Bio-inspired Intelligent Machines

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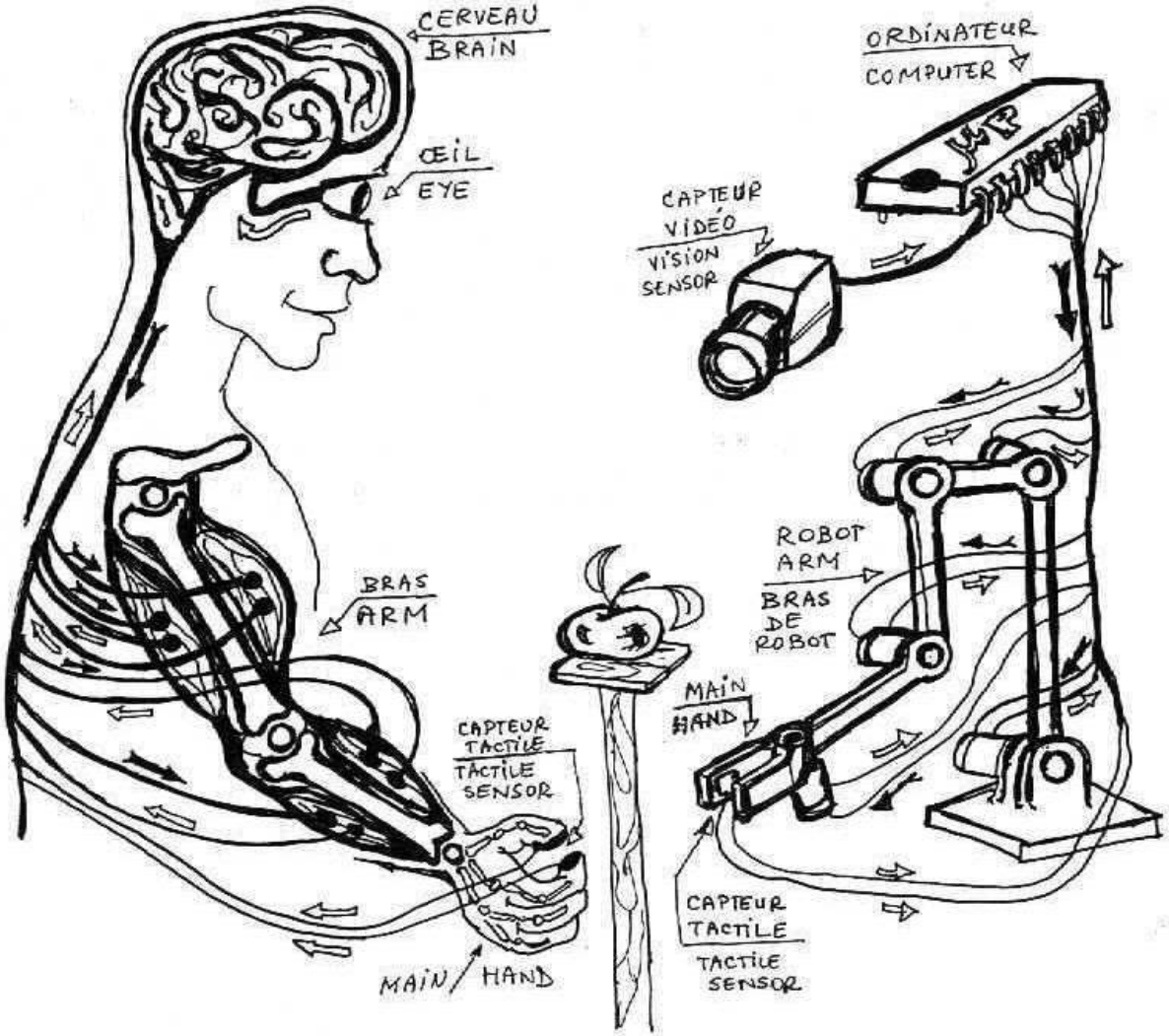
For many centuries, engineers were building upon **mathematics** and **natural science principles from mechanics, electricity, and chemistry** in order to develop an ever growing variety of more efficient and smarter industrial artefacts and machines, including computers.

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, bio-inspired, generation of intelligent machines**.

Advocating this emergent trend, this presentation will discuss a few relevant issues such as ***humanoid robots, human-robot interaction for symbiotic partnership, bio-inspired neural networks, techniques that enhance human natural capabilities, as well as moral, ethical, theological, legal, and social challenges in a soon to come cyborg -society world.***

Humanoid Robots


CERVEAU
BRAIN
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ROBOT
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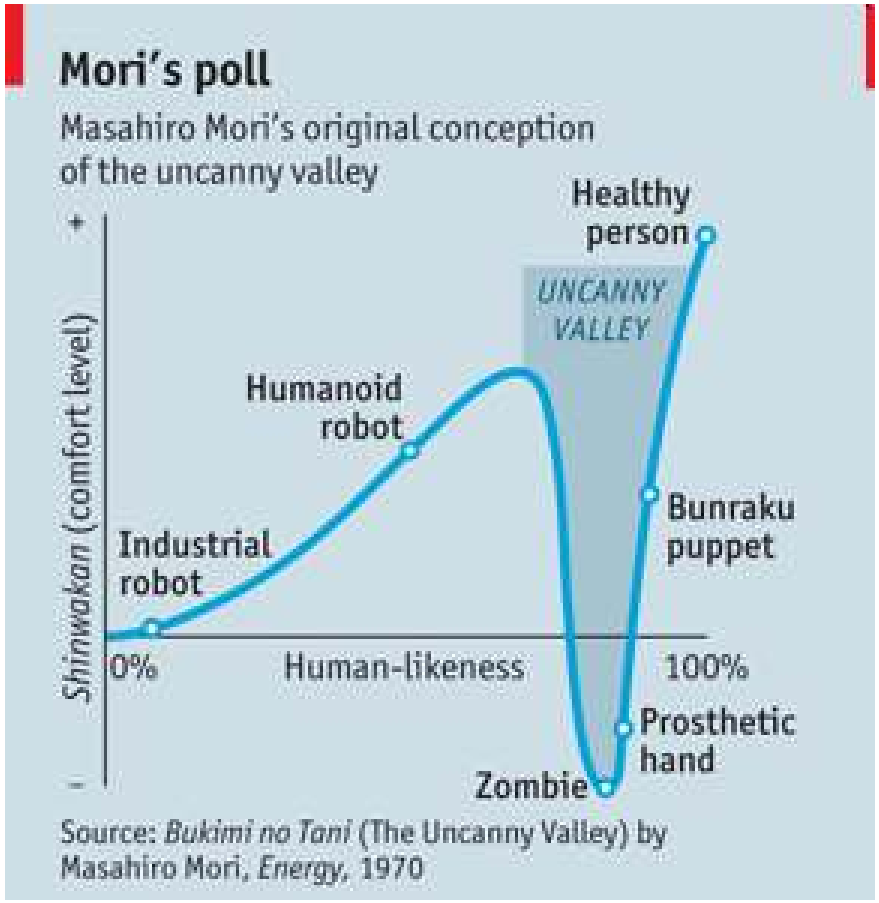
CAPTEUR
TACTILE
TACTILE
SENSOR

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

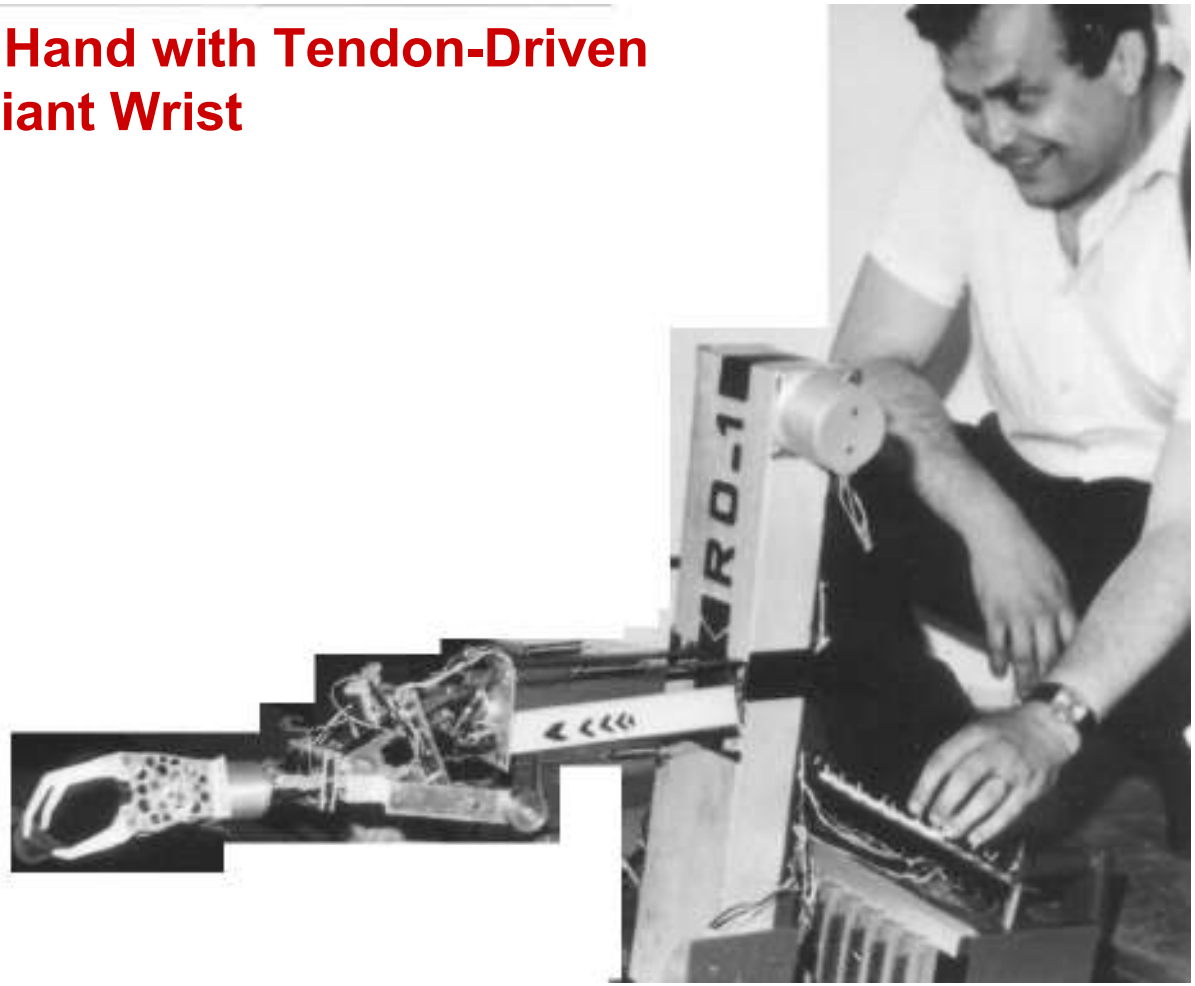
[The Economist, Nov 18th 2010 , http://www.economist.com/node/17519716]



"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**. Dr Mori drew a graph with "human-likeness" on the horizontal axis and a quality he called *shinwakan* (variously translated as "familiarity" and "comfort level") on the vertical one. As an object or image looks and behaves more like a human, the viewer's level of *shinwakan* increases. Beyond a certain point, however, the not-quite-human object strikes people as creepy, and *shinwakan* drops. This is the **uncanny valley.** Only when the object becomes almost indistinguishable from a human does *shinwakan* increase again."


