Electrical, Computer, Software, and Bio-Inspired Engineering

- a historical perspective -

Emil M. Petriu,
School of Electrical Engineering and Computer Science
University of Ottawa

Engineering Design

“Engineering design integrates mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and open-ended process, subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, environmental, societal or other interdisciplinary factors.

[CEAB – Accreditation Criteria and Procedures, sections 3.4.4.3 and 3.4.4.4]

Time Science

➢ Antiquity

- **Mathematics,**
- **Philosophy**

True Mathematical Table Surviving from Old Babylonian Mathematics ; circa 1,822 BCE – 1,784 BCE

Euclid's of Alexandria (approx. 300 BCE), *Elements,* a logic and coherent framework, including rigorous mathematical proofs.

Value	0	1	2	3	4	5	6	7	8	9
Western Arabic	٠	١	٢	٣	٤	٥	٦	٧	٨	٩
Eastern Arabic	٠	١	٢	٣	۴	۵	۶	۷	۸	۹
Devanagari	०	१	२	३	४	५	६	७	८	९
Gujarati	૦	૧	૨	૩	૪	૫	૬	૭	૮	૯
Gurmukhi	੦	੧	੨	੩	੪	੫	੬	੭	੮	੯
Limbu	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bengali	০	১	২	৩	৪	৫	৬	৭	৮	৯
Oriya	୦	୧	୨	୩	୪	୫	୬	୭	୮	୯
Telugu	౦	౧	౨	౩	౪	౫	౬	౭	౮	౯
Kannada	೦	೧	೨	೩	೪	೫	೬	೭	೮	೯
Malayalam	൦	൧	൨	൩	൪	൫	൬	൭	൮	൯
Tamil (Grantha)	௦	க	உ	ங	ச	ஞ	கூ	எ	அ	க
Tibetan	๐	๑	๒	๓	๔	๕	๖	๗	๘	๙
Burmese	၀	၁	၂	၃	၄	၅	၆	၇	၈	၉
Thai	๐	๑	๒	๓	๔	๕	๖	๗	๘	๙
Khmer	០	១	២	៣	៤	៥	៦	៧	៨	៩
Lao	๐	๑	๒	๓	๔	๕	๖	๗	๘	๙

Hindu-Arabic numeral system. The inscriptions on the edicts of Ashoka (1st mill. BCE) display this number system used by the Imperial Mauryas.

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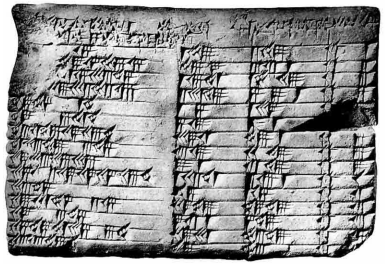
Time Science Production of Goods and Services

➢ Antiquity

- **Mathematics,**
- **Philosophy**

➢ ***Craftsmanship***:
* *Artisans*
* *Guilds*



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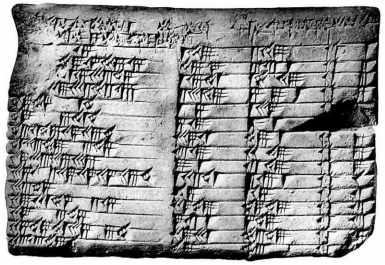
Time | Science | Production of Goods and Services | *Engineering*

➢ Antiquity

- **Mathematics,**
- **Philosophy**

➢ ***Craftsmanship**:*
** Artisans*
** Guilds*



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Hindu-Arabic numeral system. The inscriptions on the edicts of Ashoka (1st mill. BCE) display this number system used by the Imperial Mauryas.

Pyramid of Giza / **Pyramid of Khufu** 2589–2566 BCE

South Pointing Chariot one of the most complex geared Mechanisms, approx 2600 BCE, during the reign of mythical Yellow Emperor of China

The Four Great Inventions of ancient China are the Compass, Gunpowder, Papermaking, Printing.

Roman aqueduct - approx 19 BCE. Pont du Gard, France,

© *Emil M. Petriu*

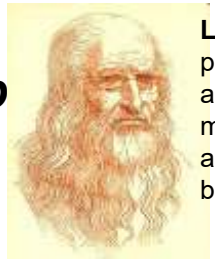
Time | Science | **Production of Goods and Services** | **Engineering**

Antiquity

XV Century

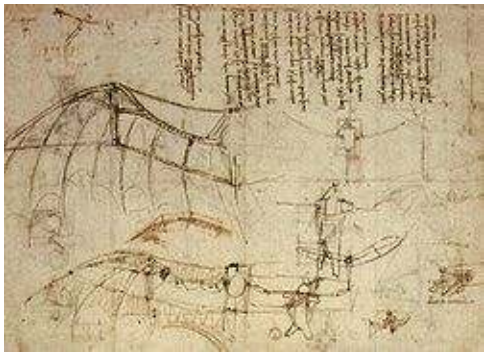
- **Mathematics,**
- **Philosophy**

➢ ***Craftsmanship***
* *Artisans*
* *Guilds*

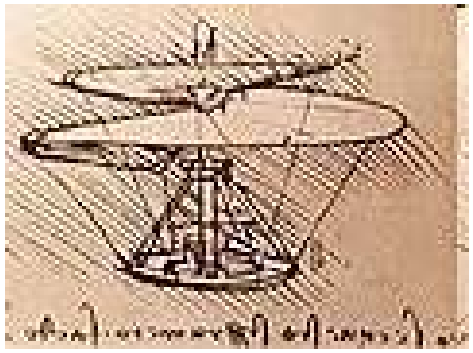


Leonardo da Vinci (1452 –1519), polymath: painter, sculptor, architect, musician, scientist, mathematician,engineer, inventor, anatomist,geologist, cartographer, botanist and writer..

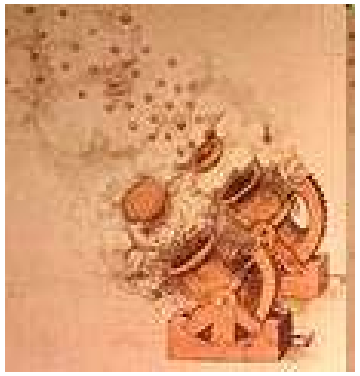
❑ ***Military Eng..***



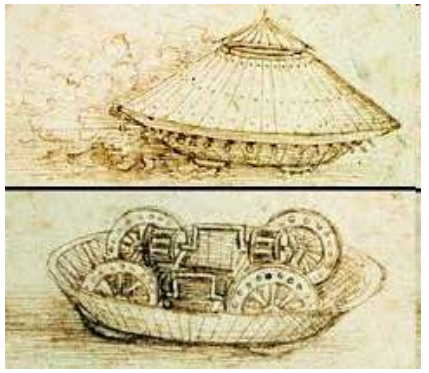
Design for a flying machine with wings based upon a bat's wings model.



"Aerial Screw", an early helicopter.



Cannons



Tank

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Time	Science	Production of Goods and Services	Engineering

- Antiquity
- *XV* Century
- *XVIII* Century
- *XIX* Century

- **Mathematics,**
- **Philosophy**
- **Chemistry,**
- **Physics**
- **Biology,**

➢ ***Craftsmanship***:
* *Artisans*
* *Guilds*

Industrial Revolution: mechanization of industry; late 1800s - early 1900s

➢ **Industry**:
- Engineers/ Product Develop.
- Capitalists
- Workers

❑ ***Military Eng***..

❑ Civil Eng..

❑ Mechanical Eng..

❑ Chemical Eng..

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Time	Science	Production of Goods and Services	Engineering

- Antiquity
- *XV* Century
- *XVIII* Century
- *XIX* Century
- XX Century

- **Mathematics,**
- **Philosophy**
- **Chemistry,**
- **Physics**
- **Biology,**

- ***Craftsmanship***:
  - * *Artisans*
  - * *Guilds*

Industrial Revolution: mechanization of industry; late 1800s - early 1900s

- **Industry**:
  - Engineers/ Product Develop.
  - Capitalists
  - Workers
  - ***Entrepreneurs***

1946 …

- ***Military Eng.***.
- Civil Eng..
- Mechanical Eng..
- Chemical Eng..
- **Electrical Eng.**.

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Time	Science	Production of Goods and Services	Engineering

- Antiquity
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- *XVIII* Century
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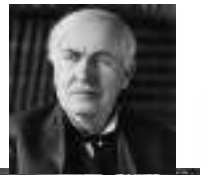

- ***Craftsmanship***:
  - * *Artisans*
  - * *Guilds*

Industrial Revolution: mechanization of industry; late 1800s - early 1900s

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  - Workers
  - ***Entrepreneurs***

1946 …

1972 …

- ***Military Eng.***.
- Civil Eng..
- Mechanical Eng..
- Chemical Eng..
- **Electrical Eng.**.

