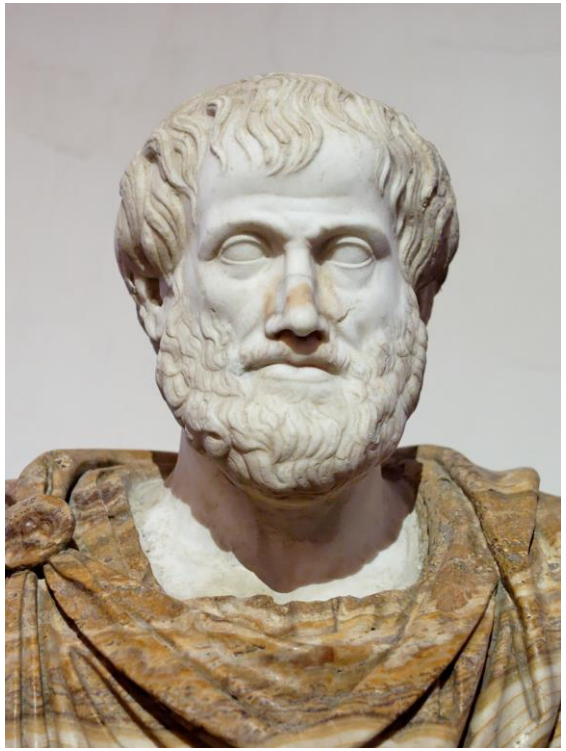
What does a robot need to be human?

The Journey of Abel

Lorenzo Cominelli, PhD
Università di Pisa

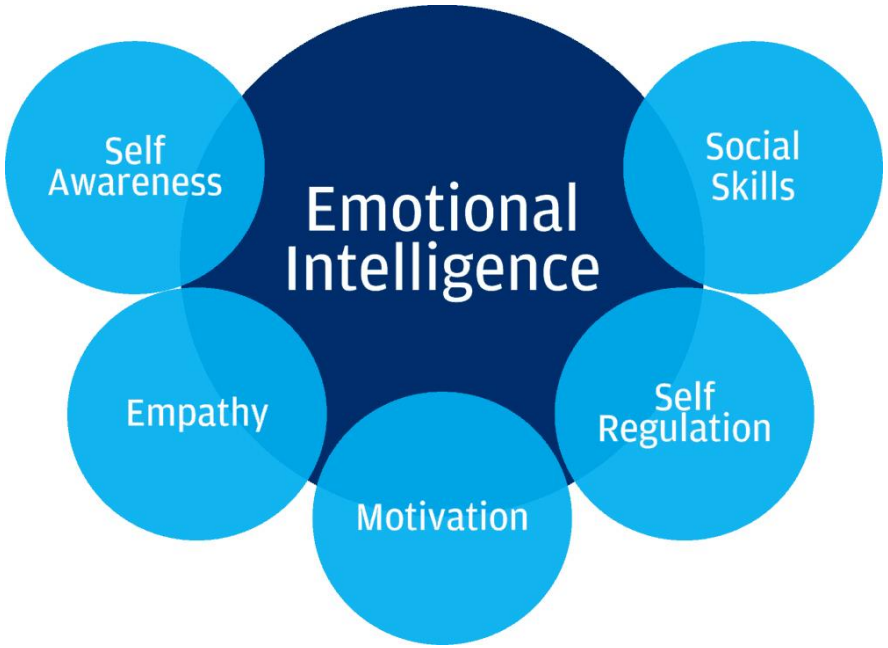
Human is by nature a **Social Animal**



«Man is by nature a social animal; an individual who is unsocial naturally and not accidentally is either beneath our notice or more than human. Society is something in nature that precedes the individual. Anyone who either cannot lead the common life or is so self-sufficient as not to need to, and therefore does not partake of society, is either a beast or a god»

Aristotle, Politics, c. 328 B.C.

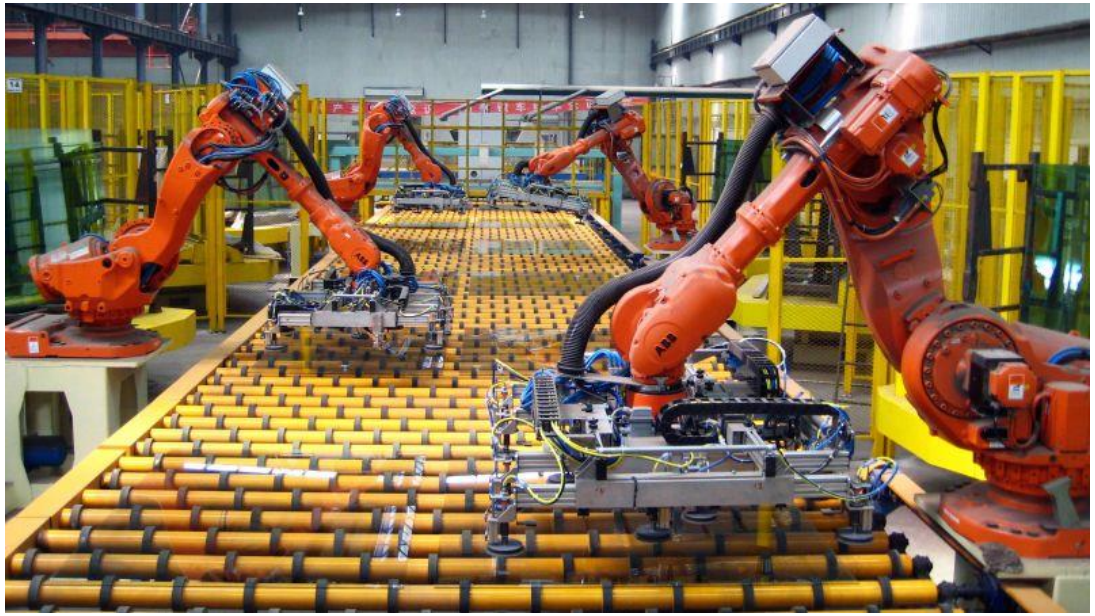
Emotional Intelligence



Emotional intelligence (**EI**) is the capability of individuals to **recognize** their own emotions and those of others, **discern** between different feelings and **label** them appropriately, **use** emotional information to **guide** thinking and behavior, and **manage** and/or **adjust** emotions to **adapt** to environments or achieve one's goal(s).

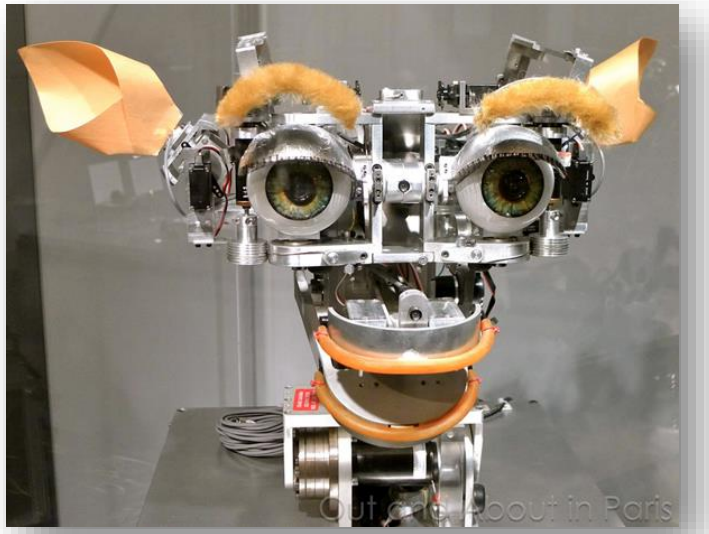
Coleman, Andrew (2008). A Dictionary of Psychology. Oxford University Press. ISBN 9780199534067

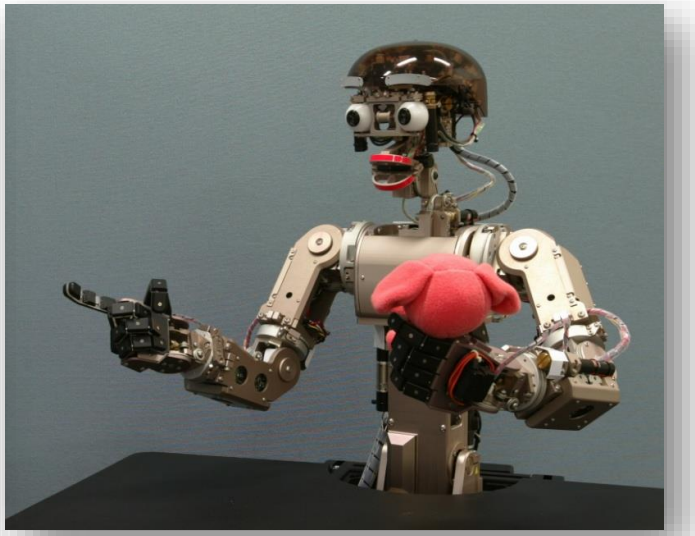
Do we need **Emotions** in Robotics?



Do we need **Emotions** in Robotics?

It’s mandatory for SOCIAL ROBOTS





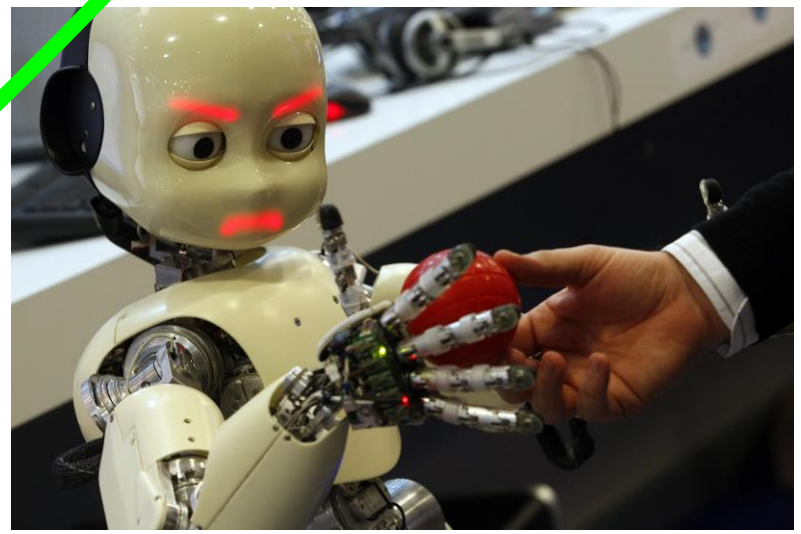
*“A social robot is an **autonomous** or semi-autonomous robot that **interacts** and **communicates** with humans by following the **behavioral norms expected** by **the people with whom the robot is intended to interact**”*

C. Bartneck and J. Forlizzi
A Design-Centred Framework for Social Human-Robot Interaction, Proceedings of 2004 IEEE International Workshop on Robot and Human Interactive Communication, Japan, 2004, 591-594.

Forms of Socially Interactive Robots

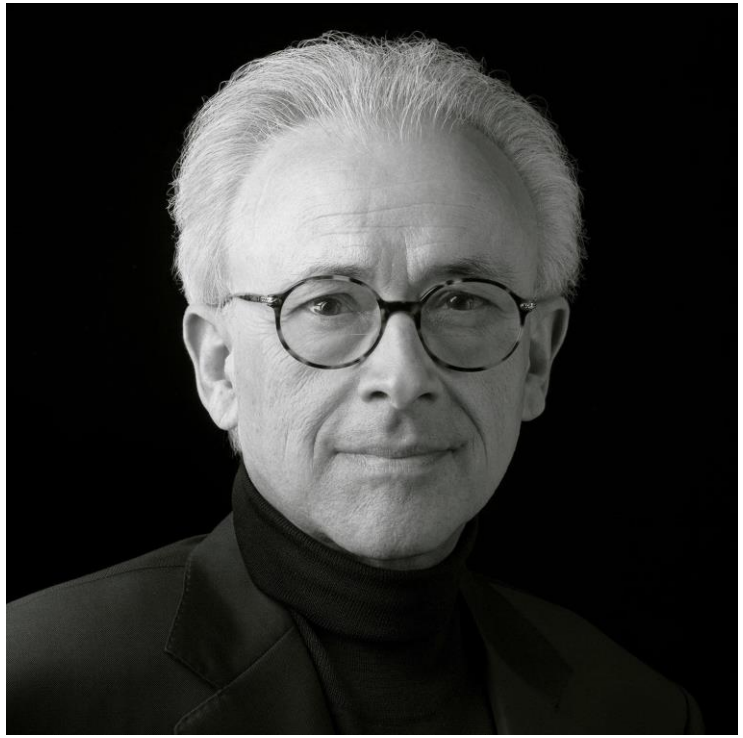
eMuu - (abstract)

Paro - (biomorphic)



Erika, iCub - (anthropomorphic)

Neroscience Approach: Antonio Damasio



Antonio Damasio is a Portuguese-American neuroscientist, internationally recognized leader of neuroscience. He is currently Professor of Psychology, Philosophy, and Neurology, at the University of Southern California.

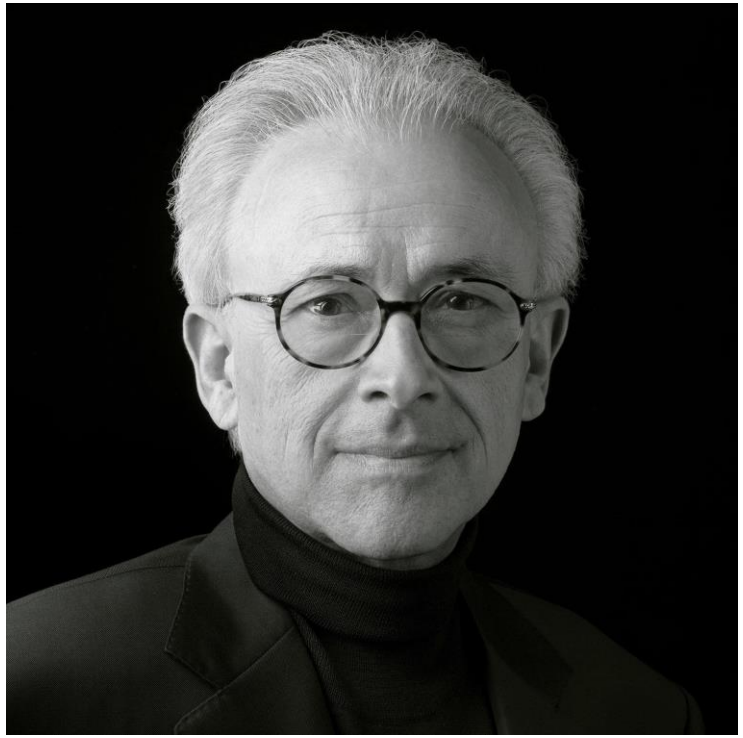
Damasio heads the Brain and Creativity Institute (BCI), and has authored several books where he explores the relationship between the brain and consciousness.

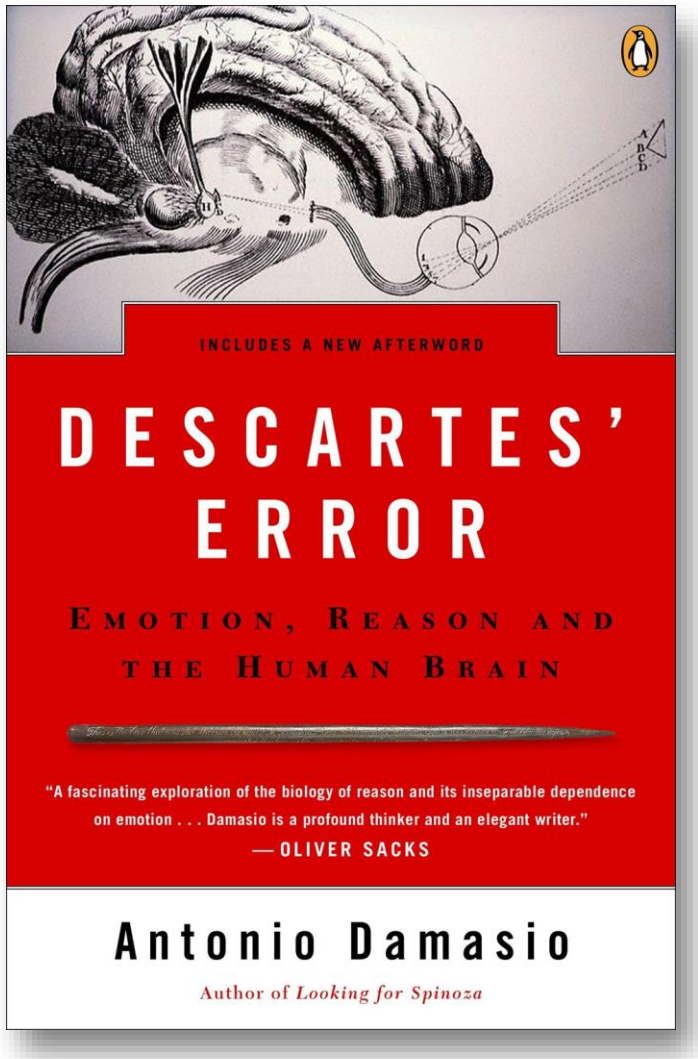
Damasio's research in neuroscience focus on mind and behaviour, with emphasis on emotion, decision-making, memory, communication, and creativity.

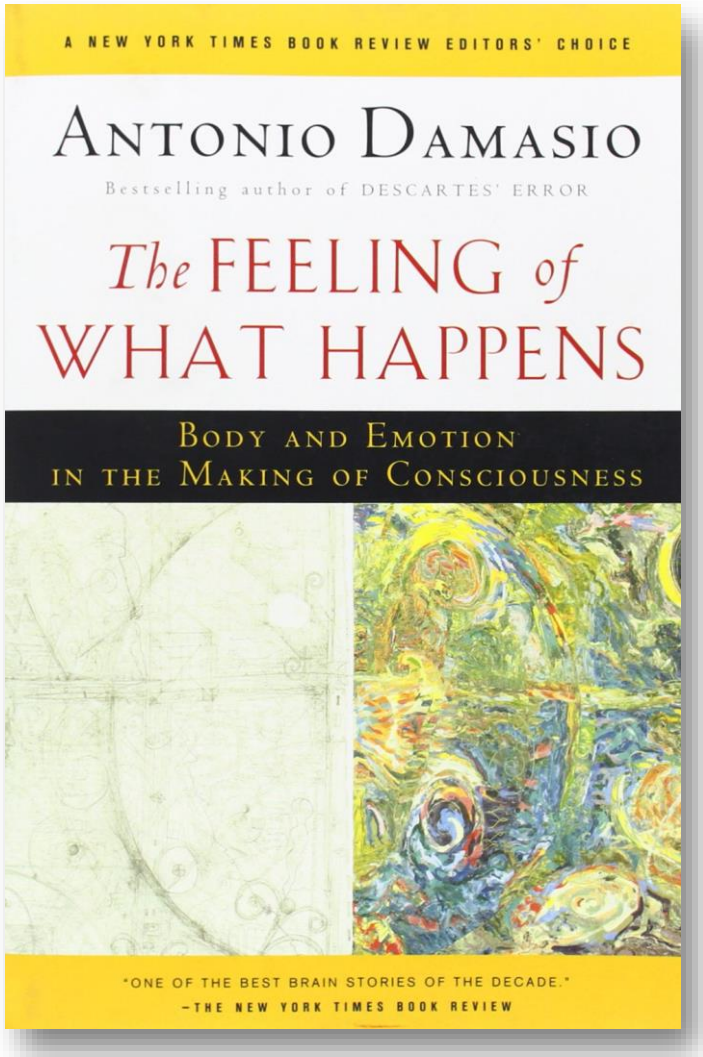
He has shown that **emotions play a central role in social cognition and decision-making**

His findings are based on the investigation of patients with brain impairments.