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

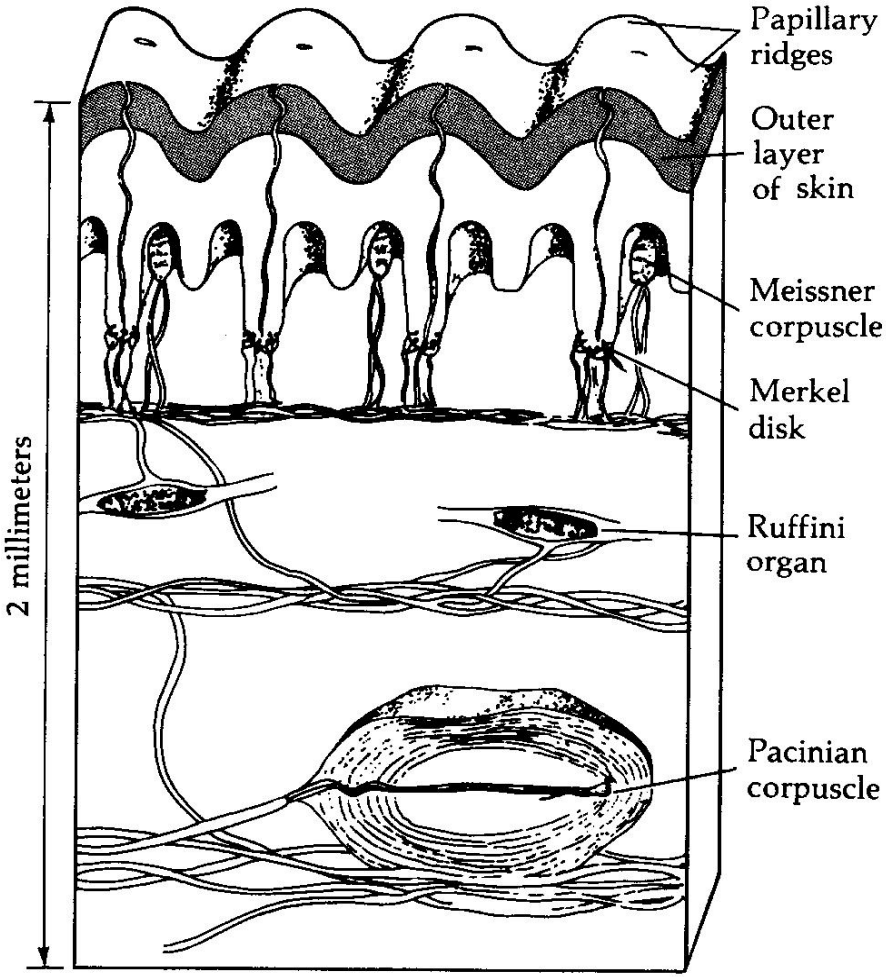
Robot Hand with Tendon-Driven Compliant Wrist

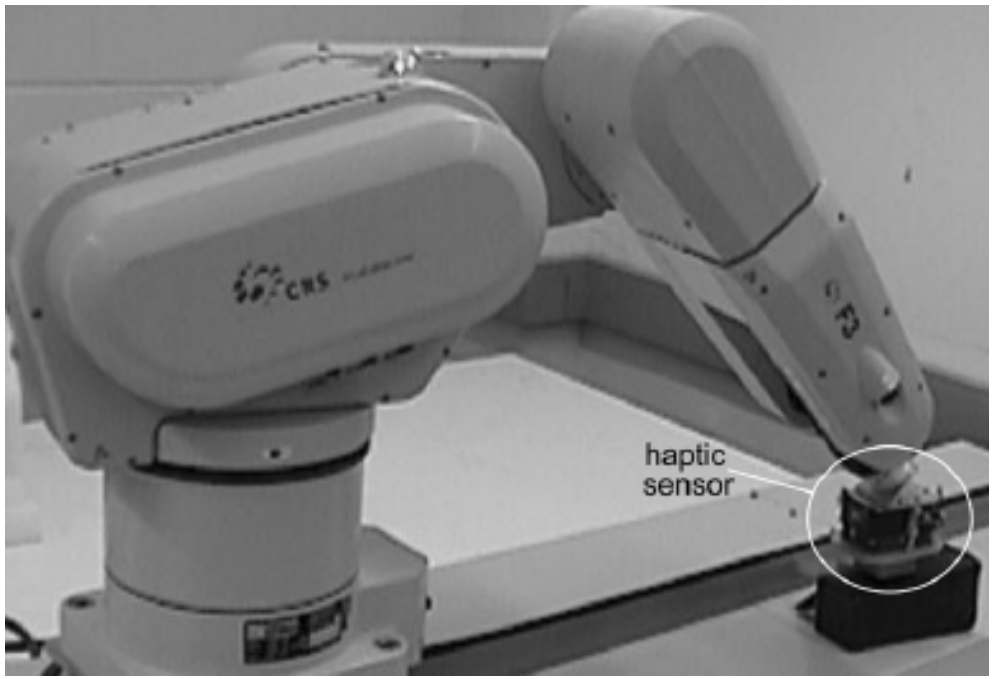


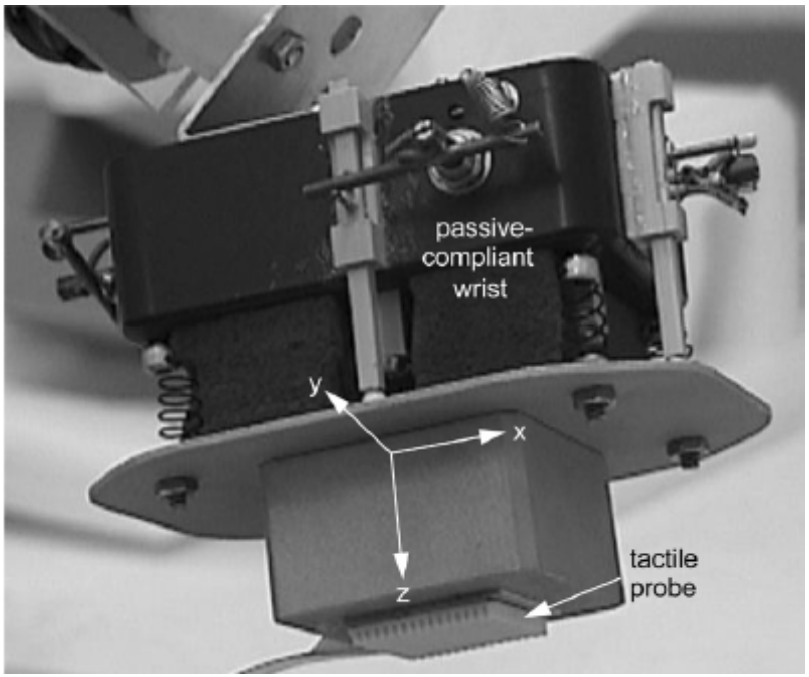
Bio-inspired Haptic Sensing

The sensory cortex: an oblique strip, on the side of each hemisphere, receives sensations from parts on the opposite side of the body and head: foot (A), leg (B, C, hip (D), trunk (E), shoulder (F), arm (G, H), **hand (I, J, K, L, M, N),** neck (O), cranium (P), eye (Q), temple (R), lips (S), cheek (T), tongue (U), and larynx (V). Highly sensitive parts of the body, such as the hand, lips, and tongue have proportionally large mapping areas, the foot, leg, hip, shoulder, arm, eye, cheek, and larynx have intermediate sized mapping areas, while the trunk, neck, cranium, and temple have smaller mapping areas.
(from [H. Chandler Elliott, *The Shape of Intelligence - The Evolution of the Human Brain*, Drawings by A. Ravielli, Charles Scribner's Sons, NY, 1969])

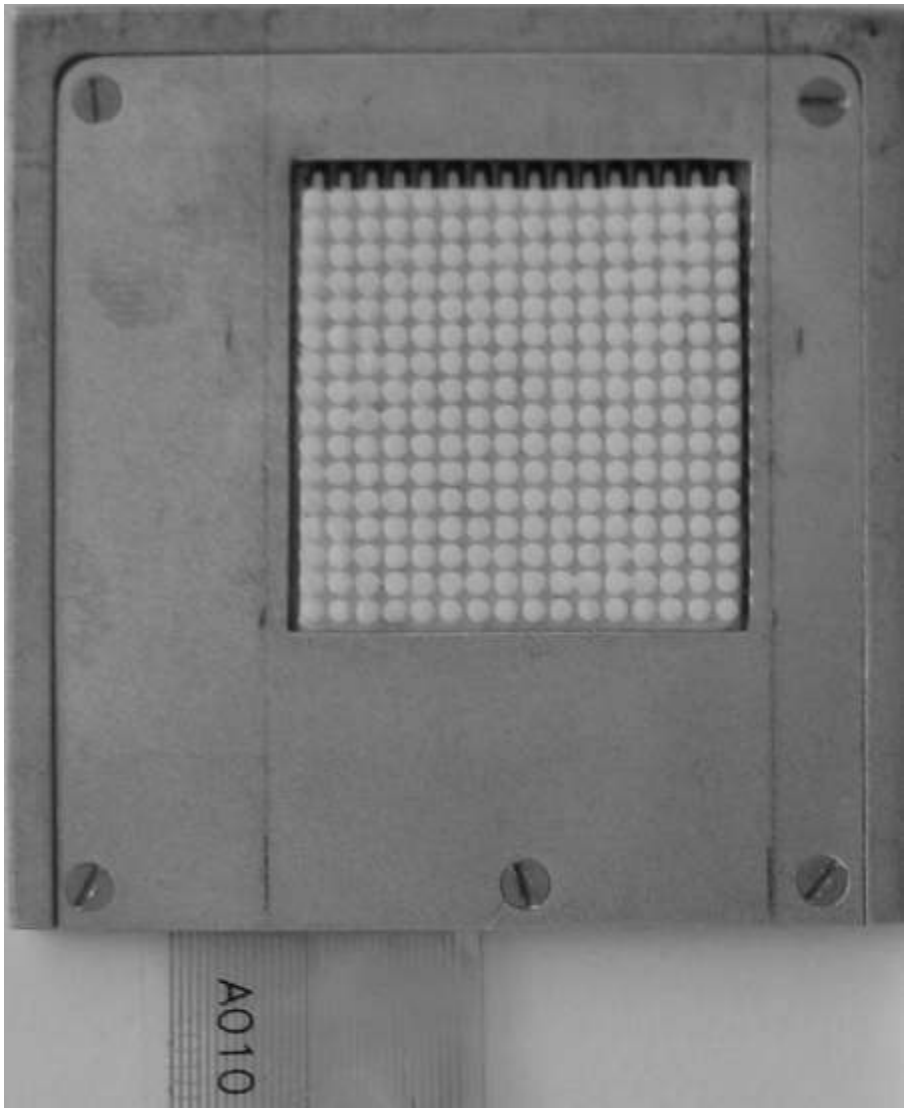
The skin of a human finger contains four types of **cutaneous sensing elements** distributed within the skin: *Meissner's corpuscles* for sensing velocity and movement across the skin; *Merkel's disks* for sensing sustained pressure and shapes; *Pacinian corpuscles* for sensing pressure changes and vibrations of about 250 Hz; and *Ruffini corpuscles* for sensing skin stretch and slip. (from R. Sekuler and R. Balke, Perception, McGraw-Hill, 1990)