CEG

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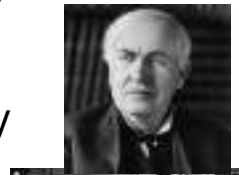
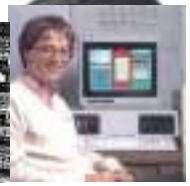
Time	Science	Production of Goods and Services	Engineering

- Antiquity
- *XV* Century
- *XVIII* Century
- *XIX* Century
- XX Century

- **Mathematics,**
- **Philosophy**
- **Chemistry,**
- **Physics**
- **Biology,**



- ***Craftsmanship***:
  - * *Artisans*
  - * *Guilds*

Industrial Revolution: mechanization of industry; late 1800s - early 1900s

- **Industry**:
  - Engineers/ Product Develop.
  - Capitalists
  - Workers
  - ***Entrepreneurs***


1946 …


1972 …

- ***Military Eng.***.
- Civil Eng..
- Mechanical Eng..
- Chemical Eng..
- **Electrical Eng.**.

CEG, SEG

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Time	Science	Production of Goods and Services	Engineering

- Antiquity
- *XV* Century
- *XVIII* Century
- *XIX* Century

- **Mathematics,**
- **Philosophy**
- **Chemistry,**
- **Physics**
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- ***Craftsmanship***:
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1946 …

1972 …

- ***Military Eng.***.
- Civil Eng..
- Mechanical Eng..
- Chemical Eng..
- **Electrical Eng.**.

CEG, SEG

AI, NanoTech, BioTech. BioInsp, NeuroScienceTech.

- ***XXI Century***

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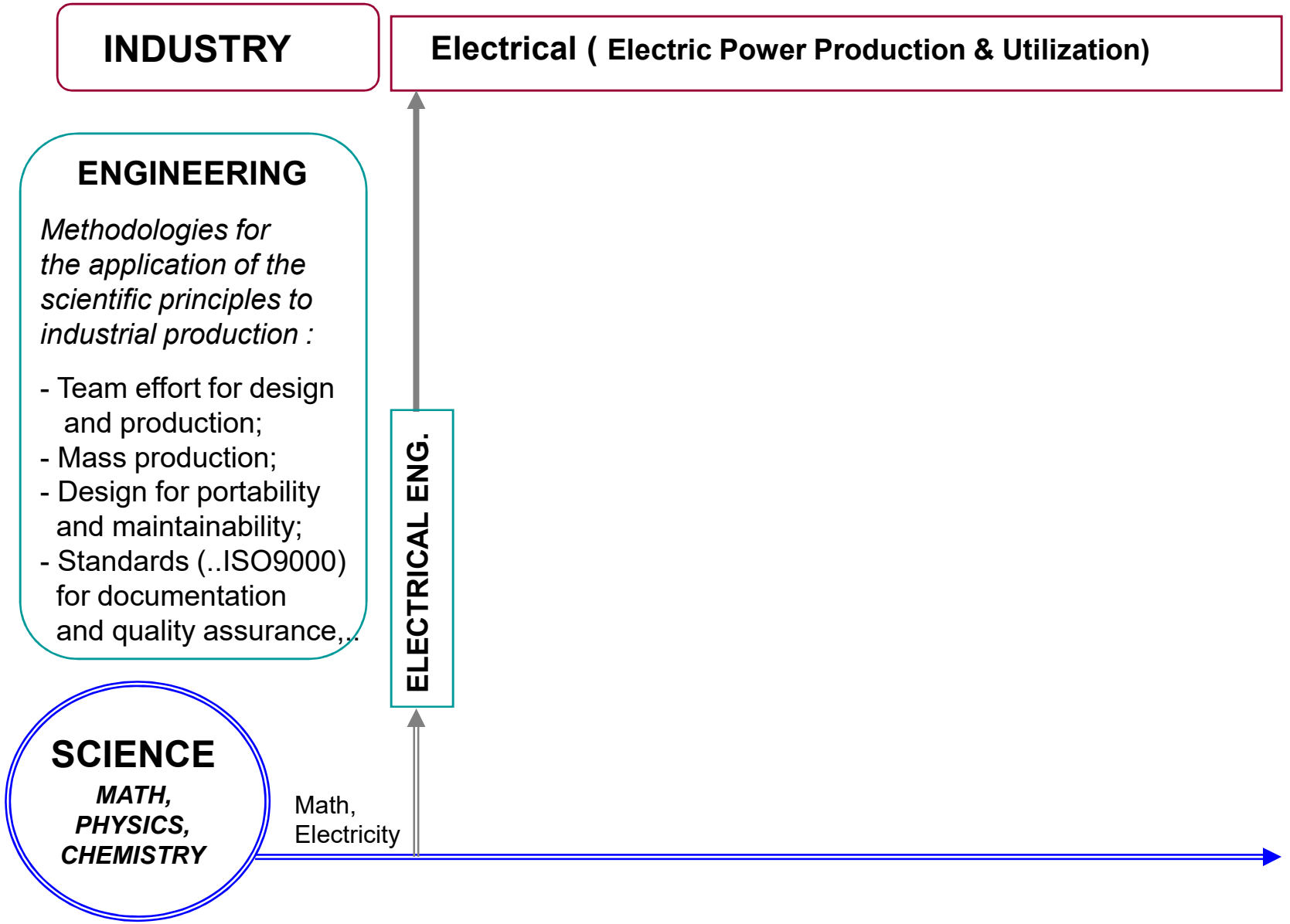

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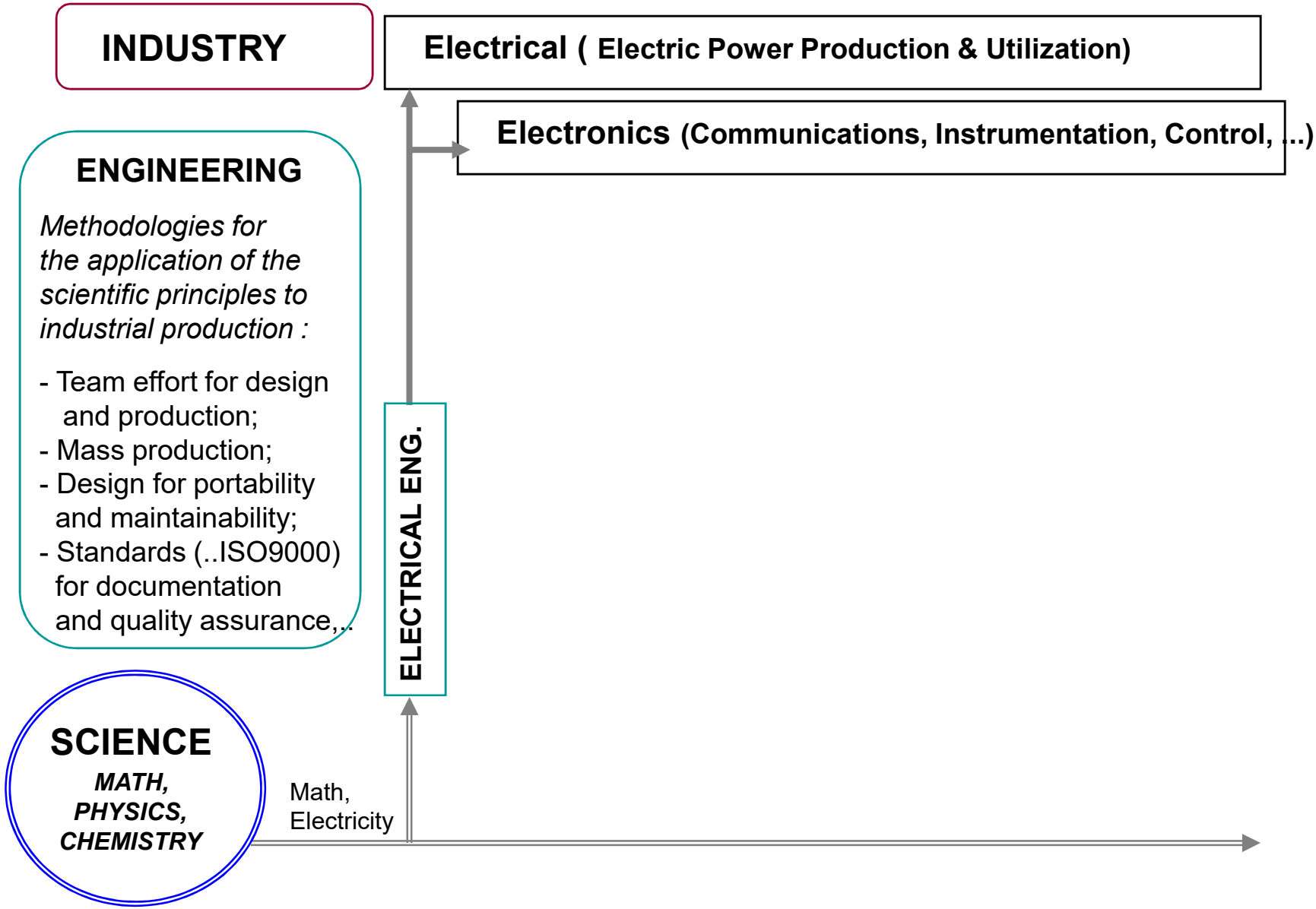

