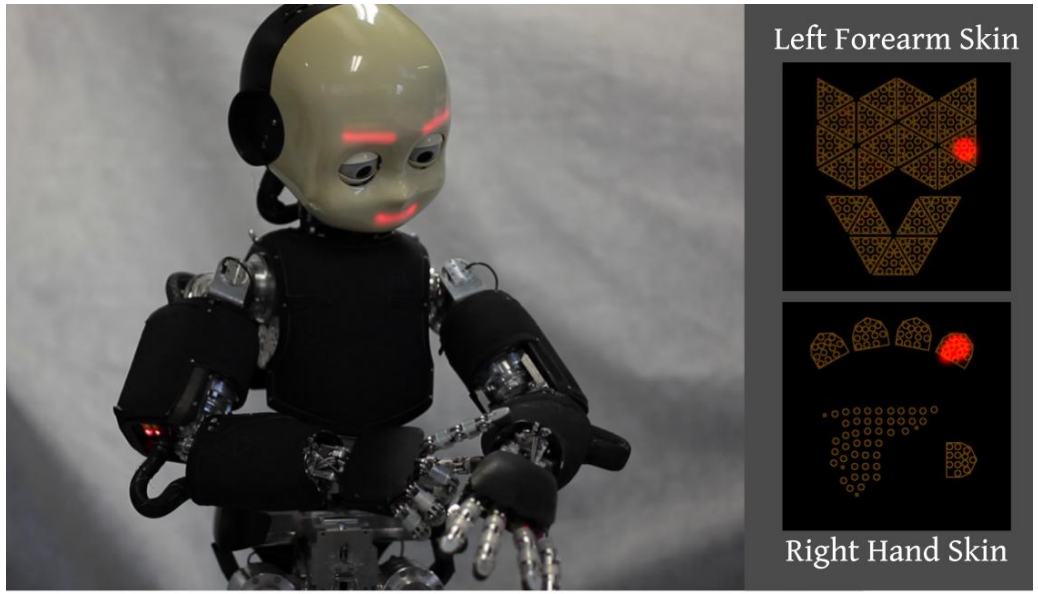
Současnost a budoucnost humanoidních robotů



doc. Matěj Hoffmann, Ph.D.
Department of Cybernetics, Faculty of Electrical Engineering
Czech Technical University in Prague
matej.hoffmann@fel.cvut.cz
https://sites.google.com/site/matejhof
https://cyber.felk.cvut.cz/research/groups-teams/humanoids/

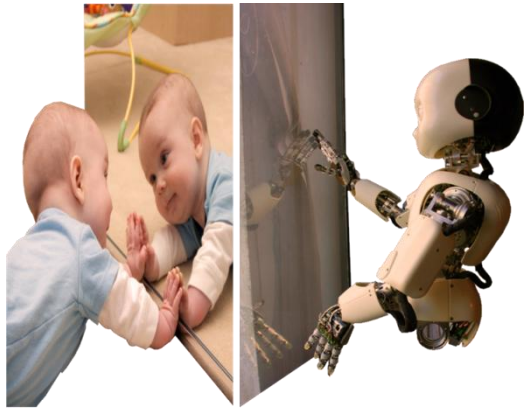
Why humanoid robots?

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

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….

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



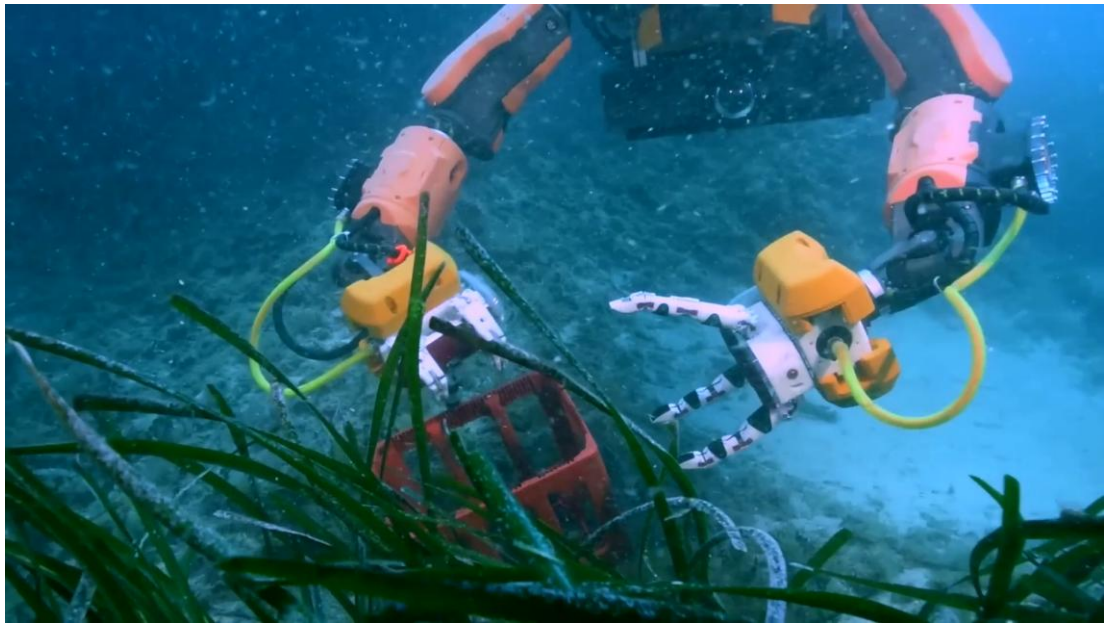
Human-like interaction. Communication…

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

Based on Fitzpatrick et al. (2016). Humanoids. In *Springer handbook of robotics*.

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.

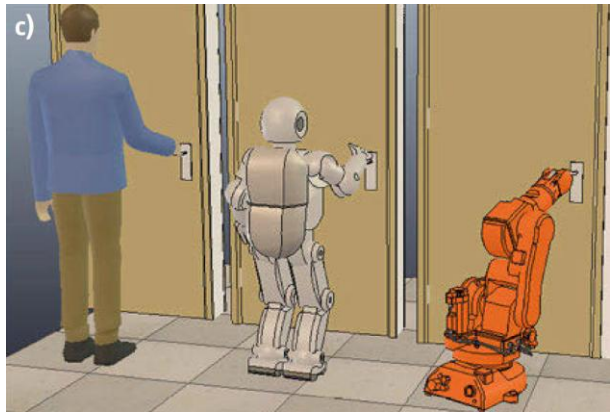
OceanOne – Oussama Khatib & Co., Stanford

