Bio-Inspired 21st Century Robotics

Emil M. Petriu University of Ottawa, Canada http://www.site.uottawa.ca/~petriu 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 number of relevant issues such as bio-inspired robot sensing and perception techniques and human-robot interaction for symbiotic partnership. Robot perception mechanisms that emulate those of the humans.



"In a way, touch can be constructed as the most reliable of the [human] sensor modalities. When the senses conflict, touch is usually the ultimate arbiter. ... Touch sensations can arise from stimulation anywhere on the body's surface. Indeed, the skin can be characterized as one large receptor **surface for the sense of touch**.... The English neurologist H. Jackson paid homage to the wonderful and complex abilities of the *human hand* by calling it the most intelligent part of the body. The skin on the human hand contains thousands of **mechanoreceptors** (sensitive to mechanical pressure of deformation of the skin), as well as a **complex set of muscle to guide the** fingers as they explore the surface of an object. The mechanoreceptors play a key role in analyzing object detail such as texture; the muscles make their big contribution when grosser features such as size, weight, and shape are being analyzed. But, whether exploring gross or small details, the hand and the finger pads convey the most useful tactile information about objects. In this respect, the hand is analogous to the eye's fovea, the region of retina associated with keen visual acuity. There is, however, a flaw in this analogy: fovea vision is most acute when the eye is relatively stationary, but touch acuity is best when the fingers move of the object of regard " (from [R. Sekuler, R. Balke, *Perception*, 2nd edition, McGraw-Hill, NY, 1990, Chapter 11. Touch, pp. 357-383]).



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])

Human Haptic Perception

Human haptic perception is the result of a complex dexterous manipulation act involving two distinct components:

- (i) cutaneous information from touch sensors which provide about the geometric shape, contact force, elasticity, texture, and temperature of the touched object area. The highest density of cutaneous sensors is found in fingerpads (but also in the tongue, the lips, and the foot).
 Force information is mostly provided by sensors on muscles, tendons and bone joints proprioceptors;
- (ii) *kinesthetic* information about the positions and velocities of the kinematic structure (bones and muscles) of the hand



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, <u>Perception</u>, McGraw-Hill, 1990)



[Burdea& Coiffet 2003] G. Burdea and Ph. Coiffet, Virtual Reality Technology, (2nd edition), Wiley, New Jersey, 2003

Cutaneous sensors =>

- 40 % are *Meissner's corpuscles* sensing velocity and providing information about the movement across the skin;
- 25% are *Merkel's disks* which measure pressure and vibrations;
- 13 % are *Pacinian corpuscles* (buried deeper in the skin) sensing acceleration and vibrations of about 250 Hz;
- 19% are *Rufini corpuscles* sensing skin shear and temperature changes.

Spatial resolution

[Burdea& Coiffet 2003]

- If the sensor has a large receptive field – it has low spatial resolution (Pacinian and Ruffini)
- If the receptive field small - it has high spatial resolution (Meissner and Merkel)



Two-point limen test: 2.5 mm fingertip, 11 mm for palm, 67 mm for thigh (*from [Burdea& Coiffet 2003]*).



Haptic perception is the result of an active deliberate contact exploratory sensing act.

A **tactile probe** provides the local "cutaneous" information about the touched area of the object.

A **robotic carrier** providing the "kinesthetic" capability is used to move the tactile probe around on the explored object surface and to provide the contact force needed for the probe to extract the desired cutaneous information (e.g. local 3D geometric shape, elastic properties, and/or termic impedance) of the touched object area .

The local *information provided by the tactile probe is integrated with the kinesthetic position parameters of the carrier* resulting in a *composite* **haptic model** (global geometric and elastic profiles, termic impedance map) of the explored 3D object.



Bio-inspired robot haptic perception system consists of a **robotic finger-like articulated structure** with instrumented **passive-compliant element** 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 robotic finger.





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.

The tactile probe is based on a 16-by-16 matrix of **Force Sensing Resistor (FSR)** elements spaced 1.58 mm apart on a 6.5 cm2 (1 sq. inch) area.

The FSR elements have an exponentially decreasing electrical resistance with applied normal force: the resistance changes by two orders of magnitude over a pressure range of 1 N/cm2 to 100 N/cm2.





Tactile probe for object surface inspection.

It consists of a **force sensitive transducer** and an **elastic overlay** that provides a *geometric profile-to-force* transduction function .





2D- SAMPLING ELASTIC OVERLAY

The *elastic overlay* has a protective damping effect against impulsive contact forces and its elasticity resets the transducer when the probe ceases to touch the object.

