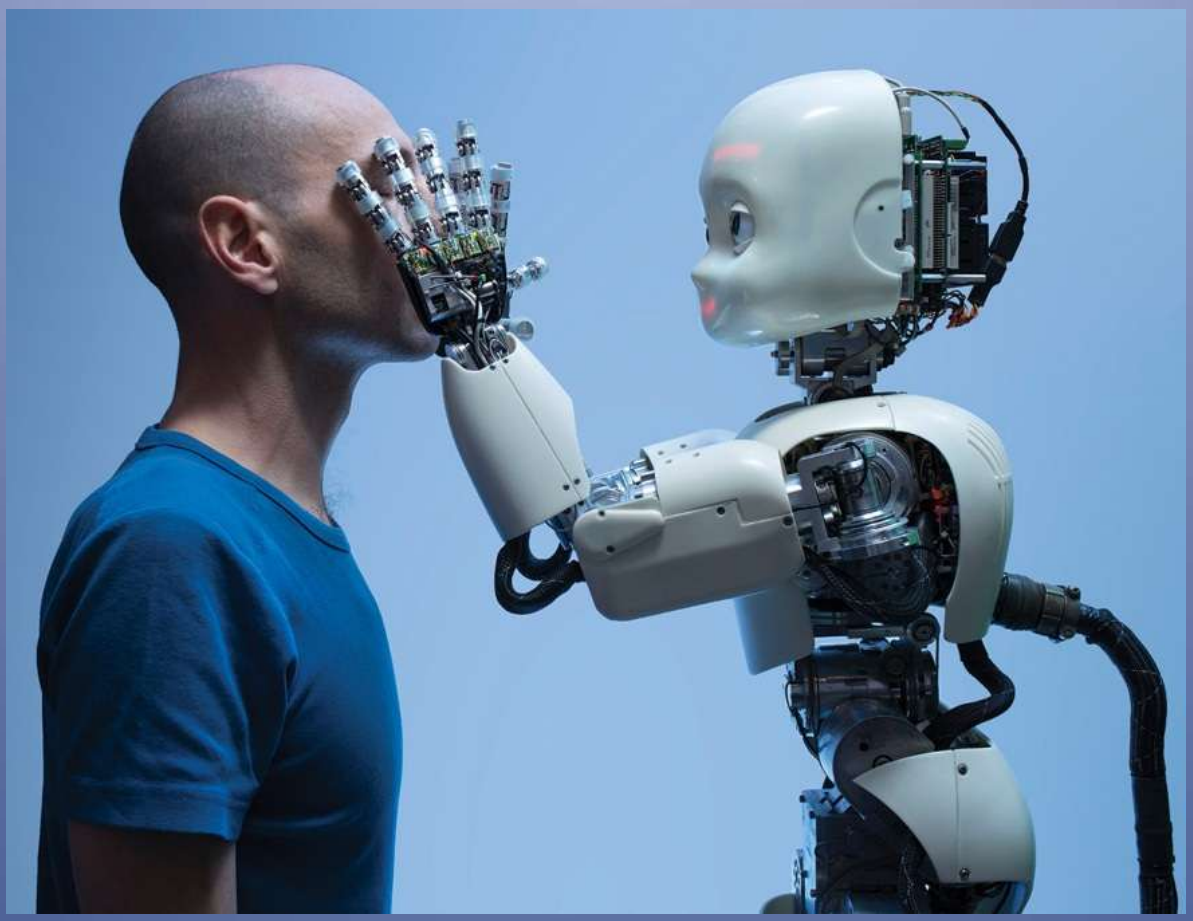


Robots & Humans

Ray Hammond

Chapters extracted from ‘SCARY-WONDERFUL: THE NEXT 50 YEARS’

ROBOTS & HUMANS

Robots have a unique place in the modern psyche. Unlike conventional, disembodied computer intelligence – whether found in the Cloud, in laptops, tablets, games consoles, or smart phones – "robots" are a term we most associate with human-like machines (humanoids) or with mechanical versions of animals ("anamaloids"). And, as soon as we come into contact with machines that approximate either humans or animals *powerful emotional forces* honed during our evolutionary development come into play and colour our thinking.

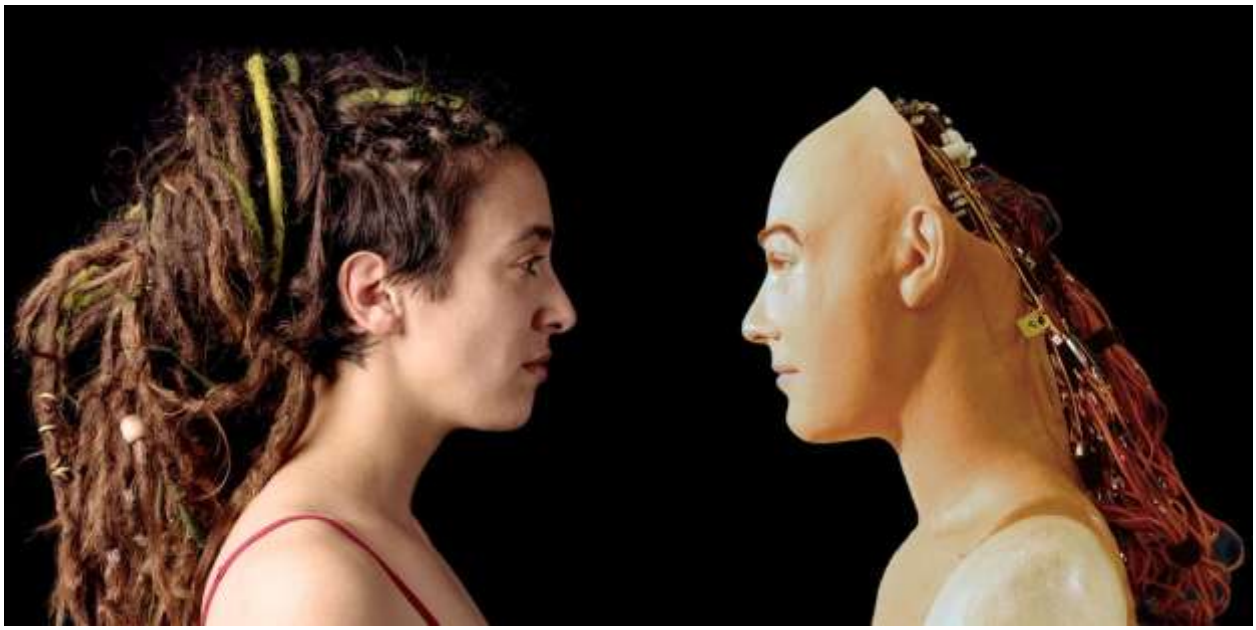
We like to think of robots[1] as having "life" or, at least, some form of sentience and we feel the desire to name them, to care for them, even to grant them certain rights.

This powerful drive will be harnessed in the development of robot entities and in the near future we may find ourselves "bringing up a robot" in a way that is not too dissimilar to raising children or training pet animals. Even when robots don't assume mammalian shape, the "anthropomorphic instinct" is so powerful that

[1] My definition of 'robot' in this context is an intelligent, autonomous machine contained within a purpose-built physical casing that may, or may not, be mobile.

people still assign names and personalities to robots which have abstract appearances[2].

I explored this human desire to anthropomorphize apparent robot intelligence in my 1999 novel, "Emergence". I wrote a scene in which a group of corporate researchers discuss how to handle children who have become attached to their toy-like, pet robot companions and who wish to transfer their existing companions' personalities to new toy-pet models. I wanted to explore the way in which human anthropomorphic desires are likely to affect our relationship with machines which appear to have life. I concluded that there will indeed be widespread attachment between humans and animate machines and, for many people, I suspect a "robot" will have become the "significant other" well before the year 2030.



Even now, 15 years after I wrote my scene, the idea of human attachment to robots still seems fanciful (and more than a little creepy) but I think we're approaching the point at which such robot 'creatures' will begin arriving in our

[2] Anthropomorphism is such a powerful instinct that U.S. soldiers in Iraq not only gave fallen robots funerals, but honoured them with 21-gun salutes, Purple Hearts and Bronze Star medals.

midst and how we respond, individually and collectively, to their arrival is likely to have a vital impact on our future – indeed, on our survival as a species.

This last claim may seem ridiculously overblown to many readers, but I believe I can make a good case for my concerns. Physical robots are just one aspect of a larger phenomenon which is the development of machine intelligence *per se*. The cognitive ability of today's cleverest stand-alone computer is puny compared to average human intelligence; by many estimates today's smartest machine is about as intelligent as an insect. (In computer terms, the latest estimate of the human brain's capacity for storing and processing information is that it is about one zettabyte, a storage capacity equivalent to 75 billion 16-gig iPads.)

But the speed of increase in machine intelligence is exponential and many mathematicians and computer scientists expect to see computers reach human levels of intelligence somewhere around the year 2030 (at that point whether the machines are 'stand-alone' or massively networked will be irrelevant. All machines will be networked – other than ultra-secure systems).

Of course, at some point after 2030 machines will become super-intelligent and they are likely to surpass human levels of problem-solving ability by mid-century, if not before. (The point at which this may occur is emotive and is hotly disputed among computer scientists: some suggest as early as 2035, some say 2050 and some believe that it will not happen at all in the 21st century. A few believe it will never happen.)

The point at which machine intelligence surpasses human problem-solving abilities is often referred to as the 'technological singularity' (because like a black hole in space, the point is one beyond which we can gather no meaningful

information about the future – who can guess what super-intelligence will bring or where it will lead?).

Neuroscientist Dr Tali Sharot of University College London has observed that humans are "hard wired" to regard the future in optimistic terms. She says this comes from an evolutionary survival strategy which necessitates that we focus only on the positive ahead of us. She suggests this is why humans find it hard to take positive action about potential negatives in the future such as climate change, asteroid strikes and pandemics. She thinks humans naturally pay less attention to future negatives as a survival strategy to preserve mental health.[3]

If Dr Sharot is right (and I suspect she is) this may explain why so few people in the world are concerned about the imminent arrival of super-intelligent machines. I first started writing about this issue 30 years ago (and I first started thinking about it 50 years ago) and in the last few decades there have been many books written on the subject and several major feature films (from *Terminator* to *Transcendence*).

OUR LAST ACHIEVEMENT?