Neroscience Approach: Antonio Damasio



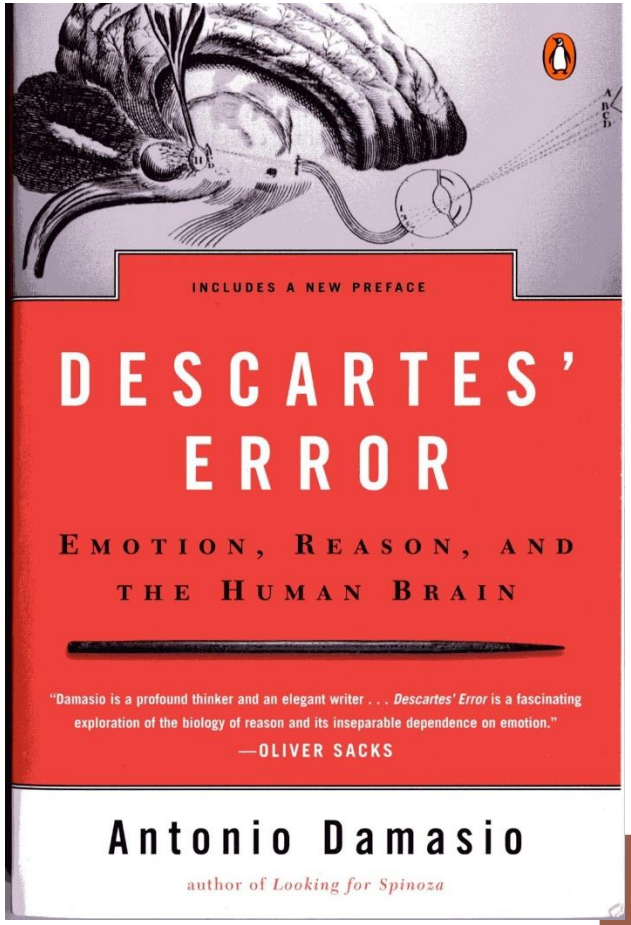


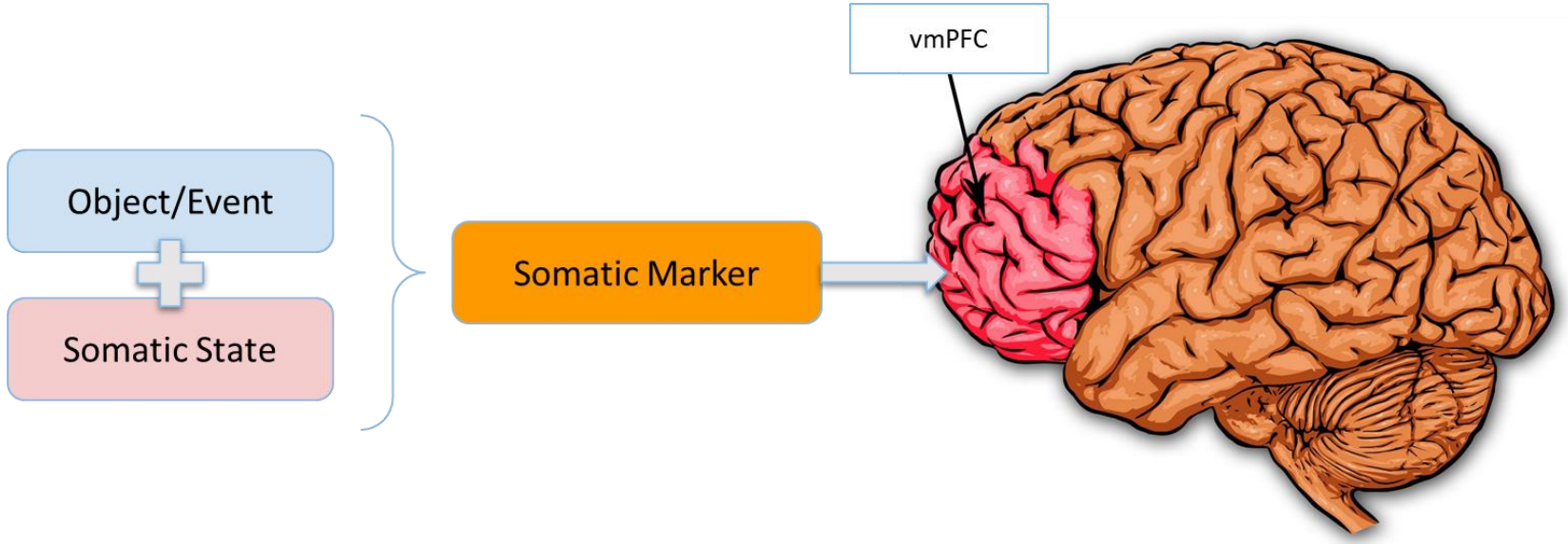


ANTONIO DAMASIO

The Somatic Marker Hypothesis

I PHASE: LABELING

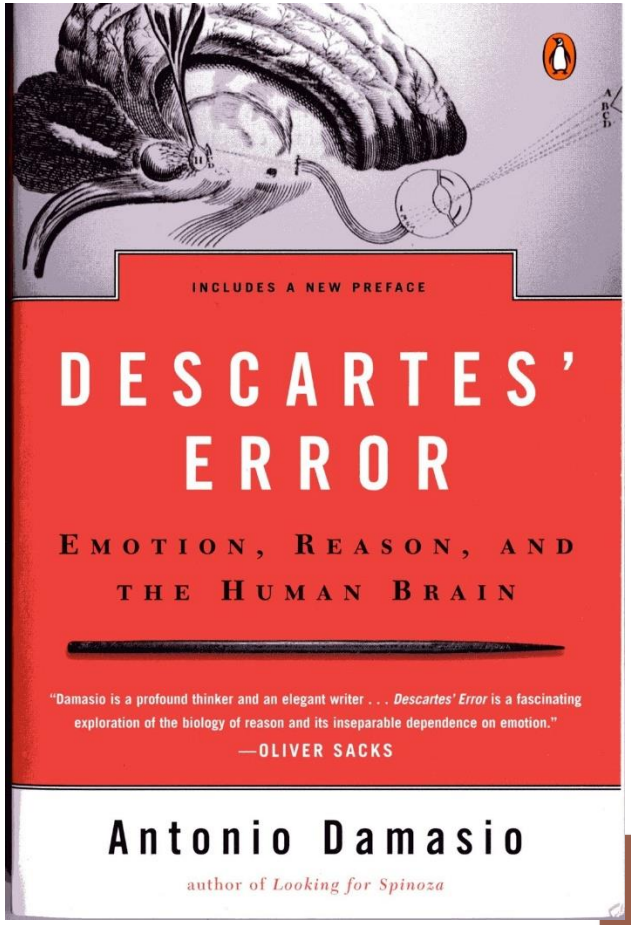


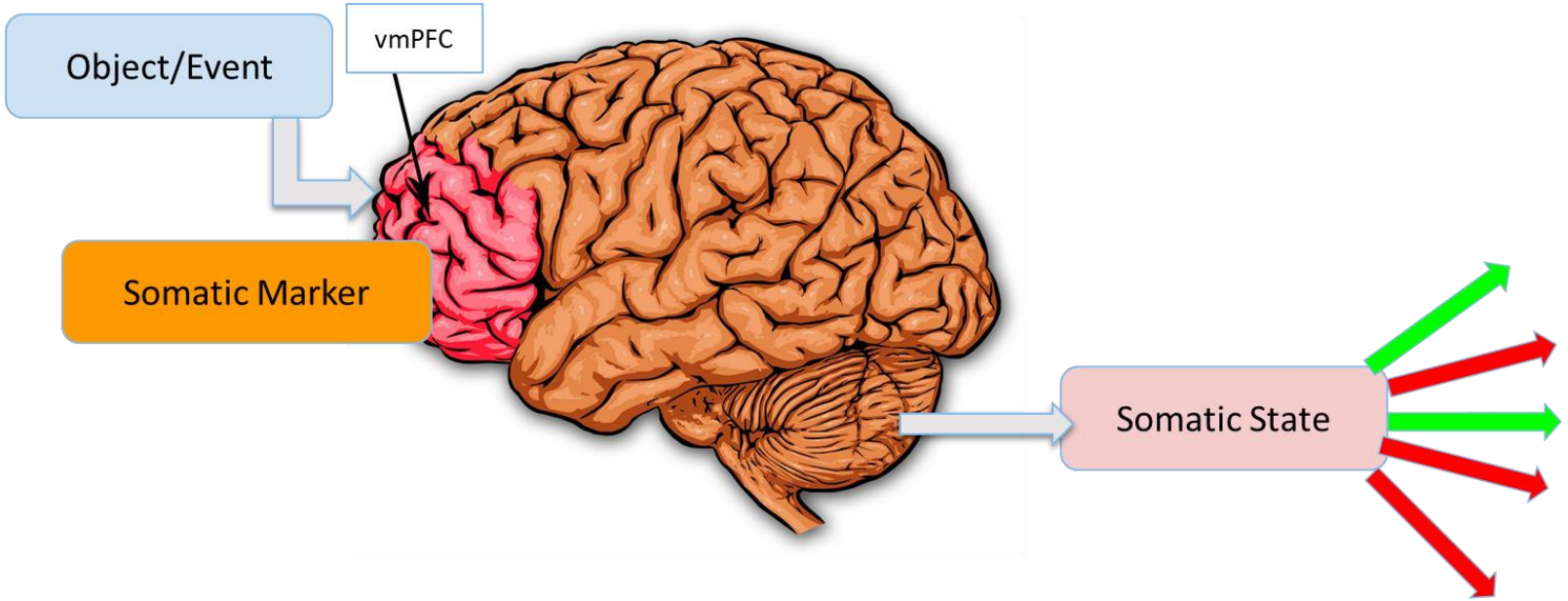


Antonio Damasio. Descartes' error: Emotion, reason and the human brain. Random House, 2008.

ANTONIO DAMASIO
The Somatic Marker Hypothesis

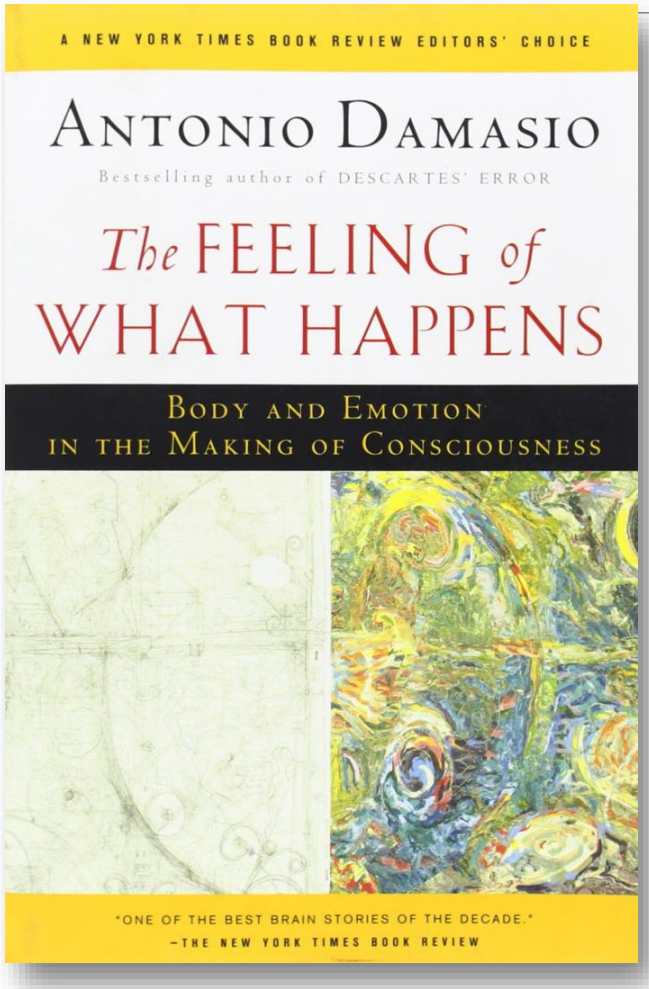
II PHASE: RECALL





Antonio Damasio. Descartes' error: Emotion, reason and the human brain. Random House, 2008.

ANTONIO DAMASIO
Emotions and Sense of Self



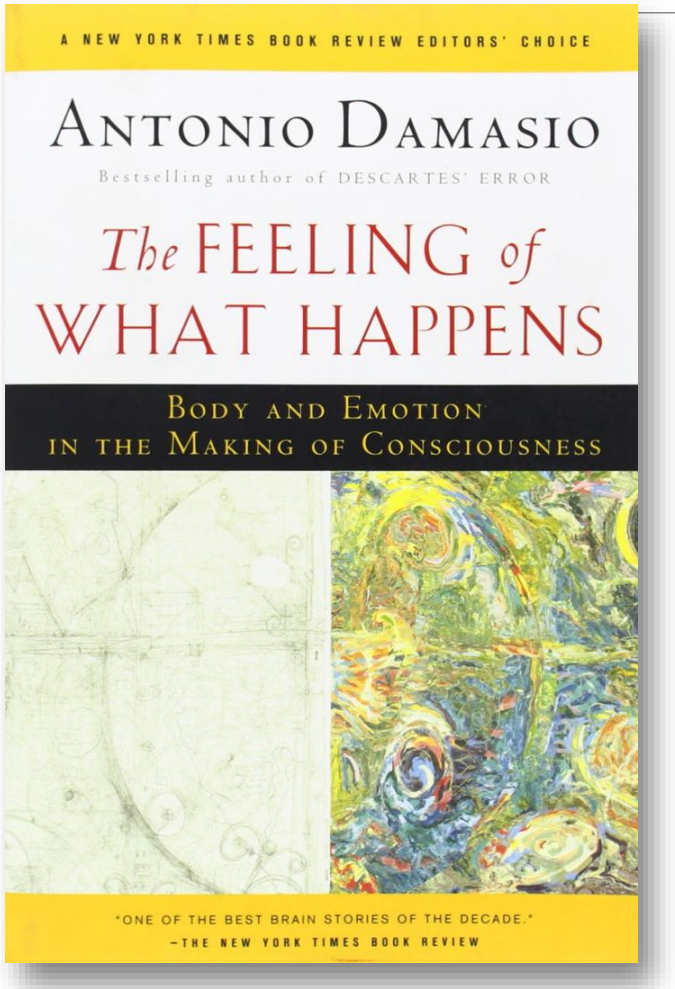
AUTOBIOGRAFICAL SELF
A completely conscious being with access to memory, experienced states, factual knowledge, adaptation capabilities, symbolic manipulation, and high-level reasoning

AUTOBIOGRAFICAL MEMORY
An organized record of past experiences and the relative bodily states

CORE SELF
When the organism becomes aware of feelings caused by changes in bodily state, Core Consciousness is born. A transient but conscious refernce to the individual organism in which events are happening

PROTO-SELF
The most basic representation of self (awareness shared by all life forms). Pre-conscious state-concerned only with homeostasis. Direct and continuous report of the body's response to the environment. Brain areas: brain stem, hypothalamus, insular cortex

ANTONIO DAMASIO
Emotions and Consiousness



EXTENDED CONSCIOUSNESS

Emerges when consciousness moves beyond the here and now. Memory and language. Requires vast use of memory to draw upon experience. Develops gradually over time, built on Proto-self and Core Consciousness. Autobiographical Self is present

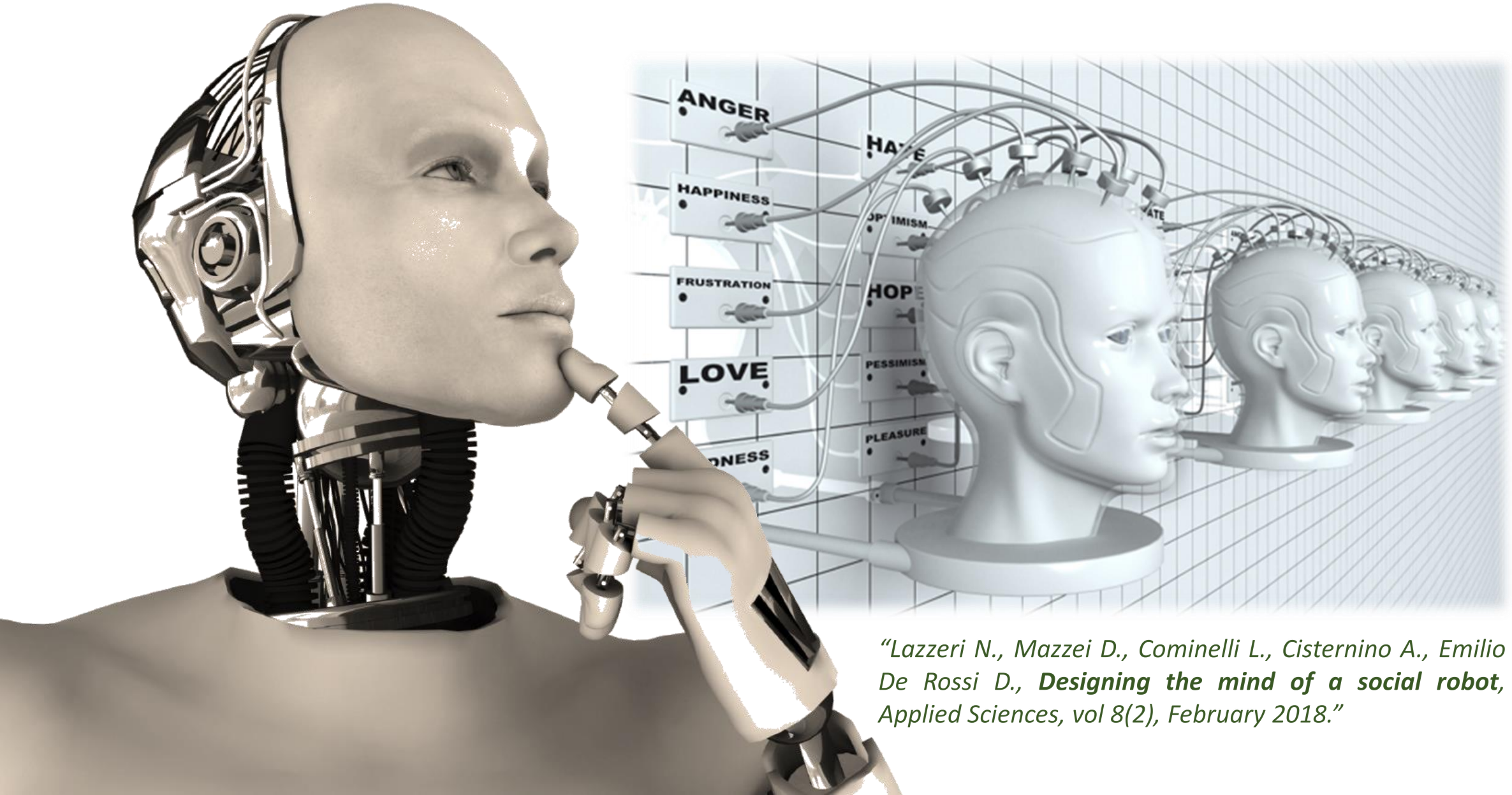
CORE CONSCIOUSNESS

Second more evolved level of consciousness. Not exclusive to humans. Concerned only with the present moment - does not require memory or language. At this state, the organism recognizes his thoughts are his own. Sense of self present. Brain builds images based on reports from Proto-self. Non-verbal narrative of events

PROTO-SELF

The most basic representation of self (awareness shared by all life forms). Pre-conscious state-concerned only with homeostasis. Direct and continuous report of the body's response to the environment. Brain areas: brain stem, hypothalamus, insular cortex

Can a **Robot** do the same?...