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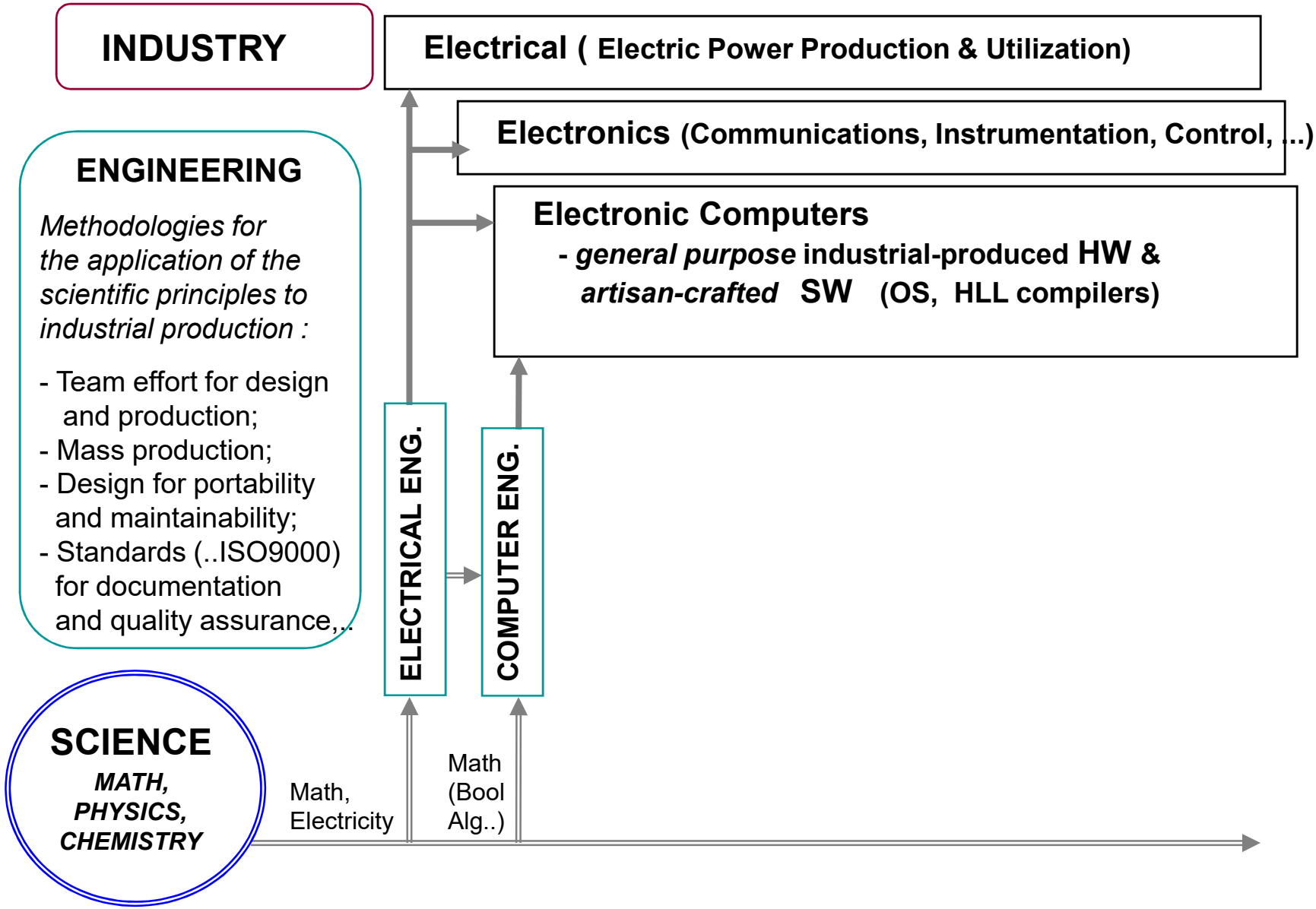

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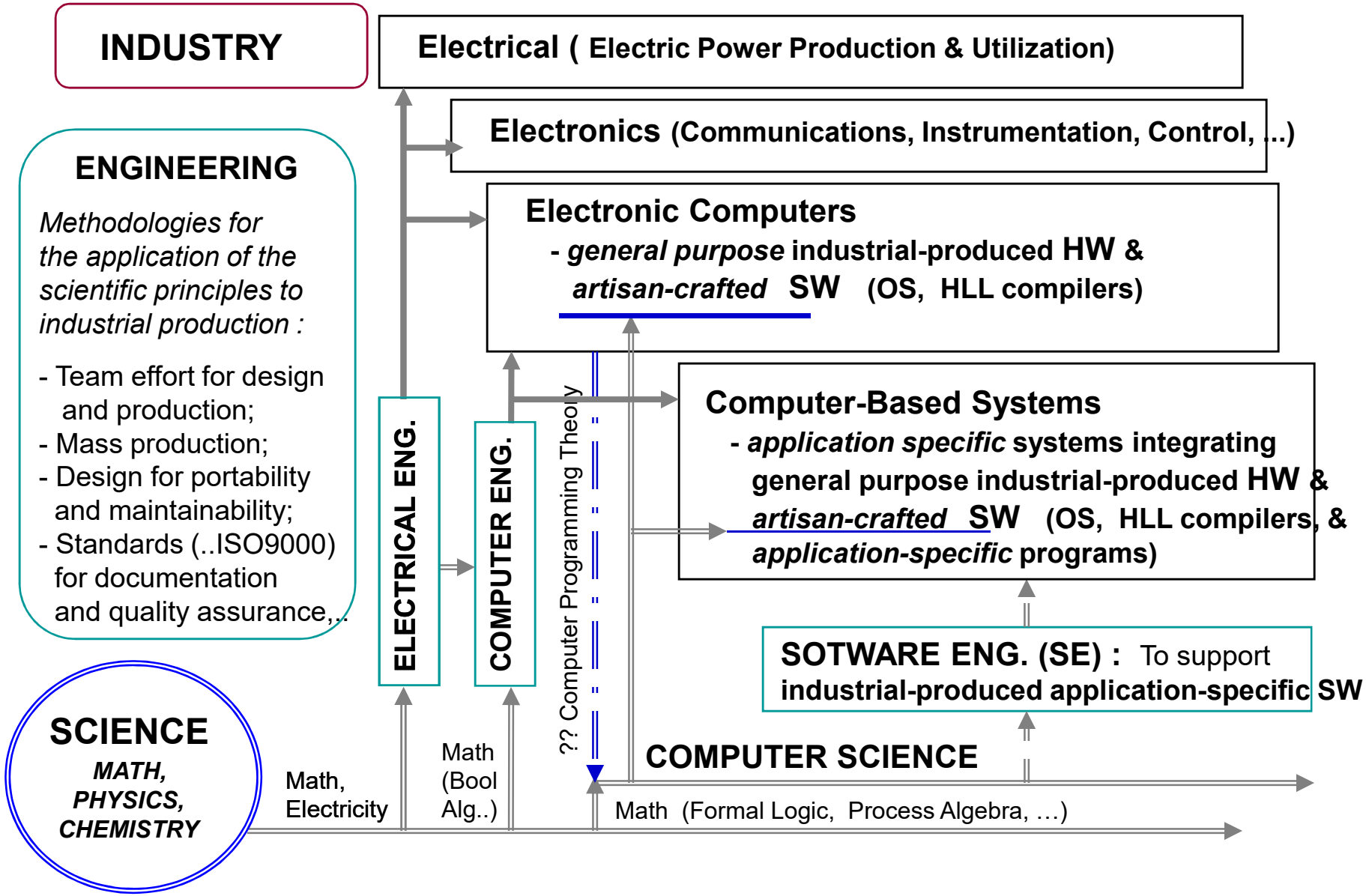