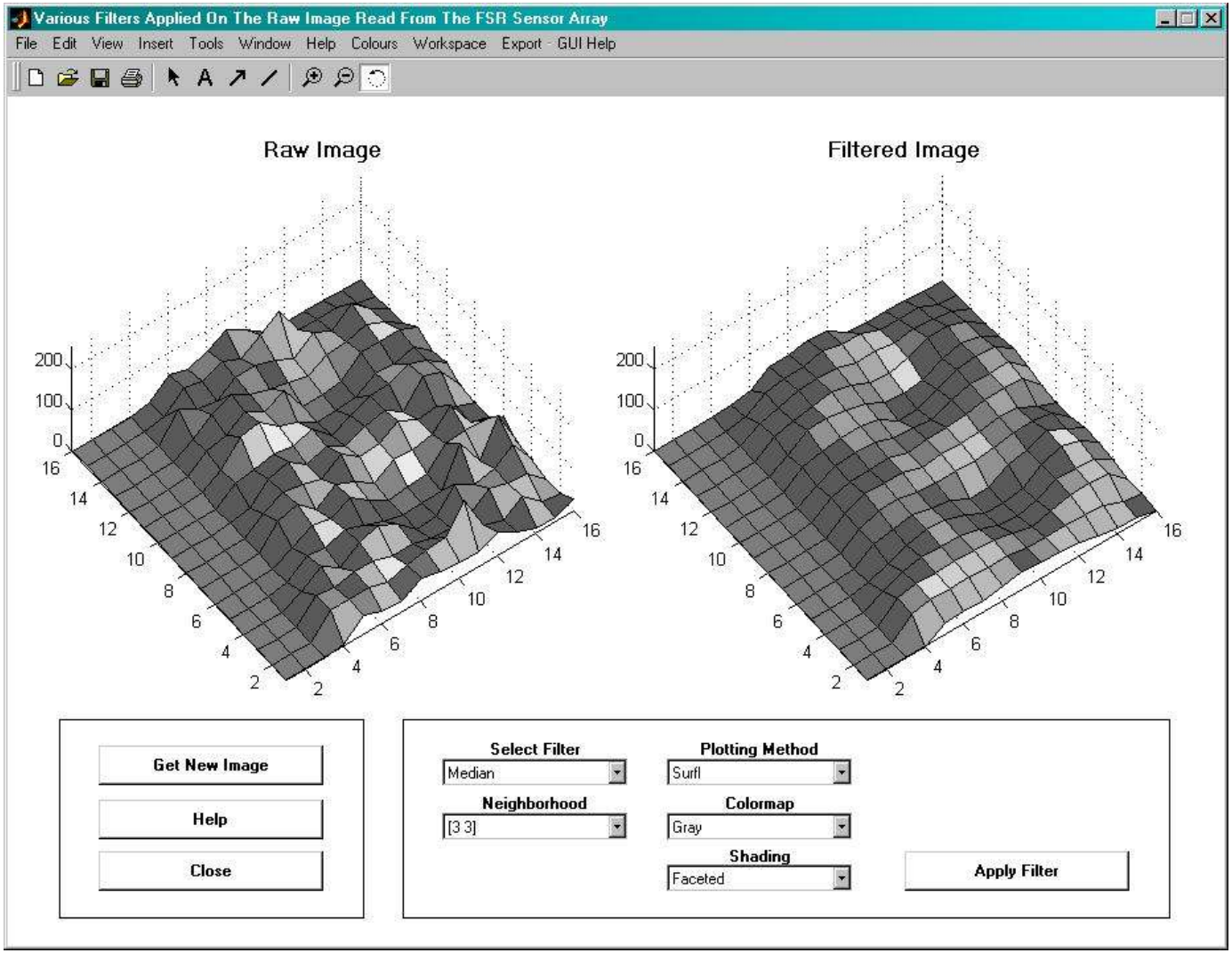


Bio-inspired robot haptic perception system consists of a **robot manipulator,** an instrumented **passive-compliant wrist** and a **tactile probe** array. Position sensors placed in the robot joints and on the instrumented passive-compliant wrist provide the kinesthetic information. The compliant wrist allows the probe to accommodate the constraints of the touched object surface and thus to increase the local cutaneous information extracted during the active exploration process under the force provided by the robot.



The tabs of the elastic overlay are arranged in a 16-by-16 array having a tab on top of each node of **Merkel's disk like matrix of FSR elements** sensing sustained pressure and shapes.

This tab configuration provides a *de facto* spatial sampling, which reduces the elastic overlay's blurring effect on the high 2D sampling resolution of the *FSR* sensing matrix.

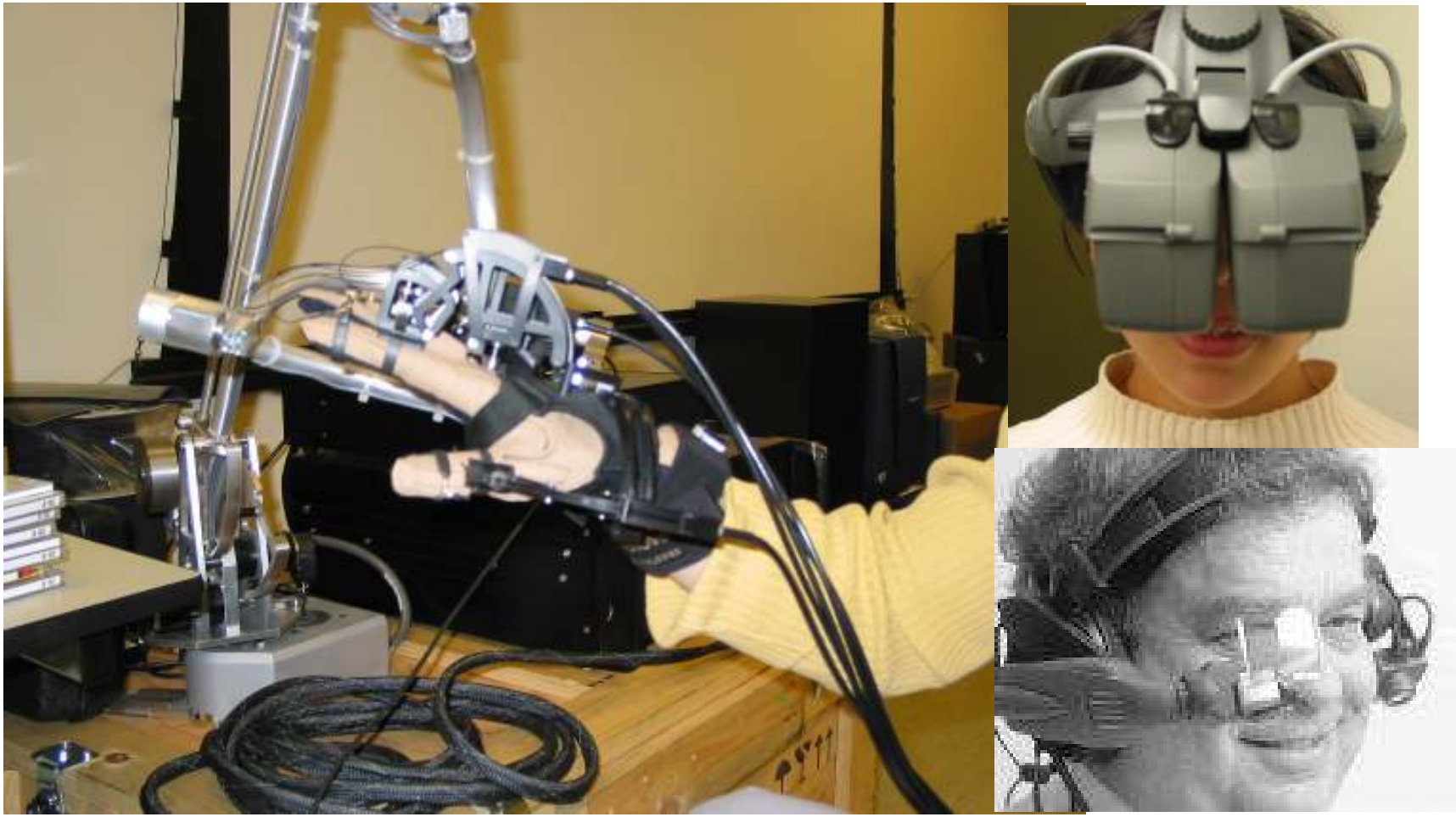


Example of GUI window (from [C. Pasca, *Smart Tactile Sensor*, M.A.Sc. Thesis, University of Ottawa, 2004])

