



Humanoid Robots & Human-Robot Interaction

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<https://cyber.felk.cvut.cz/research/groups-teams/humanoids/>



Overview

- Subject description:
 - [B3M33HRO Humanoidní roboti](#) / [BE3M33HRO Humanoid robots](#)
- Course website and rules of the game:
 - <https://cw.fel.cvut.cz/wiki/courses/hro/start>
- Literature and resources:
 - lectures and lecture slides
 - <https://cw.fel.cvut.cz/wiki/courses/hro/literature>

Team



<https://cyber.felk.cvut.cz/research/groups-teams/humannoids/>

Lectures

Matěj Hoffmann
+ guest lecturers



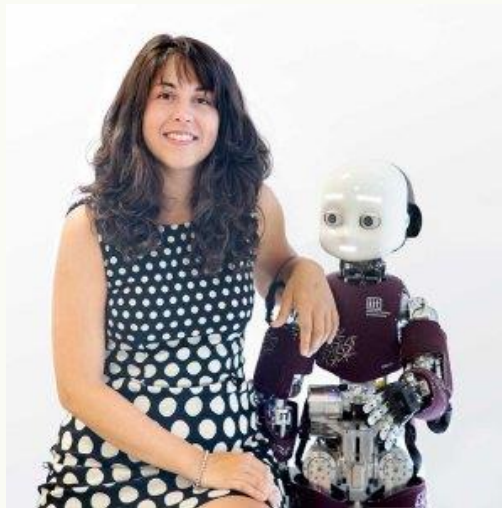
Labs

Lukáš Rustler

Giulia D'Angelo

Shubhan Patni

Jason Khoury



What is a robot?

any **automatically** operated machine that **replaces human effort**, though it **may not resemble human beings** in appearance or perform functions in a humanlike manner.

<https://www.britannica.com/technology/robot-technology>

a machine that **resembles a living creature** in being capable of moving independently (as by walking or rolling on wheels) and performing complex actions (such as grasping and moving objects)

often: such a machine built to **resemble a human being or animal in appearance and behavior**

<https://www.merriam-webster.com/dictionary/robot>

[M.H. added emphasis]

What Is a Robot?*

By Rodney Brooks

Shall I compare thee to creatures of God?
Thou art more simple and yet more remote.
You move about, but still today, a clod,
You sense and act but don't see or emote.

You make fast maps with laser light all spread,
Then compare shapes to object libraries,
And quickly plan a path, to move ahead,
Then roll and touch and grasp so clumsily.

You learn just the tiniest little bit,
And start to show some low intelligence,
But we, your makers, Gods not, we admit,
All pledge to quest for genuine sentience.

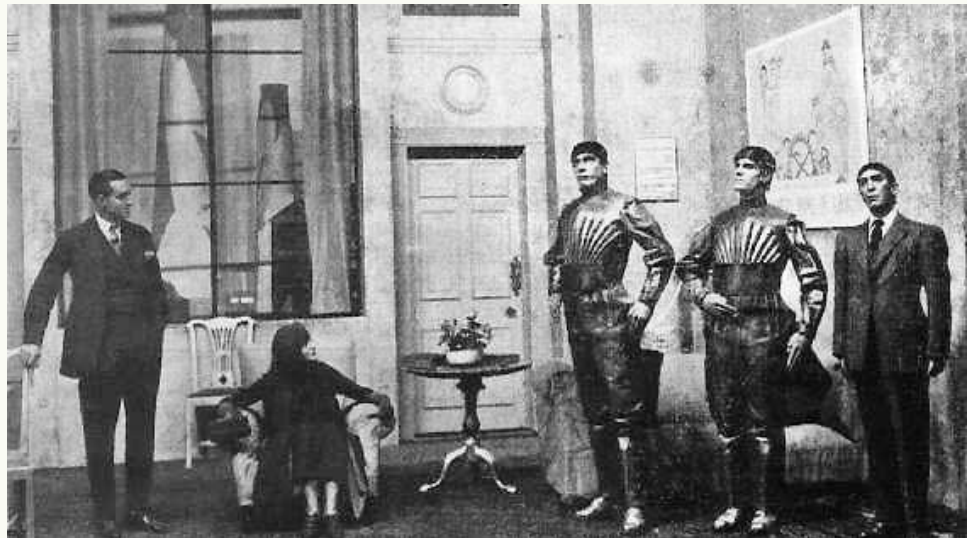
So long as mortals breathe, or eyes can see,
We shall endeavor to give life to thee.

* With thanks to William Shakespeare

History and etymology

The concept of artificial humans predates recorded history (see [automaton](#)), but the modern term *robot* derives from the Czech word *robota* ("forced labour" or "serf"), used in [Karel Čapek's](#) play [R.U.R.](#) (1920)...

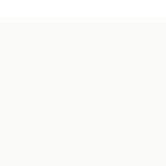
<https://www.britannica.com/technology/robot-technology>



THE ROBOTS THAT SHAPED OUR VISION OF THE FUTURE

Over the course of the past 100 years, a number of iconic robots have shaped our vision of what a robot should look like, and how it should behave. Let's take a look at the top stars from film and TV:

- 1 **Maria**
(Metropolis, 1927)
- 2 **Robby**
(Forbidden Planet, 1956)
- 3 **The Robot**
(Lost in Space, 1965)
- 4 **HAL 9000**
(2001: A Space Odyssey, 1968)
- 5 **Gort**
(The Day the Earth Stood Still, 1951)
- 6 **R2-D2 and C-3PO**
(Star Wars, 1977)
- 7 **Ash and Bishop**
(Alien Series, 1979 and 1986)
- 8 **Roy Batty**
(Blade Runner, 1982)
- 9 **Johnny 5**
(Short Circuit, 1986)
- 10 **Data**
(Star Trek: The Next Generation, 1987)
- 11 **T-800**
(The Terminator, 1984 and 1991)
- 12 **Sonny**
(I, Robot, 2004)
- 13 **Ava**
(Ex Machina, 2014)
- 14 **Dolores and Maeve**
(Westworld, 2016)



slide from Peter H. Diamandis:
2025-2035 Metatrend Report. The Rise of Humanoid Robots.
<https://metatrendreport.com/humanoid-robots-c>

Why humanoid robots?

Humans are so good...

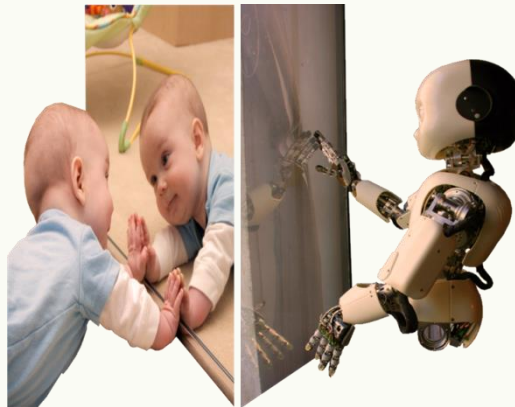
“Moreover, humans are generalists with the ability to perform a wide variety of distinct tasks. Roboticians would like to create robots with comparable versatility and skill.... Exactly what to borrow from the human example is controversial.”