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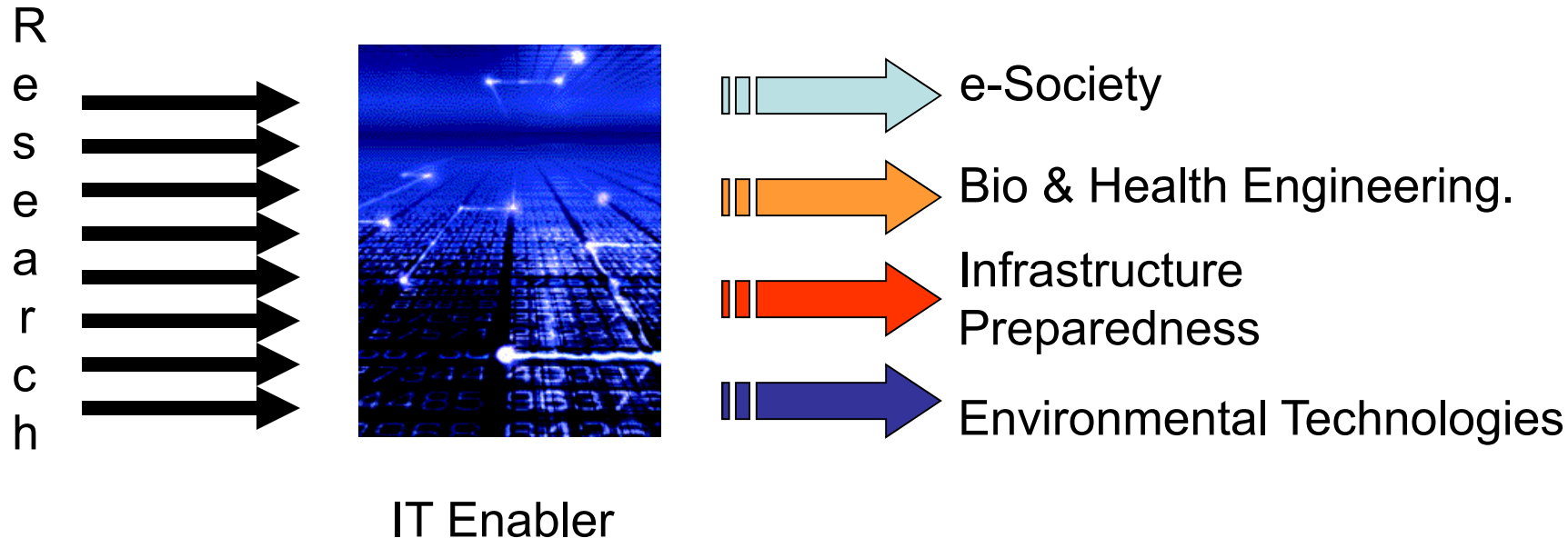
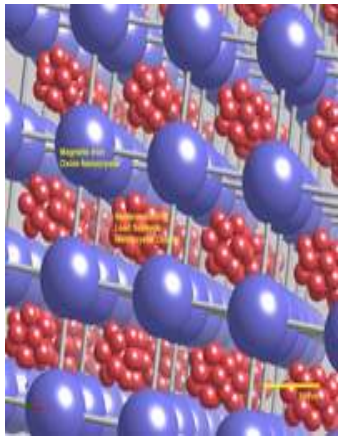
IT as an Enabler



Environmental Technologies

Environmental Technologies



Advanced Materials

Infrastructure Preparedness

Robotics
and
Automation

Mobile and
Sensor
Networks

Infrastructure
Protection and
Emergency
Preparedness

Bio and Health Engineering

IT in Health

Biomedical Engineering

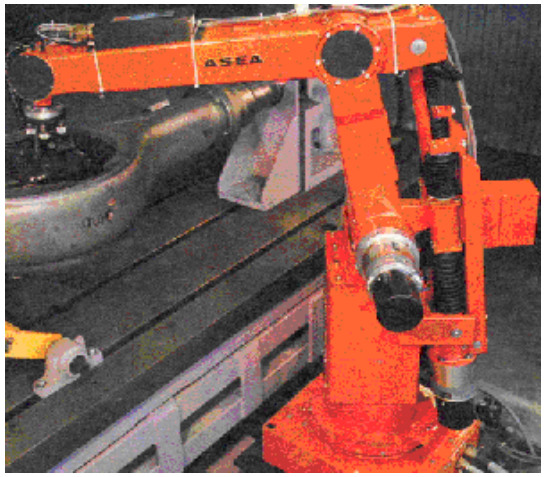
e-Society

Telecom Systems And Networks

Wireless Technologies

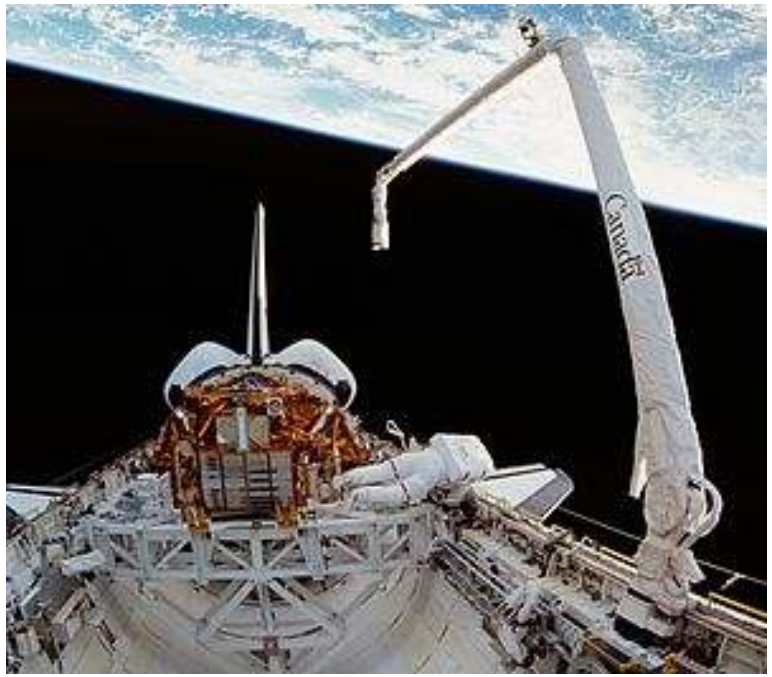
Information Security and Privacy

Multimedia, Virtual Environments and Haptics



ASEA robot performing mechanical assembly tasks.

Canadian Space Agency:
In 1981, Canada confirmed its position as a world leader in space technology with the development of **Canadarm**. the Remote Manipulator System, which can be used: to deploy and retrieve satellites, to hold targets, to explore samples, and to manipulate hardware for the Space Shuttle.
In 1988, Canada joined the international partners to build a permanently inhabited Space Station. Canada's contribution is to design, manufacture, and operate the robotic **Mobile Servicing System** for assembly, maintenance, and servicing tasks on the Space Station.



Vision-Based Sensing and Control for Space Robotics Applications

Michael E. Stieber, *Member, IEEE*, Michael McKay, George Vukovich, *Member, IEEE*, and Emil Petriu, *Senior Member, IEEE*

***Abstract*—The following problems arise in the precise positioning of payloads by space manipulators:**

1) **the precise measurement of the relative position and motion of objects in the workspace of the robot;**
2) **the design of a control system, which is robust and performs well in spite of the effects of structural flexibility and oscillations typically associated with space robots.**

This paper discusses the solution to the measurement problem by a vision system using photogrammatic image processing to determine the motion of objects in real time. Performance characteristics are presented. The control problem is addressed by a new technique dealing effectively with the challenge posed by the noncollocated sensor/actuator configuration on the flexible robot structure. The laboratory implementation of the measurement and control concepts is discussed. Preliminary results validate the concepts.

***Index Terms*— Artificial vision, control, measurement of motion, photogrammetry, robotics.**

I. Introduction

ROBOTIC systems will play an important role in reducing hazards and increasing productivity of humans in space. A prime example is the Mobile Servicing System (MSS) shown in Fig. 1 which is presently being developed by the Canadian Space Agency for the assembly and external maintenance of the International Space Station (ISS) [1]. As the tasks performed by space robots become more complex, the need for more human-like characteristics emerges. As with humans, the sense of sight is essential to enabling efficient interaction with the environment. More important than the sense of sight per se is the ability to process images in such a way as to enable more efficient, accurate and autonomous control of the robot.

This paper addresses measurement and control problems associated with the precise positioning of large space robot manipulators like the Space Station Remote Manipulator System (SSRMS) shown in Fig. 1, which typically have a very high payload-to-manipulator mass ratio (e.g. 116 000 kg/1500 kg for SSRMS) and relatively low stiffness, resulting in highly time-variant dynamic behavior with significant low-frequency oscillations. A theoretical concept for the systematic design of an instrumentation architecture for such systems was presented in [2]. This paper discusses the experimental implementation and evaluation of this concept in a laboratory setting. Section II discusses the measurement of the manipulator payload motion, including the contributions due to structural flexibility, relative to other objects in the manipulator workspace using a vision system. In Section III we extend the theoretical concept of [2] to the case of partially noncollocated sensor/actuator configurations on flexible structures and discuss the design and performance of a control system for the laboratory robot.

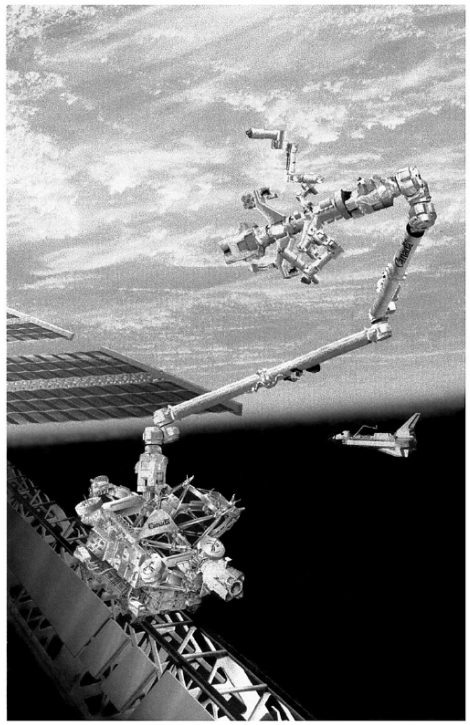


Fig. 1. Mobile Servicing System on the International Space Station.

