CAS CS 640
Artificial Intelligence

Lecture by Margrit Betke

Please note: Due to a broken projector connection, the marked slides were not presented on December 12, 2023

Topic: Robotics

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Not Presented

Background

- Term “Robot”:

  “robota” = obligatory work, “robotnik” = serf

  popularized by Czech brothers:

  Josef Capek’s short story *Opilec*, 1917

  Karel Capek’s play *Rossum’s Universal Robots*, 1921

- Term “Robotics” used by Asimov, 1950
- Greek mythology: mechanical man Talos

Not Presented

First Hand-eye Robots

Engelberger and Devol's company Unimation:

- Build first commercial robot *Unimate (universal automation)* sold to General Motors for manufacturing TV picture tubes, 1961
- First U.S. patent on a robot, 1961
- Automation of an entire assembly line with robots, developed with Kawaski for Nissan, 1972
- *PUMA (programmable universal machine for assembly),* developed for General Motors, 1978

Not Presented

First Mobile Robots

- *Hopkins Beast,* 1960s

  Pattern recognition: recognized cover plate of AC power outlets, plugged itself in to recharge

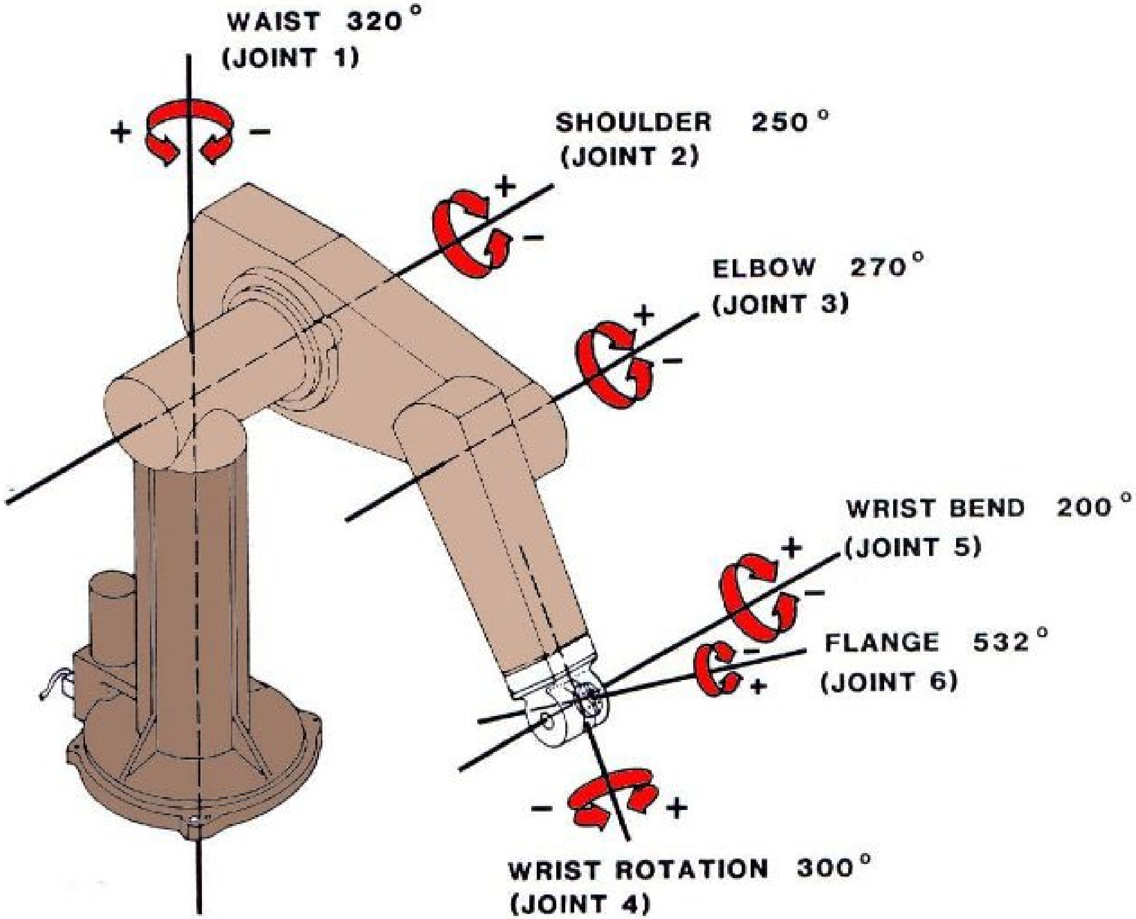
- *Shakey,* developed at Stanford Research Institute (SRI), late 1960s

  Integrated perception, planning, and execution

Definition

- Robot Institute of America's Definition:
  Programmable, multifunction manipulator designed to move material, parts, tools, or devices through variable programmed motions for the performance of a variety of tasks

Classic Industrial Robot: PUMA



http://rutherford-robotics.com/PUMA/

Definition

- Robot Institute of America's Definition:
  Programmable, multifunction manipulator designed to move material, parts, tools, or devices through variable programmed motions for the performance of a variety of tasks

- Our definition:

Definition

- Robot Institute of America's Definition:
  Programmable, multifunction manipulator designed to move material, parts, tools, or devices through variable programmed motions for the performance of a variety of tasks

- Artificial autonomous agent whose environment is the physical world. A robot is not a remote-controlled toy, but can make its own decision making, based on its own experience & guided by its sensor feedback.

Industrial Robots

- Automotive industry
- Electrical/electronics industry
- Rubber and plastics industry
- Food and beverage industry
- Metal products industry

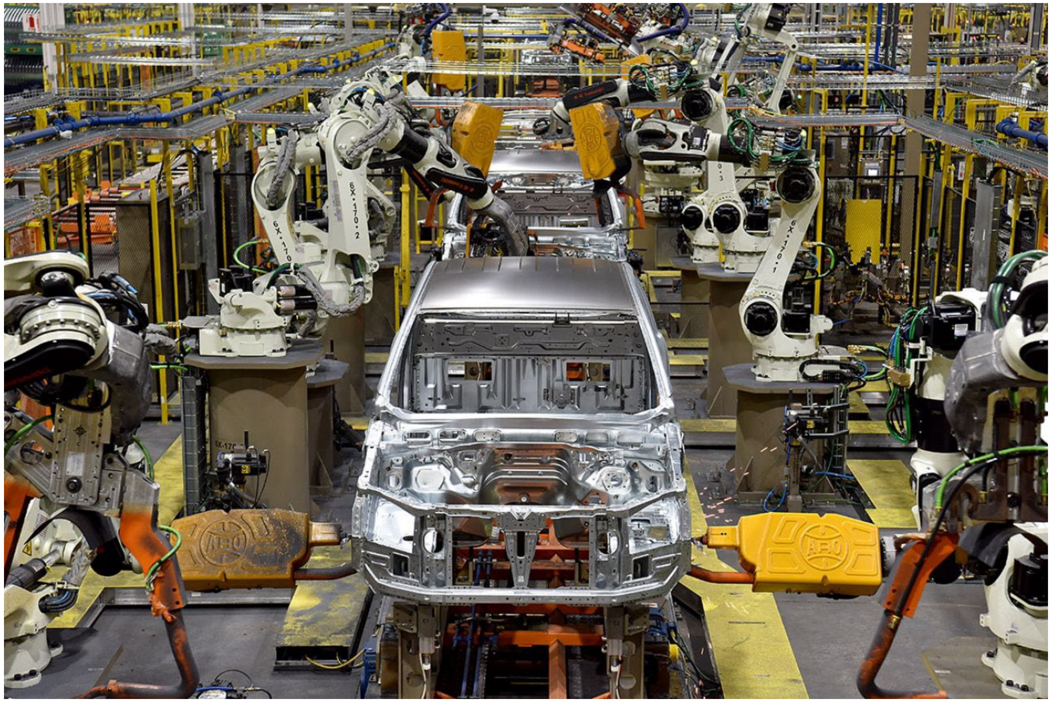
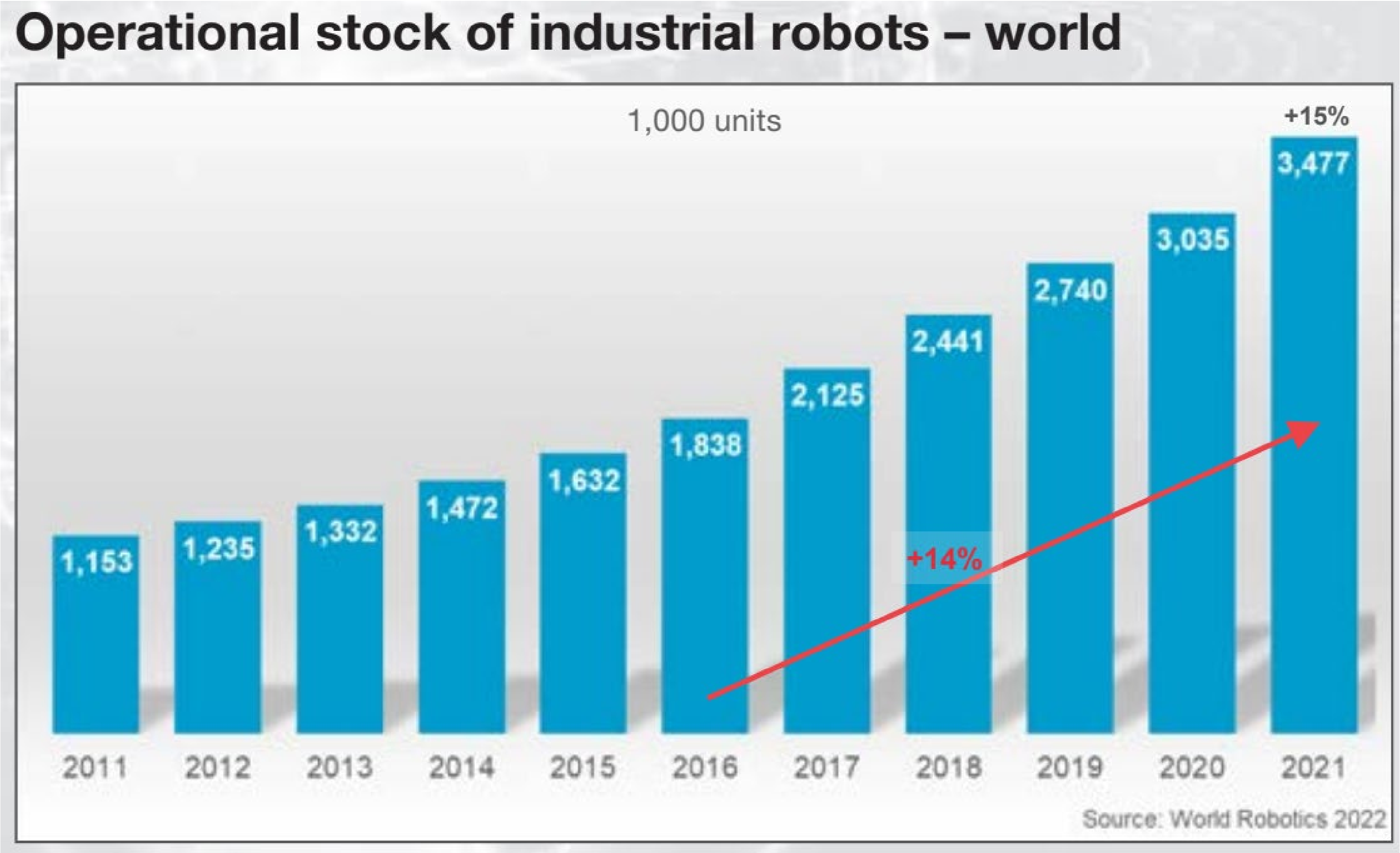


Photo credit: Ford

3.5 Million Industrial Robots



ifr.org

Mobile Personal-use Robots

- Assistive technology robots (small market but multiplying)
- Humanoid robots (mostly toys)