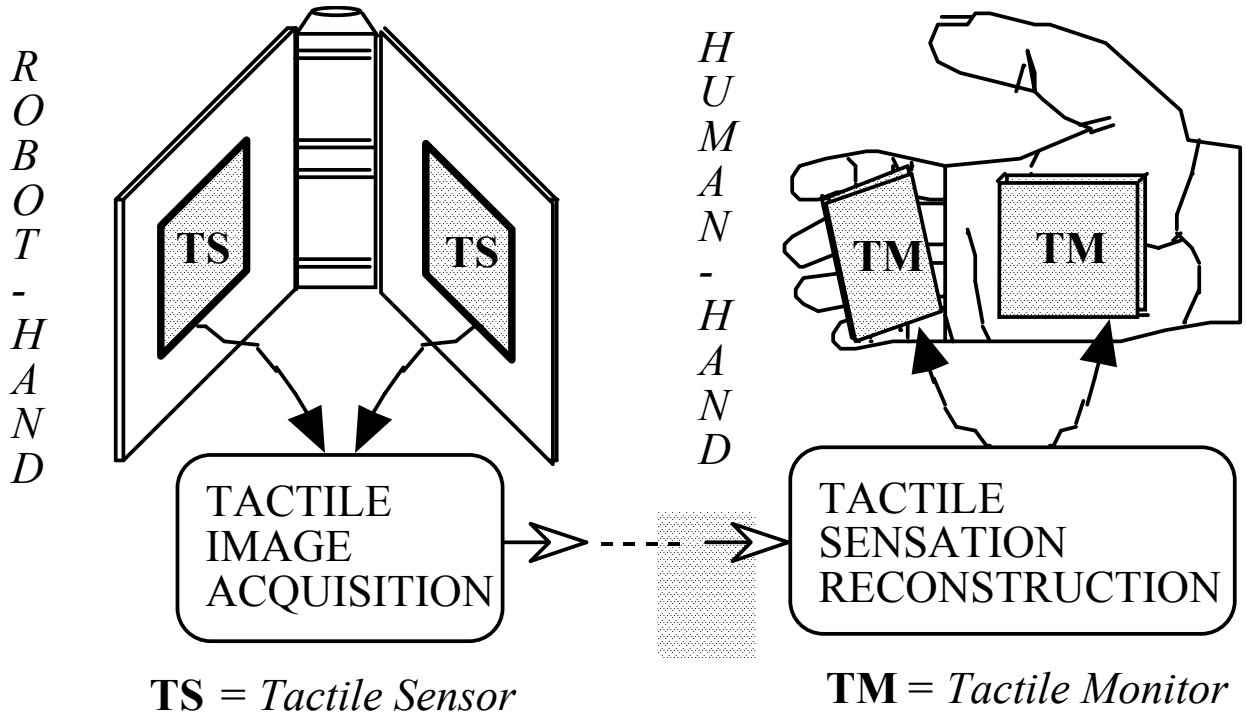
Human-Robot Interaction for Symbiotic Partnership

The *symbiotic partnership system* has a bilateral architecture allowing to connect the *human operator* and the *robotic partner* as transparently as possible.

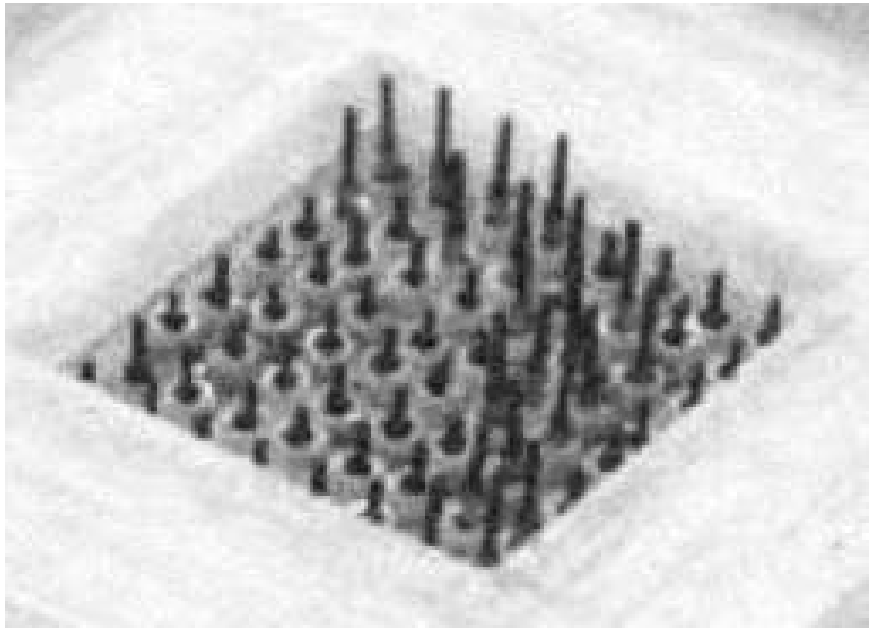
Conformal (1:1) mapping of human & robot sensory and perception frameworks



Commercial Virtual Hand Toolkit for CyberGlove/Grasp ,
Head Mounted Display, and see through visual display



A tactile human interface placed on the operator's palm allows the human operator to virtually feel by touch the object profile measured by the tactile sensors placed in the jaws of the robot gripper (from [E.M. Petriu, W.S. McMath, "Tactile Operator Interface for Semi-autonomous Robotic Applications," *Proc.Int. Symposium on Artificial Intell. Robotics Automat. in Space, i-SAIRS'92*, pp.77-82, Toulouse, France, 1992.])



Cutaneous tactile human interface developed at the University of Ottawa. It consists of an 8-by-8 array of vibrotactile stimulators. The active area is 6.5 cm2 (same as the tactile sensor).

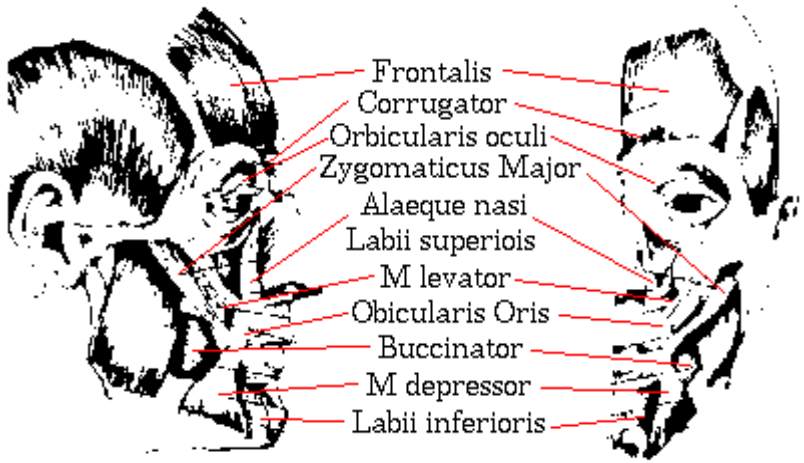
Tactile fingertip human interface developed at the University of Ottawa. It consists of miniature vibrators placed on the fingertips. The vibrators are individually controlled using a dynamic model of the visco-elastic tactile sensing mechanisms in the human fingertip.

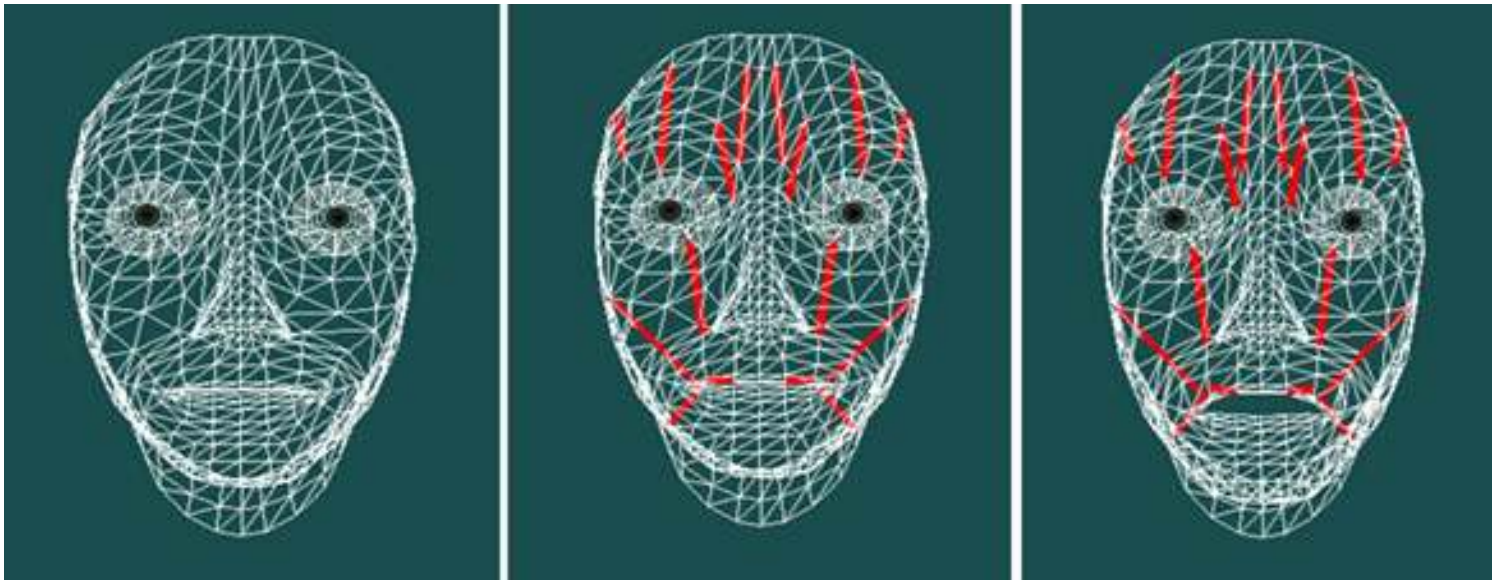
Expressive Robotic Human-like Head

Interest in facial expression can be dated back to the mid 19th century, when Charles Darwin wrote *The Expression of the Emotions in Man and Animals*. Later, two sign communication psychologists, Ekman and Friesen, developed the anatomically oriented *Facial Action Coding System* (FACS) based on numerous experiments with facial muscles. They defined the *Action Unit* (AU) as a basic visual facial movement, which cannot be decomposed into smaller units. The distinguishable expression space is reduced to a comprehensive system, which could distinguish all possible visually facial expressions by using only 46 AUs. Complex facial expressions can be obtained by combining different AUs.

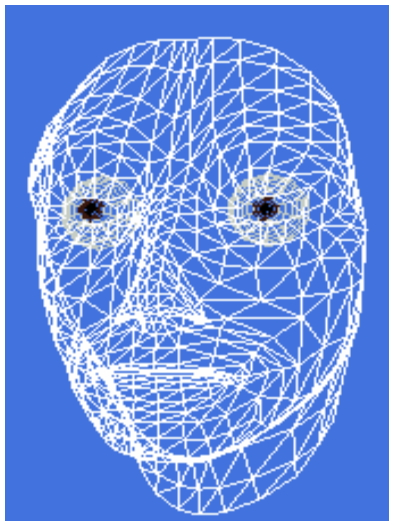
3D Face Modeling

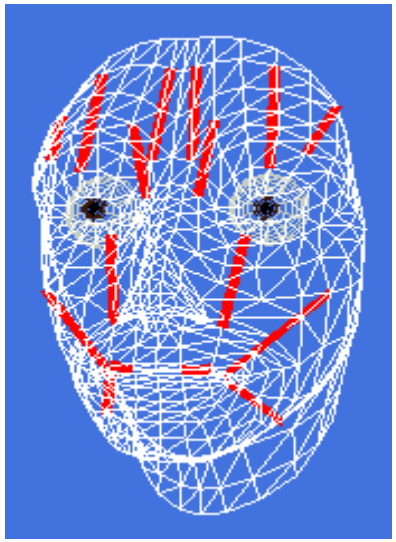
- Modeling and animating realistic faces require knowledge of anatomy
  - Anthropometric (external) representation
    - Measurements of living subjects
    - Statistics based on age, health, etc.
  - Muscle/Skin (internal) representation
    - Over 200 facial muscles
    - Over 14,000 possible expressions





3D generic face deformed using muscle-based control





Jaw	0
Left Zygomatic Major	0.00
Right Zygomatic Major	0.37
Left Anguli Depressor	0
Right Agnuli Depressor	0
Inner-Left Frontalis	0
Inner-Right Frontalis	0
Outer-Left Frontalis	0
Outer-Right Frontalis	0
Left Labii	0
Right Labii	0
Left Corrugator	0.60
Right Corrugator	0
Left Frontalis Major	0
Right Frontalis Major	0

Facial expressions are described using the ***Facial Action Coding System***, allowing to control the movements of specific facial muscles.

