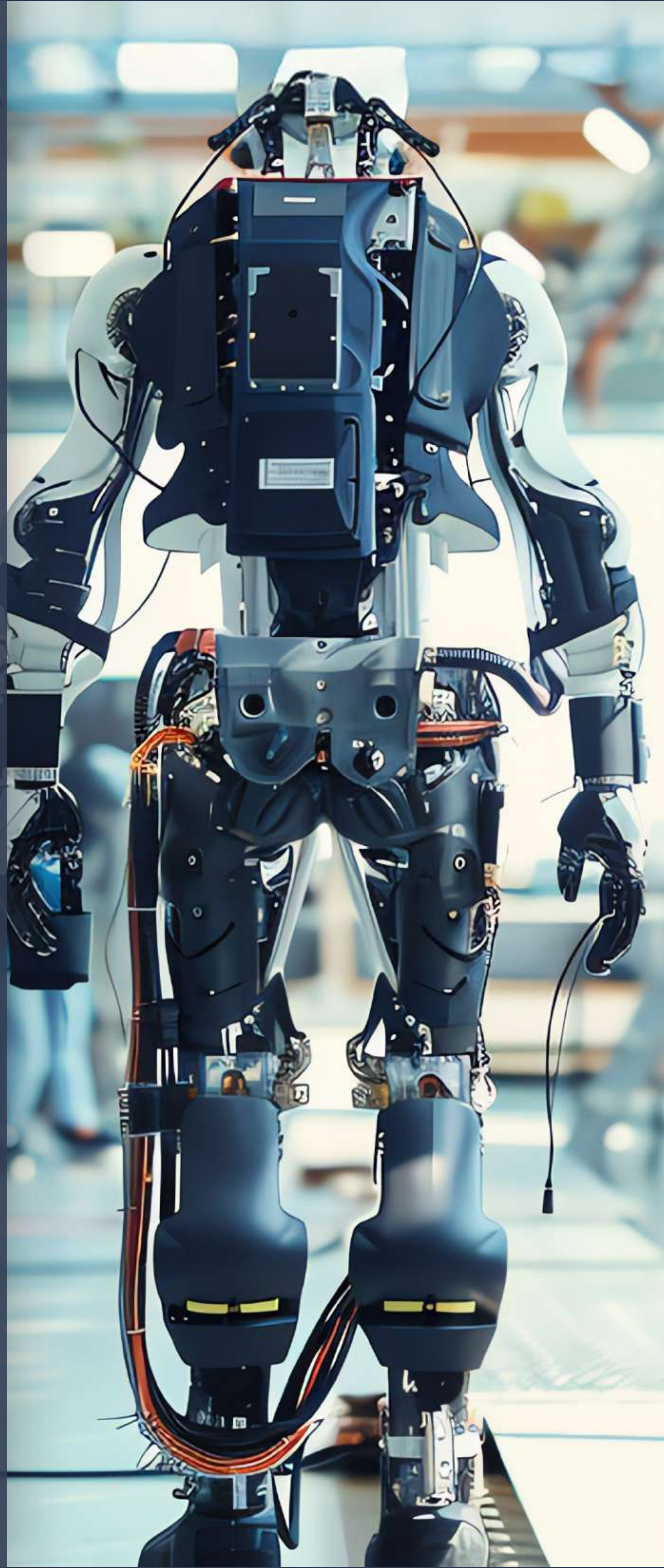
PLUG AND PLAY

Humanoid Robotics

2025 Report Teaser



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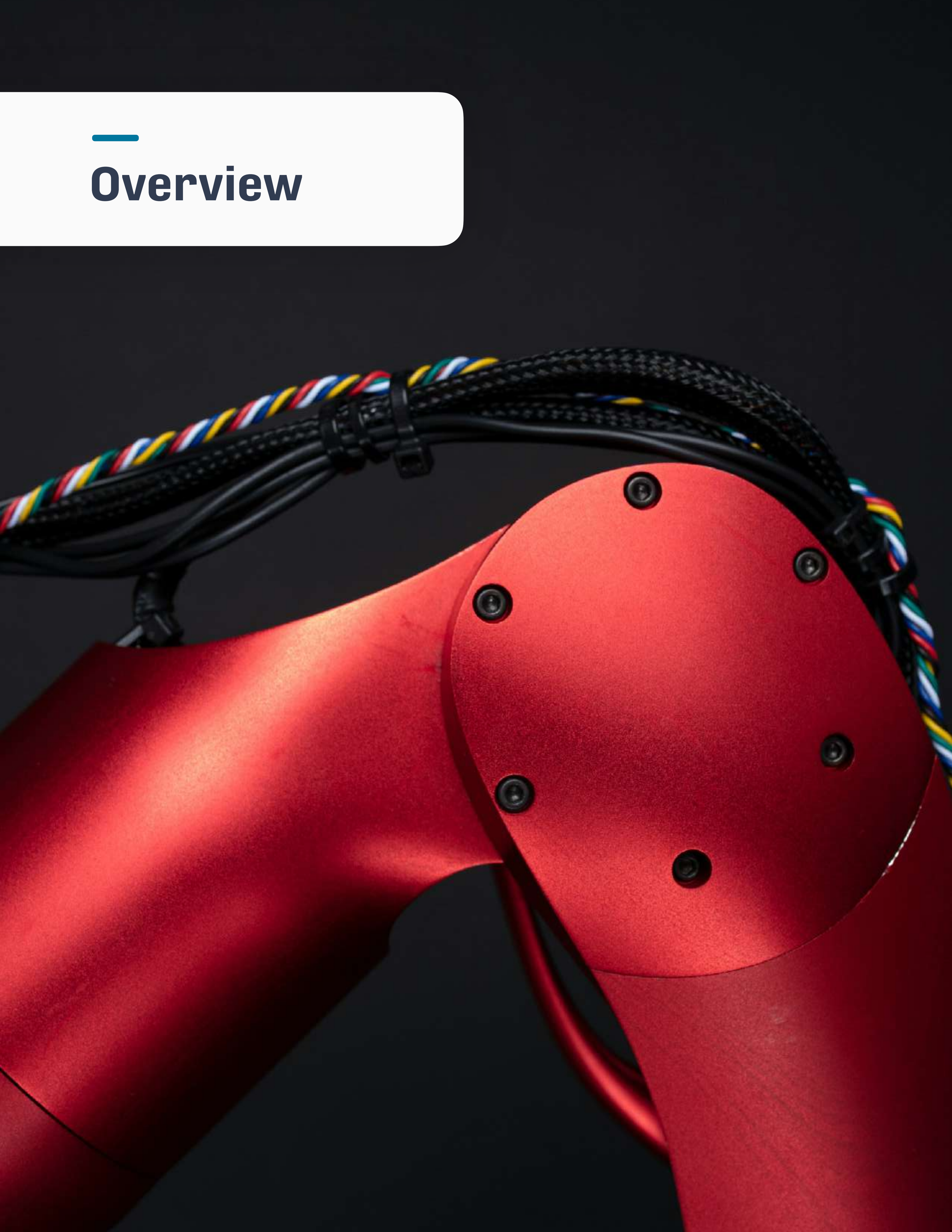
Executive Summary

PLUG AND PLAY SUPPLY CHAIN

	Americas	Europe	Asia
Startup Market	**Approaching Maturity** Defined industry leaders	**Early-Stage Market** Limited deployments with few key players	**Emerging Market** Few industry leaders with rising players
Funding	**Top Heavy & Growing** Leaders funded, smaller ones gaining traction	**Early Funding** Few funded players, limited but growing	**State Influenced & Emerging** Strong government backing, rising activity
Software Capabilities	**Industry Leader** At the forefront of software developments	**Research Driven** Progress is academic and lab focused	**Application & Data Driven** Emphasizes rapid deployments
Hardware Capabilities	**Innovation Driven** Pushing actuator and sensor advancements	**Research Oriented** Focused on academic engineering	**Scale & Cost Focused** Rapid, cost efficient iteration and production
Deployments	**Partnership & Pilot Led** Extensive corporate pilots before scaling	**Limited Commercialization** Research focused pilots, few deployments	**Rapid Horizontal Deployments** Broad rollouts, growing commercialization