Some of the world's greatest brains including Professor Stephen Hawking have warned that the creation of super-intelligence may become humanity's greatest achievement but, he suggests, it may also be our *last* achievement. He writes:

> Artificial-intelligence (AI) research is now progressing rapidly. Recent landmarks such as self-driving cars, a computer winning at *Jeopardy!* and the digital personal assistants Siri, Google Now and Cortana are merely symptoms of an IT arms race fuelled by unprecedented investments and building on an increasingly mature

[3] For the reasons humans are generally ill-equipped to think about the future please see Chapter 1 of this book.

> theoretical foundation. Such achievements will probably pale against what the coming decades will bring.
>
> The potential benefits are huge; everything that civilisation has to offer is a product of human intelligence; we cannot predict what we might achieve when this intelligence is magnified by the tools that AI may provide, but the eradication of war, disease, and poverty would be high on anyone's list. Success in creating AI would be the biggest event in human history.
>
> Unfortunately, *it might also be the last*[4], unless we learn how to avoid the risks. In the near term, world militaries are considering autonomous-weapon systems that can choose and eliminate targets; the UN and Human Rights Watch have advocated a treaty banning such weapons. In the medium term, as emphasised by Erik Brynjolfsson and Andrew McAfee in *The Second Machine Age*, AI may transform our economy to bring both great wealth and great dislocation.

But despite all of this publicity and the grave warnings being issued, few people – and no governments – are exercised about the coming of super-intelligent beings on this planet. There are no United Nations panels or committees studying the subject[5], there are no political parties promising to stop the rise of the machines and there are no social movements like modern-day Luddites which are dedicated the preventing this sort of machine-led future happening.

Over 30 years ago I asked in a book whether super-intelligent machines will become our slaves or our masters, I asked whether they would become our 'companions on Earth' or whether they would be our successor species on this planet?

Although the topic is always a hot subject for discussion when I lecture to informed business and academic audiences, amongst the general public these ideas and questions produce only bewilderment, bafflement and, inevitably, derision.

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[4] Emphasis added

[5] In May 2014 the UN's Convention on Certain Conventional Weapons panel heard evidence for the first time on the likely future performance of autonomous weapons (or "killer robots"). Further deliberations on this topic are scheduled.

There is a metaphor which I finds helps people consider this topic.

Imagine that a couple of years ago the United Nations, the U.S. Government, the European Union and the Chinese leadership had jointly announced that radio signals had been received on Earth that appeared to come from an alien civilization located in a planetary system only 30 light years away from Earth. These radio signals had reached earth and were intelligible because they were written and spoken in 20 of our world's major languages.

After exhaustive investigation the authorities had concluded that these radio signals were genuine and had, indeed, reached Earth from a point in a fairly proximate star system that contains suitable earth-like planets capable of supporting life (exoplanets).

The radio signals contained a greeting and the information that, having now received accidental radio transmissions from planet Earth, the beings from the nearby planetary system had dispatched an expedition to visit us. The signals revealed that the aliens expected to arrive at planet Earth in January 2051. The final part of the message (as received) read: "We come in peace."

HOW WOULD THE WORLD HAVE REACTED?

How would the public have felt? Would some scientists and politicians be warning us that if these aliens are able to travel at close to light speed to visit us their technology must be far, far ahead of ours? Would they be warning us that their peaceful intentions should not be taken at face value?

Would there be United Nations committees and panels established to consider how best to welcome (or repel) these alien visitors? Would governments be

frantically examining their weaponry to see how best they might deter or fight the aliens if they turned out to be hostile?

You bet! All of these things would be happening and more. It would be THE subject of the moment and it would be a topic which just wouldn't go away.

And yet this is precisely what the arrival of super-intelligent machines means for our species. It means the arrival of an alien intelligence in our midst. A visitation that, if allowed to go ahead without control, will quickly outstrip all human capability, one which will self-reproduce and one which has the potential to become our successor species. It could even lead to human extinction.

But how could world development of super-artificial-intelligence be controlled? Would it require the computer equivalent of the Nuclear Weapons Non-Proliferation Treaty? But would nations sigh up to such a treaty? After all, the development of strong AI promises enormous riches as superior computer intelligence and ubiquitous, versatile robots start to create wealth from machine labour and AI-driven innovation.

And even if the machine-intelligence equivalent of the Non-Proliferation Treaty were to come into existence, would there still be renegade nations which decided to "go it alone" for their own advantage (just as today there are rogue nuclear states)?

Unlike the development and testing of nuclear weapons, the development of strong AI leaves no physical trace in the environment. Could it possibly be safe to assume that national security agencies would foreswear such development if it meant risking losing military advantage to a potential enemy?

Which leads me to the subject of potential future wars: I am frequently asked if I foresee another major world war and I am always pleased to say that I don't – at least in terms of war as we understand it today (being fought with physical weapons between nations).

But what if World War 3 turns out to be a war fought between machines (which is the definition of cyber war)? Or even worse, a war between humans and machines?

Fanciful? I hope so.

WILL ROBOTS AND STRONG AI CAUSE MASS UNEMPLOYMENT?

Although I argue that the principal threat of uncontrolled development of robotics and strong AI is a risk to the long-term survival of our species, in the short-term the effects might be less dramatic, but still very problematic.

Since the industrial revolution began in the late 18th Century we have worried that machines will replace human labour and cause widespread unemployment. The Luddites in Britain were the first direct action group formed by workers to resist mechanisation that destroyed the need for human labour, but despite these concerns, new technology has, until very recently, seemed to create almost as many new types of job as it has destroyed.

Today, it is doubtful if this serendipitous good fortune will last for much longer. In 1930, the acclaimed economist John Maynard Keynes wrote an essay about employment prospects 100 years hence. Called 'Economic Possibilities For Our Grandchildren' he considered the likely problem of "technological unemployment":

> In spite of an enormous growth in the population of the world, which it has been necessary to equip with houses and machines, the average standard of life in Europe and the United States has been raised, I think, about fourfold. The growth of capital has been on a scale which is far beyond a hundred-fold of what any previous age had known. And from now on we need not expect so great an increase of population.
>
> If capital increases, say, 2 per cent per annum, the capital equipment of the world will have increased by a half in twenty years, and seven and a half times in a hundred years. Think of this in terms of material things—houses, transport, and the like.
>
> At the same time technical improvements in manufacture and transport have been proceeding at a greater rate in the last ten years than ever before in history. In the United States factory output per head was 40 per cent greater in 1925 than in 1919. In Europe we are held back by temporary obstacles, but even so it is safe to say that technical efficiency is increasing by more than 1 per cent per annum compound. There is evidence that the revolutionary technical changes, which have so far chiefly affected industry, may soon be attacking agriculture. We may be on the eve of improvements in the efficiency of food production as great as those which have already taken place in mining, manufacture, and transport. In quite a few years—in our own lifetimes I mean—we may be able to perform all the operations of agriculture, mining, and manufacture with a quarter of the human effort to which we have been accustomed.
>
> For the moment the very rapidity of these changes is hurting us and bringing difficult problems to solve. Those countries are suffering relatively which are not in the vanguard of progress. We are being afflicted with a new disease of which some readers may not yet have heard the name, but of which they will hear a great deal in the years to come—namely, *technological unemployment*. This means unemployment due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour.
>
> But this is only a temporary phase of maladjustment. All this means in the long run *that mankind is solving its economic problem*. I would predict that the standard of life in progressive countries one hundred years hence will be between four and eight times as high as it is to-day. There would be nothing surprising in this even in the light of our present knowledge. It would not be foolish to contemplate the possibility of a far greater progress still.

So, in terms of robot labour and strong AI, where are we today? Here's the mid-2014 view of an American journalist writing in Rightsidendews:

> There are already more than 101 million working age Americans who are not employed and 20 percent of the families in the entire country do not have a single member that has a job.
>
> So what in the world are we going to do when robots start taking millions upon millions more of our jobs? Thanks to technology, the balance of power between employers and workers in the USA is shifting dramatically in favor of the employers.
>
> Many employers today are wondering why they are dealing with so many human worker "headaches" when they can just use technology to get the same tasks done instead. When you replace a human worker with a robot, you solve a whole bunch of problems.

And this is not something that is coming at some point in "the future". This is already happening.

Robots are coming – and coming soon. Low cost, "soft" robots that are able to work safely alongside humans will soon transform workplaces large and small. But what will be the effect on the human workforce?

Robot workers never take a day off, they never get tired, they never get sick, they never complain, they never show up late, they never waste time surfing the web and they always do what bosses tell them to do.

Robot technology has recently advanced to the point where it is becoming cheaper to buy robots than it is to hire humans for a vast variety of different tasks. From the narrow standpoint of economic efficiency, this is a good thing. But what happens to society when robots are able to do just about everything less expensively and more efficiently than humans can? How many people will be put out of work and where will new jobs come from?

A US computer magazine recently published a report on a new warehouse robot known as "UBR-1". This robot is intended to perform tasks "normally done by human workers". The UBR-1 is a 4-foot tall, one-armed robot that could make warehouses and factories more efficient by performing tasks normally done by human workers.

Unlike the industrial robots widely used in manufacturing today – usually large machines isolated from people for safety reasons – this robot can work alongside humans or autonomously in a workspace filled with people.

This little robot costs $50,000, and it can work all day and all night. It just needs a battery change every once in a while. The creators of this robot envision it performing a vast array of different tasks.

"We see the robot as doing tasks, they could be dull, they could be dirty, they could be dangerous and doing them repetitively all day in a light manufacturing environment," said Melonee Wise, Unbounded Robotics CEO and co-founder. Those tasks include stocking shelves, picking up objects and assembling parts.

The UBR-1 isn't designed for small component assembly, but it can manipulate objects as small as dice or a Lego piece, Wise says. Unbounded Robotics is targeting companies that want some automation to speed up their manufacturing process, but can't afford to fully automate their businesses.

On a larger scale there will be 10,000 robots working to fulfil customer orders in Amazon's American warehouses by the end of 2014. What happens if every distribution company starts using these kinds of robots for manual work? What will that do to ordinary warehouse jobs?

To many business leaders this prospect may sound very exciting. But what if a robot took your sister's job, or the job of another close family member? Would it be exciting then? And is mass unemployment the only likely outcome of the robot revolution? If it is, the negative impact on the wages of those still in work will be severe.