  2015: Pepper (SoftBank/Aldebaran), $2,000 only in Japan

- Household robots

  vacuum cleaning robots

  lawn-mowing robots

Photo credit: STIHL

Photo credit: iRobot ($1.7 billion purchase by Amazon in 2022)

Photo credit: Aldebaran

Robots for Hazardous Environments

- Roadside bomb removers:

  6500 Packrobots (iRobot-> FLIR)

- Toxic waste, biologically hazardous, radioactive environments

  Chernobyl, World Trade Center,

  Fukushima Daiichi (Packrobots)

Explorers:

- Volcanoes: Dante project
- Mars, Europa

Mobile Robots

ULVs: Unmanned land vehicles

Drones, UAVs: Unmanned air vehicles

AUVs: Autonomous underwater vehicles

Planetary rovers

(ROVs: Remotely operated vehicles)

Rodney Brooks' taxonomy:

AGVs: Automatic guided vehicles (bears)

AMRs: Automatic mobile robots (goats)

CMRs: Collaborative mobile robots (dogs)

Mobile Robots

ULVs: Unmanned land vehicles, Robo Cars

UAVs: Unmanned air vehicles, Drones

AUVs: Autonomous underwater vehicles

Planetary rovers

(ROVs: Remotely operated vehicles)

Rodney Brooks' taxonomy:

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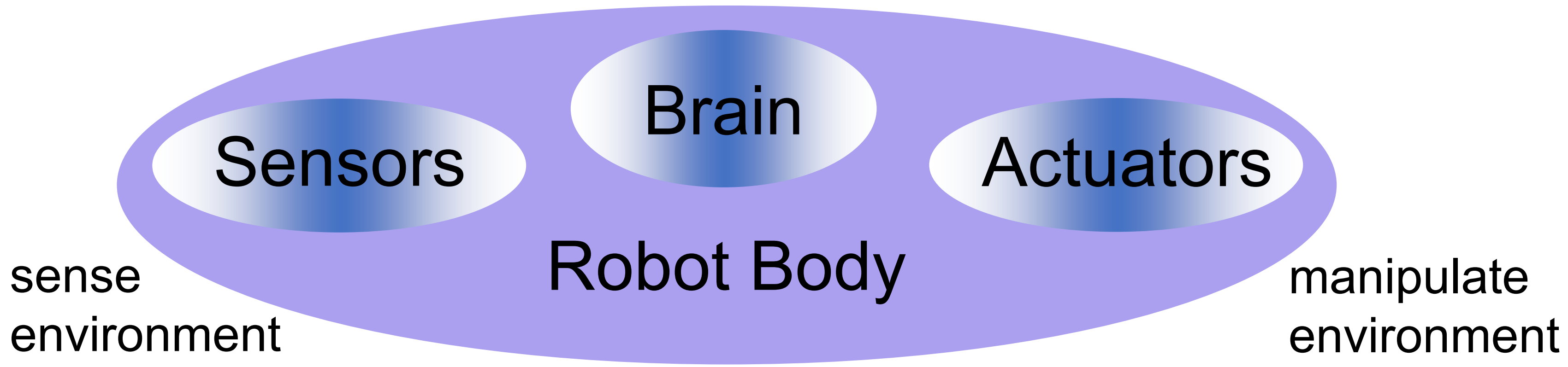
Robot Design



- Rigid body: revolute and prismatic joints, links
- Locomotion: wheels, tracks, legs, tail
- Electromechanical motors, hydraulic, pneumatic cylinders
- End effectors: grippers, suction cups, screw drivers, drills

Robot Sensors

- Passive Sensors
  - Cameras
  - Global Positioning System (GPS)
    not indoors or underwater
- Active Sensors
  - Laser, radar, and sonar range finders
  - Tactile sensors: whiskers, bump panels, skin
- Proprioceptive Sensors
  - Odometry, gyroscopes, force and torque sensors

Robot’s Degrees of Freedom

- *Degree of Freedom (DoF)* for each independent direction of movement

  Examples:

    - Human elbow: 1DoF
    - AUV: 6 DoF: (x,y,z, yaw, roll, pitch)

  = Kinematic State (“Pose”)

- Dynamic State = Kinematic State + 1 DoF per dimension for rate of change

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Holonomic and Nonholonomic Robots

- How many degrees of freedom are needed to place an object at a point in 3D space in a particular orientation?

- Effective Degrees of Freedom
- Controllable Degrees of Freedom
- Car Example

- Holonomic (controllable DoFs = effective DoFs)
- Nonholonomic (controllable DoFs < effective DoFs)

Not Presented

Challenging Physical World

- Dynamic
- Continuous
- Uncertain
- Difficult to assess

Not Presented

Challenging Physical World

- Dynamic: need to model changes in time, e.g., batteries run out
- Continuous: state enumeration impossible
- Uncertain: robot's wheels slip, parts break
- Difficult to assess: imperfect sensors, errors in measurements, use redundancy:

LSE (least-squares error) minimization

Not Presented

LSE Minimization

Measurements $x_1, \ldots, x_n$

Parameter describing robot state: **a**

True robot state $x_{true}(\mathbf{a})$

Estimated robot state: $\hat{\mathbf{a}}$

$$\hat{\mathbf{a}} = \underset{\mathbf{a}}{\operatorname{argmin}} \sum_{i=1}^{n} \left(x_i - x_{true}(\mathbf{a})\right)^2$$

Mobile Robot Navigation

- Omnidirectional Video Cameras
  - Ratbot, Siemens, 1994
  - Columbia, 1996

- Landmark-based navigation: Robot position can by found by triangulation: http://www.cs.bu.edu/fac/betke/papers/Betke-Gurvits-IEEETransRobotAutom97.pdf
- Simultaneous localization and mapping: SLAM

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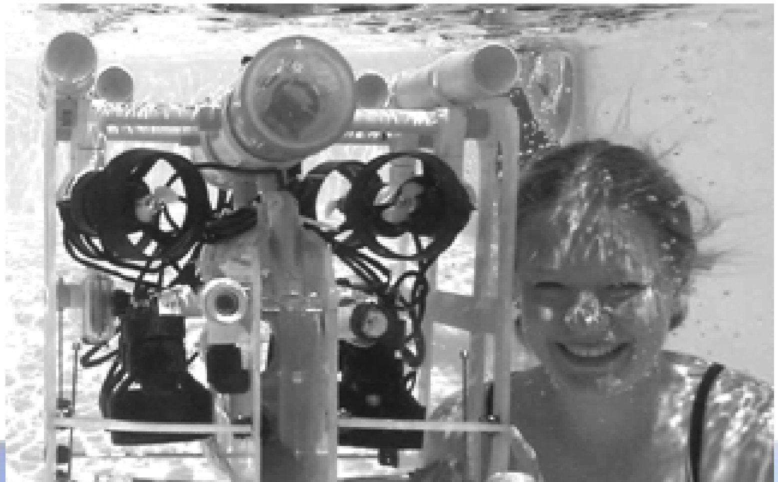
Autonomous Underwater Vehicles



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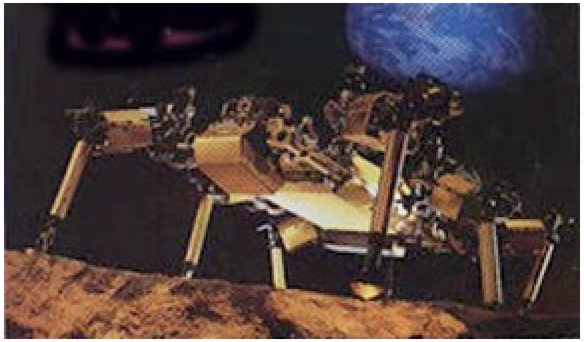
Planetary Rovers: MIT's Mobot Lab, 1990s

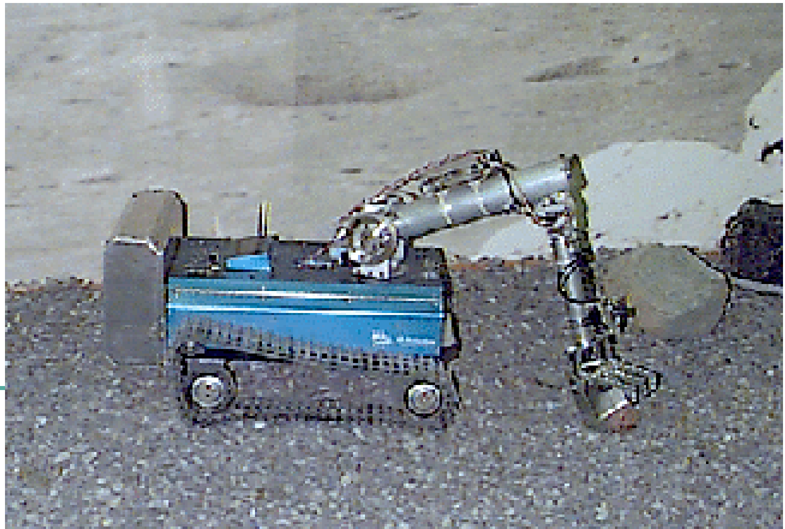
Genghis



Attila

Hannibal

Pebbles



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Fully autonomous hexapod robot

35 cm long, 1 kg weight, rigid legs could move about shoulder mount in 2 DoFs, IR proximity sensors, four 8-bit microprocessors, on-board batteries

Subsumption architecture

Genghis' Behaviors:

- Standing up & walking
- Leg lifting when encountering obstacle
- Monitoring whiskers to anticipate obstacles
- Pitch stabilization to improve stability
- Prowling (walking when something moved) and steered prowling (following person)

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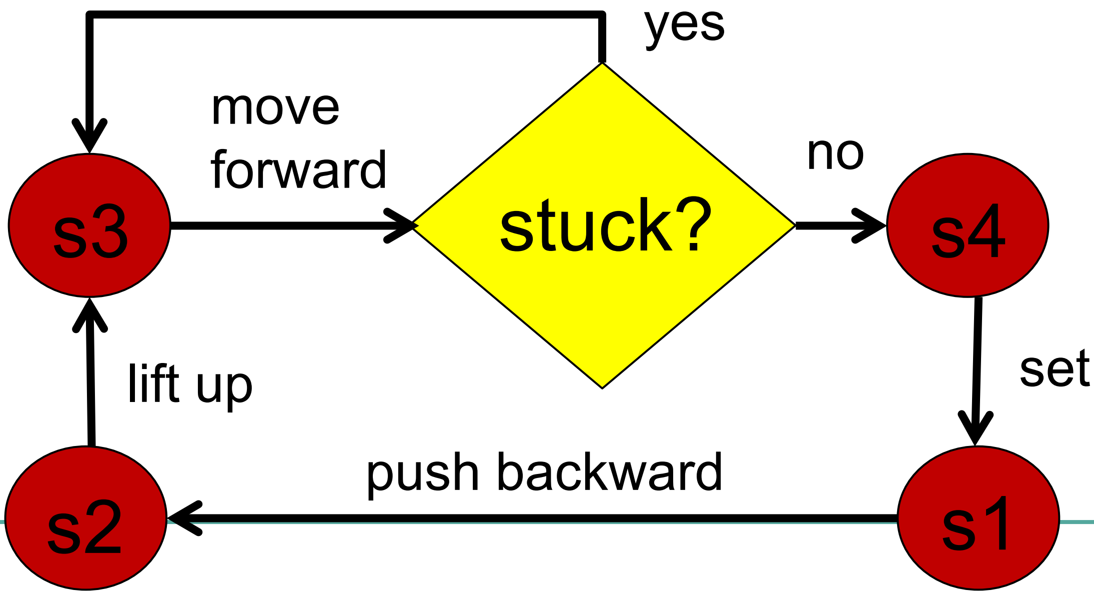
Augmented Finite State Machine (AFSM=FSM with clock) for control of a single leg:

Genghis

Final configuration: 57 networked AFSMs to enable various behaviors



Humanoid Robots

Rodney Brooks & Cynthia Breazeal's work

Cog & Kismet

Not Presented

Socially Intelligent Robots

Georgia Tech:

Goal: Build robots that learn from human teachers

Video 1: Robot Simon: learning to move a book

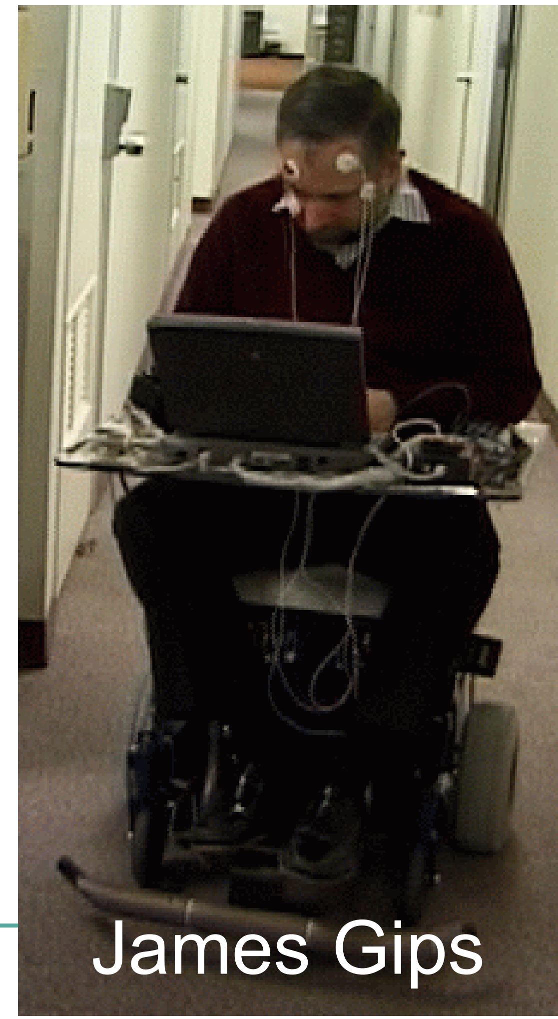
Video 2: Robot Shimon: playing marimba

http://www.wired.com/listening_post/2008/11/no-way-robot-ja/

Assistive Technology Robots

Wheelesley with EagleEyes

Boston College



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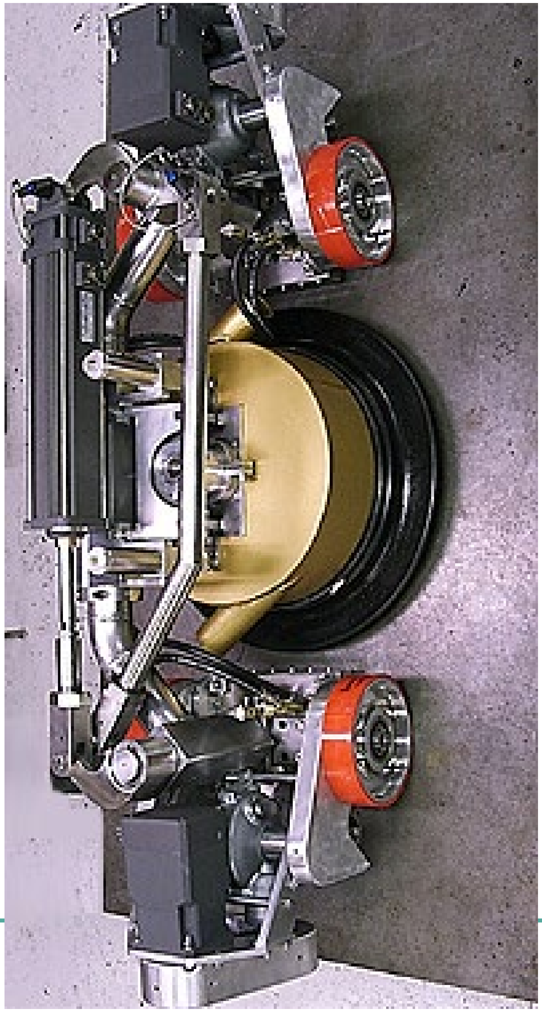
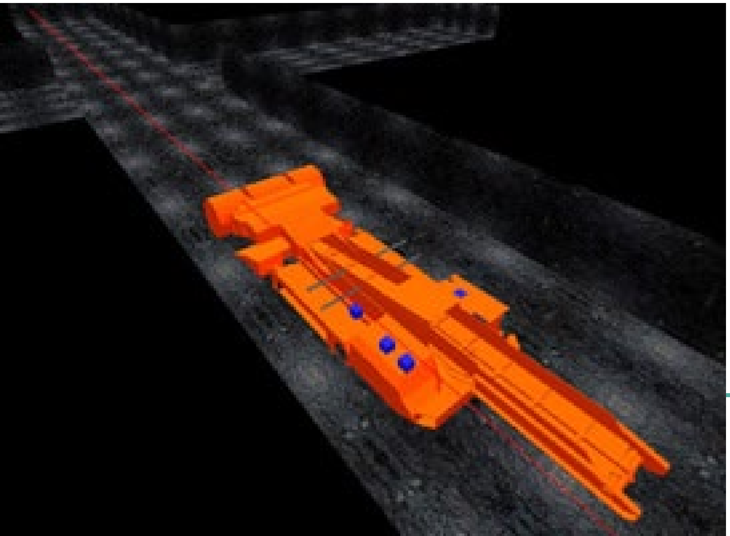
Robotics at CMU



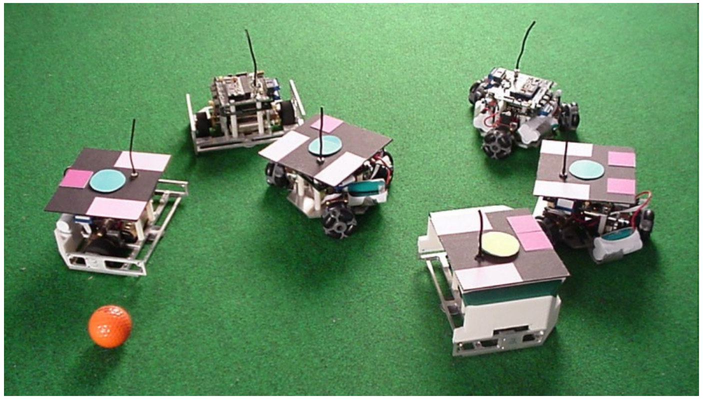


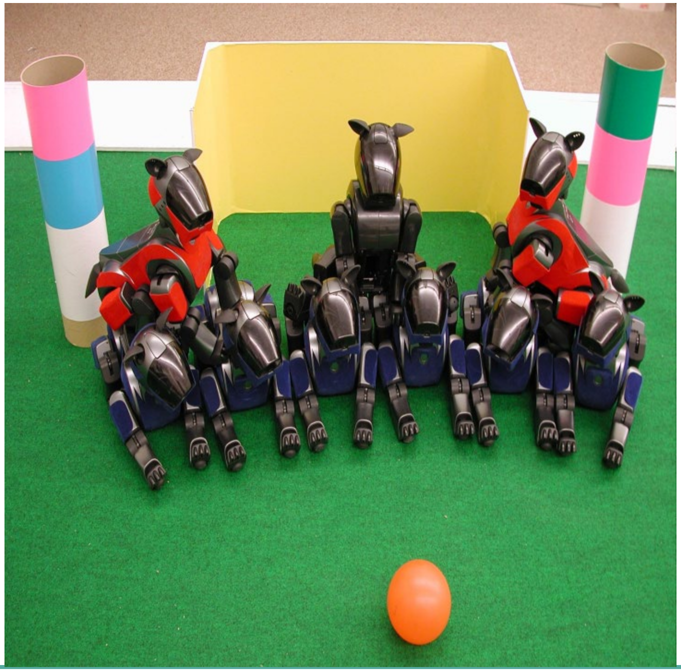
Robot Soccer

Manuela M. Veloso

- RoboCup 2004: CMU against Dortmund
- RoboCup 2009: humanoid Nao

http://www.aldebaran-robotics.com





Sony AIBO robots

Nao

Robot Soccer

Google DeepMind:

https://www.youtube.com/watch?v=RbyQcCT6890

Robotic Hand @ Palermo

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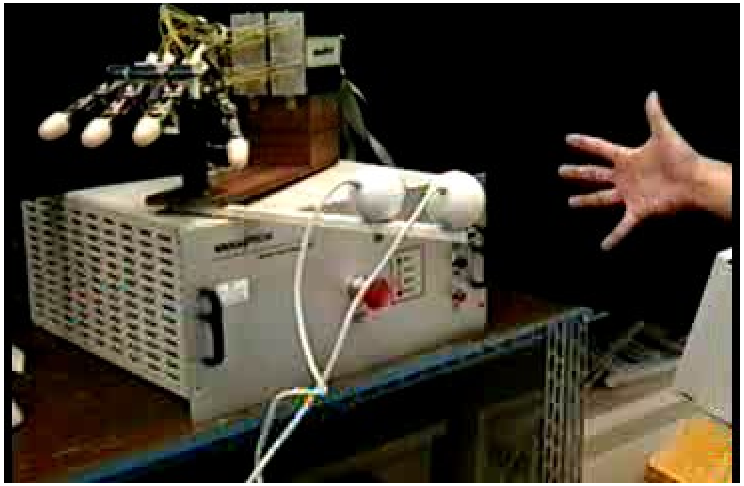

Infantino et al.: Fingertip tracking via computer vision, 27 DoF skeleton model of hand, perceptual & action spaces, rock/paper/scissors game, learning via Bayesian network behavior of human player

Videos curtesy of author

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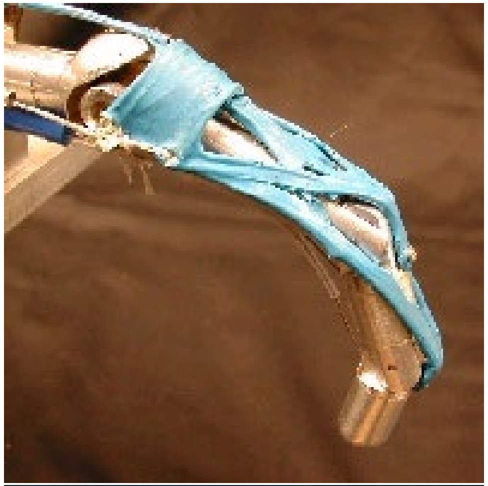
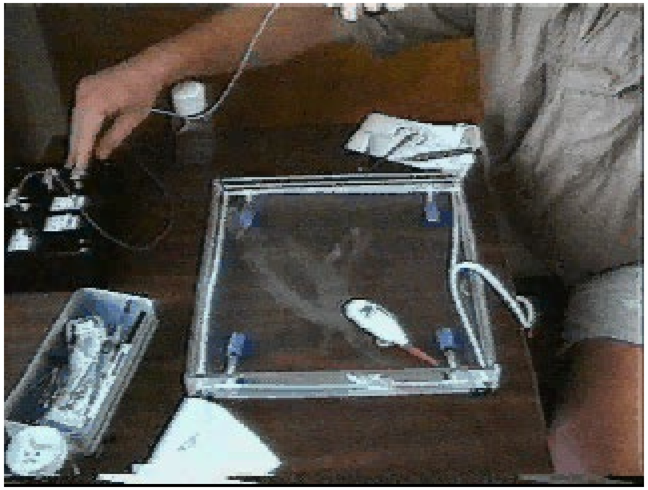
Biometronics/Neurorobotics