Table of Contents

Overview



Introduction

PLUG AND PLAY SUPPLY CHAIN

In recent years, the excitement surrounding humanoid robots has reached new heights. From Wall-E-sized robots that can clean up after us to a T800 Arnold Schwarzenegger that can kick down my door muttering "Hasta La Vista," science fiction has long fueled the belief that robots will one day walk among us. The excitement has captured the imagination of investors, technologists, and the public alike, leading to investments of over $1.5 billion in 2024 to bring these ideas closer to reality.

This report is the result of extensive interviews with founders of major startups, robotics experts from top universities, and industry leaders who have piloted the technology. It combines extensive research from academic papers and market analytics.

The Plug and Play 2025 Humanoid Report builds on the 2024 edition and incorporates new insights from our team in China, adding coverage of Chinese humanoid startups. It highlights current achievements, explores potential developments, and examines the hurdles to broader adoption, offering a nuanced perspective on the evolving technological landscape.

Humanoid Categories

Full Humanoid

The full humanoid form factor refers to robots designed to replicate the human body and its capabilities. In general, they have:

- Two arms
- Torso
- Two legs
- End Manipulators


Semi-Humanoid

Semi-humanoid robots offer capabilities comparable to full humanoids, typically featuring a humanoid upper body mounted on an autonomous mobile robot (AMR) base. In general, semi-humanoids include:

- Torso
- Two arms
- Wheelbase
- End Manipulators


Humanoid-Like

A humanoid-like form factor refers to a robot that resembles the human form in appearance but lacks human-like capabilities. These robots are typically built for specific, limited tasks — such as acting as a registration assistant — rather than serving broader functional purposes.

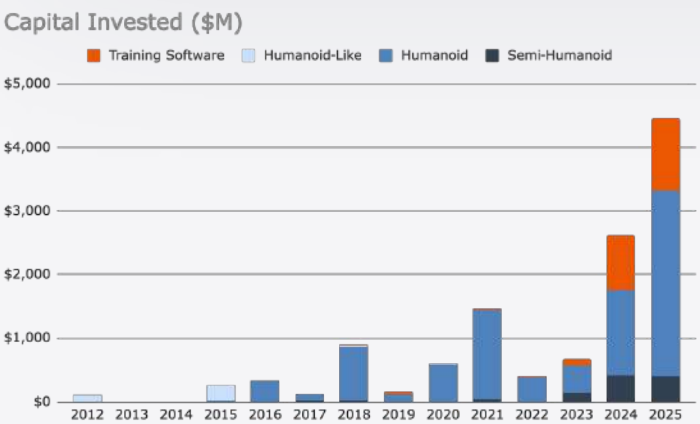

Funding

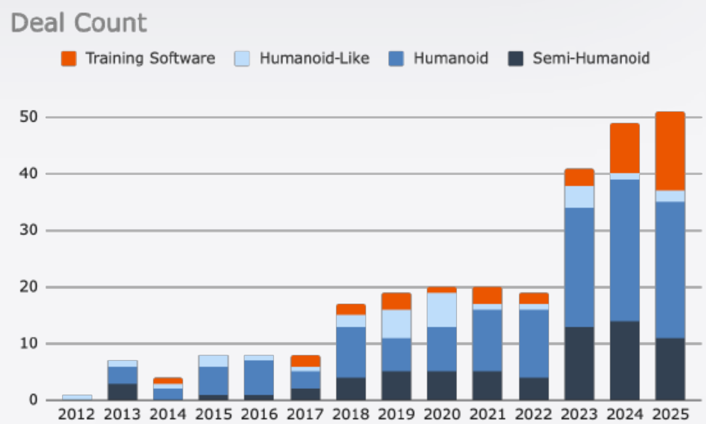
Below is the total funding of over 85 startups and companies within the humanoid and robotic AI sectors, broken down by category.