Neutral

Happy

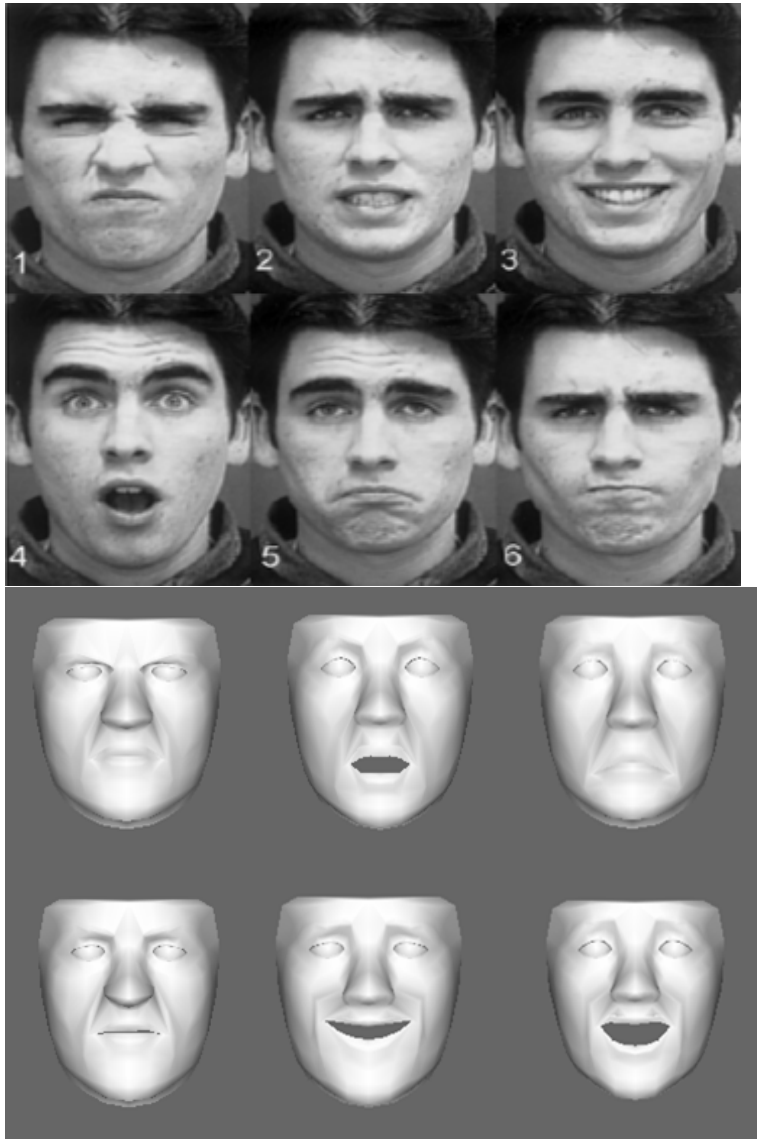
Sad

Surprised

Combining different muscle actions it becomes possible to obtain a variety of ***facial expressions*** of Marius' avatar:

A humanoid robot, without its facial skin, is displayed at Japan's largest robot convention in Tokyo on Nov. 28, 2007.

Facial Expression Recognition using a 3D Anthropometric Muscle-Based Active Appearance Model



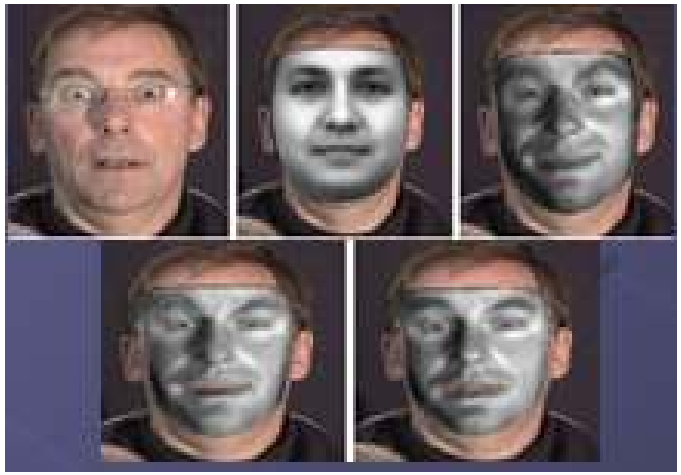
- Facial Action Coding System
  - 7 pairs of muscles + “Jaw Drop” = Expression Space
- Muscle “contractions” control mesh deformation in “Anthropometric-Expression (AE)” space
- Texture intensities are warped into the geometry of the shape
  - Shape: apply PCA in AE space
  - Appearance: apply PCA in texture space
- Model defined by rigid (rotation, translation) and non-rigid motion (AE)
- Model instances synthesized from AE space,

Facial Expression Recognition

- Person Dependent

AU	Signification	No.	Correct	False	Missed	Confused	Recognition Rate
0	Neutral	20	19	1	0	0	95%
1	Inner Brow Raiser	24	21	0	3	0	87.5%
2	Outer Brow Raiser	52	41	1	9	1	78.8%
4	Brow Lowerer	42	41	0	0	1	97.6%
12	Lip Corner Puller	51	48	3	0	0	94.1%
15	Lip Corner Depressor	18	17	0	1	0	94.4%
26	Jaw Drop	74	55	0	19	0	74.3%
Total		281	242	5	32	2	86.1%
False Alarm: 1.7%, Missed: 11.3%							

- Person Independent

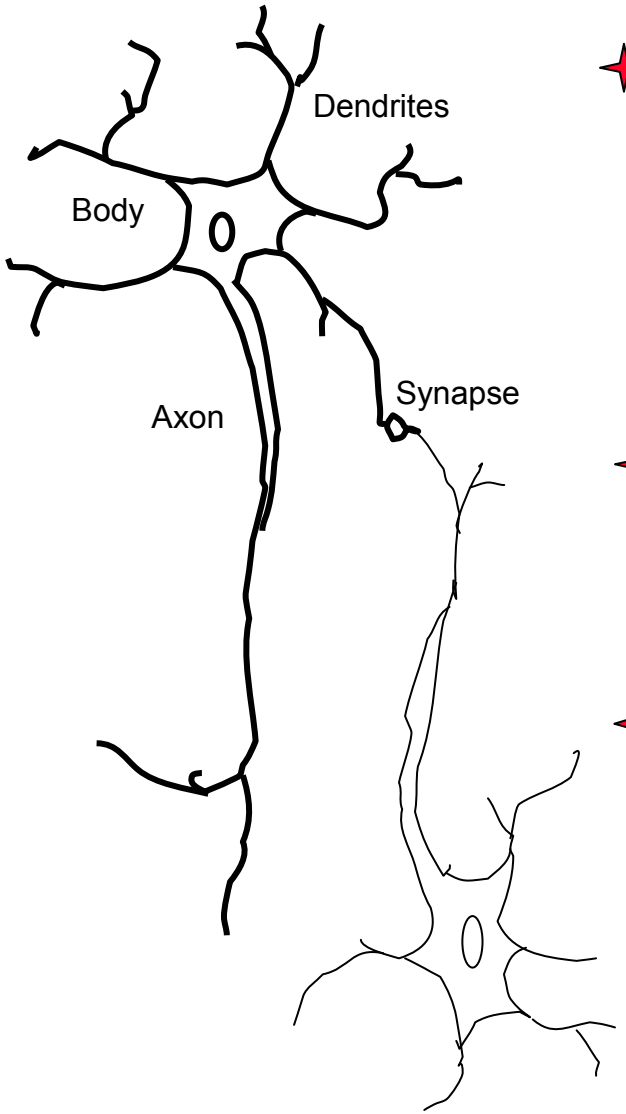


AU	Signification	No.	Correct	False	Missed	Confused	Recognition Rate
0	Neutral	20	17	3	0	0	85.0%
1	Inner Brow Raiser	10	8	0	2	0	80.0%
2	Outer Brow Raiser	27	20	1	5	1	74.0%
4	Brow Lowerer	24	21	1	1	1	87.5%
12	Lip Corner Puller	17	13	0	4	0	76.4%
15	Lip Corner Depressor	13	10	1	2	0	76.9%
26	Jaw Drop	24	14	0	10	0	58.3%
Total		135	103	6	24	2	76.2%
False Alarm: 4.4%, Missed: 17.7%							

