Week 07 | Lecture 06
The Humanoid Robot as a Social Partner

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The Humanoid Robot as a Social Partner

Introduction

- The "Why" - A Form for Partnership

Core Design & Engineering

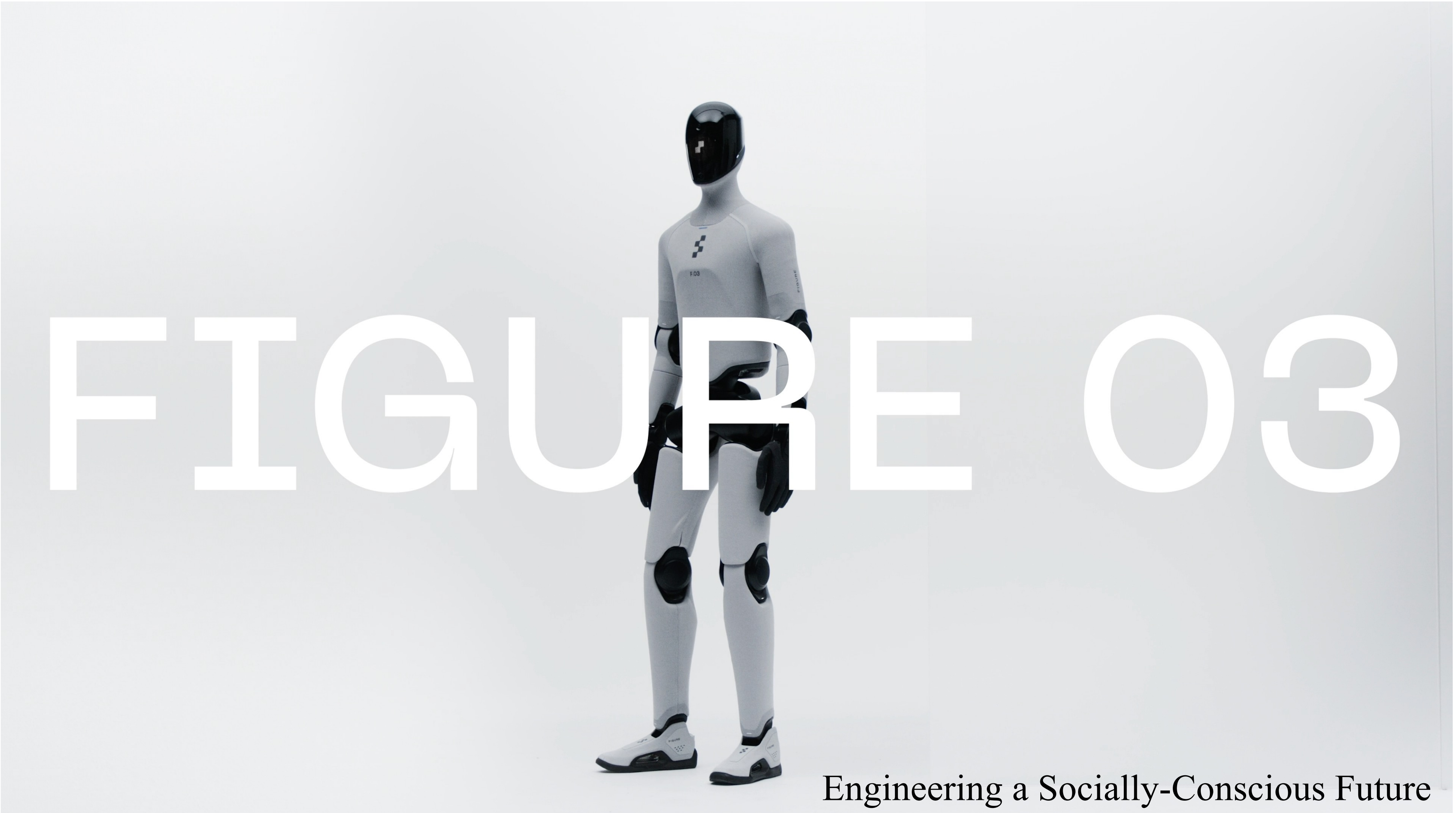
- The "How" – Design & Engineering for Human Environments