Aside from the 2021 acquisition of Boston Dynamics for $880M, funding in the humanoid and robotic AI space had been relatively modest until the last two years.

In 2024, however, we've seen significant funding rounds, including 1X and Cobot raising $100M each, and Figure AI securing $675M for hardware. On the software side, Physical Intelligence and Skild AI raised $400M and $300M, respectively.

While funding in 2024 had taken off, it has exploded even further this year. Landmark rounds include Field AI raising over $400M, Genesis AI securing $105M, Figure AI closing a massive $1.5B round, Apptronik raising $350M, and Agility Robotics raising over $100M. With momentum still building, who knows where funding levels will be by year's end?.

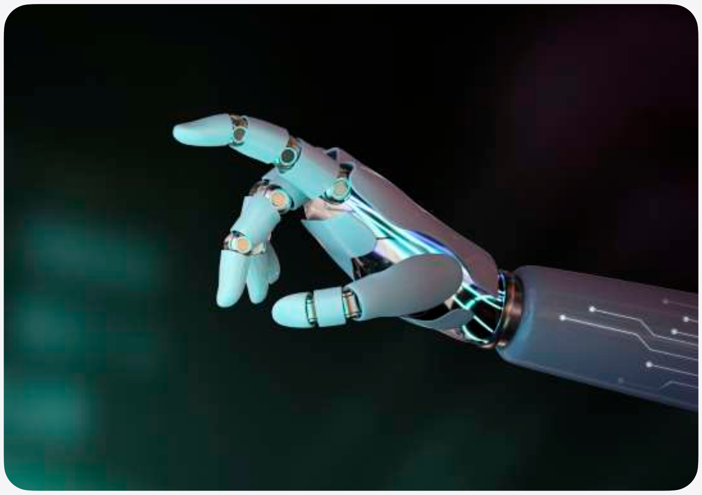




Capabilities & Challenges

Software Capabilities & Challenges

In humanoid robotics, the software stack can be broken down into four main categories: perception, reasoning, locomotion, and manipulation. Each of these components play a crucial role in enabling robots to interact with and navigate their environments, making them more adaptable and capable of performing complex tasks. In this section, we will explore these components, as well as the differences between traditional and modern artificial intelligence, highlighting advancements in AI and how they have influenced the development of humanoid robots.



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Category 1: Perception

Perception for humanoid robotics is the ability to identify and locate objects and obstacles in its surroundings. This capability is broken down into two key aspects: "what" and "where."

Capability 1: What is the Object?

Perception for humanoid robotics involves identifying objects and obstacles in the robot's environment. Object detection, particularly through vision, has largely been solved, allowing humanoid robots to detect and label objects they have been trained to recognize. While the technology still requires some time for learning new objects, it is expected to become less of a concern for humanoid startups in the near future as AI models continue to improve.

Capability 2: Where is the Object?

Determining the location of objects in relation to the robot, however, is still a challenge. While vision sensors can identify objects, they do not fully assess their position in 3D space relative to the robot. To address this, humanoid startups are utilizing sensor fusion techniques, which combine vision sensors with 3D LiDAR and other sensors to detect objects in three-dimensional space (e.g., determining the position of a cup in relation to the robot). Although this technology is not yet perfect, it is expected to be solved within the next five years. The complexity arises from the fact that humanoid robots have more degrees of freedom (DoF) than autonomous vehicles — while self-driving cars have 2 DoF, humanoid robots can have over 30, adding significant complexity to the task. While the basic principles of sensor fusion are similar to those used in autonomous cars (e.g., Waymo), scaling the technology for humanoid robots will take time due to their added complexity.