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

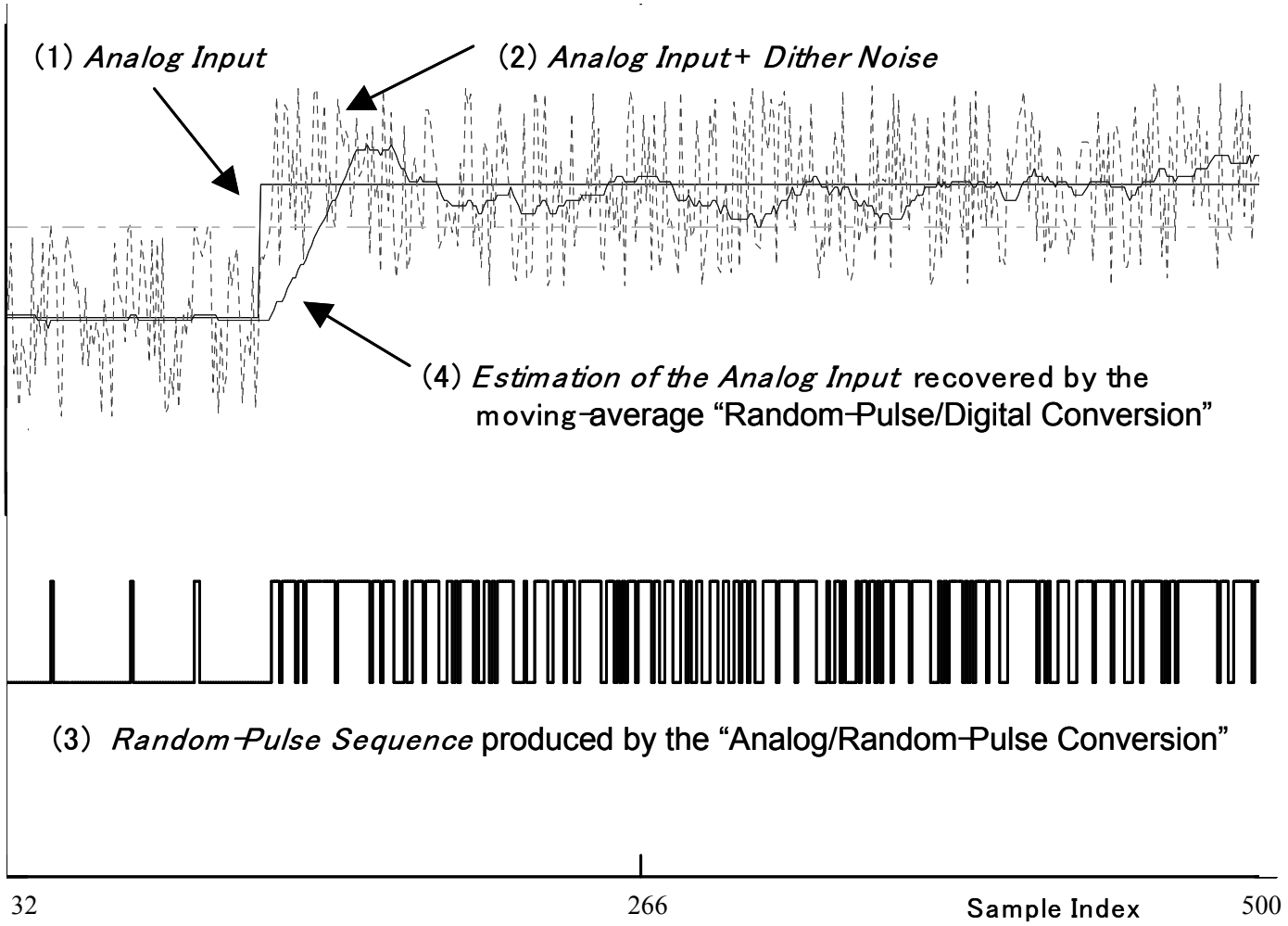


- **Dendrites** carry electrical signals in into the neuron body. The neuron **body** integrates and thresholds the incoming signals.The **axon** is a single long nerve fiber that carries the signal from the neuron body to other neurons. A **synapse** is the connection between dendrites of two neurons.

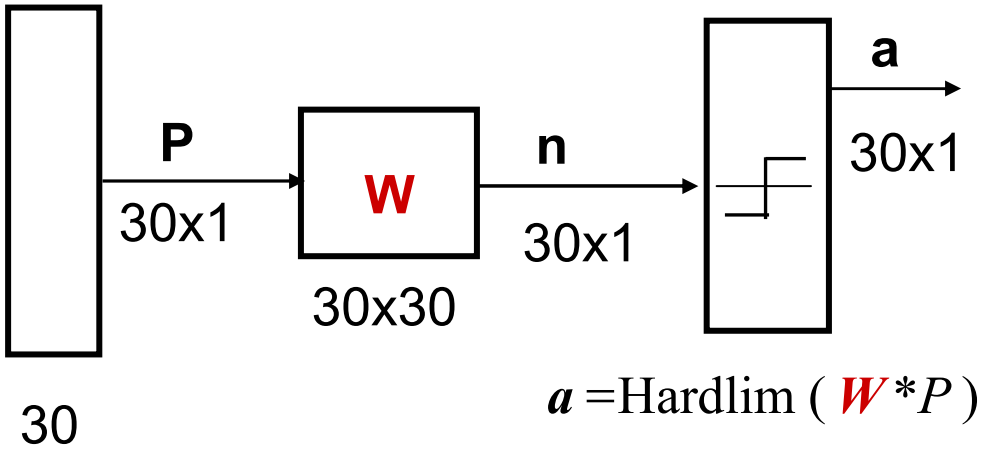
- *Memories* are formed by the modification of the **synaptic strengths** which can change during the entire life of the neural systems.

- **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).

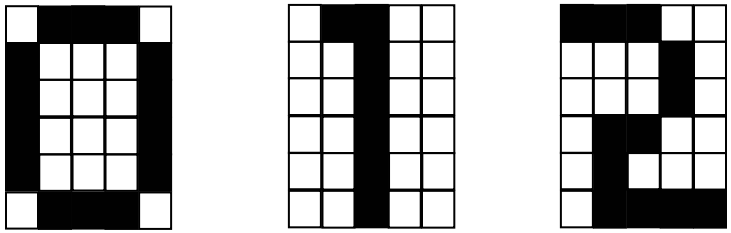
Analog/Random-Pulse and Random-Pulse/Digital Conversion



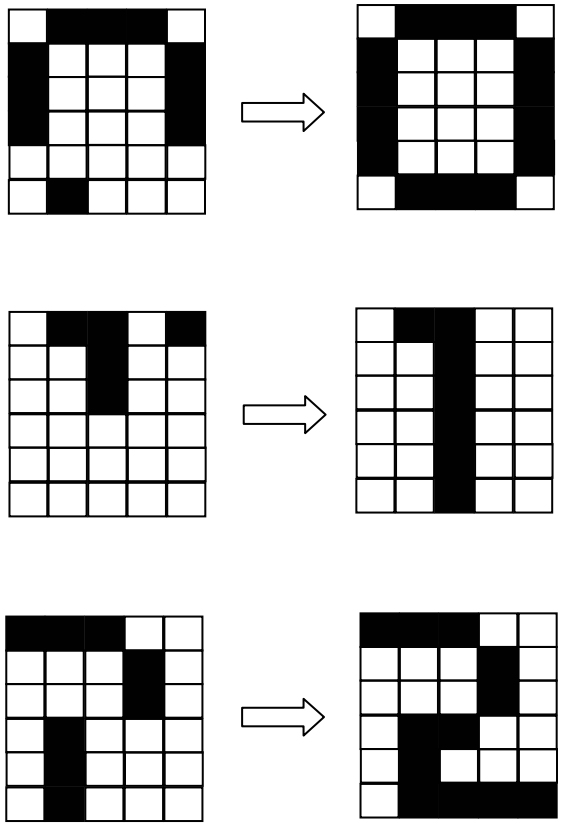
Auto-associative memory NN architecture



$$\boldsymbol{a} = \text{Hardlim}\,(\boldsymbol{W}*P)$$



Training set



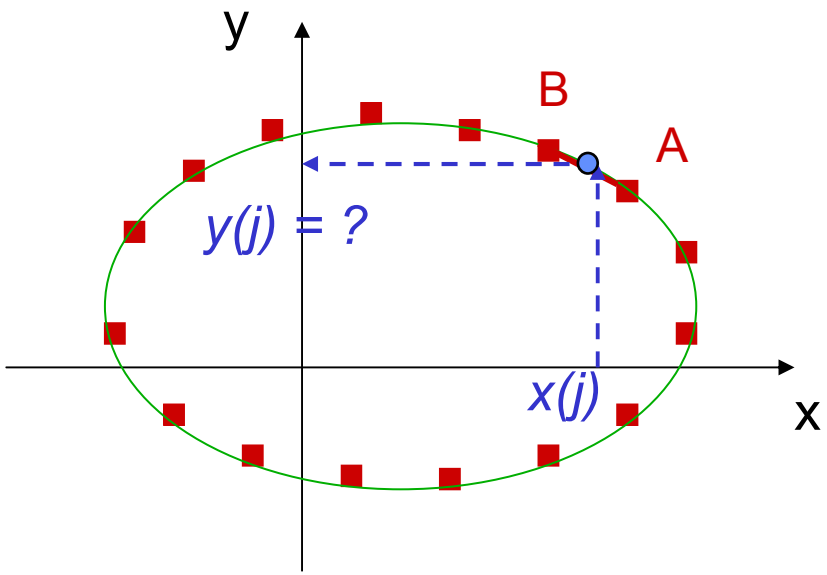
Recovery of 30% occluded patterns

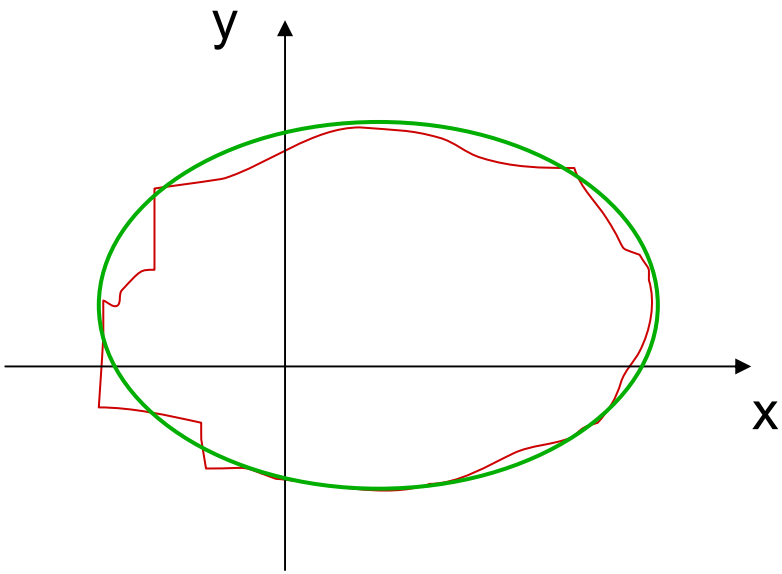
Neural Network vs. Analog Computer Modelling

- Both the **Analog Computers** and **Neural Networks** are ***continuous modelling devices***.

- **Neural Networks don't require a prior mathematical models.** A *learning algorithm* is used to adjust by trial and error during the learning phase the synaptic weights of the neurons.

Discreet vs. Continuous Modelling of Physical Objects and Processes





DISCREET MODEL

- ***sampling*** *=> INTERPOLATION COST*

  y(j) = y(A) +

  [x(j)-x(B)] · [y(B)-x(A)] / [x(A)-x(B)]

CONTINUOUS MODEL

- *NO sampling =>*

  NO INTEPPOLATION COST

Enhancing Human Natural Capabilities … Including Survivability

IMPAIRED or HEALTHY HUMAN

Heart + Pacemaker

Eye + Artificial Cornea

Ear + Hearing Aid Implant

Nose + Artificial Smell

Tongue + Artificial Taste

Hand + Artificial Hand

Knee Joint + Artificial Knee Joint

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

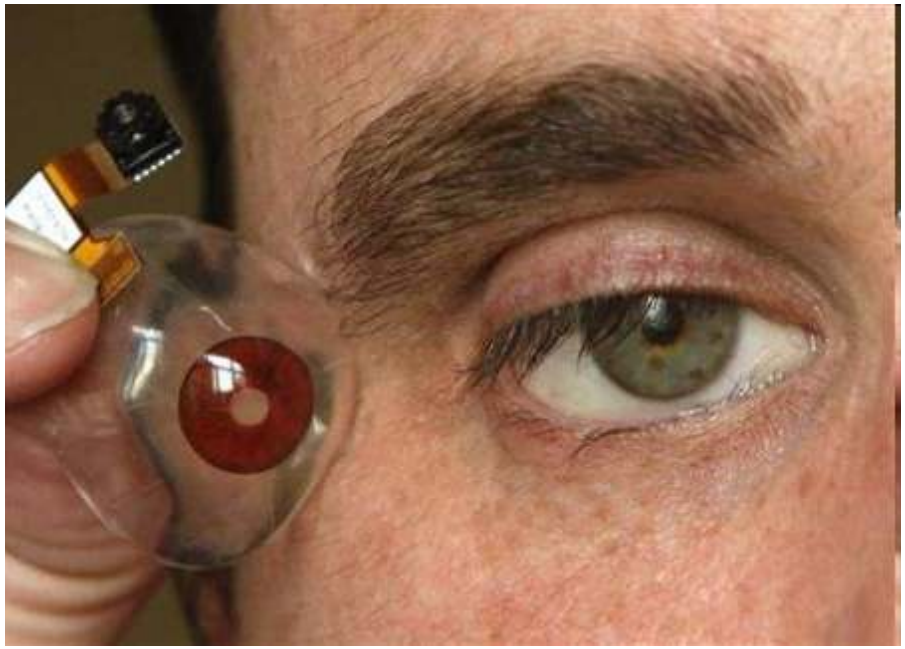
gloves (baseball glove), hand tools

footwear, skates, bike, exoskeleton,..