This is what Time magazine had to say about the robot future:

> We can see jobs vanishing before our eyes. Airport ticket counters used to teem with employees; now only a handful stand by to assist customers who use kiosks. Travel agencies once brightened streets with posters touting sunny destinations; now people book vacations online. From accountants to X-ray technicians, technology has chipped away at a virtual alphabet of occupations. This revolution is likely to blame, in part, for the slow growth in jobs since the crash of 2008.
>
> The automation of human labor is as old as the Industrial Revolution. From the steam engine and the cotton gin to the desktop computer and the robotic welder, machines have enabled leaps of efficiency that create far more jobs than they destroy. And yet many economists and technologists believe that things are different this time, that society is entering a new and troubling phase as computing power and other advances enable the creation of ever-more-powerful robots. What if the economic growth of the future produces more jobs for more robots, leaving humans behind? What if we're heading toward a future in which a handful of creative humans marshal an army of ever-more-intelligent machines while everyone else languishes? How does the world work without ... work?

Of course, nobody is suggesting we ban robots. And you can't force companies to hire humans rather than robot workers. But we could potentially have major problems in our society as jobs at the low end of the wage scale quickly disappear.

Restaurants in Japan, the USA and elsewhere are now going over to automated service and, in a widely cited paper published last year, University of Oxford researchers estimated that there is a 92 per cent chance that fast-food preparation and serving will be automated in the coming decades. The same report predicted that overall 47 per cent of today's jobs will disappear because of automation in the next 20 years.

In ten years or so commercial drivers could be replaced en masse by self-driving cars, buses, trucks and drones. In food preparation, there are start-ups offering robots for bartending and gourmet hamburger preparation and a food processing company in Spain now uses robots to inspect heads of lettuce on a conveyor belt, throwing out those that don't meet company standards.

In China, iPhone manufacturer Foxconn is in the process of buying one million robots to replace human workers. The company is reportedly paying $25,000 per robot – about three times a Chinese worker's average salary – and they will replace humans in precision assembly tasks.

And in 2014 Business Week reported:

> Step into the factory of Chinese SUV and truck maker Great Wall Motors, and it's easy to forget you're in the world's most populous country. Swiss-made robots

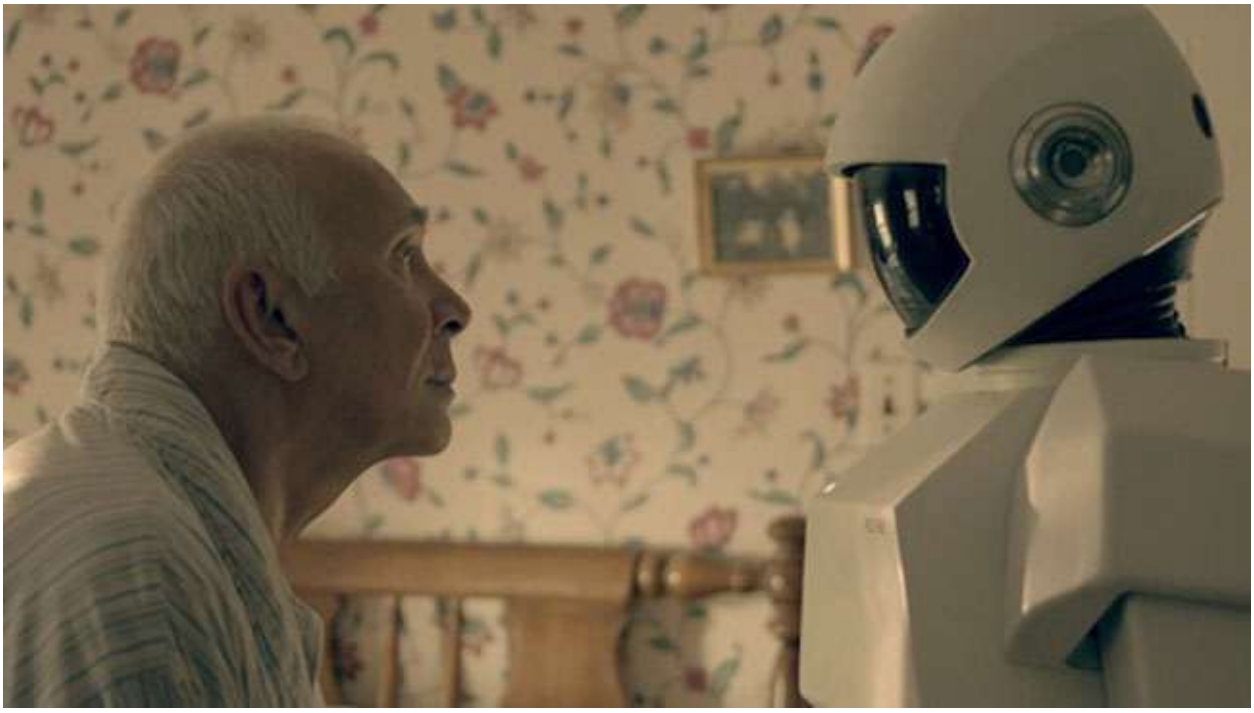
pivot and plunge, stamping metal door frames and soldering them to the skeletal vehicle bodies of a mini-SUV called the Haval M4. The blue-smocked workers in yellow hard hats are few and far between here in Great Wall's largest factory complex, located in Baoding, some 90 miles southwest of Beijing.

"With automation, we can reduce our head count and save money," says Hao Jianjun, Great Wall's general manager, who has invested $161 million into mechanizing four plants with 1,200 robots. The average price of a factory-floor robot is around $50,000 before installation. "Within three years, this cost will be completely paid for in savings from reduced worker wages," says Hao. After the robots were added, the number of welders at Great Wall dropped from 1,300 to around 400.

Robots seem to have many advantages over humans. Humans are messy, they always want more money, and having many of them in one factory is often a recipe for unrest. But what happens after the manufacturing halls are emptied of young men and women workers and are instead full of whirring robots?

Even jobs requiring "the human touch" may be taken over by robots. Imagine you're 85, and living alone. Your children are halfway across the country, and there are no close friends around. You have a live-in aide – but it's not human. Your personal robot reminds you to take your medicine, monitors your diet and exercise,

plays games with you, and even helps you connect with family members on the internet.



And, as this chapter was being prepared, a new robot was launched for the building and construction industry to take over some of the heavier jobs currently done by humans.

Our workplace is changing at a pace that is almost inconceivable.

John Maynard Keynes said, “When change is radical, the only antidote is radical thought.”

Keynes made that observation in 1930, the same year that he predicted that there would be “widespread unemployment caused by technology” by 2030. Will his long-range forecast turn out to be accurate?

If we employ radical thinking to the arrival of low-cost robot labour might we not be able to expand output instead of just cutting human jobs? And might we not be able to create new roles of "robot facilitator" in which humans oversee a robot worker's every need – e.g. maintenance, upgrades and creating innovative new workflows suitable for robot labour?

Is it possible that new economies in manufacturing facilitated by robot labour will bring small-scale manufacturing back to North America and Western Europe? I think this is very likely and a re-birth of small-scale domestic manufacturing will create thousands of new jobs for humans.

And the robot industry itself is creating new jobs. A new report from the International Federation of Robotics (IFR), suggests that for every robot deployed, 3.6 new jobs are created. By 2016, robotics is predicted to account for an extra 110,000 jobs in the electronics sector, globally. (But they would say that, wouldn't they?)

It is clear that robots may take some existing jobs but it is also likely that many thousands of completely new jobs will be created. Robots will bring even more change to our society but they also promise to bring significantly increased prosperity.

In the longer term, however, will robots be our slaves or our masters?

Ends

Appendices

Further reading, useful links and scraps of research that may be of interest to readers interested in further details about robots and their implications:

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The march of progress is, however, unlikely to be impeded. A McKinsey report last year estimated the potential global economic impact of robotics and autonomous systems (RAS) would be between $1.9 trillion (£1.1 trillion) and $6.4 trillion a year by 2025, providing the politicians with a big number to bandy around.

*

"The technology has reached the point where a new age of robots is emerging. The next generation of anthropomorphic machines will move beyond the factories and warehouses to work beside humans in new capacities. Where robots in the factories were cells of articulated-armed, fast-moving steel machines that had to be caged in controlled production environments to protect human workers; the next generation of robots is working side-by-side with their human counterparts.

"Robotics is evolving away from the large, complex, and expensive industrial robotics toward inexpensive, smaller, and safer people-friendly systems. This new generation of robots will not only look more human, but will be taking on human tasks, both in the workplace and even in the home.

*

Robotics appears to be gathering pace in terms of technological advances and sales, with the main centres of research centred on universities in Massachusetts, California and Japan. In the last year, the US tech giant Google has bought eight robotics companies, generating much anticipation of breakthroughs in the next few years.

Universal Robots grew out of a cluster of tech boffins at the Danish Technological Institute and the University of Southern Denmark in the city of Odense in 2005.

The three founders, Esben Østergaard, Kasper Støy and Kristian Kassow, wanted to create a light robot that was easy to install and programme after doing analysis of the special requirements of robots in the food industry.

Until then, robots used in manufacturing were heavy, unwieldy and unsuitable for smaller and more nimble tasks. Universal helped to revolutionise the market for robots used in small and

medium-sized enterprises. Its robot arms cost about €22,000, plus the same again for set-up expenses, which many customers have recouped in less than a year.

*

When Amazon first unveiled in December its revolutionary delivery drone concept, Prime Air, reactions fell along a spectrum of awe, praise, skepticism, and fear.

Regardless of what anyone has said about the project since, one of the undeniable truths is that robots are being accepted into the mainstream as much more than something out of a science-fiction movie.

Robotic technology is here and ready to work.

In fact, robotic technology has been at work for some time now. But experts on a panel hosted by the **Commonwealth Club** on Wednesday suggested that robot-designated jobs could all have been labeled as one of the "three D's." Those would be dirty, dangerous or dull.

That's not the case anymore.

As another piece of recent evidence, just look at Google's recent acquisition of Boston Dynamics, which could be another moonshot or the future of Android.

Rich Mahoney, director of the robotics program at nonprofit research institute SRI International, remarked that he doesn't view robots as an independent technology, but rather part of a technology continuum — notably a consumer electronics continuum.

Looking at how robots are evolving, Mahoney posited, we're just beginning to see robots (or at least elements of robotics) in the physical world become more accessible and low-cost, highlighting integration on everything from low-emission vehicles (LEV) to video telepresence systems.