“The pleasing mirror. Humans are humanity’s favorite subject.” “People are highly attuned to human characteristics.”

Human-like interaction.
Communication...



Fig. 56.1 The humanoid robot HRP-1S driving a backhoe (Courtesy of Kawasaki Heavy Industries, Tokyu Construction and AIST). The robot can be teleoperated by a human operator to control the backhoe remotely. The same robot could potentially interface with many different unmodified machines



Human environments.
Stairs, doors, tables,
human tools...
Humanoids vs.
specialized machines
and drive-by-wire....

Test-bed for theories
from psychology and
neuroscience.
Understanding
(human) intelligence
by building.

Why humanoid robots (cont.)?

Teleoperation



- Bimanual manipulation needed for dexterity.
- Two cameras needed for depth.
- Head and two arms, set up such that you can see your arms.
- Force feedback through haptic interface.

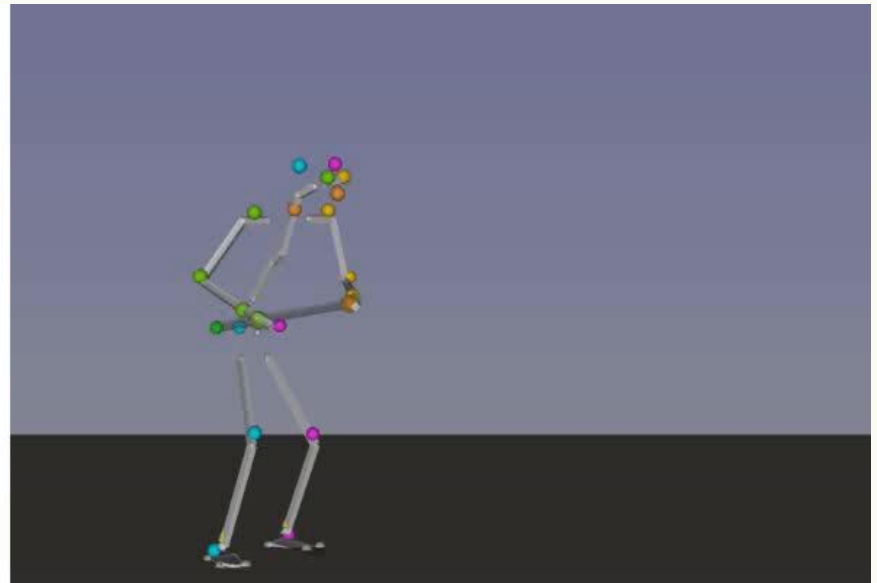
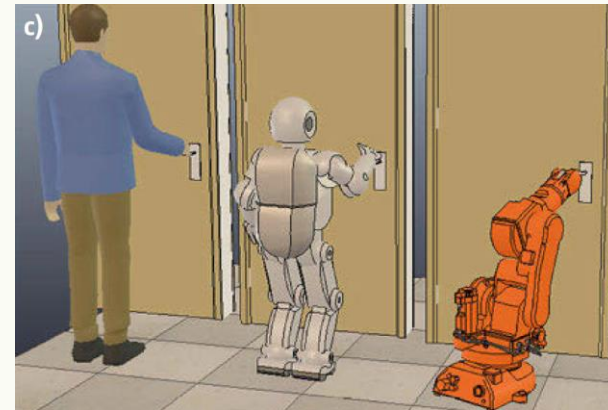
OceanOne – Oussama Khatib & Co., Stanford

<https://youtu.be/pIHmgP9I4VY?si=eMkAu0zXD4q3Q275>

Why humanoid robots (cont.)?

Learning from humans

Billard, A. G., Calinon, S., & Dillmann, R. (2016). Learning from humans. Springer handbook of robotics, 1995-2014.



[Li, Sedlar, Carpentier, Mansard, Laptev, Sivic, Best paper finalist CVPR 2019; Extended version, IJCV 2022]

Digit – Human-centric vs. humanoid



<https://youtu.be/RgT3fLz-9tA?si=J8tqe6ormHlqdHwR>

Robots and humans

Robots and Humans

Front Matter

Pages 1789-1789

Humanoids

Paul Fitzpatrick, Kensuke Harada, Charles C. Kemp, Yoshio Matsumoto, Kazuhito Yokoi, Eiichi Yoshida
Pages 1789-1818

Human Motion Reconstruction

Katsu Yamane, Wataru Takano
Pages 1819-1834

Physical Human–Robot Interaction

Sami Haddadin, Elizabeth Croft
Pages 1835-1874

Human–Robot Augmentation

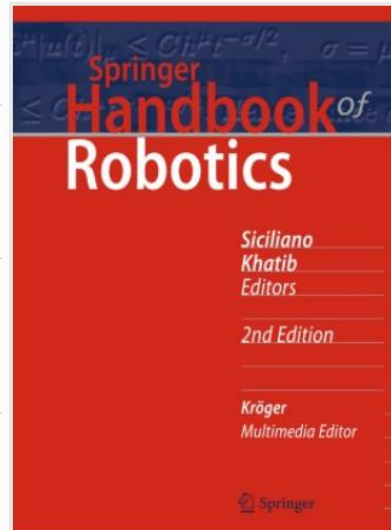
Massimo Bergamasco, Hugh Herr
Pages 1875-1906

Cognitive Human–Robot Interaction

Bilge Mutlu, Nicholas Roy, Selma Šabanović
Pages 1907-1934

Social Robotics

Cynthia Breazeal, Kerstin Dautenhahn, Takayuki Kanda
Pages 1935-1972



Socially Assistive Robotics

Maja J. Matarić, Brian Scassellati
Pages 1973-1994

Learning from Humans

Aude G. Billard, Sylvain Calinon, Rüdiger Dillmann
Pages 1995-2014

Biologically Inspired Robotics

Fumiya Iida, Auke Jan Ijspeert
Pages 2015-2034

Evolutionary Robotics

Stefano Nolfi, Josh Bongard, Phil Husbands, Dario Floreano
Pages 2035-2068

Neurorobotics: From Vision to Action

Patrick van der Smagt, Michael A. Arbib, Giorgio Metta
Pages 2069-2094

Perceptual Robotics

Heinrich Bülthoff, Christian Wallraven, Martin A. Giese
Pages 2095-2114

Robotics for Education

David P. Miller, Illah Nourbakhsh
Pages 2115-2134

Roboethics: Social and Ethical Implications

Gianmarco Veruggio, Fiorella Operto, George Bekey
Pages 2135-2160



Humanoid robots - history

Humanoid robots – history – WABOT

- 1973 – WABOT-1 - Ichiro Kato et al. @ Waseda University

“The WABOT robots integrated functions that have been under constant elaboration since: visual object recognition, speech generation, speech recognition, bimanual object manipulation, and bipedal walking.”