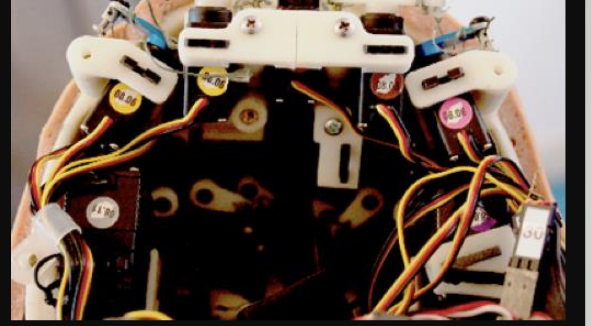


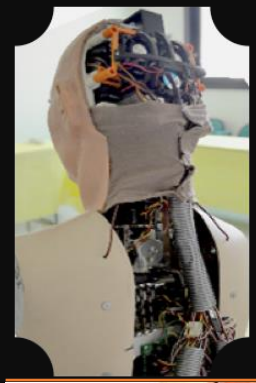
"Lazzeri N., Mazzei D., Cominelli L., Cisternino A., Emilio De Rossi D., ***Designing the mind of a social robot****, Applied Sciences, vol 8(2), February 2018."*

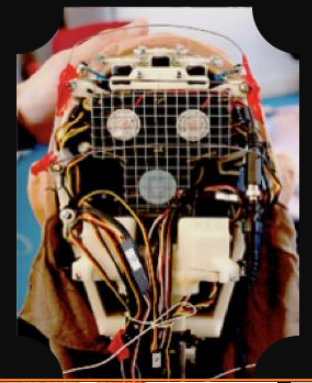
FACE

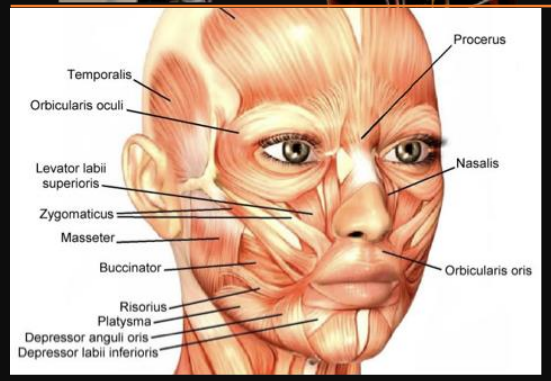
Facial Automaton for Conveying Emotions

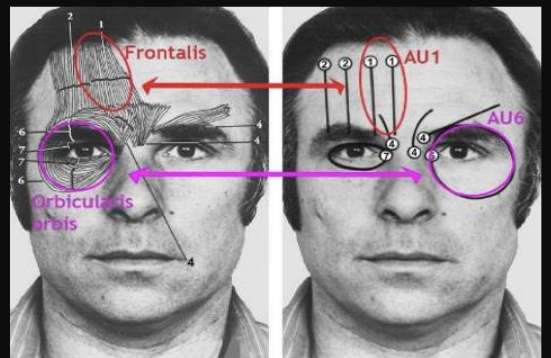
- Mechatronics made by David Hanson (Hanson Robotics)
- 3D Printed Skull designed to host 27 servomotors to control the gynoid's facial expression, 4 for controlling the neck
- Skin-like material FRUBBER® to reproduce mechanical behavior and aesthetics of human skin
- Study based on Paul Ekman's Facial Action Coding System (FACS); Facial Muscles are grouped in Action Units (AU)
- FACE has been used in ASD Therapy and involved in the EASEL EU Project

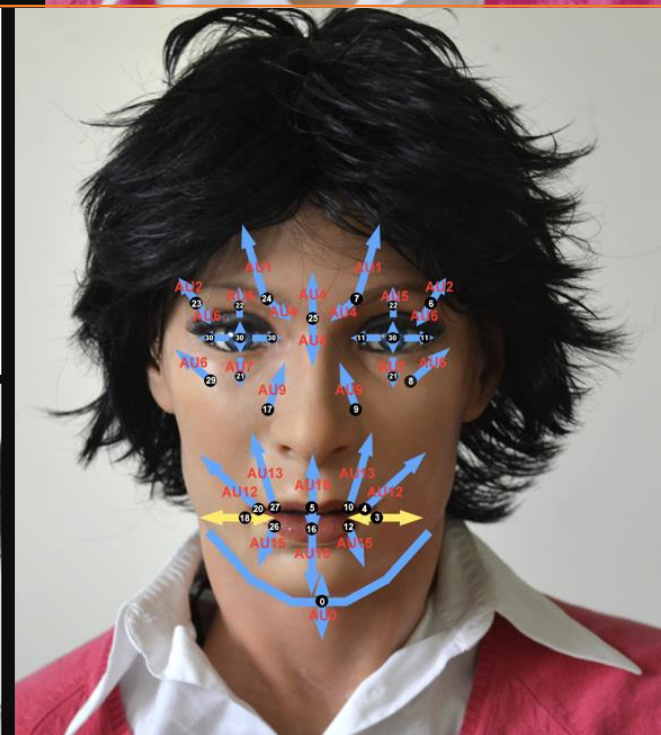


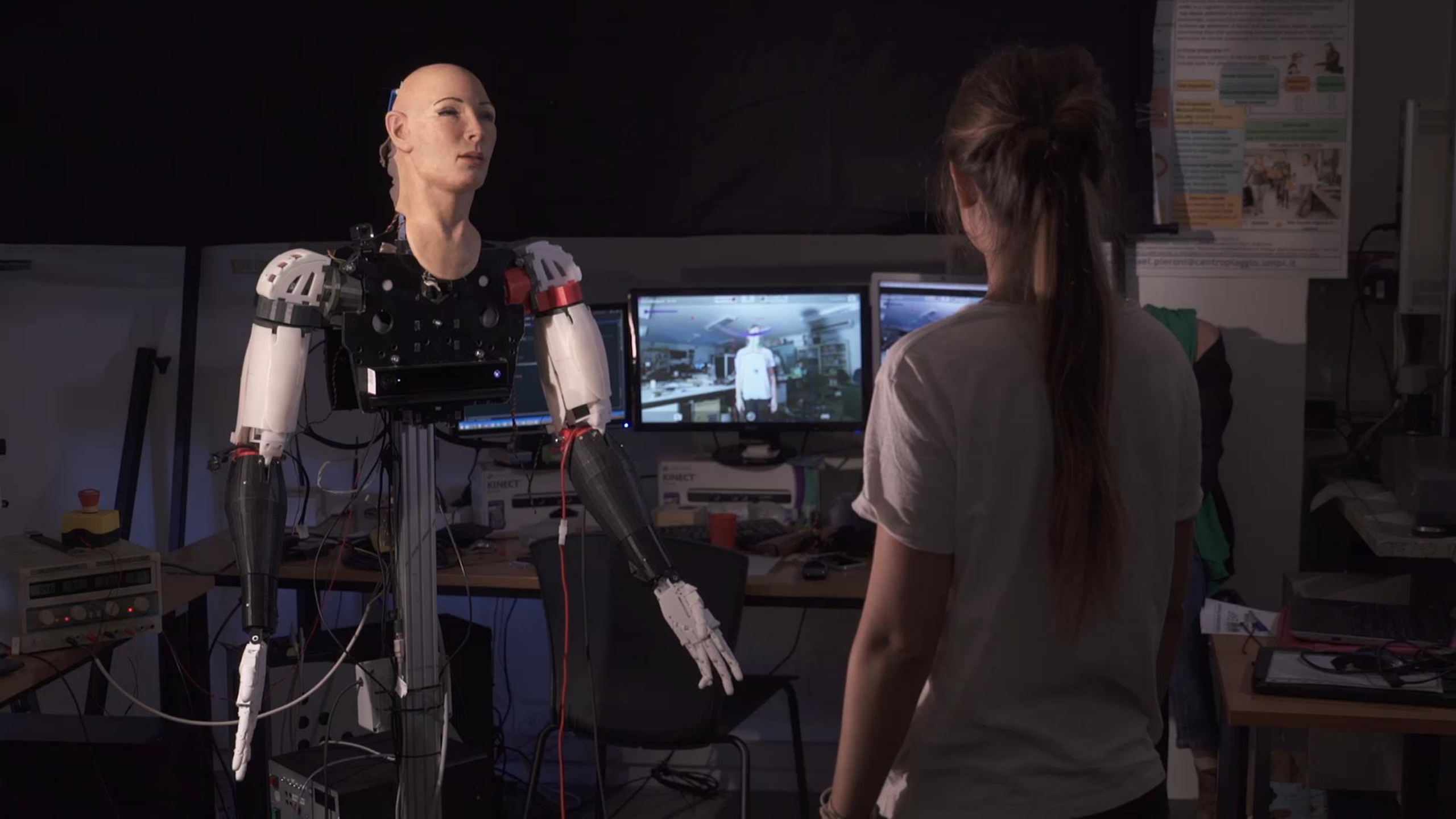








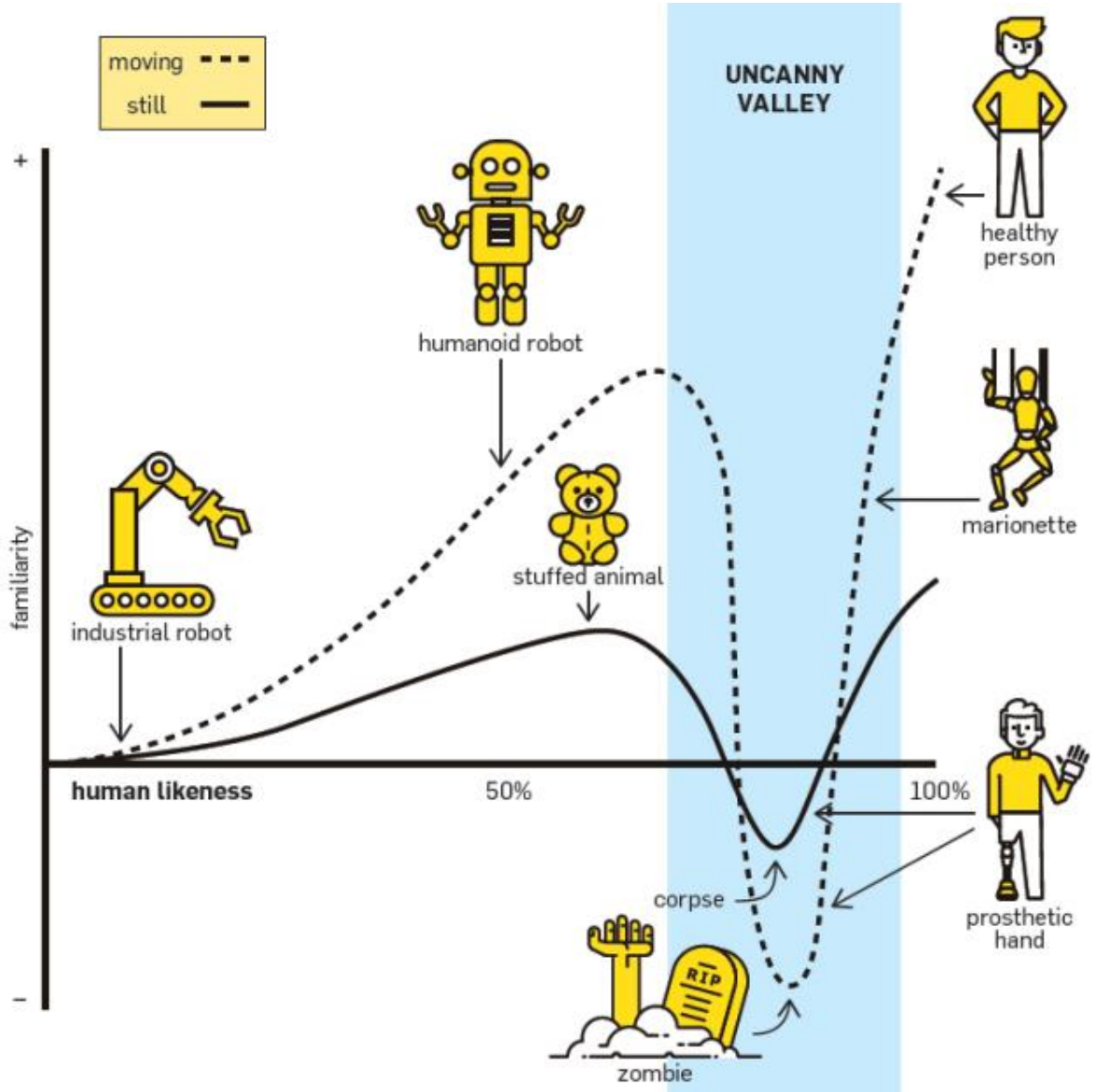




The UNCANNY VALLEY problem

Conceived of by Japanese roboticist Masahiro Mori in **1970** to explain the psychological reaction to anthropomorphic robots, or more broadly, any human fac-simile, the uncanny valley is a graph (on the right) that tracks **human emotional responses to anthropomorphic machines or other humanoid figures**.

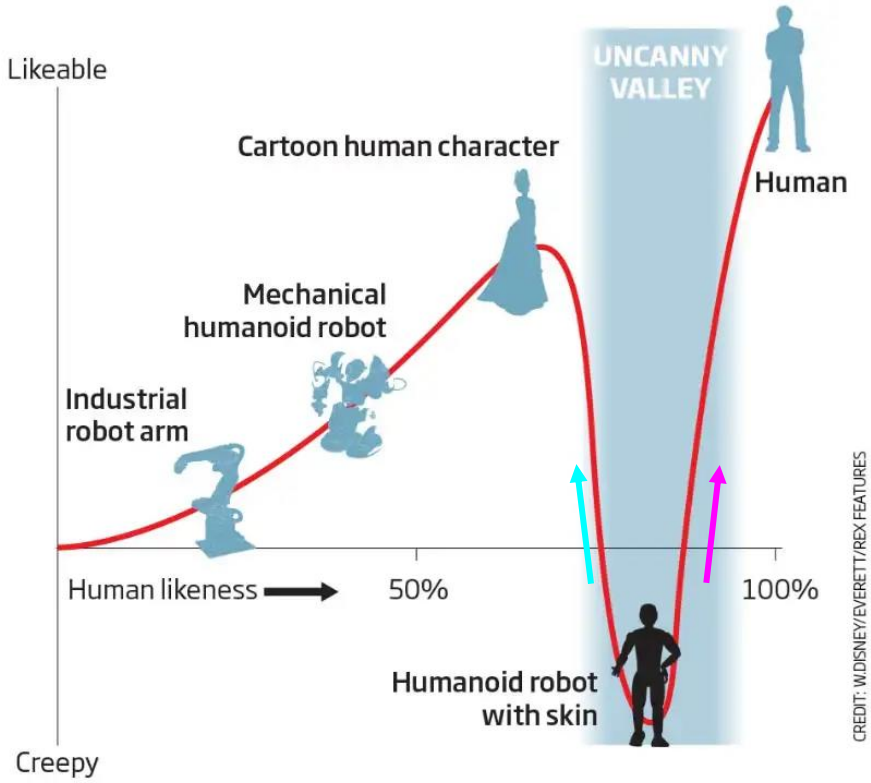
Mori found that **humans react positively to robots that approach human-like appearance**, but there is a point where we see a steep dropoff – i.e. a negative emotional response – when robots or other human facsimiles look *too* human, but still not quite right. This dropoff is called the **uncanny valley**, the point at which robots stop being cool and start giving us the creeps.



Mori, Masahiro (1970). Bukimi no tani - The uncanny valley (K. F. MacDorman & T. Minato, Trans.). Energy, 7(4), 33–35. (Originale in Giapponese, traduzione inglese)

Main Critics to the Uncanny Valley Hypothesis

- The Hp is impractical, because neither Anthropomorphism nor Emotional Response easily lend themselves to being described by one-dimensional variables
- it depends on cultural context (now cross-cultural studies)
- exposure to robots
- short vs long-term interactions
- it's a matter of expectations!
  - ...they can be lowered
    simpler embodiement
    (e.g., abstract, biolike, more exposed robotics)
    = reduce cognitive mismatch
  - ...they can be better satisfied
    evolve robot movements
    improve robot cognitive capabilities
    = reduce cognitive mismatch



Motor Resoncance -> Social Resonance

Chaminade, Thierry, and Gordon Cheng. "Social cognitive neuroscience and humanoid robotics." *Journal of Physiology-Paris* 103.3-5 (2009): 286-295.

Gustav Hoegen

Founder of **Biomimic Studio**, Animatronic/Creature FX Artist

Growing up in the eighties Gustav Hoegen developed a huge passion for the Practical effects, heavy sci-fi and fantasy films of that period. Influenced by these films such as the Alien and Star Wars franchise it became clear early on in Gustav's life that this would be the career he'd pursue. In 1996 Gustav left Holland and moved to London to follow his dream of working in the special FX industry. In 1998 Gustav got offered an internship at the Special FX company Artem. He spent three years there honing his craft working on many adverts and the occasional feature film.

During Gustav's time at Artem he started to specialise in **Animatronics**. The ability to combine design, anatomy translated through mechanics, study of movement and the aesthetics of engineering made Animatronics and Creature FX very appealing to Gustav.

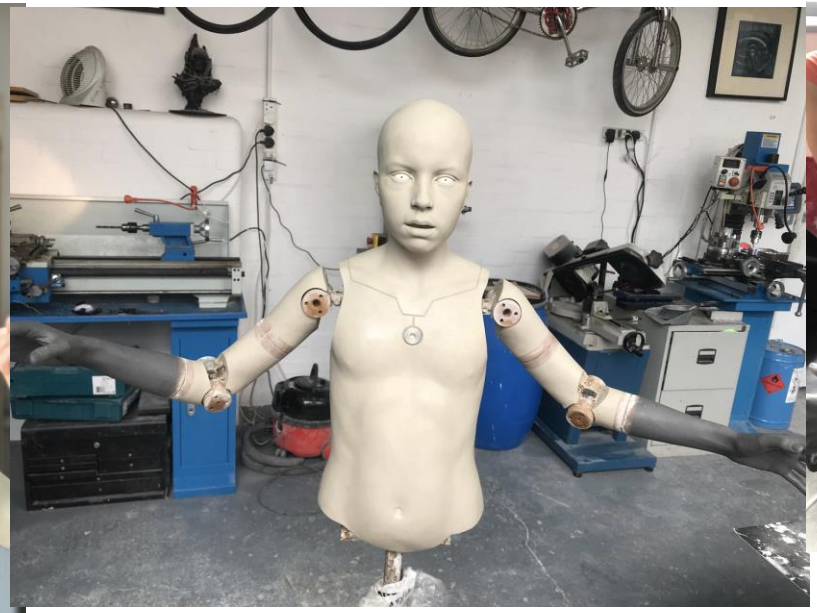
In 2001 Gustav entered the freelance world as an Animatronic designer working on numerous films, amongst them are Terry Gilliam's Brothers Grimm, Tim **Burton's Charlie and the Chocolate Factory** and Ridley Scott's **Prometheus**. After a 12 year career as a freelancer Gustav decided to set up his own workshop under the name of Biomimic Studio. During the period of setting up his Studio, Gustav received the offer of a lifetime. Lucas Film approached him to run the Creature FX department for the new series of **Star Wars** movies. Eventually he teamed up with Neal Scanlan who helmed the whole Creature department while Gustav supervised the Animatronic department. Gustav has been working on every new Star Wars movie so far as well as running his studio.