"Basically, when you want to move something from Point A to Point B, you need a road and a vehicle," Santana explained, continuing that the brainstorm shifted toward determining whether or not they could just settle for a vehicle that "moves like the Internet."

Historically, one of the biggest barriers in bringing robots to the forefront was the platform, according to Brian Gerkey, CEO of the Open Source Robotics Foundation.

These days, Maloney concurred, robotics — much like any line of technology — starts with identifying a problem.

Maloney also pointed out that while robotics typically require many more resources (namely financial) compared to software startups, the required investment in hardware dropping dramatically, fueling the movement even further.

One of the most familiar types of robots in widespread circulation today is the unmanned aerial vehicle (UAV), colloquially known as a drone.

NPR tech correspondent and panel moderator Steve Henn observed that drones might have a public relations problems to overcome first, largely due to military operations, commenting that there has been a large public backlash to just the word "drone."

Gersky followed up that drones present many more possibilities, but it depends on developing the right algorithms and software.

Delivery appears to be the frontrunner, based on Amazon Prime Air (or the satirical jab from Netflix) as well as a similiar program being tested in China as of last fall.

Entertainment might be another, given that Henn cited that many of the zero-gravity scenes in the Alfonso Cuarón's Oscar-nominated *Gravity* were made possible thanks to robotic technology.

Paola Santana, co-founder of drone network maker Matternet, said that one of the motivations for launching her business was to use robots to solve poverty in developing nations from the Caribbean to Africa.

In order to set up the organization and serve people in need, Santana described that Matternet wasn't interested in investing in "traditional infrastructure models."

"Basically, when you want to move something from Point A to Point B, you need a road and a vehicle," Santana explained, continuing that the brainstorm shifted toward determining whether or not they could just settle for a vehicle that "moves like the Internet."

Robots satisfied that question, and Santana affirmed that the cost of launching approximately 150 of these unmanned drones in the same area was the same as building two-kilometer road.

"It was a no-brainer," Santana said flatly.

But Santana stressed that "Matternet is not about drones," but rather having vehicles that can fly from landing stations, which help the drone to be "smart" so that they do not take off and fly forever. She noted that Matternet also developed its own software, which she said acts as a "corridor" in order to manage vehicles in the airspace in real-time.

But in referencing the dream of drones simply showing up at a doorstep dropping off packages like magic, Santana quipped, "It will not happen as Amazon showed in the commercial. There's no way."

*

In 1955, Walter Reuther, head of the US car workers' union, told of a visit to a new automatically operated Ford plant. Pointing to all the robots, his host asked: "How are you going to collect union dues from those guys?" Mr Reuther replied: "And how are you going to get them to buy Fords?"

*

Many fear that a robotic takeover of manufacturing jobs will keep humans out of work. But one inventor shows how tomorrow's manufacturing robots will be smaller, smarter, and co-worker friendly—and they'll let manufacturers stop chasing around the world for low-wage workers.

In the next forty years, the world will be transformed by demographics. By 2050, the ratio of working-age people to retirees in Europe, much of Asia, and the United States will be very different from what it is today. The United States is also about to undergo a massive increase in the population older than 65, so policy makers are worried about how that will affect Social Security.

But this shrinking of the working-age population doesn't just affect national budgets. It affects services. There will be fewer workers to provide services to older people. More competition for those services means prices will go up. So productivity per worker will have to go up. To do that, we will need more robots to help people be more productive. This is why industrial robotics has become my focus.

I became concerned about the lack of innovation in industrial robotics after spending time in Shenzhen, China, as we set up the production line for the Roomba vacuum cleaner. I saw people building a million robots a year and doing it by hand. This isn't unusual in electronics manufacturing. Consider that the iPad is touched by 325 pairs of hands during assembly. That means that, despite growing interest and anxiety about automation and robotics taking away manufacturing jobs, most of our *stuff*—the low-cost consumer items that we buy from Wal-Mart—is still made by hand.

People sometimes think manufacturing is dead in the United States. In fact, manufacturing activity comprises a $2 trillion portion of the U.S. economy, very similar to the dollar value it comprises in China and Europe. In Japan, that number is about $1 trillion.

The United States has kept that manufacturing activity by increasing worker productivity, which has gone up about 3.7% per year for 60 years—a good run. The United States has kept the higher-value-added manufacturing and let the lower-value-added manufacturing go elsewhere.

And the definition of “elsewhere” has changed over time. The manufacture of simple goods is constantly moving to the location with the lowest wages.

Ethically and environmentally, this is a complex and controversial subject. I argue that—from the perspectiveof business—it’s unsustainable.

*

But an immediate robotics effort under way in the Seattle retailer's warehouses could save the company more than $900 million a year, according to an analyst.

Amazon's rollout of robots from a company it bought last year, Kiva Systems Inc., could help pare 20% to 40% off the $3.50 to $3.75 cost of fulfilling a typical order, said Shawn Milne, a Janney Capital Markets analyst. The robots can shuttle shelves full of merchandise to warehouse workers, relieving of the workers of having to dash throughout the warehouse.

….Amazon disclosed in its third-quarter earnings report that it has 1,400 Kiva robots in three of its warehouses.

"Amazon is very secretive, when they start talking about something, you better pay attention," Mr. Milne said in an interview. He estimated that a broad rollout of Kiva robots could save Amazon $458 million to $916 million a year.

*

Google has bought seven robotics companies in recent months as part of a strategy to develop its own robots that can be used for warehouse, manufacturing and delivery work, the *New York Times* reported Wednesday.

The report said that Google had placed Andy Rubin in charge of the project. Rubin is the highly regarded executive who led the development of Android into the world's most widely used smartphone software.

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Robots will become more capable and more richly integrated in society, and this is where Google's recent announcements become relevant. Google has begun a major effort in robotics by purchasing at least seven companies to build a strong starting lineup. The talents these acquisitions bring are telling: these are companies devoted to understanding the electronics and mechanics of manipulation and mobility. They build the most advanced wheel drives and dexterous arms on the market, and these will be the crown jewels of any effort to create robots that can manipulate every object in a factory and navigate smoothly on an even floor. The most obvious first application for Google's robotics project will be the highly controlled environment of a factory or warehouse where the contingencies of misplaced children's toys, tasseled carpets and staircases have no impact.

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"Epson's autonomous dual-arm robot is able to accurately recognize the position and orientation of objects in three-dimensional space. The two robot arms are equipped with newly developed force sensors that give the robot human-like control over the force exerted by the arms, enabling the robots to transport and assemble objects without damaging them. A multipurpose end effector can grasp, clamp, and insert objects of various shapes and sizes. The robot can be made to perform a wide range of tasks simply by teaching it objects and task scenarios."

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For the first time, Volkswagen has installed an industrial robot to work alongside humans in an engine production plant in Germany without any form of protective barrier between the robot arm and the human workers.

The lightweight arm is being used to insert glow plugs into cylinder heads at VW's engine production plant in Salzgitter.

The six-axis robotic arm, supplied by the Danish robot-maker Universal Robots, has a built in safety mode (that complies with EN ISO 10218), allowing it to work safely with people without needing any mechanical guards.

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Roughly half of all the robots in the world are in Asia, 32% in Europe, and 16% in North America, 1% in Australasia and 1% in Africa.[54] 40% of all the robots in the world are in Japan,[55] making Japan the country with the highest number of robots.

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It seems more top-tier economists are coming around to the idea that robots and technology could be having a greater influence on the economy (and this crisis in particular) than previously appreciated. Paul Krugman being the latest.

But first a quick backgrounder on the debate so far (as tracked by us).

Probably the first high-profile advocate of the idea — in recent times — that "technology and computers were changing the economy in weird ways" was Alan Greenspan in the 1990s, when he attributed a mysterious lack of inflation, high productivity and low unemployment rate to the arrival of a technologically rich "New Economy".

As we've written before, once the tech bubble burst — and Greenspan was supposedly proved so very wrong — the whole idea of technology being a fundamental force in the real economy

was abandoned. This is well illustrated by the sudden fall in references to technology in FOMC meetings (as tracked by us):

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Jairus Dennis, a packer for the ritzy online retailer Gilt Groupe, works on a kind of warehouse dream team. Every few seconds, colleagues fetch him heavy shelves stacked with skinny jeans and red dresses. No one ever complains or slows down.

Dennis's colleagues are orange and just 18 inches tall: they are robots, and they do much of the work in Gilt's sprawling logistics center near Louisville, Kentucky. Sixty of the automated dollies crisscross the floor carrying shelves to humans, who pick, pack, and ship items without ever taking more than a couple of steps.

Dennis, a 21-year-old who has worked in the warehouse for a year and a half, likes the robotic help. "I prefer it. You don't have to walk around eight hours a day," he says.

The presence of the robots reflects a major shift for warehouses, where conveyer belts, forklifts, and a lot of manual labor have been the norm. Until recently, robots were too awkward and expensive to make much of a difference. But that is changing as Web retailers look for an edge in a business with low margins and sharp competition.

"As prices drop and become more accessible to more companies, you'll see a rapid incline in growth" in warehouse robotics, predicts Marc Wulfraat, president of MWPVL International, a supply chain and logistics consulting company.

Earlier this year, Amazon gave its endorsement to warehouse automation by acquiring Kiva Systems, the manufacturer of the robotic systems used by Gilt. Amazon, which was already a customer of Kiva's through its Diapers.com business, paid $775 million to acquire the company. In addition to Amazon, Kiva's customers include Office Depot, Staples, Crate & Barrel, Toys "R" Us, and Saks Fifth Avenue.

Gilt started in 2007 as a flash-shopping site where customers have a limited time to buy discounted designer fashions. That recipe caught on quickly, turning Gilt into an e-commerce darling. From its Louisville facility, Gilt now ships more than 20,000 items on an average day.

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We've been following Unbounded Robotics, the final spin-off from Willow Garage, since we first learned of the company's existence back in April. Unbounded has been working in stealth mode for the past year, but our best guess was that they were developing a low-cost mobile manipulator for research and education: something like a PR2, except (we were hoping) significantly cheaper. Today, Unbounded is unveiling UBR-1, a shiny new human-scale one-

armed robot designed to completely revolutionize the market for research and education robotics and beyond, for just a tiny fraction of the cost of similar platforms.

f you didn't catch all of those specs, here's the basics of what we're looking at: UBR-1 is a 13-DoF mobile robot that includes a 7-DoF arm. It navigates with a laser scanner in its base, and uses a PrimeSense 3D sensor in its head for perception. Thanks to a torso lift, the robot can pick objects up off the floor, and put them onto tables and countertops. It's got a beefy computer in the torso, along with two big fat batteries that'll keep it running for up to 5 hours continuously, or up to 10 if it's not moving around too much, and you can get a charging dock so that you never have to plug it in. UBR-1 runs ROS, and comes out of the box with the ability to navigate and interact with objects. And (arguably) the most important spec of all is that UBR-1 **starts at just $35,000**, which is wicked cheap for a robot this capable.