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Software Capabilities & Challenges *(cont.)*

Category 2: Reasoning & Planning

Reasoning and planning in humanoid robots refer to its ability to understand commands and determine the appropriate actions in response. Robots can now grasp high-level tasks and autonomously figure out how to execute them. With the advent of Large Language Models (LLMs), there has been a significant leap in cognitive reasoning and planning for robotics. While reasoning for specific tasks, such as "pick up and move," is relatively simple, humanoid robots are increasingly capable of generating their own reasoning for tasks. However, this ability remains use case-dependent and tends to be more effective for pre-trained, specific tasks.

Path planning and collision avoidance are well-established in humanoid robots. For advanced reasoning, such as human interaction or speech processing, these capabilities are improving, but are not critical for making humanoid robots commercially viable. Robots can still be programmed to complete tasks or follow instructions without advanced reasoning, and existing control systems are effective. Reasoning capabilities are likely to evolve faster than perception systems.

Category 3: Locomotion

Locomotion software controls the lower half of a humanoid robot (bipedal), managing movements such as standing, walking, running, and crouching.

Training

To achieve locomotion in humanoid robots, training simulations are often used to replicate diverse environments. Tools like NVIDIA's Omniverse allow for the randomization of environments, including various floor types, stairs, and more, generating large amounts of data to train the robot for different settings.

Transitioning to real-world deployment still requires fine-tuning, despite significant progress and promising results in simulations. Reducing the sim-to-real gap requires precise modeling of the robot's capabilities. Once model adjustments are made, however, robots are able to perform effectively in real-world scenarios.

Category 4: Manipulation

Manipulation is one of the largest challenges in humanoid robotics, primarily due to the vast diversity of tasks and environments. Unlike locomotion, where the goal is to control a robot's ability to stand and move, manipulation involves a wide range of actions, such as grabbing objects, pouring water into a cup, or opening a box.

Reasoning for manipulation is significantly less advanced than reasoning for planning. While the outcome for manipulation tasks is often clear — like grabbing an object — the complexity lies in determining where and how to grip objects. For instance, without specific training, a robot struggles to know where to grab a cup or how to hold it, as autogripping remains an unsolved challenge. Additionally, the vast number of objects that need to be modeled and the extensive effort required to create accurate and precise models increase the difficulty. 'Fine' manipulation remains unsolved, with many humanoid robotics startups and companies working towards this goal.

Software Capabilities & Challenges *(cont.)*

Manipulation (cont.)

