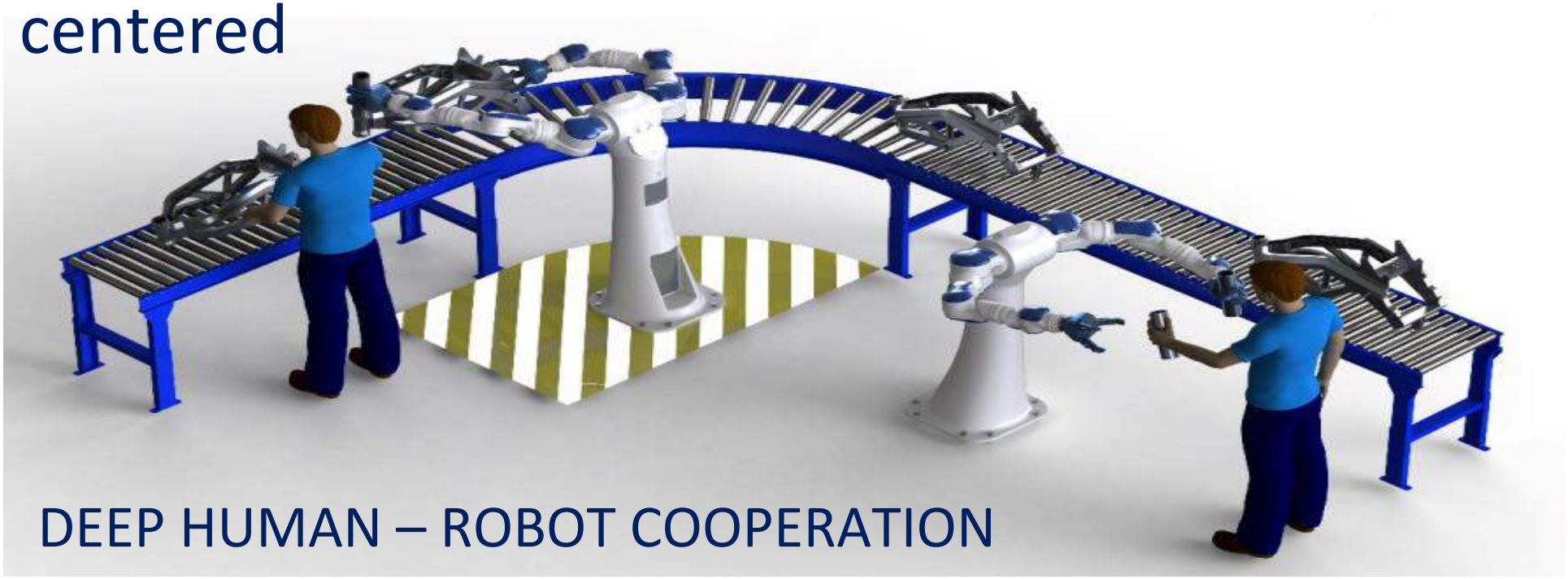
From: World Scientists' Warning to Humanity: A Second Notice

BioScience. Published online November 13, 2017. doi:10.1093/biosci/bix125

* William J. Ripple Christopher Wolf Thomas M. Newsome Mauro Galetti Mohammed Alamgir Eileen Crist Mahmoud I. Mahmoud William F. Laurance 15,364 scientist signatories from 184 countries

Robots on the Shop-floor

BIO-AUTOMATION: the new frontier of automation ‘eco’, bio-inspired and human centered



DEEP HUMAN – ROBOT COOPERATION

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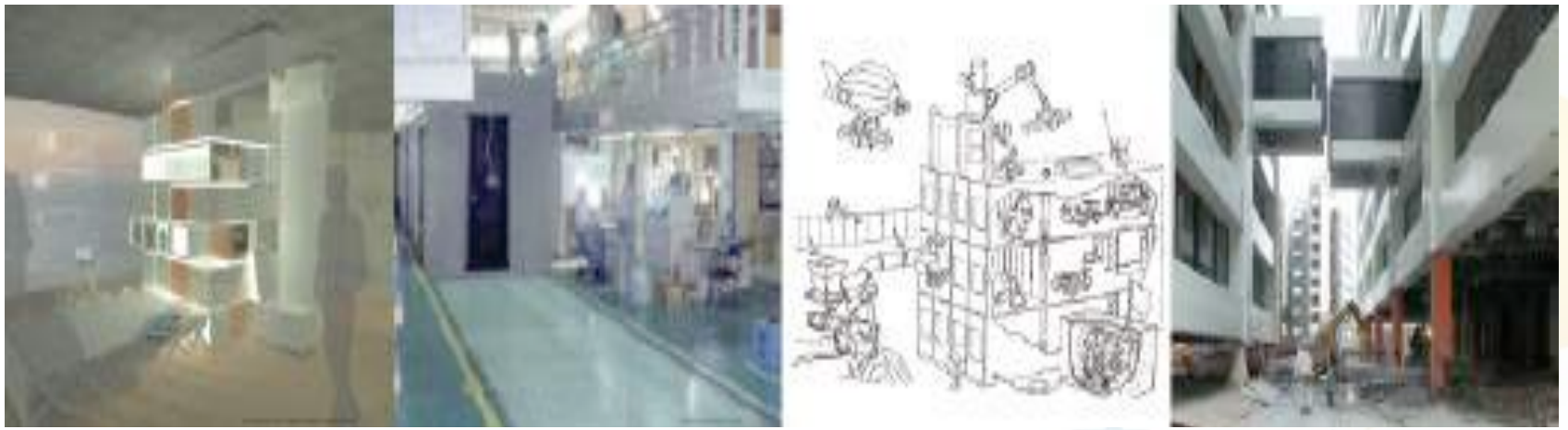
A nice side-effect of Industry 4.0 and CE: Economically and eco-sustainable refurbishment of low quality urban areas

Richard and Su Rogers. Zip-Up Enclosures No. 1 and 2, 1968-71 Model. On behalf of Rogers Stirk Harbour + Partners

KieranTimberlake Associates, Stephen Kieran and James Timberlake. Cellophane House (Exterior)

Pictures from: K. Tadashi Oshima, R. Waern (authors), B. Bergdoll and P. Christensen (eds). Home Delivery, The Museum of Modern Art, New York, (2008)

Urban Refurbishment



a) Ambient Innovation; b) Industrialization; c) Site Automation; d) Robotic Deconstruction ('dismantling of buildings and built environments')

from T. Block. TARSA, Teaching Automation, Robotics and Services to Architects, (2010)

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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.**

Not everything worked as expected!

The second wave: the current approach shows some limitations

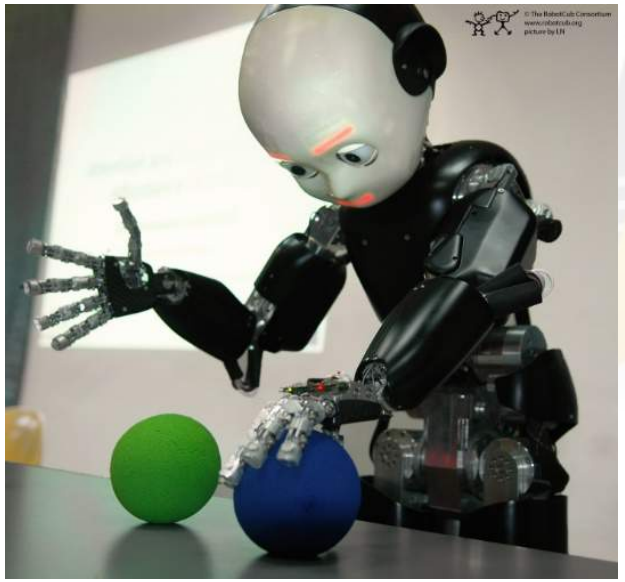
On the other hand the debriefing of DARPA DRC shows clearly that humanoid robots are **still far from the required level of capabilities in fact many metrics**, **such as time-to-completion, are highly application or task specific.**