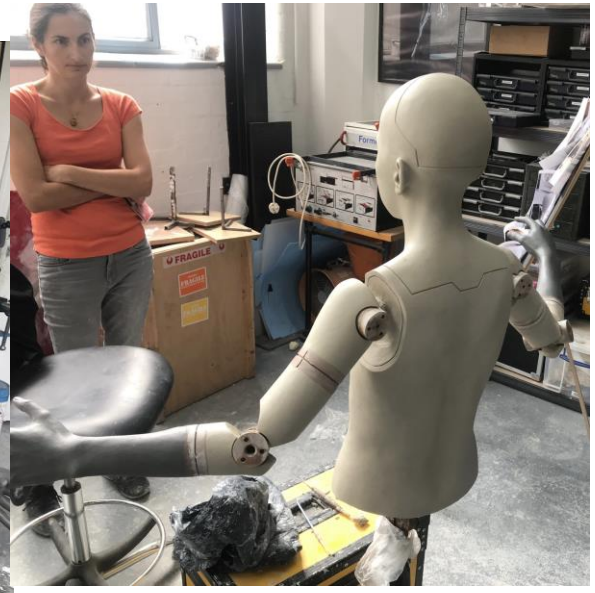
Biomimic Studio https://www.biomimicstudio.org

Creation of the Master

Livia Turco https://www.thefigurativesculptureschool.com/about

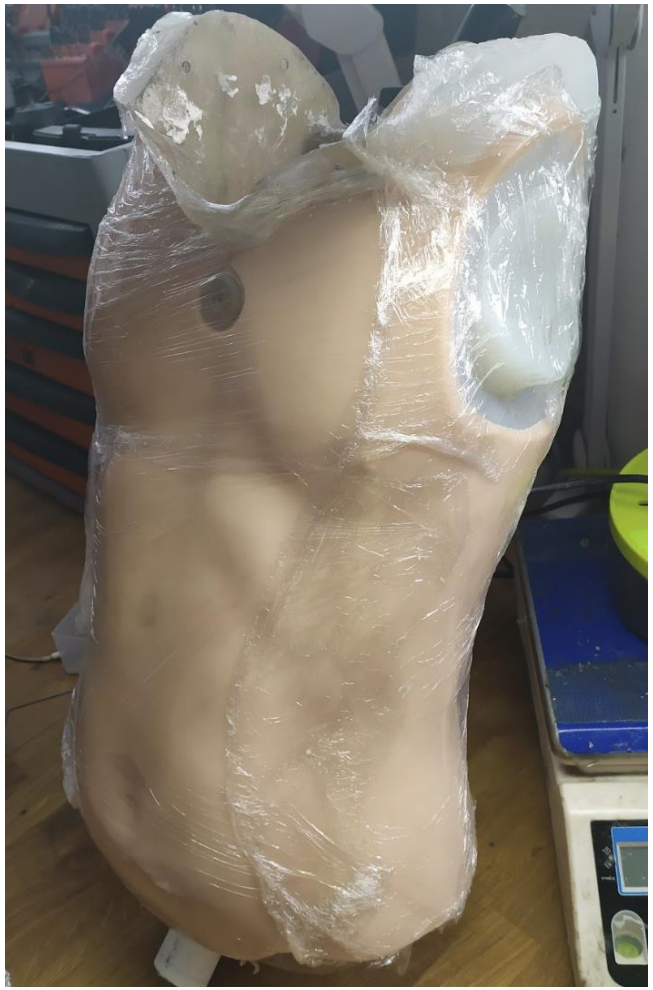
Creation of the Master



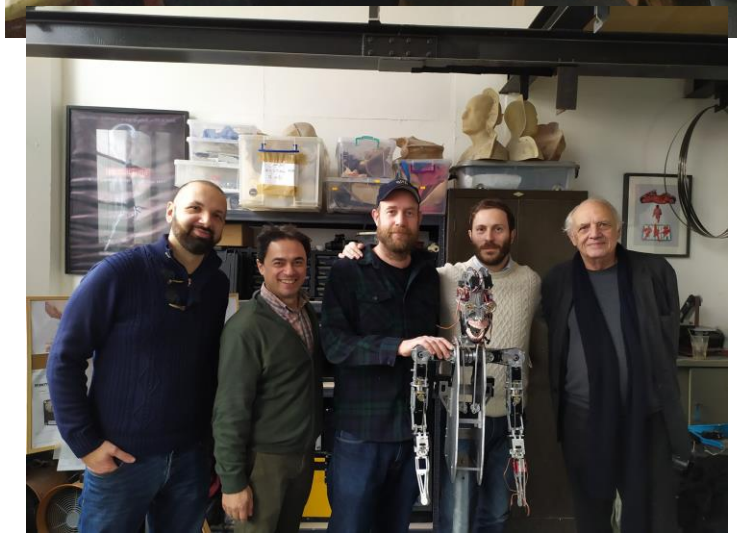


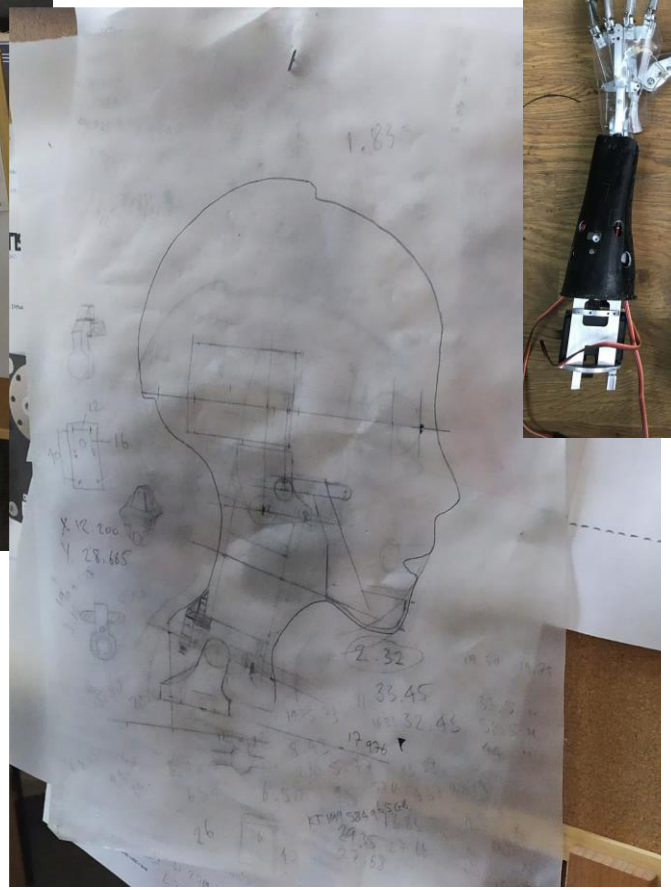
Production of the molds

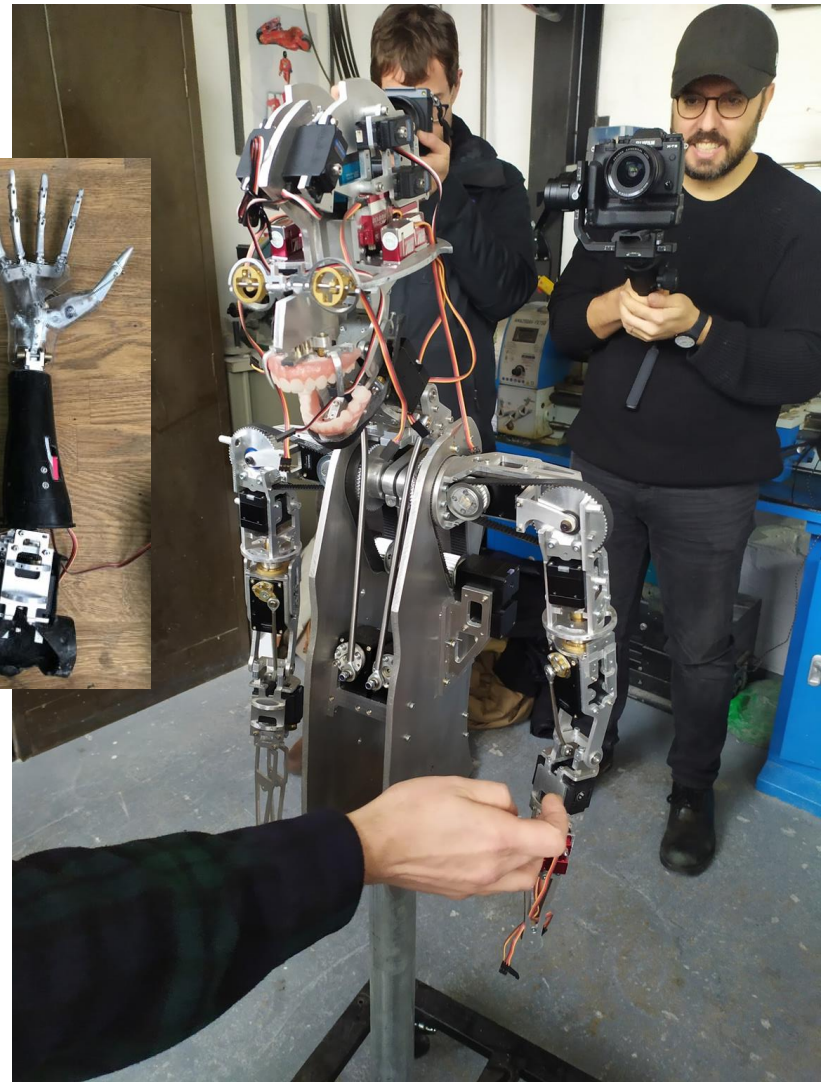
Casting of flesh-like material



Mechatronics and assembly







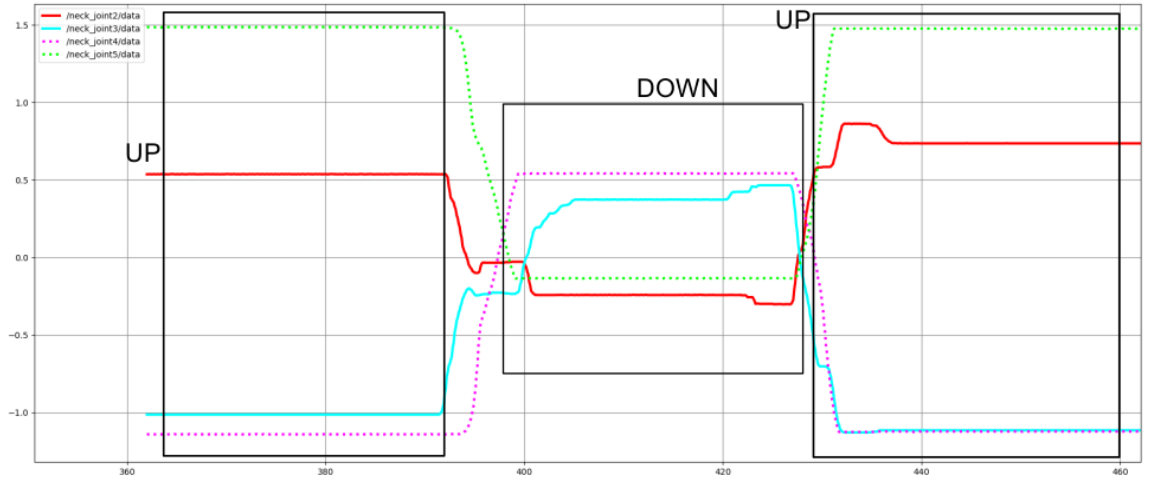
ABEL

- Hyper-realistic humanoid kid designed in collaboration with **Gustav Hoegen** (Biomimics)
- Head, neck, arms and hands are robotic controllable parts
- 43 servos: 22 to move the facial expression, 5 for the neck, 5 for each arm, 3 for each hand
- Mouth movements to perform realistic verbal communication
- Eyes movements to perform believable gaze
- Bio-inspired Social Emotional Artificial Intelligence (**SEAI**) based on NN algorithms to extract features from the environment and a Rule-based Expert System to perform abstract reasoning, logical deduction/induction and symbolic manipulation of the information gathered by sensors

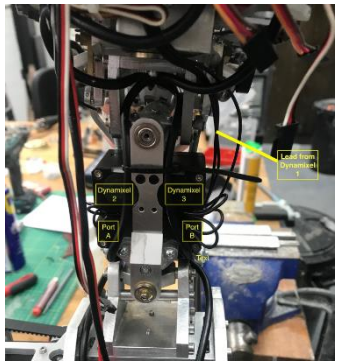
Neck reverse engineering

The robot was not provided with schematics or CAD files, and it was not possible to remove the neck skin to study the inner workings.

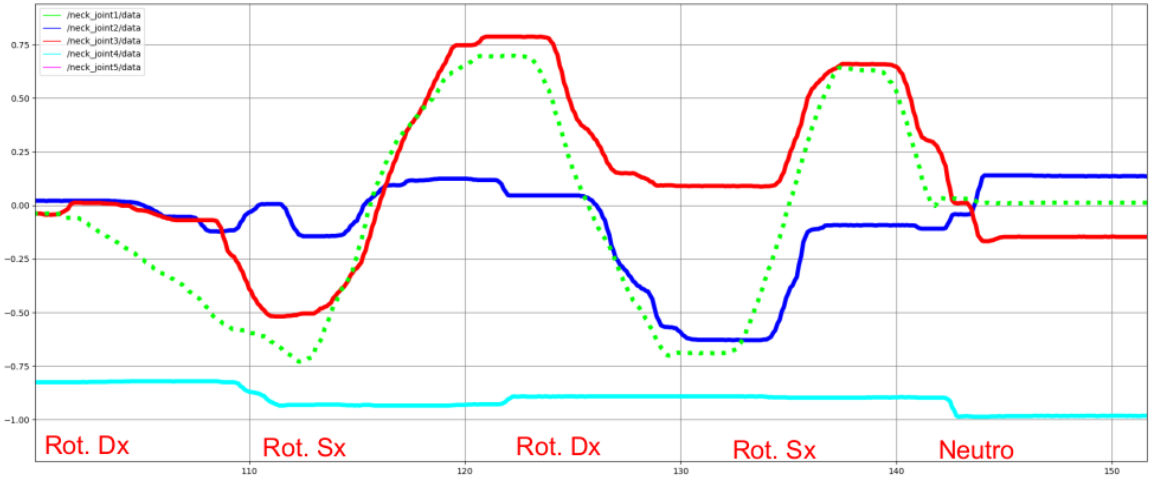
A **reverse approach** was used to control the neck joints, starting with manual handling of the neck and treating the system as a black box.



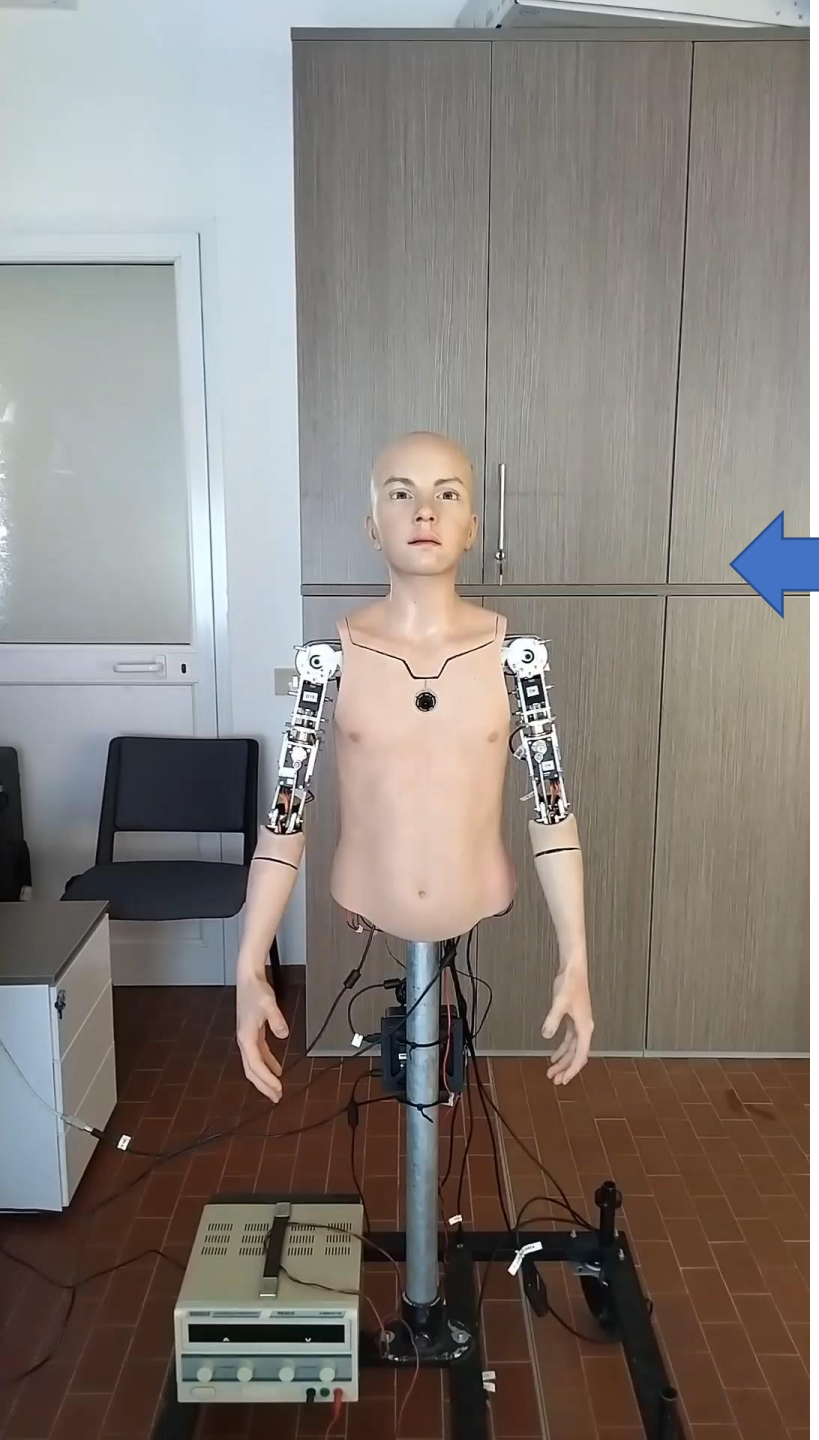
Move the joints



Estimate function



By <u>experimental analysis</u> of the joint data shown in the figures, a function for neck movement was approximated that was inspired by the natural movements made by human muscles