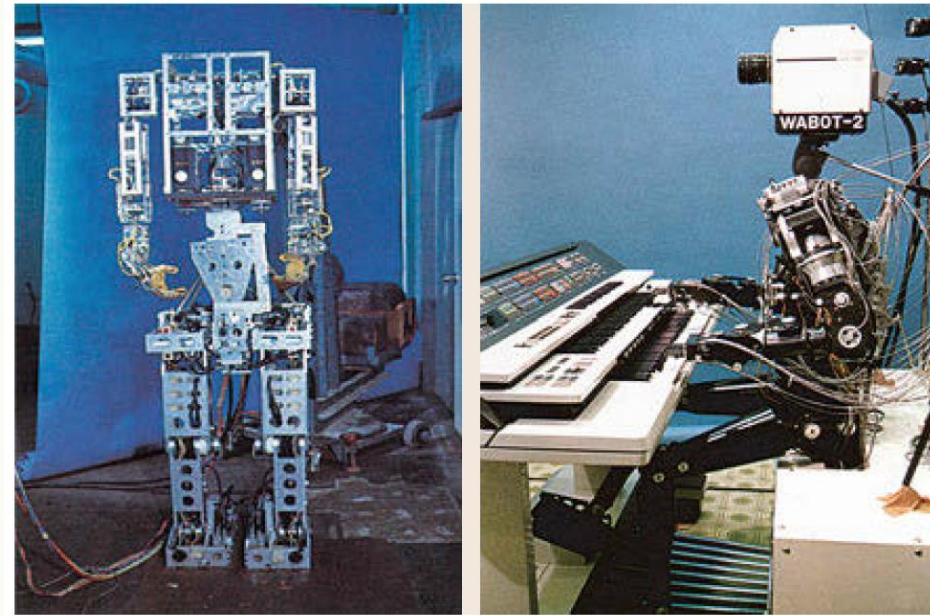
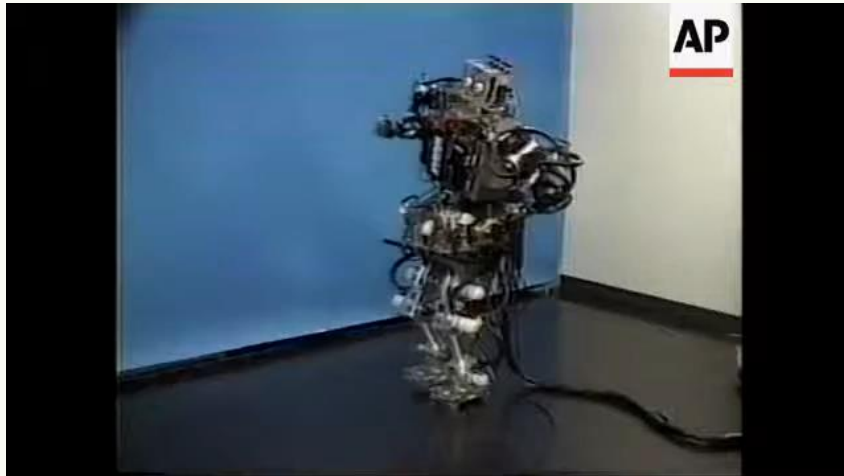


Fig. 67.8 (a) WABOT-1 (1973) and (b) WABOT-2 (1984; courtesy Humanoid Robotics Institute, Waseda University)



check also

<https://robots.ieee.org/robots/>

<https://youtu.be/E9PyANzjeaY>

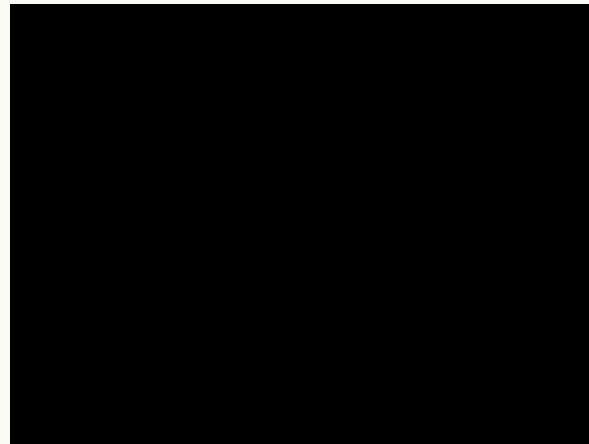
Humanoid robots – history – Honda ASIMO

- Honda project, i.e. not a university project.
- Started in 1986 as a confidential project to create a humanoid biped.
- In 1996, Honda unveiled the Honda Humanoid P2
 - first full-scale humanoid capable of stable bipedal walking with onboard power and processing
- leap forward in sturdiness, using specially cast lightweight high-rigidity mechanical links, and harmonic drives with high torque capacity.



Fig. 67.9 (a) Honda P2 (180 cm tall, 210 kg), (b) P3 (160 cm, 130 kg), and (c) advanced step in innovative mobility (glossnoidx-ASIMO advanced step in innovative mobility) (120 cm, 43 kg) (after [67.31]; courtesy Honda)

<https://youtu.be/NZngYDDdfW4>

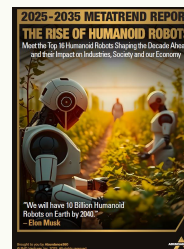


Note:
anthropomorphization

Honda ASIMO evolution



Honda's ASIMO robot development (left to right) from 1986 to today.