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

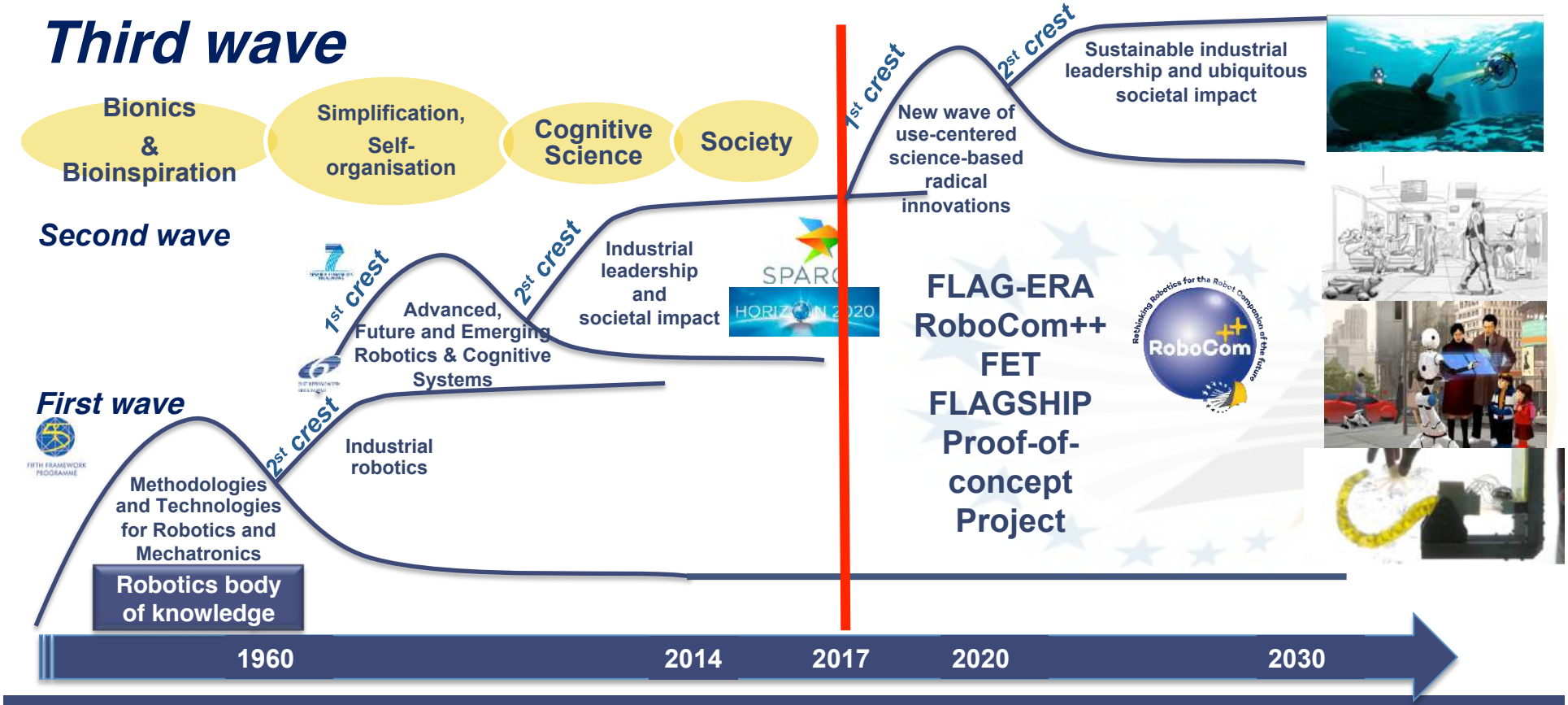
Pursuing new frontiers:
The robotics bottleneck

Today, more functionality means:

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

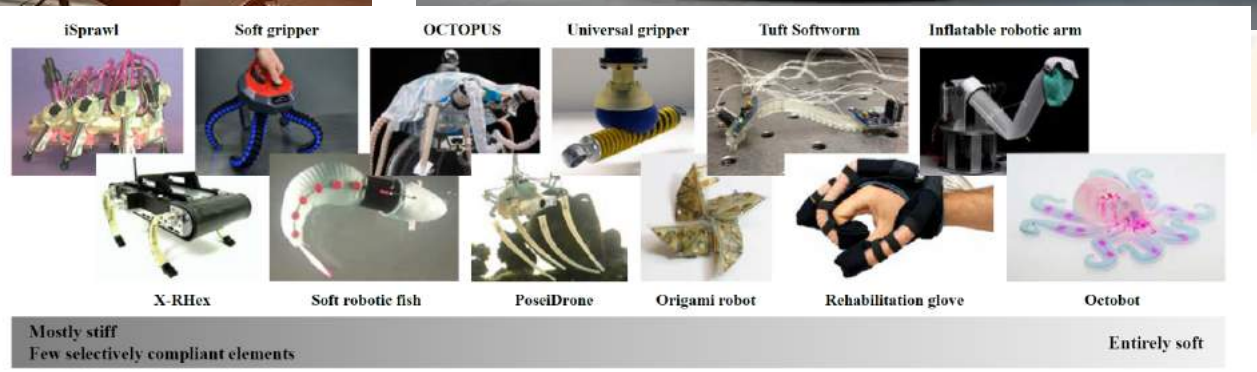


The Robotics waves



SCIENCE ROBOTICS

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



Also spracht 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

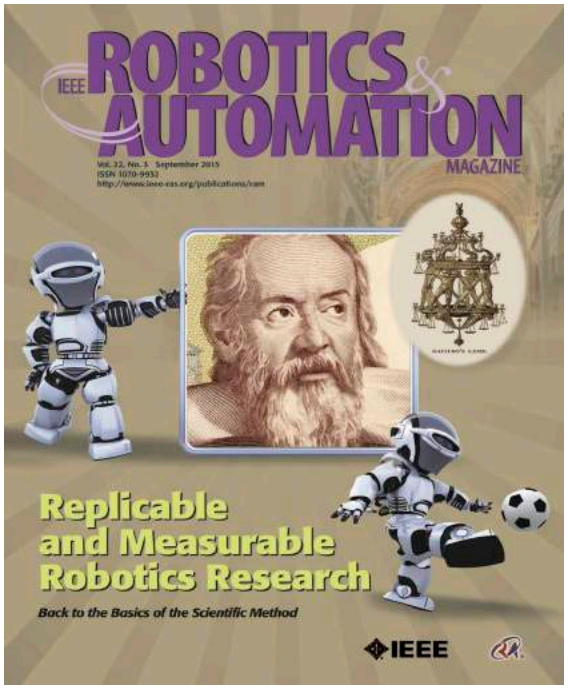
- 2008 Euron establishes the GEM SIG (coordinated by me, John Hallam, Angel P. del Pobil as a small fundednetworking project
- Reproducibility issues in Robotics exposed at Euron General Meeting in Prague.
- Many meetings help define the issues related to Benchmarking and Good Experimental methodology 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!

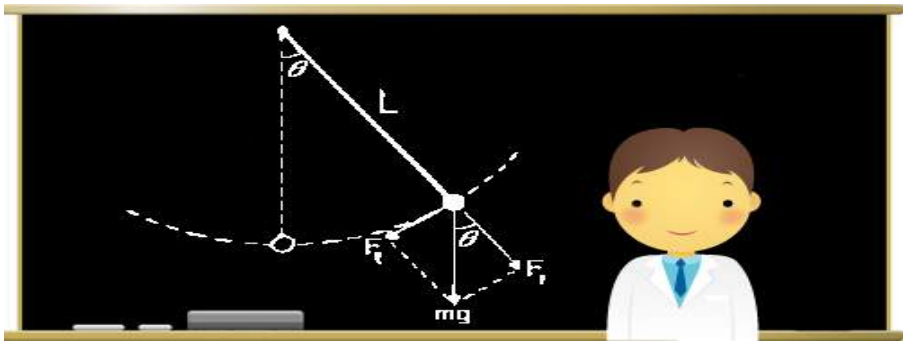


The September ‘15 RAM's issue leads the way to RR (Reproducible Research) in Robotics and AI.

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

What exactly is (still) missing?

Reminder: the pendulum experiment by Galileo

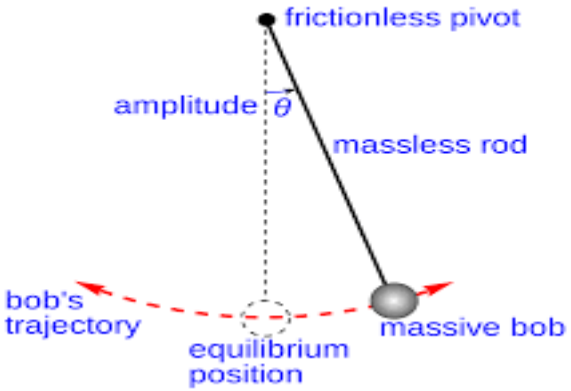


$$\frac{d^2\theta}{dt^2} + \frac{g}{\ell}\sin\theta = 0$$

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

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.)

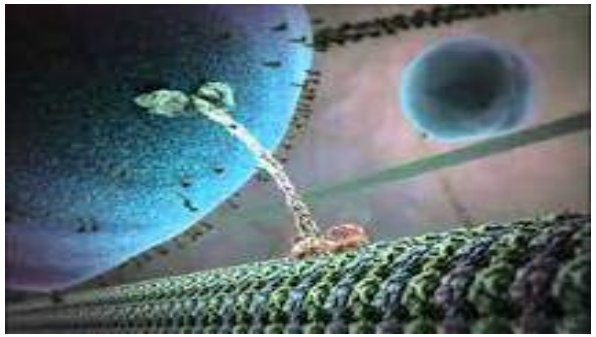
Performance evaluation

Dyson's robot vacuum cleaner should be considered more intelligent than the Roomba?