Training

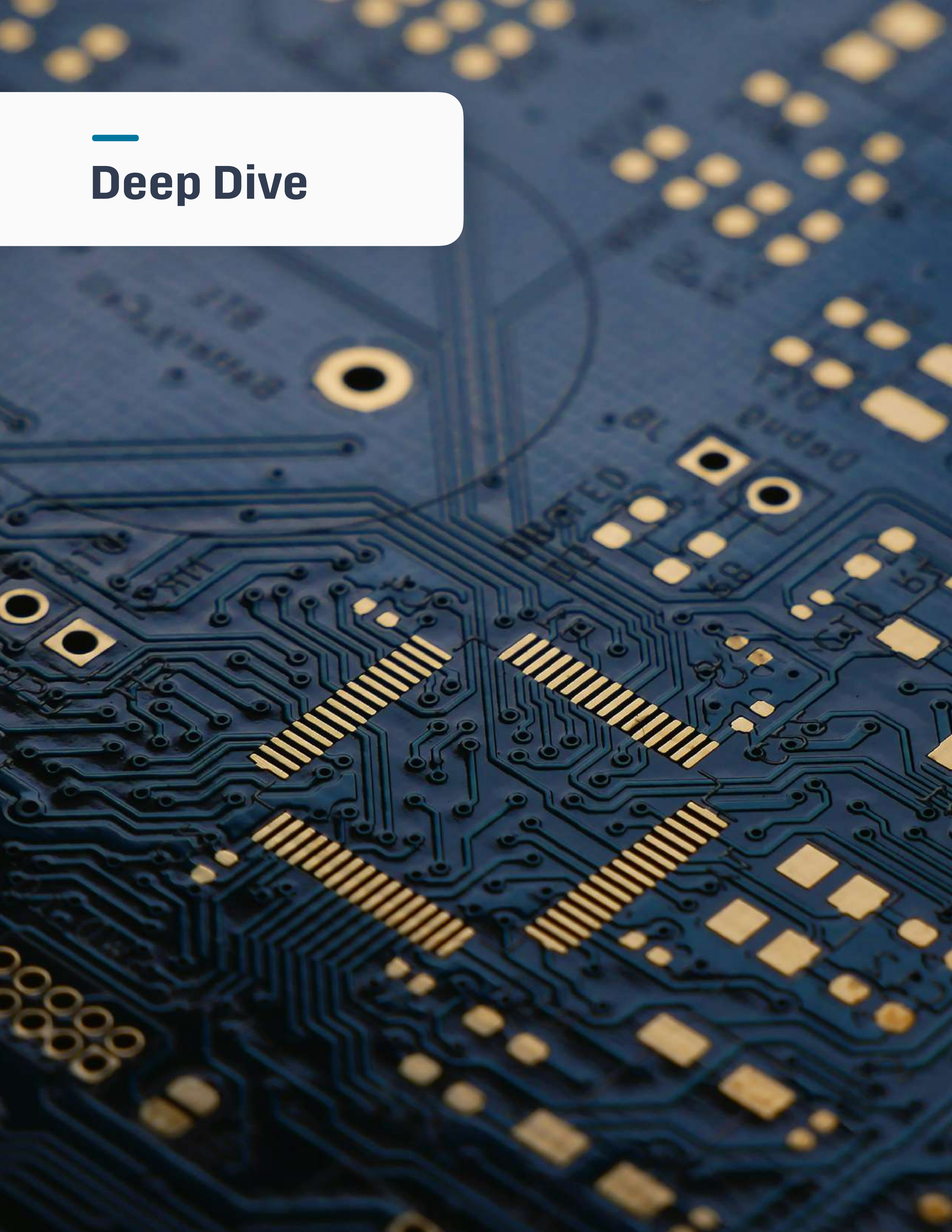
Currently, humanoid robots lack significant data for fine manipulation. Unlike autonomous vehicles, which have years of driving data available, humanoid robots have little to no specialized data to draw from.

There are two primary approaches to training AI in robotics: data-driven and model-driven approaches.

Approach 1: Data-Driven Approach

The data-driven approach focuses on learning from vast amounts of data. AI models are created to analyze and learn from this data to make predictions, recommendations, or decisions. With a data-driven approach, it requires exponentially more data to achieve desired capabilities for humanoid robots. It is still unknown if data-driven models, such as those used in large language models (LLMs), can generate both accurate and precise outcomes at scale, which is required for tasks in the real world. For example, while LLMs like ChatGPT excel in generating creative content, they can't consistently deliver precise answers. Precision is paramount in the real world, and a pure data-driven approach does not currently achieve the required precision.

At present, most humanoid robotics companies are taking the data-driven approach when building models for their humanoid robots and exploring how to collect sufficient data, often relying on teleoperated robots for training. As the use case set grows, a data-driven approach will continue to require more data and deployments of teleoperated robots to gather the necessary information. Data is critical for humanoid startups, and many are working to build a "data flywheel" to help scale their operations: cheaper robots lead to more robots deployed, which in turn generates more data, enabling better models



Deep Dive

Overview & Comparison

Software Comparison | USA/Europe vs. China

When comparing humanoid robotics software capabilities across the USA/Europe, and China, the difference lies not just in technological maturity, but also in strategic focus. USA and European companies tend to lead in model-centric, general-purpose robotics.

Interview Perspectives

Interview Insights

Buyer Perspective

The buyer perspective is based on insights gathered from interviews with major corporations that have either piloted humanoid robots or have a deep understanding of the humanoid robotics landscape.

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