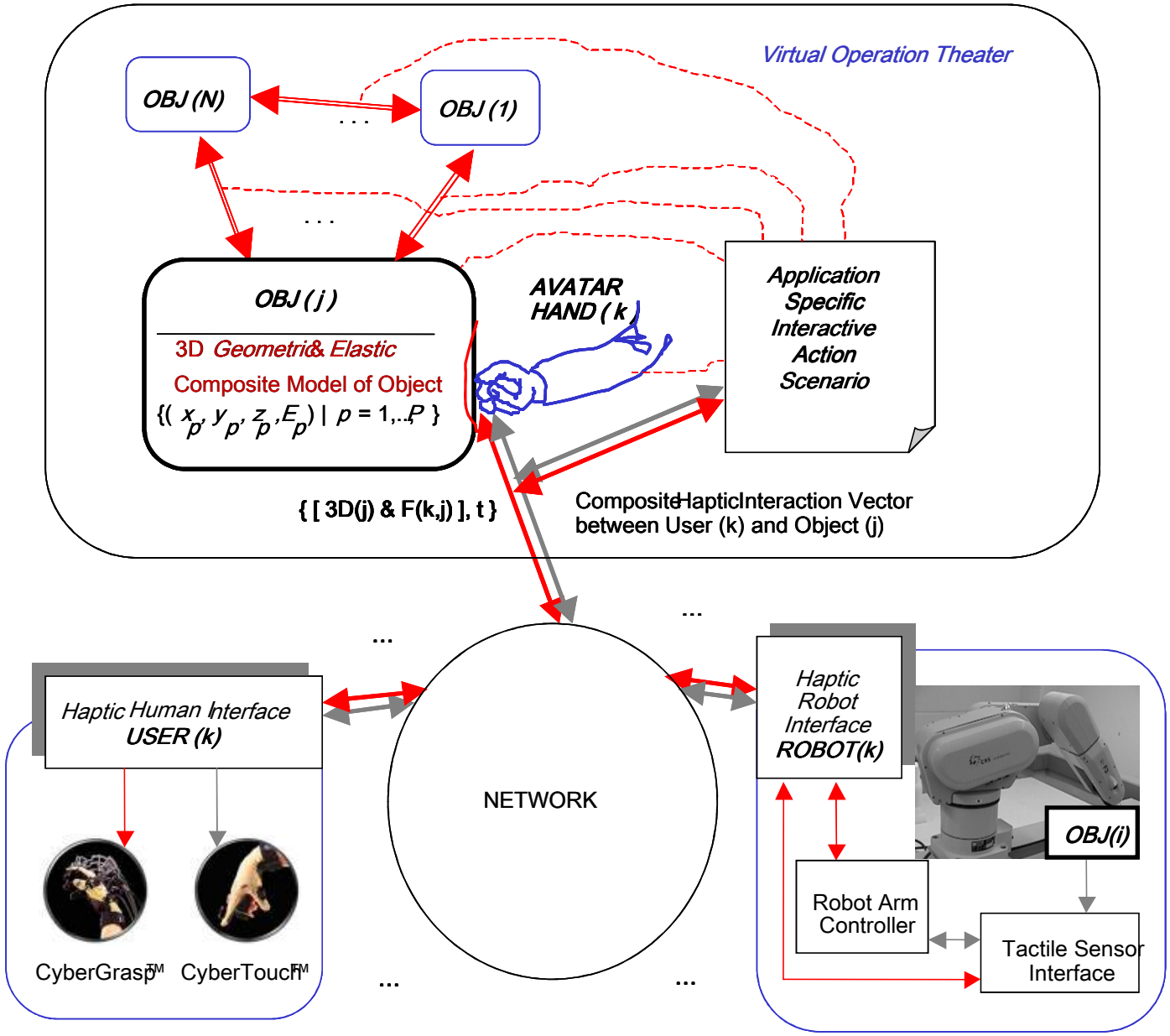
Manuscript received May 23, 1996; revised April 12, 1999.

M. E. Stieber and G. Vukovich are with the Canadian Space Agency, St. Hubert, P.Q., Canada.

M. McKay is with the Department of National Defense, Ottawa, Ont., Canada.

E. Petriu is with the University of Ottawa, Ottawa, Ont., K1N 6N5, Canada.

Publisher Item Identifier S 0018-9456(99)06676-0.



Interactive Model-Based Hapto-Visual Teleoperation - a human operator equipped with haptic HCI can telemanipulate physical objects with the help of a robotic equipped with haptic sensors.

Da Vinci Surgical System is a robotic surgical system made by the American company Intuitive Surgical. Approved by the Food and Drug Administration (FDA) in 2000, it is designed to facilitate complex surgery using a minimally invasive approach, and is controlled by a surgeon from a console.

Da Vinci System allows the surgeon's hand movements to be translated into smaller, precise movements of tiny instruments inside the patient's body.

As of June 30, 2014, there were installed 3,102 units worldwide. …. an estimated 200,000 surgeries conducted in 2012

Evolution of Car Technologies

…

Ford T : **[engine & wheels]** + [hand cranked to start, brut_force_steering & breaks, manual horn, manual gear_box] + **[human _diver]**

[engine & wheels] + [starter, electronic_ignition, power_assited steering & breaks, automatic_gear_box] + **[human _diver]**

[engine & wheels] = [starter, electronic_ignition, power_assited_steering&breaks, automatic_gear_box, automatic_breaks, cruise_control, rear_cameras, collisin_ avoidance_sensors, GPS] = **[human _diver]**

Autonomous car : **[engine & wheels]** + [starter, electronic ignition, power assisted steering & breaks, automatic gear box, automatic breaks, cruise control, all around cameras, collision avoidance_sensors, GPS] + **[robotic_driver]**

…

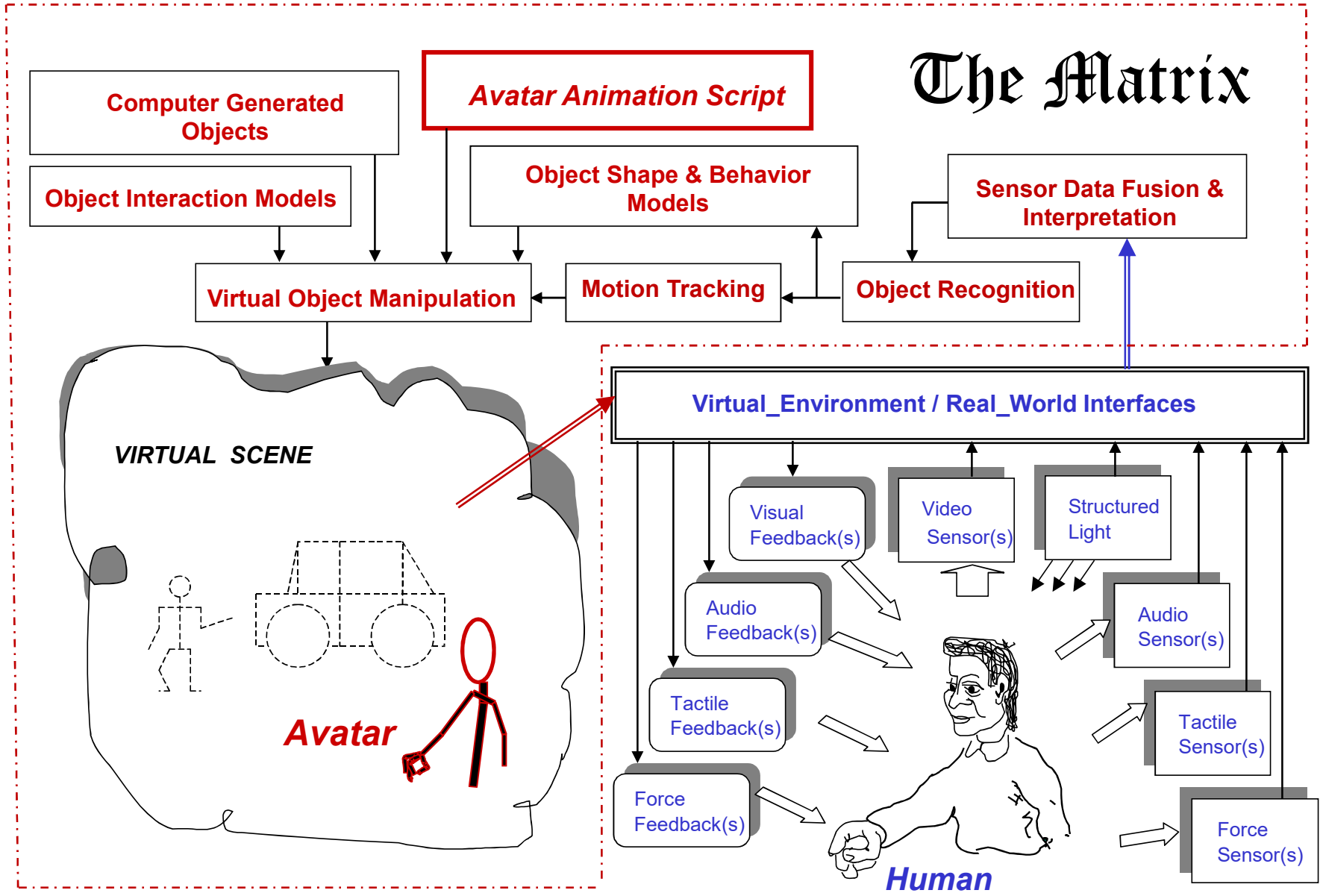
“Robots to affect up to 30% of UK jobs, says PwC”
(BBC, 24 March 2017)
http://www.bbc.com/news/business-39377353