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

Is It Alive?

Big Questions lie in front of us!



Two views of intelligence

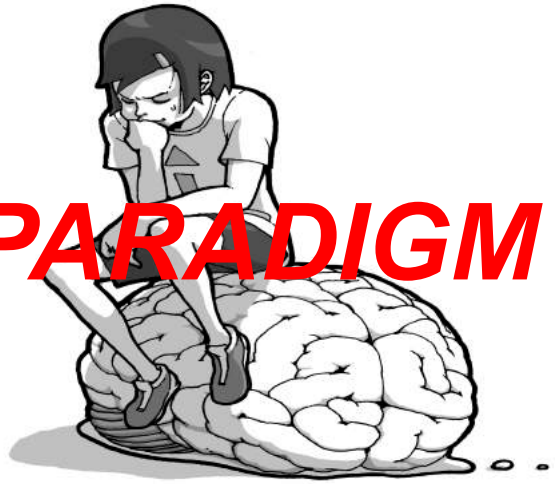
classical:
cognition as computation

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

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Rolf Pfeifer and Josh C. Bongard, *How the body shapes the way we think: a new view of intelligence*, The MIT Press, Cambridge, MA, 2007

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

PARADIGM CLASHES

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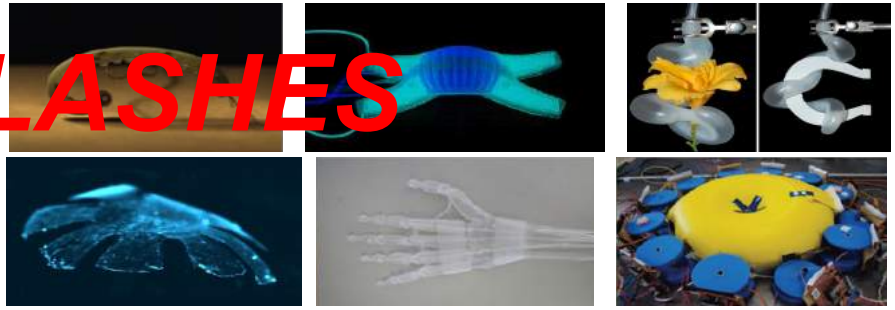
IEEE Robotics and Automation Magazine, Special Issue on Soft Robotics, 2008
A. Albu-Schaffer et al. (Ed.s)

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)

Outline of the talk

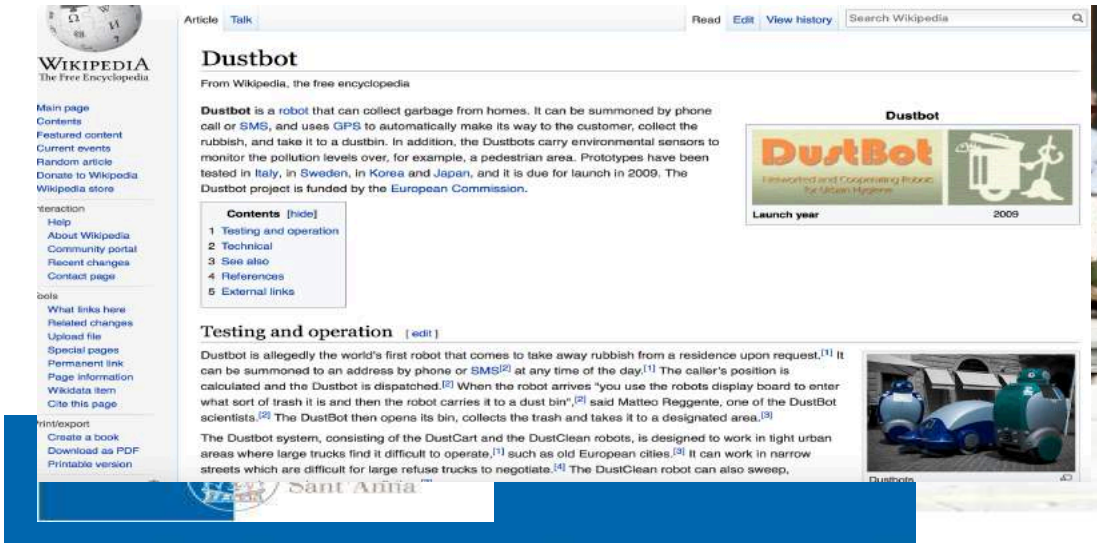
- Robotics ‘waves’
- Industry 4.0
- I4.0 impact on the Circular Economy
- Another I4.0 side effect: impact on Construction Industry
- Open issues with current ‘paradigms’ and approaches, and the road ahead
- Societal impacts
- Last but not least: the Koans!

Not 'academic issues'

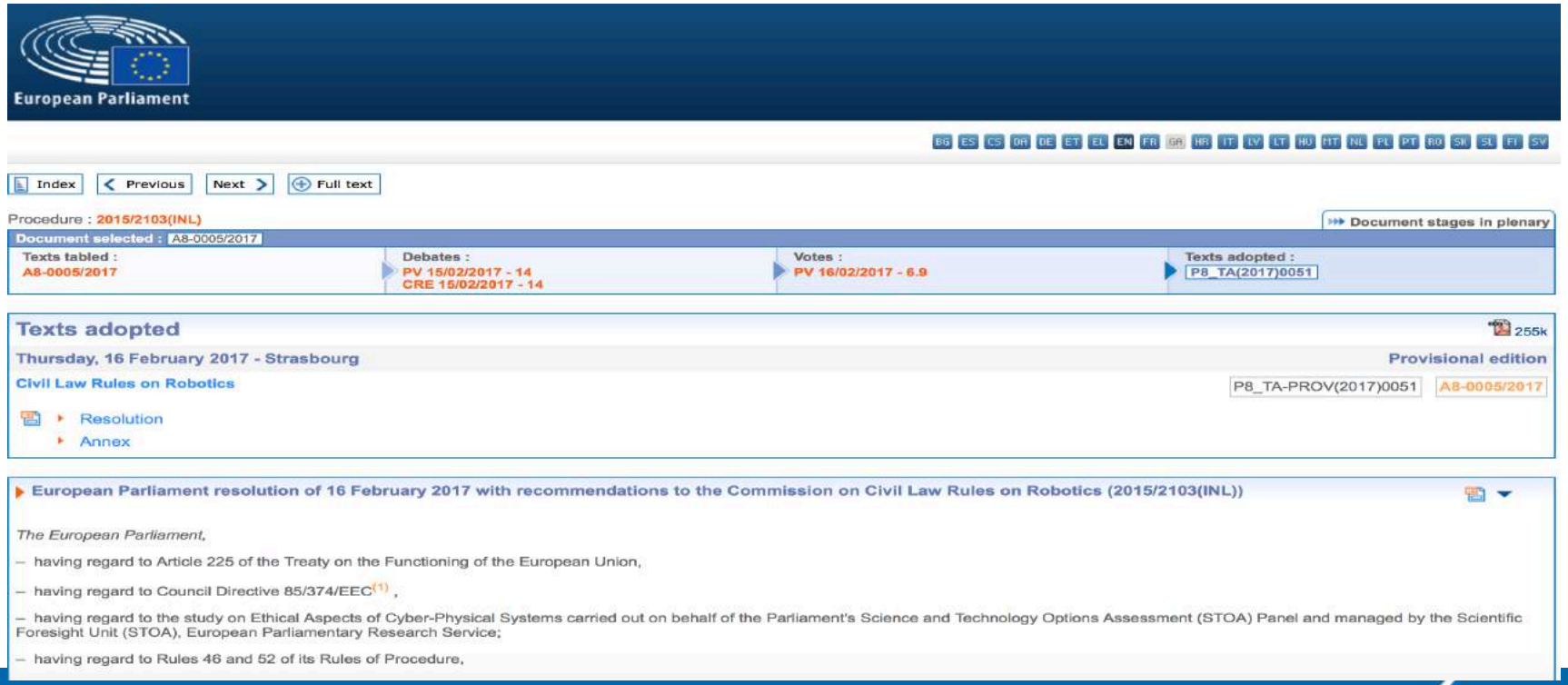
The crashed Tesla S car involved in the first fatal self driving car accident on May 7th 2016. Source: Reuters

As early as in 2001 the first RoboEthics workshop was held in Pisa at SSSA

DustBot FP6 Project 2006-2009 took waste collecting robots in the streets of the Tuscan 'borgo' of Peccioli…From that experience 'Law issues' with massive deployment of robots became clear ….Guess who started the discussion leading to the RoboLaw Project 2011-2014) coordinated by SSSA.



