Bio-Inspired Robot Sensing and Control Solutions

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photo by Peter Thornton, *uOttawa Gazette*

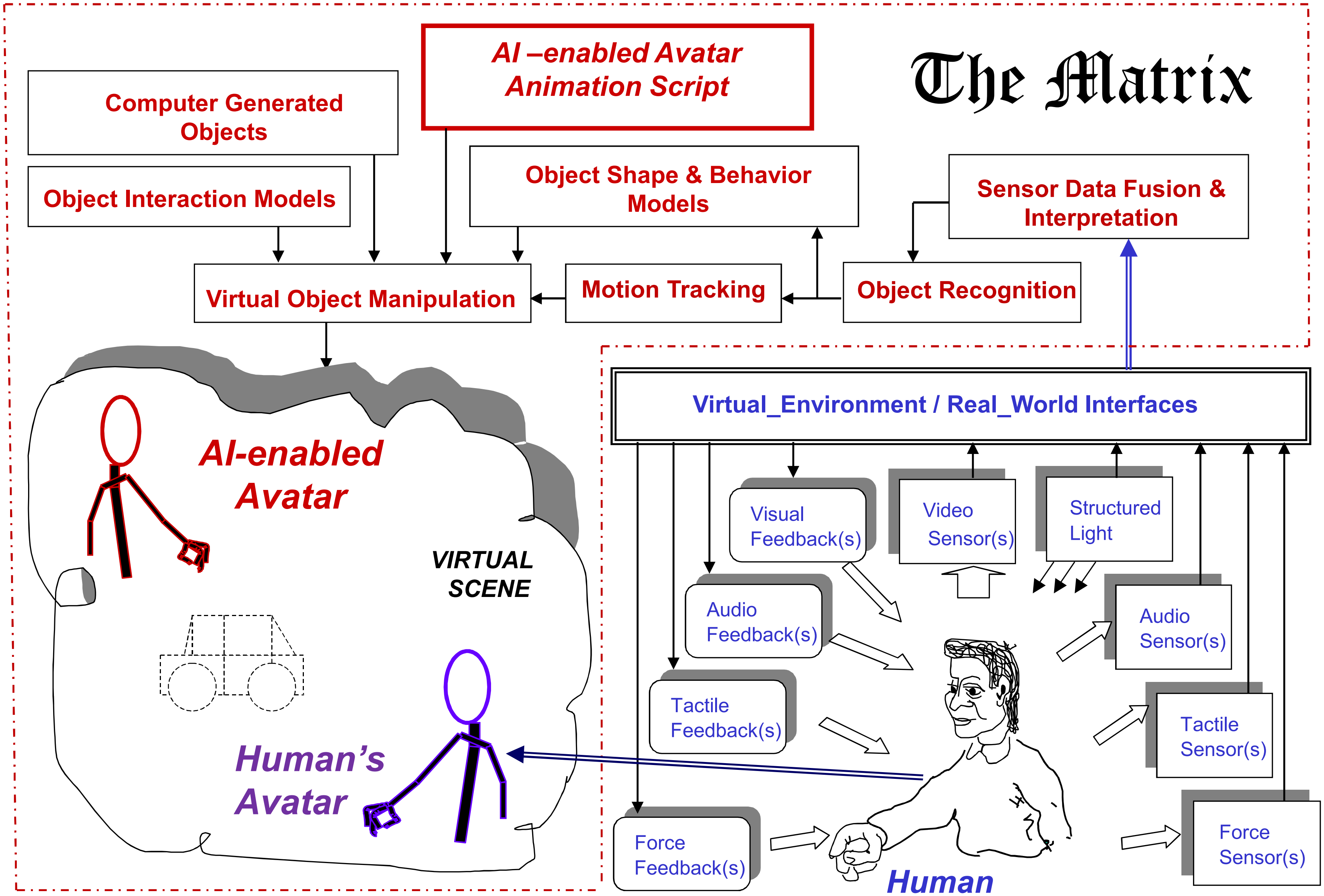
In order to naturally blend within human society, **the new-generation robots should not only look as humans, but should also behave as much as possible as humans.** They are expected to be, as initially *imagined by Čapek in his R.U.R. Rossum's Universal Robots* play, anthropomorphic artefacts, **androids,** enabled to think on their own and *governed by Asimov's laws of robotics hardwired into every robot's positronic brain.*

While for a long time, engineers have built upon mathematics, physics and chemistry in order to develop an ever growing variety of industrial artefacts and machines, this approach cannot anymore rise to the challenge of designing these androids.

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

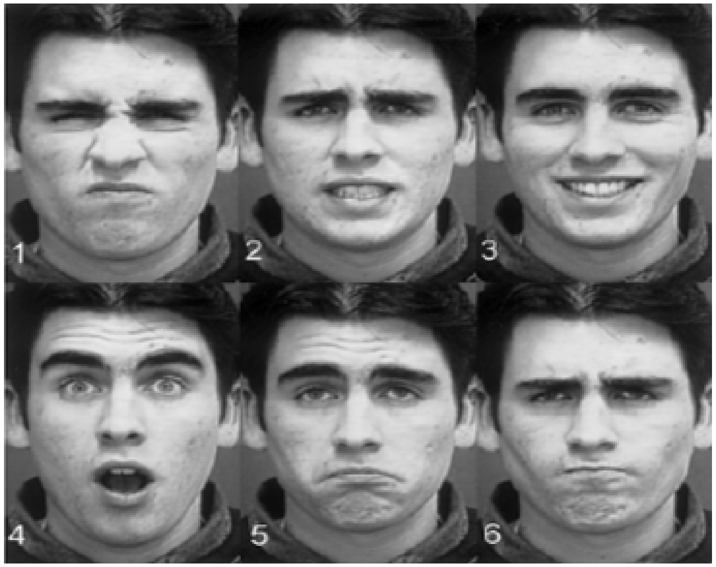
Advocating this emergent trend, this presentation will discuss a number of relevant issues such as bio-inspired robot sensors and neural networks, human-robot interaction techniques for symbiotic partnership, as well as moral, ethical, theological, legal, and social challenges in a soon-to-be cyborg-society world.

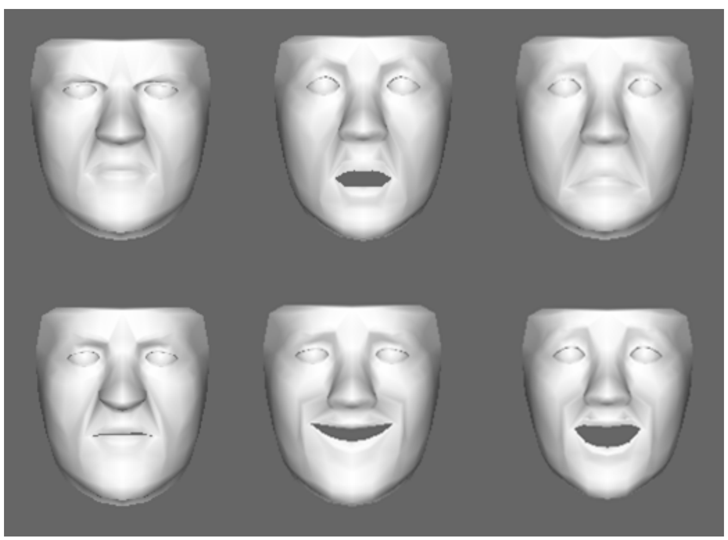
… HUMANS GETTING INTO THE MATRIX AS AVATARS



AI –enabled Avatar Animation Script
The Matrix
Computer Generated Objects
Object Interaction Models
Object Shape & Behavior Models
Sensor Data Fusion & Interpretation
Virtual Object Manipulation
Motion Tracking
Object Recognition
AI-enabled Avatar
VIRTUAL SCENE
Human's 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

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,

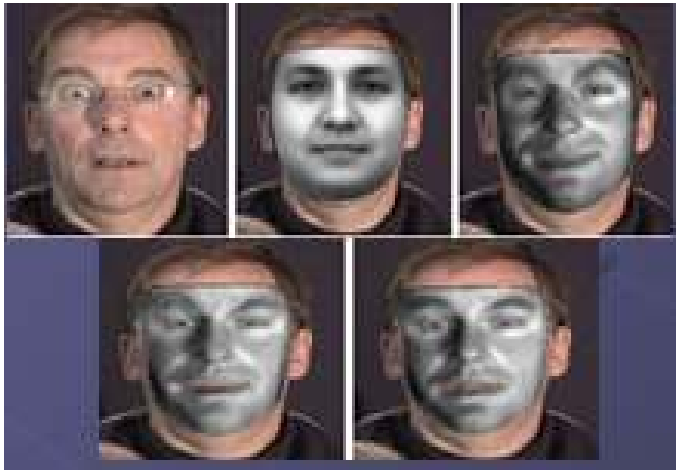
M.D. Cordea, E.M. Petriu, D.C. Petriu, "Three-Dimensional Head Tracking and Facial Expression Recovery Using an Anthropometric Muscle-Based Active Appearance Model," *IEEE Trans. Instrum. Meas.*, vol. 57, no. 8, pp. 1578 – 1588, 2008.

Facial Expression Recognition

- Person Dependent

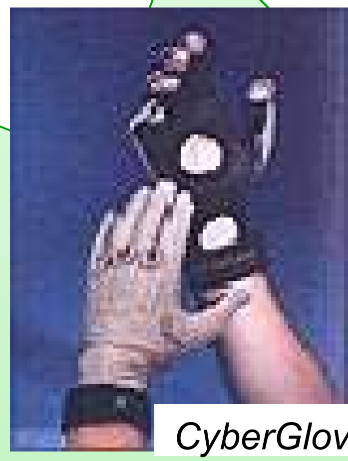
AU	Signification	No.	Correct	False	Missed	Confused	Recognition Rate
0	Neutral	20	19	1	0	0	95%
1	Inner Brow Raiser	24	21	0	3	0	87.5%
2	Outer Brow Raiser	52	41	1	9	1	78.8%
4	Brow Lowerer	42	41	0	0	1	97.6%
12	Lip Corner Puller	51	48	3	0	0	94.1%
15	Lip Corner Depressor	18	17	0	1	0	94.4%
26	Jaw Drop	74	55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