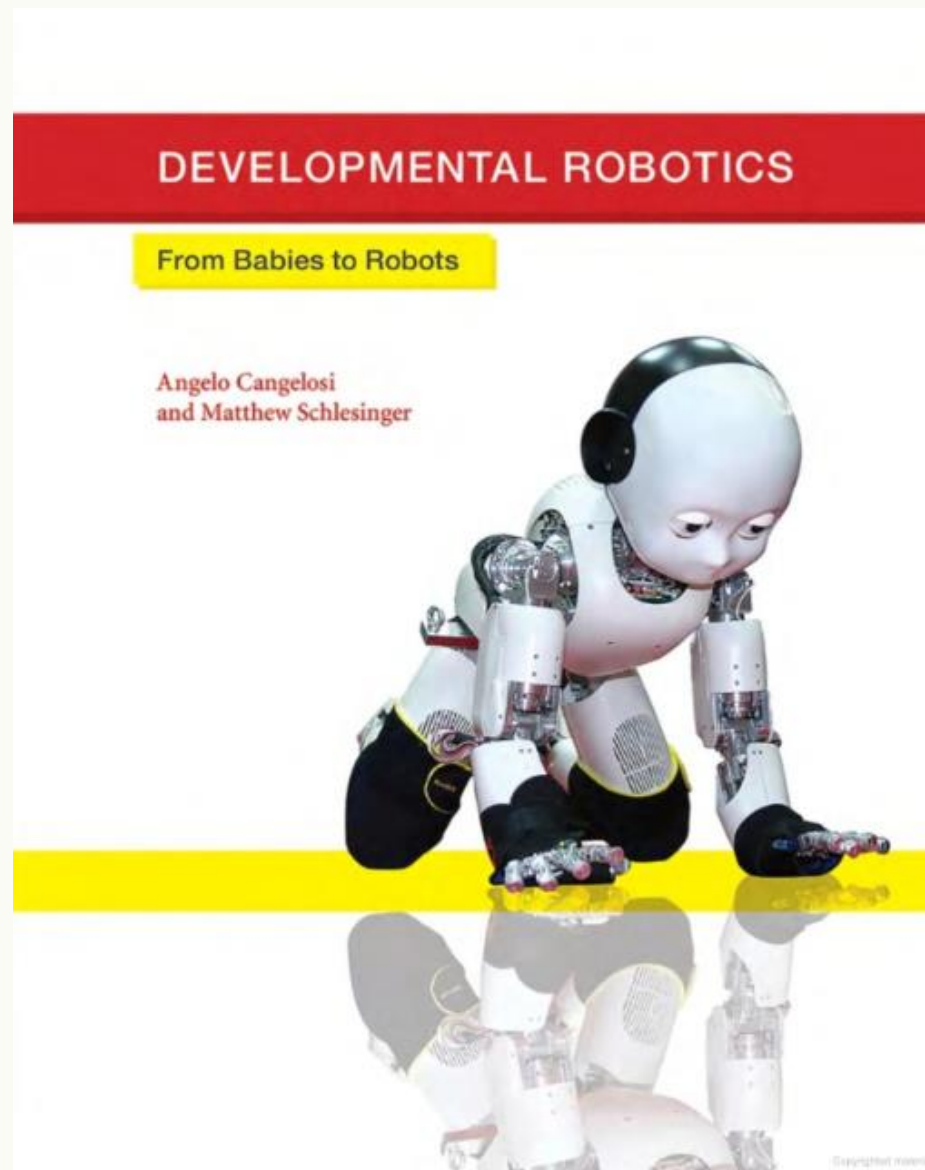


slide from Peter H. Diamandis:
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Rise of Humanoid Robots.
<https://metatrendreport.com/humanoid-robots-c>



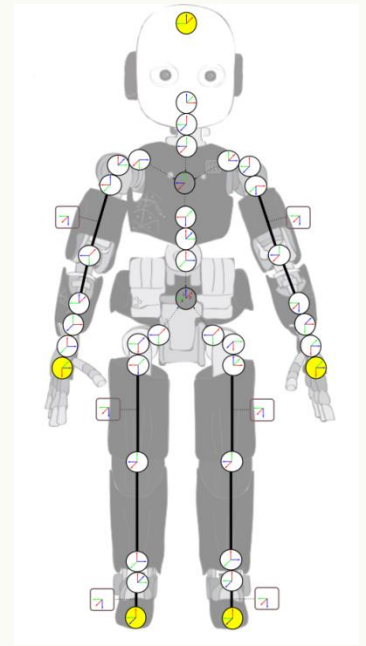
Humanoids in our lab

iCub baby humanoid robot



The iCub humanoid (2004 – now)

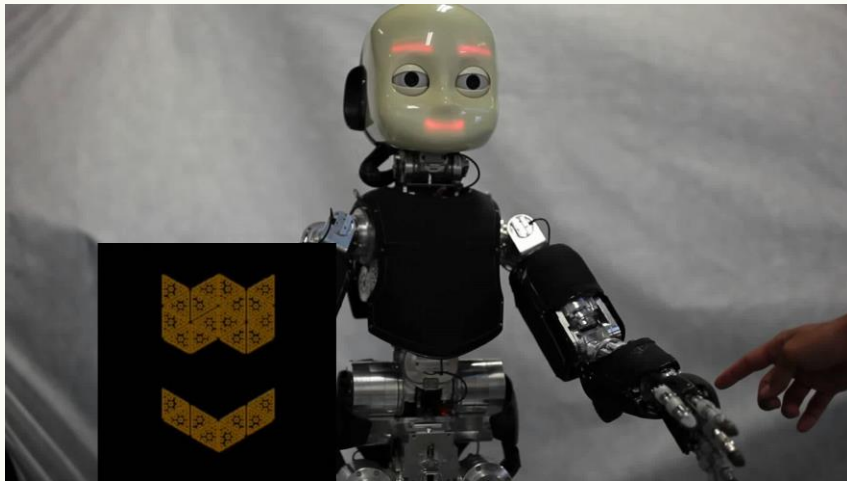
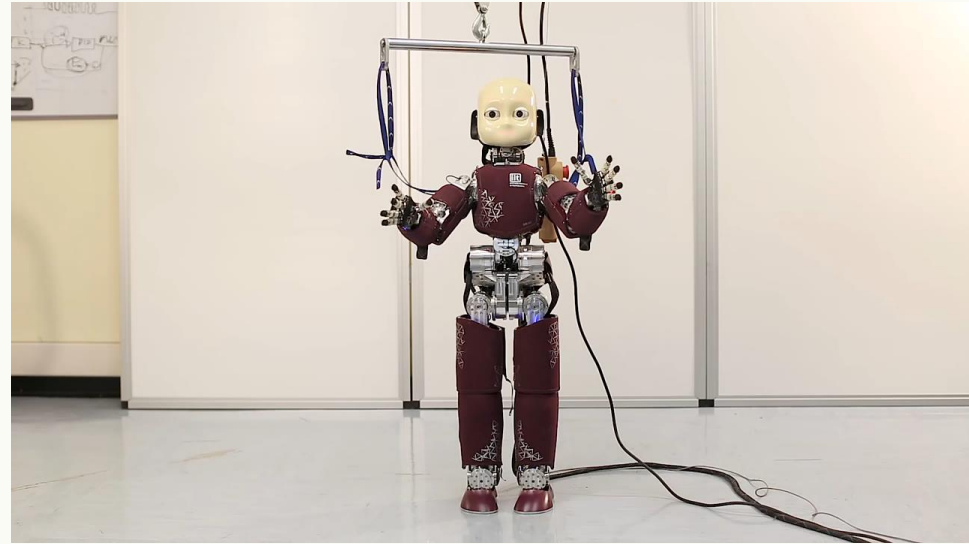
- Size of a 4-year old child
- Motor / proprioception (joint angles)
 - 53 DOF
- **Tactile information**
 - cca 4000 pressure-sensitive tactile elements (taxels) on the whole body
- Vision
 - 2 standard cameras in biomimetic DOF setup (pan, tilt, vergence)
- Force/torque sensors
- Inertial sensors
- Microphones...



iCub (videos)

iCub youtube channel: <https://www.youtube.com/channel/UCXBFWo4IQFkSJBfqdNrE1cA>

<https://youtu.be/UPQLcE1vwAQ>



<https://youtu.be/pfse424t5mQ>

Roncone, A.; Hoffmann, M.; Pattacini, U. & Metta, G. (2014), Automatic kinematic chain calibration using artificial skin: self-touch in the iCub humanoid robot, in IEEE ICRA 2014.

iCub at the center of this course

- Why?
 - it is a universal versatile platform – we can study kinematics, dynamics, reaching, grasping, gaze, walking, balancing, ...
 - it is a standard research platform – with 50 exemplars around the world (see <https://robot-bazaar.iit.it/robots>)
 - it is open source; large collection of modules and training materials available (<https://github.com/robotology>, <https://github.com/vvv-school>, <https://github.com/icub-training>)
 - it is available in our lab!