RoboLaw's Guidelines and SSSA have already heavily influenced the EU's Lawmakers work…



European Parliament

BG ES CS DA DE ET EL EN FR GA HR IT LV LT HU MT NL PL PT RO SK SL FI SV

Index | Previous | Next | Full text

Procedure : 2015/2103(INL) — Document stages in plenary

Document selected : A8-0005/2017

Texts tabled :	Debates :	Votes :	Texts adopted :
A8-0005/2017	PV 15/02/2017 - 14 CRE 15/02/2017 - 14	PV 16/02/2017 - 6.9	P8_TA(2017)0051

Texts adopted — 255k

Thursday, 16 February 2017 - Strasbourg — Provisional edition

Civil Law Rules on Robotics — P8_TA-PROV(2017)0051 — A8-0005/2017

- Resolution
- Annex

European Parliament resolution of 16 February 2017 with recommendations to the Commission on Civil Law Rules on Robotics (2015/2103(INL))

The European Parliament,

– having regard to Article 225 of the Treaty on the Functioning of the European Union,

– having regard to Council Directive 85/374/EEC[1] ,

– having regard to the study on Ethical Aspects of Cyber-Physical Systems carried out on behalf of the Parliament's Science and Technology Options Assessment (STOA) Panel and managed by the Scientific Foresight Unit (STOA), European Parliamentary Research Service;

– having regard to Rules 46 and 52 of its Rules of Procedure,

Not only issues!!!Daily Workplace and Home activities

CE Directives on ‘Machines’, ‘Low Tension’, ‘Electromagnetic Pollution’, ‘ATEX’ and many others identify many ‘hazards’:

- Mechanical
- Electrical/Electromagnetical
- Biological
- Environmental
- Ionizing radiations (radioactive)
- …

They are a blueprint for intelligent robotics implementation!

Other more mundane questions waiting to be answe

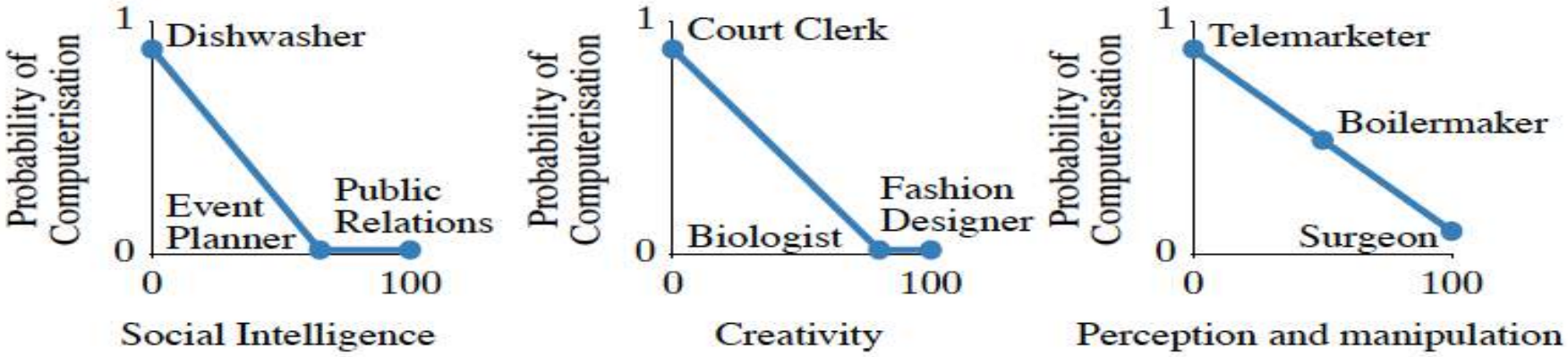


FIGURE I. A sketch of how the probability of computerisation might vary as a function of bottleneck variables.

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 Work Space, Awkward Positions	How often does this job require working in cramped work spaces that requires getting into awkward positions?
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.

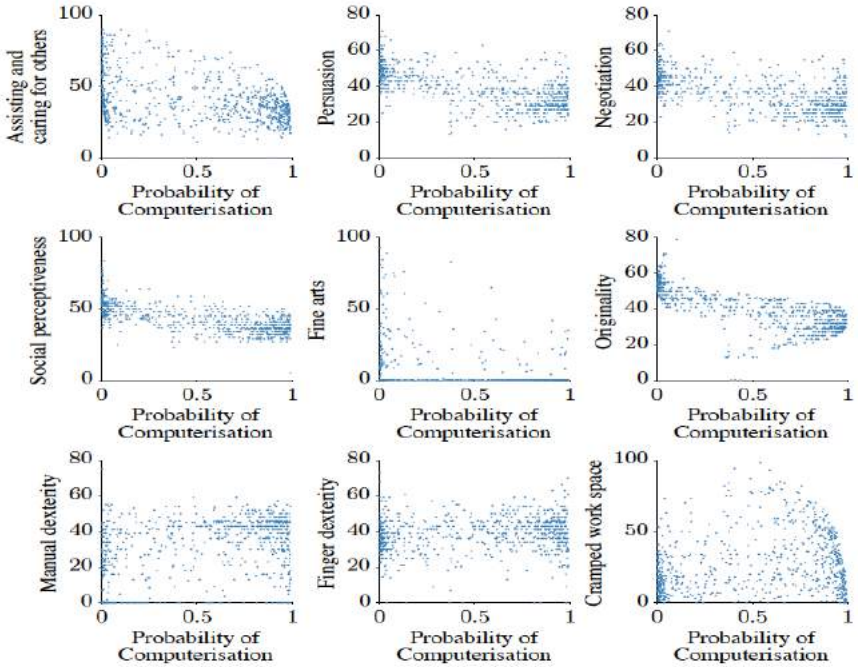


FIGURE II. The distribution of occupational variables as a function of probability of computerisation; each occupation is a unique point.

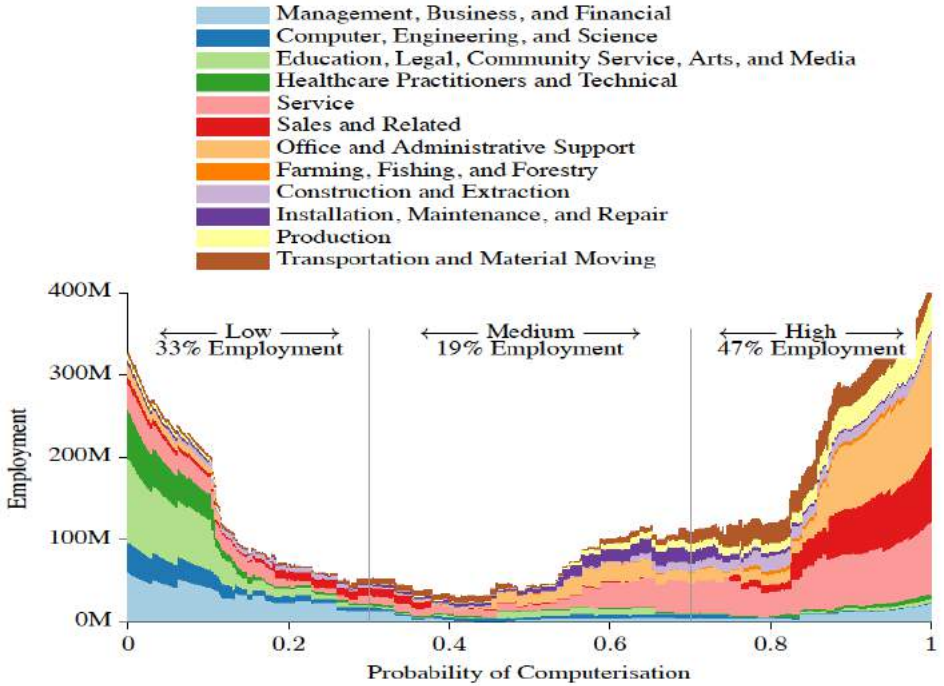


FIGURE III. The distribution of BLS 2010 occupational employment over the probability of computerisation, along with the share in low, medium and high probability categories. Note that the total area under all curves is equal to total US employment.