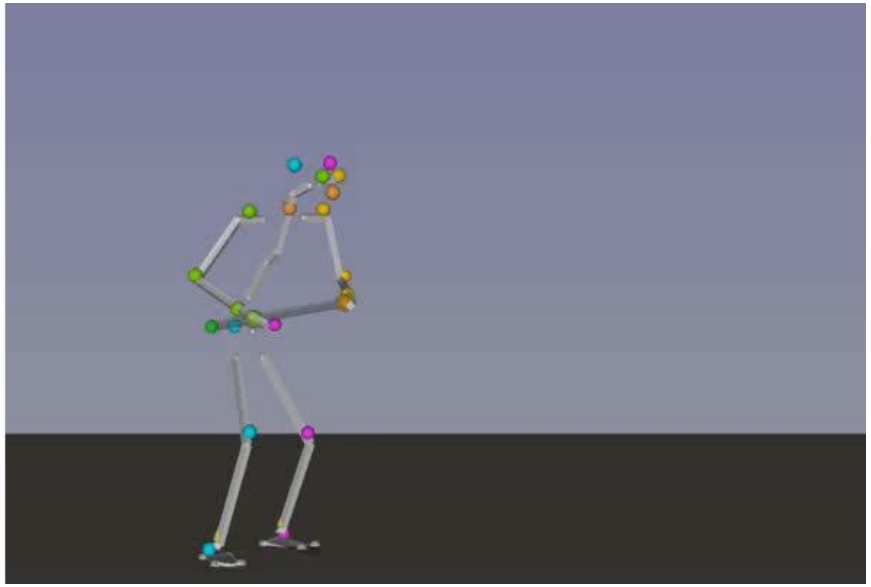
https://youtu.be/p1HmgP9l4VY?si=eMkAu0zXD4q3Q275

Why humanoid robots (cont.)?

Learning from humans

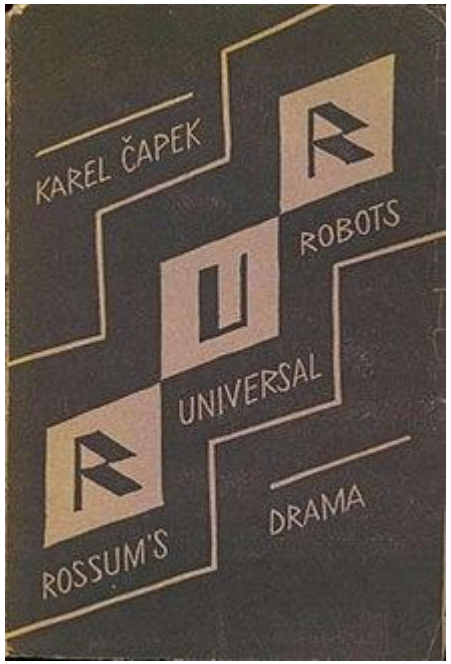
Billard, A. G., Calinon, S., & Dillmann, R. (2016). Learning from humans. Springer handbook of robotics.





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

Karel Čapek (1920): R.U.R. Rossum's Universal Robots



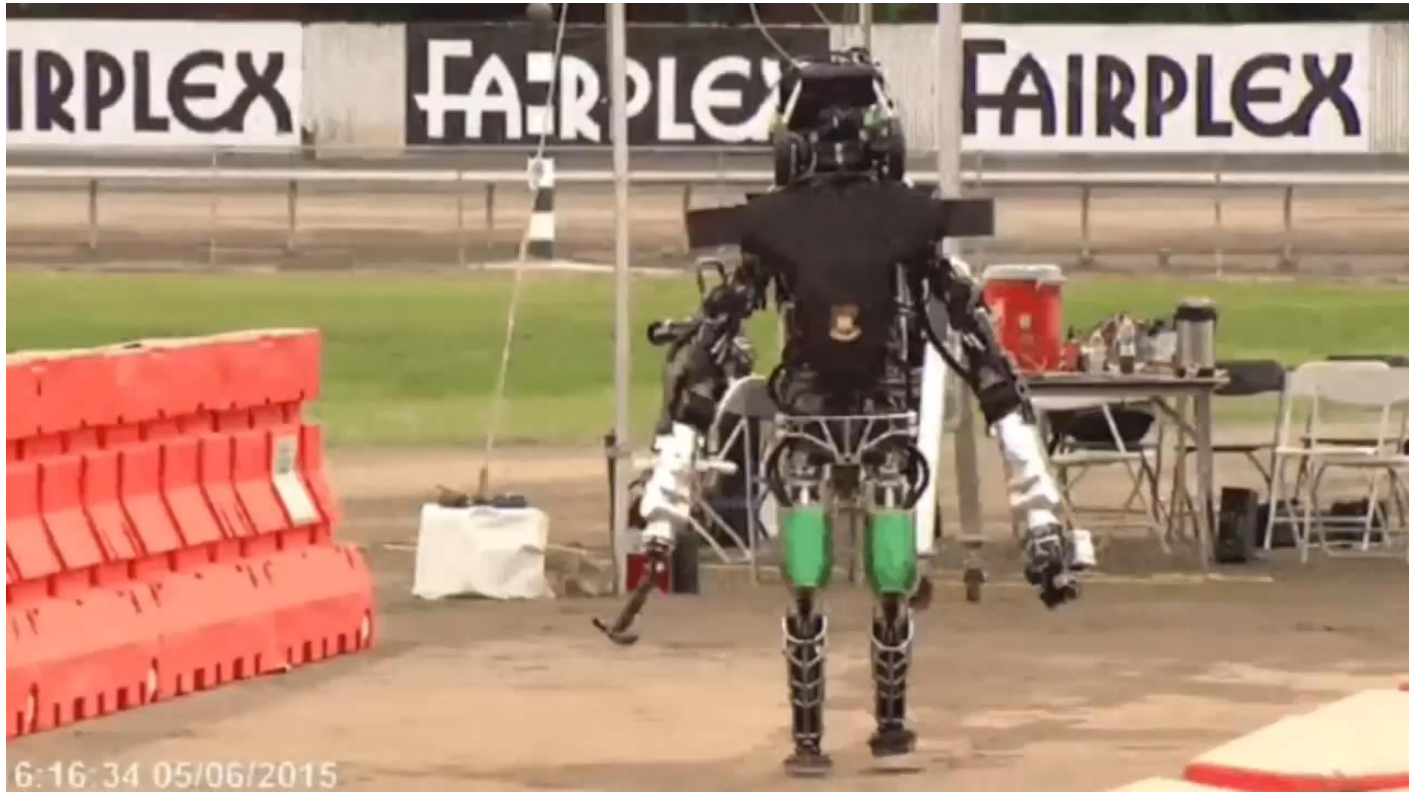
Universal workers

- Humans don’t have to work anymore.
- Do we have such robot workers today?