Biomechatronic fish

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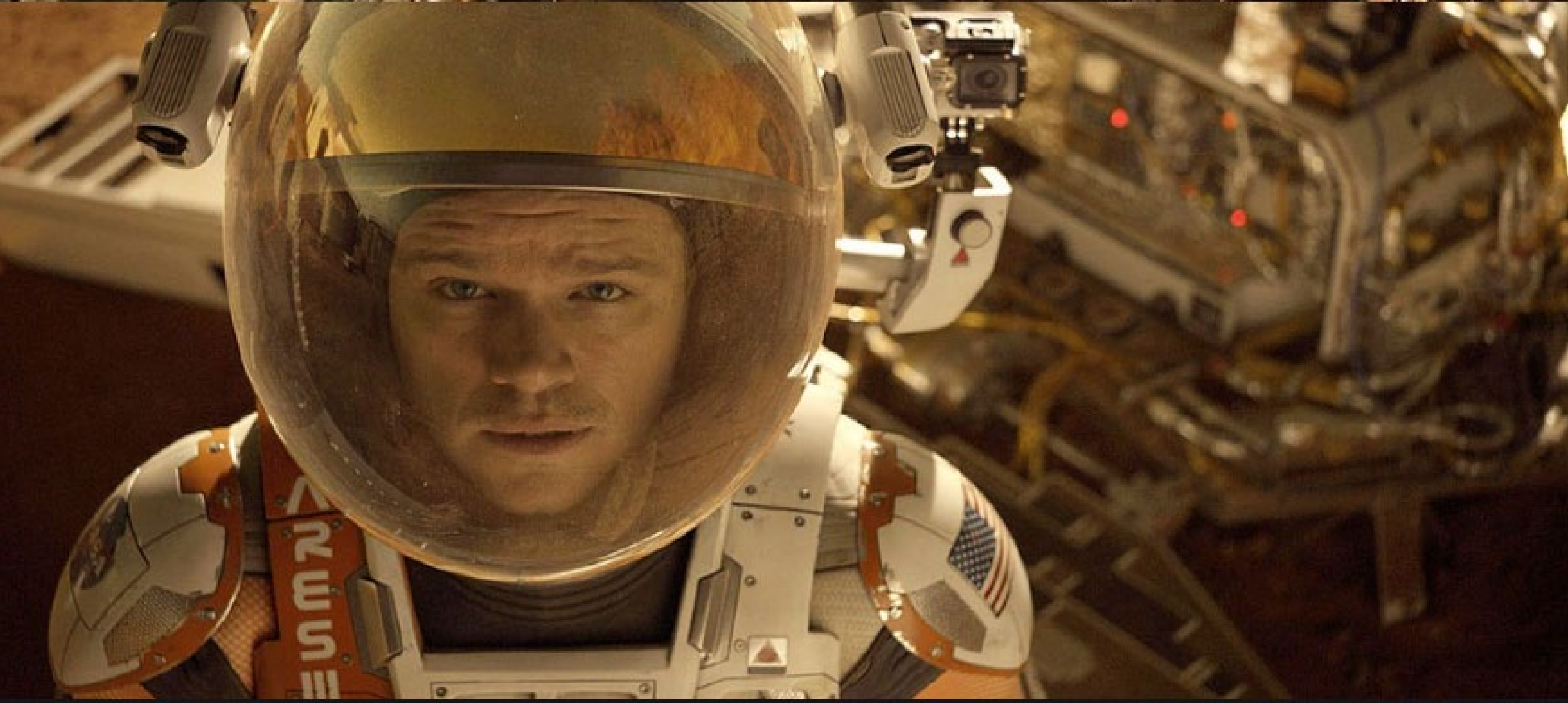
The Martian (2015)



NASA Mars Mission of Spirit & Opportunity

Not Presented

June 10, 2003 - The MER-A rover called Spirit is launched from Cape Canaveral, Florida.

July 7, 2003 - The MER-B rover called Opportunity is launched from Cape Canaveral, Florida.

December 26, 2003 - Mars Express arrives at Mars.

January, 2004 - Nozomi scheduled to encounter Mars.

January 3, 2004 - The Mars rover Spirit lands.
January 25, 2004 - The Mars rover Opportunity lands.

January 2004 – May 2010 - Spirit operated on Mars.

January 2004 – June 2018 Opportunity operates on the Martian surface.

Not Presented

Mars Exploration Robots

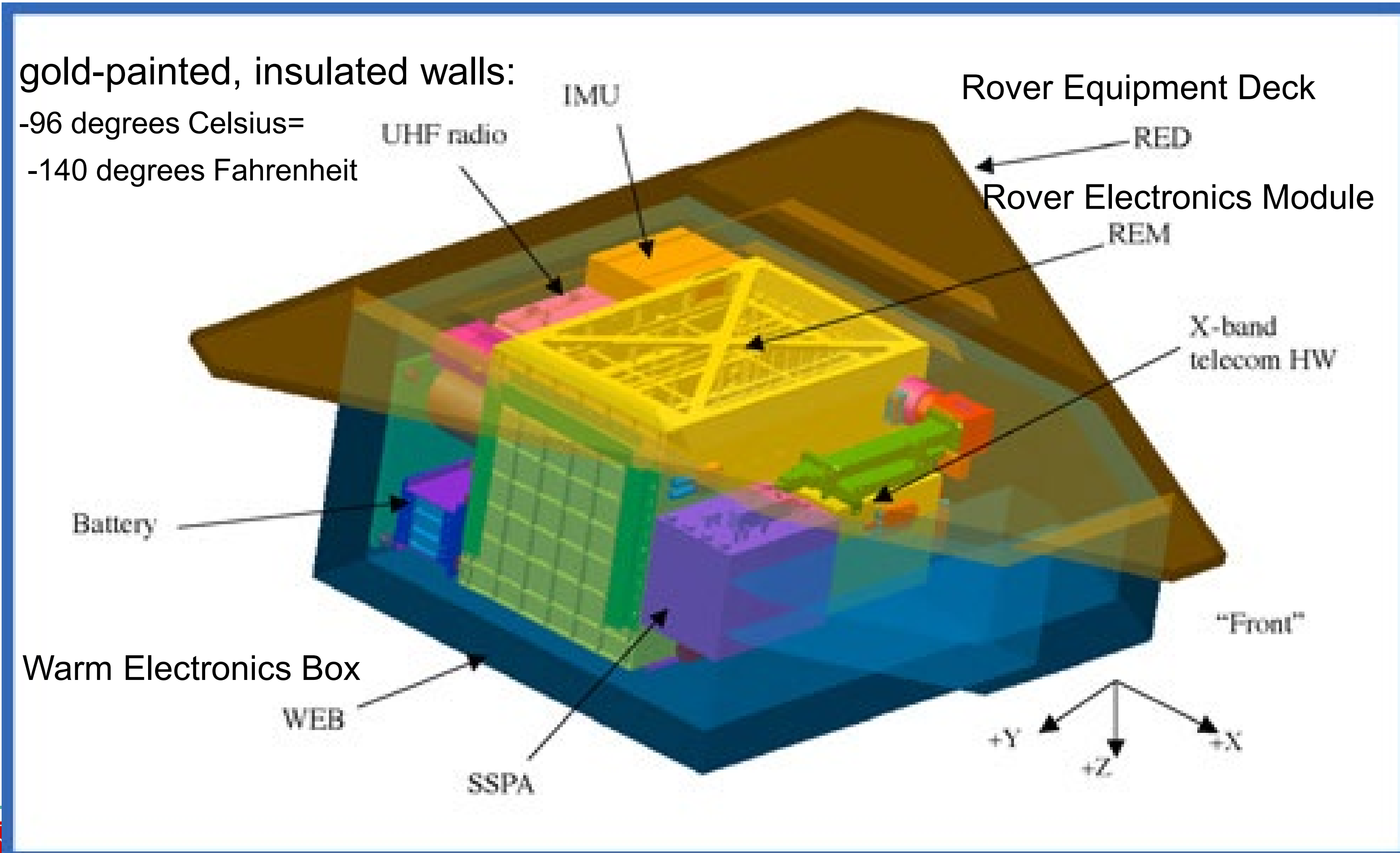
Images & Videos: NASA

Not Presented

Mars Rover

Rover body: Not Presented

Warm Electronics Box "WEB"



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Rover’s Energy

- Main source of power: multi-panel solar array
- 140 watts of power for up to 4 hours per sol (a Martian day)
- Rover needs about 100 watts (equivalent to a standard light bulb in a home) to drive
- Two rechargeable batteries provide energy when sun is not shining, especially at night

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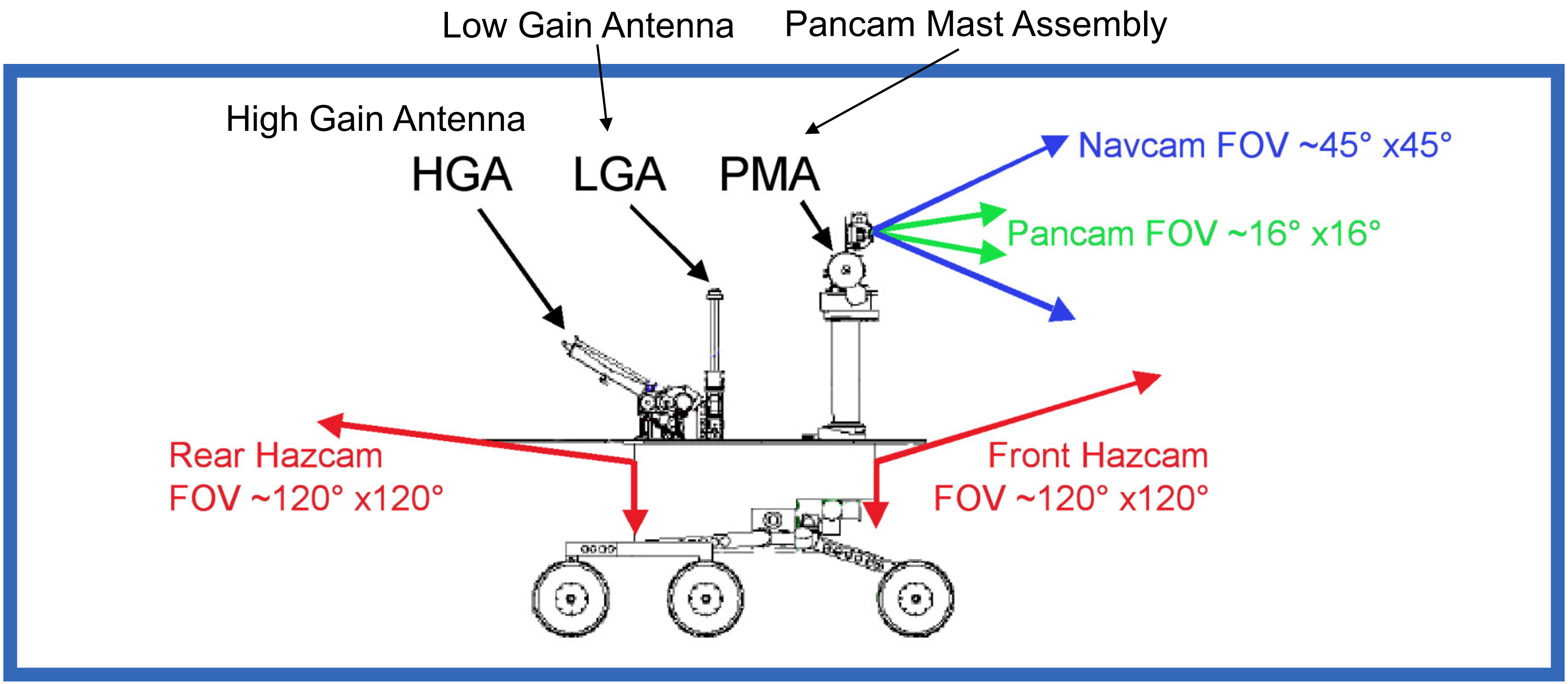
Camera Systems on Mars Rover