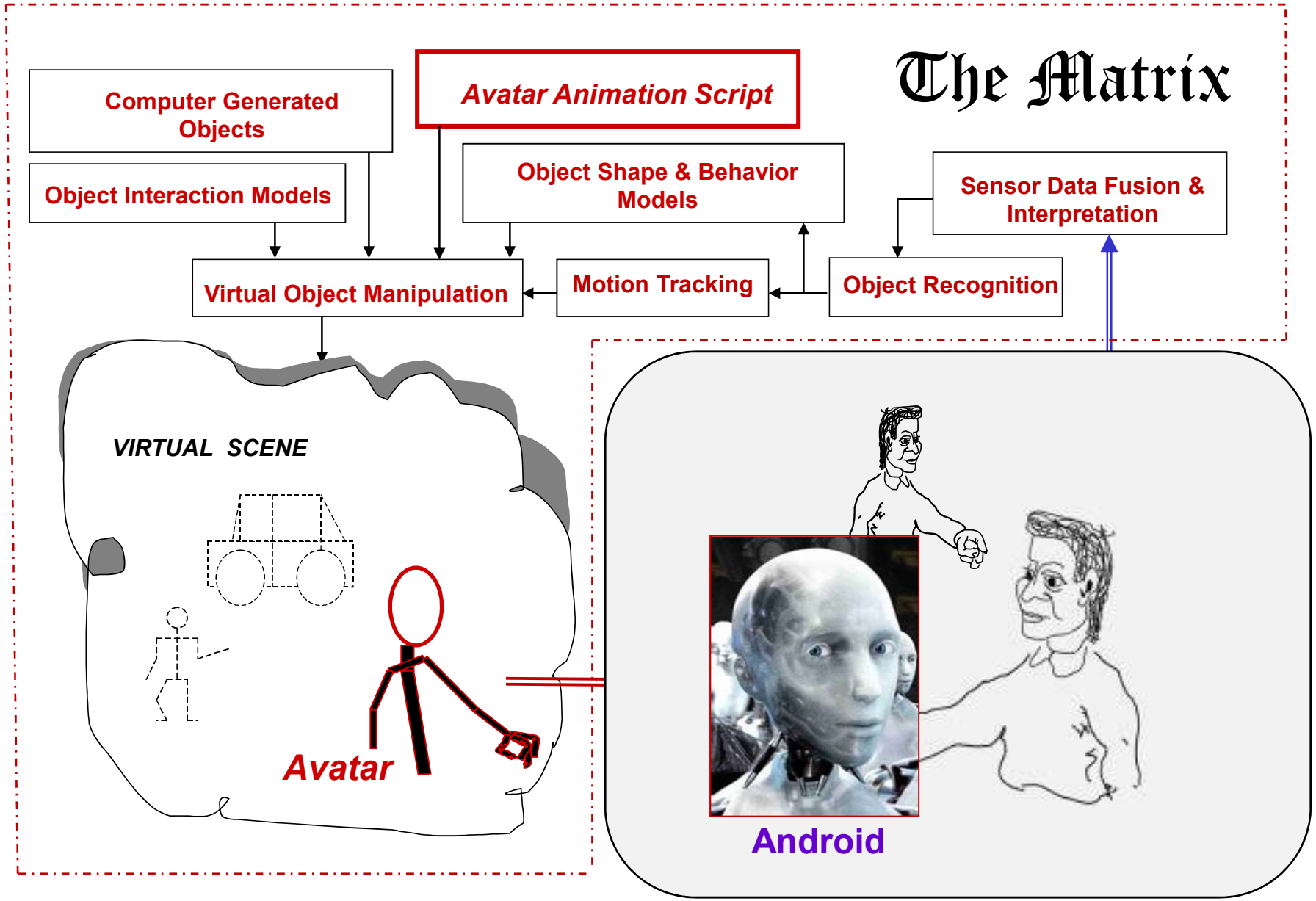
- Transportation and storage - 56% of jobs at high risk from automation
- Manufacturing - 46%
- Wholesale and retail trade - 44%
- Administrative and support services - 37%
- Financial and insurance - 32%
- Professional, scientific and technical - 26%
- Construction - 24%
- Arts and entertainment - 22%
- Agriculture, forestry and fishing - 19%
- **Human health and social work - 17%**
- Education - 9%

Bio-Inspired Engineering

For many centuries, engineers were building upon **mathematics** and **natural science principles from mechanics, electricity, and chemistry** in order to develop an ever growing variety of more efficient and smarter industrial artefacts and machines.

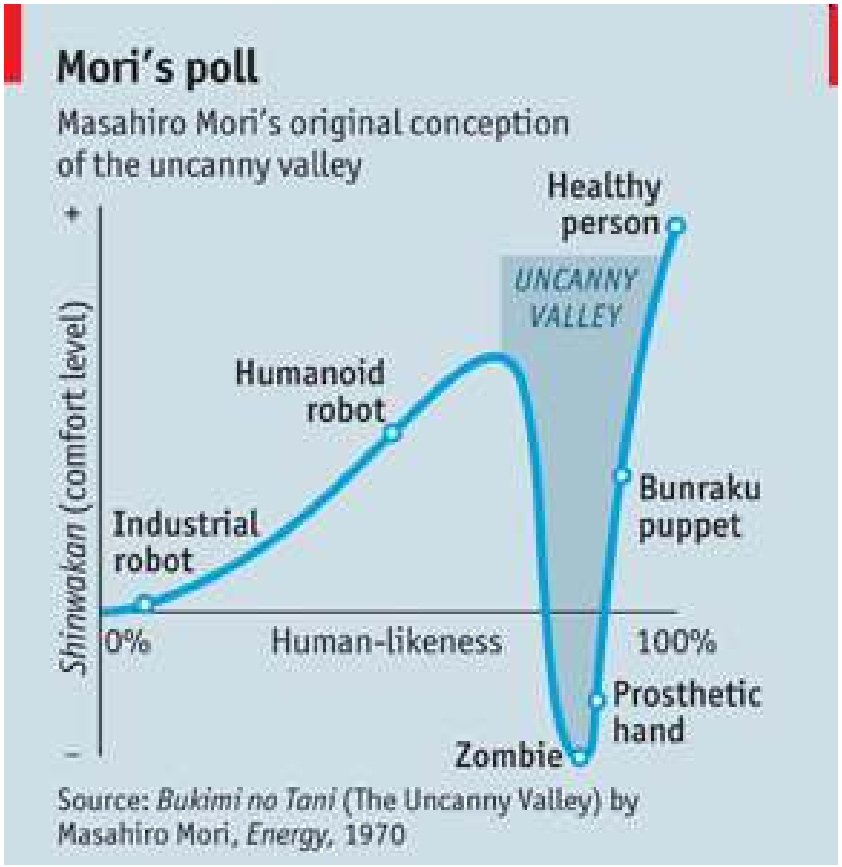
The time has now arrived to **add biology -** and more specifically, **human anatomy, physiology and psychology – to the scientific sources of knowledge** for engineers to develop **a new generation of bio-inspired intelligent machines**.


The Matrix
Computer Generated Objects
Avatar Animation Script
Object Interaction Models
Object Shape & Behavior Models
Sensor Data Fusion & Interpretation
Virtual Object Manipulation
Motion Tracking
Object Recognition
VIRTUAL SCENE
Avatar
Virtual_Environment / Real_World Interfaces
Visual Feedback(s)
Video Sensor(s)
Structured Light
Audio Feedback(s)
Audio Sensor(s)
Tactile Feedback(s)
Tactile Sensor(s)
Force Feedback(s)
Force Sensor(s)
Human


The Matrix
Computer Generated Objects
Avatar Animation Script
Object Interaction Models
Object Shape & Behavior Models
Sensor Data Fusion & Interpretation
Virtual Object Manipulation
Motion Tracking
Object Recognition
VIRTUAL SCENE
Avatar
Android

Crossing the uncanny valley: As computer graphics and robots get more human, they often seem more surreal