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Unbounded will start shipping the first UBR1s next summer. Within the next two years, Wise expects to see businesses start putting them to work at tasks such as bin picking or stocking shelves in warehouses. “We’re in the business of getting robots out of the lab and making them a platform for businesses to use,” she says. “This is the Model T of robots.”

Though robots have long been a part of manufacturing, they have traditionally worked in isolation. But in recent years, thanks to advances in hardware and software, new kinds of robot have begun to appear among human workers in factories and warehouses. A company called Kiva Systems, acquired by Amazon in 2012, makes robots that can haul items around (see “In Warehouses, Kiva’s Robots Do the Heavy Lifting”), while startup Rethink Robotics’ flagship two-armed robot can work alongside humans on a production line (see “Baxter: The Blue-Collar Robot”).

These systems have limitations, though. Kiva’s robots require dedicated support infrastructure to be installed, and although the $22,000 Baxter is capable of two-handed manipulation, it cannot move around. Mobile robots capable of manipulation could function more like real human workers, Wise says, but so far they have remained in the research lab.

Before the UBR1 can start work in the real world, Unbounded will have to significantly improve the software available for the robot, which is today essentially a blank slate that requires a buyer to program in the desired capabilities. By contrast, Baxter is configured to be able to learn some manipulation tasks out of the box. Wise says her company will develop modular software packages that UBR1 owners can download to give their robots practical abilities. “We see ourselves developing basic capabilities that people will download and use on their robots, such as ‘open a door’ and ‘pick up a cup,’” she says.

*

Israeli robot maker Roboteam Ltd. won a fast track deal with the U.S. Department of Defense to supply it with stair-climbing micro-robots, the Pentagon's Combating Terrorism Technical Support Office said, U.S. defense magazine Defense News reported.

Roboteam's Micro Tactical Ground Robot is being rapidly deployed to special operations forces, the U.S. Department of Homeland Security and other users in parallel to ongoing operational tests by the Pentagon. The Pentagon's CTTSO, the authority managing the program on behalf of the U.S. assistant secretary of defense for special operations and low-intensity conflict, said it has earmarked 100 robots for "priority fielding" to special ops forces and EOD war fighters, while another 35 are destined for domestic use by interagency tactical units.

Roboteam also produces a 1.1-kg Individual Robotic Intelligence System (IRIS), which functions as a mobile camera for a squad, and can be sent through air vents into a basement or balcony for reconnaissance, and the Probot (Professional Robot), a 120-kg unit that carries nearly double its weight in payload.

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At RoboBusiness Silicon Valley, Universal Robots' CTO Esben Østergaard will present how a small Danish company became the successful industry pioneer of collaborative robots that can operate alongside employees without safety guarding.

The global achievements of Universal Robots have proven that collaborative robots are here to stay; Within the last year, the company has opened subsidiaries in China and North America, doubled revenue and employees, seen Volkswagen and BMW integrate the robots into mass production, and expanded distribution networks into a total of 50 countries worldwide.

On October 23-25, Universal Robots will demo the collaborative robots at booth 525 at RoboBusiness in Silicon Valley. At this leading business development event for the global robotics industry, the CTO and founder of Universal Robots, Esben Østergaard, will also share with the audience how the Danish robot manufacturer saw a market opportunity and acted.

Østergaard co-founded Universal Robots after realizing that while all robots are not created equal, what they do have in common is that most are large, expensive, unwieldy, and potentially dangerous.

"That's a challenge for end users of robotics technology, as well as a problem for the entire robotics community," says Østergaard, who addressed the shortcomings of traditional industrial robots by developing a collaborative robot—a highly-specialized, low-cost robot that can work alongside employees with no safety guarding.

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Ed Mullen attributes a significant part of his company's success in North America to the UR robots' ability to make small and medium sized business competitive.

"Our robots address the heart of the 'reshoring' debate by optimizing production in companies that would have otherwise lost orders to overseas competitors," he says. "We've succeeded in creating a robot for a market segment that never thought they'd be able to employ a robot due to cost and complexity."

With the UR5, Universal Robots pioneered user friendly, yet sophisticated, 3D programming via an intuitive tablet interface. This has enabled users with no previous programming experience to quickly set up and operate the UR5 robots allowing the machine operators to be promoted to robot programmers. Training a UR robot to perform a task can easily be done via the arrow keys on the tablet—or by simply grabbing the robot arm to demonstrate desired movement.

"We're distinctly different because we offer an out-of-box experience in less than an hour. That's the time it takes to unpack the robot, mount it and program the first tasks," says Mullen, who has created a network of 16 distributors now providing full coverage of both Canada and USA.

Eighty percent of the more than 2,000 UR robots deployed globally operate with no safety guarding in the immediate vicinity of employees.

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Next Generation of Robots Will Have a Gentle Touch

The new field of soft robotics aims to produce robots made of materials which are more adaptable, flexible and less hazardous than traditional steel and hard plastic. Swiss institutions are at the forefront of research in this novel field.

Robots are becoming more and more a feature of everyday life. They are no longer to be found just in factories, tirelessly assembling auto parts, but also in the home, vacuuming the living room or mowing the lawn, and even in the children's rooms, where a robot in the shape of a dinosaur or a dog might be seen entertaining the youngest members of the family.

All these robots have one thing in common: they have a rigid body, with a metal or plastic surface. This makes them robust, but also inflexible. They work accurately and without a break, but only in a precisely defined, very limited context.

What's more, traditional "hard" robots can be a hazard to their human owners. Industrial robots have to be kept in protective cages so that people working on the shop floor don't get too close to them and risk a blow from one of the fast-moving steel arms. Surgeons still have considerable reservations about the use of robots in the operating theatre, as they may cause slight injuries to the patient.

To make robots more flexible, adaptable and safe for humans to be around, the new research field of soft robotics has arisen in the past decade. Researchers in the field have been taking their cue from living organisms.

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"While A Small Elite Of The Corporate Managers and knowledge workers reap the benefits of the high-tech world economy, the Amercian middle class continues to shrink and the workplace becomes more stressful" Jeremy Rifkin: The End Of Work

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Phew, The Robots Are Only Going To Take 45 Percent Of All The Jobs

An interesting little piece of research that shows that the robots are likely to take 45% of all the jobs over the next few decades. Cue the usual worriers insisting that this will mean unemployment rates of over 50%. And I'm afraid I have to tell you that economies just don't work that way. The little bit that everyone misses is that the economy destroys millions upon millions of jobs every year. So much so that that 45% of all jobs is rather smaller than what we expect to see in entirely normal times.

Here's something about that report:

Rapid advances in technology have long represented a serious potential threat to many jobs ordinarily performed by people.

A recent report (which is not online, but summarized here) from the Oxford Martin School's Programme on the Impacts of Future Technology attempts to quantify the extent of that threat. It concludes that 45 percent of American jobs are at high risk of being taken by computers within the next two decades.

There's nothing at all wrong with the methods they've used to construct this figure: indeed, it's quite good. They've looked at current jobs that people do, tried to project out what computerisation and robotics are likely to be able to do in coming decades and then counted up those jobs currently done which could be replaced by the machines. Sure, there will be some assumptions in there that we can argue with but the basic idea is fine.

The problem isn't with the report it's with what people will make of that result. We've enough people running around shouting that the robots will take all out jobs so therefore disaster and the collapse of civilisation. We really don't need more doing so.

The important thing to note is that the economy, in its normal run of the mill operation, destroys more jobs than this. No, really, it does. These numbers are a little old but still give us an idea of the jobs turnover:

These job flow statistics reveal the tremendous amount of churning underlying the annual net employment growth rate of 3.3 percent. The sum of the job creation and job destruction rates, which is 34.1 percent, tells us that more than one in three jobs is either created or destroyed between March 1999 and March 2000. Specifically, 18.7 percent of jobs in March 2000 did not exist one year earlier, and 15.4 percent of jobs in March 1999 do not exist one year later. Furthermore, 15.0 percent of establishments opened and 13.0 percent of establishments closed between March 1999 and March 2000. These statistics demonstrate that there are a sizable number of jobs and businesses that appear and disappear during the relatively short time frame of one year.

We generally think of unemployment as being the number of people who have lost their jobs. In one sense of course that's true but it isn't in the way we normally think about it. The unemployment figures are not really the number of those who have lost their jobs: they are the number who have done so and have not found a new one. And it's true that in recessions there's no great leap in the number of people losing their jobs. But there is a slump in the number of people being able to find new ones, thus the lengthening unemployment lines.

Further, look at the number of jobs that are destroyed every year: 15.4%. That number is a little old but we're only estimating things here. There's some 130 million jobs in the US and 15% of them are destroyed each and every year: and yes, a lot of that is indeed technological advancement. Or, roughly, 20 million peoples' jobs are destroyed each and every year. That unemployment doesn't rise by 20 million each year is because some to all of them find other jobs, among those jobs newly created.

Now back to our prediction that 45% of all jobs are vulnerable to being done by the computers/robots. Over two decades note. Over two decades we would actually expect some 400 million jobs to be destroyed: 15% of all jobs every year. And they're claiming that 45% will be destroyed by the robots: that 45% of current jobs, or 60 million or so.

This would appear to be something that the economy can take in its stride. The robots (or computerisation) are going to cause only 15% of all job destruction over the period. This sounds like a portion that we can cope with given that we cope with much more than this all the time. For as Timothy Taylor says:

Given that the U.S. and other high-income economies have been experiencing technological change for well over a century, and the U.S. unemployment rate was below 6% as recently ago as the four straight years from 2004-2007, it seems premature to me to be forecasting that technology is now about to bring a dearth of jobs. Maybe this fear will turn out to be right this time, but it flies in the face of of a couple of centuries of economic history.

We've coped with this sort of thing before. There's no reason at all to think that it's going to be different this time. The increasing computerisation, roboticisation, of the economy is no more than a slight uptick in the normal rate of job destruction.

