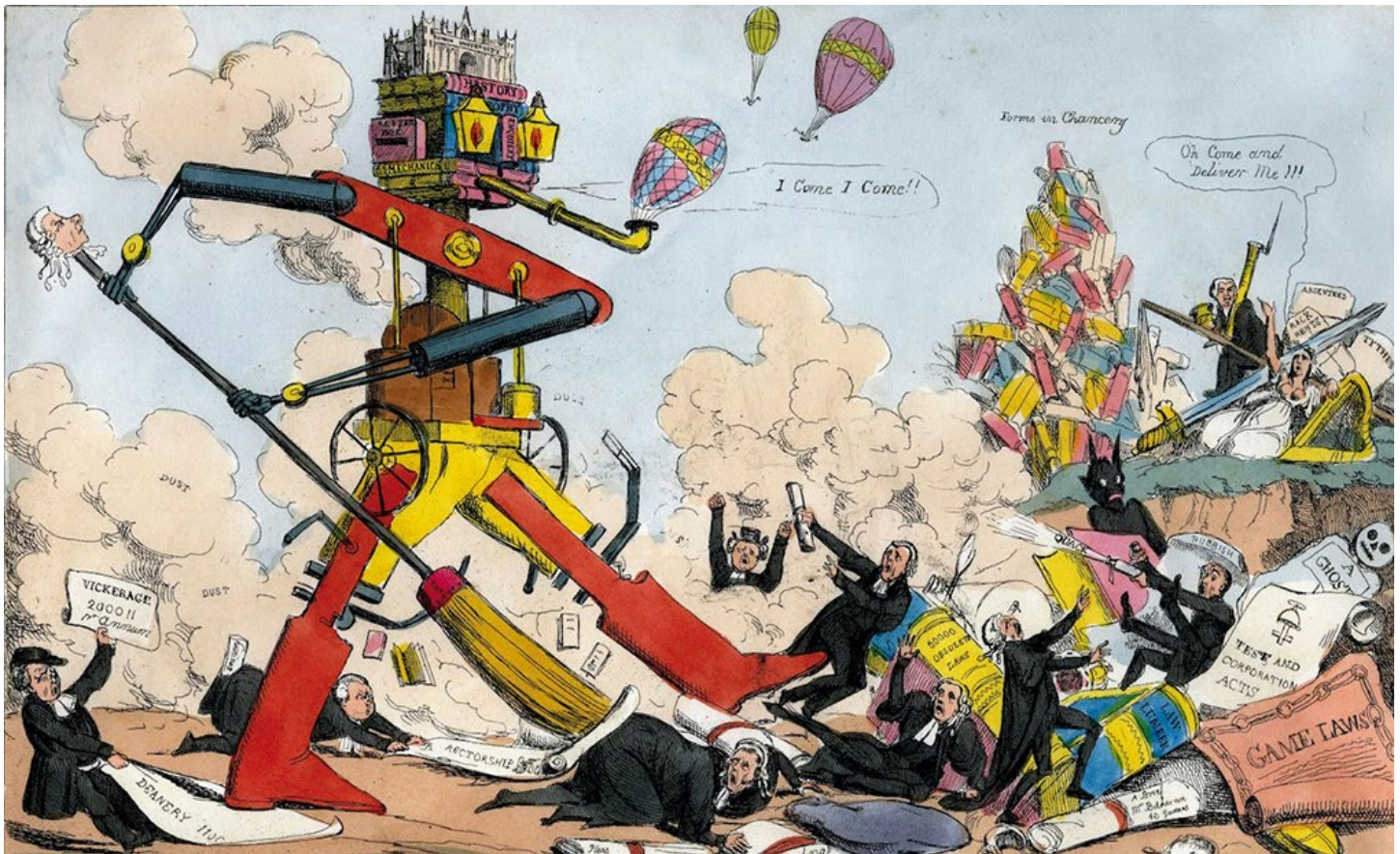


Rise of the Machines (For Real This Time)

Companies have tried to build and sell humanoid robots for decades but are now figuring out how to do it profitably

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Key Takeaways

- Tesla, Xiaomi, Unitree, and scores of competitors are racing to perfect and sell humanoid robots
- The goal is to get the price low enough to make them reasonably affordable, around US\$20,000
- With robots, parts suppliers such as Sanhua Intelligent Controls and Harmonic Drive are finding new uses for existing products, helping drive down costs

The 1939 World's Fair in New York introduced futuristic, fantastic products and ideas to the millions who attended, including televisions, air conditioning, nylon stockings, and color film for cameras. IBM showed off an "electric calculator," the forerunner of today's computers. General Motors sponsored an exhibit called "Futurama" that predicted a vast interstate highway system connecting modern cities and sprawling suburbs.