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

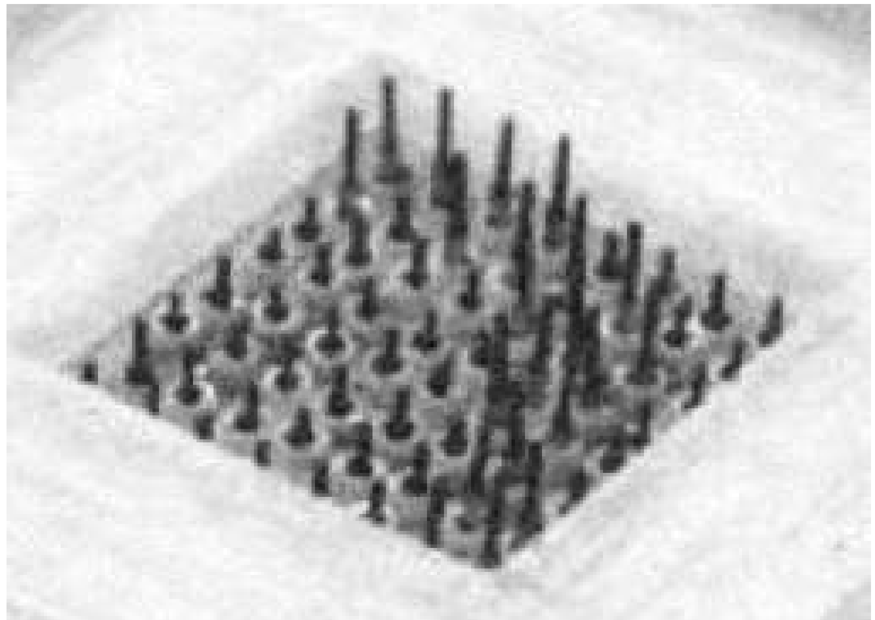


CyberGlove®

CyberTouch™

CyberGrasp™

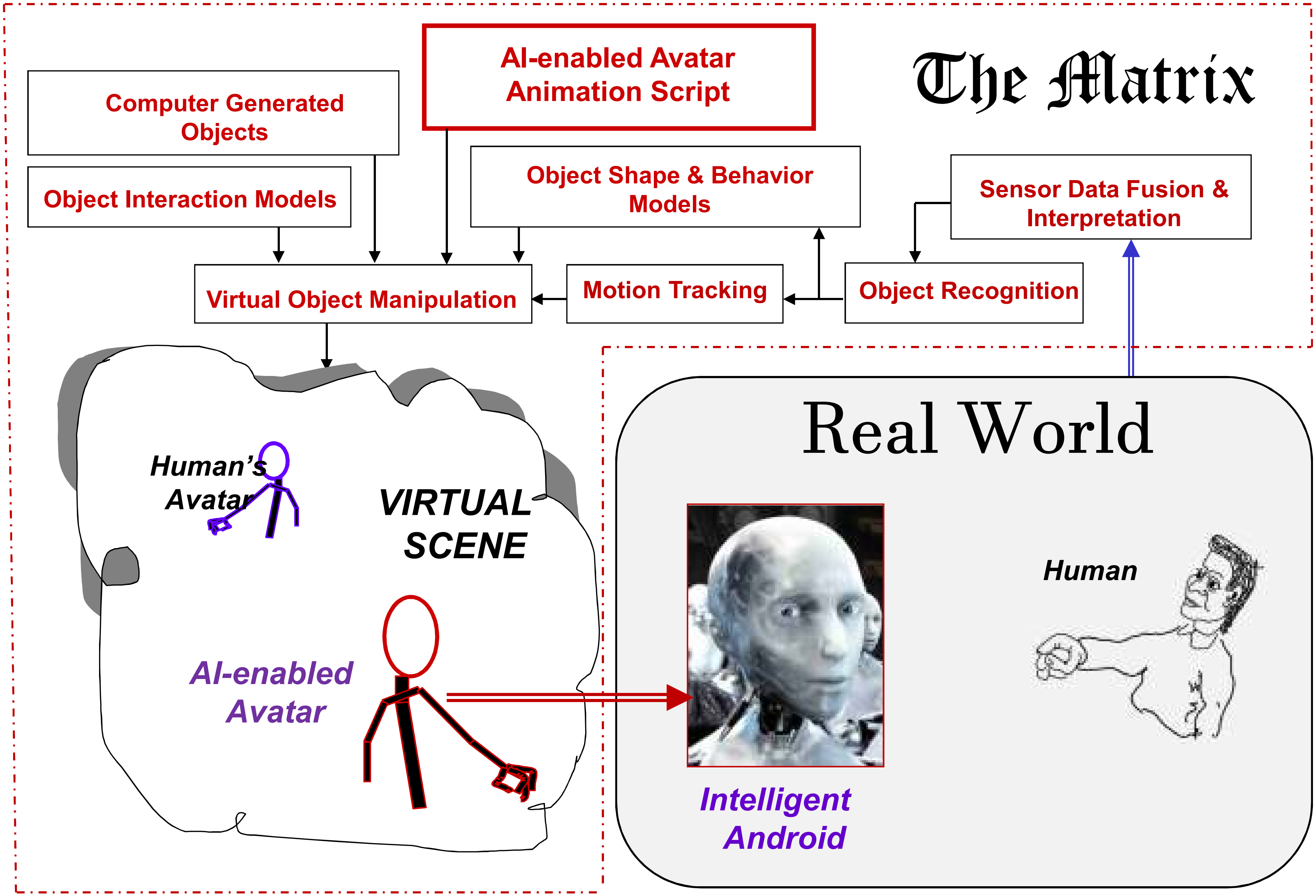
CyberForce®



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 (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.)

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.

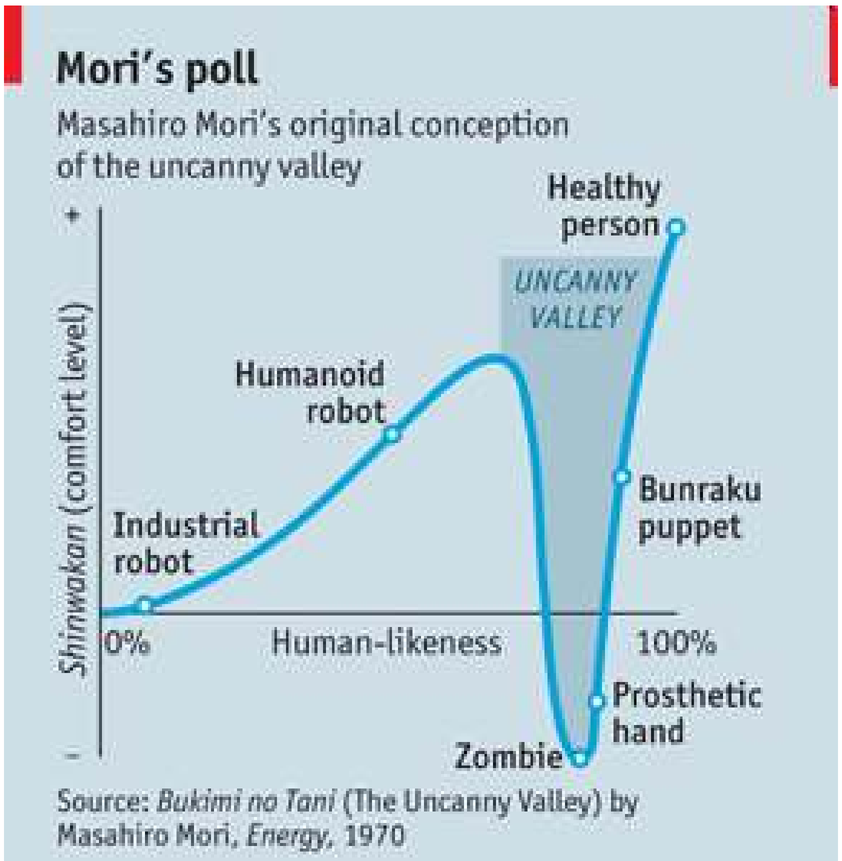
… AI – ENABLED AVATARS GETTING OFF THE MATRIX AS INTELLIGENT ANDROIDS



***Matrix*-trained, AI – enabled, avatar gets into the *Real World* as an intelligent android able to interact and collaborate with humans**

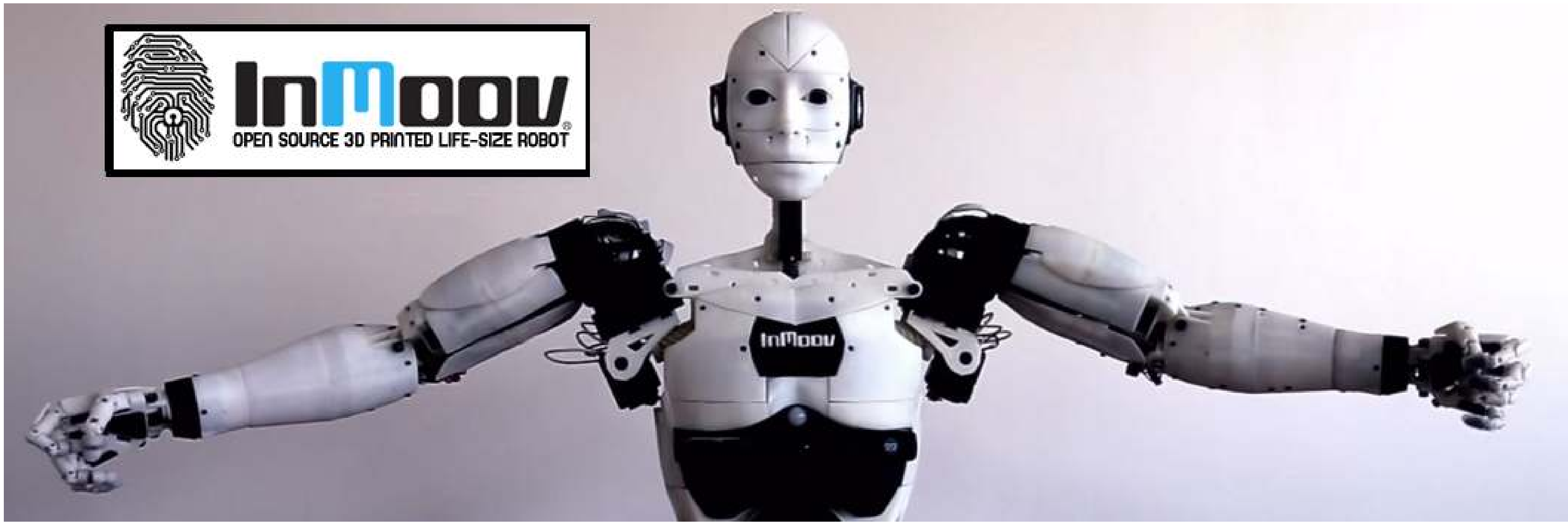
Crossing the uncanny valley: As computer graphics and robots get more human, they often seem more surreal

[*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



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

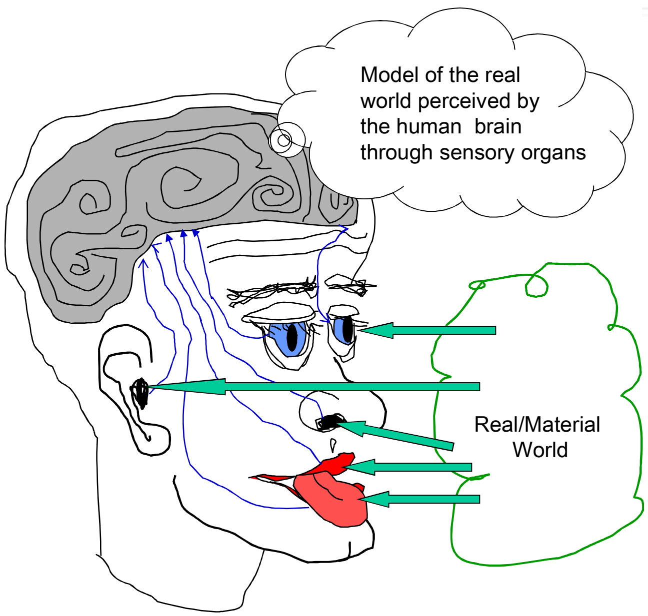
"*Gael Langevin* is a French model maker and sculptor. He works for the biggest brands since more than 25 years. *InMoov* is his personal project, it was initiated in January 2012 *InMoov* is the first Open Source 3D printed life-size robot. Replicable on any home 3D printer with a 12x12x12cm area, it is conceived as a development platform for Universities, Laboratories, Hobbyist, but first of all for Makers."