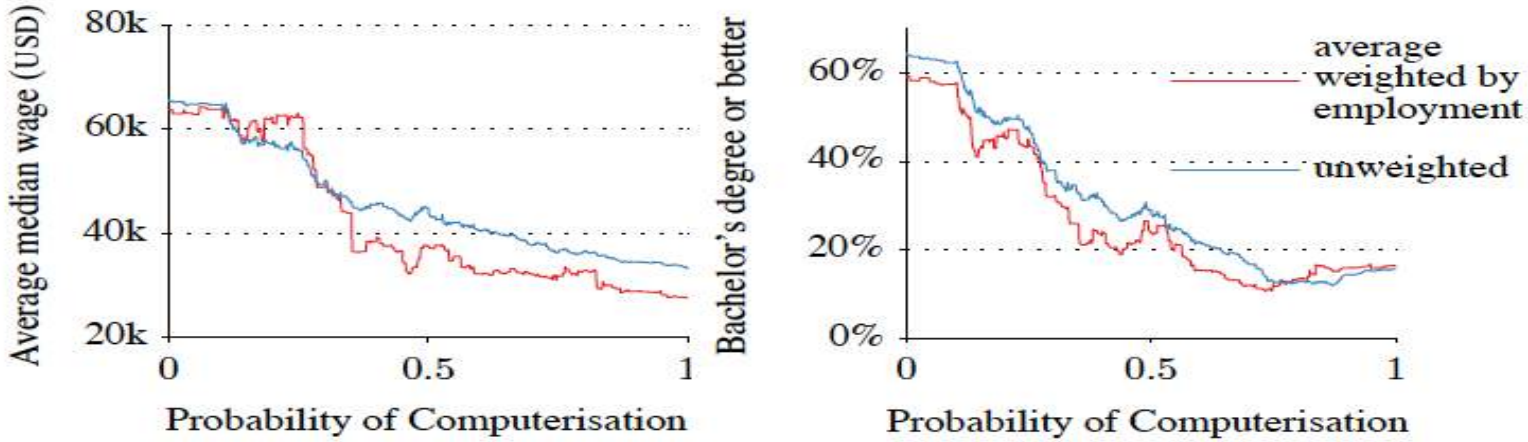


FIGURE IV. Wage and education level as a function of the probability of computerisation; note that both plots share a legend.

WORLD ECONOMIC FORUM

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Global Challenge Insight Report

The Future of Jobs

Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution

January 2016

Economists May Be Underestimating How Fast the Robots Are Coming

by **Scott Hamilton**
1 marzo 2017, 13:24 CET

- BOE blog says technological change may be quicker than thought
- Developed economies in danger of not adapting quickly enough

Economists may be underestimating the impact on labor markets of increasing automation and the rise of artificial intelligence, according to a post published on the Bank of England's staff blog on Wednesday.


Charging China, lousy Latam
Manufacturing wages per hour ($), constant prices
2005
2016
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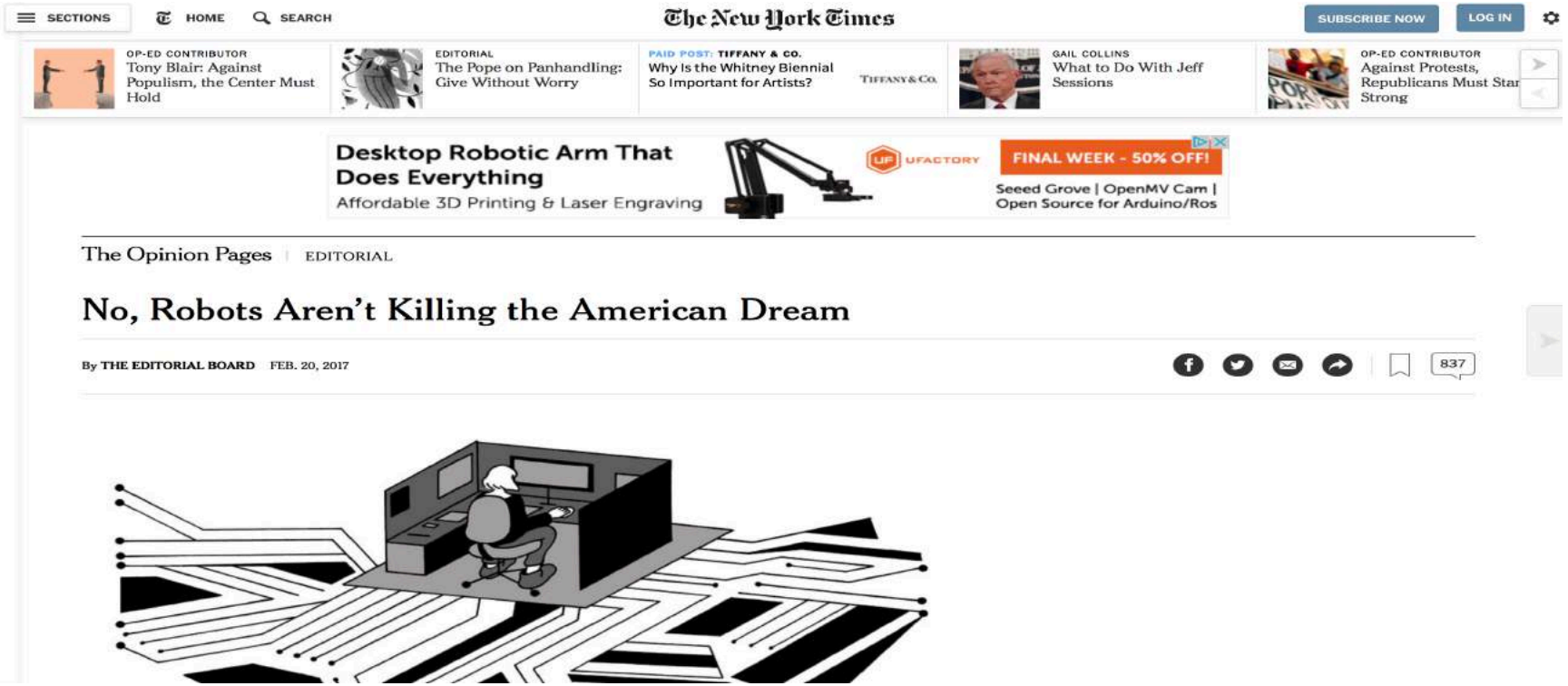
Portugal 6.3
4.5 Portugal
3.6 China
Brazil 2.9
2.7 Brazil
2.5 Argentina
Mexico 2.2
Argentina 2.1
2.1 Mexico
2.0 Thailand
1.7 Colombia
Thailand 1.4
Colombia 1.4
China 1.2
Source: Euromonitor International
FT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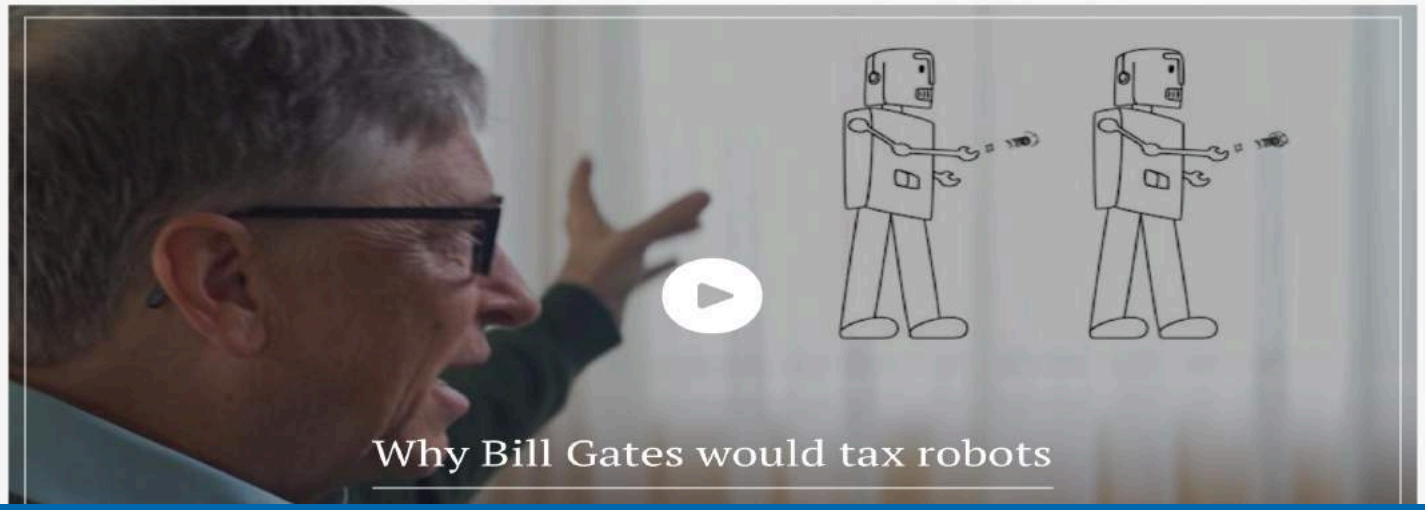
The Opinion Pages | EDITORIAL
No, Robots Aren't Killing the American Dream
By THE EDITORIAL BOARD FEB. 20, 2017
837

DROID DUTIES

The robot that takes your job should pay taxes, says Bill Gates




BUSINESS INSIDER
TECH INSIDER
SAMSUNG
29.03.17
Mark Cuban calls universal basic income 'one of the worst possible responses' to robot automation
Chris Weller
Feb. 22, 2017, 11:49 AM
34,141
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INNOVATION & TECHNOLOGY

YANIS VAROUFAKIS

Yanis Varoufakis, a former finance minister of Greece, is Professor of Economics at th
Athens.