Humanoid robots – immediate past

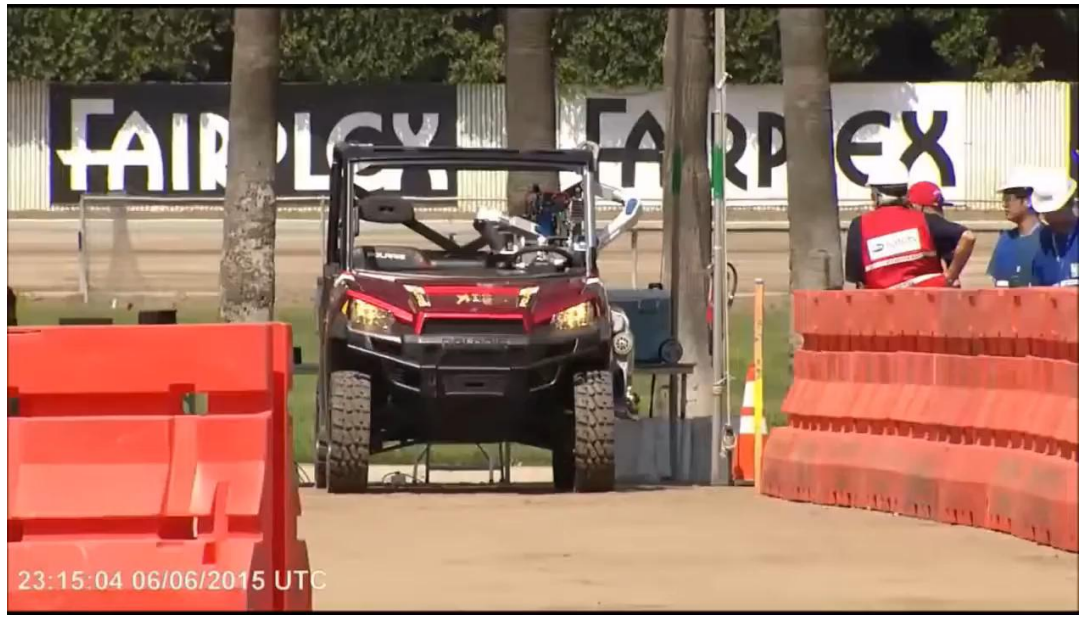
DARPA Robotics Challenge (DRC) (2012-2015)

- 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)



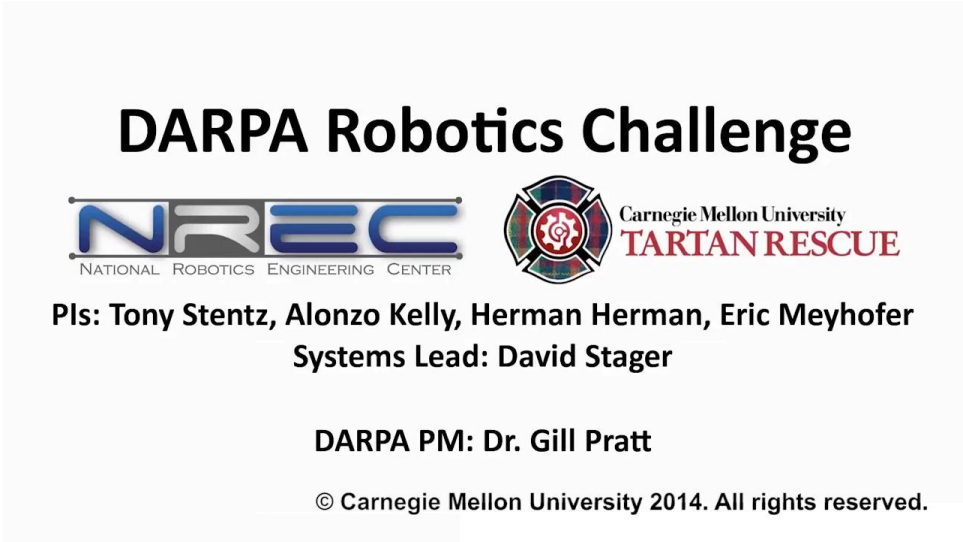
https://youtu.be/g0TaYhjpOfo

Alternative designs



Winner: KAIST – DRC Hubo
https://youtu.be/H3PptkxA5CU

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



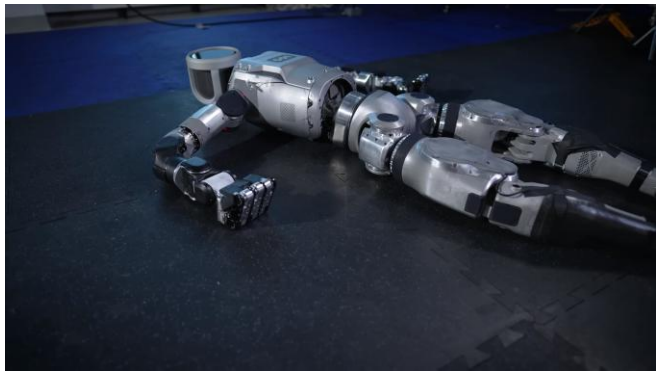
Humanoid robots – present

Real progress or shows for the media?

Atlas
Boston Dynamics
Electric Atlas (2024)

Optimus – Gen 2 | Tesla (2024)
https://youtu.be/cpraXaw7dyc?si=wvQ6VODTA6J5ok6E

What Dance Would You Like to Perform with Unitree G1? (2025)
https://youtu.be/p0xFou30hWI?si=ATh4OnLh5VxKgrfZ



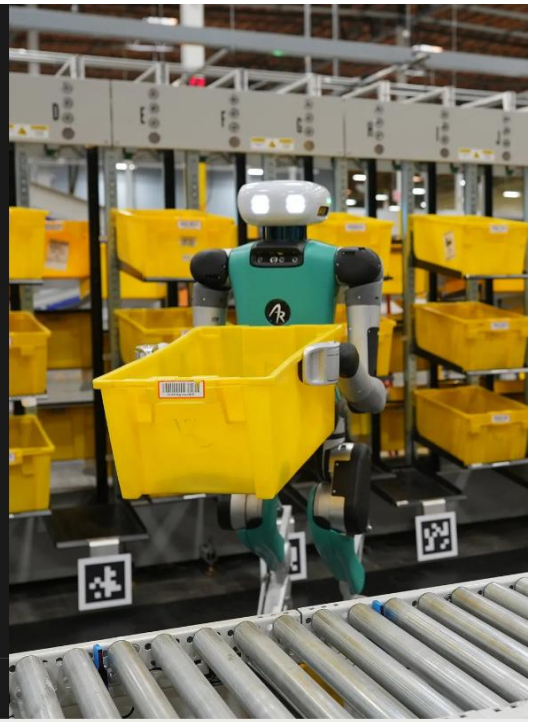
https://youtu.be/29ECwExc-_M?si=pqKfr7ycbFy80Y9S

- How smart / autonomous do you think the robots actually are?
  - How much AI is there?

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

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.

Apollo
Apptronik

Apptronik 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. Apptronik plans to field its robots in 10 pilot projects in 2024, with a full commercial release of Apollo in 2025.

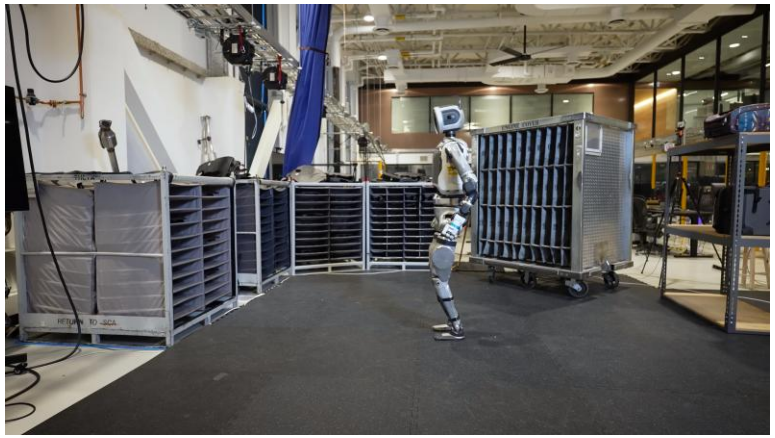
Neo
1X Technologies

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."