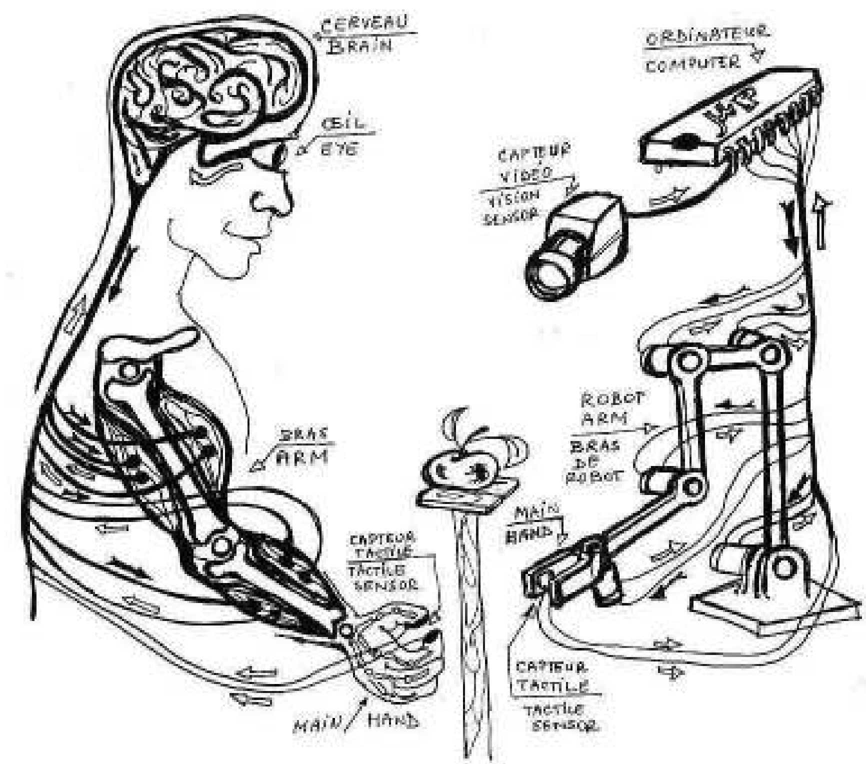
https://www.youtube.com/watch?v=JKtHCFToYPY

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**.

Biology-Inspired Robot Perception & Action Mechanisms for Androids

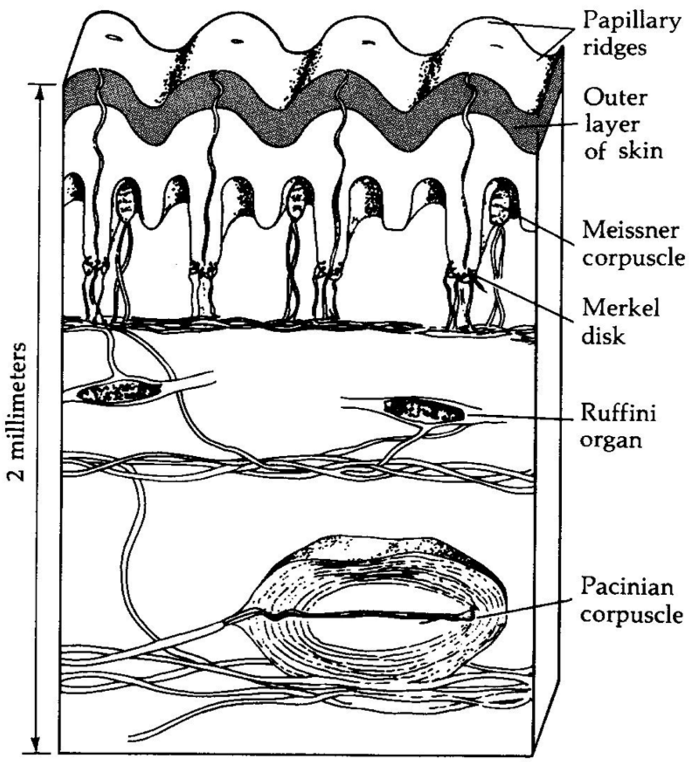




BIO-INSPIRED ROBOT SENSING AND ACTUATION

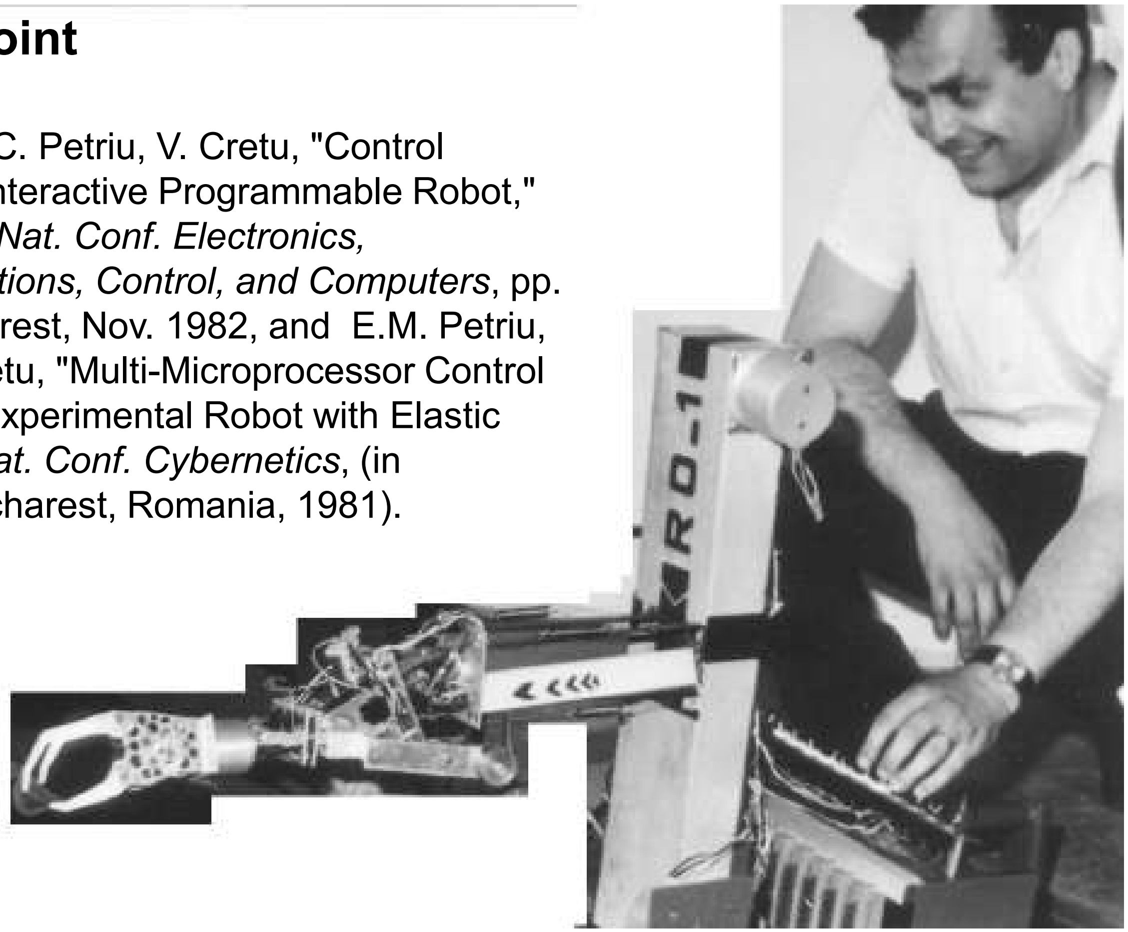
Human Tactile Sensing

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)

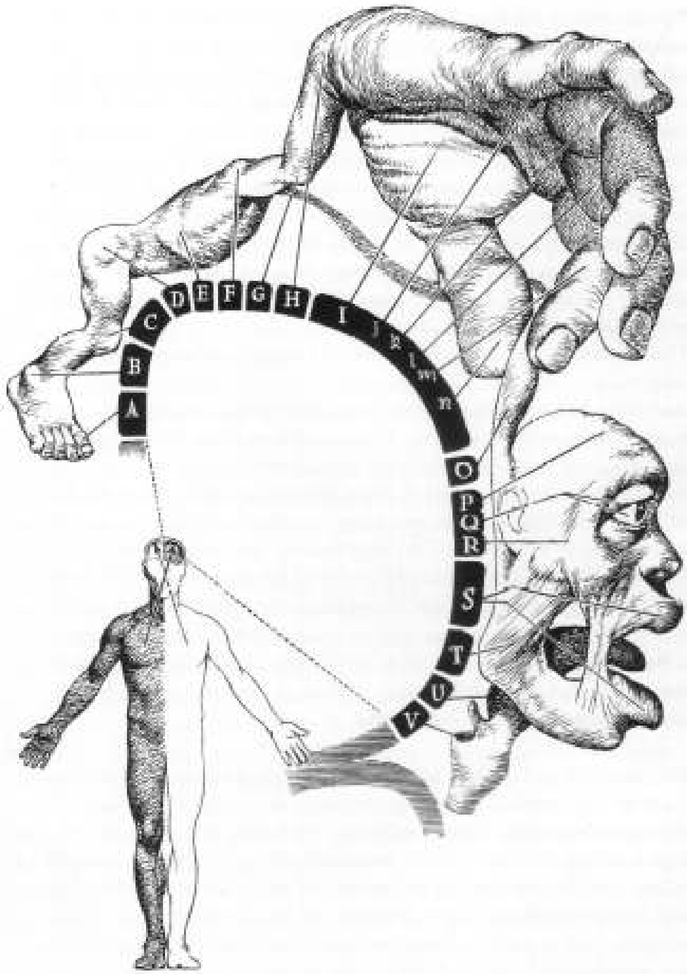


Robot arm with tendon driven compliant joint

(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, Nov. 1982, and E.M. Petriu, D. Petriu, V. Cretu, "Multi-Microprocessor Control System for an Experimental Robot with Elastic Joints," *Proc. Nat. Conf. Cybernetics*, (in Romanian), Bucharest, Romania, 1981).