Educational and social robots

Nao robot (2008 – now)

- 2008, Aldebaran/Softbank
- Currently in V6
- Used as a unified platform for research, social HRI in particular
- Used also for robot football - Robocup
- Allows easy control via Choregraphe

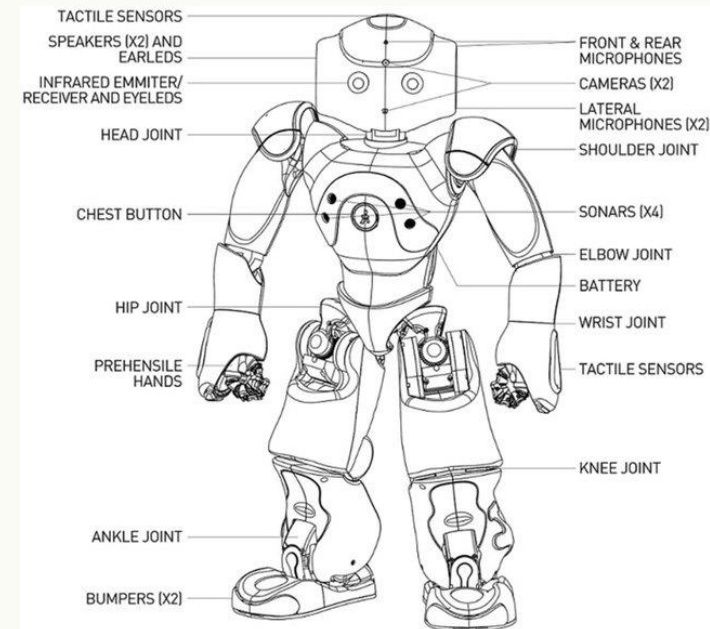
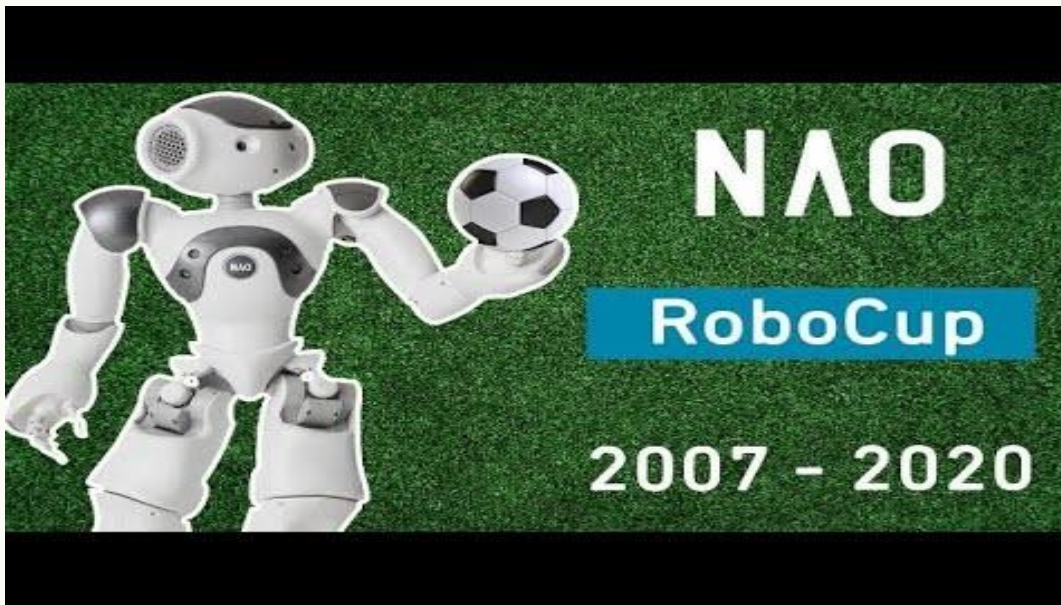


image courtesy of [Softbank robotics](https://www.softbankrobotics.com)

Pepper robot (2014 – now)

- Spiritual successor to Nao, 2014
- Humanoid robot aimed at social interaction
- More widely used in practice (e.g., stores)
- Similar basic design, equipment, and software

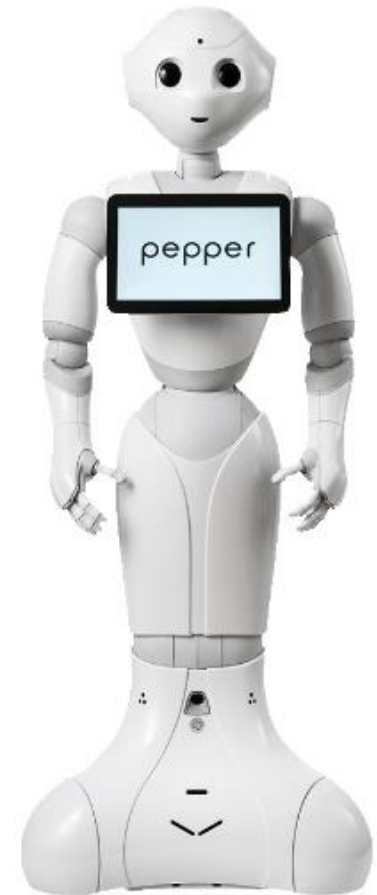
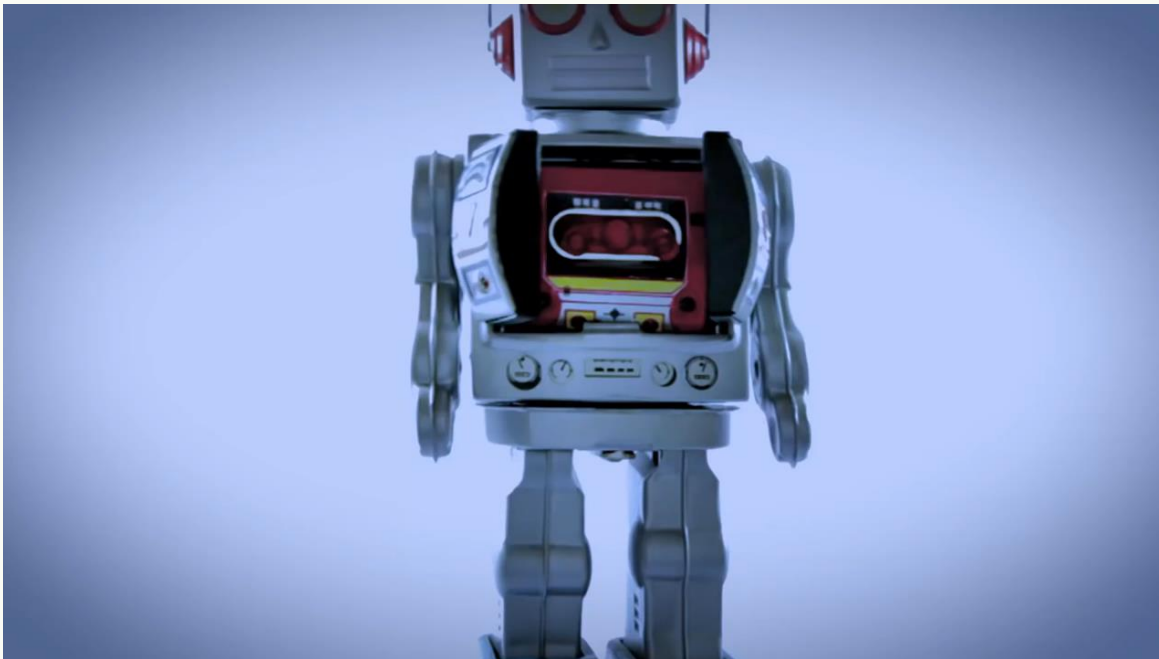


image courtesy of [IEEE robots](#)