IEEE Spectrum

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

Humanoids in manufacturing?



Atlas Goes Hands On (2024)
https://youtu.be/F_7IPm7f1vI?si=CxbwQcqodOvzt2pA

Figure Status Update - BMW Use Case (2024)
https://youtu.be/WlUFoZstcWg?si=jkSRfmmcLzb6s0xK

First (claimed) commercial deployment
Digit's First Day of Work at GXO, Agility Robotics, 2024
https://youtu.be/AJpTpUqjgrY?si=SuYlDpJvxtSxPuM9

Proof of concept or real deployment?

Why legs?

Why our humanoid robot has legs,
Agility Robotics, 2024
https://youtu.be/mHmmySGdaoM?si=IdShAK1_E9ddJM1c

Stretch,
Boston Dynamics
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
@IN/LORAKOLODNY/

SHARE

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 Aindrea 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

1 Barclays announc strategic

2 Russia d Russian treason; North Ko luxury ca

3 Capital C Discover Services all-stock

4 Disney st CEO: Bri launches startup b VCs

5 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

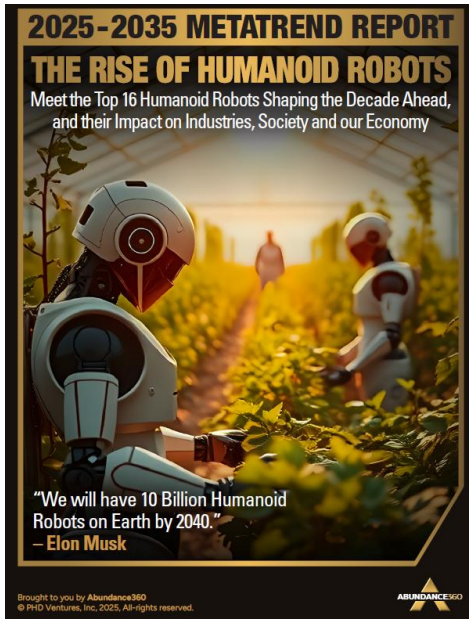
- The Shanghai-based company plans to begin mass production of its GR-1 robot by end of 2023 and deliver thousands of units next year
- Fourier hopes to collaborate with major AI companies to work on the 'brain' of its bipedal robot

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



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

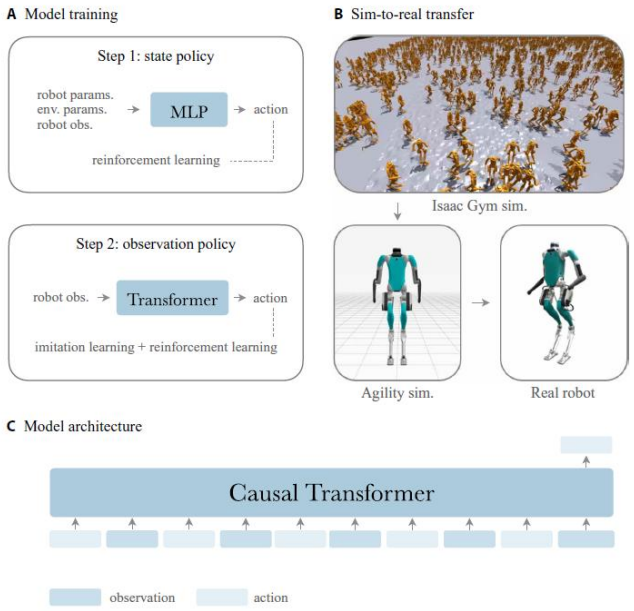
slide from Peter H. Diamandis: 2025-2035 Metatrend Report. The Rise of Humanoid Robots. https://metatrendreport.com/humanoid-robots-c

Enablers

technological

societal & market

AI – LLMs, VLMs, code LMs
- for reasoning & common sense
- perception
- communication
- for walking and manipulation (?)
  - imitation learning



Radosavovic et al. (2024). Real-world humanoid locomotion with reinforcement learning. *Science Robotics*.

realistic simulators and compute power

realistic simulators and NVIDIA Isaac Groot

Get Started Developing Humanoid Robots

Get the software and infrastructure you need to advance your humanoid robot development with GROOT foundational technologies.

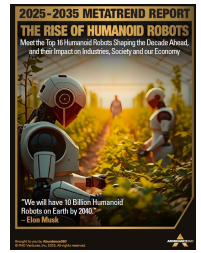
advances in **battery** technologies

elderly care crisis

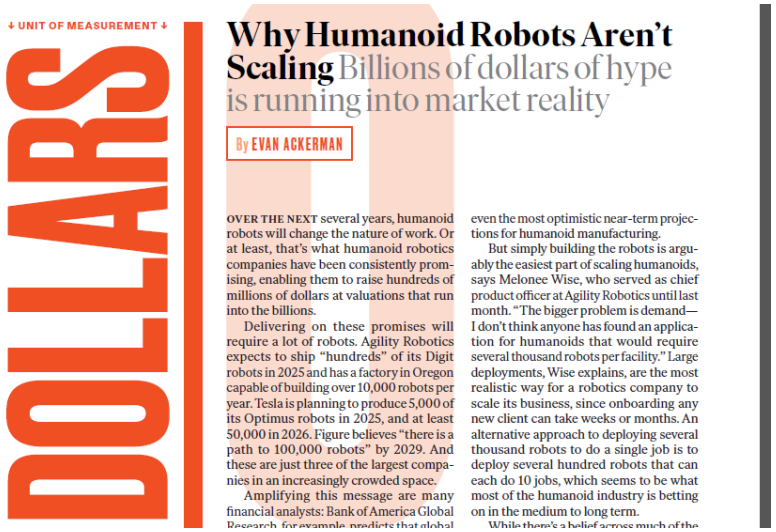
shortage of labor in manufacturing

falling costs

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



Or a bubble which will burst?



↓ UNIT OF MEASUREMENT ↓

DOLLARS

Why Humanoid Robots Aren't Scaling Billions of dollars of hype is running into market reality

By EVAN ACKERMAN

OVER THE NEXT several years, humanoid robots will change the nature of work. Or at least, that's what humanoid robotics companies have been consistently promising, enabling them to raise hundreds of millions of dollars at valuations that run into the billions.

Delivering on these promises will require a lot of robots. Agility Robotics expects to ship "hundreds" of its Digit robots in 2025 and has a factory in Oregon capable of building over 10,000 robots per year. Tesla is planning to produce 5,000 of its Optimus robots in 2025, and at least 50,000 in 2026. Figure believes "there is a path to 100,000 robots" by 2029. And these are just three of the largest companies in an increasingly crowded space.