TECHNOLOGICALLY ENHNCED HUMAN - *CYBORG*

Prosthetic Eye [REUTERS/Yves Herman]

Canada's filmmaker Rob Spence, who lost his right eye when he was a child, shows a prototype of a prosthetic eye which will be transformed into a video camera, during a conference in Brussels March 5, 2009. Spence, director and producer in Toronto, said he would use the eye-cam the same way he uses a video camera to carry out the so-called "EyeBorg Project". In using his eye as a wireless video camera, Spence wants to make a documentary about how video and humanity intersect especially with regards to surveillance.



http://www.reuters.com/news/pictures/rpSlideshows?articleId=USRTXCF63#a=6

Honda to Showcase Experimental

Walking Assist Device at BARRIER FREE 2008

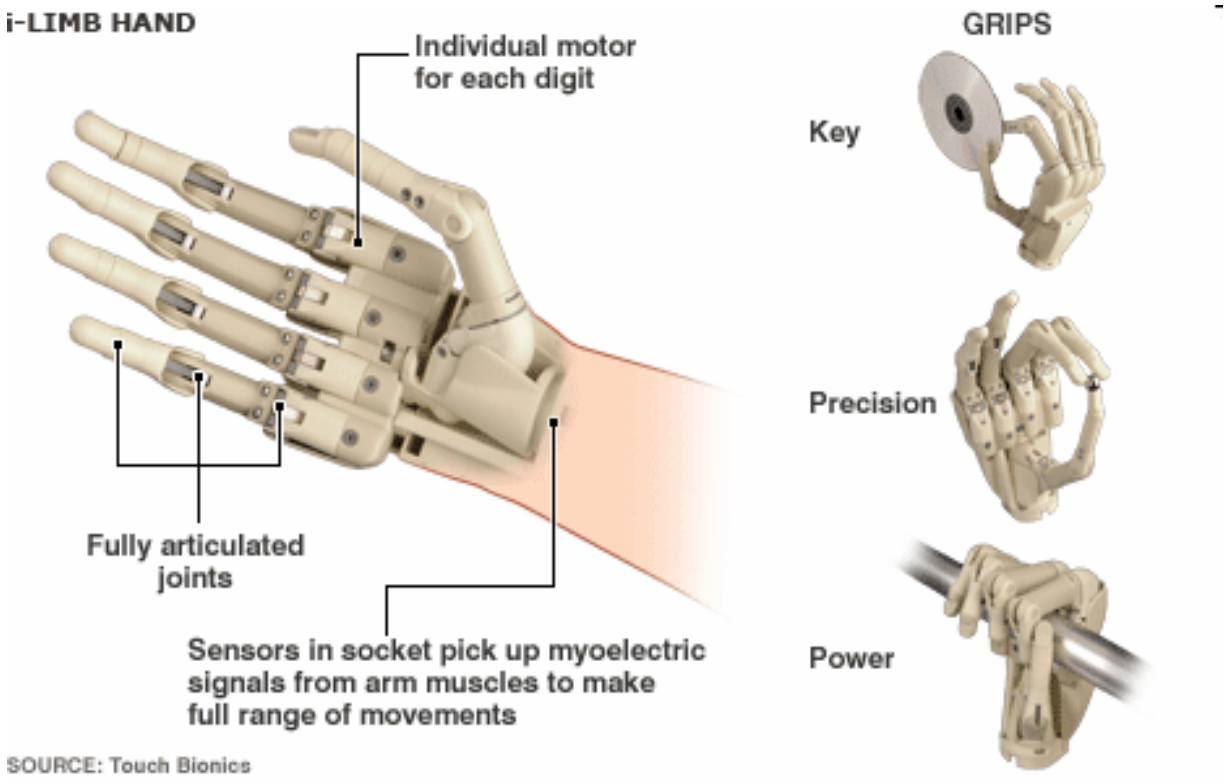
http://world.honda.com/news/2008/c080422Experimental-Walking-Assist-Device/

TOKYO, Japan, April 22, 2008– Honda Motor Co., Ltd. will showcase an experimental model of a walking assist device which could support walking for the elderly and other people with weakened leg muscles, at the Int. Trade Fair on Barrier Free Equipments & Rehabilitation for the Elderly & the Disabled (BARRIER FREE 2008) … at Intex Osaka, April 25 -27, 2008 Honda began research of a walking assist device in 1999 with a goal to provide more people with the joy of mobility. .....

The cooperative control technology utilized for this device is a unique Honda innovation … Applying cooperative control based on the information obtained from hip angle sensors, the motors provide optimal assistance based on a command from the control CPU.

The i-LIMB, a prosthetic device with five individually powered digits, beat three other finalists to win 2008 MacRobert award.
http://news.bbc.co.uk/2/hi/science/nature/7443866.stm

"The hand has two main unique features," explained Stuart Mead, CEO of Touch Bionics. "The first is that we put a motor into each finger, which means that each finger is independently driven and can articulate. "The second is that the thumb is rotatable through 90 degrees, in the same way as our thumbs are. "The hand is the first prosthetic hand that replicates both the form and the function of the human hand."



Brain & Brain Prosthesis

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.

Machines will achieve human-level artificial intelligence by 2029, a leading US inventor has predicted.

http://news.bbc.co.uk/2/hi/americas/7248875.stm

Humanity is on the brink of advances that will see tiny robots implanted in people's brains to make them more intelligent, said **Ray Kurzweil.**
The engineer believes machines and humans will eventually merge through devices implanted in the body to boost intelligence and health.

Tiny machines could roam the body curing diseases

Man versus machine

"I've made the case that we will have both the hardware and the software to achieve human level artificial intelligence with the broad suppleness of human intelligence including our emotional intelligence by 2029," he said… "We'll have intelligent nanobots go into our brains through the capillaries and interact directly with our biological neurons," The **nanobots, he said, would "make us smarter, remember things better and automatically go into full emergent virtual reality environments through the nervous system".**

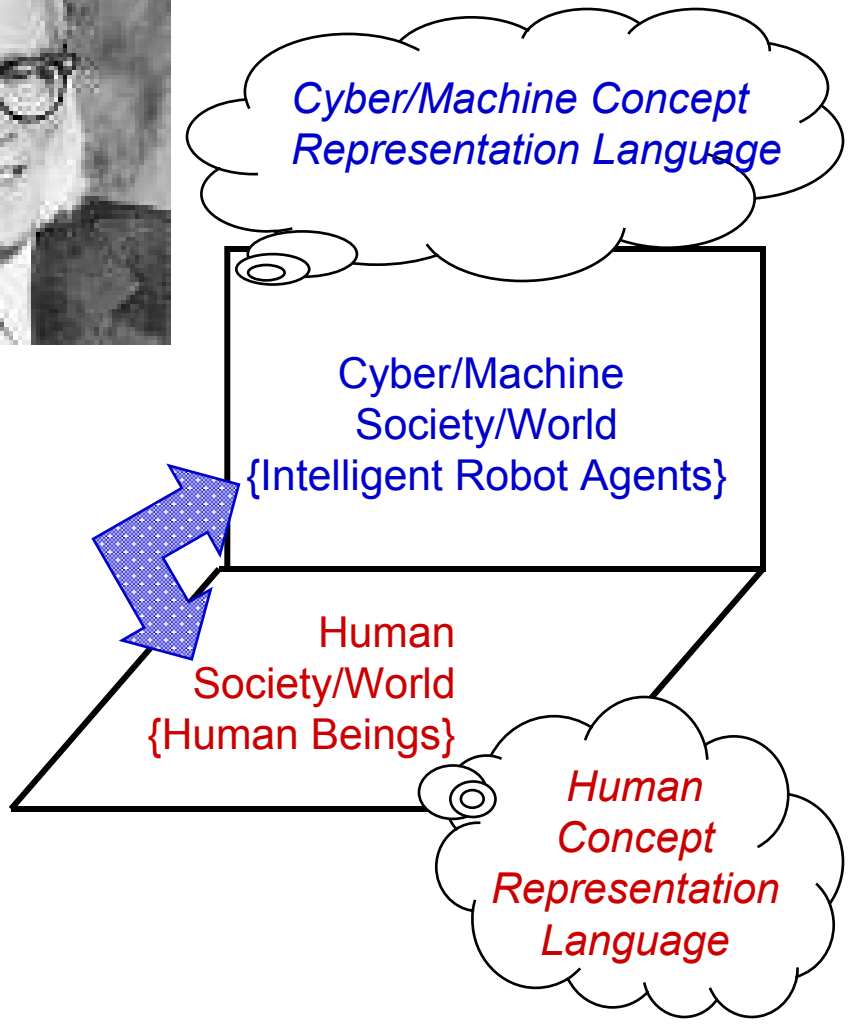
Mr Kurzweil *is one of 18 influential thinkers chosen to identify the great technological challenges facing humanity in the 21st century by the US National Academy of Engineering.*