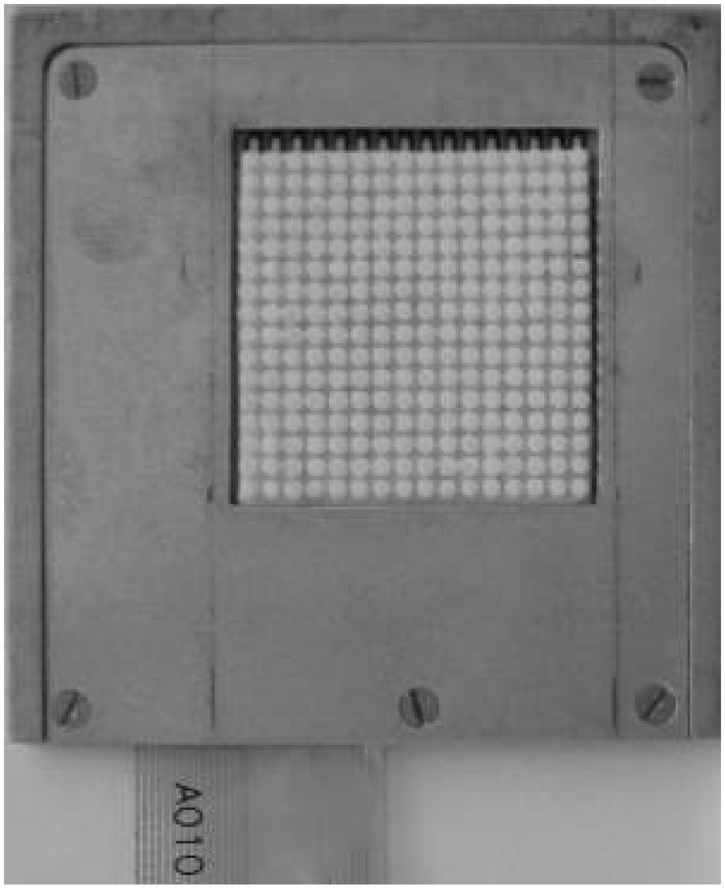


Bio-Inspired Sensing & Perception



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]

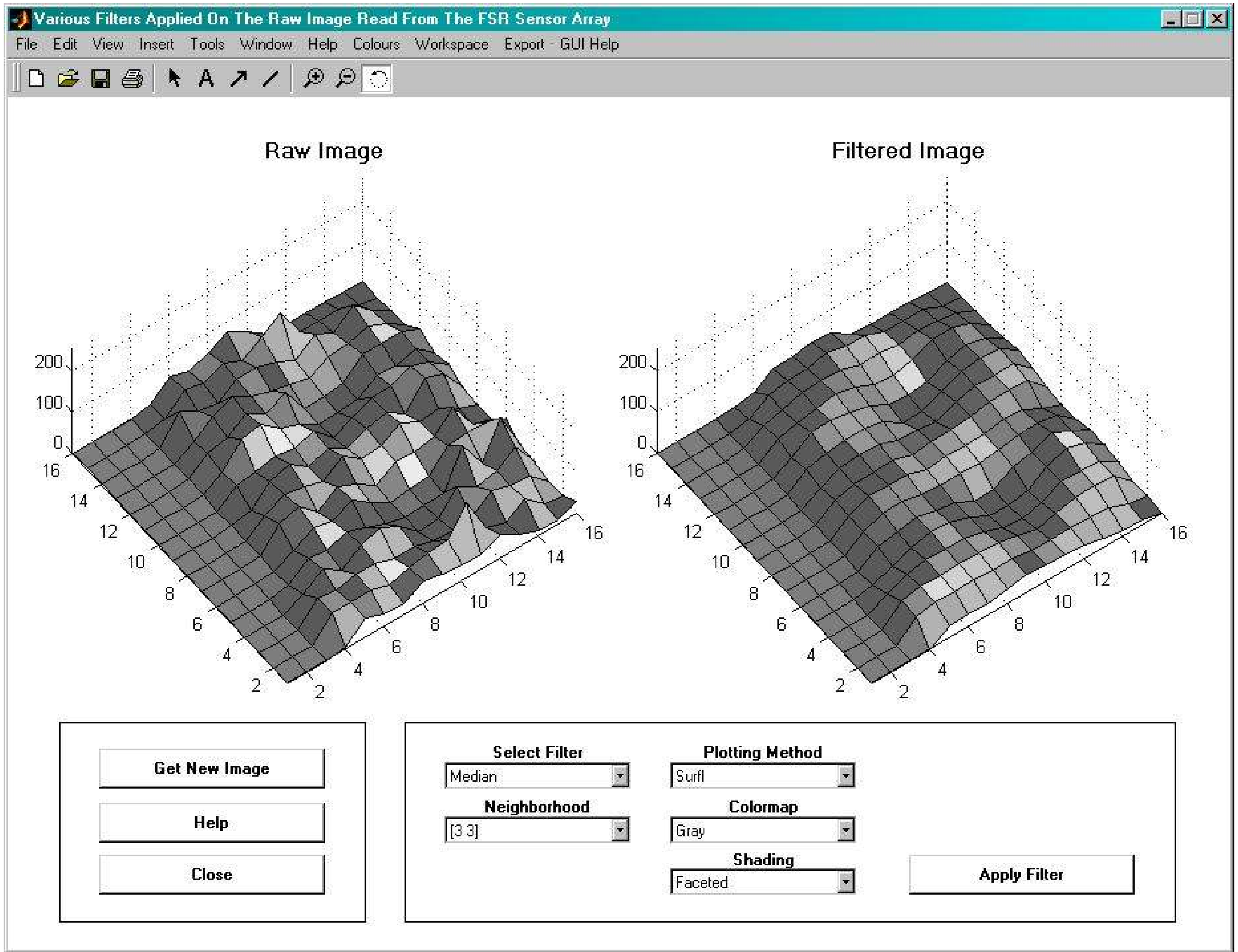


Tactile Sensor

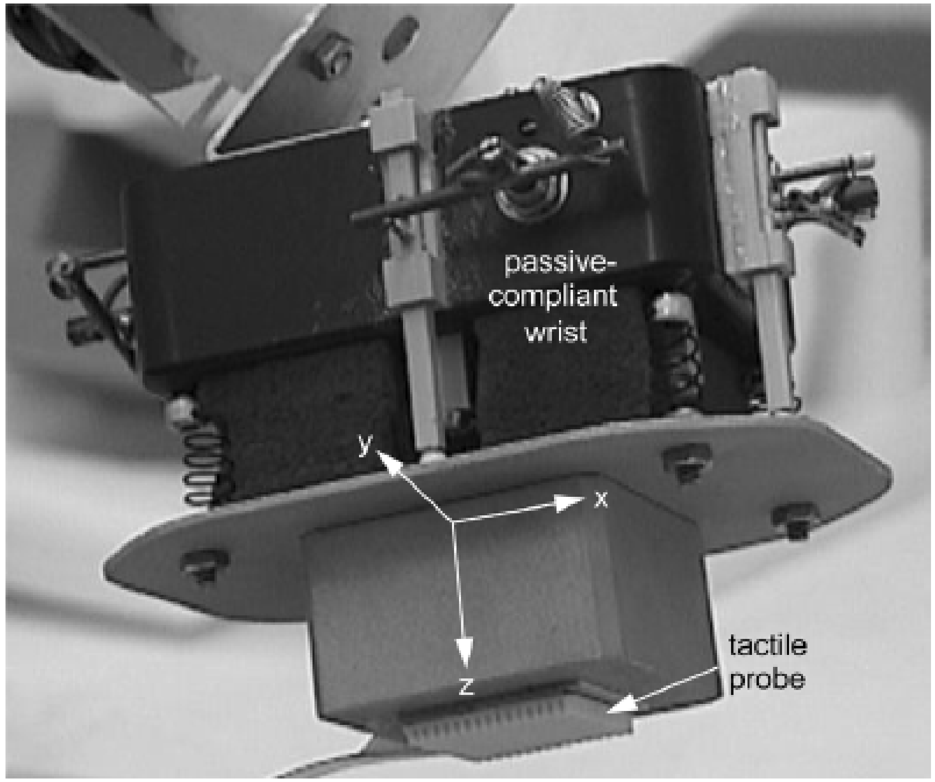
The tabs of the elastic overlay are arranged in a 16-by-16 array having a tab on top of each node of **Merkel's disk-like matrix of FSR elements** sensing sustained pressure and shapes.

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.

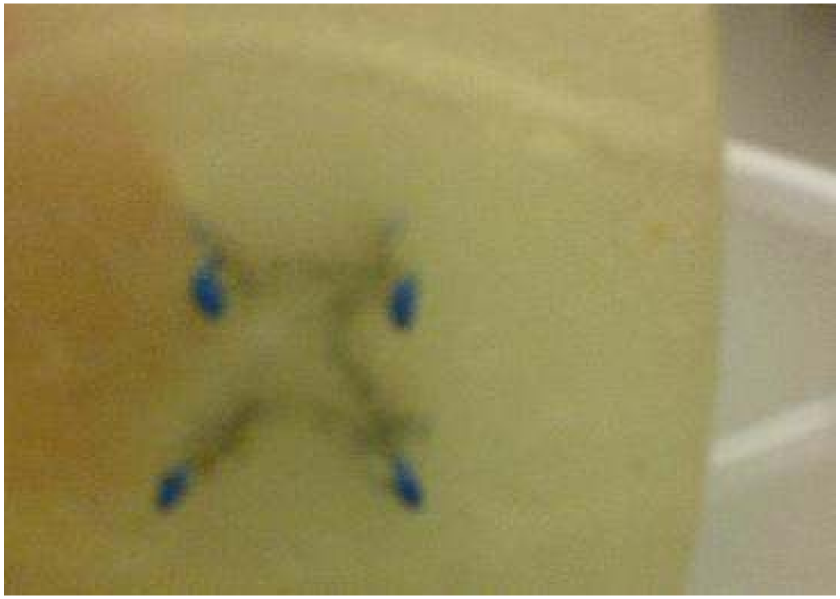
- P. Payeur, C. Pasca, A.-M.Cretu, E.M. Petriu, “Intelligent Haptic Sensor System for Robotic Manipulation,” *IEEE Trans. Instrum. Meas.*, Vol. 54, No. 4, pp. 1583 – 1592, 2005,
- W.S. McMath, S.K.S. Yeung, E.M. Petriu, "Tactile Sensing for Space Robotics," *Proc. IMTC/89, IEEE Instrum. Meas. Technol. Conf.*, pp.128-131, Washington, DC., 1989.



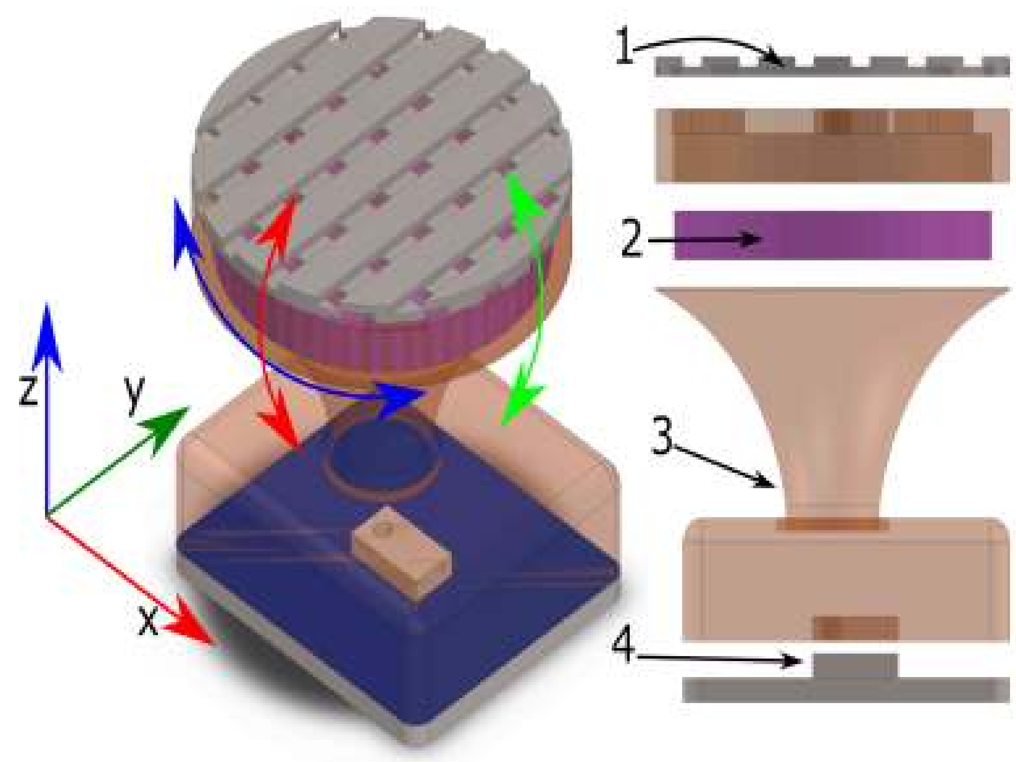
Example of GUI window (from [C. Pasca, *Smart Tactile Sensor*, M.A.Sc. Thesis, University of Ottawa, 2004])



Bio-inspired robot passive-compliant wrist allowing the tactile 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.