Amplifying this message are many financial analysts: Bank of America Global Research, for example, predicts that global

even the most optimistic near-term projections for humanoid manufacturing.

But simply building the robots is arguably the easiest part of scaling humanoids, says Melonee Wise, who served as chief product officer at Agility Robotics until last month. "The bigger problem is demand—I don't think anyone has found an application for humanoids that would require several thousand robots per facility." Large deployments, Wise explains, are the most realistic way for a robotics company to scale its business, since onboarding any new client can take weeks or months. An alternative approach to deploying several thousand robots to do a single job is to deploy several hundred robots that can each do 10 jobs, which seems to be what most of the humanoid industry is betting on in the medium to long term.

While there's a belief across much of the

Evan Ackerman, IEEE Spectrum 10/2025

RODNEY BROOKS *Robots, AI, and other stuff* BLOG MIT ROBUST.AI

Search ...

RECENT POSTS

A Prophetic Poem about Artificial

POST: WHY TODAY'S HUMANOIDS WON'T LEARN DEXTERITY

SEPTEMBER 26, 2025 — ESSAYS

Why Today's Humanoids Won't Learn Dexterity

rodneybrooks.com/why-todays-humanoids-wont-learn-dexterity/

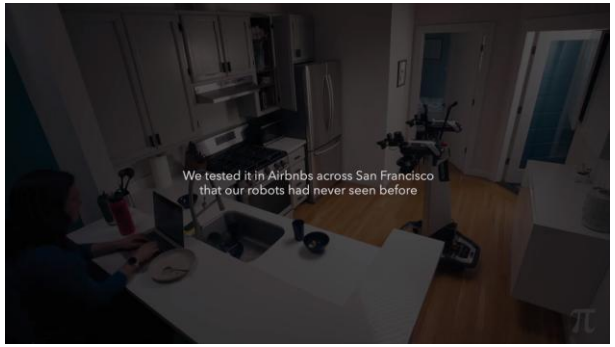
In this post I explain why today's humanoid robots will not learn how to be dexterous despite the hundreds of millions, or perhaps many billions of dollars, being donated by VCs and major tech companies to pay for their training.

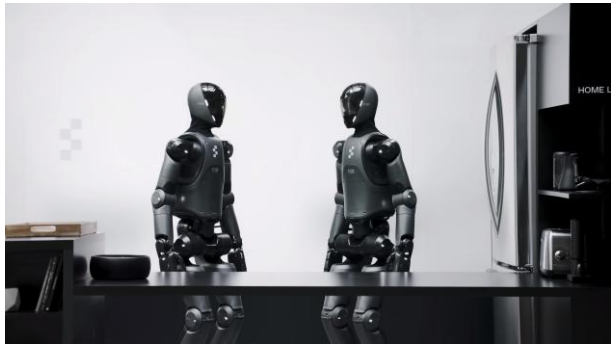
https://rodneybrooks.com/why-todays-humanoids-wont-learn-dexterity/

Perception AI … Generative AI … Agentic AI ….. Physical AI
Going to Physical AI may be harder than we think!

Universal humanoid workers

- Multi-purpose humanoid robots



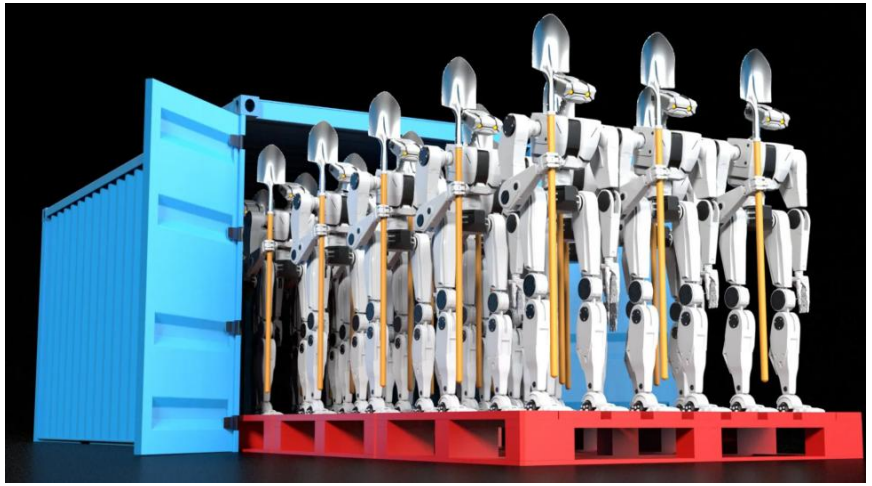


IEEE Spectrum FOR THE TECHNOLOGY INSIDER

FEATURE | ROBOTICS

REALITY IS RUINING THE HUMANOID ROBOT HYPE

The obstacles to scaling up humanoids that nobody is talking about



- How come Rossum's robots were better?

What can we learn from Rossum's robots today?

Rossum's robots (1st generation)

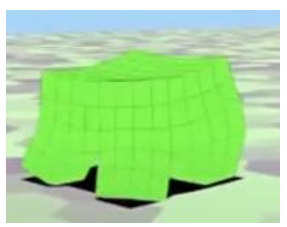
They were from living matter.

They were "learning".

"...after the living matter is prepared, individual organs, bones, nerves and veins are manufactured. Then they (Robots) are assembled like cars. After that, they are put in a store, where they get into existence. They internally adhere somehow. Many things even newly grow in them. You see, we have to leave some time for natural development."

Afterwards, they went to school.

Today's robots



only starting now (see "zenobots")

2025 Conference on Robot Learning

Rossum's robots (2nd generation)

Nerves for pain added so they don't damage themselves; "irritability"

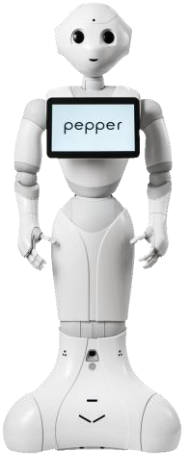
They were embodied and enactive cognitive agents.

*"We were machines, Sir; but from **horror and pain** we have become – ...souls."*

?

Humanoid and cognitive robotics @ CTU Prague, Czechia

Department of Cybernetics, Faculty of Electrical Engineering,
Czech Technical University (CTU) in Prague, Czechia
https://cyber.felk.cvut.cz/research/groups-teams/humanoids/



Head, Assoc. Prof.

Matej Hoffmann

Assistant Prof.