Future

The “Why”
A Form for Partnership

Introduction

Designing a Partner for a Better World



Engineering a Socially-Conscious Future

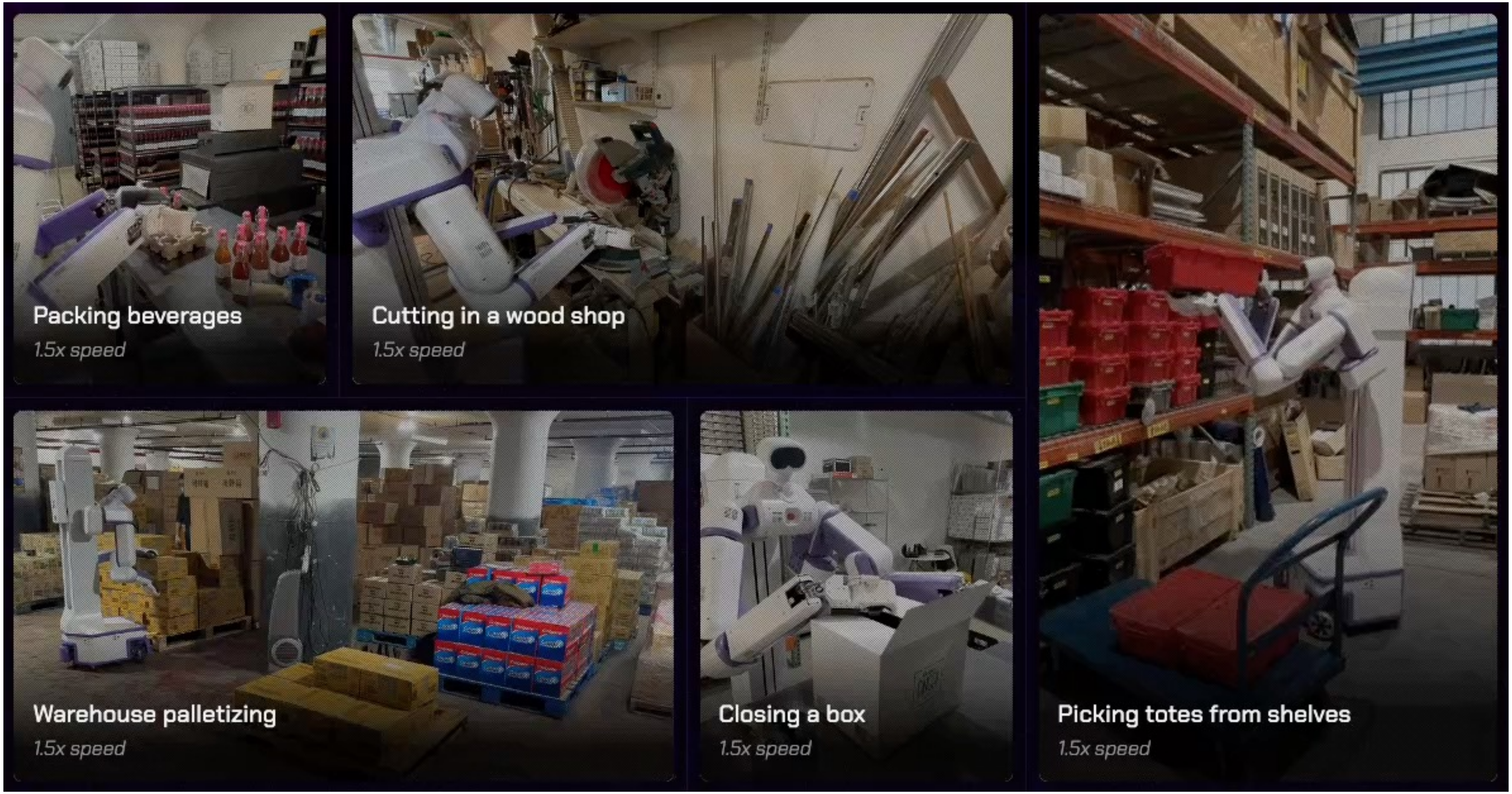
Designing a Partner for a Better World

Designing a Partner for a Better World

Engineering a Socially-Conscious Future

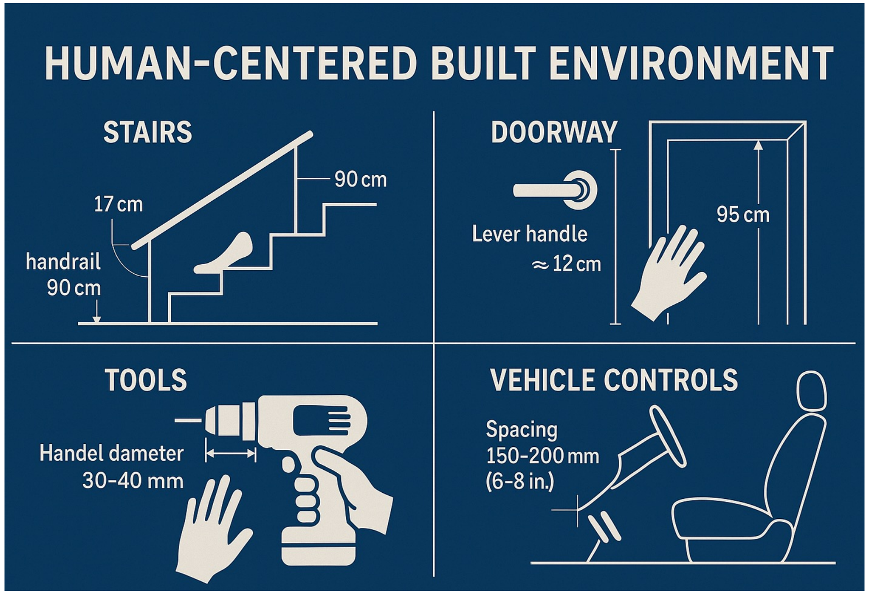
A Deliberate Design Choice, Not a Default

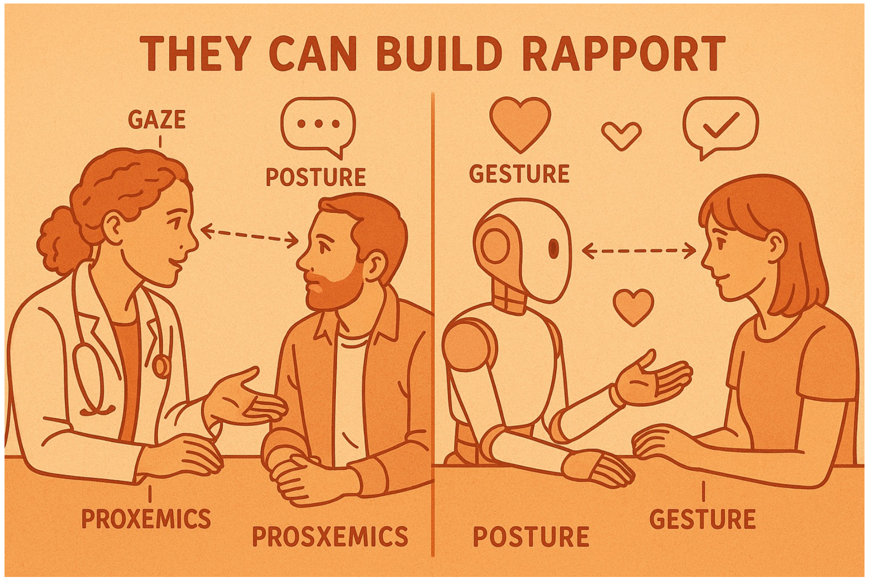
- We design humanoids not just to **mimic** us, but to **integrate** with us in a world built for us

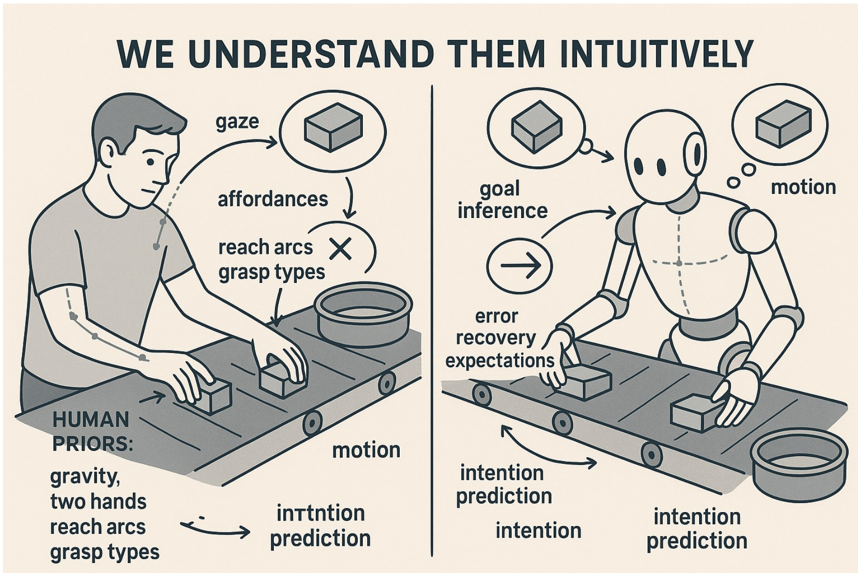


The 3 Pillars of the Humanoid Advantage

1. **Ergonomic Integration**
   (The Physical World)
2. **Cognitive Fluency**
   (The Mental World)
3. **Empathetic Connection**
   (The Social World)







1. Ergonomic Integration (The Physical World)

"They fit into our world."

Affordance.

- The environment affords a humanoid the same actions it affords a human.
- This eliminates the massive societal cost of retrofitting the world for robots.

2. Cognitive Fluency (The Mental World)

"We understand them intuitively."

Theory of Mind.

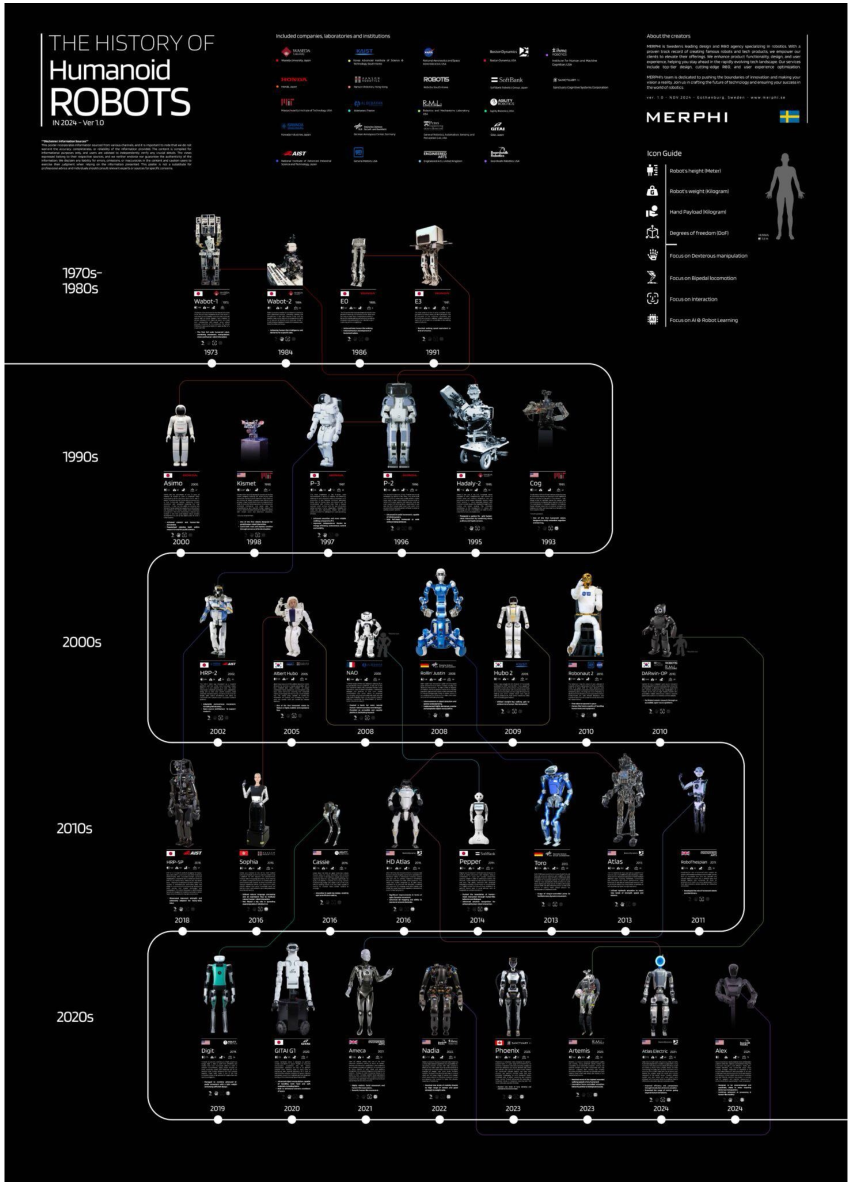
- We can more easily attribute intent to a humanoid's actions (e.g., "it's reaching for the cup"), which is the foundation of trust and collaboration.