<https://youtu.be/oDeQC1krLvc>



Humanoid robots – immediate past

DARPA Robotics Challenge (DRC) (2012-2015)

- aimed to develop semi-autonomous ground robots that could do "complex tasks in dangerous, degraded, human-engineered environments"
- 7/18 teams with Atlas (Boston Dynamics)



<https://youtu.be/g0TaYhjp0fo>

Alternative designs



Winner: KAIST – DRC
Hubo
[https://youtu.be/H3Pptkx
A5CU](https://youtu.be/H3Pptkx A5CU)

3rd – CHIMP CMU Tartan Rescue
<https://youtu.be/Wi2WsPUYDoY>

DARPA Robotics Challenge



Carnegie Mellon University
TARTAN RESCUE

PIs: Tony Stentz, Alonzo Kelly, Herman Herman, Eric Meyhofer
Systems Lead: David Stager

DARPA PM: Dr. Gill Pratt

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Atrias (Oregon State U., J. Hurst)



Atlas (Boston dynamics)



How smart / autonomous do you think the robot actually is?



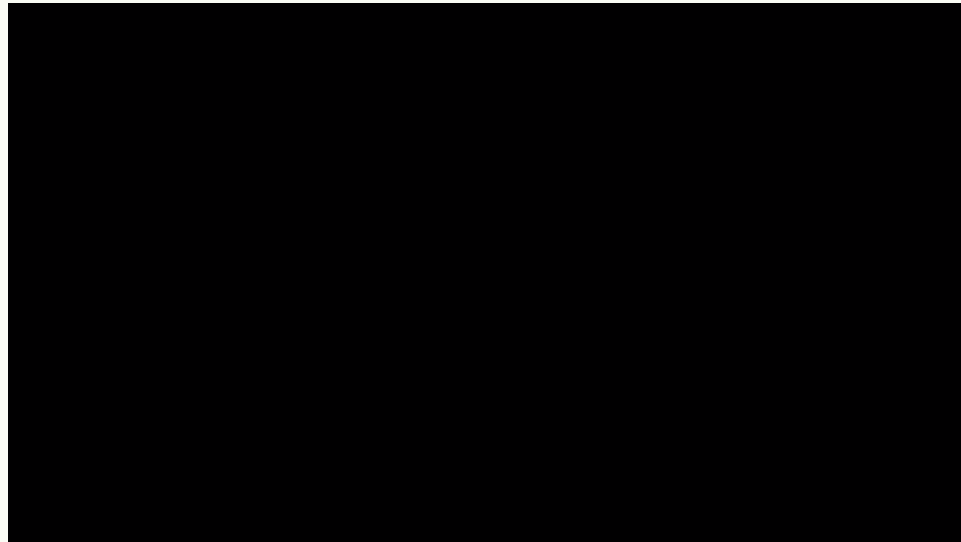
Humanoid robots – present



Karel Čapek (1920): Rossum's Universal Robots

Do we have such robot workers today?

Real progress or shows for the media?



Optimus – Gen 2 | Tesla
(2024)

<https://youtu.be/cpraXaw7dyc?si=vvQ6VODTA6J5ok6E>



What Dance Would You
Like to Perform with
Unitree G1? (2025)

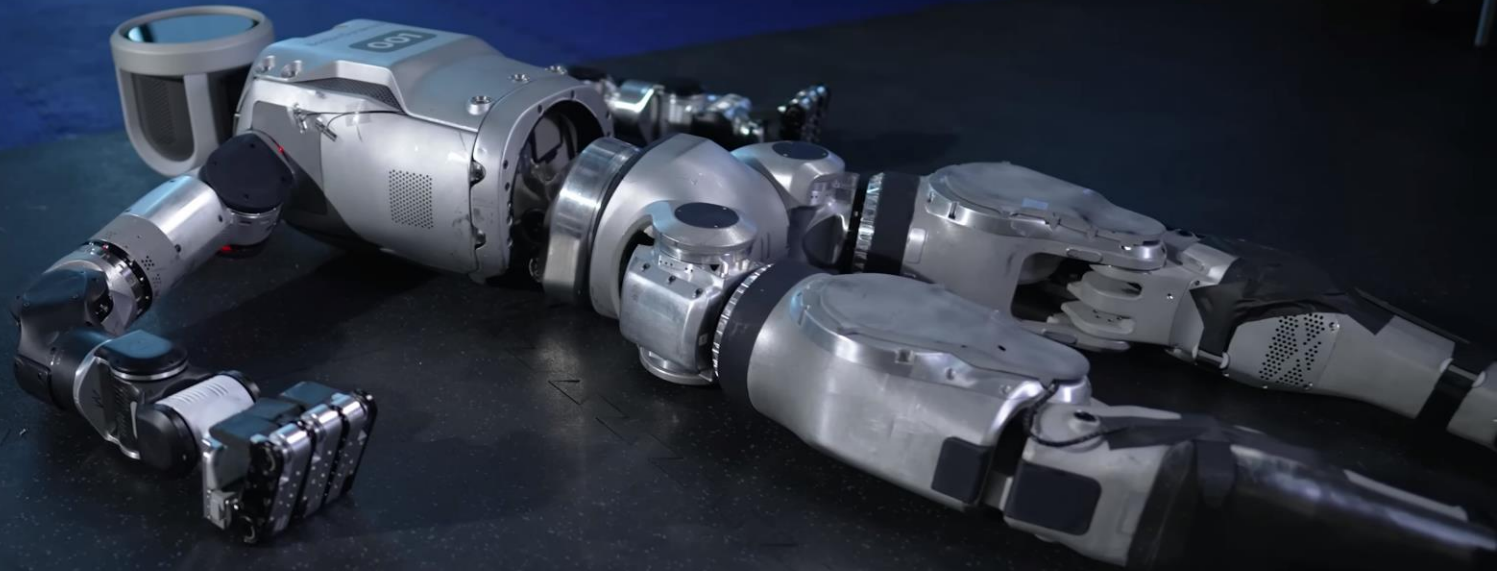
<https://youtu.be/p0xFou30hWI?si=ATh4OnLh5VxKgrfZ>