Giulia D'Angelo

Postdoc

Haofeng Chen

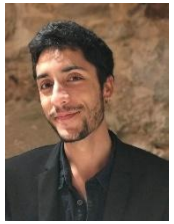
HW development & maintenance

Bedřich Himmel

PhD students

Filipe Gama

Shubhan Patni



Jason Khoury

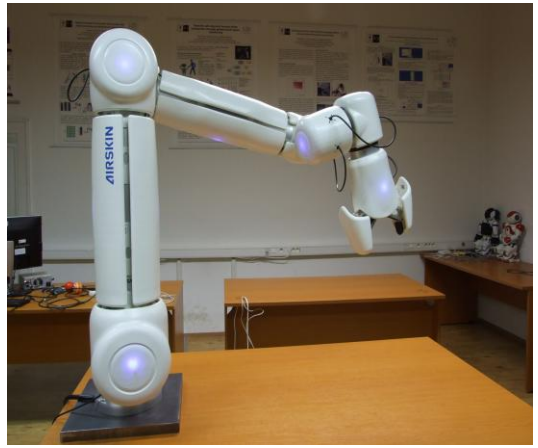
Lukáš Rustler

Šárka Lísková

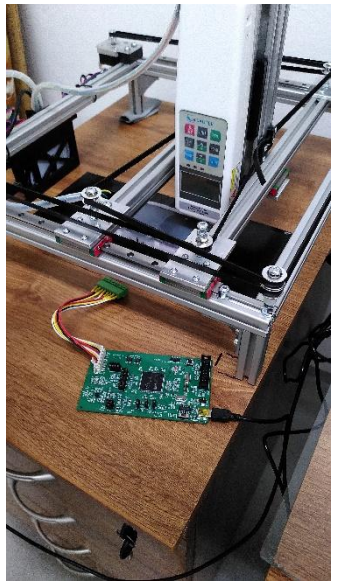
Robots with large-area electronic skins (@CTU Prague)

iCub humanoid ~ 4000 capacitive sensors

Nao humanoid retrofitted with "iCub skin" – 970 sensors



UR 10e manipulator with Airskin pressure sensors



custom development of large-area skins – electrical impedance tomography (EIT)

- Why sensitive electronic skin covering complete robot bodies?
  - human-robot interaction (HRI)
    - safety - contact detection and localization
    - social interaction
  - self-calibration

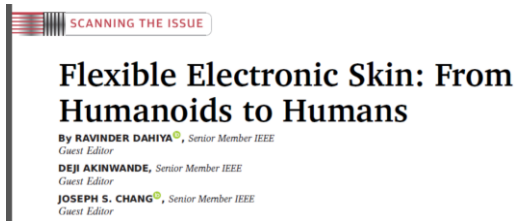

commentary

Robots with a sense of touch

Chiara Bartolozzi, Lorenzo Natale, Francesco Nori and Giorgio Metta

Tactile sensors provide robots with the ability to interact with humans and the environment with great accuracy, yet technical challenges remain for electronic-skin systems to reach human-level performance.

Bartolozzi et al., Nature Materials 2016.


SCANNING THE ISSUE

Flexible Electronic Skin: From Humanoids to Humans

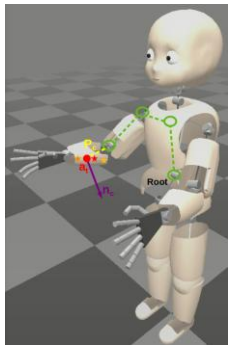
By RAVINDER DAHIYA, Senior Member IEEE
Guest Editor
DEJI AKINWANDE, Senior Member IEEE
Guest Editor
JOSEPH S. CHANG, Senior Member IEEE
Guest Editor

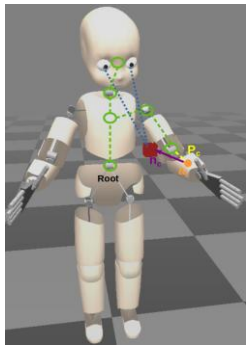
Dahiya et al., Proceedings of the IEEE, 2019.

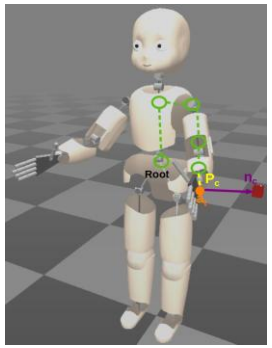
HARMONIOUS

- Use the contact location and magnitude from tactile inputs for avoidance reactions.
- Reactive motion controller that commands two arms of a humanoid robot and three torso joints (17 DoF in total).
- Unified treatment of obstacles that dynamically maps
  - tactile (postcollision) (2000 pressure-sensitive receptors)
  - visual and proximity (precollision)

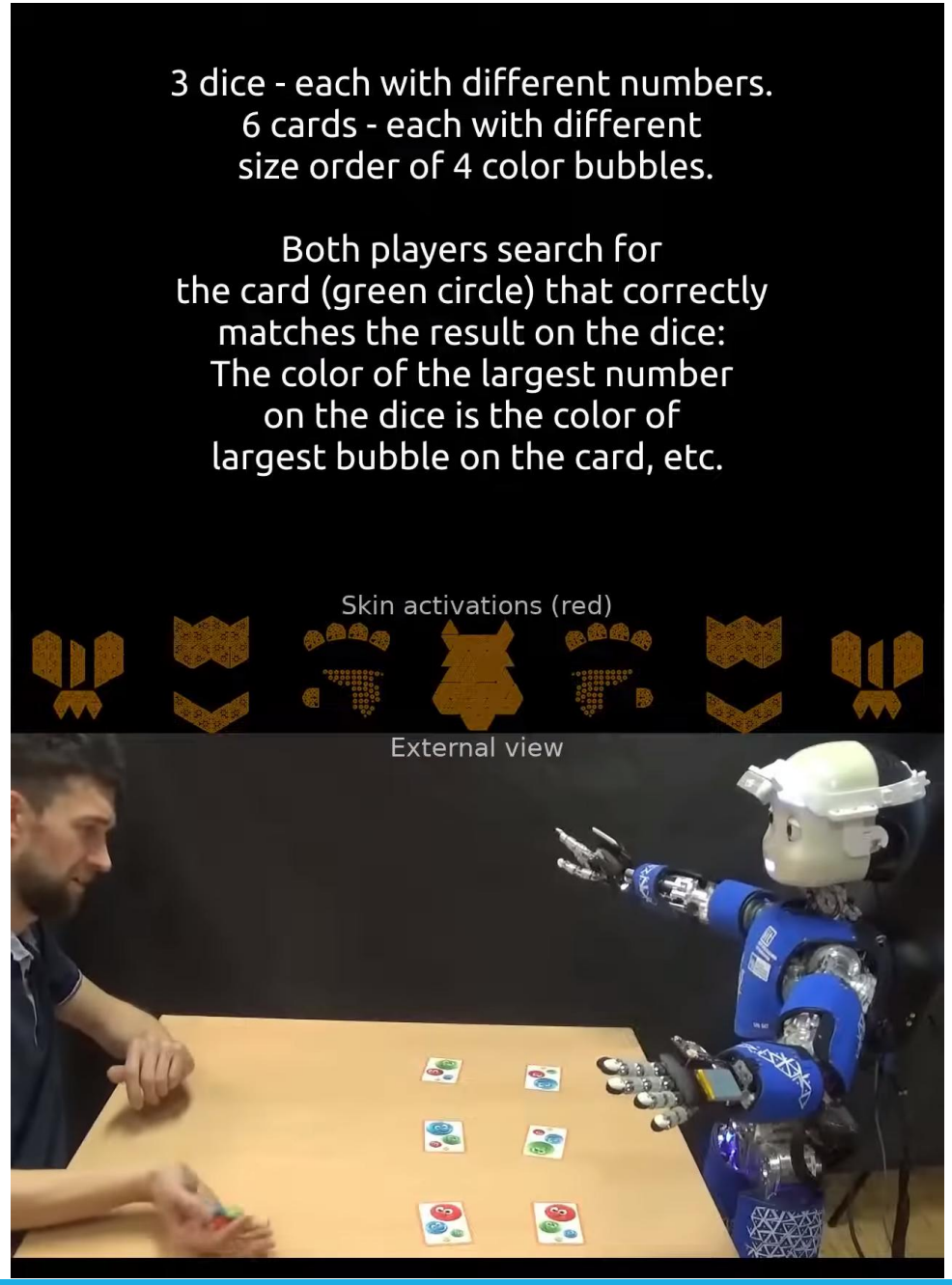
  obstacles as additional constraints to the motion controller, in a distributed fashion over the surface of the upper body of the iCub robot