The crosstalk effect present in one piece elastic pads produces considerable blurring distortions. It is possible to reduce this by using a *custom-designed elastic overlay* consisting of a relatively thin membrane with protruding round tabs. This construction allows free space for the material to expand in the *x* and *y* directions allowing for a compression in the *z* direction proportional with the stress component along this axis.



Block-diagram of the **tactile sensor interface** (from [C. Pasca, *Smart Tactile Sensor*, M.A.Sc. Thesis, University of Ottawa, 2004])





Composite tactile image of an edge

- (a) after median filtering, and
- (b) after applying Sobel gradient operators



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



Feeling the temperature and thermal conductivity of the touched object surface. Rufini corpuscles-like

thermistors and a blood-vessel like source of heat (the white coloured tube) distributed within the tactile sensor's elastic skin.

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

Sensor Enabled Robotic Telemanipulation

Robotic dexterous manipulation

is an object-oriented act which requires not only specialized *robotic hands with articulated fingers* but also *tactile, force and kinesthetic sensors* for the precise control of the forces and motions exerted on the manipulated object. As fully autonomous robotic dexterous manipulation is impractical in changing and unstructured environments, an alternative approach is to *combine the low-level robot computer control with the higher-level perception and task planning abilities of a human operator* equipped with adequate *human computer interfaces* (HCI).



Telemanipulation systems should have a bilateral architecture that allows a *human operator* to *connect in a transparent manner to a remote robotic manipulator*.

□ Human Computer Interfaces (HCI) should provide easily perceivable and *task-related sensory displays (monitors) which fit naturally* the perception capabilities of the human operator.

❑ The potential of the emergent haptic perception technologies is significant for applications requiring object telemanipulation such as: (i) robot-assisted handling of materials in industry, hazardous environments, high risk security operations, or difficult to reach environments, (ii) telelearning in hands-on virtual laboratory environments for science and arts, (iii) telemedicine and medical training simulators.



System architecture

Robot arm with tendon driven compliant wrist

Haptic & Visual Telerobotic System (from E.M. Petriu, D.C. Petriu, V. Cretu, "Control System for an Interactive Programmable Robot," *Proc. CNETAC Nat. Conf. Electronics, Telecommunications, Control, and Computers*, pp. 227-235, Bucharest, Romania, Nov. 1982).



Haptic Telerobotic System: (a) the tactile probe, and (b) the tactile human feedback (from E.M. Petriu, D.C. Petriu, V. Cretu, "Control System for an Interactive Programmable Robot," *Proc. CNETAC Nat. Conf. Electronics, Telecommunications, Control, and Computers*, pp. 227-235, Bucharest, Romania, Nov. 1982.)



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



A desktop *hapto-visual human interface* allows a human teleoperator to experience the haptic feeling profiles at the point of contact as well as to see the image of a larger area around the point of contact on the explored object as captured by a video camera mounted on the robot manipulator. It includes a *PHANTOM® 6DOF* haptic device representing the **handheld replica of the probing rode** that provides the haptic feedback consisting of the 3D geometric coordinates of the point of contact measured by the laser range finder system and the force vector and torque components measured by the 6 DOF force-torque sensor at the point of contact.

Immersionn_3D Interaction <http://www.immersion.com/>





CyberTouch™



CyberGrasp™



CyberForce®



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

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- 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	<u>.</u>

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









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



• Person Independent



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 Comer 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%							

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 Comer Puller	17	13	0	4	0	76.4%
15	Lip Comer 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 10¹¹ highly connected neurons (approx. 10⁴ connections per neuron).

Analog/Random-Pulse Conversion



Random-Pulse/Digital Conversion

The *deterministic component of the random-pulse sequence*, conveniently unbiased and rescaled for this purpose to take values +1 and -1 (instead of 1 and respectively 0), can be calculated as a **statistical estimation** from the quantization diagram:

$$E[VRP] = (+1) .p[VR>=0] + (-1) .p[VR<0] = p(VRP) - p(VRP')$$

= (FS+V)/(2.FS) - (FS-V)/(2.FS) = V/FS;

This finally gives the deterministic analog value V associated with the binary VRP sequence:

V = [p(VRP) - p(VRP')] . FS;

where the apostrophe (') denotes a logical inversion.

Random-Pulse/Digital Conversion using the Moving Average Algorithm .



$$V *_{N} = \frac{1}{N} \sum_{i=1}^{N} VRP_{i} = \frac{1}{N} (\sum_{i=1}^{N-1} VRP_{i} + VRP_{N});$$
$$V *_{N} = V *_{N-1} + \frac{VRP_{N} - VRP_{0}}{N};$$

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



Stochastic Data Representation



Generalized b-bit analog/random-data conversion

E.M. Petriu, L. Zhao, S.R. Das, V.Z. Groza, A. Cornell, "Instrumentation Applications of Multibit Random-Data Representation," *IEEE Trans. Instrum. Meas.*, Vol. 52, No. 1, pp. 175-181, 2003.