But the phone company Westinghouse presented the most futuristic and fantastic exhibit: a seven-foot-tall metal machine with a head, arms, and legs that walked, talked, told corny jokes, and even smoked cigarettes. They called it "Elektro the Moto-Man." It was rudimentary and nowhere near ready for mass production, but it was an actual, operational, working robot.

In the 85 years since the fair, most of those gee-whiz technologies that consumers first encountered there have become commonplace. Except Elektro. While robots are a staple of pop culture, and various robots have become common in industrial settings, companies and research labs have not been able to build and perfect commercially viable humanoid robots. But that may be about to change.

That's right. You, too, could soon trade dad jokes with your own Elektro. And possibly much more.

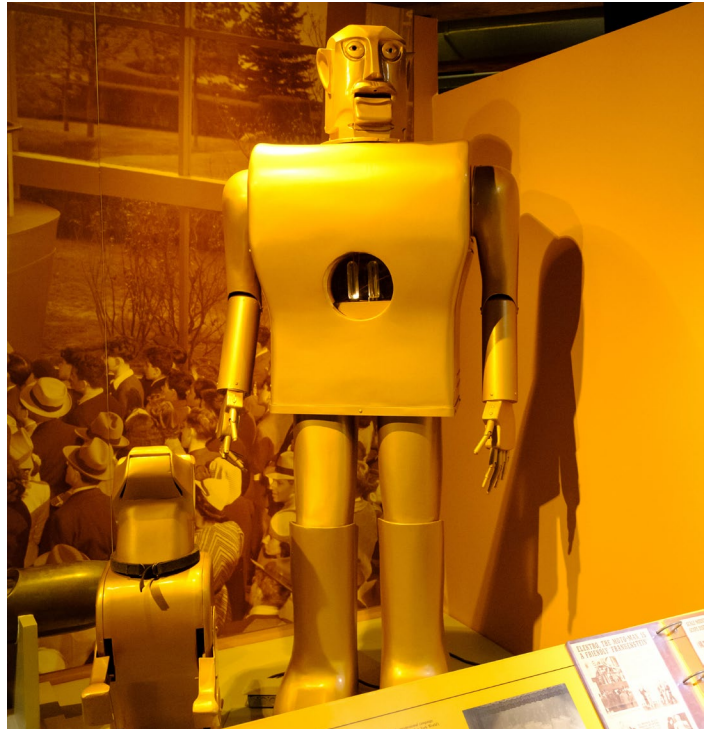
Elektro the Factory Worker

Elektro was ultimately just an elaborate mechanical puppet; it worked only in response to very specific instructions and could only complete tasks for which it was pre-programmed. But now, there are several companies that collectively appear on the cusp of creating humanoid robots at scale.

Tesla is probably the most well-known, but there are also hundreds of high-tech companies in China and Japan involved, such as Xiaomi and Unitree, and myriad parts suppliers including Sanhua Intelligent Controls and Harmonic Drive. "Too many well-run companies have been investing too much for this to be a joke," says Lee Gao, an analyst and portfolio manager at Harding Loevner.

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This new wave of humanoid robots can be disturbingly lifelike, can mimic virtually every human motion, and with AI-enabled "brains," they can act like people, too. That makes them seem well positioned for domestic tasks, and indeed most companies tend to show off their robots making pancakes or doing laundry or other domestic chores. The likely first buyers won't be individuals, though, but companies; the first place these robots show up will be in factories.



Westinghouse introduced the first "real" humanoid robot, Elektro the Moto-Man, in 1939.

Robots have existed in factories for decades. Industrial robots allow for better quality and consistency and higher productivity. But the entire layout of the factory must be tailored to specific robots, from the manufacturing process to inventory management. Humanoid robots offer much more flexibility, both literally and figuratively (though purpose-built robots can do their jobs with greater speed and accuracy). With humanoid robots, the factory floor doesn't need to be revamped to meet the requirements of robotic equipment. Instead, the robots can simply step into the spot formerly occupied by a human and take over that worker's tasks.