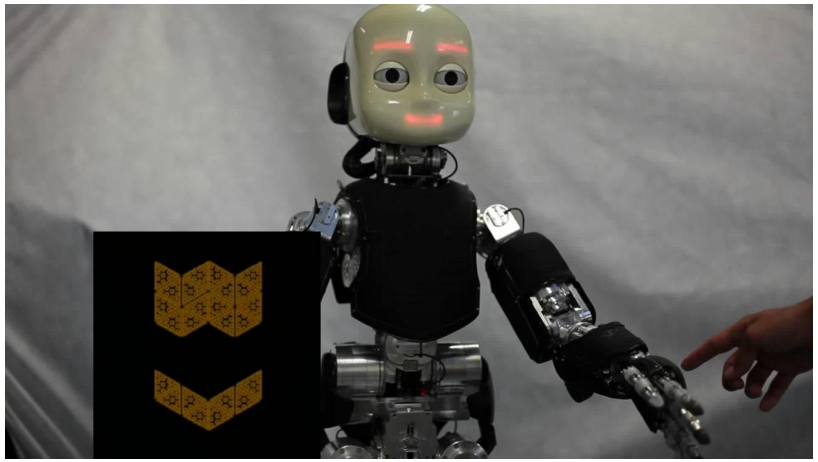




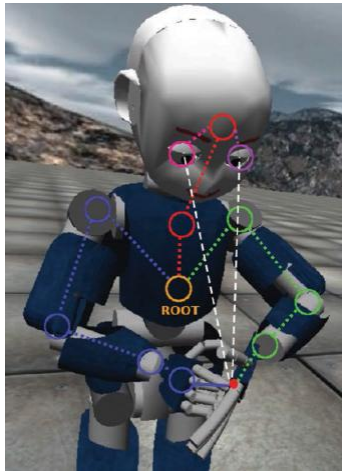
Rozlivek, J.; Roncone, A.; Pattacini, U. & Hoffmann, M. (2025), 'HARMONIOUS – Human-like reactive motion control and multimodal perception for humanoid robots', IEEE Transactions on Robotics 41, 378 - 393. https://sites.google.com/site/matejhof/publications/harmonious

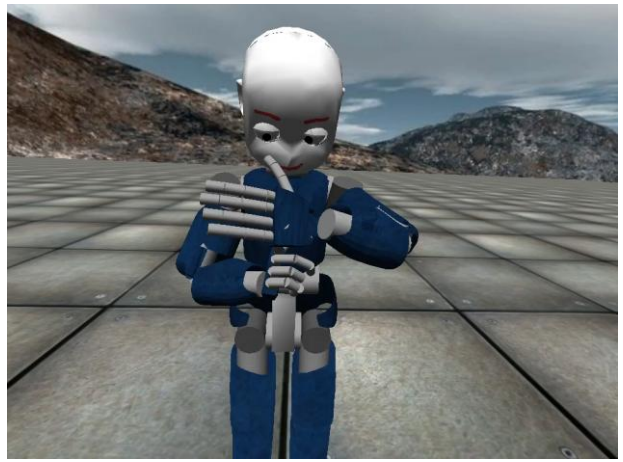


Multisensorial self-contained robot calibration

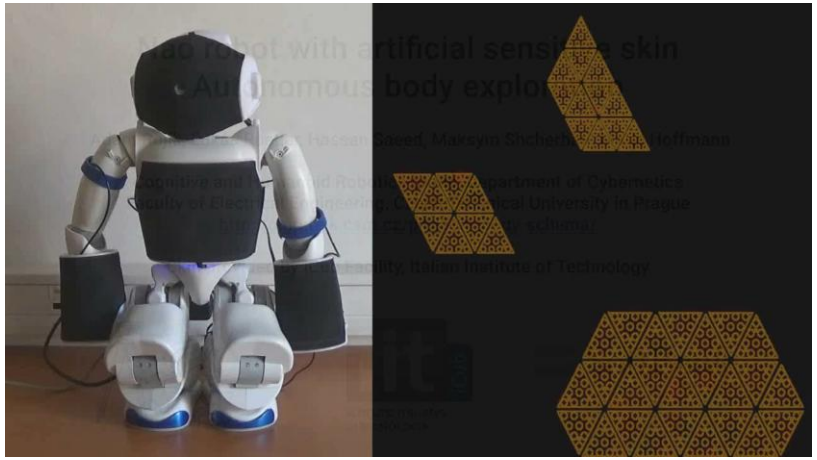


Roncone et al., ICRA 2014.

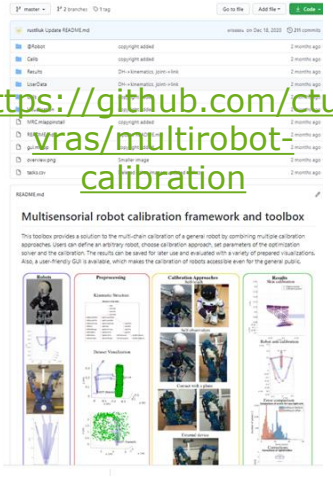




Stepanova, K et al., *IEEE RAL 2019.*



Rustler, L. et al., IEEE Humanoids 2021.