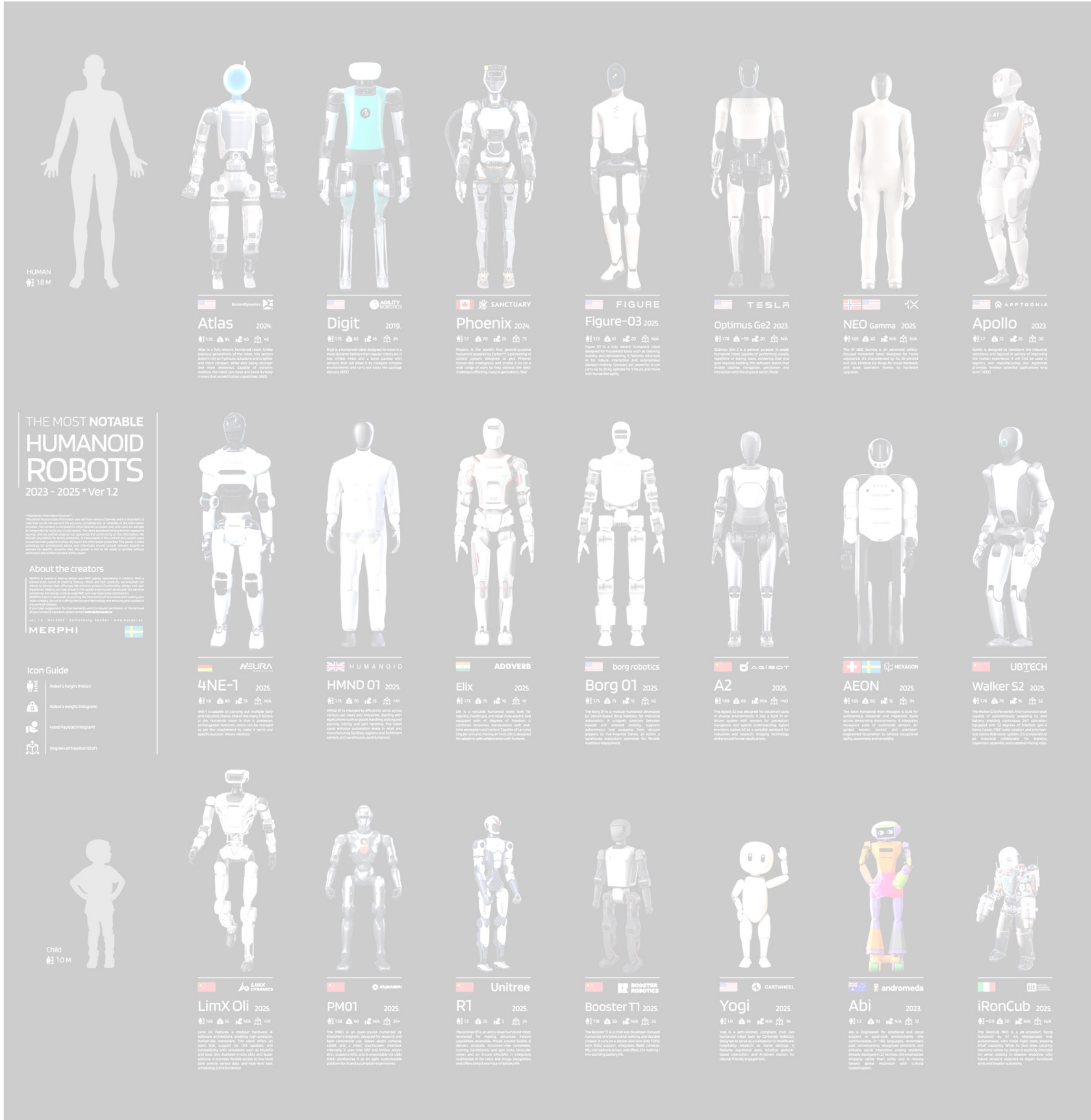
3. Empathetic Connection (The Social World)

“*They can build rapport*.”

- A human-like form can leverage gaze, posture, and gesture to communicate non-verbally.
- This is critical for applications requiring social acceptance.