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.

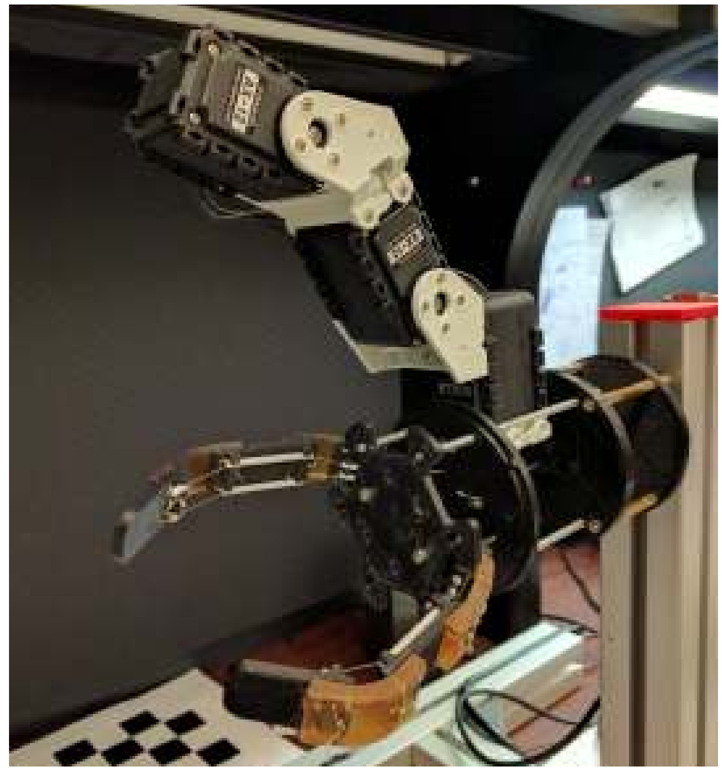


Bio-Inspired Tactile Sensing Module: (1) Merkel disk- and Meissner corpuscle–like shape, pressure, local skin deformation, and slippage sensitive tactile array - 32 taxels; (2) Rufinni corpuscle–like vibration and stretch sensitive MARG sensor; (3) compliant structure; (4) Pacinian corpuscule-like deep pressure sensor;

[from T.E. Alves de Oliveira, A.-M. Cretu, E.M. Petriu, "Multimodal Bio-Inspired Tactile Sensing Module," *IEEE Sensors Journal*, Vol. 17, Issue 11, pp. 3231 – 3243, 2017]

Multi-Finger Dexterous Robot Hand

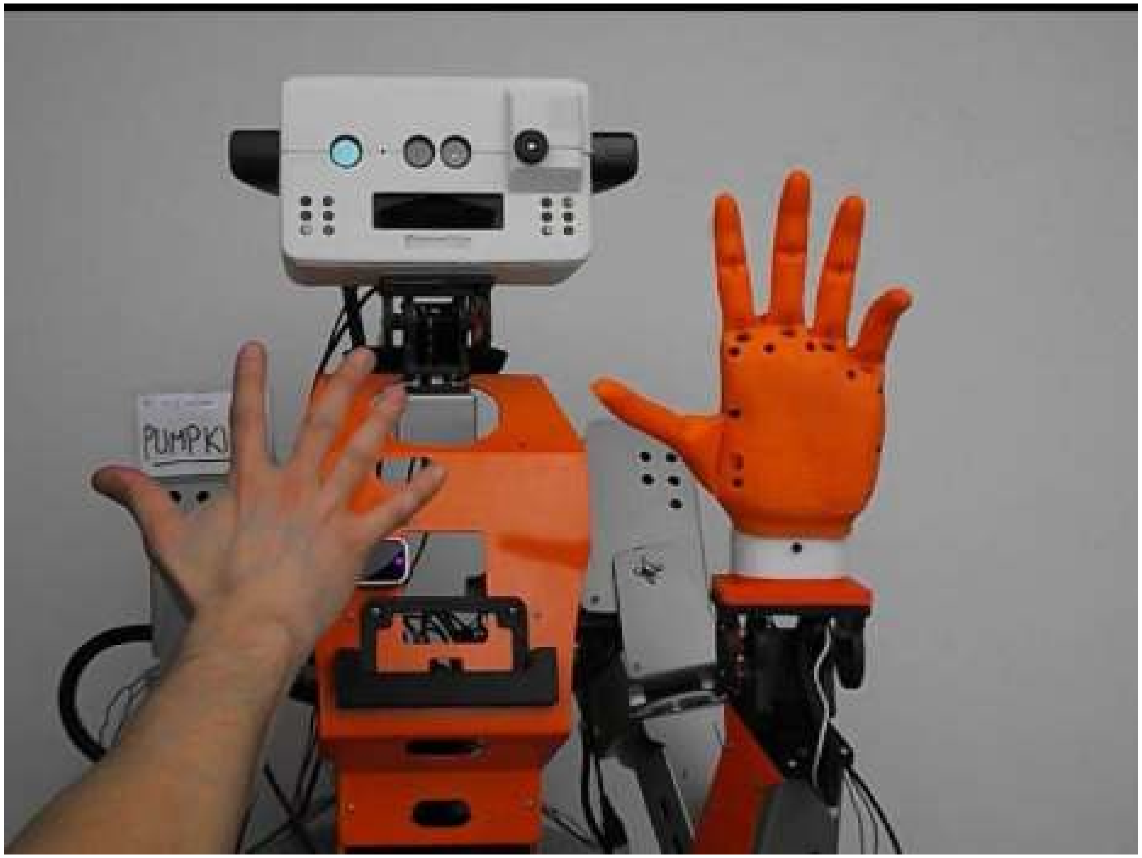
Vision, tactile, and flex joint sensors allow tracking finger phalanges' position, provide information of the object's unknown orientation for in-hand manipulation by **the two -finger underactuated hand with a fully-actuated intelligent thumb** capable of trajectory planning. A **fuzzy logic controller** allows to obtain a stable grasp After grasp, the manipulate object can be reoriented by the thumb taking advantage of the compliance of the flex joint fingers



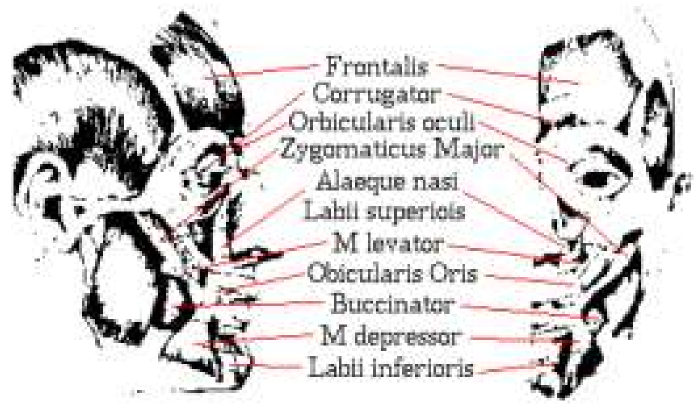
[from V. Prado da Fonseca, D.J. Kucherhan, T. E. Alves de Oliveira, D. Zhi, E.M. Petriu "Fuzzy Controlled Object Manipulation using a Three-Fingered Robotic Hand," 10th *Annual IEEE Int. Systems Conference - SysCon 2017*, pp. 346 - 351, Montreal, Que, April 2017].

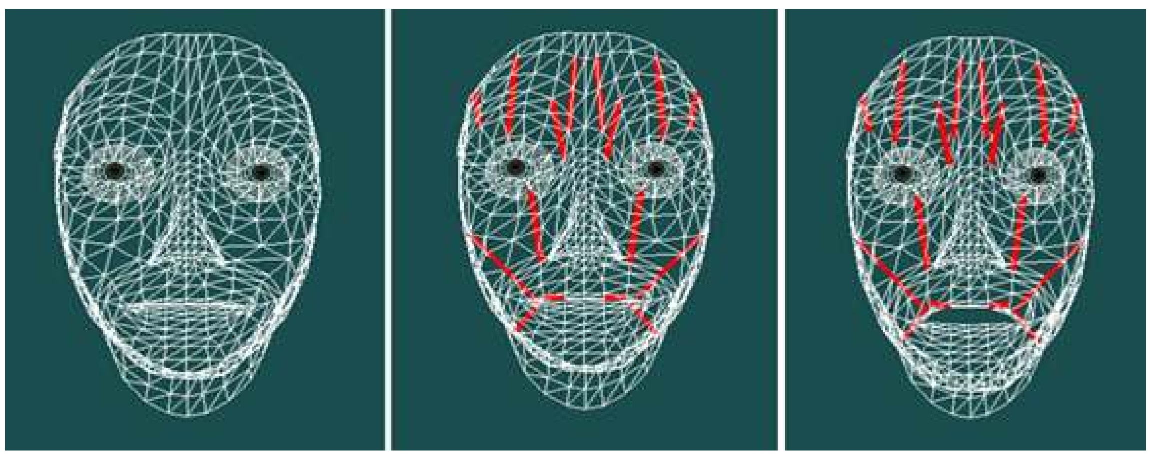
Vision- and *Cyberglove-Based* Control of Five-Finger Robot Hand