Unitree G1

Humanoid agent AI avatar

Price from \$16K

Electric Atlas (Boston dynamics) (2024)



https://youtu.be/29ECwExc-_M?si=pqKfr7ycbFy80Y9S

<https://bostondynamics.com/atlas/>

HUMANOID ROBOTS ARE GETTING TO WORK

Humanoids from Agility Robotics and seven other companies vie for jobs




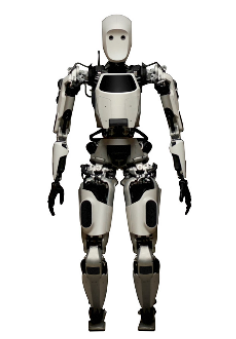

BY EVAN ACKERMAN

30 DEC 2023 | 7 MIN READ



Agility Robotics' Digit carries an empty tote to a conveyor in an Amazon research and development warehouse. AGILITY ROBOTICS

Robots to Look for in 2024

Digit Agility Robotics	Apollo Aptronik	Neo 1X Technologies
		
<p>Digit is most accurately described as "bipedal" rather than "humanoid." It has two legs, but its legs look more like those of an ostrich rather than a human's. This is a side effect of Agility's design process, the goal of which was to maximize the efficiency and robustness of legged locomotion.</p>	<p>Aptronik has worked on more than half a dozen humanoid robots over the past eight years, including NASA's Valkyrie. Apollo is the culmination of all this experience and is designed for manufacturability. Aptronik plans to field its robots in 10 pilot projects in 2024, with a full commercial release of Apollo in 2025.</p>	<p>1X's soft, tendon-based robot is designed to have very low inertia with the goal of building a robot that's safe for humans to be around. The robot will weigh just 30 kilograms, with a carrying capacity of up to 20 kg. 1X, backed by OpenAI, hopes that Neo will become "an all-purpose android assistant to your daily life."</p>

IEEE Spectrum

<https://spectrum.ieee.org/humanoid-robots>

Humanoids in manufacturing?



Atlas Goes Hands
On (2024)

[https://youtu.be/F_7IPm7f1vI
?si=CxbwQcqodOvzt2pA](https://youtu.be/F_7IPm7f1vI?si=CxbwQcqodOvzt2pA)



Figure Status
Update - BMW Use
Case (2024)

[https://youtu.be/WIUFoZstcWg
?si=jkSRfmmclZb6s0xK](https://youtu.be/WIUFoZstcWg?si=jkSRfmmclZb6s0xK)

Proof of concept or real deployment?

First (claimed) commercial deployment

Digit's First Day of Work at GXO, Agility Robotics, 2024

<https://youtu.be/AJpTpUqjgrY?si=SuYIDpJvxjSxPuM9>

Why legs? (Digit – Agility Robotics)

Why our humanoid robot has legs, Agility Robotics, 2024

https://youtu.be/mHmmySGdaoM?si=IdShAK1_E9ddJM1c

Stretch (Boston Dynamics)

- Legs impractical for warehouse?



<https://youtu.be/8WZoVJIV9V0?si=5Jku06AqTUCAL7qU>



Humanoid robots – future

Mass production of humanoids?

TECH

Agility Robotics is opening a humanoid robot factory, beating Tesla to the punch

PUBLISHED MON, SEP 18 2023-11:27 AM EDT | UPDATED MON, SEP 18 2023-1:34 PM EDT



Lora Kolodny
@LORAKOLODNY

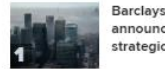
SHARE [f](#) [t](#) [in](#) [✉](#)

KEY POINTS

- Agility Robotics is opening a first-of-its-kind factory in Salem, Oregon where it will mass produce a line of humanoid robots called Digit.
- The new factory, which Agility has dubbed the RoboFab, will produce up to 10,000 units a year and employ 500 people, according to COO Andrea Campbell, formerly Apple's senior director of iPad operations.
- Digit was designed to function as a "robotic co-worker" that can maneuver around warehouses and factories, traversing steps or crouching into small spaces.



TRENDING NOW



Barclays announce strategic



Russia d Russian treason; North Korea luxury ca



Capital C Discover Services all-stock



Disney st CEO: Bri launches startup b VCs



Magnific exceed a country i Should w

Tech / Tech Trends

World's first mass-produced humanoid robot? China start-up Fourier Intelligence eyes two-legged robots with AI brains

- The Shanghai-based company plans to begin mass production of its GR-1 robot by end of 2023 and deliver thousands of units next year
- Fourier hopes to collaborate with major AI companies to work on the 'brain' of its bipedal robot

[Listen to this article](#)



Ann Cao in Shanghai [+ FOLLOW](#)


Published: 8:00am, 13 Aug, 2023 -

[Why you can trust SCMP](#)



Fourier Intelligence's GR-1 robot walks past the company logo at its headquarters in Shanghai. Photo: Handout

2025-2035 METATREND REPORT
THE RISE OF HUMANOID ROBOTS
 Meet the Top 16 Humanoid Robots Shaping the Decade Ahead,
 and their Impact on Industries, Society and our Economy



"We will have 10 Billion Humanoid Robots on Earth by 2040."
 — **Elon Musk**

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ABUNDANCE360

DASHBOARD

POTENTIAL MARKET SIZE

\$38 billion
Goldman Sachs

\$3 trillion
Macquarie Group

\$24 trillion
Ark Invest

UNIT COST TODAY

\$250,000
Morgan Stanley

UNIT COST PREDICTED

\$20,000
Elon Musk

TOP 5 INDUSTRIES IMPACTED

- Agriculture
- Construction
- Eldercare
- Logistics
- Manufacturing

TOP 5 PLAYERS IN 2025

- Figure AI
- Tesla Optimus
- Agility Robotics
- Boston Dynamics
- Unitree



LEADERSHIP THOUGHTS



"If you've got a sentient humanoid robot that is able to navigate reality and do tasks at request, there is no meaningful limit to the size of the economy."

— **Elon Musk, CEO, Tesla**



"We are in the human-labor business, and today 50% of Global Domestic Product (GDP) is paying humans to do work every day, in other words human labor. That amounts to a marketplace of \$40 trillion a year. It's 10 times bigger than all of transportation combined."

— **Brett Adcock, CEO, Figure AI**



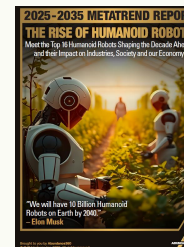
"Humanoid robots will be as common as cars are today. 100 years from now, it's very clear, we'll have humanoid robots everywhere. They will likely be the largest volume mechanical system the world makes."

— **Jensen Huang, CEO, NVIDIA**



"By 2040 there could be a billion bipedal robots doing a wide range of tasks, freeing humans from the slavery of the bottom 50% of really undesirable jobs like assembly line and farm workers. This could be a larger industry than the auto industry."