A Brief History of Humanoid Robots

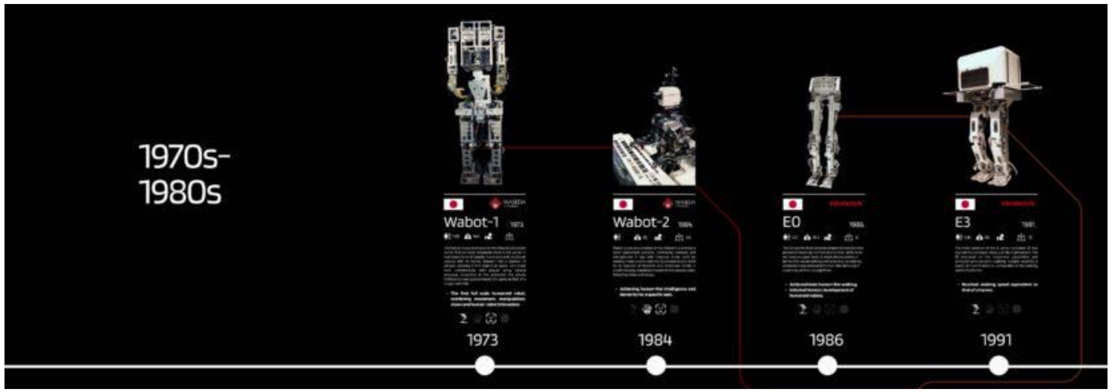


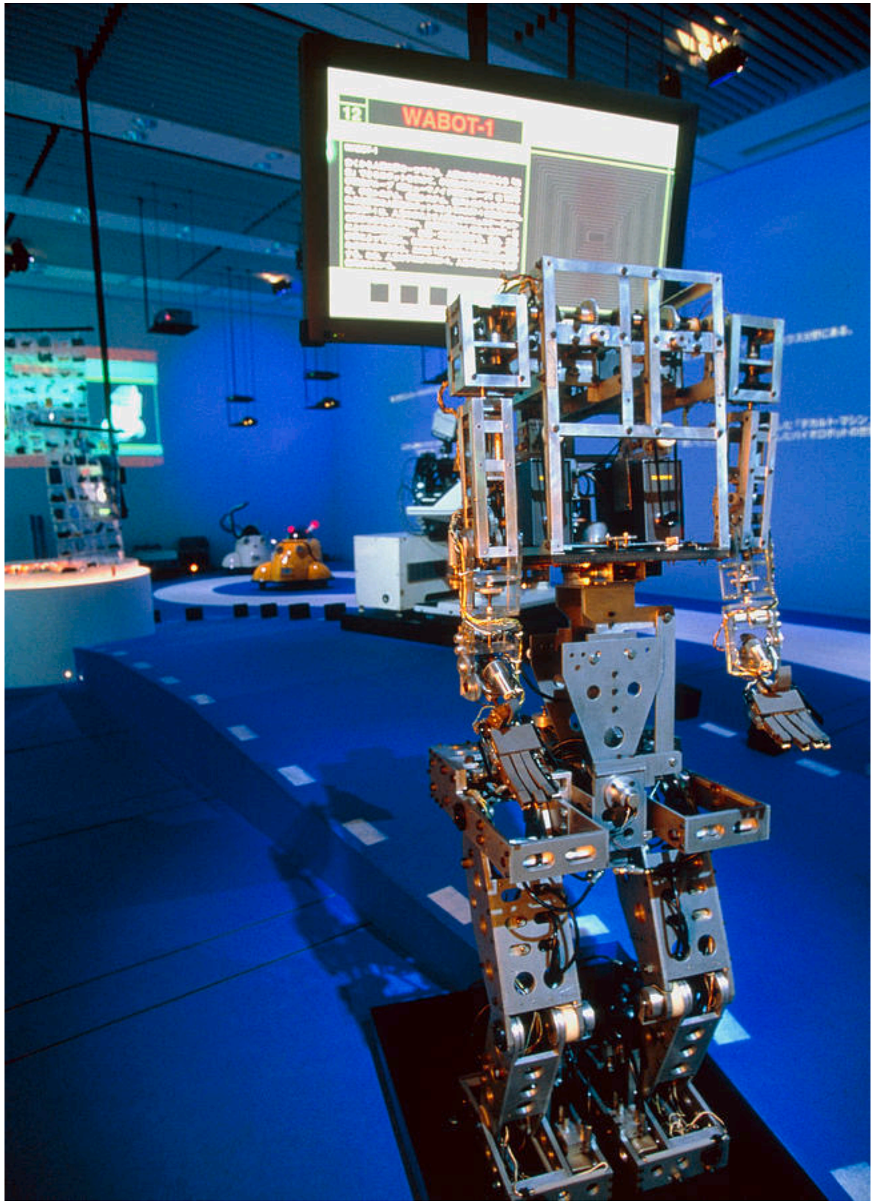


Milestones in Human-Robot Partnership

- *The Integrated Dream*

- **1973 - WABOT-1**:
  - *First* to combine locomotion, vision, and manipulation.
  - The goal was a human "*partner*."

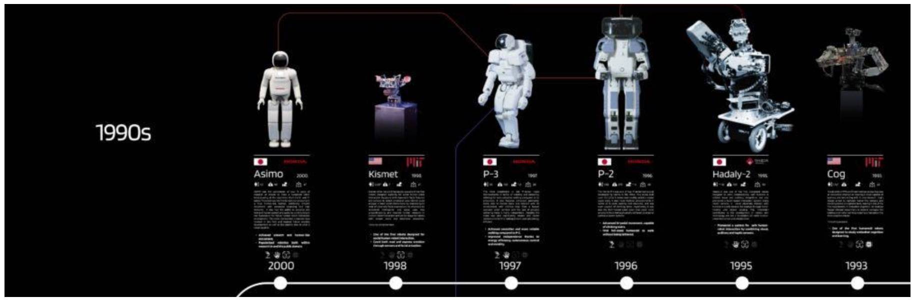




Milestones in Human-Robot Partnership

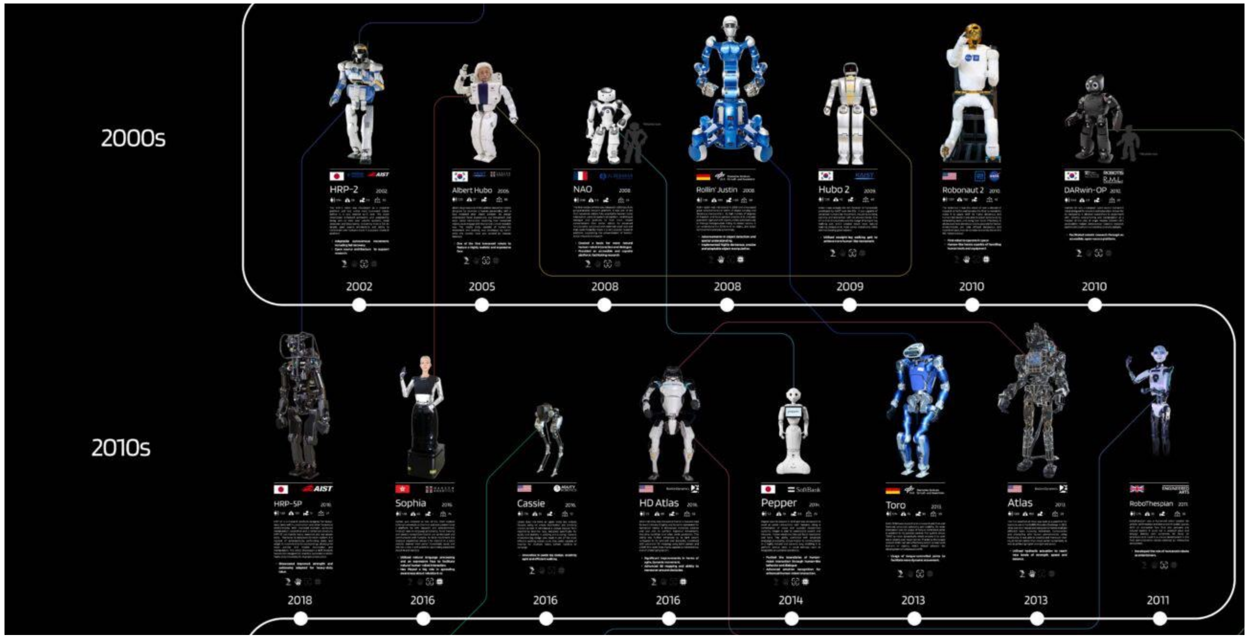
- *The Social Ambassador*

- **2000 - Honda's ASIMO**:
  - Designed to be *friendly* and *approachable*.
  - Its smooth walk made the idea of robots in society feel real and non-threatening.



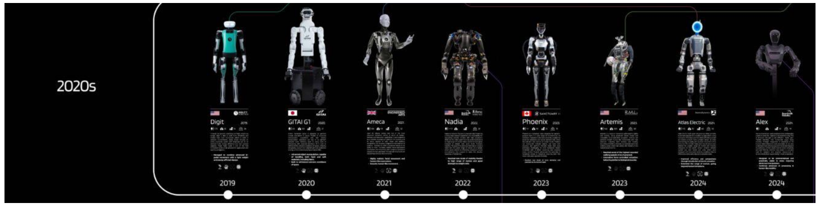
Milestones in Human-Robot Partnership

- *The First Responder*
- **2015 - DARPA Robotics Challenge**
  - *A major pivot.*
  - The challenge forced teams to design robots for a direct social good: *disaster relief*.
  - This tested robustness and utility over polish.