No, perhaps my insisting that we can all go back to sleep on this point isn't enough for you. Perhaps you'd like a plan for what we should be doing about this, admittedly minor, problem. In which case you can have a plan. For we can also note the following:

It's well understood that existing companies of all sizes constantly create – and destroy – jobs. Conventional wisdom, then, might suppose that annual net job gain is positive at these companies. This study, however, shows that this rarely is the case. In fact, net job growth occurs in the U.S. economy only through startup firms.

The study bases its findings on the Business Dynamics Statistics, a U.S. government dataset compiled by the U.S. Census Bureau. The BDS series tracks the annual number of new businesses (startups and new locations) from 1977 to 2005, and defines startups as firms younger than one year old.

The study reveals that, both on average and for all but seven years between 1977 and 2005, existing firms are net job destroyers, losing 1 million jobs net combined per year. By contrast, in their first year, new firms add an average of 3 million jobs.

(*Note that that's net job destruction in large firms, not the gross destruction number I use above.*)

So, if we want to make sure that this higher number of people having their jobs destroyed do manage to get another of those newly created jobs we want to increase the number of start up companies. For they are the part of the economy that produces those new jobs that people can move to. And how can we do that?

Well, think of the regulatory problems that companies like Uber and Lyft are having. In every city they try to launch their new services they find an entrenched bureaucracy insisting that they jump through a series of regulatory hoops. Such regulatory costs of course reduce the number of start up companies. So, if we want more start ups and more job creation then we need to reduce the burden of the regulatory environment.

We can even point to the European experience on this. The Latin countries, those below or in the Olive Belt, have highly regulatory states. They also do very badly on job creation and have high unemployment rates. The Nordics, underneath those icy and extortionate tax rates are the most economically liberal economies in the world (liberal here meaning classical liberal, closer to libertarian, not current American "liberal"). There is little to no job protection, no minimum wage, the basic employment contract is fire at will. There is indeed decent unemployment pay and retraining: but so also is it possible to launch a business doing pretty much whatever you want with the minimum of fuss or paperwork. Or bureaucrats demanding a licence. They also

have a very good job creation record and a low unemployment rate: there is a connection between these things, believe me.

The two takeaway points from all of this being that the robots may indeed be coming for 45% of all jobs in the next couple of decades. But this is no more than a small rise in the normal job destruction rate we'd expect over that timescale. If you are, even so, worried about where all the new jobs are going to come from then the answer is quite simple: clear away some to all of the bureaucracy that makes it so difficult to start up a new business. For it is those start ups that produce all of the job growth in the economy anyway.

Indeed, even if you're not worried about the robots but are purely about the current unemployment rate then you should still be in favour of cutting the regulatory bureaucracy.

Finally we can note that this prescription is exactly the opposite of what Jaron Lanier proposes. He thinks we should have more regulation, greater bureaucracy and licencing requirements, in order to protect those middle class jobs. But then we all already knew that we should be doing the opposite of what Mr. Lanier proposes, didn't we?

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No, seriously. For the notoriously insular Japanese, the idea of a friendly robot in the house to see to your every need is widely thought far preferable to a culturally alien immigrant. As we grow older, and can do fewer things for ourselves, we need servants. An artificial one, bought in much the same way as a car, provides a possibly better, less costly and less intrusive solution than a human one.

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Skilled Work, Without the Worker

By JOHN MARKOFF

DRACHTEN, the Netherlands — At the Philips Electronics factory on the coast of China, hundreds of workers use their hands and specialized tools to assemble electric shavers. That is the old way.

At a sister factory here in the Dutch countryside, 128 robot arms do the same work with yoga-like flexibility. Video cameras guide them through feats well beyond the capability of the most dexterous human.

One robot arm endlessly forms three perfect bends in two connector wires and slips them into holes almost too small for the eye to see. The arms work so fast that they must be enclosed in glass cages to prevent the people supervising them from being injured. And they do it all without a coffee break — three shifts a day, 365 days a year.

All told, the factory here has several dozen workers per shift, about a tenth as many as the plant in the Chinese city of Zhuhai.

This is the future. A new wave of robots, far more adept than those now commonly used by automakers and other heavy manufacturers, are replacing workers around the world in both manufacturing and distribution. Factories like the one here in the Netherlands are a striking counterpoint to those used by Apple and other consumer electronics giants, which employ hundreds of thousands of low-skilled workers.

“With these machines, we can make any consumer device in the world,” said Binne Visser, an electrical engineer who manages the Philips assembly line in Drachten.

Many industry executives and technology experts say Philips’s approach is gaining ground on Apple’s. Even as Foxconn, Apple’s iPhone manufacturer, continues to build new plants and hire thousands of additional workers to make smartphones, it plans to install more than a million robots within a few years to supplement its work force in China.

Foxconn has not disclosed how many workers will be displaced or when. But its chairman, Terry Gou, has publicly endorsed a growing use of robots. Speaking of his more than one million employees worldwide, he said in January, according to the official Xinhua news agency: “As human beings are also animals, to manage one million animals gives me a headache.”

The falling costs and growing sophistication of robots have touched off a renewed debate among economists and technologists over how quickly jobs will be lost. This year, Erik Brynjolfsson and Andrew McAfee, economists at the Massachusetts Institute of Technology, made the case for a rapid transformation. “The pace and scale of this encroachment into human skills is relatively recent and has profound economic implications,” they wrote in their book, “Race Against the Machine.”

In their minds, the advent of low-cost automation foretells changes on the scale of the revolution in agricultural technology over the last century, when farming employment in the United States fell from 40 percent of the work force to about 2 percent today. The analogy is not only to the industrialization of agriculture but also to the electrification of manufacturing in the past century, Mr. McAfee argues.

“At what point does the chain saw replace Paul Bunyan?” asked Mike Dennison, an executive at Flextronics, a manufacturer of consumer electronics products that is based in Silicon Valley and is increasingly automating assembly work. “There’s always a price point, and we’re very close to that point.”

But Bran Ferren, a veteran roboticist and industrial product designer at Applied Minds in Glendale, Calif., argues that there are still steep obstacles that have made the dream of the universal assembly robot elusive. “I had an early naïveté about universal robots that could just do anything,” he said. “You have to have people around anyway. And people are pretty good at

figuring out, how do I wiggle the radiator in or slip the hose on? And these things are still hard for robots to do."

Beyond the technical challenges lies resistance from unionized workers and communities worried about jobs. The ascension of robots may mean fewer jobs are created in this country, even though rising labor and transportation costs in Asia and fears of intellectual property theft are now bringing some work back to the West.

Take the cavernous solar-panel factory run by Flextronics in Milpitas, south of San Francisco. A large banner proudly proclaims "Bringing Jobs & Manufacturing Back to California!" (Right now China makes a large share of the solar panels used in this country and is automating its own industry.)

Yet in the state-of-the-art plant, where the assembly line runs 24 hours a day, seven days a week, there are robots everywhere and few human workers. All of the heavy lifting and almost all of the precise work is done by robots that string together solar cells and seal them under glass. The human workers do things like trimming excess material, threading wires and screwing a handful of fasteners into a simple frame for each panel.

Such advances in manufacturing are also beginning to transform other sectors that employ millions of workers around the world. One is distribution, where robots that zoom at the speed of the world's fastest sprinters can store, retrieve and pack goods for shipment far more efficiently than people. Robots could soon replace workers at companies like C & S Wholesale Grocers, the nation's largest grocery distributor, which has already deployed robot technology.

Rapid improvement in vision and touch technologies is putting a wide array of manual jobs within the abilities of robots. For example, Boeing's wide-body commercial jets are now riveted automatically by giant machines that move rapidly and precisely over the skin of the planes. Even with these machines, the company said it struggles to find enough workers to make its new 787 aircraft. Rather, the machines offer significant increases in precision and are safer for workers.

And at Earthbound Farms in California, four newly installed robot arms with customized suction cups swiftly place clamshell containers of organic lettuce into shipping boxes. The robots move far faster than the people they replaced. Each robot replaces two to five workers at Earthbound, according to John Dulchinos, an engineer who is the chief executive at Adept Technology, a robot maker based in Pleasanton, Calif., that developed Earthbound's system.

Robot manufacturers in the United States say that in many applications, robots are already more cost-effective than humans.

At an automation trade show last year in Chicago, Ron Potter, the director of robotics technology at an Atlanta consulting firm called Factory Automation Systems, offered attendees a spreadsheet to calculate how quickly robots would pay for themselves.

In one example, a robotic manufacturing system initially cost $250,000 and replaced two machine operators, each earning $50,000 a year. Over the 15-year life of the system, the machines yielded $3.5 million in labor and productivity savings.

The Obama administration says this technological shift presents a historic opportunity for the nation to stay competitive. “The only way we are going to maintain manufacturing in the U.S. is if we have higher productivity,” said Tom Kalil, deputy director of the White House Office of Science and Technology Policy.

Government officials and industry executives argue that even if factories are automated, they still are a valuable source of jobs. If the United States does not compete for advanced manufacturing in industries like consumer electronics, it could lose product engineering and design as well. Moreover, robotics executives argue that even though blue-collar jobs will be lost, more efficient manufacturing will create skilled jobs in designing, operating and servicing the assembly lines, as well as significant numbers of other kinds of jobs in the communities where factories are.

And robot makers point out that their industry itself creates jobs. A report commissioned by the International Federation of Robotics last year found that 150,000 people are already employed by robotics manufacturers worldwide in engineering and assembly jobs.

But American and European dominance in the next generation of manufacturing is far from certain.

“What I see is that the Chinese are going to apply robots too,” said Frans van Houten, Philips’s chief executive. “The window of opportunity to bring manufacturing back is before that happens.”

A Faster Assembly Line

Royal Philips Electronics began making the first electric shavers in 1939 and set up the factory here in Drachten in 1950. But Mr. Visser, the engineer who manages the assembly, takes pride in the sophistication of the latest shavers. They sell for as much as $350 and, he says, are more complex to make than smartphones.

The assembly line here is made up of dozens of glass cages housing robots made by Adept Technology that snake around the factory floor for more than 100 yards. Video cameras atop the cages guide the robot arms almost unerringly to pick up the parts they assemble. The arms bend wires with millimetric accuracy, set toothpick-thin spindles in tiny holes, grab miniature plastic gears and set them in housings, and snap pieces of plastic into place.