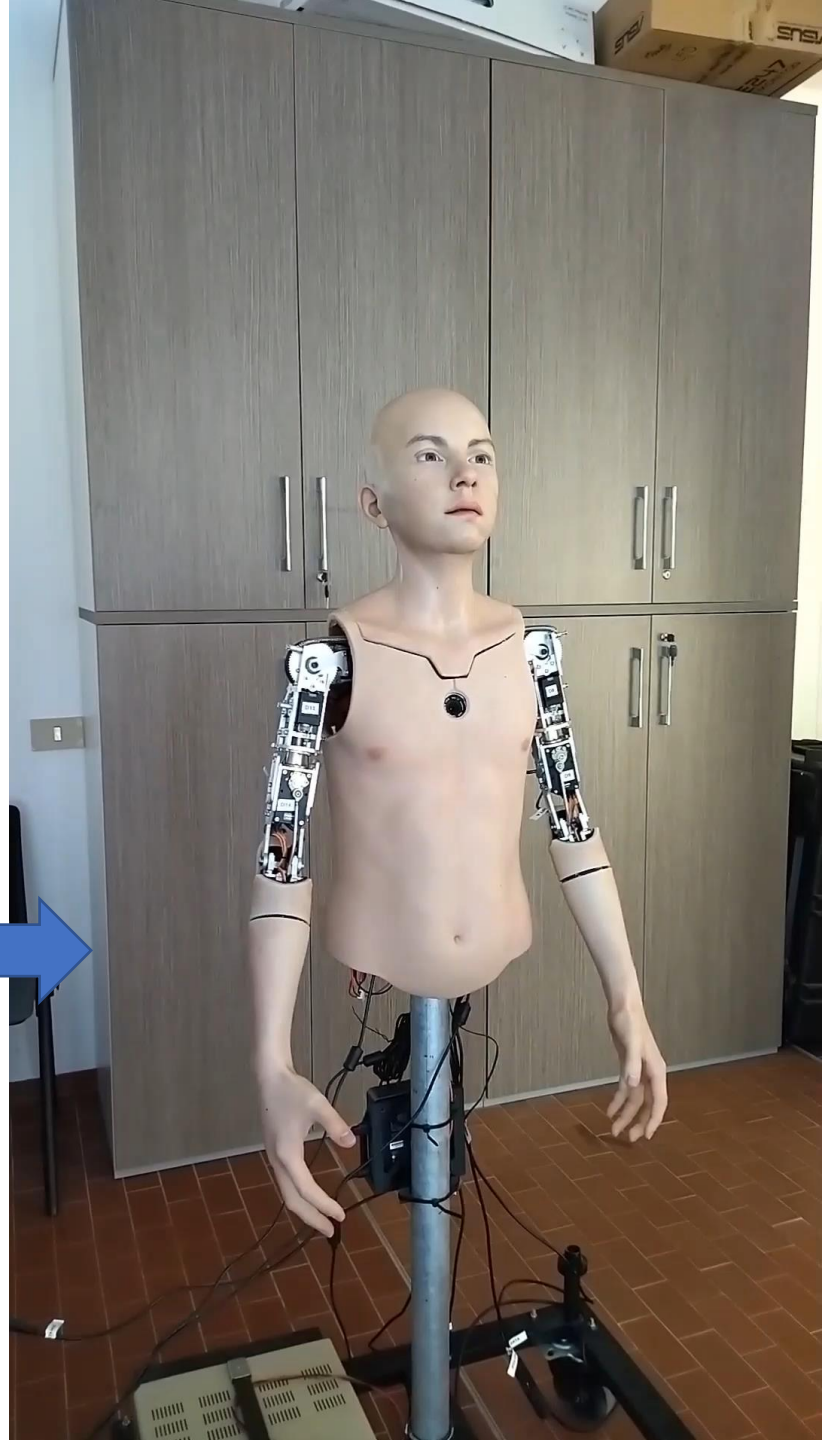


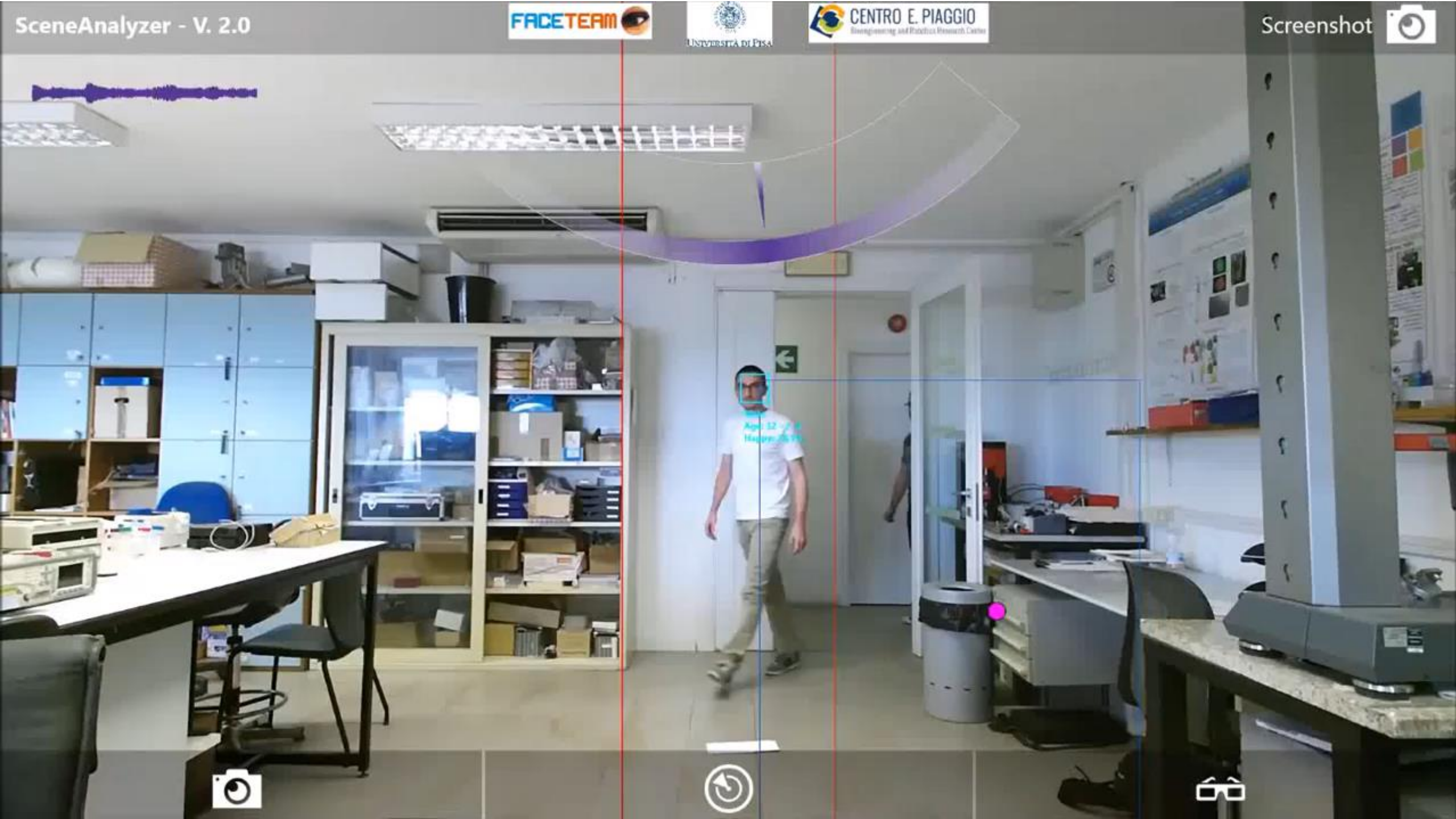
The single-peaked bell velocity profile is experimentally found to be the most suitable for controlling Abel's movements.

On the left, a configuration with a **triangular velocity profile**, no minimum jerk trajectory generation and poor arm coordination.

On the right a configuration with **Profile Velocity set at 60 rev/min** and **Profile Acceleration at 3 rev/min^2**.

Minimum jerk trajectory generation, fifth order polynomial and bell-shape velocity profile.