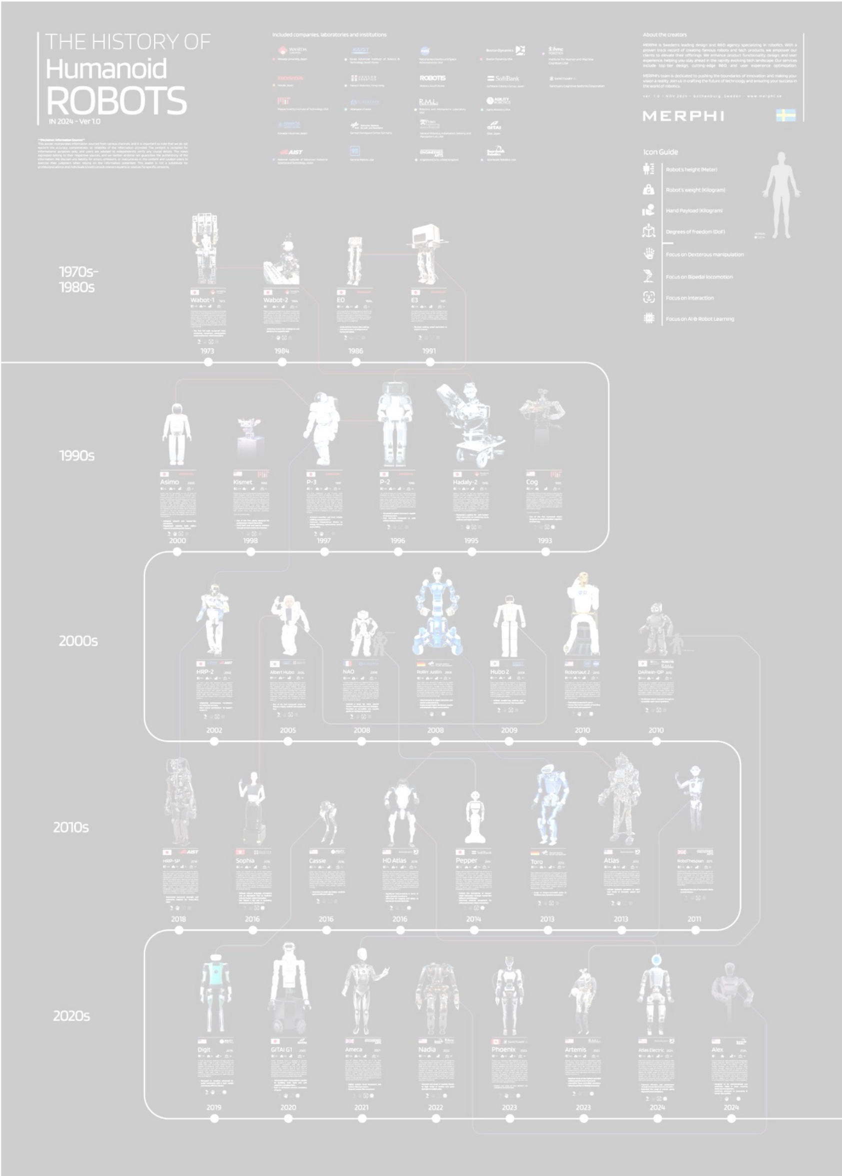


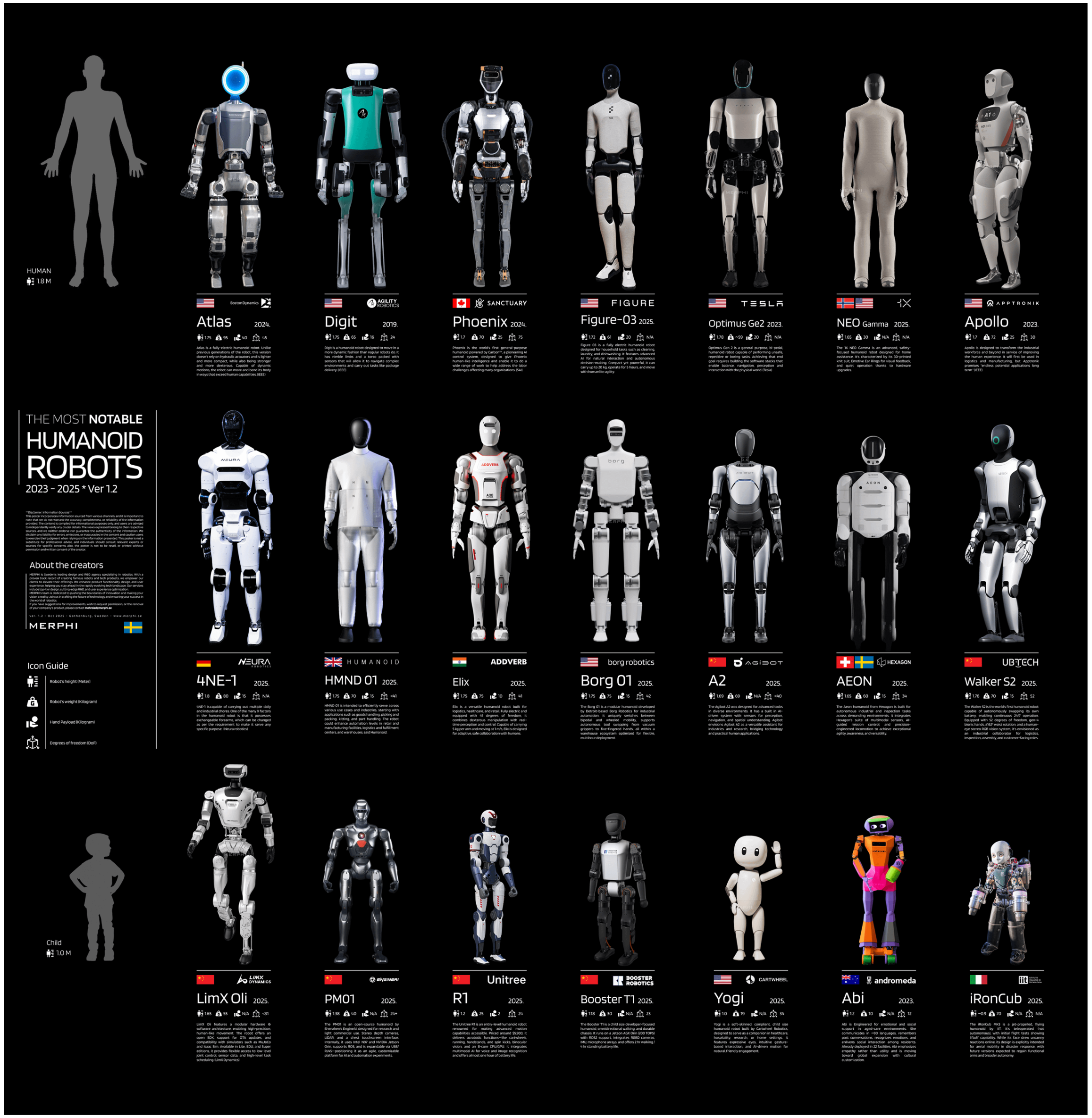
Milestones in Human-Robot Partnership

- **Today - The Commercialization Era**:
  - focusing on labor and assistance
  - bringing the concept from lab to life