For factory and industrial work, the cost of these robots will matter as much as their capabilities. Companies with large warehouses will increasingly become interested in using humanoid robots to replace labor as the price comes down. If it gets to a point where using humanoid robots becomes cheaper than using humans, then companies are likely to start buying humanoid robots. However, that doesn't mean a mass wave of layoffs for people. It is likely to be at least three to five years before humanoid robots make a dent in the world's industrial automation industry, and even then, industrial robots are likely to still comprise the majority of factory and warehouse robots, meaning there will still be a role for humans.

Outside the factory, humanoid robots could be used in a variety of different tasks. There are robots that handle cleaning, such as the Roomba. There are wheeled robots that are used for patrolling and maintenance. A company called Yijahe makes wheeled robots that are used for cleaning and maintenance in outdoor areas. Humanoid versions of these robots would expand their potential uses, allowing them to maneuver off paved roads or lots, or go

up and down stairs. And the kinds of mundane, unskilled, or even dangerous labor that humans don't want to do would be a natural target for humanoid robots. These machines could be used in mines, war zones, or high-altitude work. In China, there are robots that clean airport carpets or even serve customers in restaurants. Hotels employ robots for cleaning and delivery. Humanoid robots would be able to handle even more tasks.

And, eventually, they are expected to show up in the home. Ostensibly, they could do many of the jobs people do now. "They could be caretakers and nannies," Gao said. "They could be nurses. They could be maids, like Rosie the Robot from *The Jetsons*. It's at an early stage; no one really knows what the applications are."

The Magic Number

The humanoid robot industry is paradoxically both longstanding and nascent. There have been a number of humanoid robots over the years, including Honda's Asimo and Sony's QRIO. Even as far back as the 1970s, a group of engineers from Waseda University in Tokyo constructed a humanoid robot named WABOT that could play the piano (well!) The main problem wasn't necessarily the technology, it was the cost. Humanoid robots were so expensive that mass producing them wasn't an option.

A decade ago, Japan's SoftBank began selling a small humanoid robot it called Pepper. The four-foot-high robot had wheels instead of legs, sold for about US\$2,000, and used advanced technology to recognize human emotions and interact with people. More recently, a Chinese company called Unitree began selling a humanoid robot it calls G1 with a price tag starting at US\$16,000. It's four feet tall, weighs 77 pounds, and can run for about two hours on a battery. The original model had a three-fingered hand; the newer model has a five-fingered hand. The latest model also has an optional AI chip from NVIDIA.



Softbank introduced Pepper in 2016, and sold 1,000 within a minute. But it sold only 27,000 more over the next six years.



Companies are closer than ever to perfecting the decades-old dream of building and selling humanoid robots. Watch as Harding Loevner analyst Lee Gao guides us through the history, development, and potential of this burgeoning field.

There is burgeoning competition. At the World Robot Conference in Beijing in August 2024, more than two dozen companies showed off a variety of humanoid-robot models. The companies participating included both manufacturers and parts suppliers. The robots resembled Elektro in form only. Tesla's Optimus, for instance, is a hair under six feet tall, weighs about 120 pounds, with a smooth black shield where a face would go and mainly encased in a white shell. Optimus has ten fingers with sensors in each finger that allow it to manipulate eggs and other fragile objects. It has joints in all the places where people have them: ankles, knees, hips, wrists, elbows, shoulders. Others had startlingly lifelike visages. A company called Ex-Robots showed off robots that had hair and skin and faces that made eerily lifelike expressions.

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The costs are also coming down. Two years ago, it cost roughly US\$250,000 to make one humanoid robot, Goldman Sachs estimated. A year later the price tag had fallen to US\$150,000, and Goldman expects it to keep falling. Goldman estimates that by 2035, companies could ship 1.4 million units a year in a US\$38 billion market. The expectation is that as the supply chain ramps up prices will drop, and eventually manufacturers will hit a "magic number," a price at which these robots will be profitable to build and sell and still reasonably affordable for customers, which in turn could spur adoption. Elon Musk suggests that magic number is around US\$20,000. Getting the price down to that level will likely be critical in persuading people to try them and see what they can do. "What you do with something at US\$500,000 is very different than at US\$20,000," Gao says. "What exactly are the applications that justify investing so much money? I think everyone's trying to figure that out."

The Suppliers

An entire industry of parts manufacturers is rising up to support the construction of humanoid robots with various gears and rods and chips, and as more enter the market, the expectation is competition will drive down the prices of components.