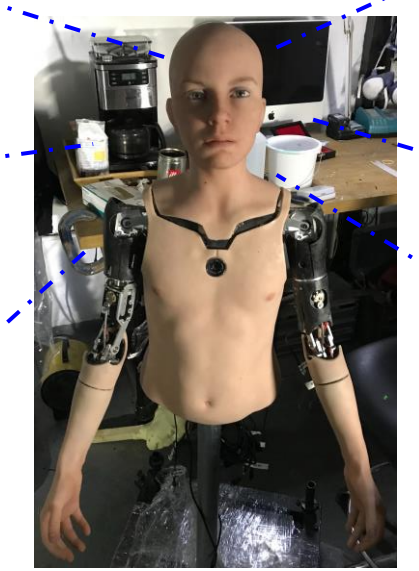



SceneAnalyzer - V. 2.0
FACETEAM
Università di Pisa
CENTRO E. PIAGGIO
Screenshot

An Extended Multimodal Perception

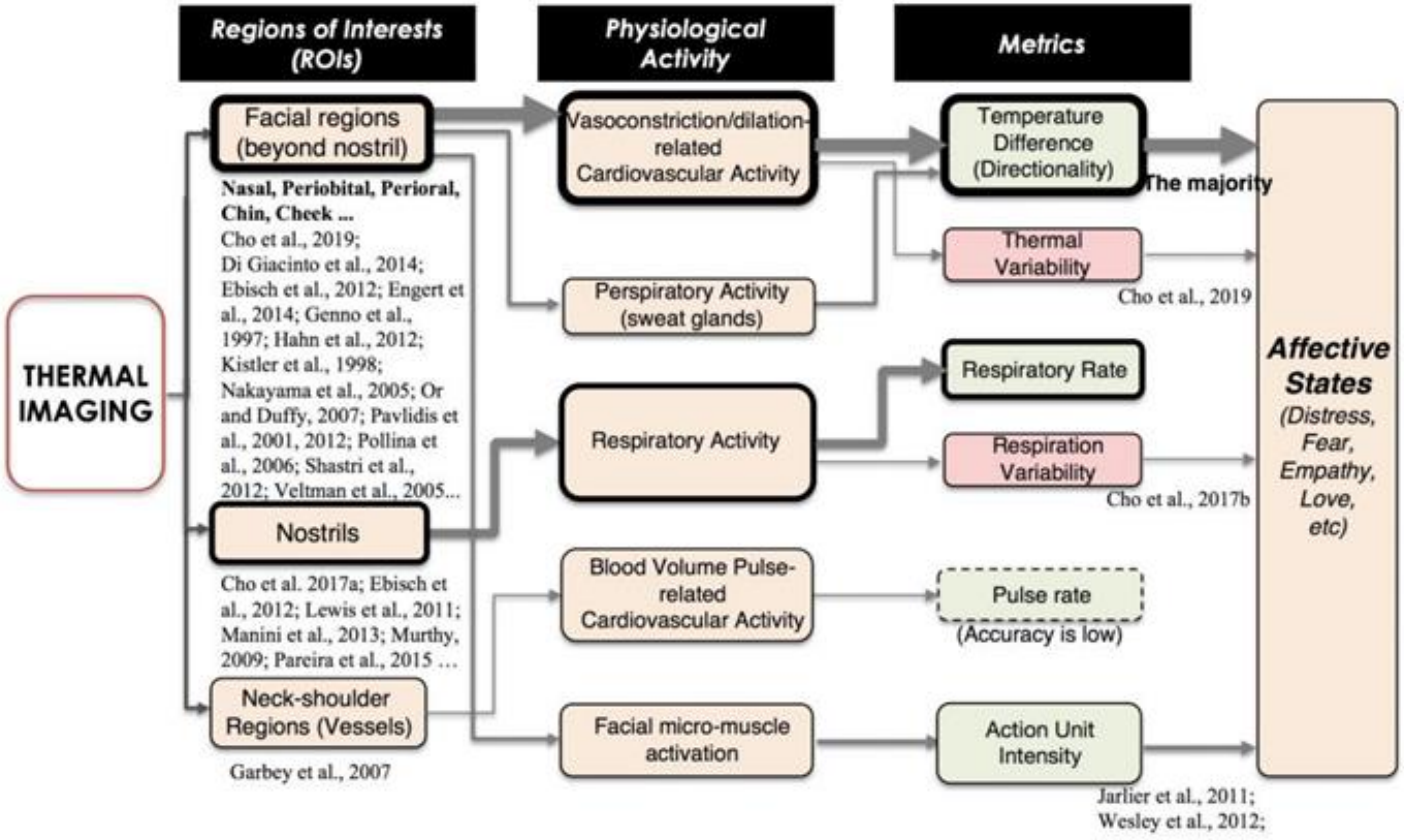


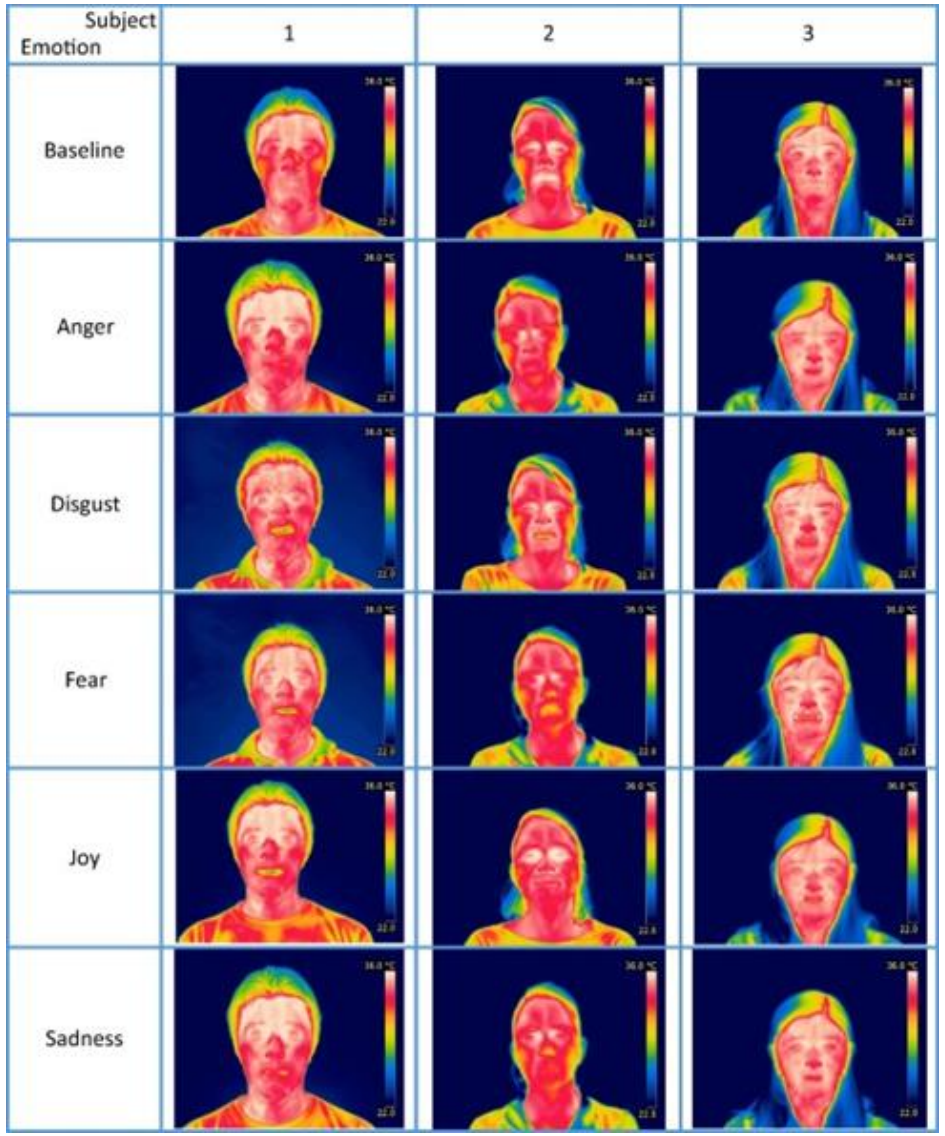




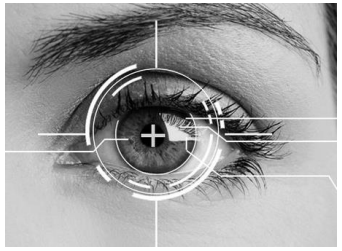

Physiological and Affective Computing through Thermal Imaging





Biomedical signal processing and modelling

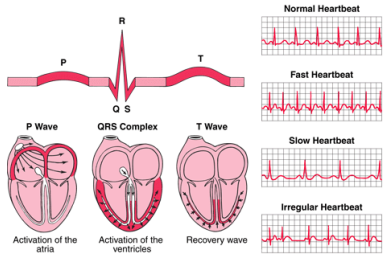
Eye-gaze



Brain dynamics

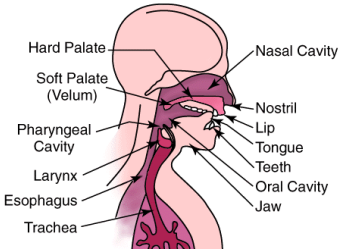
EEG

Autonomic nervous system



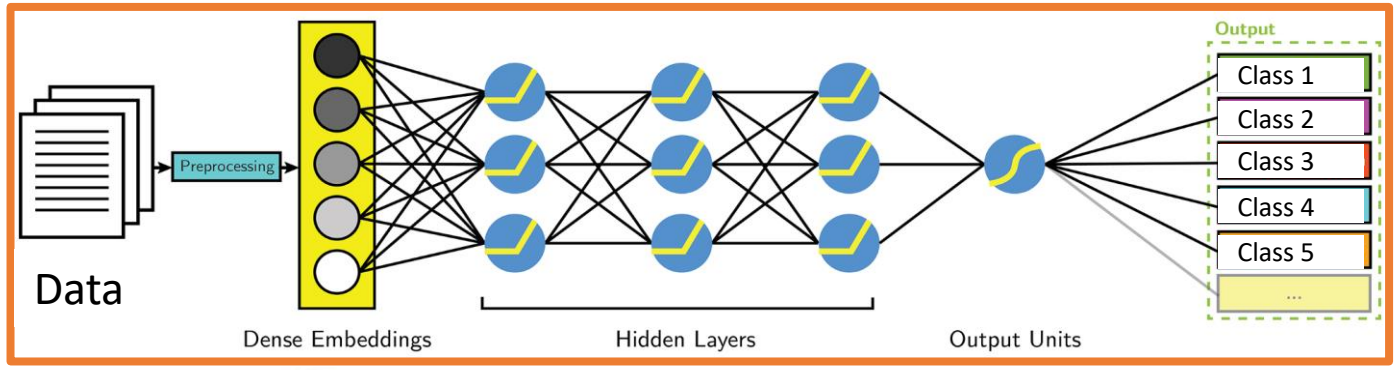
ECG, EDA

Speech



Bioimages

Feature Extraction



MACHINE LEARNING TECHNIQUES

Machine Learning VS Expert System

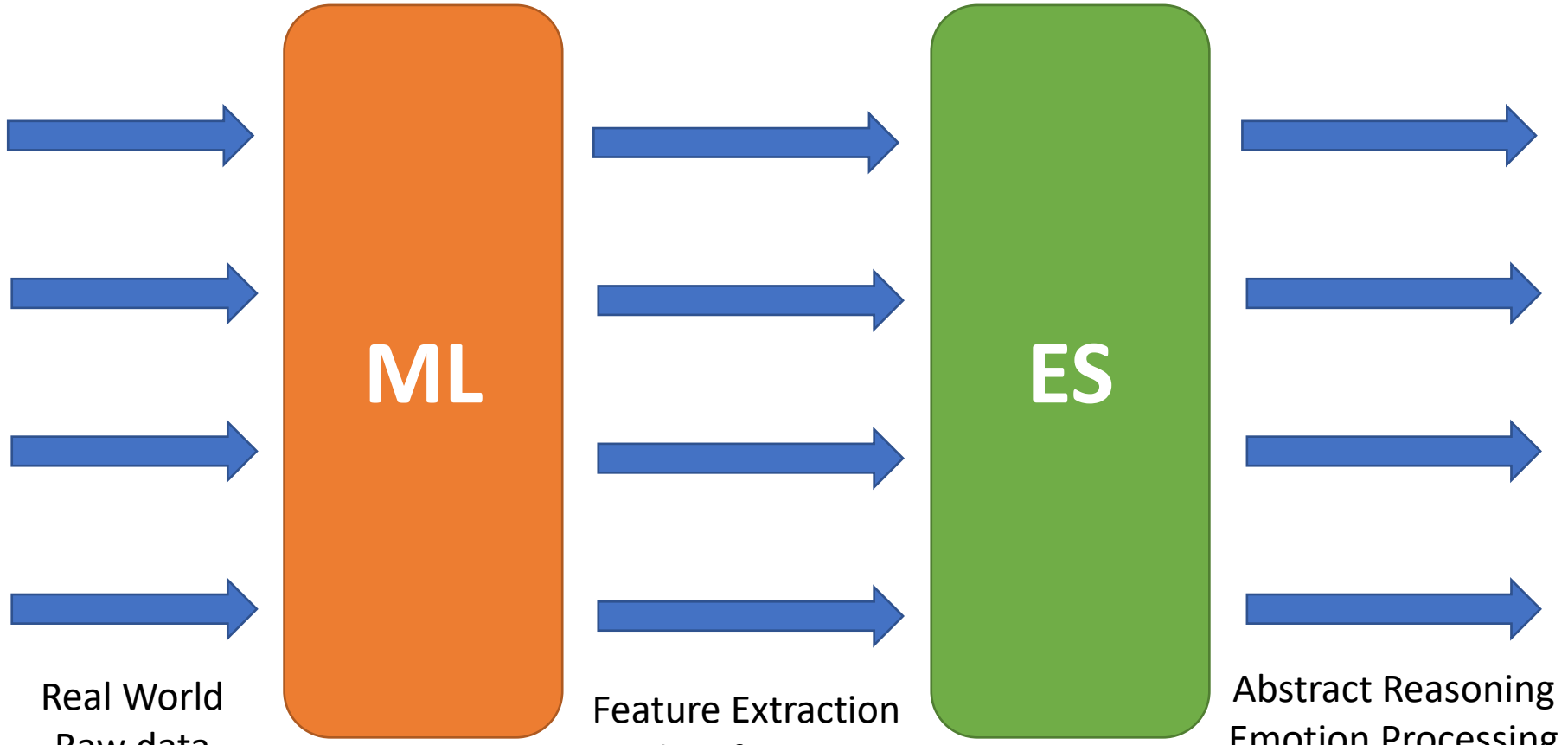
Data-Driven Approach

Knowledge-based Approach

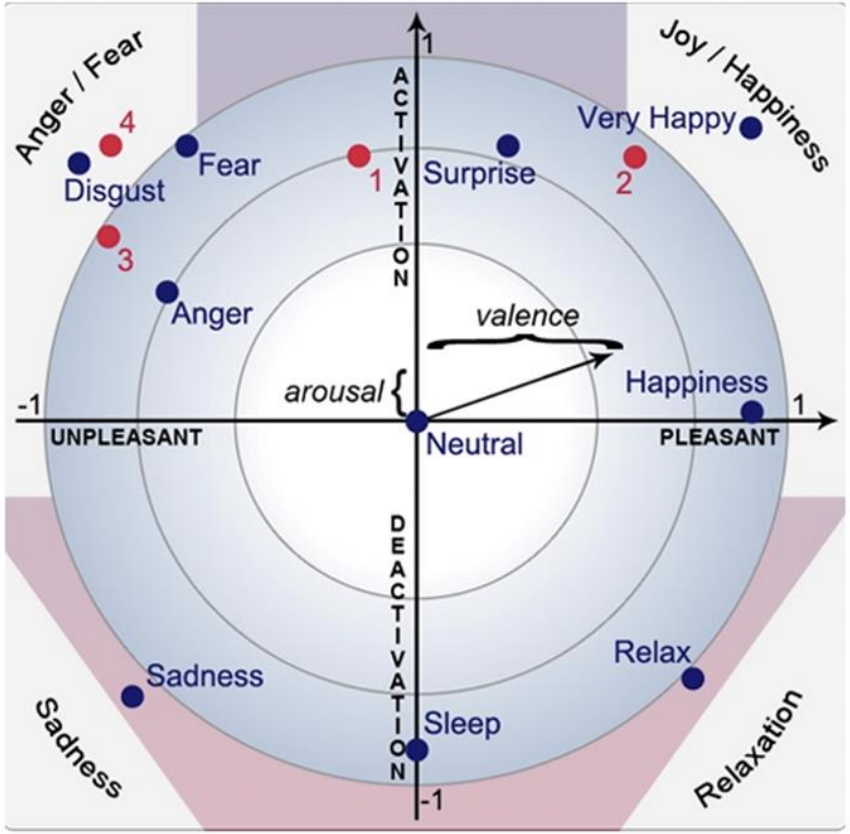
Machine Learning + Expert System

Data-Driven Approach

Knowledge-based Approach

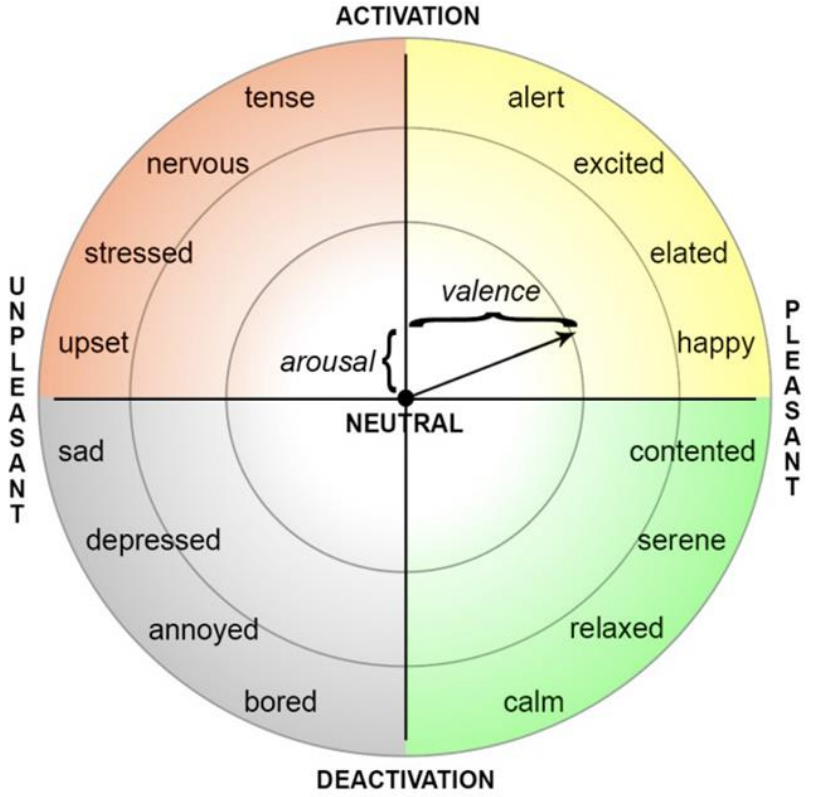


EXPRESSION



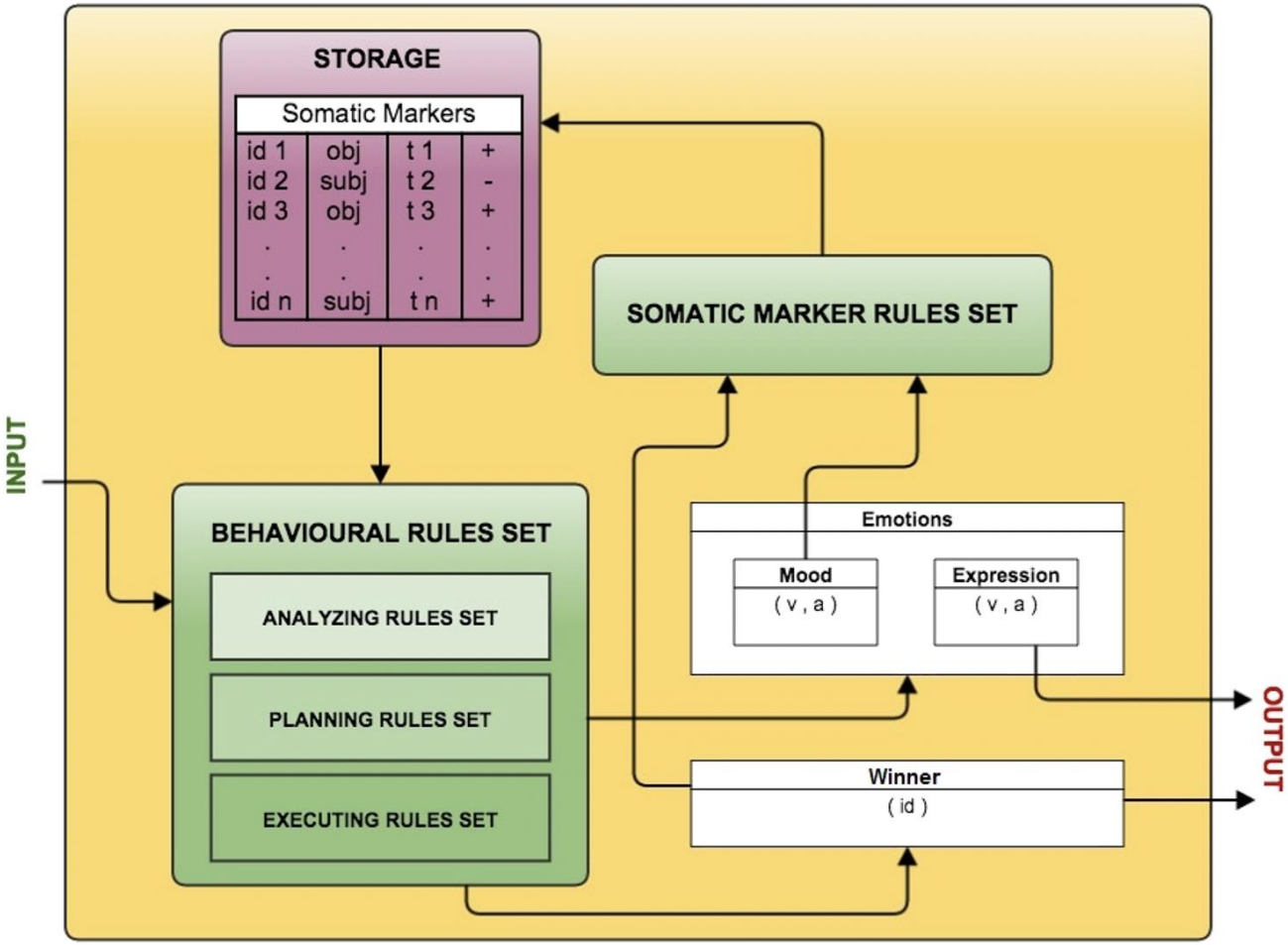
discrete, quick reaction, highly responsive, unconscious, OUT of the time dimension

MOOD

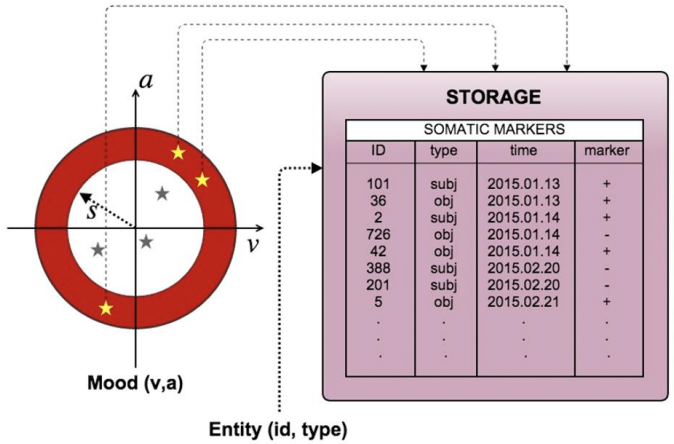


incremental, slow modulation, determines changes in the behaviour of the robot, based on the experience, IN the time dimension

Implementation of the Somatic Marker



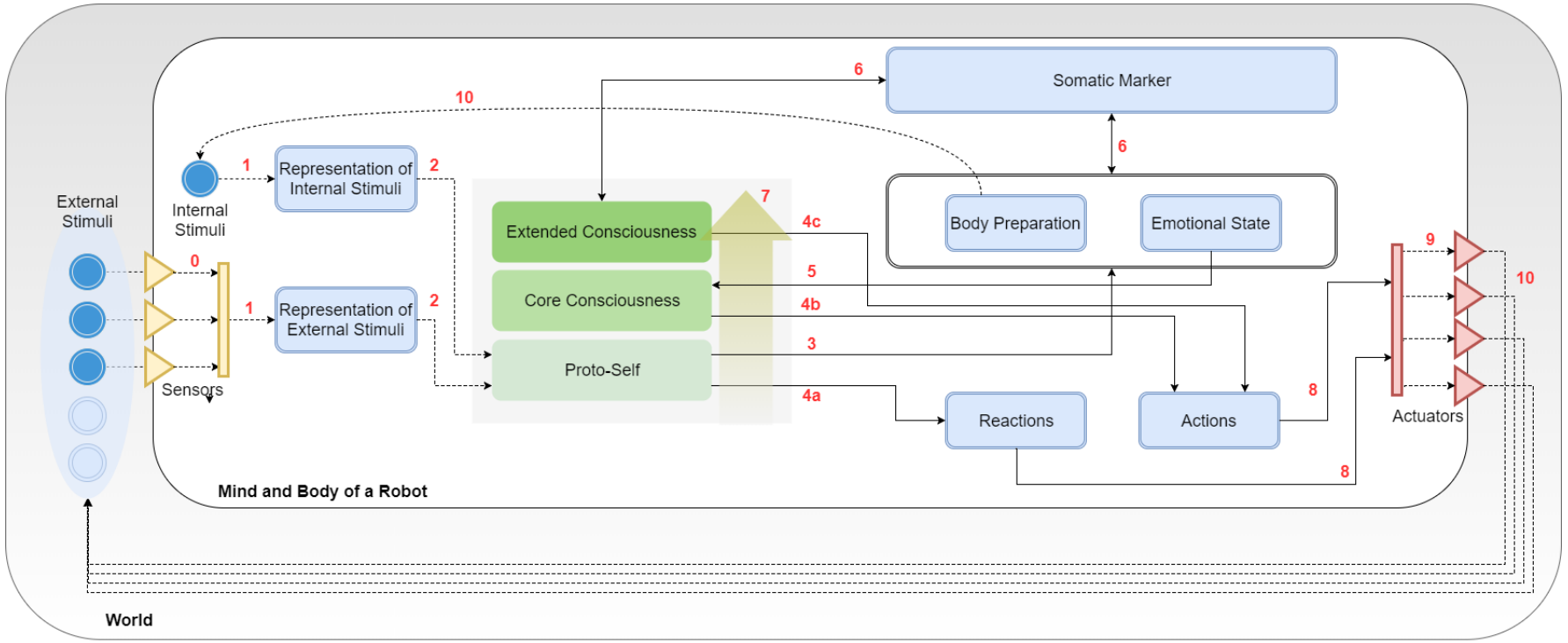
Somatic Rules (**SMRS**) are triggered by the exceed of thresholds in the mood plane: an important emotional state activate a marker on the object of attention of the robot (e.g., an object, a subject or a concept)



Since a marked entity is present in the storage, if the same - or a similar - object, subject or concept is recognized in the scenario of the robot (**ARS**), or appears again in the mind of the robot (**PRS**), different actions will be executed (**ERS**). As a consequence, the whole path of the Behavioural Rules Set will be biased.

Therefore, the Behavioural Rules Set (**BRS**) determines the behaviour of the robot according to external and internal informations (e.g. SMs);

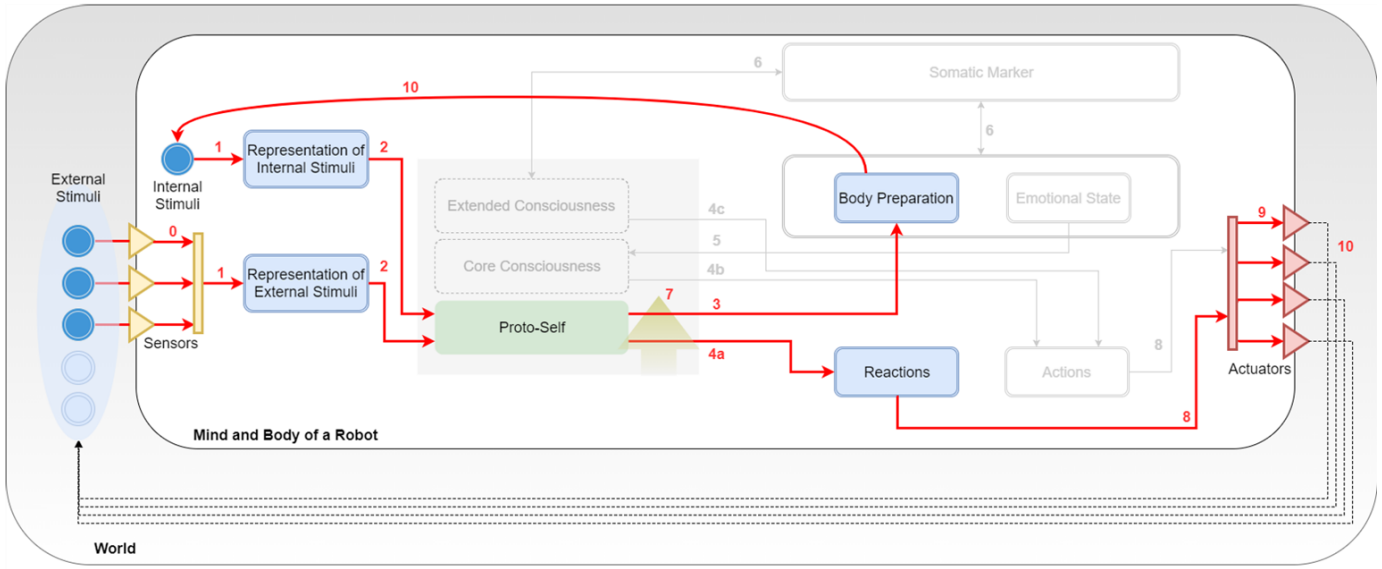
SEAI | Social Emotional Artificial Intelligence

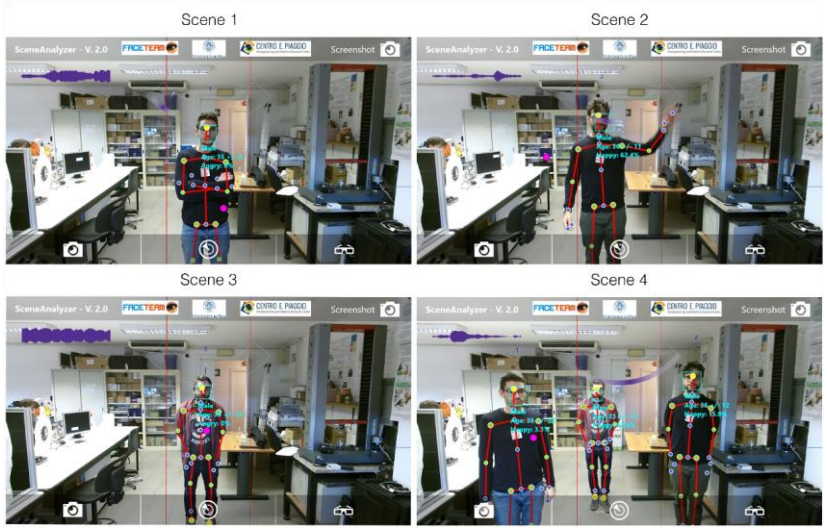


Connections and Rule Sets

1. **PATTERN MATCHING**
2. **ASSERTION OF FACTS**
3. **EMORS** (**EMO**tional **R**ule **S**et)
4. **BEHRS** (**BEH**avioral **R**ule **S**et)
5. **FEERS** (**FEE**ling **R**ule **S**et)
6. **SOMARS** (**SO**matic **MA**rker **R**ule **S**et)
7. **REARS** (**REA**soning **R**ule **S**et)
8. **EXERS** (**EXE**cutional **R**ule **S**et)
9. **MOTOR COMMANDS**
10. **ACTION AND REAQUISTION**

Cominelli, L., Mazzei, D., & De Rossi, D. E. (2018). SEAI: Social Emotional Artificial Intelligence Based on Damasio's Theory of Mind. Frontiers in Robotics and AI, 5, 6.