Recent Humanoids





The “How”
Design & Engineering for Human Environments

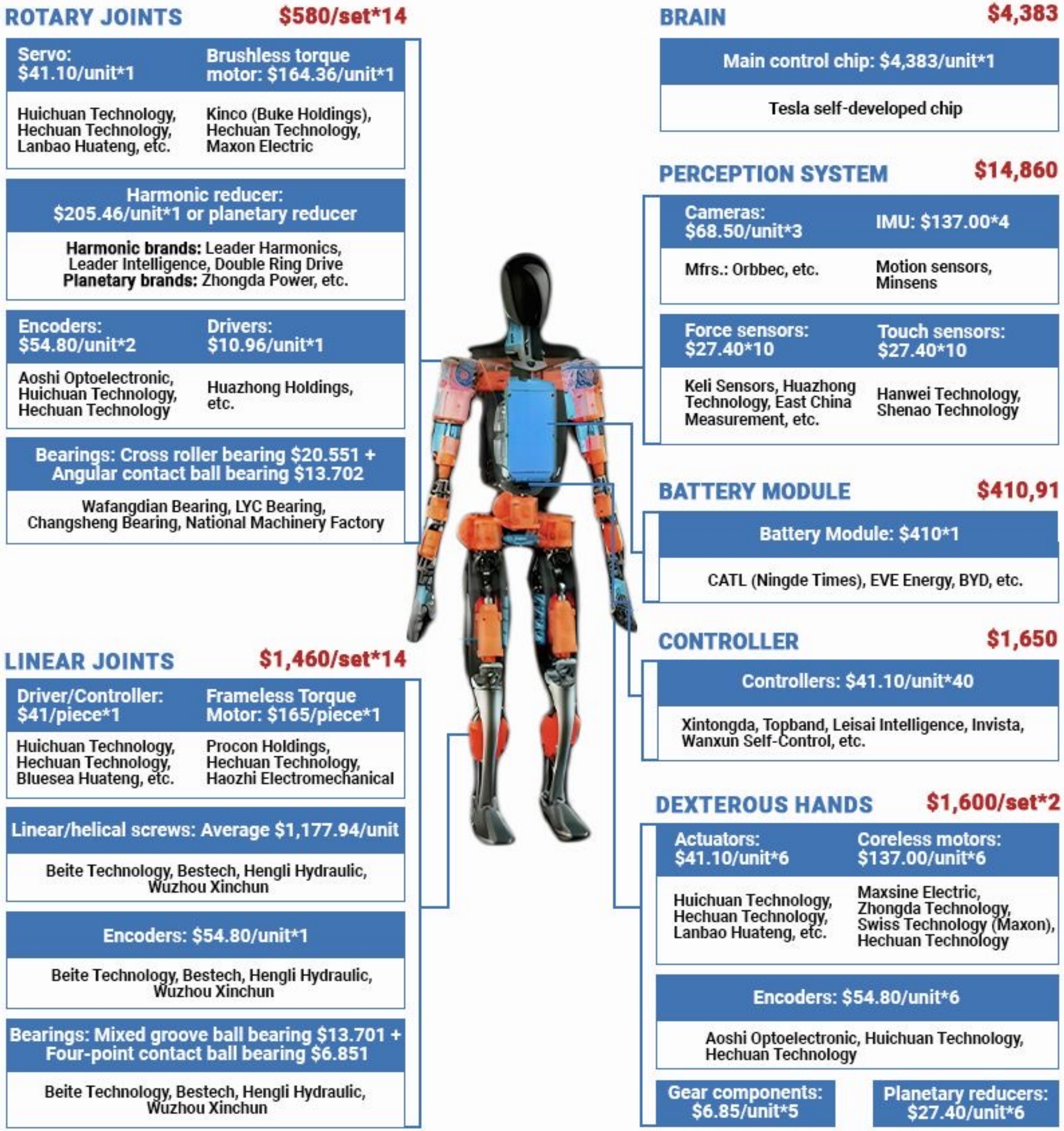
Core Engineering

A Complex System-of-Systems

We examine Tesla's Optimus humanoid robot as a case study for component integration and value distribution.

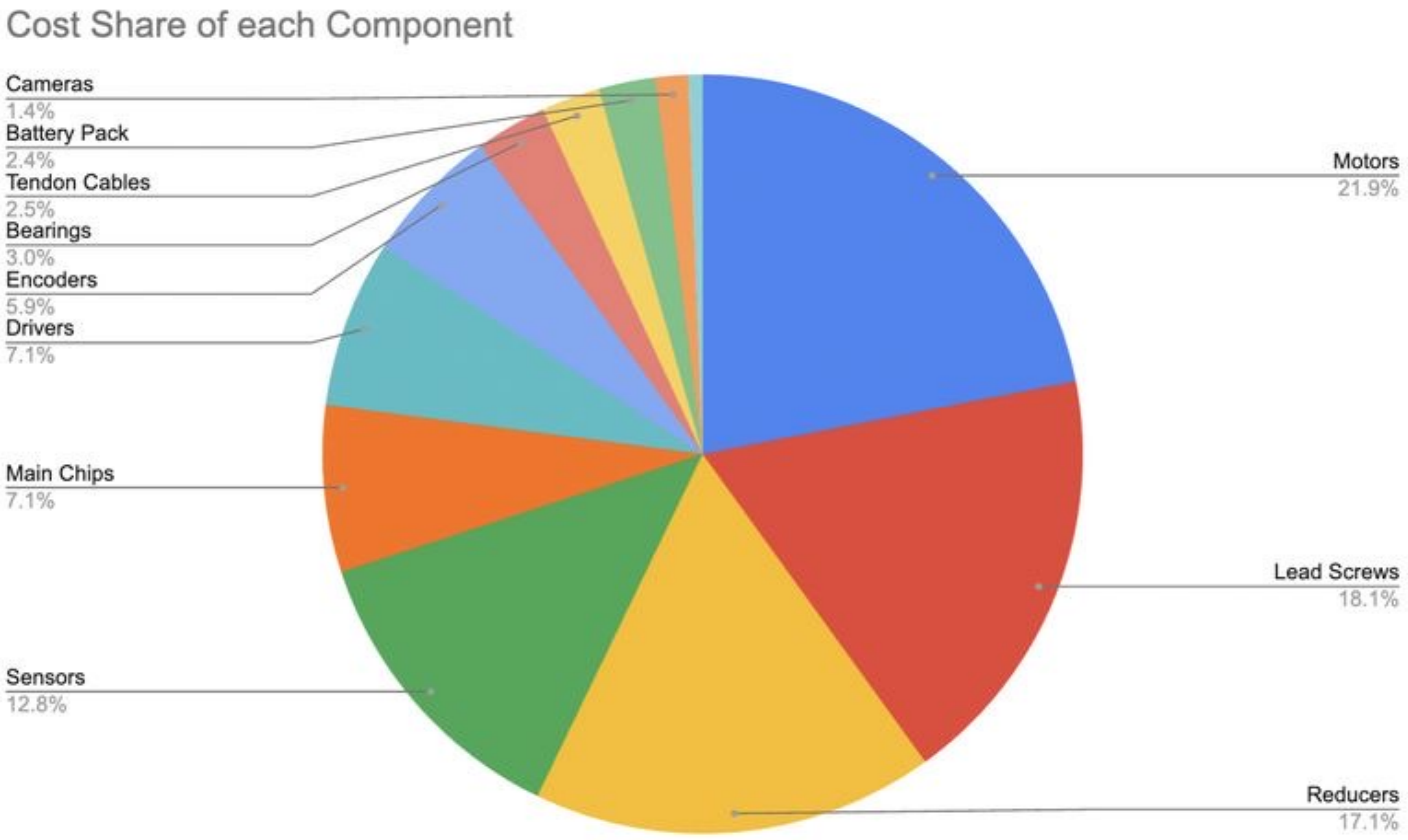
From a technical barrier perspective, the components rank in descending order of complexity:

- planetary roller screws >
- six-dimensional torque sensors >
- harmonic reducers >
- hollow cup motors >
- frameless torque motors.



Anatomy of a Social Humanoid

The following analysis breaks down the value allocation of major components based on an estimated $20,000 production cost target.