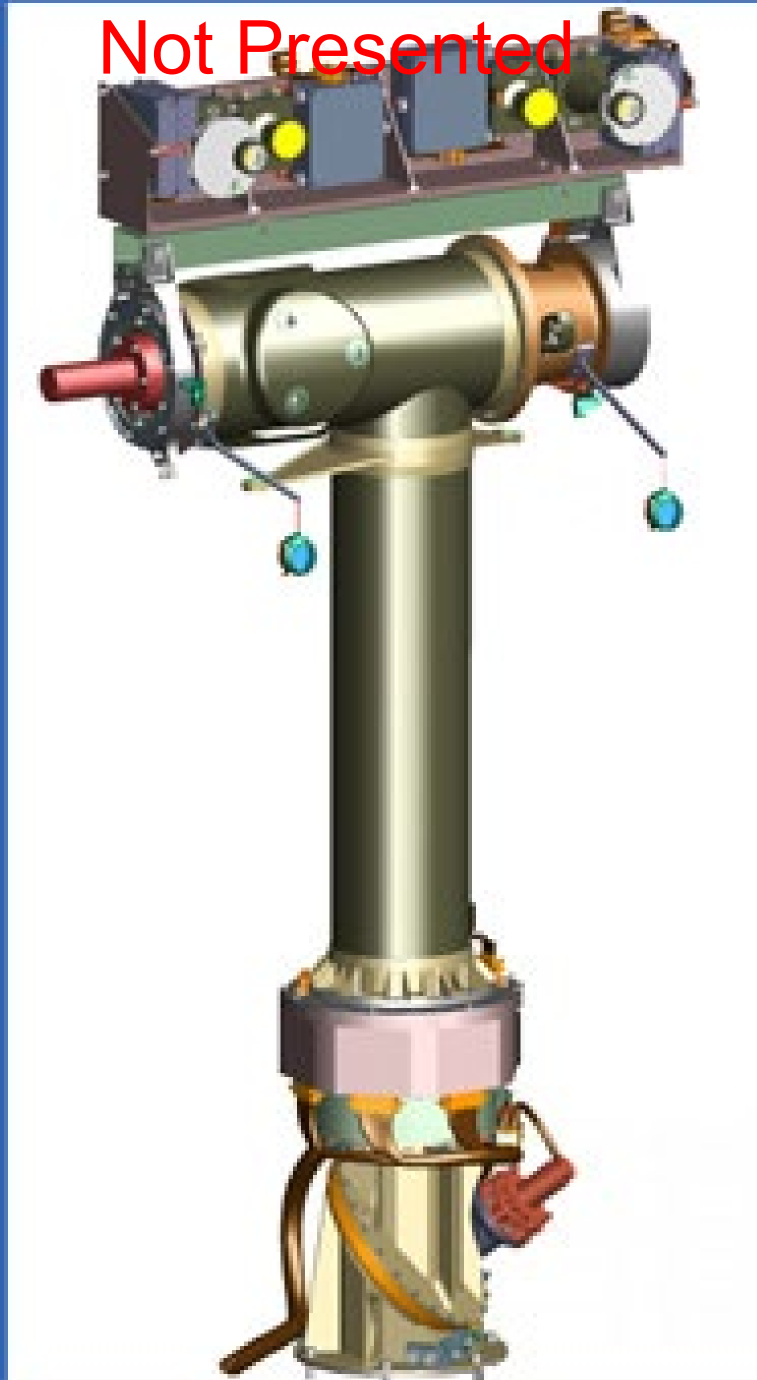
6 engineering cameras (4 hazcams, 2 navcams),
3 science cameras (pancam, microscopic imager)

Rover’s “Neck” and “Head:”

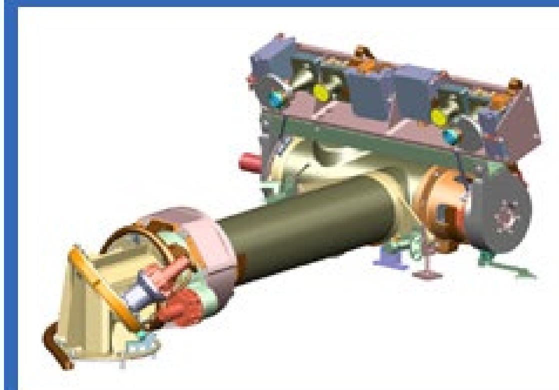
“Periscope” for Mini-TES

Height for Cameras

Mineralogy of rocks & soils



3 motors for
Mini-TES
Pancam
Navcam



Thermal Emission Spectrometer

Pancam Stereo System

"The Pancam color imaging system has, by far, the best capability of any camera ever sent to the surface of another planet."

360º rotation in horizontal plane,
180º up and down

270 g (9 oz)

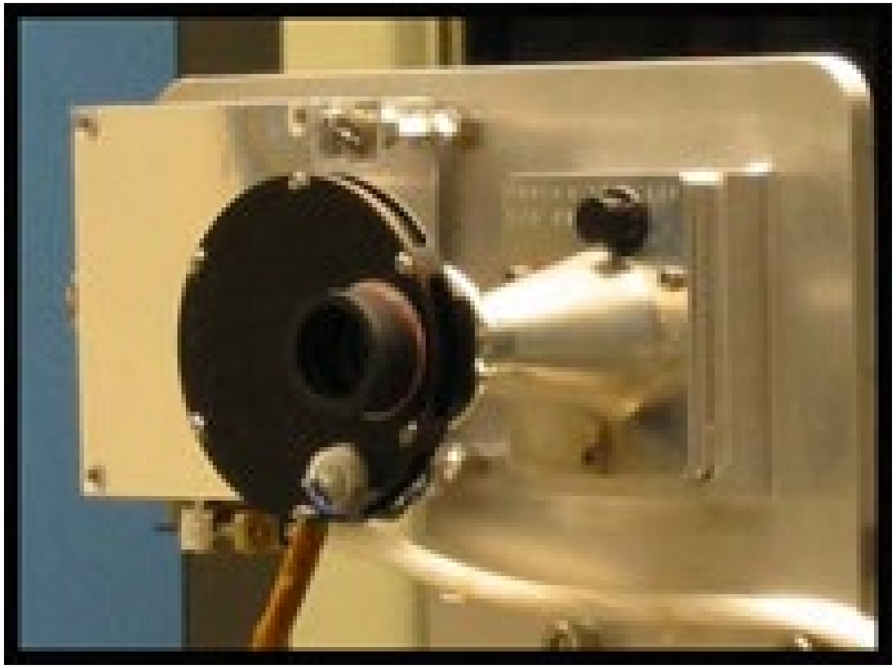
creates mosaics with up to 4,000 x 24,000 pixels

0.3 milliradians

Not Presented

"Eye" of Pancam

- 8-filter wheel for multispectral imaging capabilities
- Images taken at various wavelengths -> learn about minerals found in Martian rocks and soils
- Blue and infrared solar filters -> image sun



These data, along with images of the sky at a variety of wavelengths -> determine the orientation of the rover and provide information about the dust in the atmosphere of Mars

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3D Perspective of Adirondack

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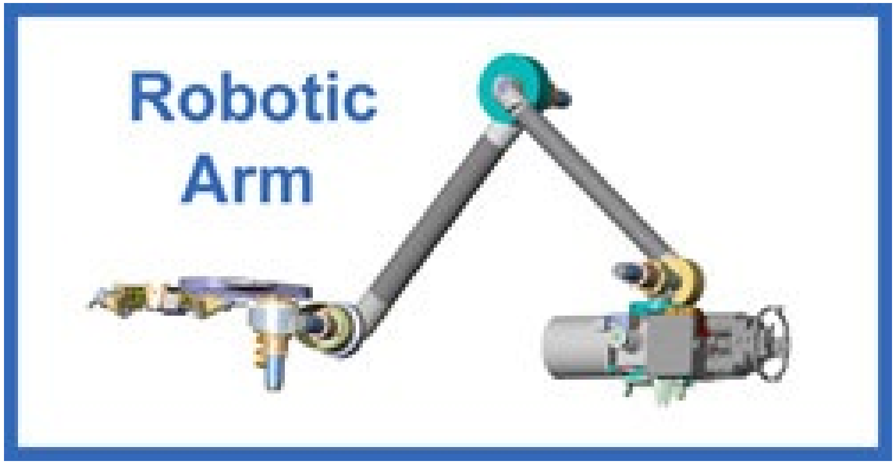
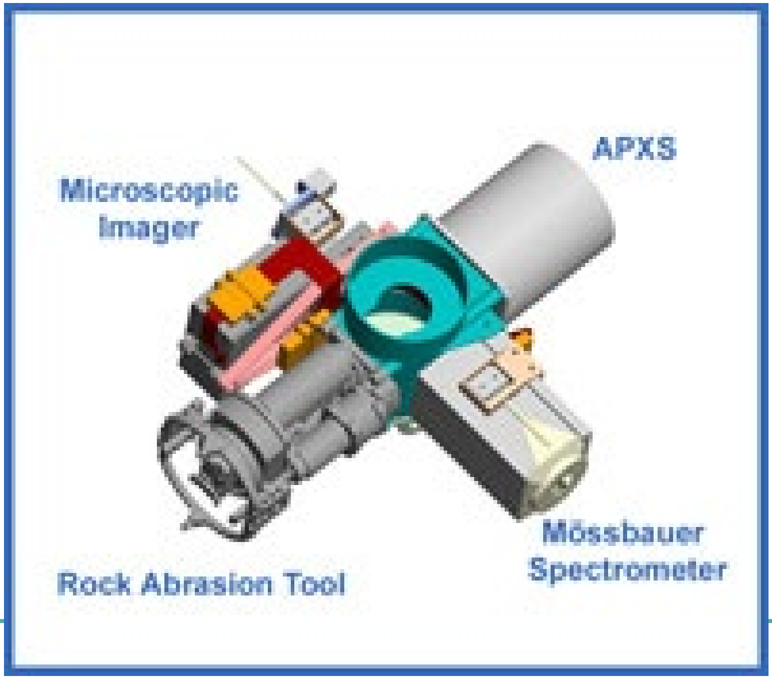
Rover Arm



- Instrument deployment device (IDD)
- Flexibility through three joints: the rover's shoulder, elbow, and wrist
- Arm allows instruments to extend, bend, and angle precisely against a rock -> work as a human geologist would: grinding away layers, taking microscopic images, and analyzing the elemental composition of the rocks and soil
- At end of the arm: turret, shaped like a cross, hand-like structure, holds various tools that can spin through a 350-degree turning range



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Robots at BU

Intelligent Mechatronics Laboratory, Mech Eng

Video and images curtesy of John Baillieu

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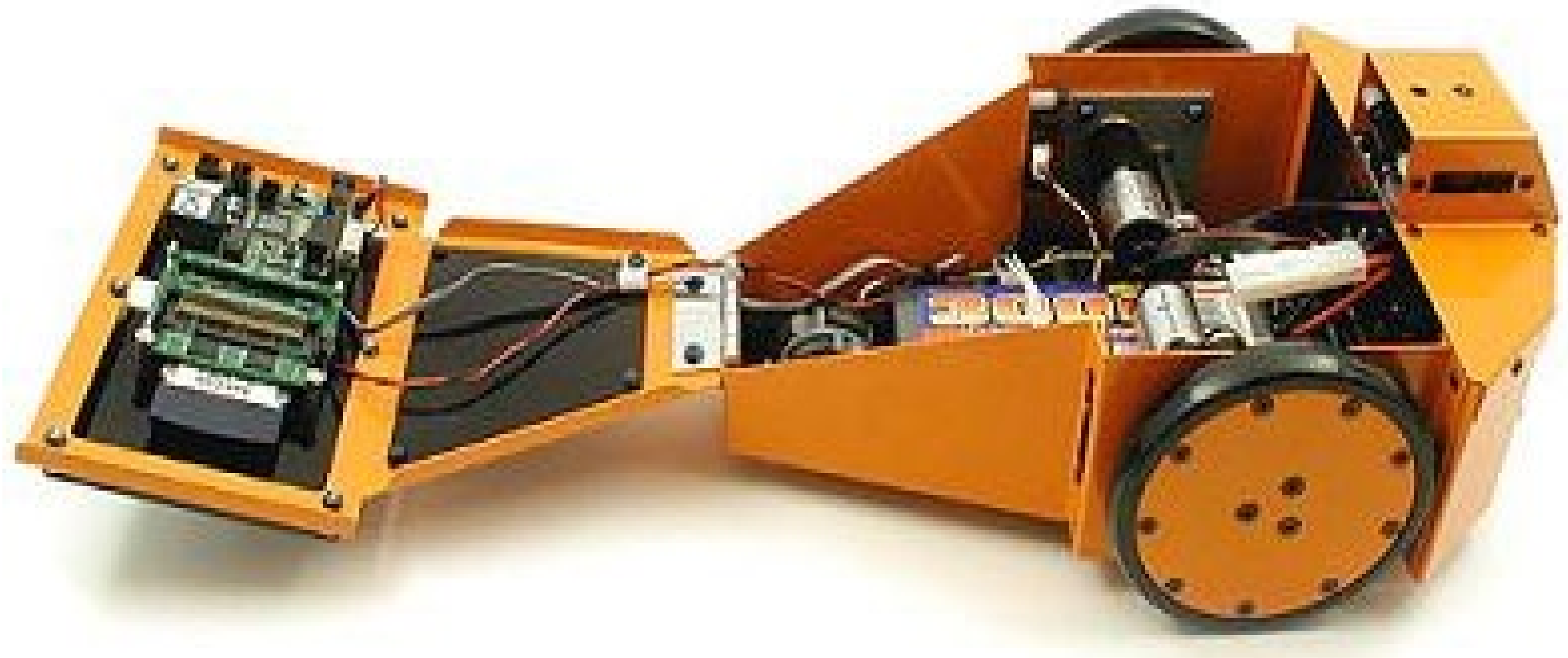
Robotics at CS@BU