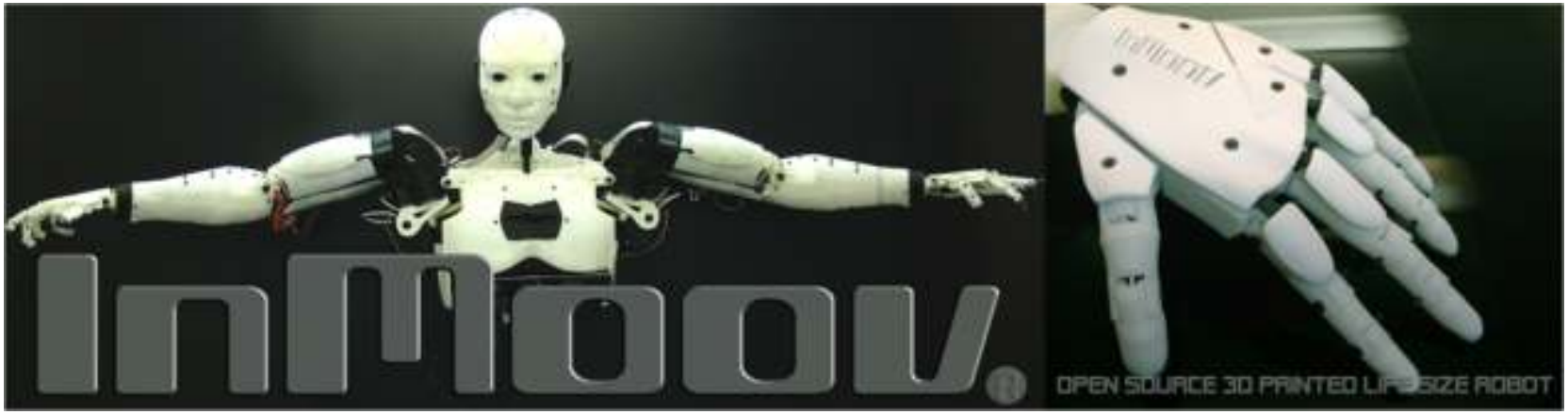
[*The Economist, Nov 18th 2010* , http://www.economist.com/node/17519716]



"The idea of the **uncanny valley** was proposed by Masahiro Mori in 1970. His idea was that **increasing humanness in a robot was positive only up to a certain point** …. beyond which, the not-quite-human object strikes people as creepy."


ASIMO
The Honda Humanoid Robot ASIMO
"While we were sleeping"
1986
1991
1993
2000
History
Robot Development Process

Robonaut is a dexterous humanoid robot built and designed at NASA Johnson Space Center in Houston, TX.



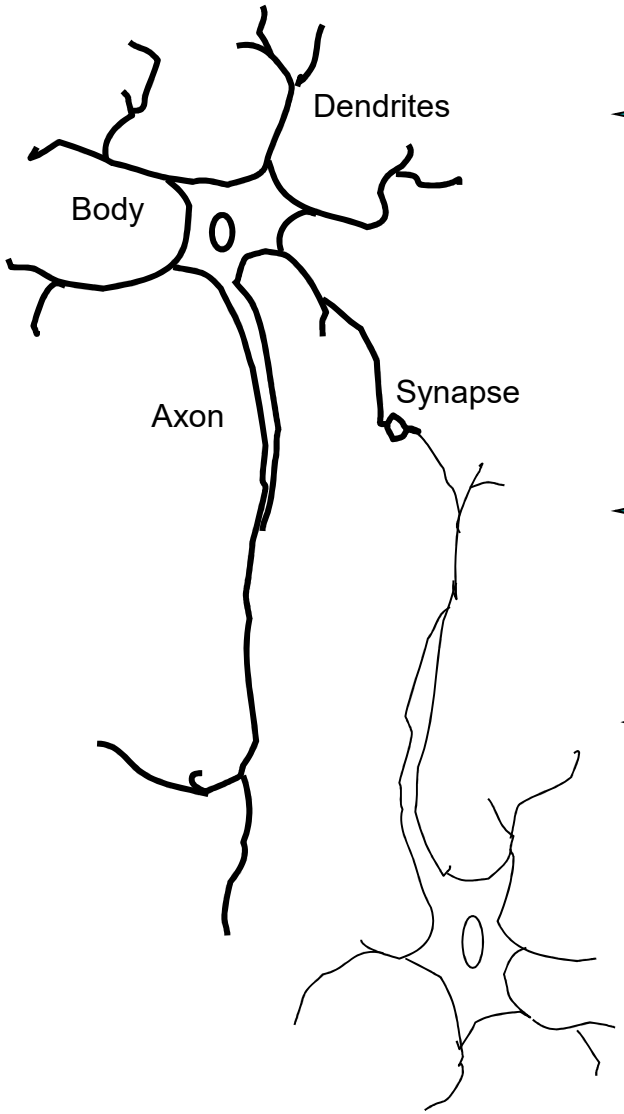
“InMoov”, the first Open Source life size humanoid robot you can 3D print and animate, ***Gael Langevin’s project, January 2012***
http://www.inmoov.fr/project/

“Gael Langevin is a French modelmaker and sculptor. He works for the biggest brands since more than 25 years. InMoov is his personal project, it was initiated in January 2012
InMoov is the first Open Source 3D printed life-size robot. Replicable on any home 3D printer with a 12x12x12cm area, it is conceived as a development platform for Universities, Laboratories, Hobbyist, but first of all for Makers. It’s concept, based on sharing and community, gives him the honor to be reproduced for countless projects through out the world.”

BIO-INSPIRED NEURAL NETWORKS

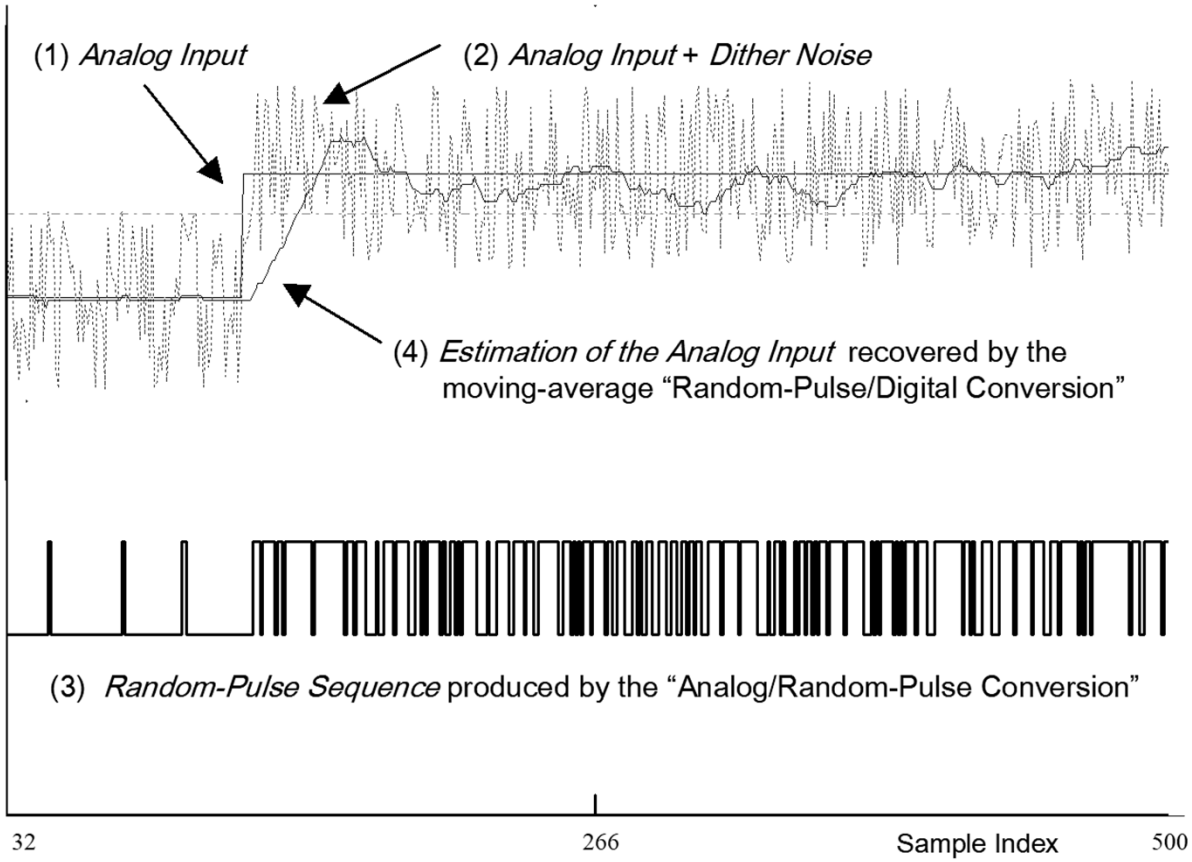
Looking for a model to prove that algebraic operations with analog variables can be performed by logic gates, Professor **J. von Neuman** advanced in 1956 the *idea of representing analog variables by the mean rate of random-pulse streams [J. von Neuman, "**Probabilistic logics and the synthesis of reliable organisms from unreliable components**," in Automata Studies, (C.E. Shannon, Ed.), Princeton, NJ, Princeton University Press, 1956].*

Biological Neurons



- **Dendrites** carry electrical signals in into the neuron body. The neuron **body** integrates and thresholds the incoming signals.The **axon** is a single long nerve fiber that carries the signal from the neuron body to other neurons. A **synapse** is the connection between dendrites of two neurons.
- *Memories* are formed by the modification of the **synaptic strengths** which can change during the entire life of the neural systems.
- **Neurons are rather slow (10^{-3} s)** when compared with the modern electronic circuits. ==> The brain is faster than an electronic computer because of its massively parallel structure. The **brain has approximately 10^{11} highly connected neurons** (approx. 10^4 connections per neuron).