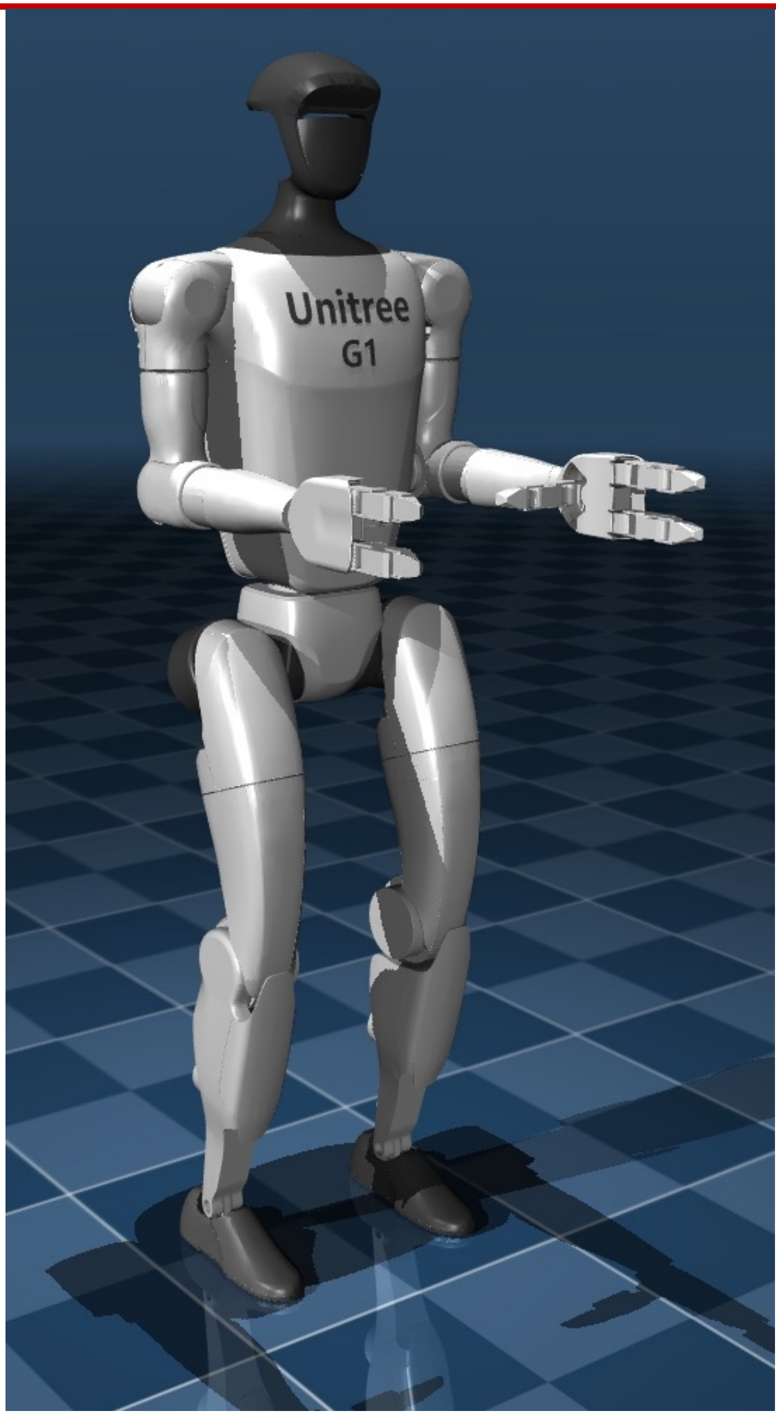


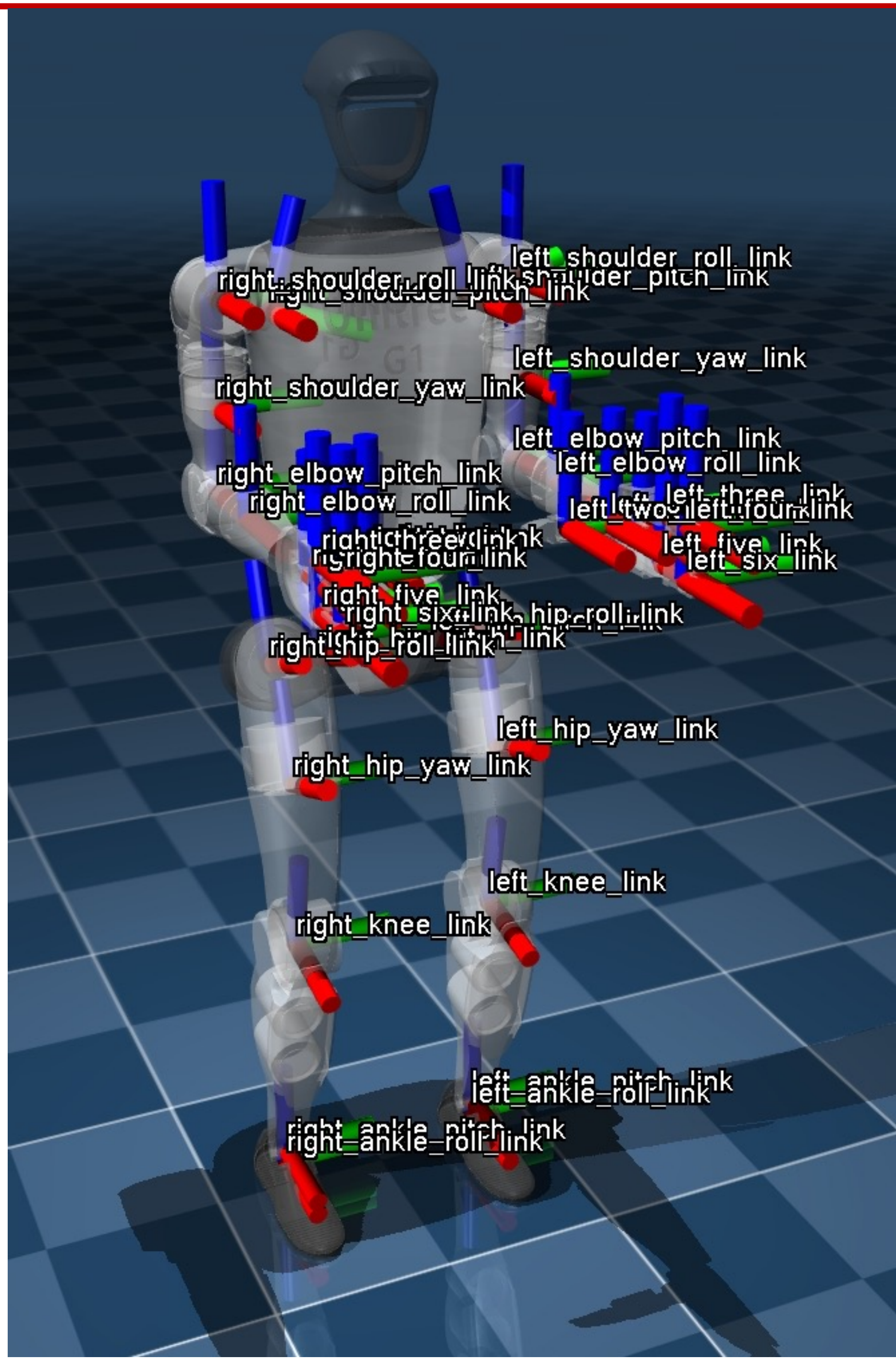
A Complex System-of-Systems

- **Structure**:
  - The strength-to-weight ratio.
  - *Every gram you add to the foot has to be accelerated and carried by the knee, the hip, the torso... it's a cascading penalty.*
  - Materials: 6061/7075 Aluminum, Carbon Fiber Composites.

- **Actuation**:
  - Motors + Gearing (The "Muscles").
  - High-torque brushless DC motors and zero-backlash gearboxes (Harmonic Drives).
  - This is where the robot gets its precision.

- **Sensing & Computation**:
  - The "Nervous System."
  - Proprioceptive (internal state: joint angles, IMU for balance)
  - Exteroceptive (external world: LiDAR, Cameras, Microphones)