https://www.youtube.com/watch?v=Q89jhZHZ_hw

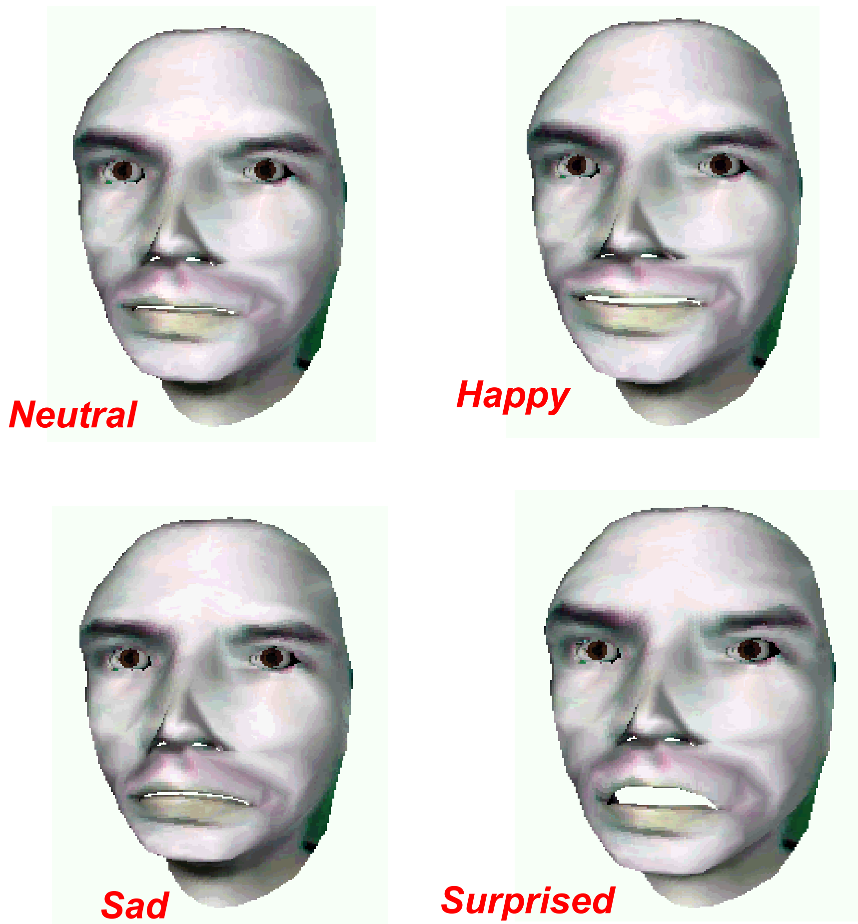


Avatar Face





3D generic face deformed using muscle-based control



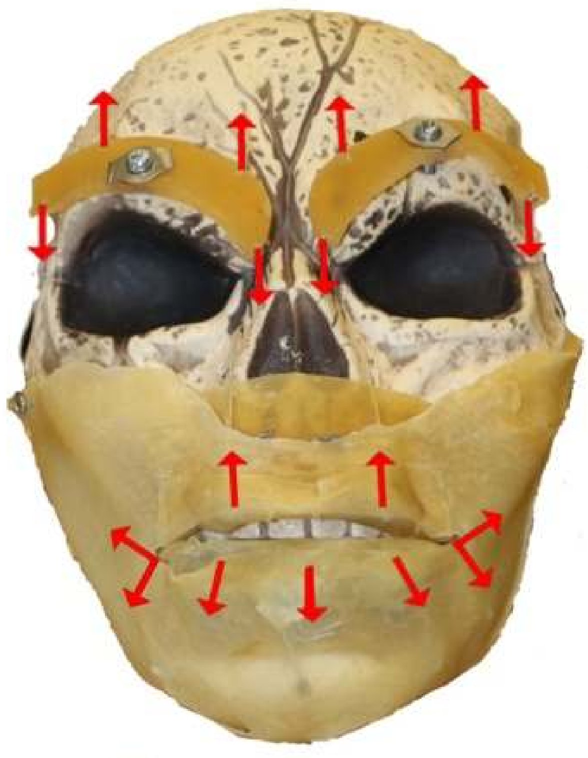
Combining muscle actions it becomes possible to obtain a variety of ***facial expressions*** of Marius' avatar:

M.D. Cordea, E.M. Petriu, "A 3-D Anthropometric-Muscle-Based Active Appearance Model**,"** *IEEE Trans. Instrum. Meas.,* Vol. 55, No. 1, pp. 91 - 98, 2006.

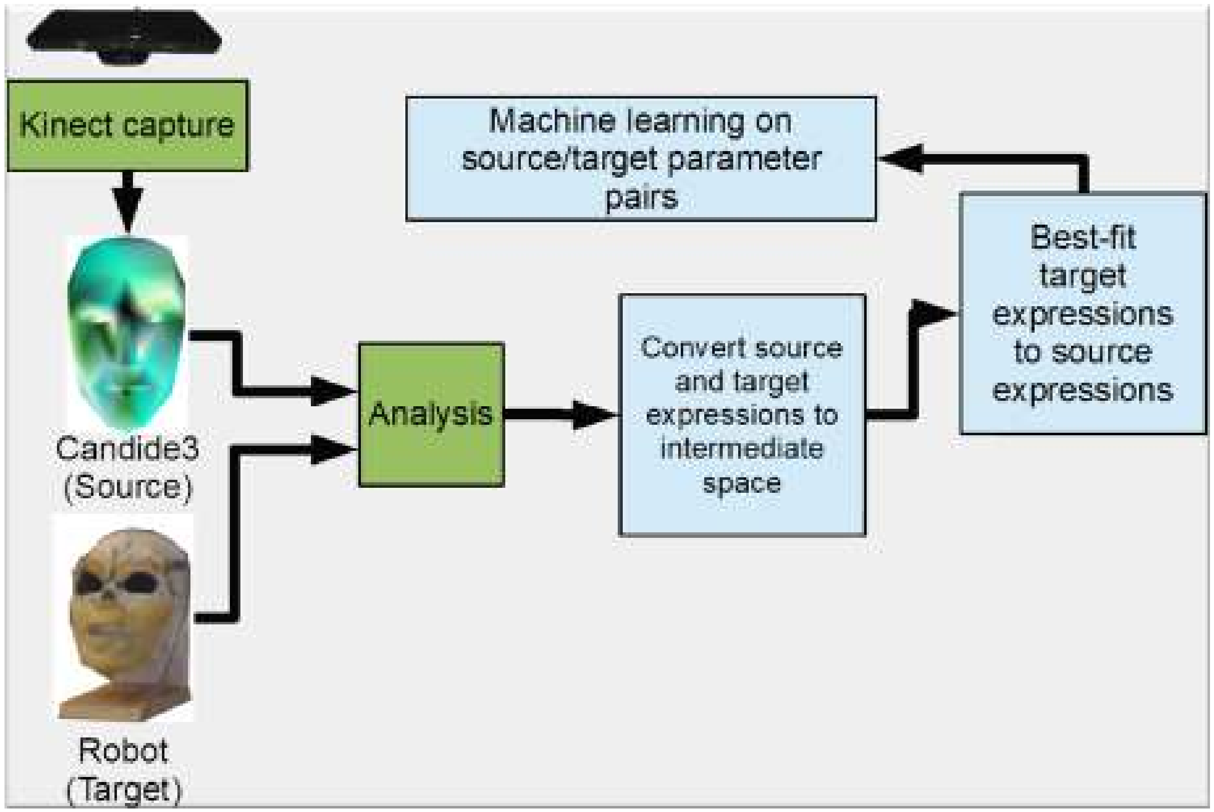
Expressive Android Face

https://www.youtube.com/watch?v=za-WWPVRSEw

by Erbene de Castro Maia Jr. and Lidia Brigido Santiago Melo .

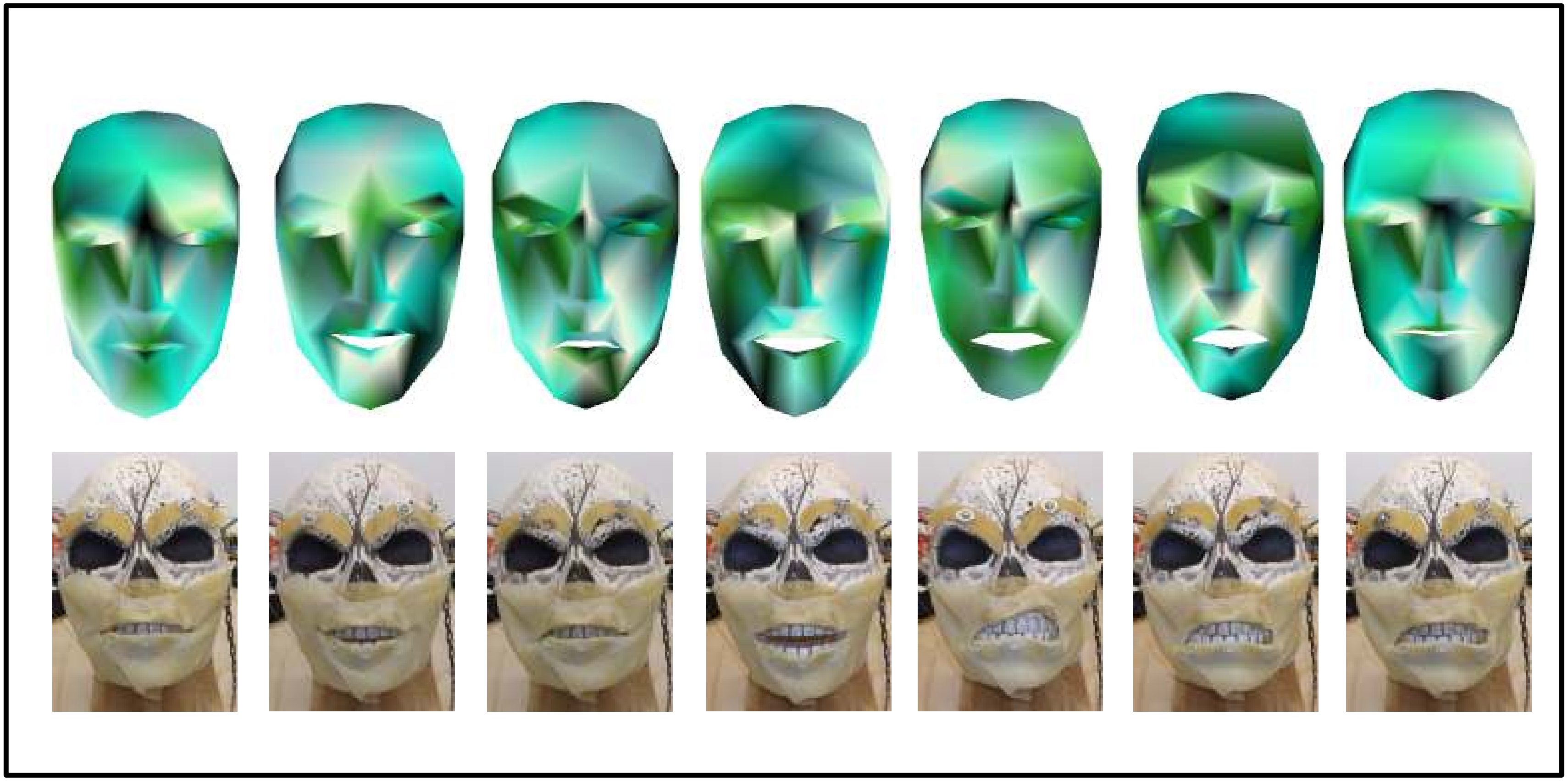


P. Santos, E. de Castro Maia Jr., M, Goubran, E.M. Petriu, “Facial Expression Communication for Healthcare Androids,” *Proc. MeMeA2013, 8th IEEE Int. Symp. on Medical Measurement and Applications*, pp. 44-48, Ottawa, ON, Canada, May 2013



P. Santos, E. de Castro Maia Jr., M, Goubran, E.M. Petriu, “Facial Expression Communication for Healthcare Androids,” *Proc. MeMeA2013, 8th IEEE Int. Symp. on Medical Measurement and Applications*, pp. 44-48, Ottawa, ON, Canada, May 2013