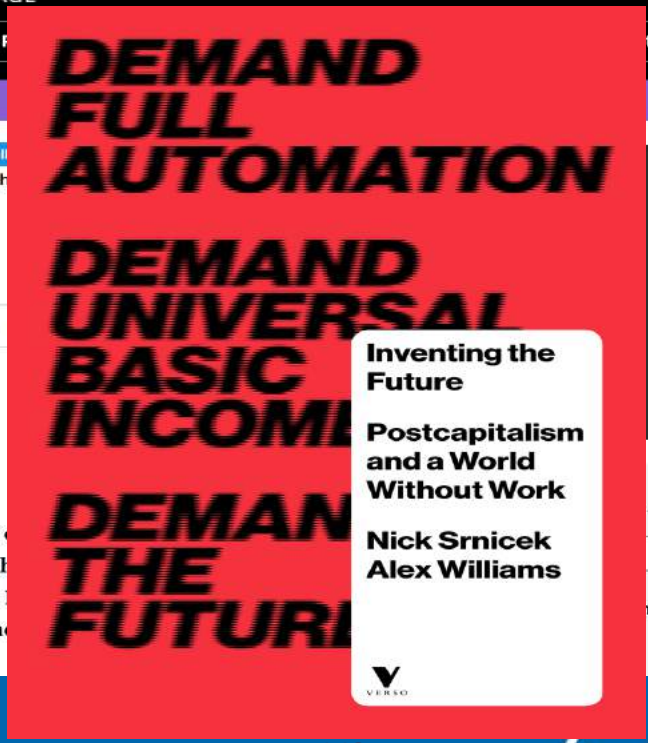
FEB 27, 2017 31

English

A Tax on Robots?

Tweet | Share 1.2K | Share 97 | G+1 14

ATHENS – Ken makes a decent living operating a large harvester on behalf
Luke. Ken's salary generates income tax and social security payments that
government programs for less fortunate members of his community. Alas,
to replace Ken with Nexus, a robot that can operate the harvester longer, m
any weather, and without lunch breaks, holidays, or sick pay.



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United Nations
Department of Economic and Social Affairs

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World population projected to reach 9.7 billion by 2050

29 July 2015, New York

The current world population of 7.3 billion is expected to reach 8.5 billion by 2030, 9.7 billion in 2050 and 11.2 billion in 2100, according to a new UN DESA report, "World Population Prospects: The 2015 Revision", launched today.

"Understanding the demographic changes that are likely to unfold over the coming years, as well as the challenges and opportunities that they present for achieving sustainable development, is key to the design and implementation of the new development agenda," said Wu Hongbo, UN Under-Secretary-General for Economic and Social Affairs.

Most of the projected increase in the world's population can be attributed to a short list of high- mainly in Africa, or countries with already large populations. During 2015-2050, half of the worl growth is expected to be concentrated in nine countries: India, Nigeria, Pakistan, Democratic R Congo, Ethiopia, United Republic of Tanzania, United States of America (USA), Indonesia and according to the size of their contribution to the total growth.

NATIONAL GEOGRAPHIC

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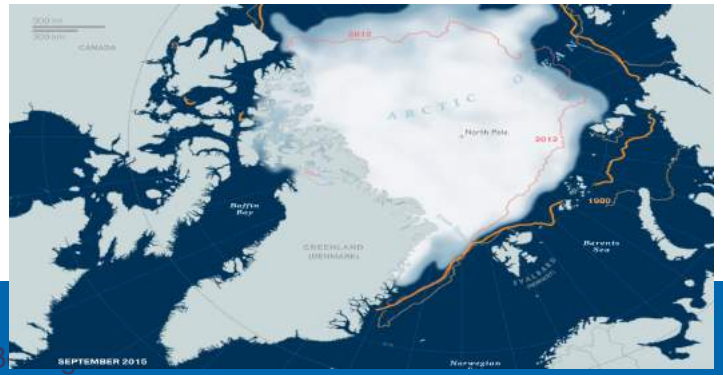
MAGAZINE | JANUARY 2016

See for Yourself: How Arctic Ice Is Disappearing

Since satellites began regularly measuring Arctic sea ice in 1979, it has declined sharply in extent and thickness. Much of the ice that's there in winter is thin stuff that doesn't survive the summer. The loss of ice is affecting the entire Arctic ecosystem, from plankton to polar bears. And some scientists think that, by altering the jet stream, it's affecting weather—and people—around the Northern Hemisphere.

Graphics and maps by **Lauren James, Jason Treat, Ryan Williams, Chiqui Esteban,** and **Chris Combs**

PUBLISHED DECEMBER 14, 2015

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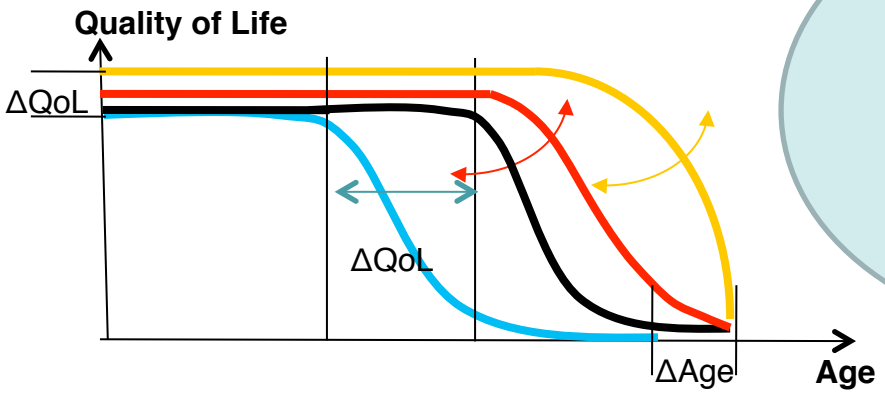
africa middle east cities development europe US americas asia
Sydney
Dispatch
Australia's new normal ... as city temperatures hit 47C people shelter from the deadly heat
In Sydney's baking suburbs, fans have sold out – and fears about the effects of climate change are mounting

Uncoped issues:
The new Needs of ageing societies



Without devices and services

Effects of prevention

Effects of support and compensation

Effects of indipendent and active ageing

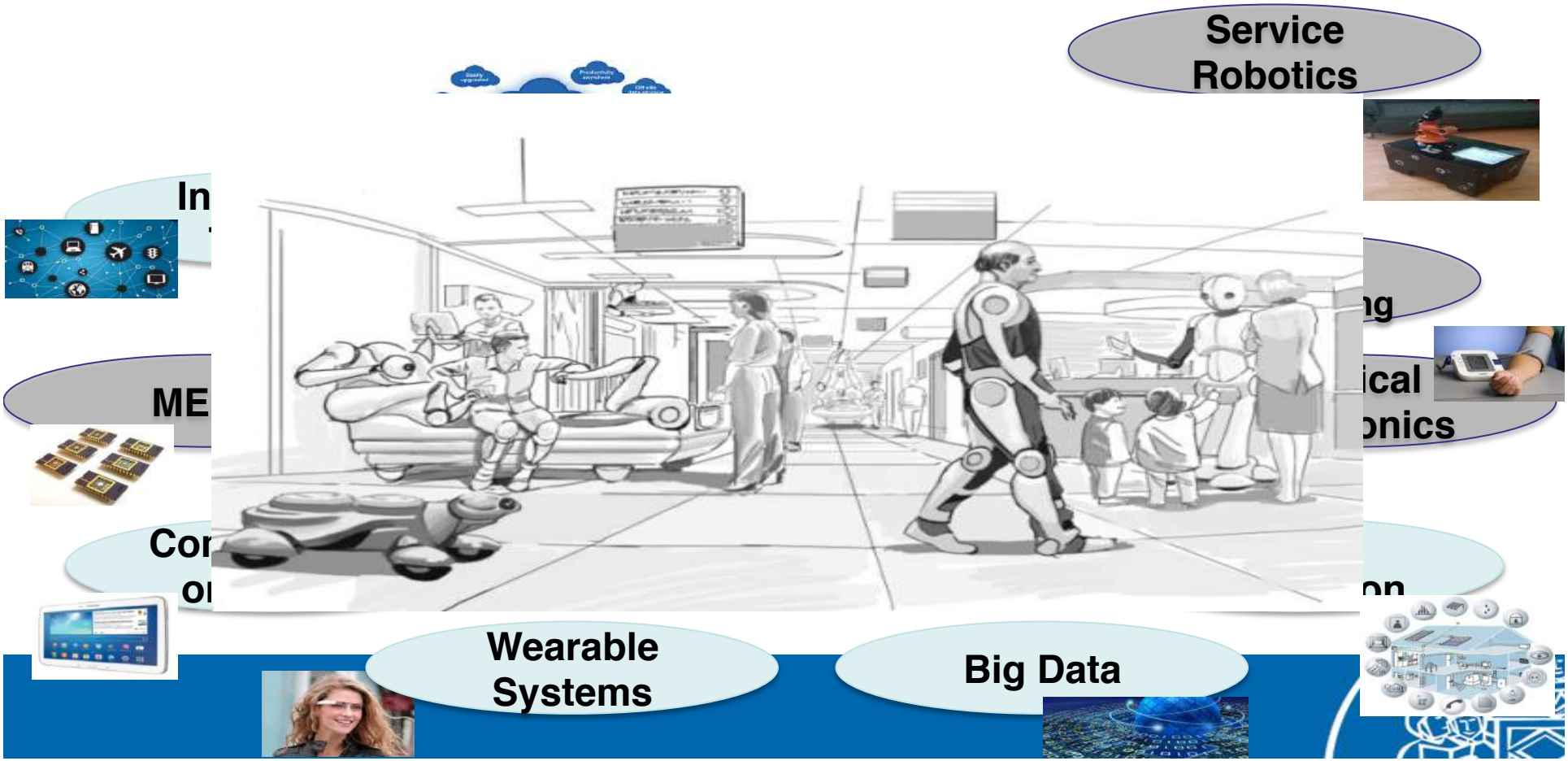
PREVENTION
Supporting and maintaining cognitive and motor abilities before severe diseases