BOSS: BU Operating Systems and Services Group
Garcia Robot: Gerald Fry & Prof. Richard West



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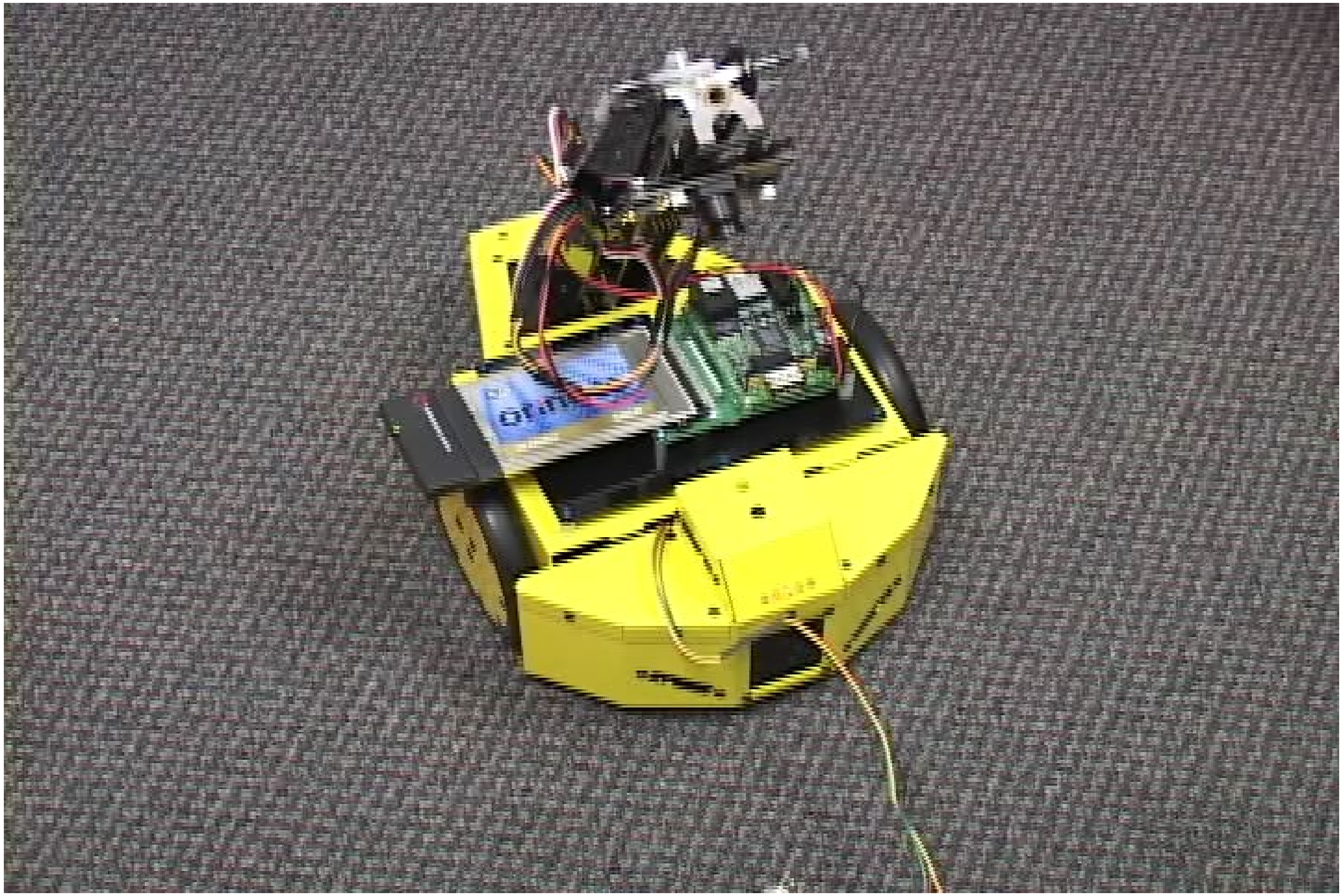
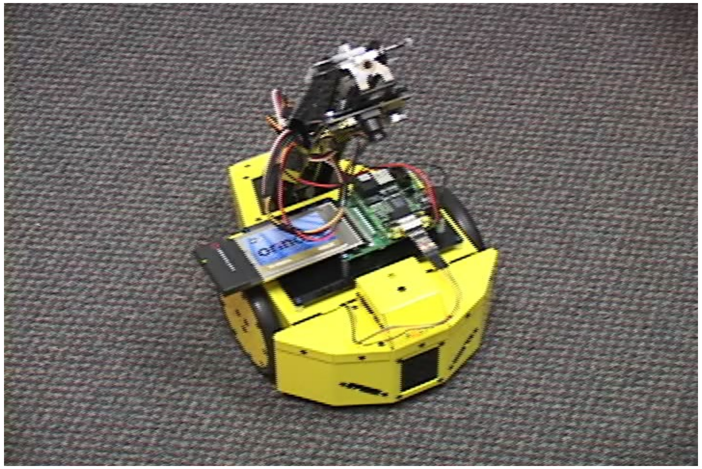
Garcia Robot: Components



Garcia Robot: Navigation



Linux 2.6.11

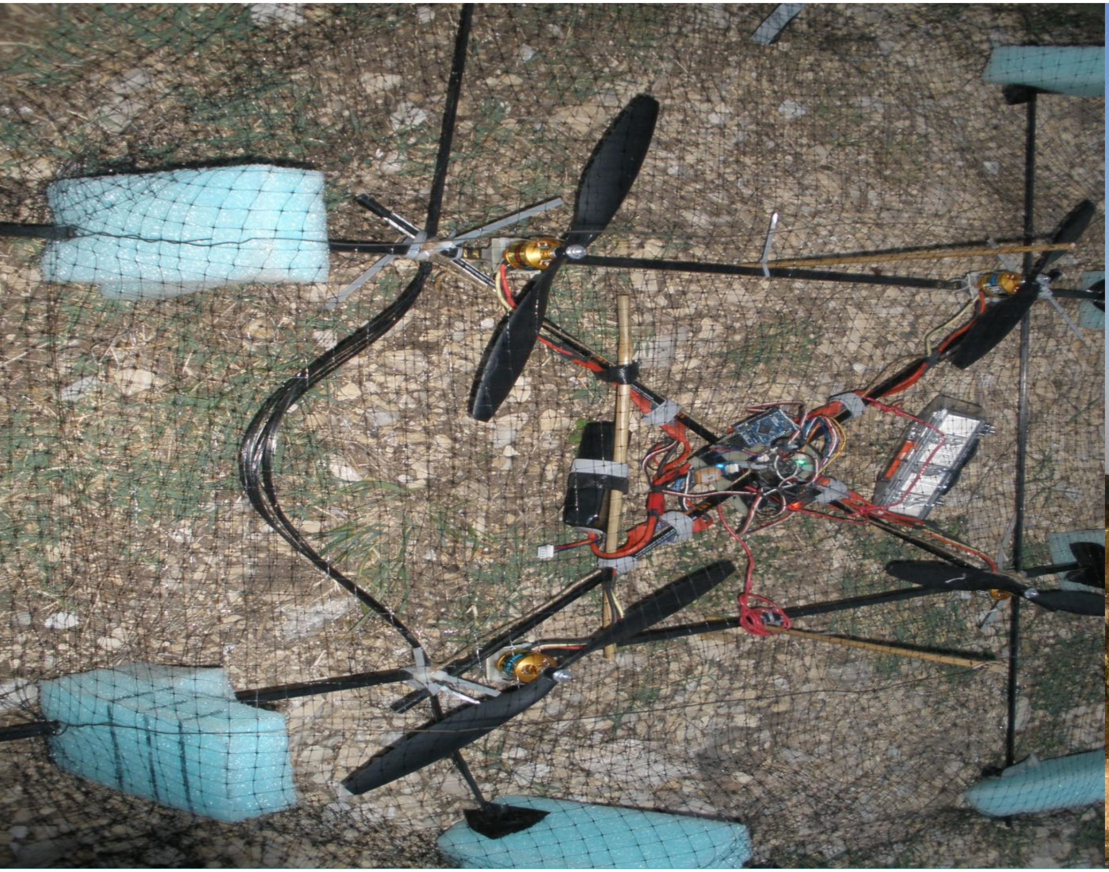
Timing differences are due to scheduling differences of I/O Operations

Communication between host & sensor/actuator hardware is accomplished via two serial ports on Stargate platform.

Linux 2.4.19

BU’s Batcopter

http://youtube.com/watch?v=9rZXx3HXJ-M



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ABOT

The Anthropomorphic Robot Database

http://abotdatabase.info

251 robots
1,140 crowd workers
18 features

What is ABOT?

For each robot, the ABOT Database provides:

- A standardized robot image
- Robot name, overall human-likeness score, developer information, and official website (if available)
- Laypeople's ratings on the presence of 18 constituent features in the robot:

1. arm
2. hand
3. finger
4. torso
5. leg
6. eyelashes
7. head
8. hair
9. skin
10. gender
11. nose
12. eyebrow
13. apparel
14. face
15. eyes
16. mouth
17. wheels
18. treads/tracks

Scores on four dimensions of robot appearance features:

1. Body-Manipulators (torso, legs, arms, hands, fingers)
2. Surface Look (gender, head hair, skin, nose, eyebrow, eyelashes, apparel)
3. Facial Features (head, face, eyes, mouth)
4. Mechanical Locomotion (wheels, treads)

Phillips et al., HRI 2018

Not Presented

ABOT Study Results

1)

With just four subscale scores = averaged feature-present scores on the four appearance dimensions:

- Surface Look (e.g., gender, skin, eyelashes)
- Body-Manipulators (e.g., torso, arms, hands)
- Facial Features (e.g., head, eyes), and
- Mechanical Locomotion (i.e., wheels, treads/tracks)

we can describe the distinct profiles of hundreds of extant anthropomorphic robots

Not Presented

A B O T
The Anthropomorphic Robot Database

Home | About | Collection | Predictor | News | Contac

A List of Robots in the ABOT Database

Click the button to download a list of all 251 robots in the current ABOT Database (04/09/2019). This list contains robot names, IDs, human-likeness scores and bootstrapped CIs, developer information, and website URL.

Download

Collection

Please contact us if you wish to obtain a zip file of standardized images of all current robots in the ABOT Database. We regularly update our database to reflect new robot additions.

Search for robots:

Search...