Analog/Random-Pulse and Random-Pulse/Digital Conversion



- E.M. Petriu, K. Watanabe, T. Yeap, "Applications of Random-Pulse Machine Concept to Neural Network Design," *IEEE Trans. Instrum. Meas*., Vol. 45, No.2, pp.665-669, 1996,
- E. Pop, E.M. Petriu, "Influence of Reference Domain Instability Upon the Precision of Random Reference Quantizer with Uniformly Distributed Auxiliary Source," *Signal Processing* (EURASIP), North Holland, Vol. 5, pp.87-96, 1983

HUMAN

Heart + Pacemaker

Eye + Artificial Cornea

eye glasses, binoculars, IR night vision, HMD for augmented VR,...

Ear + Hearing Aid Implant

Nose + Artificial Smell

Tongue + Artificial Taste

Hand + Artificial Hand

gloves (baseball glove), hand tools

Knee Joint + Artificial Knee Joint

footwear, skates, bike, exoskeleton,..

TECHNOLOGICALLY ENHNCED HUMAN - *CYBORG*

***Asimov's laws of the robotics*:**

1st law: "A robot must not harm a human being or, through inaction allow one to come to harm".

2nd law: "A robot must always obey human beings unless that is in conflict with the 1st law".

3rd law: "A robot must protect itself from harm unless that is in conflict with the 1st and 2nd law".

Cyber/Machine
Society/World
{**Intelligent Androids**}

Human
Society/World
{**Human Beings**}

***Asimov's laws of the robotics*:**

0th law: "A robot may not injure humanity or, through inaction, allow humanity to come to harm."

1st law- updated: "A robot must not harm a human being or, through inaction allow one to come to harm, unless this would violate the 0th law."

2nd law: "A robot must always obey human beings unless that is in conflict with the 1st law".

3rd law: "A robot must protect itself from harm unless that is in conflict with the 1st and 2nd law".

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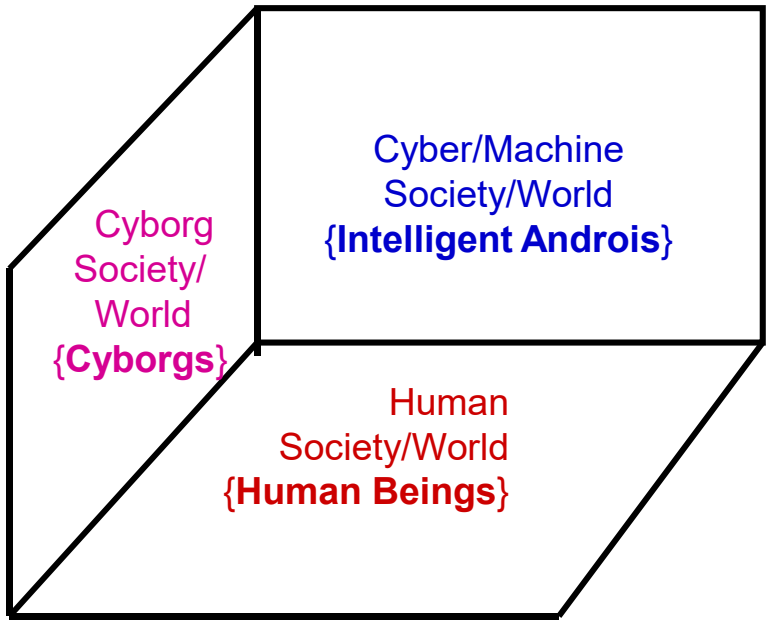
[*] I. Asimov, Robots and Empire, Doubleday & Co., NY 1985, p.291

Moral, Ethical, Theological, Legal, Biological, Psychological Social, Economic Challenges



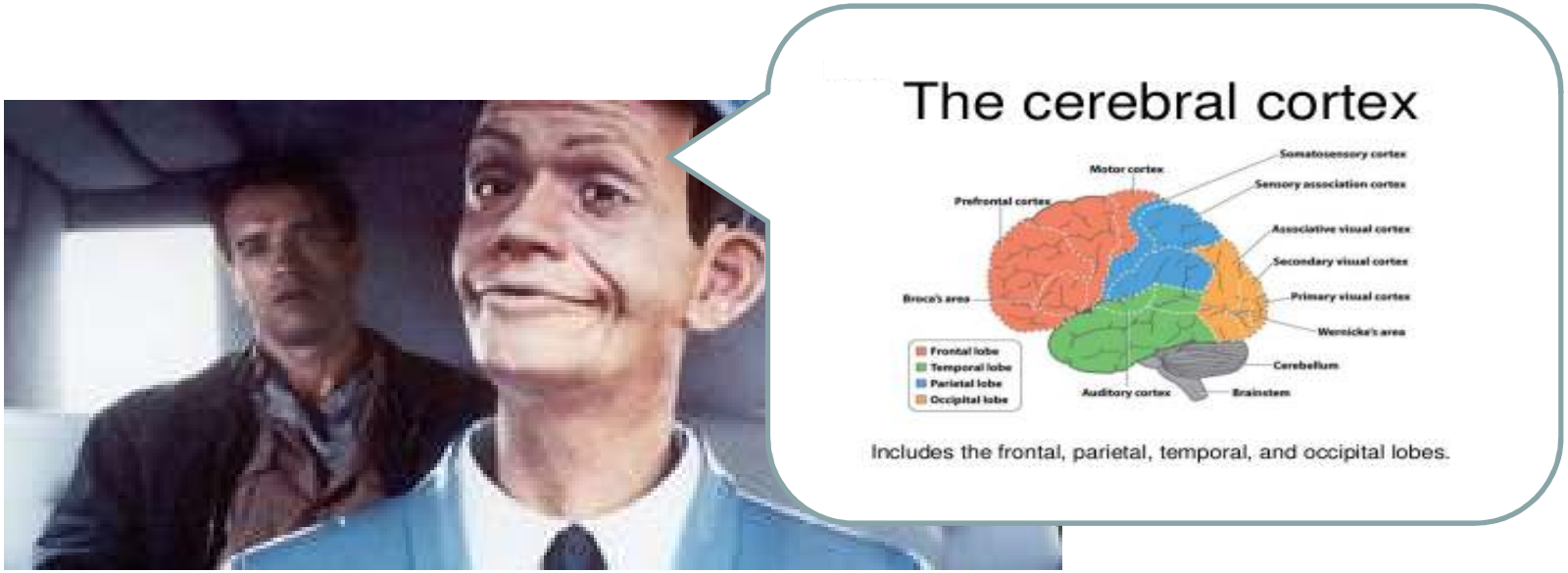
Brain Prosthesis

"**Immortality by 2045 or bust: Russian tycoon wants to transfer minds to machines**
Russian billionaire Dmitry Itskov speaks to the Global Future 2045 Congress, Saturday, June 15, 2013 at Lincoln Center in New York. Some of humanity's best brains are gathering in New York to discuss how our minds can outlive our bodies." [Ottawa Citizen, June 15, 2013, http://www.ottawacitizen.com/business/Immortality+2045+bust+Russian+tycoon+wants+transfer+minds/8531949/story.html]

Brain Prosthesis which learns/models with an ever increasing fidelity the behaviour of the natural brain so it can be used as *behavioural-memory prosthesis* (**BMP**) to make up for the loss in the natural brain's functions due to dementia, Alzheimer disease, etc. It is quite conceivable that such a BMP could arrive in extremis to complete replace the functions of the natural brain.

Soft Computing AI

In Isaac Asimov's science-fiction short story, "Sally" (1953), **autonomous cars have "positronic brains"** and communicate via honking horns and slamming doors, and save their human caretaker.

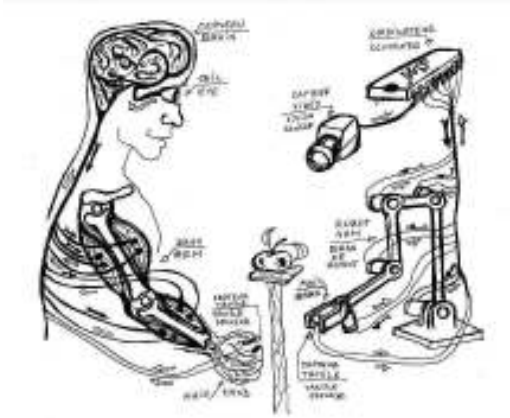


➡ **Intelligent control** does not use classic analytic model-based techniques, but soft computing-based adaptive and learning techniques

The IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems released, on 13 December 2016, the first version of its document, Ethically Aligned Design intended to provide a key reference for Artificial Intelligence and Autonomous Systems (AI/AS) technologists to help them prioritize values-driven, ethically aligned design in their work.

Ethically Aligned Design: A Vision for Prioritizing Human Wellbeing with Artificial Intelligence and Autonomous Systems

http://standards.ieee.org/develop/indconn/ec/ead_brochure.pdf



Thank You!