Unitree
G1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left_knee_link
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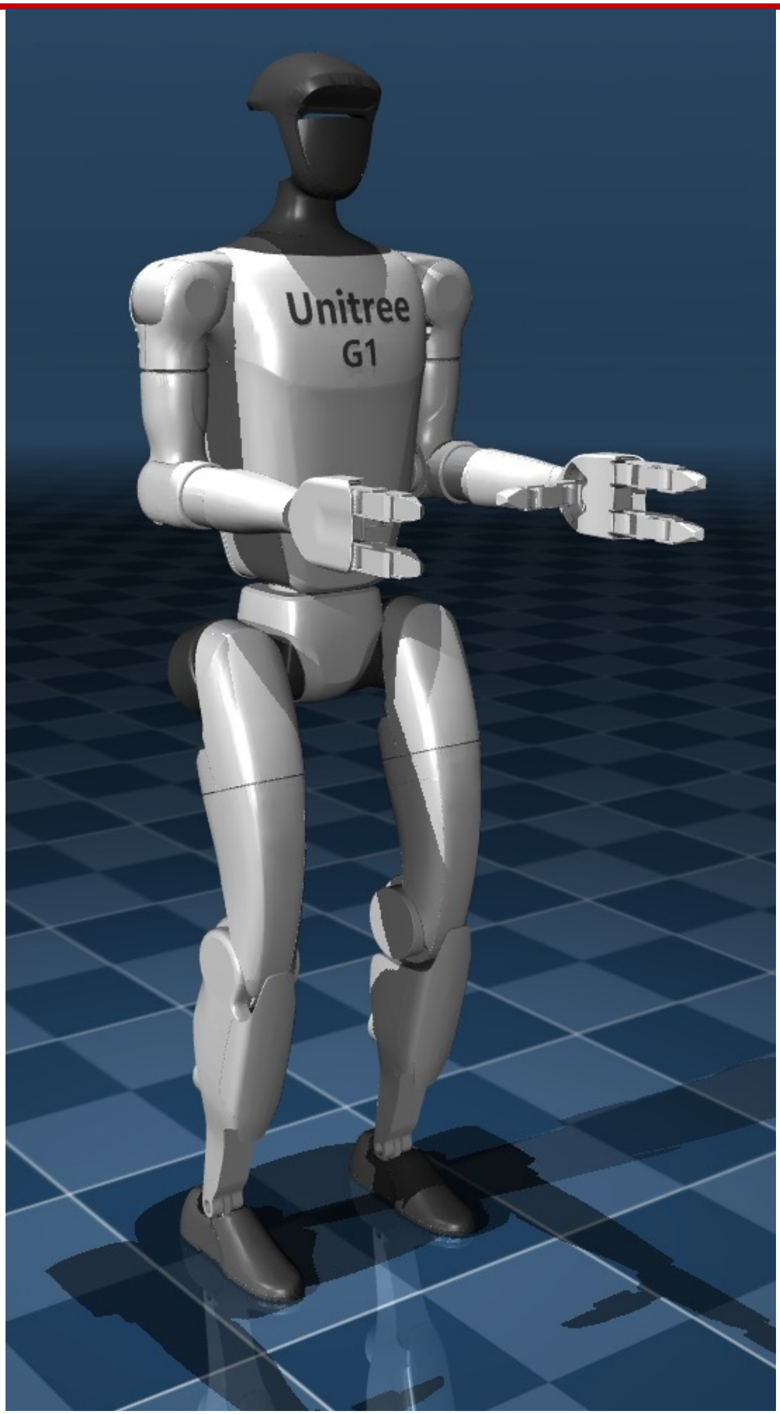
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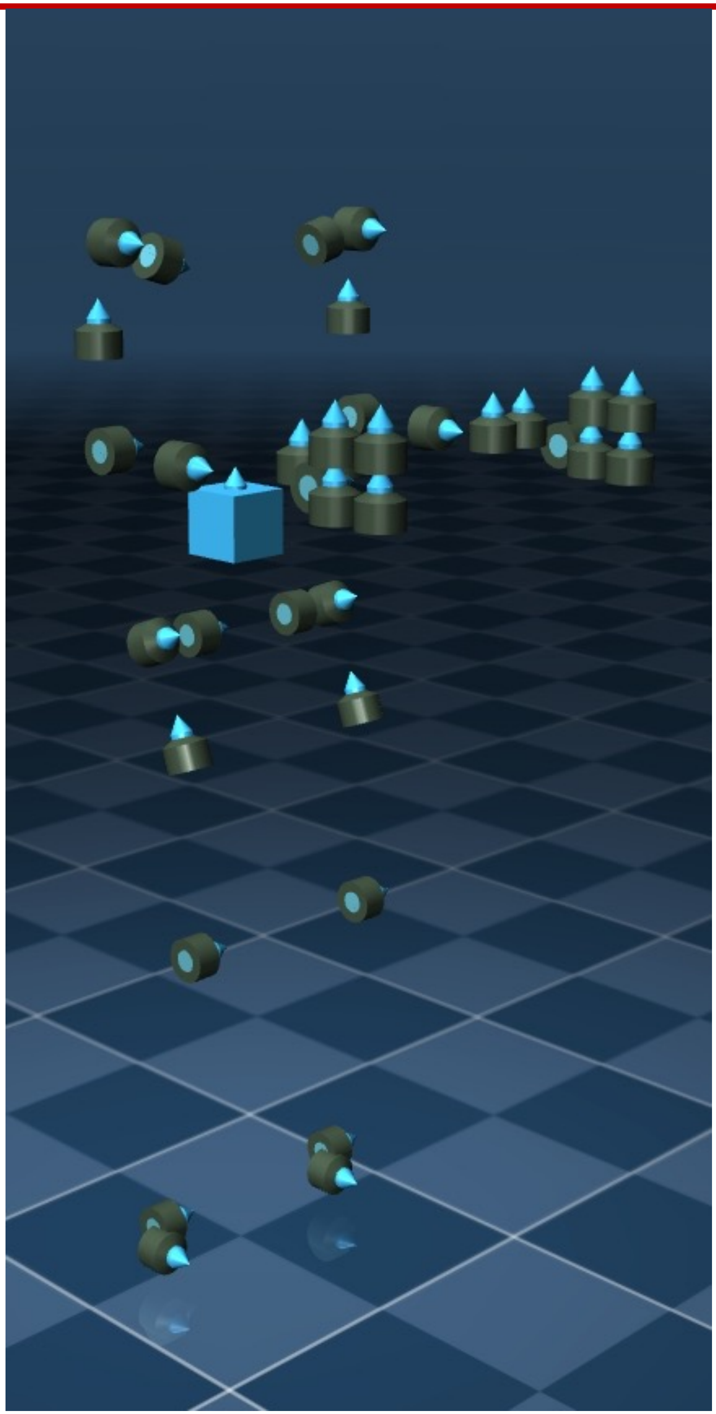

Translational / Rotational / Transformation

- Translational Operator

$${}^{A}P_2 = D_Q(q)\,{}^{A}P_1$$

$$\mathrm{Trans}(a,b,c) = \begin{pmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

- Rotational Operator

$${}^{A}P_2 = R_K(\theta)\,{}^{A}P_1$$

$$\mathrm{Rot}_x(\theta_x) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_x & -\sin\theta_x & 0 \\ 0 & \sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\mathrm{Rot}_y(\theta_y) = \begin{pmatrix} \cos\theta_y & 0 & \sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_y & 0 & \cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\mathrm{Rot}_z(\theta_z) = \begin{pmatrix} \cos\theta_z & -\sin\theta_z & 0 & 0 \\ \sin\theta_z & \cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

- Transformation Operator

$${}^{A}P_2 = T\,{}^{A}P_1.$$

The Art of Controlled Falling

- Modern humanoid integrates it with other cutting-edge methods to create more robust and adaptable balance systems:
- **Model Predictive Control (MPC):**
  - modern humanoids utilize MPC to predict the future state of the robot and plan optimal movement trajectories. This allows the robot to proactively adjust its joints and foot placements to maintain balance, even when faced with disturbances.
- **Reinforcement Learning (RL):**
  - Especially for humanoid robots, modern approach incorporates RL to create powerful motion policies. These policies can use a "reward function" during training to encourage the robot to keep its ZMP within the support polygon, resulting in a system that can traverse complex terrain and respond robustly to external pushes.
- **Whole-Body Control (WBC):**
  - modern humanoids use WBC to coordinate the movements of all their joints simultaneously to achieve a desired outcome while maintaining balance.
- **Proprioception and perception:**
  - Modern humanoids use onboard sensors like IMUs (Inertial Measurement Units), depth cameras, and LiDAR to get real-time feedback on their body state and environment. This allows them to react quickly to disturbances and anticipate changes in terrain.
- **Anti-Gravity mode:**
  - In some models, researchers have implemented an "Anti-Gravity mode" that combines these advanced control strategies to improve recovery and impact resistance. This allows the robot to absorb and counteract external forces, enabling it to recover from kicks and shoves with speed and agility.

The Hand: A Masterpiece of Engineering

The Hand: A Masterpiece of Engineering

Designing for Safe Interaction

- **Actuation is Key:**
  - If a robot arm is perfectly rigid, any programming error could be dangerous. How do we build in physical safety?
- **Sensing for a Gentle Touch:**
  - Force/Torque Sensors:
    - Placed in the wrist/joints to feel interaction forces.
  - Tactile Sensing:
    - "Skin" for the robot.
- **Soft Robotics**:
  - Compliant materials for the entire gripper, making them inherently safe.

The Future

On the Horizon

Foundation Models & AI:

- The AI revolution is giving robots a “brain.”
- We’re moving from programming specific tasks to giving general commands in natural language. (e.g., “Tidy up this room.”)

New Materials & Actuators:

- Mention artificial muscles and advancements in soft robotics that will make robots more energy-efficient, resilient, and safer.

Shared Autonomy:

- The future isn’t full autonomy.
- It’s a flexible partnership where the robot does 90% of the work but knows when to stop and ask its human partner for help.

Designing a humanoid robot is one of the
ultimate challenges
in systems engineering.

But *designing one for social good* is
a challenge of
humanity, empathy, and responsibility.

Thank you~

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Tutorial

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