The next generation of robots for manufacturing will be more flexible and easier to train.

Witness the factory of Tesla Motors, which recently began manufacturing the Tesla S, a luxury sedan, in Fremont, Calif., on the edge of Silicon Valley.

More than half of the building is shuttered, called “the dark side.” It still houses a dingy, unused Toyota Corolla assembly line on which an army of workers once turned out half a million cars annually.

The Tesla assembly line is a stark contrast, brilliantly lighted. Its fast-moving robots, bright Tesla red, each has a single arm with multiple joints. Most of them are imposing, 8 to 10 feet tall, giving them a slightly menacing “Terminator” quality.

But the arms seem eerily human when they reach over to a stand and change their “hand” to perform a different task. While the many robots in auto factories typically perform only one function, in the new Tesla factory a robot might do up to four: welding, riveting, bonding and installing a component.

As many as eight robots perform a ballet around each vehicle as it stops at each station along the line for just five minutes. Ultimately as many as 83 cars a day — roughly 20,000 are planned for the first year — will be produced at the factory. When the company adds a sport utility vehicle next year, it will be built on the same assembly line, once the robots are reprogrammed.

Tesla’s factory is tiny but represents a significant bet on flexible robots, one that could be a model for the industry. And others are already thinking bigger.

Hyundai and Beijing Motors recently completed a mammoth factory outside Beijing that can produce a million vehicles a year using more robots and fewer people than the big factories of their competitors and with the same flexibility as Tesla’s, said Paul Chau, an American venture capitalist at WI Harper who toured the plant in June.

The New Warehouse

Traditional and futuristic systems working side by side in a distribution center north of New York City show how robotics is transforming the way products are distributed, threatening jobs. From this warehouse in Newburgh, C & S, the nation’s largest grocery wholesaler, supplies a major supermarket chain.

The old system sprawls across almost half a million square feet. The shelves are loaded and unloaded around the clock by hundreds of people driving pallet jacks and forklifts. At peak times in the evening, the warehouse is a cacophony of beeping and darting electric vehicles as workers with headsets are directed to cases of food by a computer that speaks to them in four languages.

The new system is much smaller, squeezed into only 30,000 square feet at the far end of the warehouse and controlled by just a handful of technicians. They watch over a four-story cage

with different levels holding 168 “rover” robots the size of go-carts. Each can move at 25 miles an hour, nearly as fast as an Olympic sprinter.

Each rover is connected wirelessly to a central computer and on command will race along an aisle until it reaches its destination — a case of food to retrieve or the spot to drop one off for storage. The robot gathers a box by extending two-foot-long metal fingers from its side and sliding them underneath. It lifts the box and pulls it to its belly. Then it accelerates to the front of the steel cage, where it turns into a wide lane where it must contend with traffic — eight robots are active on each level of the structure, which is 20 aisles wide and 21 levels high.

From the aisle, the robots wait their turn to pull into a special open lane where they deposit each load into an elevator that sends a stream of food cases down to a conveyor belt that leads to a large robot arm.

About 10 feet tall, the arm has the grace and dexterity of a skilled supermarket bagger, twisting and turning each case so the final stack forms an eight-foot cube. The software is sophisticated enough to determine which robot should pick up which case first, so when the order arrives at the supermarket, workers can take the cases out in the precise order in which they are to go on the shelves.

When the arm is finished, the cube of goods is conveyed to a machine that wraps it in clear plastic to hold it in place. Then a forklift operator summoned by the computer moves the cube to a truck for shipment.

Built by Symbotic, a start-up company based in the Boston area, this robotic warehouse is inspired by computer designers who created software algorithms to efficiently organize data to be stored on a computer’s hard drive.

Jim Baum, Symbotic’s chief executive, compares the new system to a huge parallel computer. The design is efficient because there is no single choke point; the cases of food moving through the robotic warehouse are like the digital bits being processed by the computer.

Humans’ Changing Role

In the decade since he began working as a warehouseman in Tolleson, Ariz., a suburb of Phoenix, Josh Graves has seen how automation systems can make work easier but also create new stress and insecurity. The giant facility where he works distributes dry goods for Kroger supermarkets.

Mr. Graves, 29, went to work in the warehouse, where his father worked for three decades, right out of high school. The demanding job required lifting heavy boxes and the hours were long. “They would bring in 15 guys, and only one would last,” he said.

Today Mr. Graves drives a small forklift-like machine that stores and retrieves cases of all sizes. Because such workers are doing less physical labor, there are fewer injuries, said Rome Aloise, a Teamsters vice president in Northern California. Because a computer sets the pace, the stress is now more psychological.

Mr. Graves wears headsets and is instructed by a computerized voice on where to go in the warehouse to gather or store products. A centralized computer the workers call The Brain dictates their speed. Managers know exactly what the workers do, to the precise minute.

Several years ago, Mr. Graves's warehouse installed a German system that automatically stores and retrieves cases of food. That led to the elimination of 106 jobs, roughly 20 percent of the work force. The new system was initially maintained by union workers with high seniority. Then that job went to the German company, which hired nonunion workers.

Now Kroger plans to build a highly automated warehouse in Tolleson. Sixty union workers went before the City Council last year to oppose the plan, on which the city has not yet ruled.

"We don't have a problem with the machines coming," Mr. Graves told city officials. "But tell Kroger we don't want to lose these jobs in our city."

Some jobs are still beyond the reach of automation: construction jobs that require workers to move in unpredictable settings and perform different tasks that are not repetitive; assembly work that requires tactile feedback like placing fiberglass panels inside airplanes, boats or cars; and assembly jobs where only a limited quantity of products are made or where there are many versions of each product, requiring expensive reprogramming of robots.

But that list is growing shorter.

Upgrading Distribution

Inside a spartan garage in an industrial neighborhood in Palo Alto, Calif., a robot armed with electronic "eyes" and a small scoop and suction cups repeatedly picks up boxes and drops them onto a conveyor belt.

It is doing what low-wage workers do every day around the world.

Older robots cannot do such work because computer vision systems were costly and limited to carefully controlled environments where the lighting was just right. But thanks to an inexpensive stereo camera and software that lets the system see shapes with the same ease as humans, this robot can quickly discern the irregular dimensions of randomly placed objects.

The robot uses a technology pioneered in Microsoft's Kinect motion sensing system for its Xbox video game system.

Such robots will put automation within range of companies like Federal Express and United Parcel Service that now employ tens of thousands of workers doing such tasks.

The start-up behind the robot, Industrial Perception Inc., is the first spinoff of Willow Garage, an ambitious robotics research firm based in Menlo Park, Calif. The first customer is likely to be a company that now employs thousands of workers to load and unload its trucks. The workers can move one box every six seconds on average. But each box can weigh more than 130 pounds, so the workers tire easily and sometimes hurt their backs.

Industrial Perception will win its contract if its machine can reliably move one box every four seconds. The engineers are confident that the robot will soon do much better than that, picking up and setting down one box per second.

“We’re on the cusp of completely changing manufacturing and distribution,” said Gary Bradski, a machine-vision scientist who is a founder of Industrial Perception. “I think it’s not as singular an event, but it will ultimately have as big an impact as the Internet.”

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Robots mean that labor costs don’t matter much, so you might as well locate in advanced countries with large markets and good infrastructure (which may soon not include us, but that’s another issue). On the other hand, it’s not good news for workers!

This is an old concern in economics; it’s “capital-biased technological change”, which tends to shift the distribution of income away from workers to the owners of capital.

Twenty years ago, when I was writing about globalization and inequality, capital bias didn’t look like a big issue; the major changes in income distribution had been among workers (when you include hedge fund managers and CEOs among the workers), rather than between labor and capital. So the academic literature focused almost exclusively on “skill bias”, supposedly explaining the rising college premium.

But the college premium hasn’t risen for a while. What has happened, on the other hand, is a notable shift in income away from labor:

If this is the wave of the future, it makes nonsense of just about all the conventional wisdom on reducing inequality. Better education won’t do much to reduce inequality if the big rewards simply go to those with the most assets. Creating an “opportunity society”, or whatever it is the likes of Paul Ryan etc. are selling this week, won’t do much if the most important asset you can have in life is, well, lots of assets inherited from your parents. And so on.

I think our eyes have been averted from the capital/labor dimension of inequality, for several reasons. It didn’t seem crucial back in the 1990s, and not enough people (me included!) have looked up to notice that things have changed. It has echoes of old-fashioned Marxism — which

shouldn't be a reason to ignore facts, but too often is. And it has really uncomfortable implications.

But I think we'd better start paying attention to those implications.

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Robots caring for the elderly

As the baby boomer generation grows old and if the number of elderly care workers fails to grow with it, many people might end up being cared for by robots. According to the Health and Human Services Department, there will be 72.1 million Americans over the age of 65 by 2030, which is nearly double the number today. According to the Bureau of Labor Statistics, the country will need 70 percent more home aide jobs by 2020, long before that bubble of retirees. But filling those jobs is proving to be difficult because the salaries are low. In many states, in-home aides make an average of $20,820 annually.

"There are two trends that are going in opposite directions. One is the increasing number of elderly people, and the other is the decline in the number of people to take care of them," said Jim Osborn, a roboticist and executive director of the Robotics Institute's Quality of Life Technology Center at Carnegie Mellon University. "Part of the view we've already espoused is that robots will start to fill in those gaps."

Researchers at the Georgia Institute of Technology have developed Cody, a robotic nurse the university says is "gentle enough to bathe elderly patients." There is also HERB, which is short for Home Exploring Robot Butler. Made by researchers at Carnegie Mellon, it is designed to fetch household objects like cups and can even clean a kitchen. Hector, a robot that is being developed by the University of Reading in England, can remind patients to take their medicine, keep track of their eyeglasses and assist in the event of a fall.

The technology is nearly there. But some researchers worry that we are not asking a fundamental question: Should we entrust the care of people in their 70s and older to artificial assistants rather than doing it ourselves?

Sherry Turkle, a professor of science, technology and society at the Massachusetts Institute of Technology and author of the book "Alone Together: Why We Expect More From Technology and Less From Each Other," did a series of studies with Paro, a therapeutic robot that looks like a baby harp seal and is meant to have a calming effect on patients with dementia, Alzheimer's and in health care facilities. The professor said she was troubled when she saw a 76-year-old woman share stories about her life with the robot.