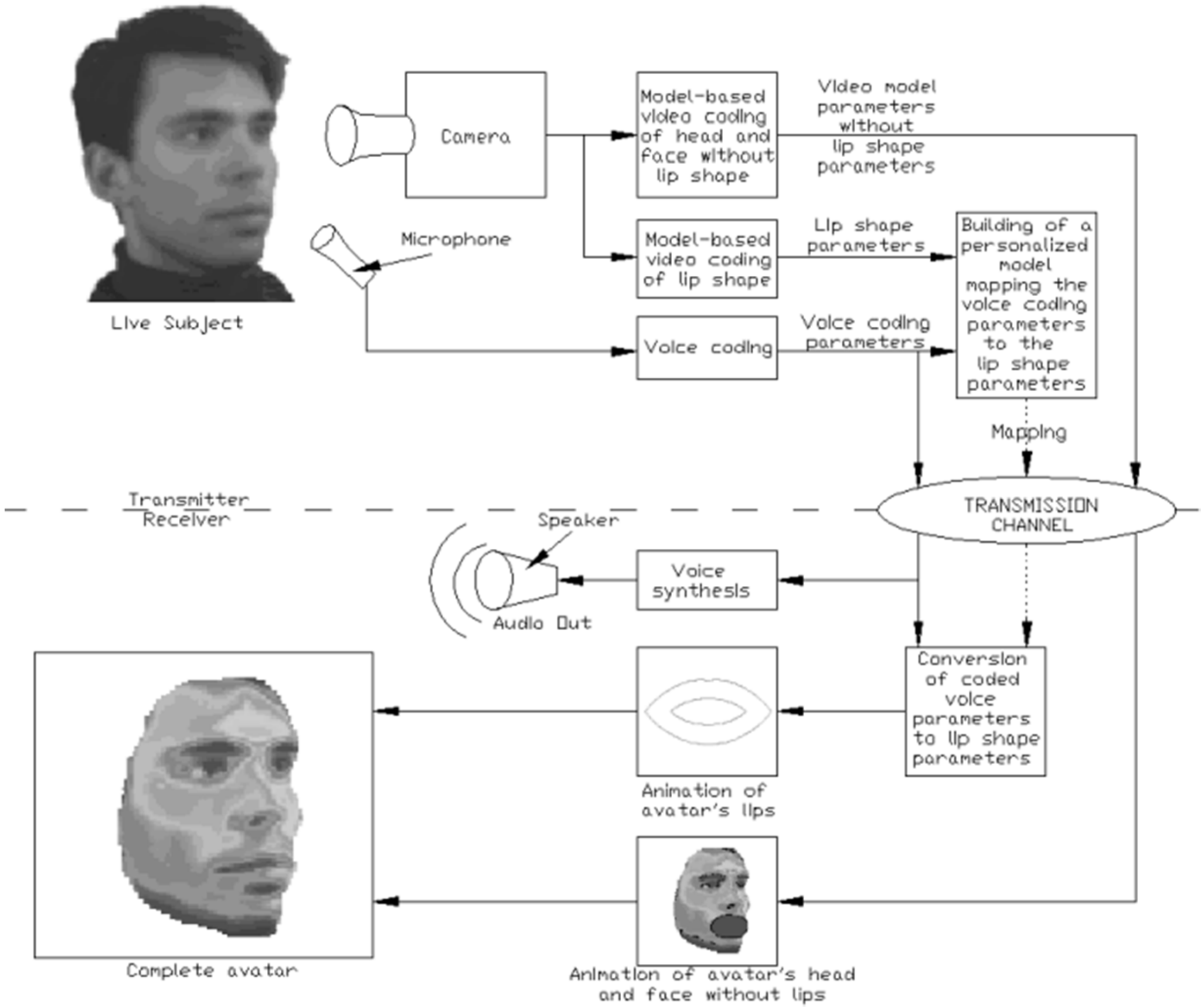
Avatar-Android Face Expressions Mapping



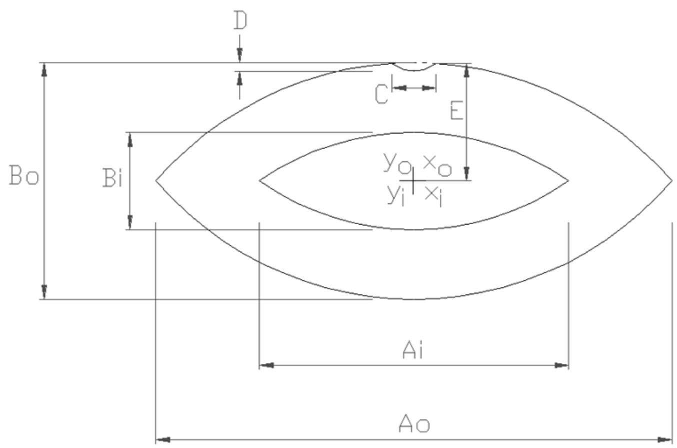
From left to right: neutral, happiness, sadness, surprise, anger, fear, disgust

P. Santos, E. de Castro Maia Jr., M, Goubran, E.M. Petriu, “Facial Expression Communication for Healthcare Androids,” *Proc. MeMeA2013, 8th IEEE Int. Symp. on Medical Measurement and Applications*, pp. 44-48, Ottawa, ON, Canada, May 2013

Face and Lip Animation Using Model-based Audio and Video Coding

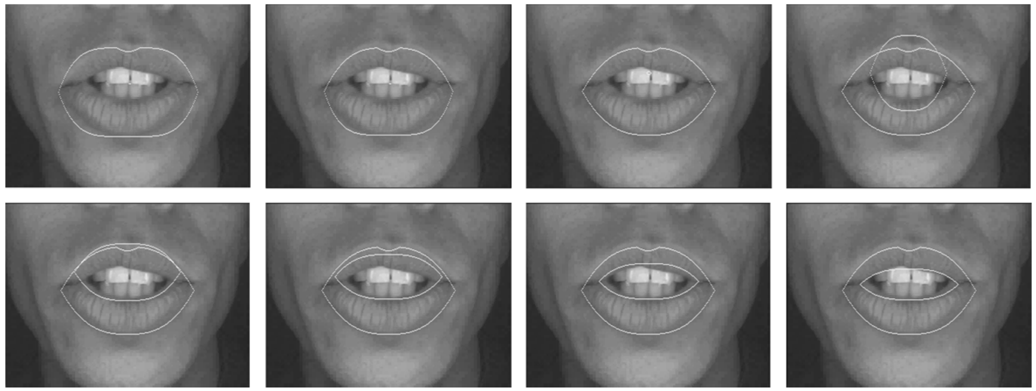


M. D. Bondy, E. M. Petriu, M. D. Cordea, N. D. Georganas, D. C. Petriu, T. E. Whalen, "Model-based Face and Lip Animation for Interactive Virtual Reality Applications", *Proc. ACM Multimedia 2001*, pp. 559-563, Ottawa, ON, Sept. 2001

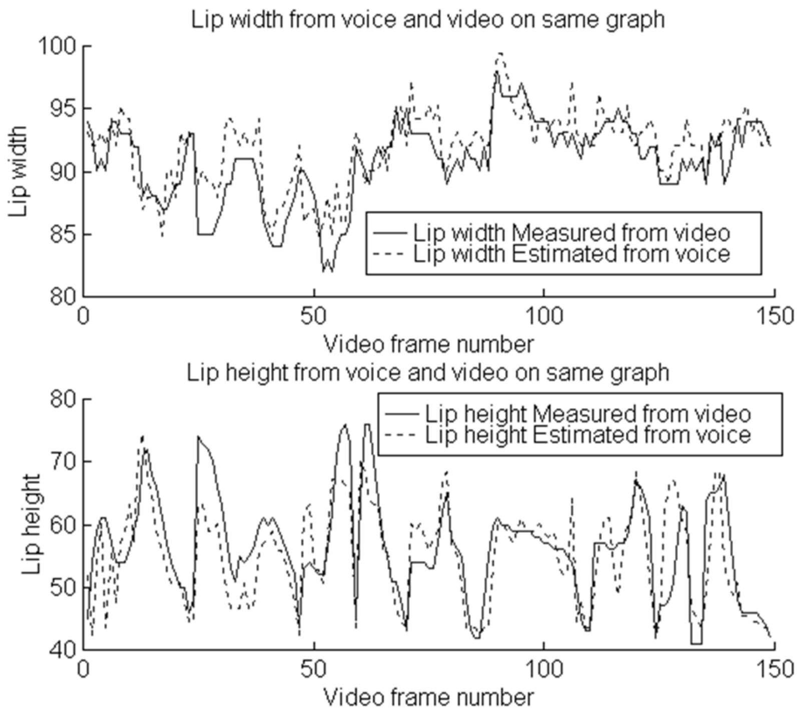


The parameters of the lip contour model
xo, yo = the origin of the outside parabolas; *xi, yi* = the origin of the inside parabolas; *Bo* = outer height; *Bi* = inner height; *Ao* = outer width; *Ai* = inner width; *D* = depth of 'dip'; *C* = width of 'dip'; *E* = offset height of cosine function; *tordero* = top outside parabola order; *bordero* = bottom outside parabola order; *orderi* =inside parabola order (same on both top an bottom).

The lip contur model used in the mapping:
The only parameters of the lip model that are associated to the cepstral coefficients are the outer width $\mathbf{A_o}$ and the outer height $\mathbf{B_o}$. Relations can be found linking the parameter values of the inner contour of the lip model to the parameter values of the outer contour. Therefore, estimating the inner contour values from the audio signal would be redundant.



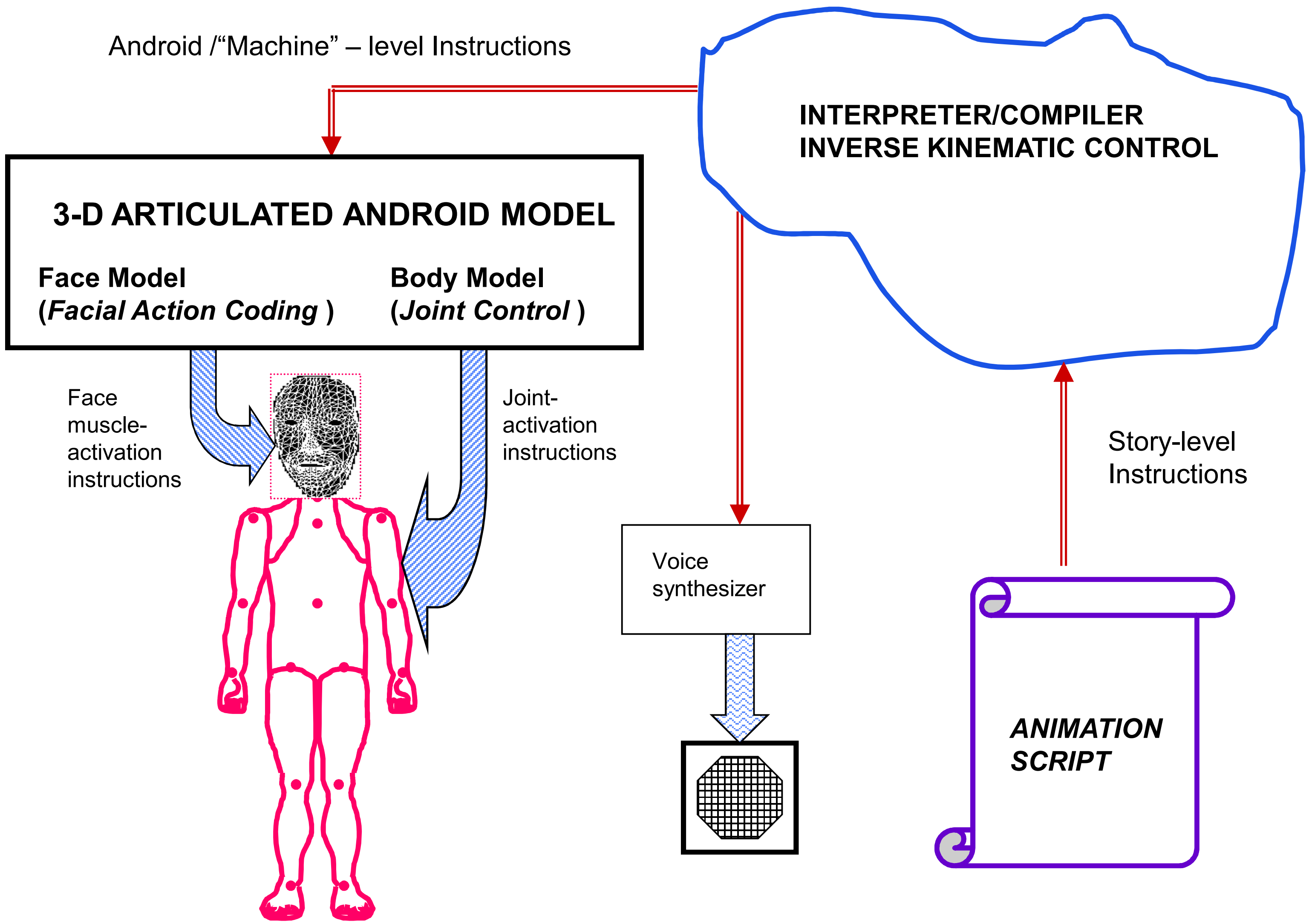
Examples of the lip model being molded to the shape of the speaker lips



Comparing the speech-driven and the real lip shape for a female speaker saying in French the ten digits: *zero, un, deux,...neuf.*

M. D. Bondy, E. M. Petriu, M. D. Cordea, N. D. Georganas, D. C. Petriu, T. E. Whalen, "Model-based Face and Lip Animation for Interactive Virtual Reality Applications", *Proc. ACM Multimedia 2001*, pp. 559-563, Ottawa, ON, Sept. 2001

Behaviour-Based Android Control


Android /“Machine” – level Instructions
INTERPRETER/COMPILER
INVERSE KINEMATIC CONTROL
3-D ARTICULATED ANDROID MODEL
Face Model
(Facial Action Coding)
Body Model
(Joint Control)
Face muscle-activation instructions
Joint-activation instructions
Voice synthesizer
Story-level Instructions
ANIMATION SCRIPT

STORY-LEVEL INSTRUCTIONS

…..