— **Vinod Khosla, Khosla Ventures**



slide from Peter H. Diamandis:
 2025-2035 Metatrend Report. The
 Rise of Humanoid Robots.
<https://metatrendreport.com/humanoid-robots-c>

Enablers

technological

societal & market

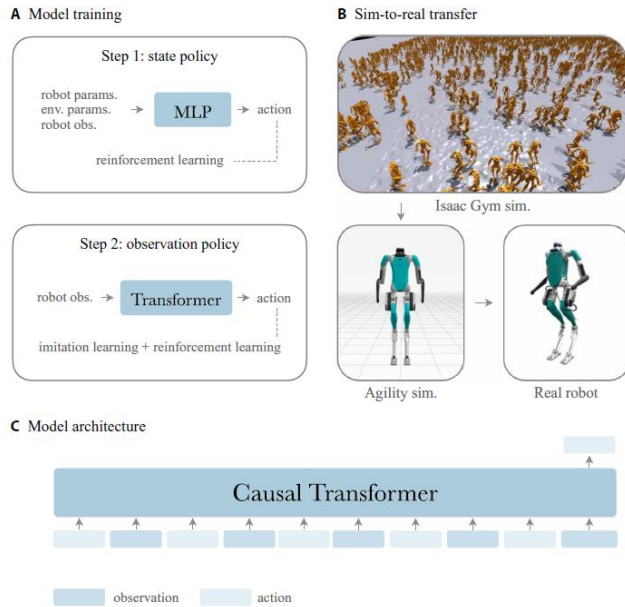
AI – LLMs, VLMs, code LMs

- for reasoning & common sense
- perception
- communication
- for walking and manipulation (?)
 - imitation learning

advances in
battery
technologies

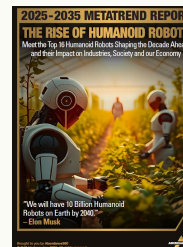
elderly care
crisis

shortage of
labor in
manufacturing



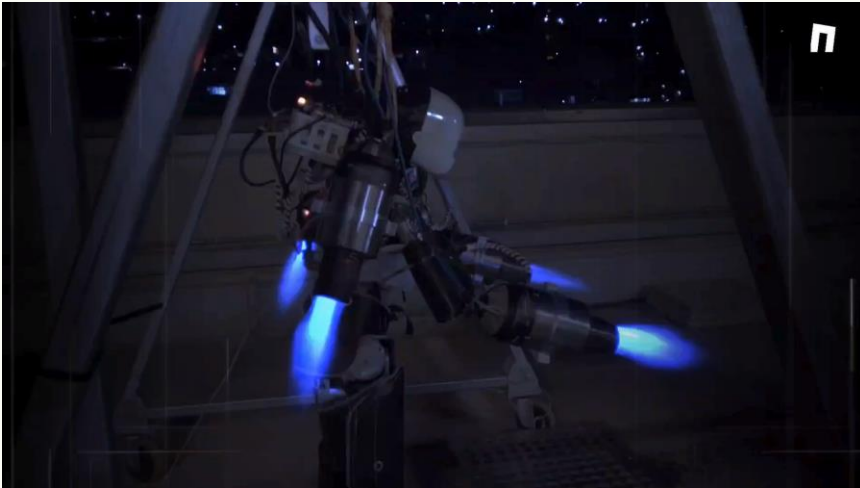
falling costs

Radosavovic, I., Xiao, T., Zhang, B., Darrell, T., Malik, J., & Sreenath, K. (2024). Real-world humanoid locomotion with reinforcement learning. *Science Robotics*, 9(89), eadi9579.



Ride side of slide from Peter H. Diamandis:
2025-2035 Metatrend Report. The
Rise of Humanoid Robots.
<https://metatrendreport.com/humanoid-robots-c>

Flying humanoids? iRonCub



iRonCub Flight Simulation in a Disaster Scenario



Revolutionizing Disaster Relief: The Jet-Powered Humanoid Robot iRonCub Takes Flight! (2024)

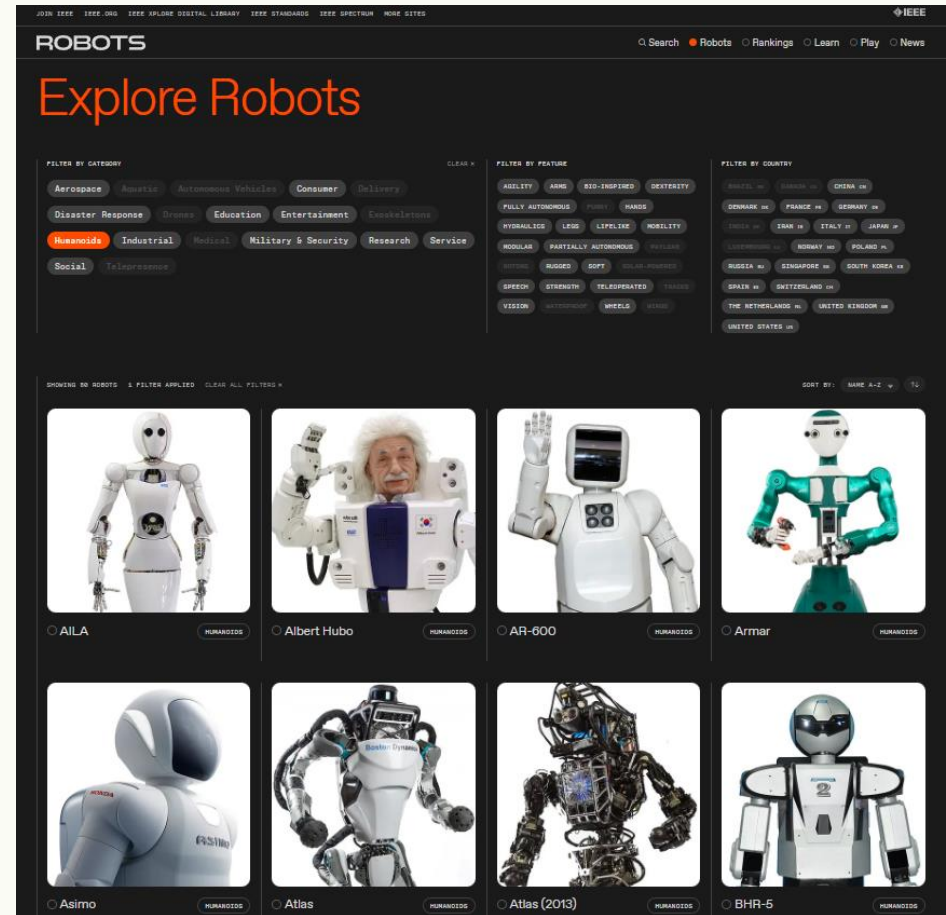
<https://youtu.be/6hTeE4eqjOE?si=a2cxeSBwlf61wByA>

iRonCub Flight Simulation in a Disaster Scenario (2021)

<https://youtu.be/hBEYEF0g4WY?si=RgMcF5ikBLUp0PK7>

Resources

- Fitzpatrick, P., Harada, K., Kemp, C. C., Matsumoto, Y., Yokoi, K., & Yoshida, E. (2016). Humanoids. In *Springer handbook of robotics* (pp. 1789-1818). Springer, Cham.
- Peter H. Diamandis, 2025-2035 Metatrend Report. The Rise of Humanoid Robots. <https://metatrendreport.com/humanoid-robots-c>
- [Progress of Humanoids in 2024](#) - report by Seznam Zprávy with interview of Matej Hoffmann. [in Czech]



<https://robotsguide.com/>