COMPENSATION & SUPPORT
Supporting cognitive and motor abilities after severe diseases

INDEPENDENT & ACTIVE AGEING
Supporting independence of elderly

Some outcomes from AAL2 and RobotEra Projects, Paolo Dario coordinated RobotEra. Filippo Cavallo (also from our group) was the pm.

How can STI (Science, Technology and Innovation) contribute to the new needs of ageing societies?



Legal and Insurance issues

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 asses the convivence of humans and intelligent robots and systems

- **DATA, DATA, DATA!!!**

A glimpse to the future

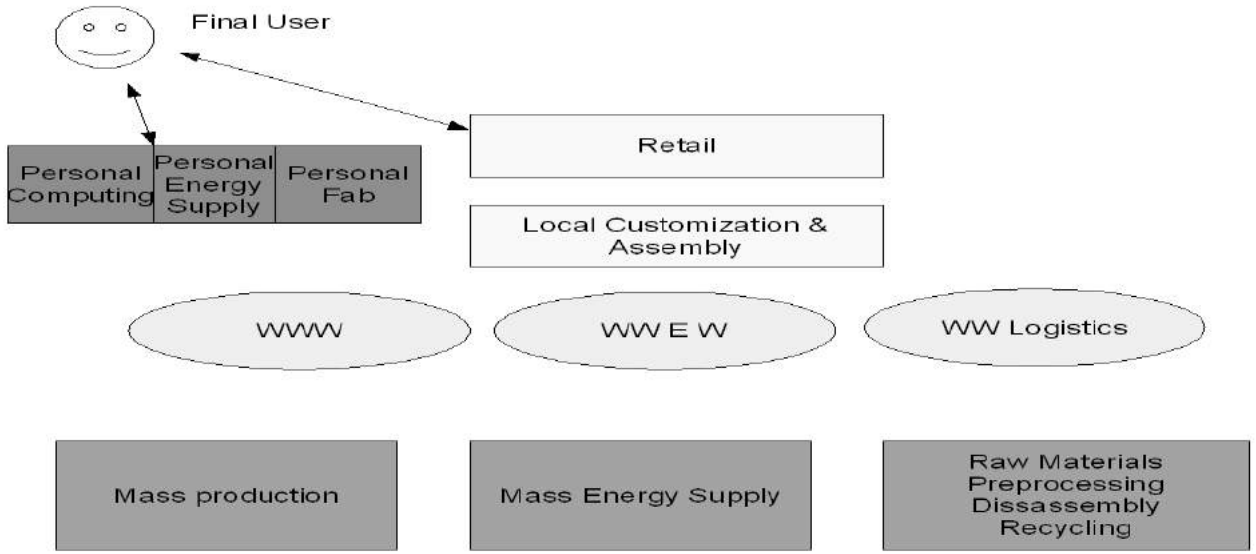
In a 5-15 year perspective a radical *paradigm change* in the full cycle of consumer service-products from raw materials to disposal will likely become mature.

- continuous progress in the price/performance ratio of computing equipment (see R. Kurzweil, 'The singularity is near') and new paradigm computing (neuromorphic, quantum…)
- transition from a 'browsing' internet to internet computing,
- continuous reduction in the cost of manufacturing – towards personal fabrication
- expected progress in cognition sciences, robotics and AI
- the emergence of *bio-automation*

Swarm intelligence eco/bio inspired systems should connect the consumers to the intelligent service agents in the physical and cyber world negotiating between demand and supply and *continuosly adaptively managing* the available resources (material, energy) , *cognitive physical agents* (from mining to manufacturing to distribution to disposal), intelligent autonomous design/supply management sytems, etc. to meet users needs.

A totally new sustainable ecology of service/products might emerge.

A concept picture of the envisioned manufacturing and supply system



Towards a 'new' industry?

The achievements in the theory and practice of autonomous intelligent physical agents already obtained, and those expected by the *third wave*, make possible a complete redesign of the manufacturing technologies and a drastical improvement of production practice and economics.

Are we close to yet another industrial revolution?

Far beyond what it is called Industry 4.0?

Outline of the talk

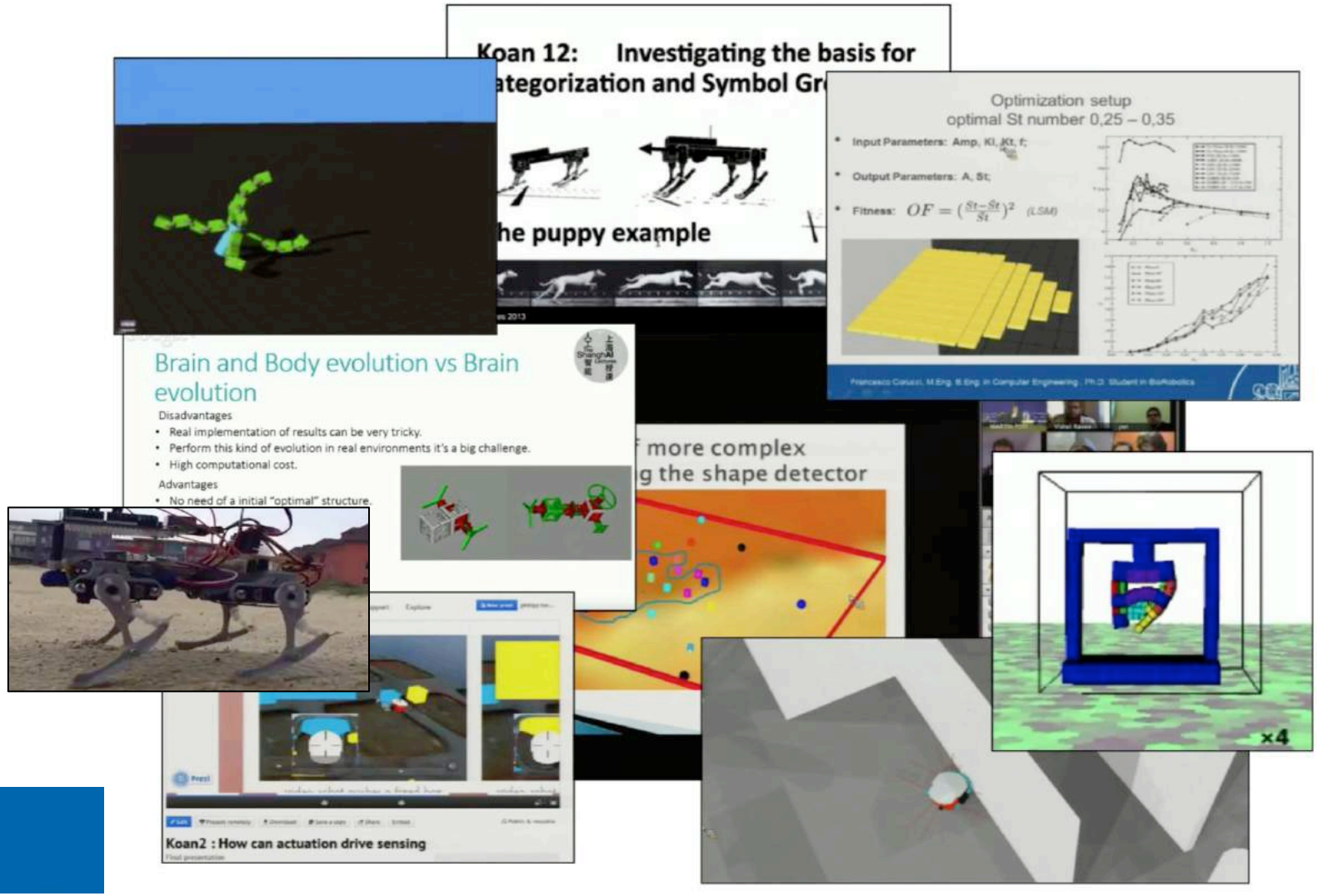
- Robotics ‘waves’
- Industry 4.0
- I4.0 impact on the Circular Economy
- Another I4.0 side effect: impact on Construction Industry
- Open issues with current ‘paradigms’ and approaches, and the road ahead
- Societal impacts
- Last but not least: the Koans!