DaneelA sits on the chair#4.

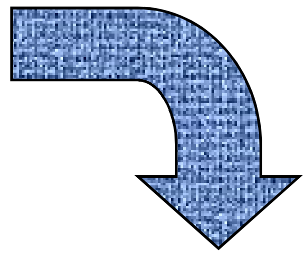
DanielA writes "Hello" on stationary.

He sees HappyCat under the white table .

DaneelA starts smiling.

HappyCat grins back.

……



BEHAVIOUR-LEVEL ("MACRO") INSTRUCTIONS

…..

DanielA's right hand moves the pen to follow the trace representing "H".

DanielA's right hand moves the pen to follow the trace representing "e".

DanielA's right hand moves the pen to follow the trace representing "l".

DanielA's right hand moves the pen to follow the trace representing "l".

DanielA's right hand moves the pen to follow the trace representing "o".

……

BEHAVIOUR-LEVEL (“MACRO”) INSTRUCTIONS

…

DanielA’s right hand moves the pen to follow the trace representing “H”.

…

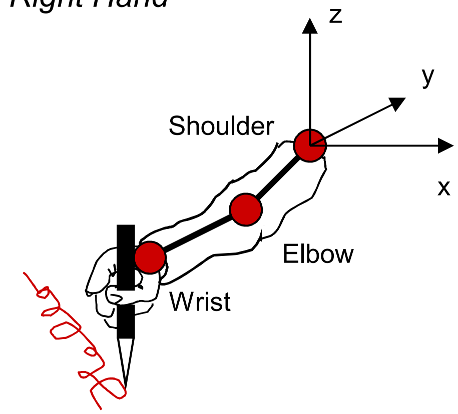
DanielA’s specific style of moving his right arm joints to write “H”
(NN model capturing DanielA’s writing personality)

Rotate Wrist to a^{i}

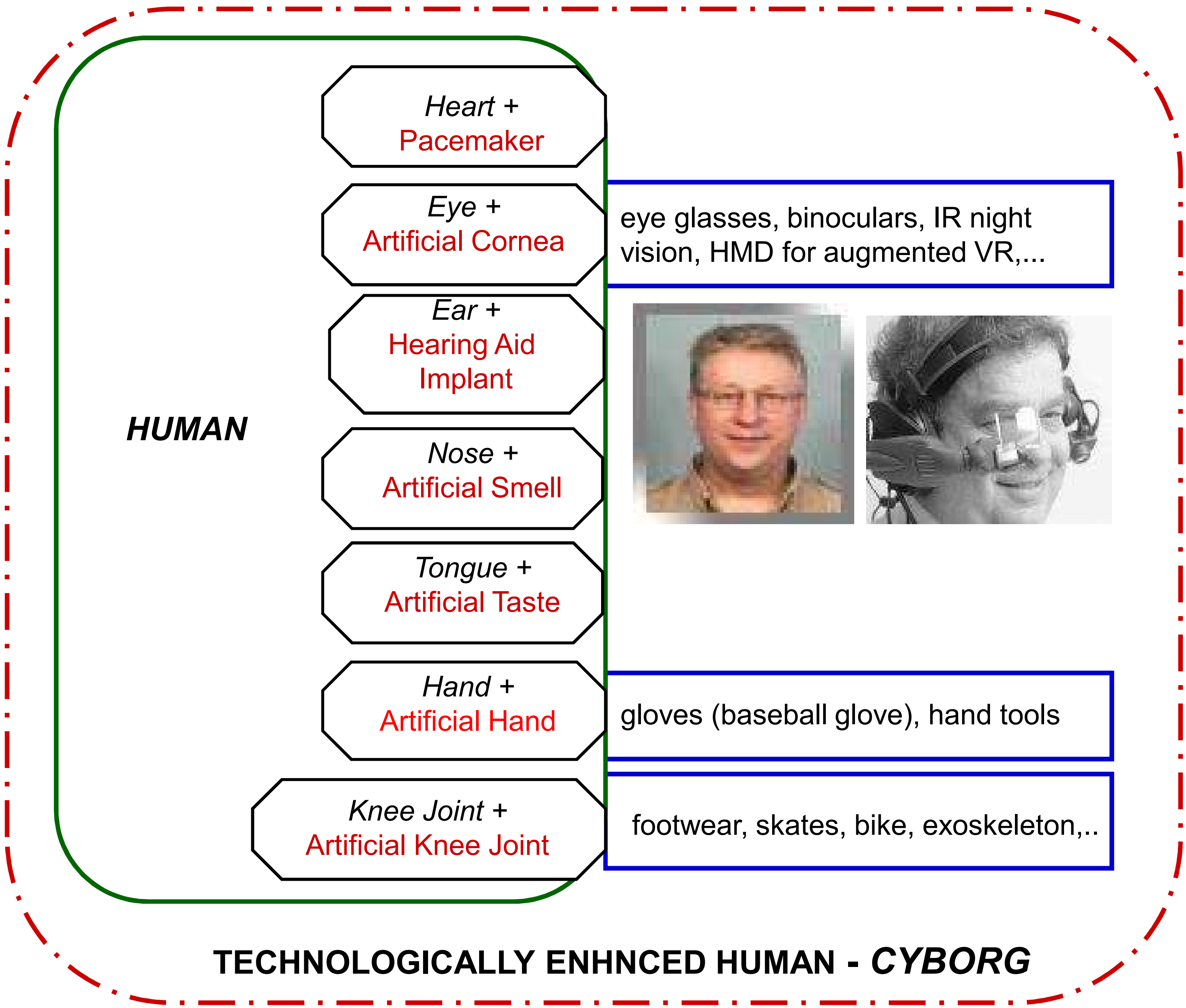
Rotate Elbow to b^{j}

Rotate Shoulder to g^{k}

3-D Model of DanieA’s Right Hand



Human & Android & Cyborg Hyper-Society



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

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]

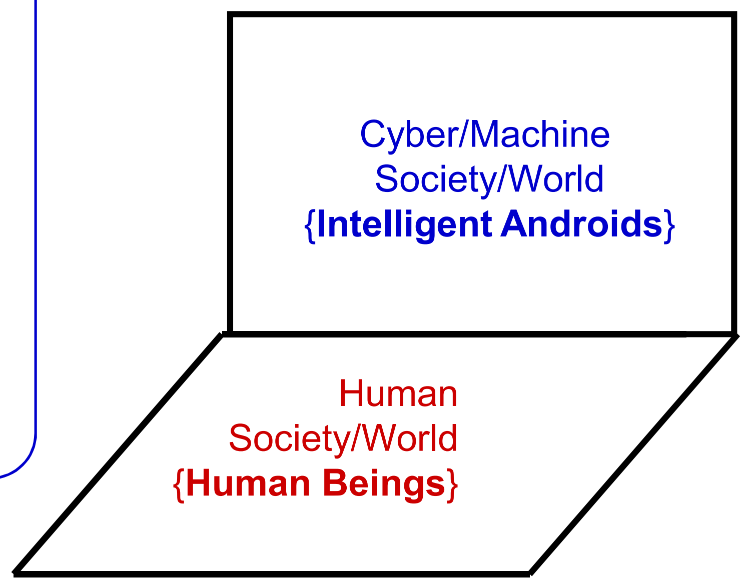
Brain Prosthesis which learns/models with an ever increasing fidelity the behaviour of the natural brain so it can be used as *behavioural-memory prosthesis* (**BMP**) to make up for the loss in the natural brain's functions due to dementia, Alzheimer disease, etc. It is quite conceivable that such a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

***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*:**

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

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

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

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

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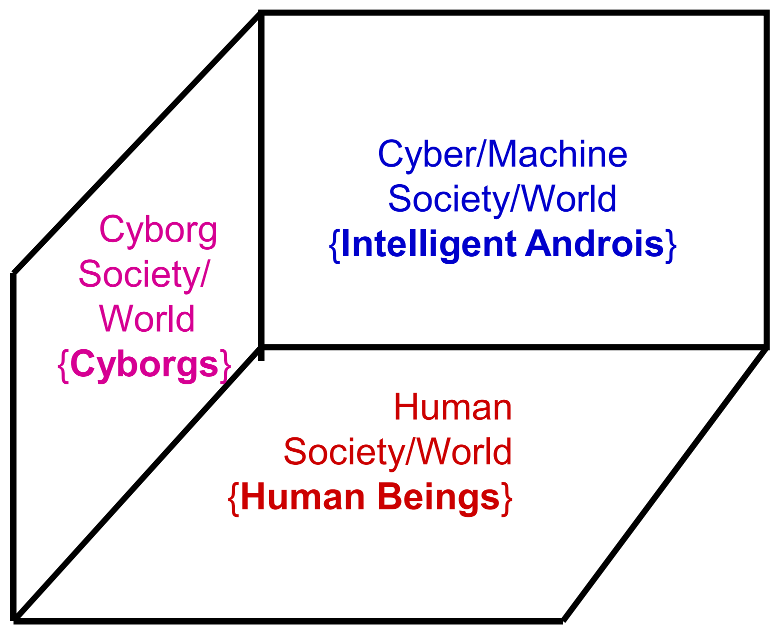
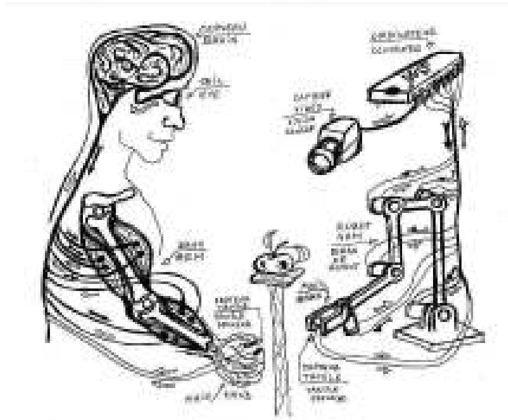
[*] I. Asimov, Robots and Empire, Doubleday & Co., NY 1985, p.291

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





Thank You!