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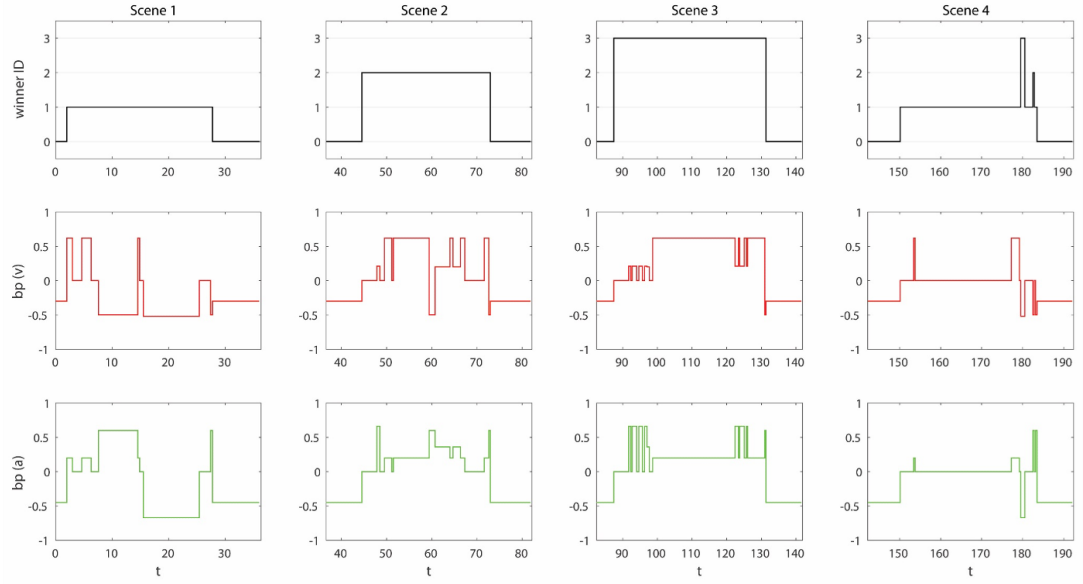
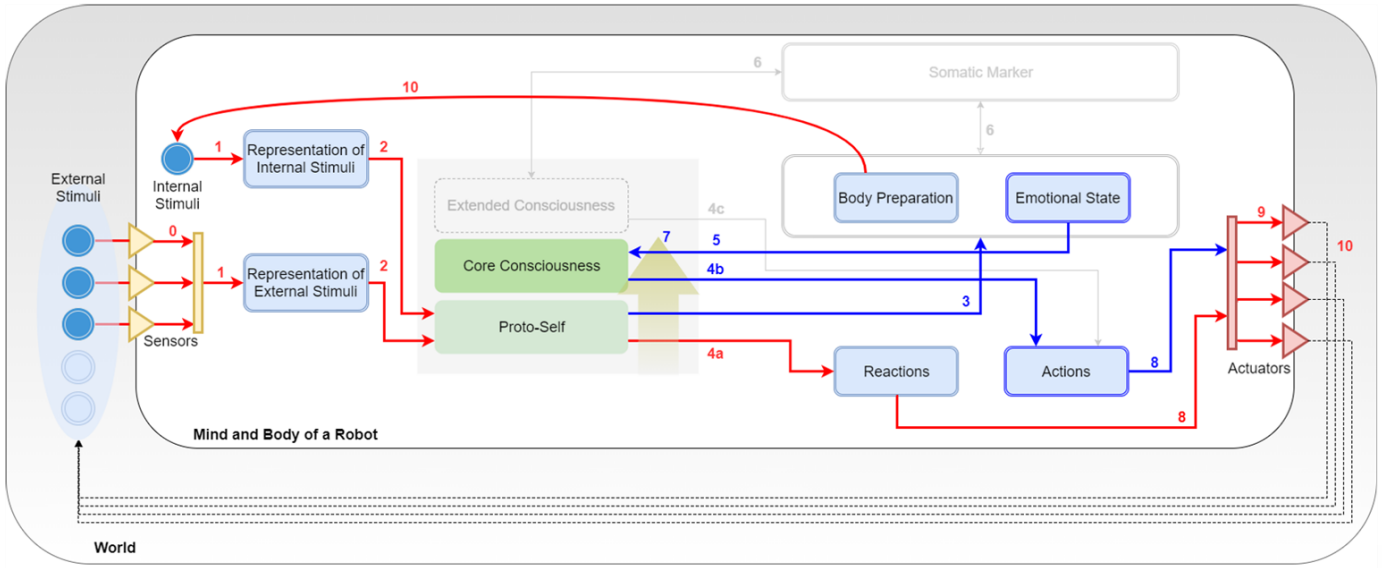
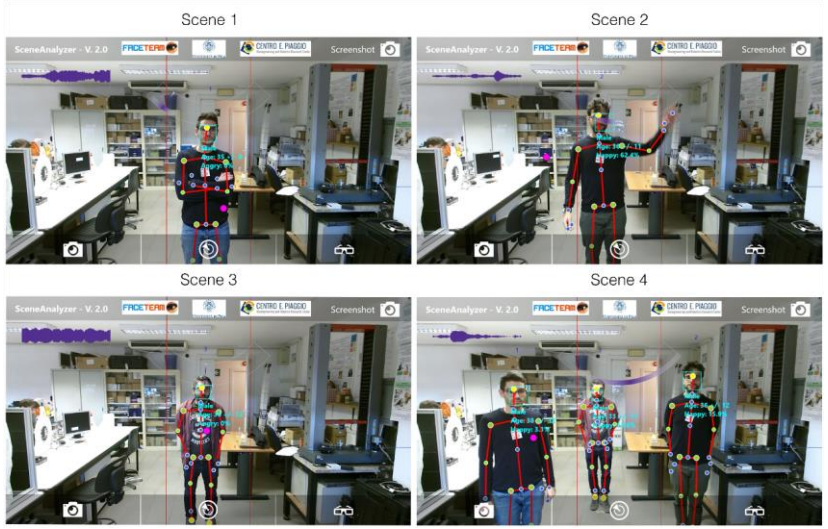
9. **MOTOR COMMANDS**
10. **ACTION AND next AQUISTION**







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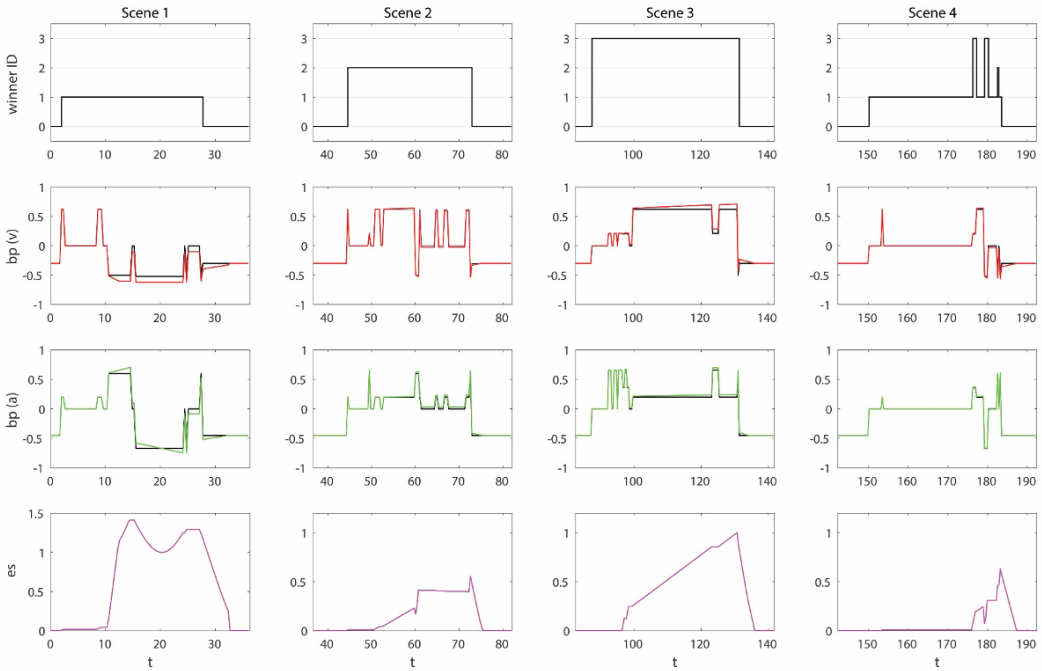