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

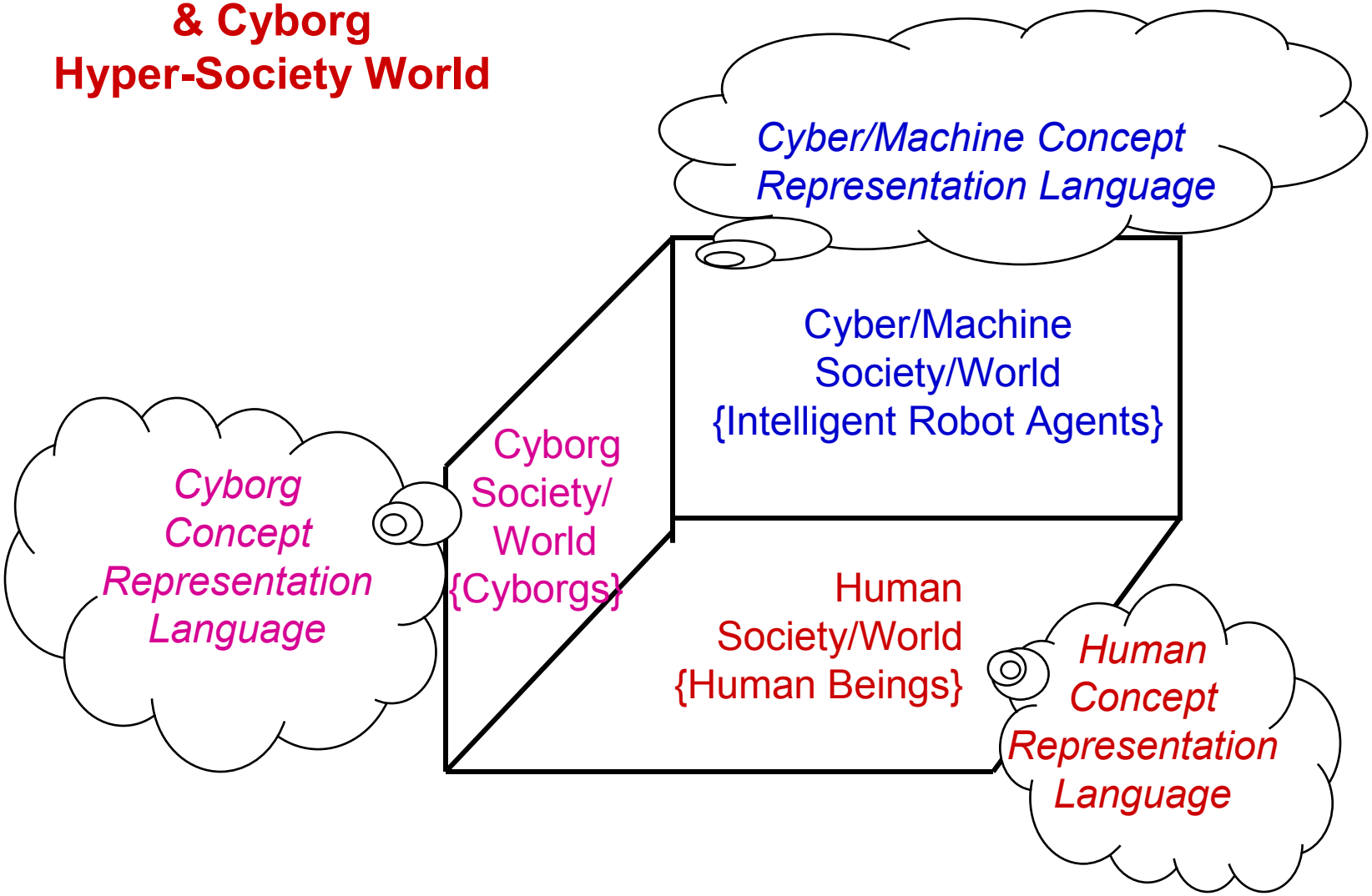
1st law: "A robot must not harm a human being or, through inaction allow one to come to harm".

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".



Multi-Cultural
Human & Cyber
& Cyborg
Hyper-Society World



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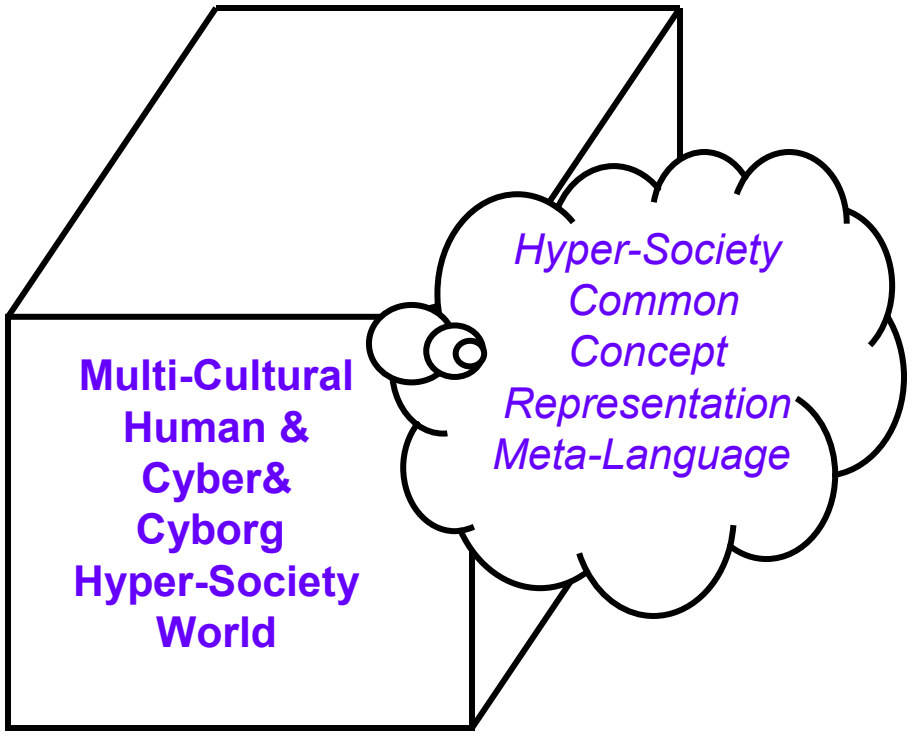
[*] I. Asimov, *Robots and Empire*, Doubleday & Co., NY 1985, p.291



Moral, Ethical, Theological, Legal, Biological, Psychological, Social, …. Challenges in a CYBORG Hyper-Society World

Moral, Ethical, Theological, Legal, Biological, Psychological Social, Economic, Challenges in a CYBORG Hyper-Society World

[Normal Human Partner] + [Pacemaker-fitted Human Partner]
= [Acceptable Married (incl. Lovers) Couple]

[Normal Human Partner] + [Advanced Augmented Symbiont Partner]
= [Acceptable Married (incl. Lovers)_Couple] ?

[Normal Human Partner] + [Robot Partner]
= [Acceptable Married (incl. Lovers)_Couple] ???

Sex and marriage with robots? It could happen Robots soon will become more human-like in appearance, researcher says

http://www.msnbc.msn.com/id/21271545/

By Charles Q. Choi / Special to LiveScience, Fri., Oct. 12, 2007

Humans could marry robots within the century. And consummate those vows. "My forecast is that around 2050, the state of Massachusetts will be the first jurisdiction to legalize marriages with robots," artificial intelligence researcher David Levy at the University of Maastricht in the Netherlands told LiveScience.

Will we humans one day truly love robots just like we love other humans?

http://blogs.spectrum.ieee.org/automaton/2008/04/08/will_we_humans_one_day_truly_love_robots_just_like_we_love_other_humans.html

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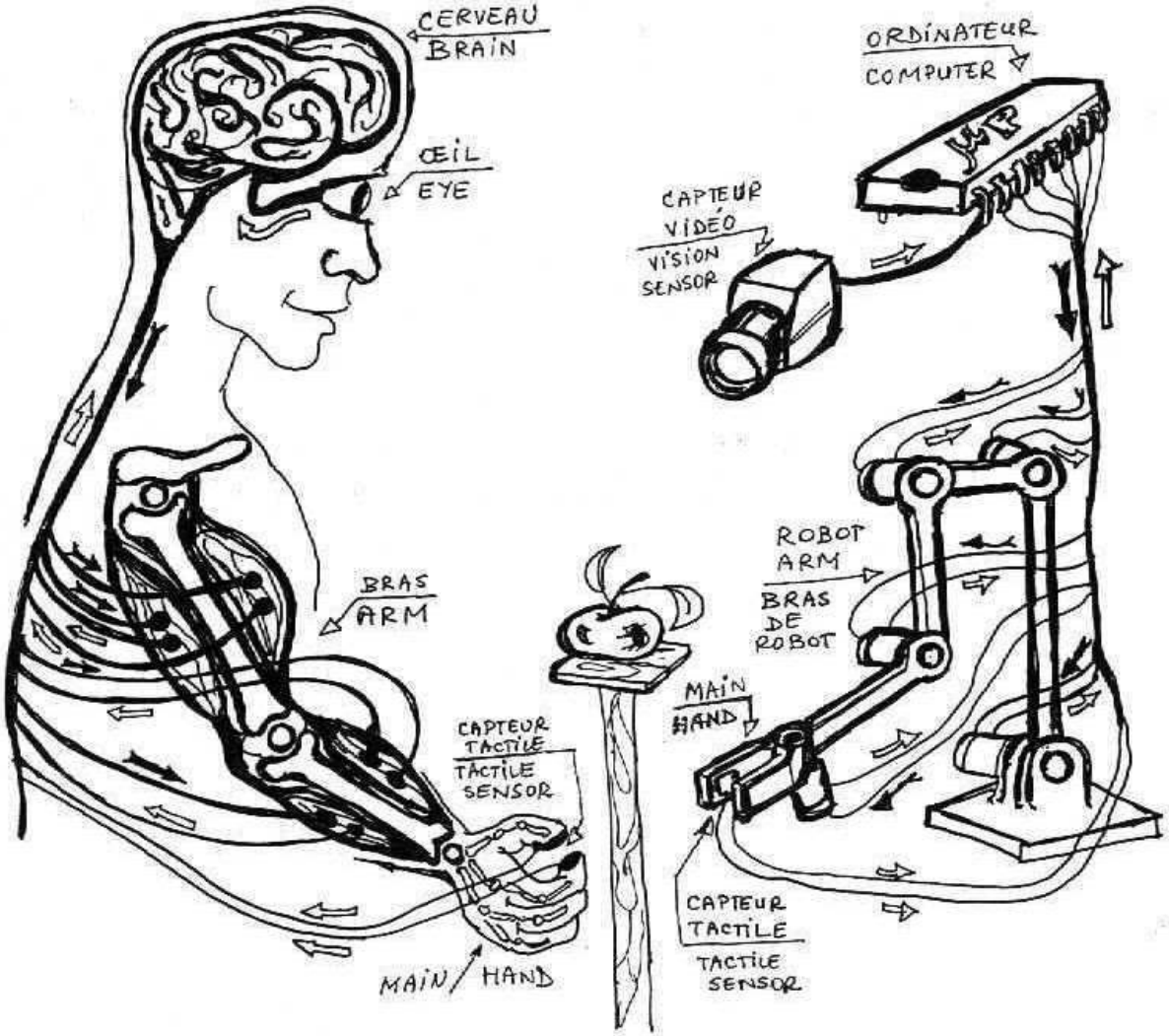
Rent an Actroid to love and marry

http://blogs.spectrum.ieee.org/automaton/2008/04/09/rent_an_actroid_to_love_and_marry.html


CERVEAU
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ORDINATEUR
COMPUTER
CAPTEUR
VIDÉO
VISION
SENSOR
ROBOT
ARM
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ROBOT
MAIN
HAND
CAPTEUR
TACTILE
TACTILE
SENSOR

Thank you!