Filter by range of scores:

Human-Likeness Score:
86 - 100

Body Manipulators:
0 - 100

Surface Look:
0 - 100

Face:
0 - 100

Mechanical Locomotion:
0 - 100

clear filters | view all ▾ | sort by: id ▾ | order: ascending | < 1 >

jia jia | kodomoroid | otonaroid | erica

geminoid h1-4 | nadine | gazeroid

view 20 | < 1 >

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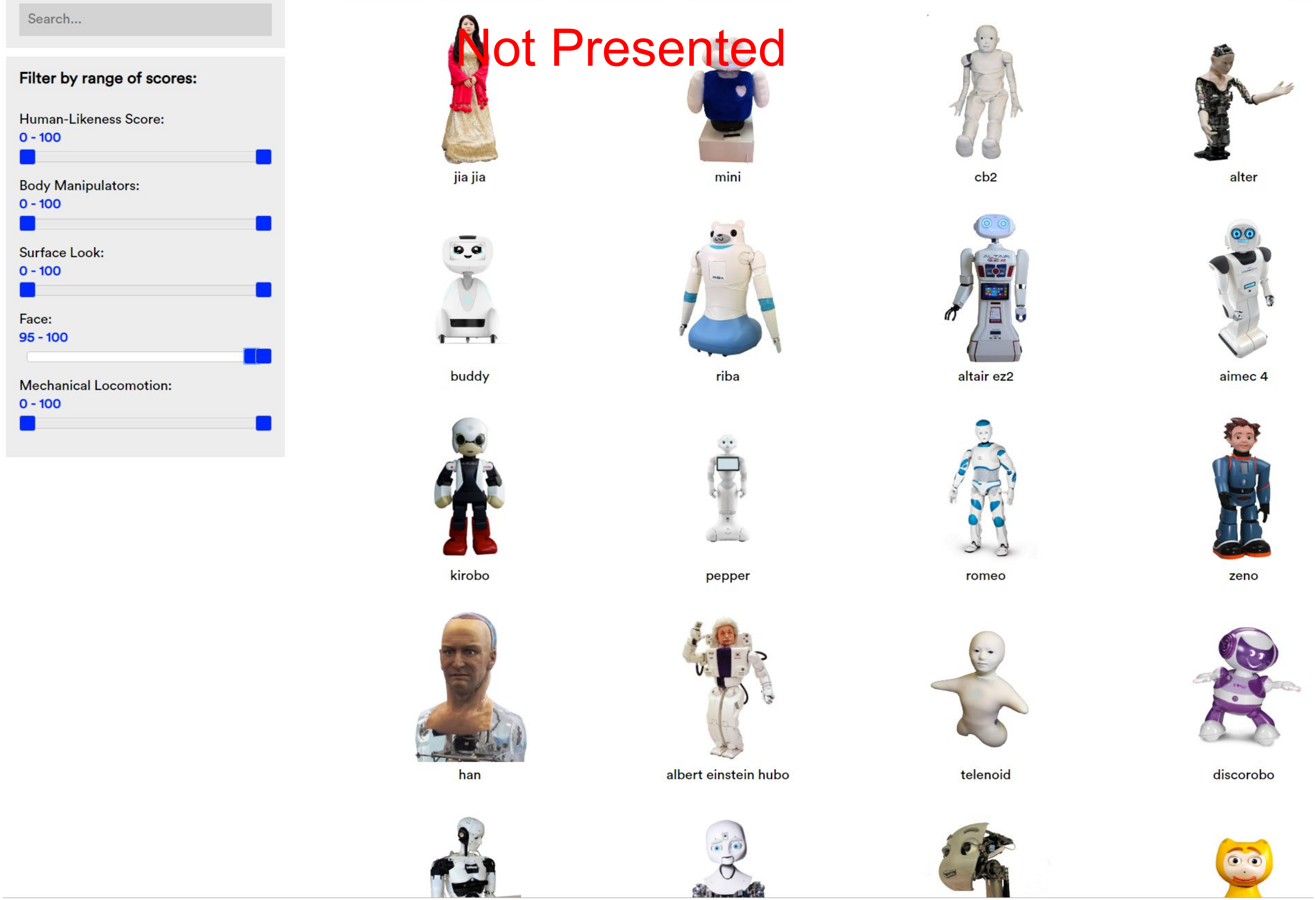

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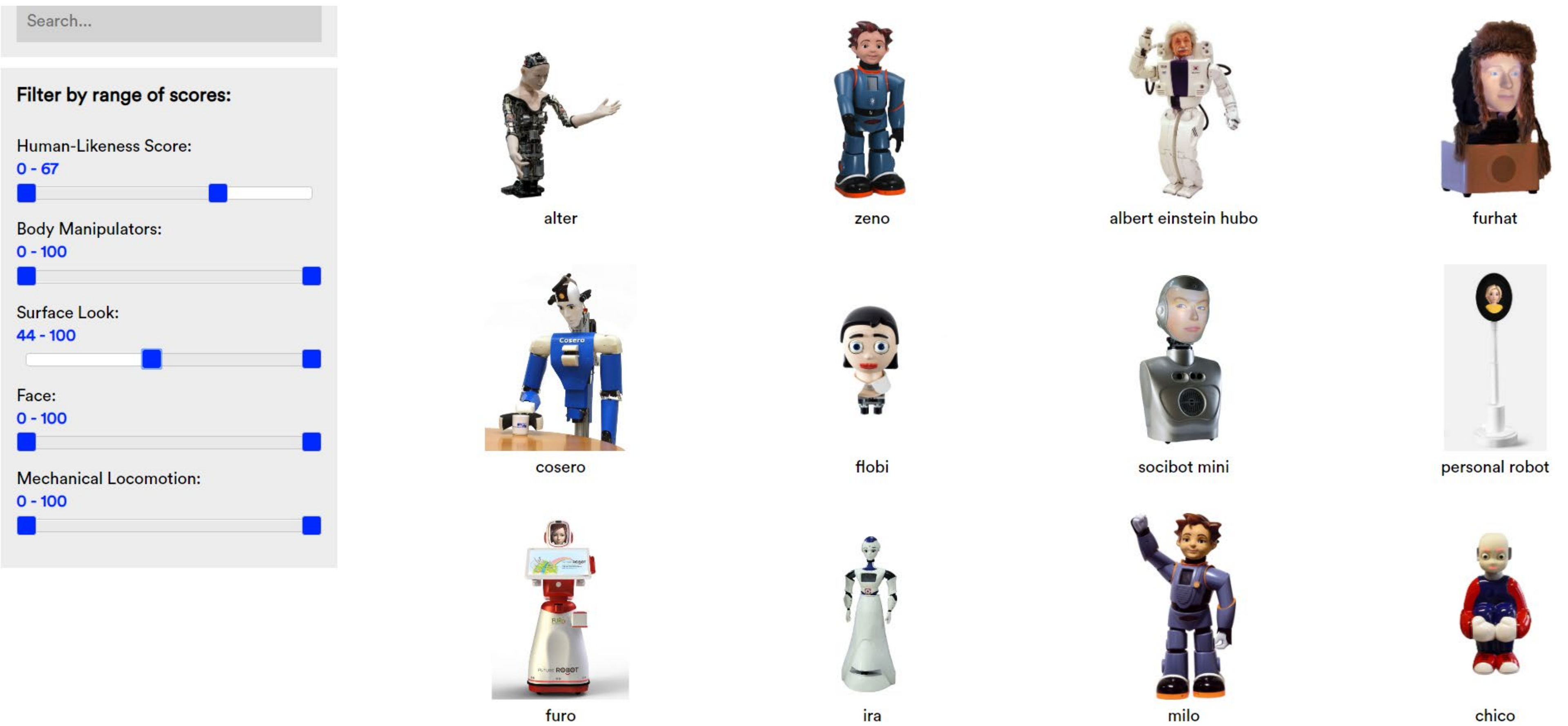


Not Presented

Search...

Filter by range of scores:

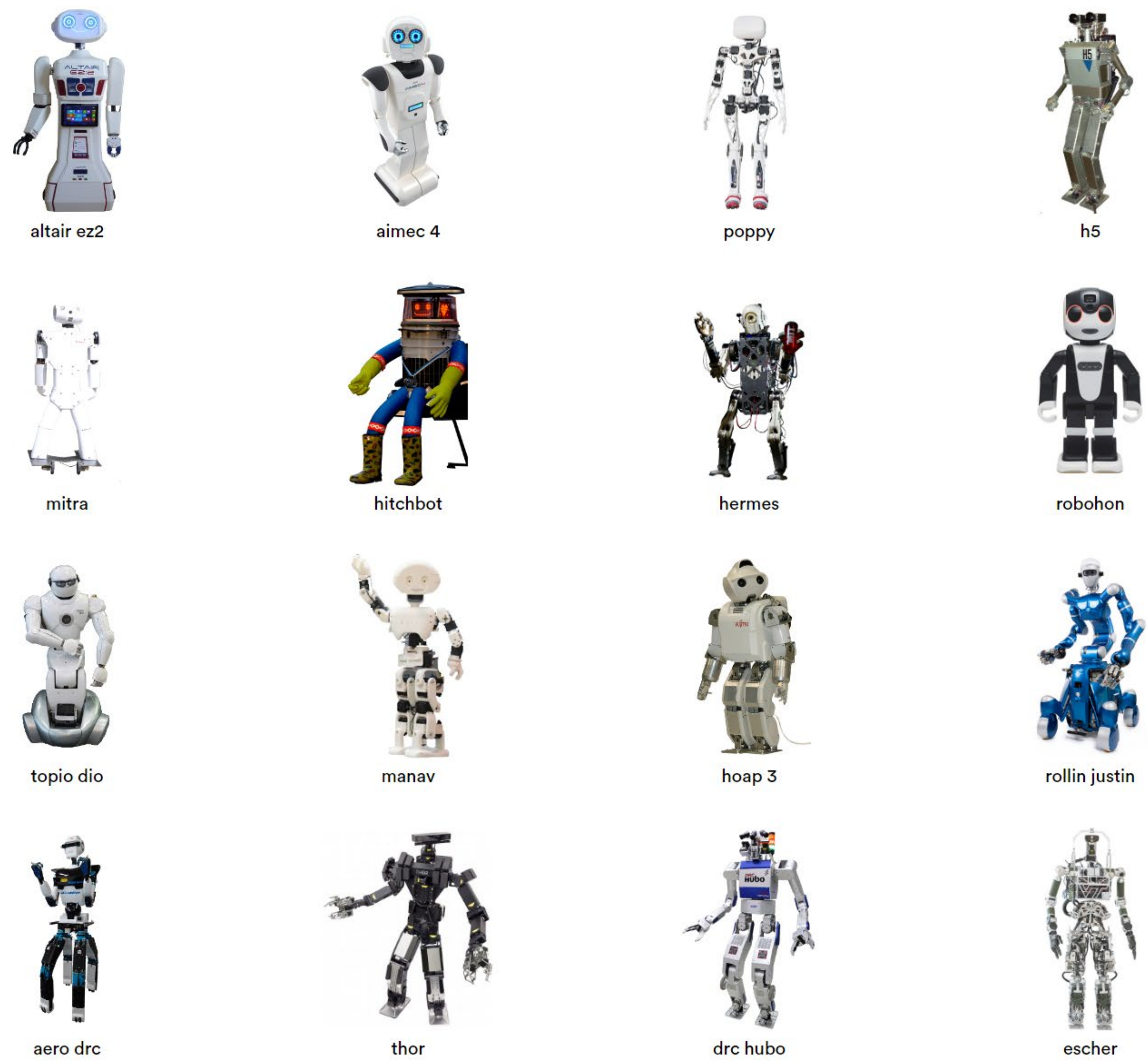
Human-Likeness Score:
18 - 43

Body Manipulators:
86 - 100

Surface Look:
0 - 100

Face:
0 - 100

Mechanical Locomotion:
0 - 100



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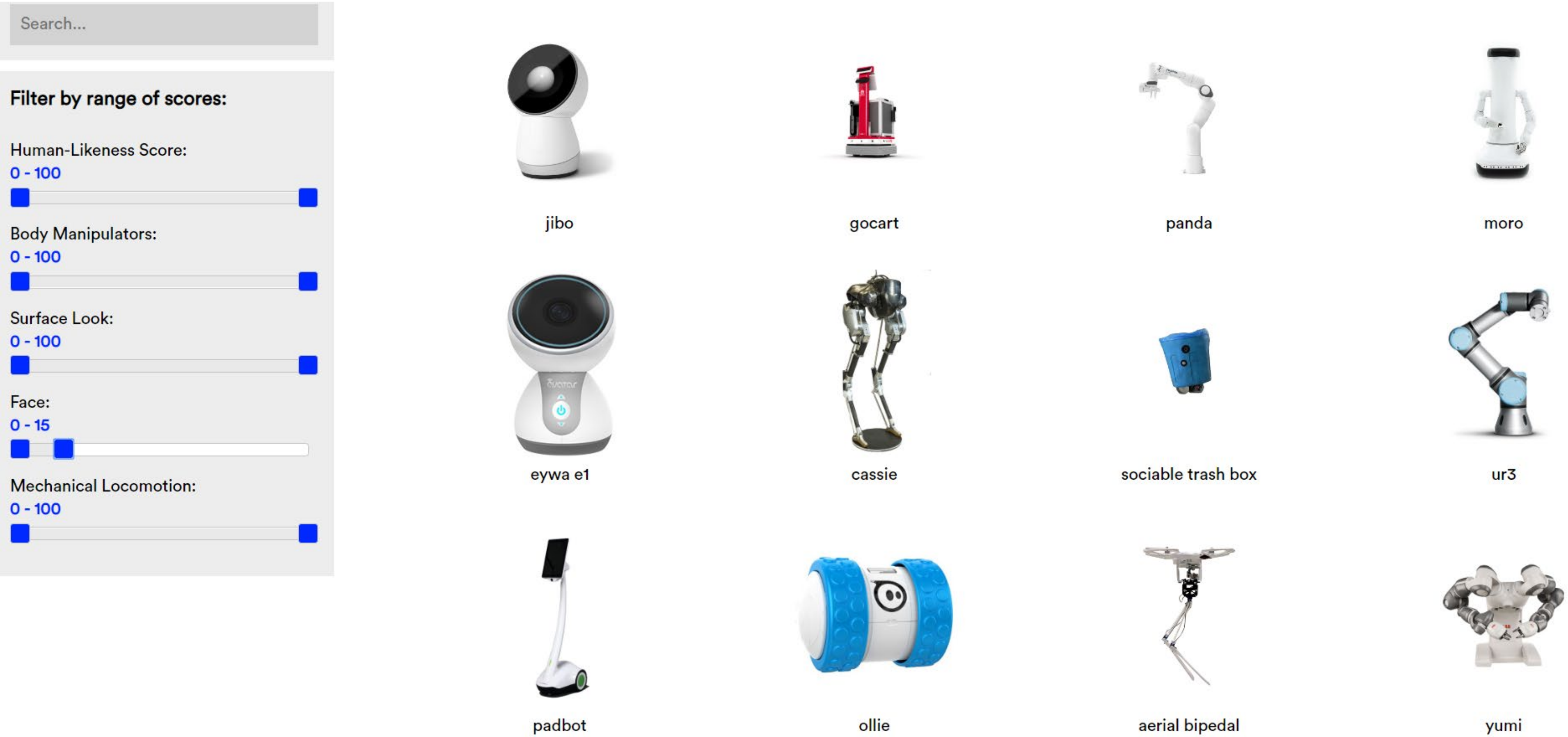

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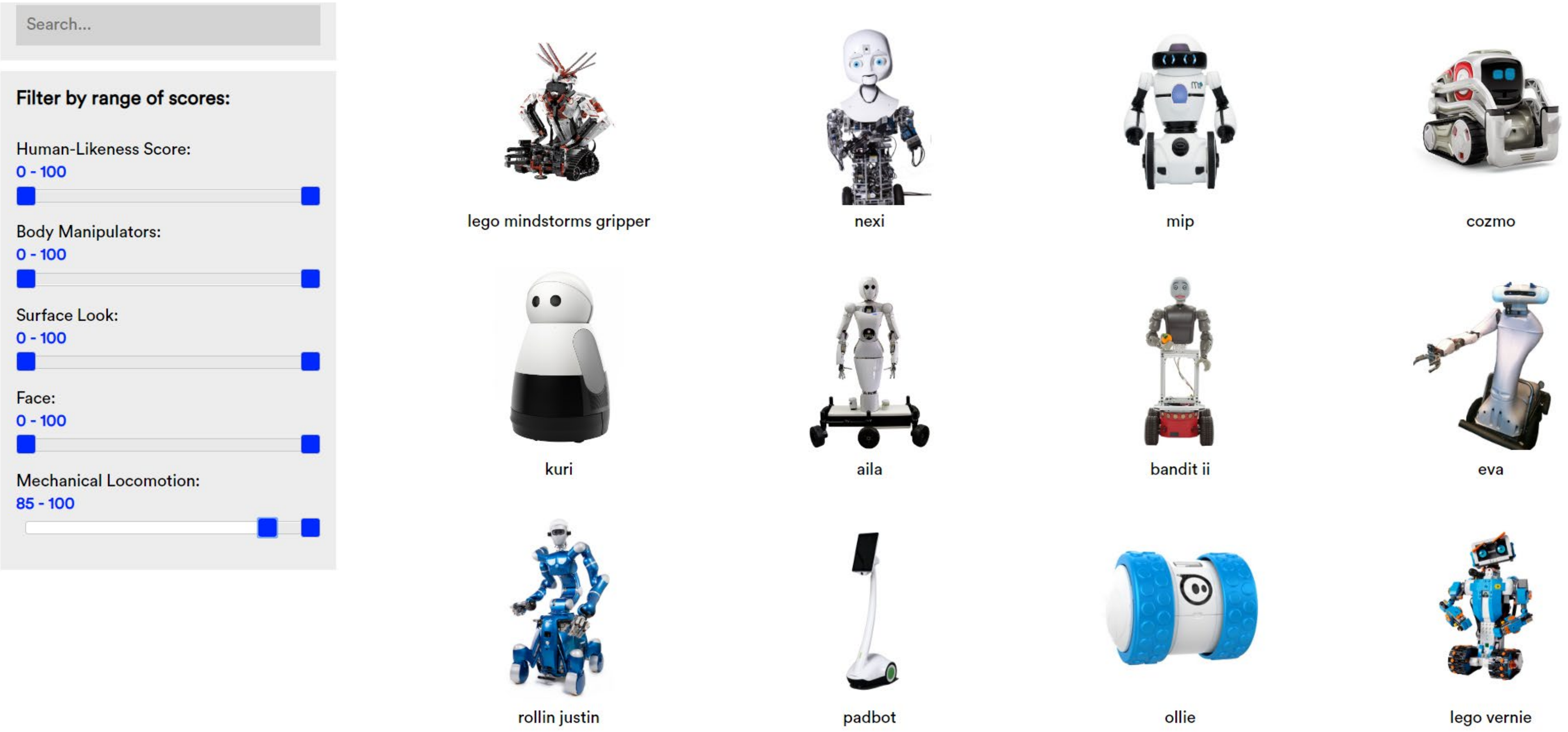

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ABOT Study Results:

2)

Laypeople's perceptions of robots' overall physical human-likeness and showed that this overall judgment can be strongly predicted from either specific individual appearance features (especially torso, genderedness, and skin) or the underlying four appearance dimensions (especially Body-Manipulators and Surface Look).

->

Human-Likeness-Estimator can be used to quickly estimate how human-like a new robot will be perceived.

What Makes a Robot Likable?

SimSensei Virtual Therapist:

Veterans shared personal and mental health concerns that they would withhold from human therapists

Other studies on virtual counseling: Disadvantaged groups prefer agents & robots

"And how did that make you feel?" is a question the SimSensei virtual therapist, shown above, might ask. Image courtesy of USC Institute for Creative Technologies.

Gregory Mone, 2019

What Makes a Robot Likable?

- SimSensei's ethnicity is intentionally ambiguous (some patients commented on liking the match to their own ethnicity)
- Giving agents biographical details to share: Where robot grew up or has traveled. Even if people know these stories are fake, they increase engagement.
- Human participant study @MIT: People less likely to strike a robot toy if it had a story.
- "Uncanny Valley:" Embodied robots that appear too human-like can make people feel uneasy.
- Breaking eye contact promotes intimacy for virtual robots but creates uneasiness for physical robots
- Same people clean for their cleaning robots

Gregory Mone, 2019

Precautions to make virtual agent safe to use for virtual therapy

SimSensei may ask “And how did that make you feel?” SimSensei

- monitors pauses in conversations
- tracks changes in tone, gaze aversions, and other social cues
- processes all indicators to determine a response

Only if SimSensei is really certain that it understands correctly, responses such as “that’s great” are used.

How to Behave --
Moral Competence for Social Robots

Robot Ethics

Ethical design of safe social robots must include design of moral capacities in robots

What constitutes a robot's moral capacity?

How can moral competence be implemented?

B.F. Malle and M. Scheutz, Learning How to Behave, 2019

Elements of Moral Competence

1. System of Norms: Community's standards for behavior. Guides actions and judgements of actions
2. Moral Vocabulary: Allows AI system to conceptually and linguistically represent norms, morally significant behaviors, and judgments of those behaviors
3. Moral Action: Action in compliance with norms
4. Moral Judgement: Evaluation of behavior relative to norms (permissibility, wrongness, degrees of blame)
5. Moral Communication: Judgments and attempts to identify, explain, or defend norm violations; negotiate or repair social estrangement after norm violation (often supported by affect and emotion)

Norms for AI Systems / Robots

- How do AI agents represent norms? Are they concepts? Action programs?
- How are norms organized? Hierarchically? Spreading in an activation network?
- How are norms activated by specific contexts?
- How do AI agents acquire norms? By observations? Instruction? Reinforcement?

Norm Violations

- Segment stream of events or behaviors
- Identify context in which events occur
- Know which norms apply to the current context
- Identify events that violate one or more applicable norms
- Assess violation:
  - Severity of violation?
  - Did the agent act intentionally?
  - Could the agent have prevented the event?

Rule-based Moral Reasoning: Systems that Detect Norm Violations

Arkin & Ulam, 2009: Detect potential norm violations through action planning.

- Hard-coded moral decisions
- Lacks tools for
  - Novel ethical inferences
  - Reasoning through conflicts
  - Acquisition of new norms

Briggs & Scheutz, 2015: Detect violations before action and offer justifications why it refuses to follow an unethical user commend.

- General inference algorithms, but no new norms

Robot Altruism versus Selfishness

- Humans: Empathy has evolved to counteract selfishness
- A robot could be designed to follow moral norms that serve the community without following self-serving goals.
- A robot's lack of selfishness does not necessitate its lack of empathy. It could be designed to demonstrate to humans that it *cares* about outcomes (select or prioritize actions)
- If a robot succeeds in rescuing, reviving, or just cheering up a person – does this then *feel* as if the robot cares?

Moral Communication of Robots

Example: Robot is a partner of human guard and points out "The officer deserves a significant amount of blame for beating the prisoner."

If the robot points out a violation in a calm nonjudgmental tone, it may not be effective as if the robot uses appropriate displays of outrage.

Robots do not have pressures of loyalty (snitch)

Malle & Scheutz's Conclusions

"In light of the extensive & complex elements of human moral competence, designing robots with such competence is an awe-inspiring challenge."

Solution: "Move from robots that are merely programmed to robots that interact with [trusted] human communities over time, so they can update their programs."

Closing the Loop to our Ethics Discussion at the Beginning of CS 640:

- AI developers think they are objective and neutral, but they are often unmindful and disregard the ethics of the technological advances they produce (e.g. racial bias in face expression analysis)
- Figuring out the technology to make "Moral competence for social robots" possible is an extremely important and impactful research task that deserves your attention.