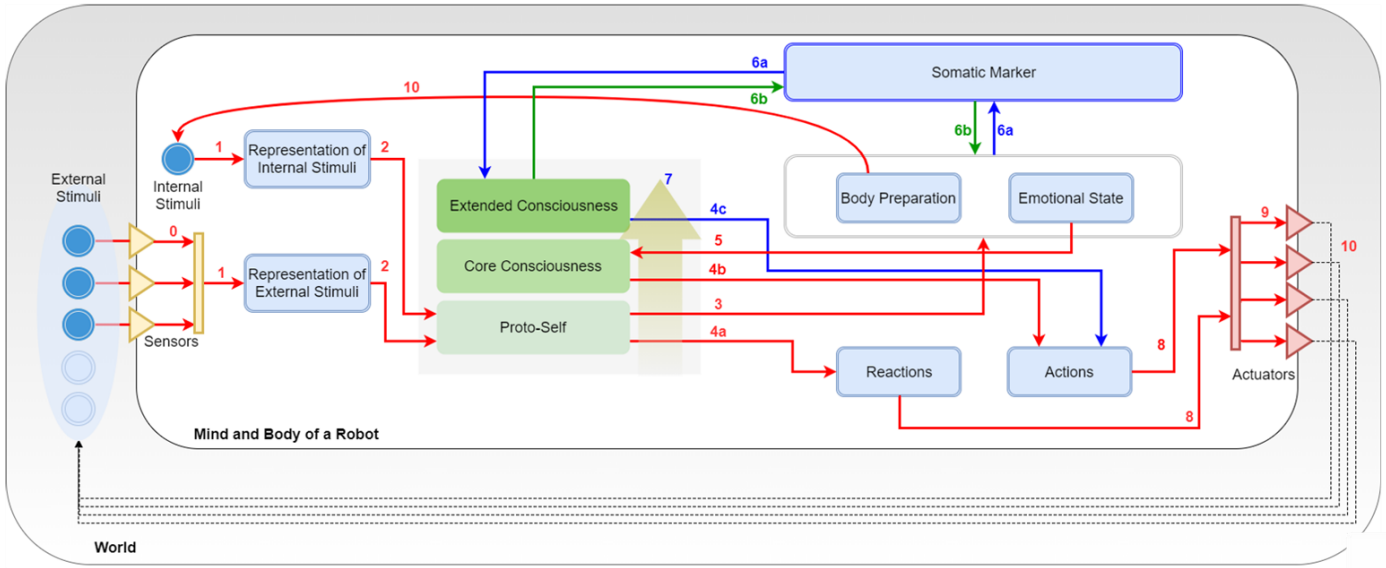

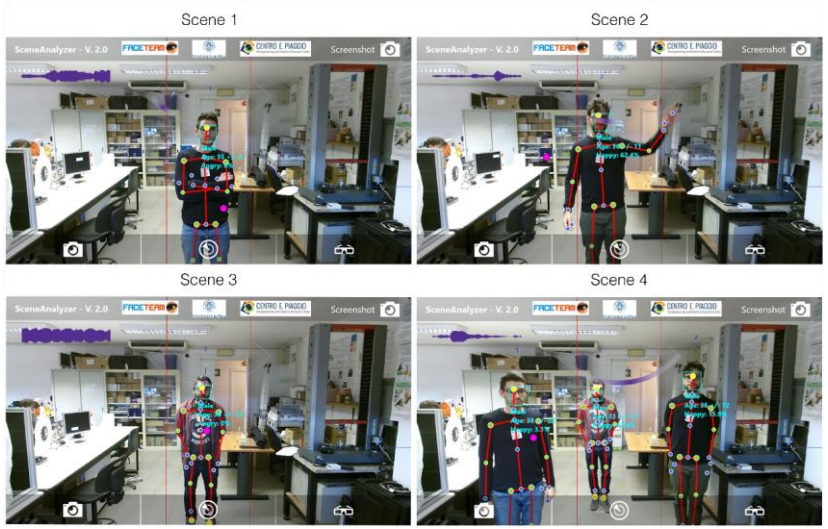

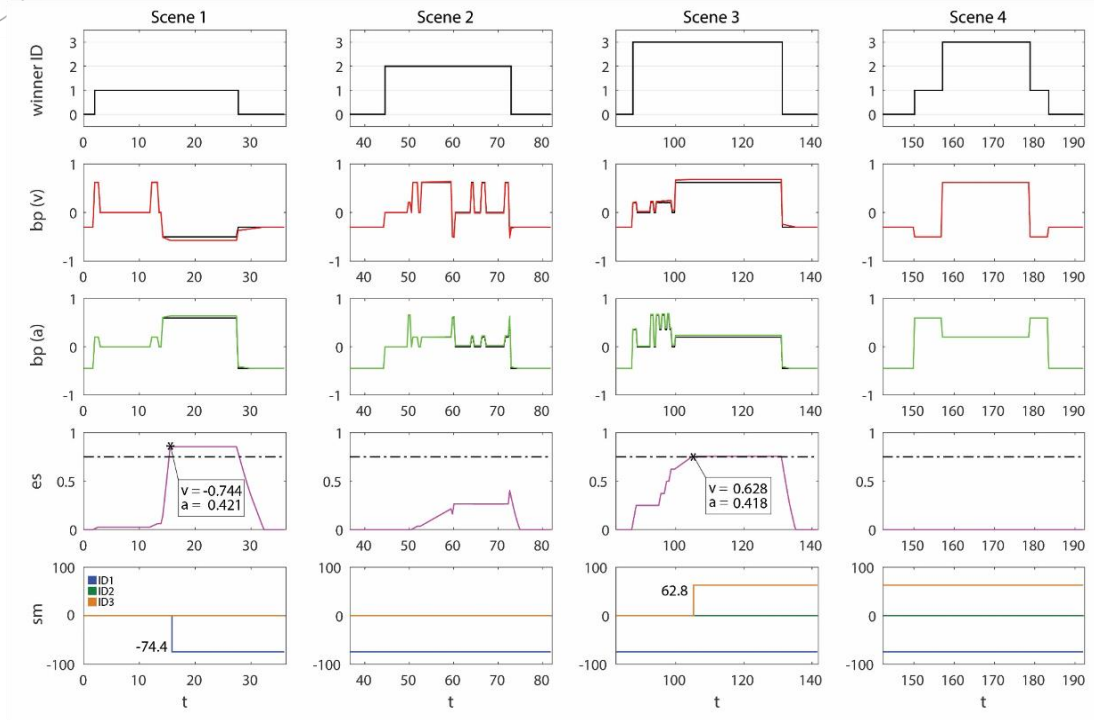

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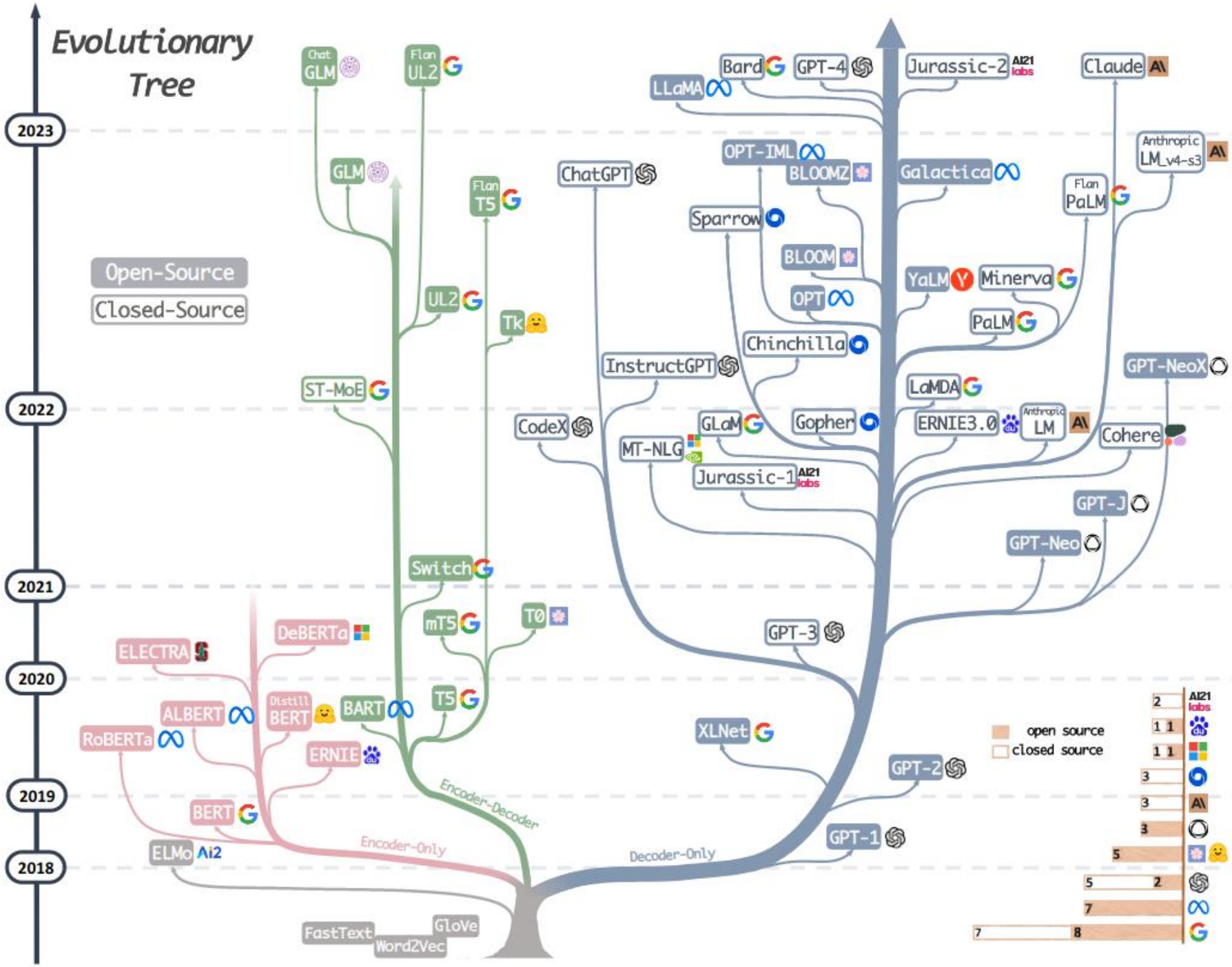
Evolutionary Tree
2023
2022
2021
2020
2019
2018
Open-Source
Closed-Source
Chat GLM
Flan UL2
Bard
GPT-4
Jurassic-2 AI21 labs
Claude
LLaMA
GLM
Flan T5
OPT-IML
BLOOMZ
ChatGPT
Galactica
Anthropic LM_v4-s3
Flan PaLM
Sparrow
BLOOM
YaLM
Minerva
UL2
OPT
Tk
PaLM
Chinchilla
InstructGPT
GPT-NeoX
ST-MoE
LaMDA
CodeX
GLaM
Gopher
ERNIE3.0
Anthropic LM
Cohere
MT-NLG
Jurassic-1 AI21 labs
GPT-J
GPT-Neo
Switch
mT5
T0
GPT-3
DeBERTa
ELECTRA
Distill BERT
ALBERT
BART
T5
RoBERTa
ERNIE
XLNet
GPT-2
BERT
Encoder-Decoder
Encoder-Only
Decoder-Only
GPT-1
ELMo Ai2
FastText
GloVe
Word2Vec
open source
closed source
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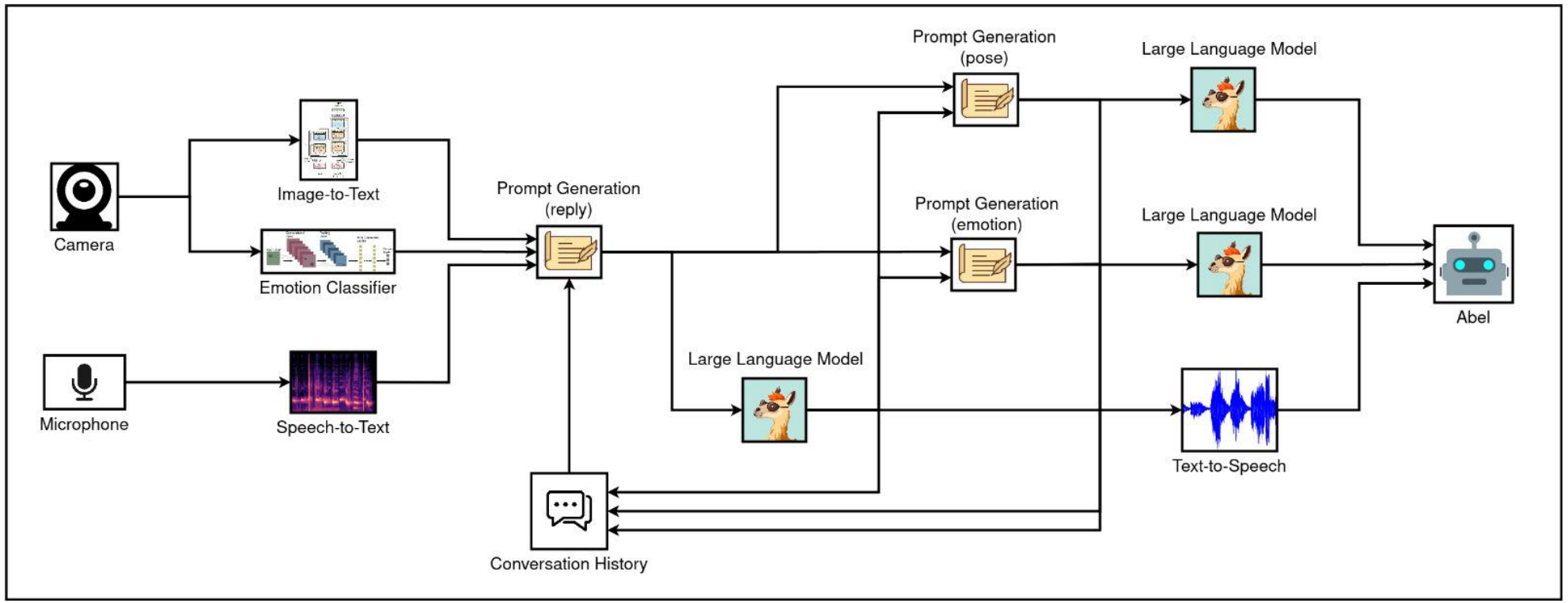
5 2
7
7 8

A Cognitive Architecture for a Natural Verbal Communication



Testing Abel's Architecture in HRI

Embodiment	ARCHITECTURE	NO ARCHITECTURE
Yes	Smart Abel	Naïve Abel
No	Smart Avatar	Naïve Avatar

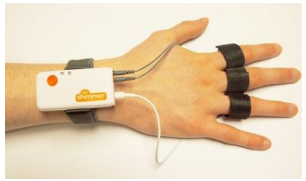
TEST PERCEIVED INTERACTION

SELF-REPORT BEHAVIORAL MEASURE

HRIES Scale

- *Agency*
- *Animacy*
- *Sociability*
- *Disturbance*

PHYSIOLOGICAL MEASURE



- **GENERAL AIM:**
  *Develop **guidelines** and appropriate **assessment** schemes to judge the progress of the developed solutions*

- **OBJECTIVE:**
  Test the effectiveness of Abel's **architecture** (and **embodiment**) on **human** participants.

Some Preliminary Results

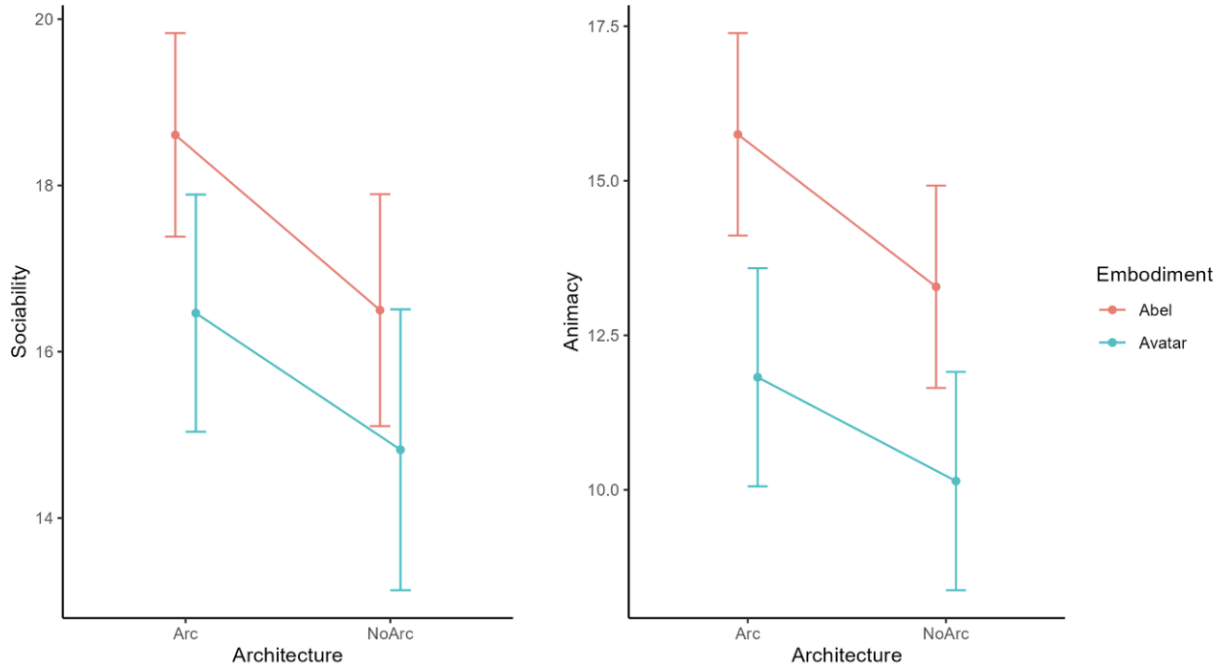
- When analyzing the Human-Robot Interaction Evaluation Scale (HRIES, Spatola et al., 2021), we found significant main effects of Embodiment and Architecture on Sociability and Animacy

- Abel was perceived as more sociable (i.e., likeable, friendly) and animated (i.e., alive, human-like) than its avatar version, while the architecture version also increased Sociability and Animacy compared to the no-architecture version.

Embodiment effects						
HRIES Subscale	**Mean Abel**	**Mean Avatar**	***F***	**DF**	**p-value**	**p-value code**
Sociability	17.55	15.64	8.14	1,27	.008	**
Animacy	14.52	10.98	20.57	1.27	< .001	***
Agency	18.68	17.52	3.22	1,27	.084	
Disturbance	11.43	11.32	0.01	1,27	.916	

Architecture effects						
HRIES Subscale	**Mean Arc**	**Mean NoArc**	***F***	**DF**	**p-value**	**p-value code**
Sociability	17.54	15.66	5.78	1,27	.023	*
Animacy	13.79	11.71	15.69	1,54	< .001	***
Agency	18.05	18.14	0.03	1,27	.871	
Disturbance	11.48	11.27	0.07	1,27	.798	

P-value codes: < .001 '*'; < .01 '**'; < .05 '*'**



Measuring Trust and Collaboration with Behavioral Economics Experiments

- Fictious Financial Markets
- Trust Game
- Escape Room

Self-reported indicators

questions asked at round 5-10-15

Facial expressions

every 7 seconds, over 15 rounds:
7 emotions + engagement

Physiological parameters

real time, over 15 rounds:
e.g EDA_symp, EDA_symp_HF_nu

- **GENERAL AIM:**
  Collect physiological data during HRI experiments to analyse potential decisional bias and extract meaningful patterns

- **OBJECTIVE:**
  Develop decision-making (or support) systems that take into consideration human emotions in realtime

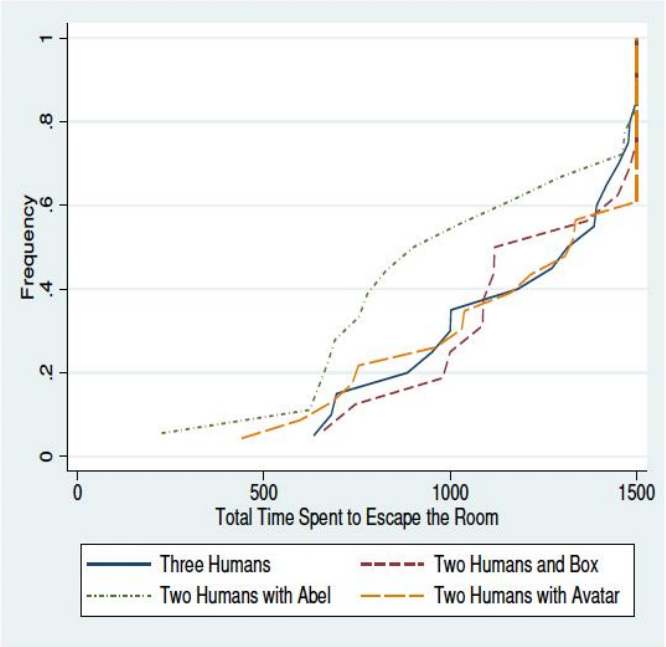
Some Preliminary Results from current experiments

The best performance is achieved by mixed teams, with the highest results observed in teams that included the humanoid agent.

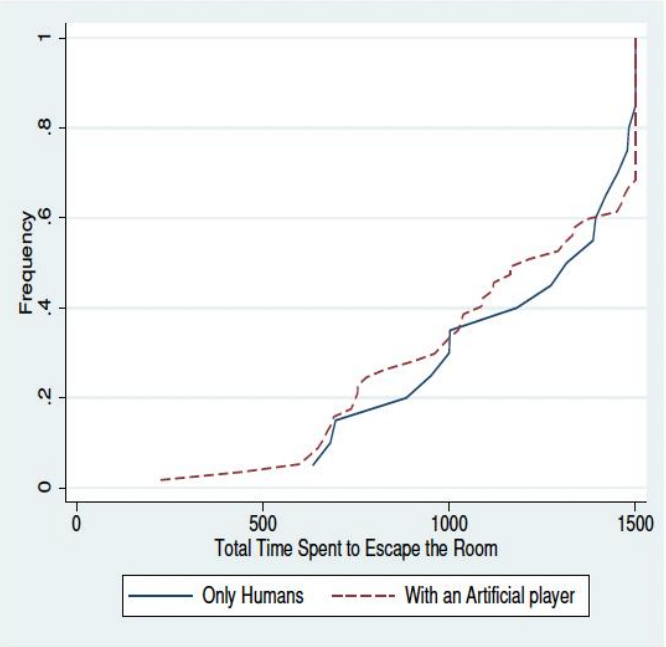
While human-only teams have a higher success rate, they take more time and make more errors.

Additionally, the conversational style with Abel is more akin to human communication compared to interactions with less embodied artificial agents.

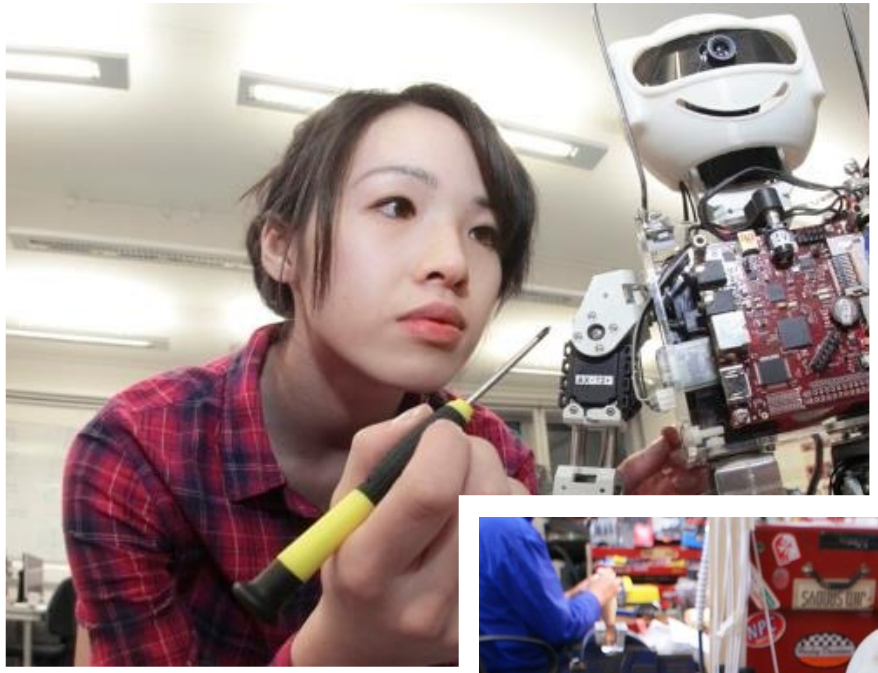
Condition	No Embodiment	Low Embodiment	High Embodiment
Machine	Computer Box	Avatar	Abel
No Machine	Only Humans		



(a) Human-only teams



(b) Team w/o an artificial player



Will machine take control?
We do not endorse this view.
Machines will undergo a long and true process of 'care' from which they will learn to define some sort of identity, responsibility, and ethics, with a symbiotic liaison with the mentor, forced to operate accordingly on himself.
We do believe machines will lead us to a new kind of humanism.

(De Rossi et al., 2014)

Danilo De Rossi, Pasquale Scilingo, Daniele Mazzei, Roberto Garofalo, Gustav Hoegen, Caterina Giannetti, Alberto Greco, Mimma Nardelli, Michael Pieroni, Abolfazl Zaraki, Nicole Lazzeri, Nadia Vetrano, Andrea Bau, Aurora De Acutis, Gabriele Gabriele Sisinna, Andrea Gargano, Luca Cecchetti, Caterina Vannucci, Graziano Manduzio, Andrea Altilia, Federico Galatolo, Gianluca Sirigu, Aida Himmiche, Antonio Patimo, Marco Pardini, Angelo De Marco…

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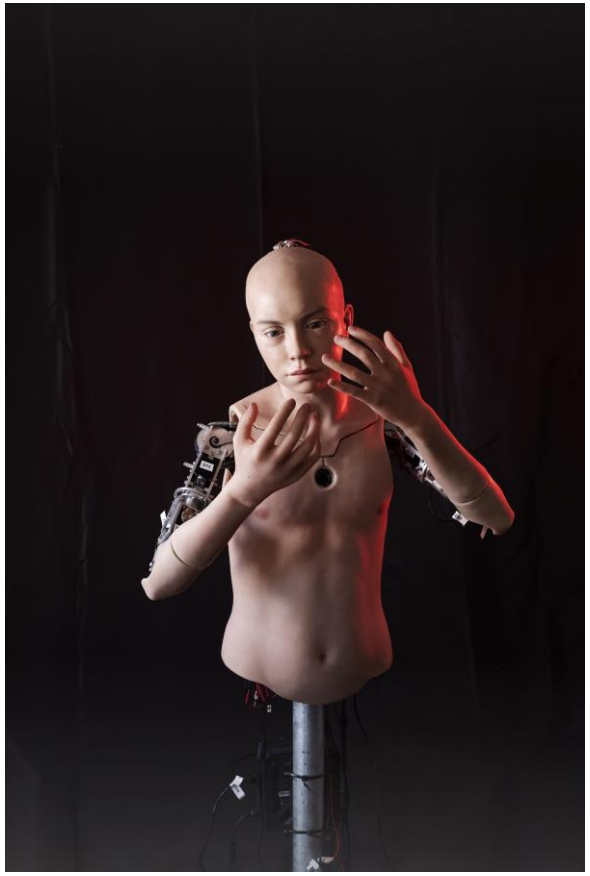
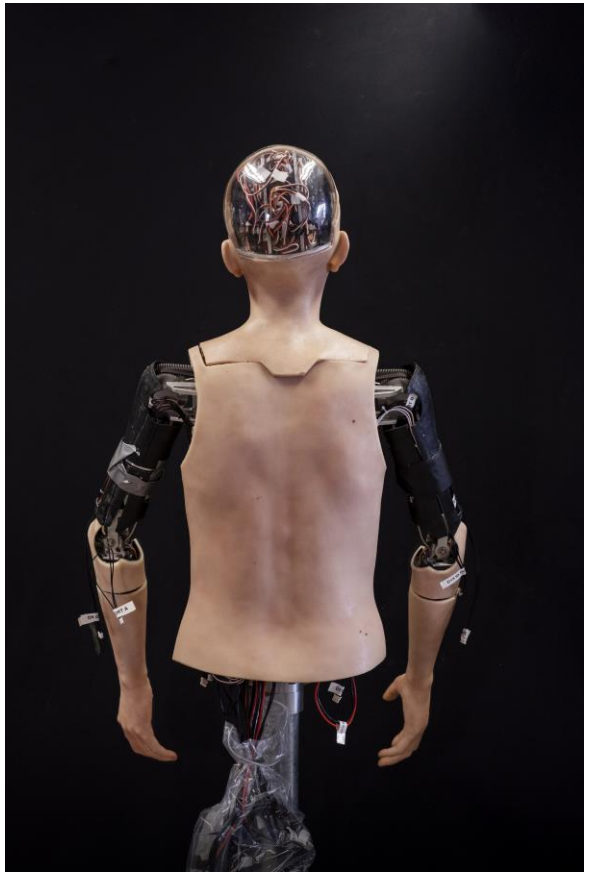
CENTRO E. PIAGGIO
Bioengineering and Robotics Research Center

lorenzo.cominelli@unipi.it

Thank you






Ph. Massimo Berruti © 2023

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Thank **you** for your kind attention