https://github.com/ctu-vras/multirobot-calibration

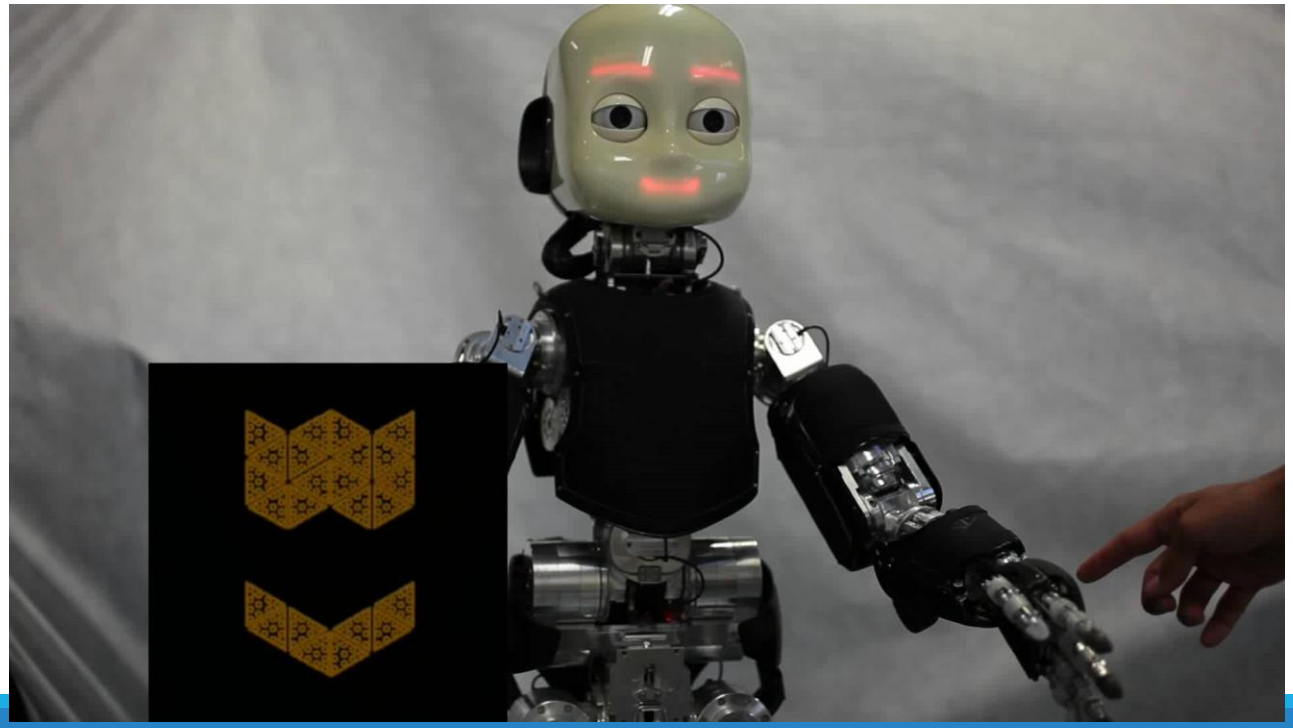
Rozlivek et al., IEEE Humanoids 2021.

Stepanova et al. RCIM 2022.

Hoffmann, M. (2022), Biologically inspired robot body models and self-calibration, *in* Marcelo Ang; Oussama Khatib & Bruno Siciliano, ed., 'Encyclopedia of Robotics', Springer.
Videos and publications at https://sites.google.com/site/matejhof/research/touch-and-selfcalibration.

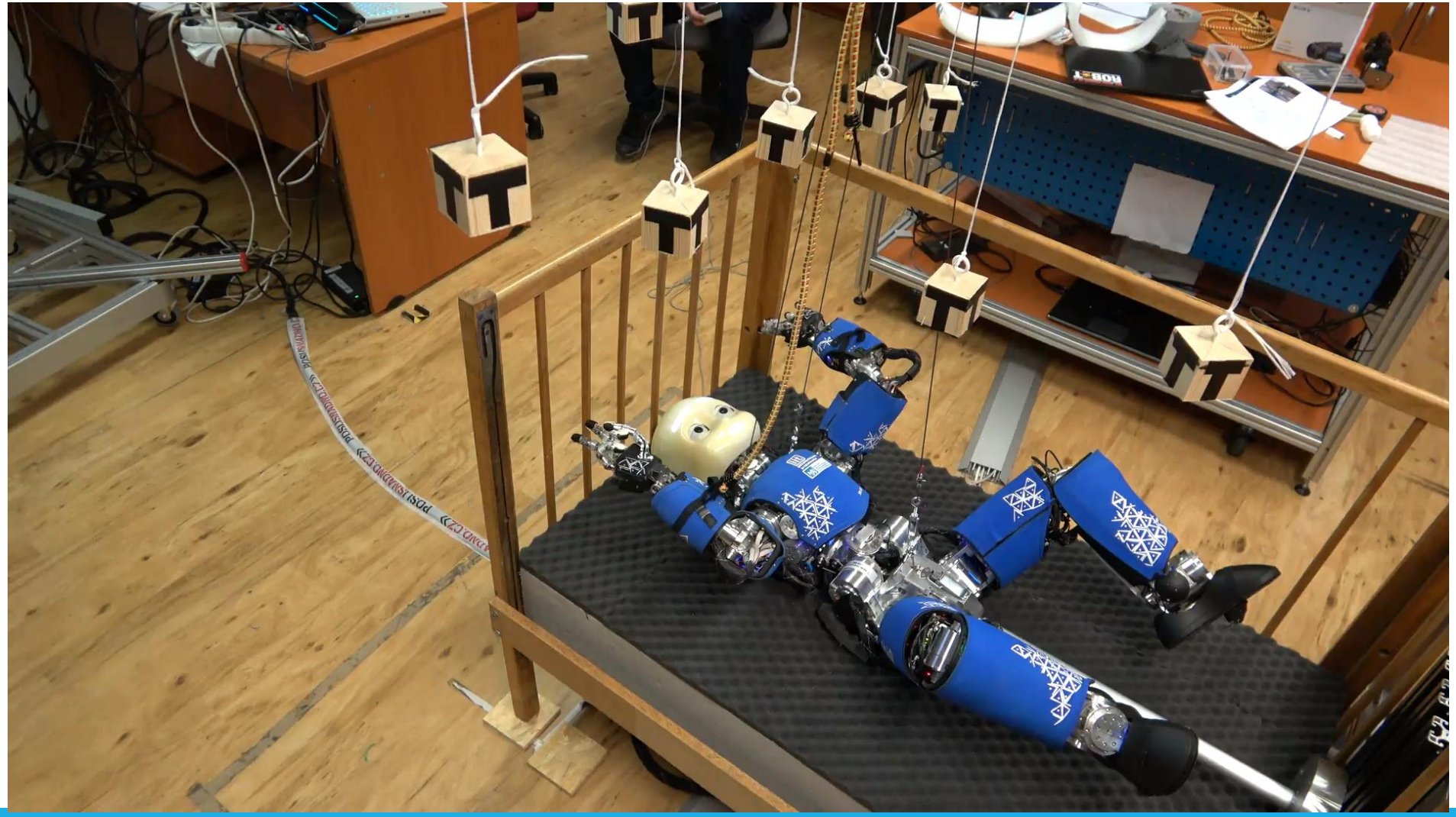
Understanding by building

robots as embodied computational models of child and brain development



- instantiation of complete sensorimotor loops is key
- robotics theory (e.g. inverse kinematics) provides normative models.

The “mobile paradigm”.
Which limb is connected to the toy?



Thank you!

Humanoid and cognitive robotics

interested in collaboration, visiting, internship, PhD, postdoc…? Contact me!

Collaborations in robotics:

- Ugo Pattacini, Chiara Bartolozzi (IIT Genoa)
- Alessandro Roncone (UC Boulder)
- Sami Haddadin (TU Munich / Mohamed Bin Zayed University of Artificial Intelligence)
- Hyosang Lee (TU Eindhoven)

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