Group Project Kōans

ShanghAI Lectures 2017

"A **Kōan** (公案) … is a story, dialogue, question, or statement, which is used in Zen-practice to provoke the 'great doubt', and test a student's progress in Zen practice."

Wikipedia


Koan 12: Investigating the basis for
ategorization and Symbol Gr
he puppy example
Optimization setup
optimal St number 0,25 – 0,35
Input Parameters: Amp, Kl, f(t, f;
Output Parameters: A, St;
Fitness: $OF = (\frac{St-St}{St})^2$ (LSM)
Brain and Body evolution vs Brain evolution
Disadvantages
Real implementation of results can be very tricky.
Perform this kind of evolution in real environments it's a big challenge.
High computational cost.
Advantages
No need of a initial "optimal" structure.
more complex
g the shape detector
Koan2 : How can actuation drive sensing
×4

Group allocation

- Assigned according to kōan preference
  - Max 5 students per group
  - We aim to make groups as international as possible
- We encourage HW solutions (e.g. 3D printing)
  - Local core of students ok for local HW (contact us)
  - But must remain open to students from other sites
- **Thinking outside of the box required!**
  - **No single “correct” answer to any of the Kōans**

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Students' TODOs

1. Read through details of the different kōans
   - This presentation will be available from website (kōans tab)
   - A living document, may be updated as we go along

2. Register for participation in the kōans by **December 26 23:59 CET**
   - Through (from this Saturday) the website or just drop an email by December 26 at the latest
   - Indicate your preferred ones (3 in order of preference)
   - You will be assigned group and tutor

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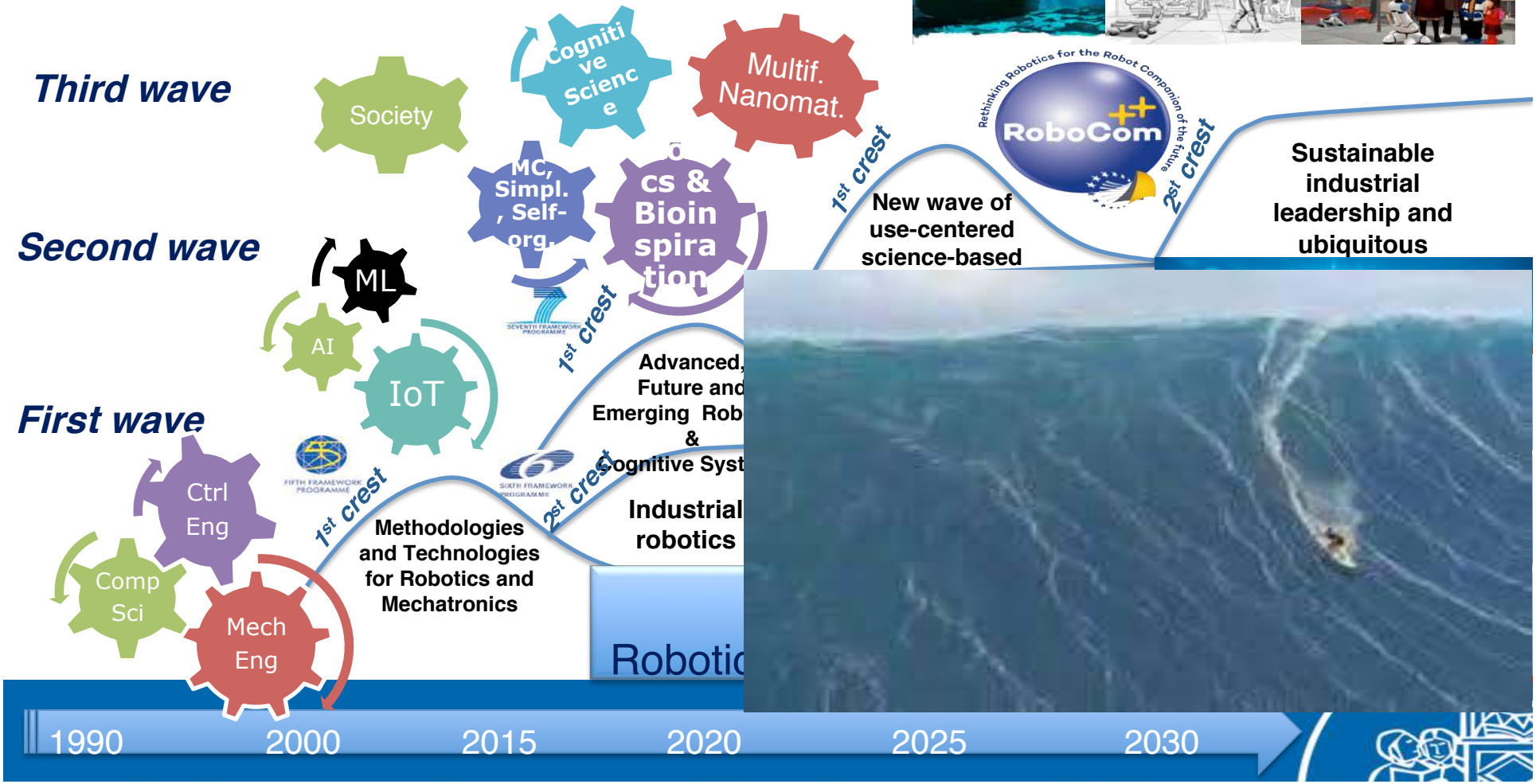
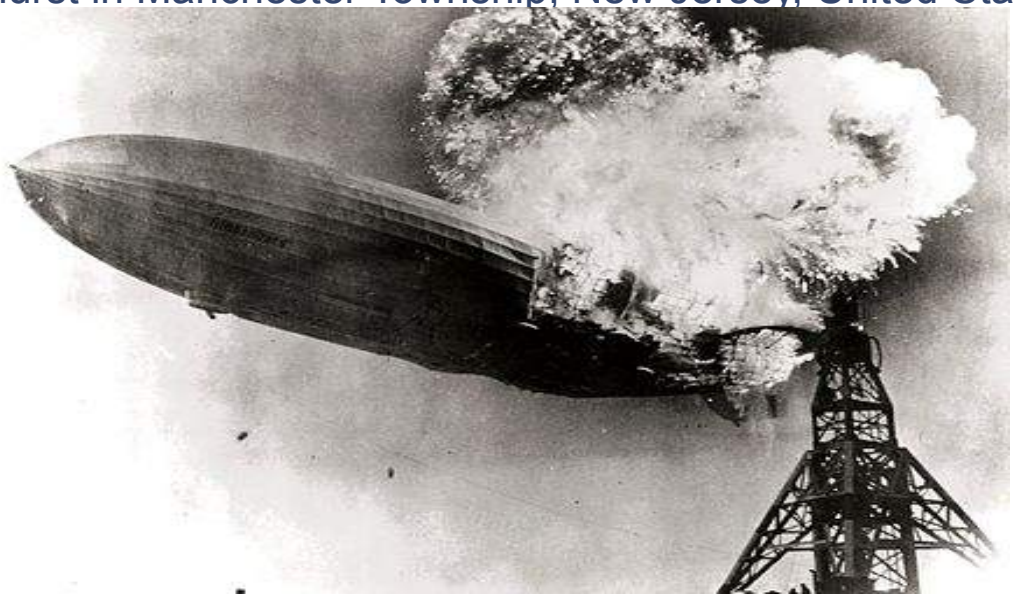
Let's surf the third wave!



The fears…

May 6, 1937
Naval Air Station Lakehurst in Manchester Township, New Jersey, United States



and the promise of robotics….

Human centered design Science, Technology, Innovation for a Global Renaissance

Thank you!