Neural Network Architectures Using Stochastic Data Representation



Neural Network for Pattern Recognition

Auto-associative memory NN architecture









30



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) +

 $[x(j)-x(B)] \cdot [y(B)-x(A)] / [x(A)-x(B)]$

CONTINUOUS MODEL

 NO sampling => NO INTEPPOLATION COST



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.

NN Modelling of 3D Object Shapes

Compare the performance of three NN architectures used for 3D object shape modelling:

- Multilayer Feedforward (*MLFF*)
- Self-Organizing Map (SOM)
- Neural Gas Network

A.-M. Cretu, E.M. Petriu, G.G. Patry, "Neural-Network-Based Models of 3-D Objects for Virtualized Reality: A Comparative Study," *IEEE Trans. Instrum. Meas.,*" Vol. 55, No. 1, pp.99-111, 2006.



MLFF Representation - Results

SOM and Neural Gas Modelling - Results





	2.4%	4.9%	1.6%	99.1%
	93.3%	3.3%	91.7%	3.1%
	95%	99.1%	5.78%	98.3%
	91.7%	6.6%	1.6%	92.5%
a for the second				

1111





Elastic ball used for experimentation.

Sampling points selected with the neural gas network for the ball.

(from A.M. Cretu, E.M. Petriu, P.Payeur "Neural Network Mapping and Clustering of Elastic Behavior from Tactile and Range Imaging for Virtualized Reality Applications," submitted to *IEEE Tr. Instr. Meas.*, Nov. 2006).



Real and modeled deformation curves using neural network for rubber under forces applied at different angles:

- a) F=65N, α_1 =10° and F=65N, α_2 =170°,
- b) F=36N, α_1 =25°, and F=36N, α_2 =155

(from .A.M. Cretu, E.M. Petriu, P.Payeur "Neural Network Mapping and Clustering of Elastic Behavior from Tactile and Range Imaging for Virtualized Reality Applications," submitted to *IEEE Tr. Instr. Meas.*, Nov. 2006).

MLFF, SOM, and *Natural Gas* Modelling Performance Comparison: Construction Time

(min) 350 300 **Construction time** 250 200 150 100 50 0 hand pliers face statue **Models**

■MLFFNN ■SOM ■Neural Gas

MLFNN

 computational time = construction time + generation time+rendering

SOM and Neural Gas

 computational time = construction time + rendering *MLFF, SOM,* and *Natural Gas* Modelling Performance Comparison: Compactness



MLFF, SOM, and *Natural Gas* Modelling of 3D Objects - conclusions -

* The use of neural network modeling is advantageous from the point of view simplicity and compactness.

* *MLFNN* – provide continuous models, information on the entire object space, convenient for many applications, however they are time consuming.

* SOM and Neural Gas – provide compressed models while maintaining the properties of the objects, have very good accuracy, and they are less time consuming

* The use of any specific techniques depends on the application requirements.





Neural Network Classification of Brain-Computer Interface Data for the Telecontrol of Symbiotic Sensor Agents

Our Brain-Computer Interfaces (BCI) system is based on the well-known oddball paradigm that uses a positive deflection in EEG signal of about 300ms (P300) after rare expected stimuli is evoked. The advantage is

that subjects do not have to be trained



to generate the P300 effect as it occurs naturally in human subjects. We are using auditory stimuli to generate the P300 responses and a less computationally intensive MLP feed-forward NN for the classification of the EEG responses. In our experimental setup a human teleoperator equipped with visual and audio HCI, and a BCI controls at the strategic level the movements of an intelligent semi-autonomous RSA equipped with an on board camera and three IR sensors that semi- autonomously navigates through a maze using a tactical-level obstacle-avoidance algorithm

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 human hand."

"The hand has two main unique features," explained Stuart Mead, i-LIMB HAND GRIPS CEO of Touch Bionics. Individual motor for each digit "The first is that we put a Key motor into each finger, which means that each finger is independently driven and can articulate. "The second is that the Precision thumb is rotatable through 90 degrees, in Fully articulated the same way as our joints thumbs are "The hand is Sensors in socket pick up myoelectric Power the first prosthetic hand signals from arm muscles to make that replicates both the full range of movements SOURCE: Touch Bionics form and the function of



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.



Man versus machine

Tiny machines could roam the body curing diseases

"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".





Asimov's laws of the robotics:

Oth 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".

[*] 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] ???

Will we humans one day truly love robots just like we love other humans? <u>http://blogs.spectrum.ieee.org/automaton/2008/04/08/</u> will_we_humans_one_day_truly_love_robots_just_like_we_love_other_humans.html



Thank you!