One big reason why the parts for these robots are becoming more affordable is that most of them have their origins in other products. Motors made by Sanhua similar to those used in HVAC systems, aluminum parts made by Tuopu, or harmonic reducers made by Leaderdrive are all finding their way into humanoid robots. NVIDIA has adapted its semiconductors for artificial intelligence into chips for humanoid robots.

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Another company sliding into the humanoid-robot market is Harmonic Drive, the world's largest producer of small precision-speed reducers (a small, round gear that controls the movement of mechanical limbs) used in industrial, non-humanoid robots. Because of that expertise, its expansion into the humanoid robot supply chain is being closely watched. The company has started taking orders for parts; earlier this year it reported an order for 15,000 speed reducers for 500 hundred robots (the gears would go on fingers, with three gears per finger on 10 fingers per robot).

That is a tiny order for the company, which can produce 130,000 of those gears every month at its Japanese factories. Which likely means two things. One, the company doesn't need humanoid robots to take off, as it already has an existing and profitable business. Two, if humanoid robots *do* take off, it will suddenly find



Tesla expects to have its Optimus robot working in its factories in 2025, and plans to sell them beginning in 2026.

itself with a new line of business without having to develop new products.

These supply chain improvements are allowing robot manufacturers to ramp up their plans. China's Xiaomi already has the G1 available. Tesla is saying the robots will be launched internally in 2025 and that it will begin selling them in 2026.

Tesla, though, has been working on Optimus for years, and founder Elon Musk is notorious for promising aggressive timelines that don't pan out. Tesla showed off a handful of its robots at a glitzy event in October, even putting a few behind the bar to serve drinks. The robots, however, were seemingly being **controlled by remote operators**. In that sense, the robots were just a more advanced version of Elektro. It is not clear whether or not the company has perfected the technology that will allow the robots to be truly independent and functional.

Xiaomi's timeline fits within a larger framework being promoted by the Chinese government. The Ministry of Industry and Information Technology in late 2023 issued a roadmap for the industry that would see breakthroughs in critical components and mass production occurring by 2025, and the maturation of an industry supply chain by 2027 that would allow China to become a global leader in humanoid robots.

Do Humans Even Want Artificial Humans?

If Goldman Sachs is right, in about a decade companies will be selling more than a million humanoid robots a year. That is tiny compared to, for example, the iPhone; Apple sells more than 200 million of them yearly, analysts estimate. But it's also enough that humanoid robots would become a fairly common sight. Their reception may be more caustic than the reception the iPhone got, however.

There are still a host of ethical and practical questions to work through, Gao said. Parents may not be comfortable with leaving their children with robots. Caregivers may not be comfortable with leaving their loved ones with robots. Workers certainly would not be happy giving up their jobs to robots. "It can get a little weird if you have something too human-like," he said. Humanoid robots may have a better chance in China, where there are fewer ethical hangups because non-humanoid robots are already a common sight, Gao said. "They're everywhere. Robots deliver packages. They're in restaurants. They carry your food to you and take away dirty dishes."

Being good at basic tasks seems like the minimum requirement. But this new crop of robots is going to have to be good at their jobs and also disarming in their interactions with actual humans. SoftBank had an initial hit with Pepper back in 2015; the company sold its first batch of 1,000 in just 60 seconds. But after selling only 27,000 in the next six years, the company halted production of Pepper in 2021 (though its website is still up, which offers a link to contact the company to talk about buying one). Pepper was

bad at many of the jobs it was given, and worse, its very presence was **creepy to some people**. Nobody is going to spend tens of thousands of dollars on something that rankles them.

Those issues won't be avoidable, but the companies don't appear inclined to wait. There is the Chinese government's aggressive roadmap, and there is Elon Musk's aggressive salesmanship propelling this industry forward. As the costs to build the robots come down, the price will become more affordable, which should attract more buyers. Assuming steady growth, at some

undetermined point those lines will cross, production will become profitable, and a critical mass will be hit. Mankind would appear to be, therefore, finally on the cusp of the age of the moto-man, with all the promise and messy complications that might entail. The next decade will reveal, with the G1 and Optimus and the others, if the tech industry perfected a project that began 85 years ago when Elektro first slid across the stage of the World's Fair, or if it has just built a more elaborate mechanical puppet.

Contributors

Analyst and portfolio manager **Lee Gao**, and analyst **Takayuki Hayano, CFA**, contributed research and viewpoints to this piece.

Disclosures

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