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Bringing robots out of their cages

AS GIANT welding robots go about their business in a modern car factory, the scene looks like a cyberpunk vision of Dante's "Inferno". Amid showers of sparks, articulated mechanical arms nearly the size of telephone poles move sections of partially built vehicles so "scarily fast" that anyone who accidentally ends up in the wrong place is as good as dead, says Rodney Brooks, the boss of Rethink Robotics, a robot-maker based in Boston. For this reason, industrial robots operate in cages or behind security fences. But by segregating robots from humans, such safety measures greatly limit the tasks that robots can perform. In car factories, for example, most of the final assembly is done, expensively, by hand.

Neither workers nor robots can reach their productive potential without interacting more closely, says Volker Grünenwald, head of systems integration at Pilz, a German engineering firm. Eager to design machines that can be used for a wider range of tasks, technologists are now figuring out how to bring robots "out of the cage" so that they can work safely and more productively with people. The aim is to combine the dexterity, flexibility and problem-solving skills of humans with the strength, endurance and precision of robots. The emergence of "co-operative" or "collaborative" robots, as these new machines are called, could also lead to robots that are better able to help out in the office, at school or in the home.

Last December, in a company first, German carmaker BMW introduced a slow-moving collaborative robot in its factory in Spartanburg, South Carolina, which co-operates with a human worker to insulate and water-seal vehicle doors. The robot spreads out and glues down material that is held in place by the human worker's more agile fingers. When this is done without the help of a robot, workers must be rotated off this uncomfortable task after just an hour or two to prevent elbow strain. Today four collaborative robots work in the facility, and more are coming, in Spartanburg and elsewhere.

COLLBORATIVE ROBOTS

BMW expects "a big, massive roll-out" of the technology in 2014 in Germany, despite the country's tighter restrictions on human-robot interaction, says Stefan Bartscher, BMW's head of innovation. The company plans to design additional tasks for collaborative robots as they are progressively introduced in five carmaking plants. These robots will require different technologies from those found in traditional, non-collaborative robots. Indeed, when it comes to dealing with humans, robots have so few skills that even a seemingly simple task such as handing over an object commonly ends in a tug-of-war, says Elizabeth Croft, a roboticist at the University of British Columbia

Handing tools over

With funding from GM, America's biggest carmaker, Dr Croft's Collaborative Advanced Robotics and Intelligent Systems Laboratory is designing robots that can execute "unscripted" handovers to humans. This requires the robot to determine whether a person wants and is authorised to have a particular item—be it a power drill, a document or a cup of tea. The robot must then present the item in the most advantageous orientation for the human, adjusting its grip as the

object's weight shifts. Finally, the robot must let go only when its sensors detect that the object is being purposefully and safely taken away.

Safety first

Dangerous industrial machinery is typically shut down the instant a worker "breaks" an infra-red light curtain or opens a door to enter a robot's cage. But safety systems of this sort have drawbacks. Breaches typically stop an entire production line, alarming employees and causing delays that may cascade throughout the plant. Pilz has developed a multi-camera computer system that monitors the area surrounding robots and adjusts their behaviour accordingly.

Safety

Called SafetyEYE, the system allows a robot to, say, rivet an aircraft wing without sectioning off the entire area from people. Aware of its surroundings, the robot can roll along the length of the wing, slowing its movements if a worker approaches or, if he gets too close, stopping altogether without disrupting activity elsewhere. Since it was launched in 2007, SafetyEYE has allowed robots to be deployed in parts of factories where setting up light curtains or safety cages would be expensive or impractical.

There are additional ways to avert accidents. Some robots have red emergency-stop buttons. Researchers have even made pressure-sensing "artificial skin" by sandwiching a rubbery silicone made with carbon black, a conductive material, between electrodes. Compressing it with a slap generates an electrical signal that instructs the robot to freeze. For an additional override function, robots could be fitted with microphones and stopped with a shout, says Per Vegard Nerseth, robotics boss at ABB, a Swiss industrial giant based in Zurich which has ramped up development of collaborative robots in the past few years.

Robots capable of teaming up with people are typically used to perform tasks that are being automated for the first time, so productivity gains are especially high—provided the devices are quick and easy to program. A one-armed robot (pictured above) made by Denmark's Universal Robots (UR) to "work right alongside employees" can be set up within an hour. Programming usually takes less than ten minutes. The user manually moves the arm and the tool it is holding from the starting point of a task to the end point, tapping a touchscreen "record" button at points along the way. Once the task is named and saved, the robot can be put to work.

Programming collaborative robots will become even easier as software improves. Already, some experimental robots can be configured using spoken commands such as "create new skill" and "save pose". Dr Nerseth of ABB reckons that it will eventually be possible to program robots using speech. And the control files for robots can be posted online for downloading by other users, who can tweak them as needed.

At the same time, better artificial intelligence is even rendering some programming unnecessary. Rethink Robotics says its two-armed collaborative robot, called Baxter (pictured

below), uses common sense to figure out some movements on its own. Factory workers use Baxter's touchscreen "face" to point out the objects it will handle. Baxter then studies them from all angles to determine if, say, a glass is best grasped by the outside or by inserting and opening its fingers. If a conveyor belt bringing items to be processed slows down, so does Baxter. More than 100 have been sold since the robot went on sale in late 2012.

For decades robots have been getting faster, stronger and more precise. The new breed of collaborative robots, by contrast, will move more slowly, lift less and be less precise. And yet this is the breed that will usher in the real robotics revolution, says Dr Brooks of Rethink Robotics, because such qualities will allow robots to team up with people. He points out that it was the advent not of mainframes but of less powerful but more user-friendly PCs that carried computing into the mainstream.

No matter how flexible, easy to program and safe they are, collaborative workers may not be welcomed by human workers to begin with. The experience of Alumotion, an Italian distributor of UR's robots, is illustrative. Workers fear being replaced by robots, says co-owner Fabio Facchinetti, so his salespeople carry demonstration units in unmarked cases and initially only meet a potential client's senior management behind closed doors.

But rather than firing workers, Alumotion's clients often end up adding shifts because production costs drop. RSS Manufacturing in Costa Mesa, California, says its new UR robot is helping the firm compete against Asian makers of brass plumbing fixtures. Geoff Escalette, the firm's boss, plans to buy more robots because without them some milling machines run at about 60% capacity for lack of a nearby worker able to load objects fast enough. It is worth remembering that people also used to worry that computers would steal jobs, notes Chris Melhuish of the Bristol Robotics Laboratory, a joint venture between the University of Bristol and the University of the West of England. Instead, computers helped people become more productive.

Don't frighten the humans

To keep human workers at ease, collaborative robots should also have an appropriate size and appearance. Takayuki Kanda of the ATR Intelligent Robotics and Communication Laboratories in Kyoto says that collaborative, humanoid robots should generally be no larger than a six-year-old, a size most adults reckon they could overpower if necessary. Large eyes make robots seem friendlier and, crucially, more aware of their surroundings.

To interact smoothly with people, robots will also need "social intelligence". It turns out, for example, that people are more trusting of robots that use metaphors rather than abstract language, says Bilge Mutlu, the head of the robotics laboratory at the University of Wisconsin-Madison. He has found that robots are more persuasive when they refer to the opinions of humans and limit pauses to about a third of a second to avoid appearing confused. Robots' gazes must also be carefully programmed lest a stare make someone uncomfortable. Timing

eye contact for “intimacy regulation” is tricky, Dr Mutlu says, in part because gazes are also used in dialogue to seize and yield the floor.

When a person enters a room, robots inside should pause for a moment and acknowledge the newcomer, a sign of deference that puts people at ease, says the University of British Columbia’s Dr Croft. Robots also appear friendlier when their gaze follows a person’s moving hands, says Maya Cakmak of Willow Garage, the California-based maker of the PR2, a $400,000 robot skilled enough to make an omelette—albeit slowly.

It will probably be a decade or two at least before the descendants of PR2, Care-O-bot, and other “home assistance” or “companion” robots will be nimble and intelligent enough to zip autonomously through houses performing chores. They will need far better sensors, movement-control actuators and batteries, and much smarter software. They must also be capable of displaying empathy or they will be rejected, says Kerstin Dautenhahn, head of a “social robotics” team at the University of Hertfordshire in Britain.

Her team’s Care-O-bot robots crunch data from 60-odd household sensors that monitor door and cupboard hinges, taps, electrical appliances and so forth. If medicine isn’t taken, say, the robot may alert relatives or the hospital. It is vital that a robot of this sort is not perceived as hostile, but as having its owner’s best interests at heart.

One way to do this is to give robots a defining human trait—the ability to make mistakes. Maha Salem, a researcher under Dr Dautenhahn, programmed a humanoid Asimo robot, made by Honda, to make occasional harmless mistakes such as pointing to one drawer while talking about another. When it comes to household robots, test subjects prefer those that err over infallible ones, Dr Salem says.

Another approach uses sensors to assess the state of nearby humans, so that robots can respond appropriately. With funding from the European Union, researchers are using bracelets equipped with electrodes to enable classroom robots to determine whether students are bored, confused or anxious. The robots can adapt their teaching style accordingly, says Iolanda Leite of the Instituto Superior Técnico, a Portuguese university participating in the programme, which is called EMOTE. One of its objectives is to foster “social bonding” between people and robots.

Such bonding could have some surprising uses. In experiments carried out at Yale University involving a biped humanoid called NAO, made by a French firm called Aldebaran Robotics, children proved to be just as willing to share secrets with it as they were with an adult. The researcher who performed the experiments, Cindy Bethel, who is now at Mississippi State University in Starkville, has also found that children who have witnessed a crime are less likely to be misled in a forensic interview with a robot than with a human expert—even one trained to obtain testimony. Mark Ballard of the Starkville police department, who has been working with Dr Bethel, reckons that the robots needed to conduct “child friendly” forensic interviews will be available by 2020.

What's next? Market research is not much good at predicting developments in the field of collaborative robots, says Bruno Bonnell of Robolution Capital, a robotics investment fund in France. For one thing, he says, people say they want complete control over robots, but once they start using them they actually prefer them to be as autonomous as possible. Working alongside robots changes the way people think about them, in other words. Whether on the factory floor, at home or in the classroom, the evolving relationship between human robots will be defined by a process of collaboration.

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On a recent morning Natanel Dukan walked into the Paris offices of the French robot maker Aldebaran and noticed one of the company's humanoid NAO robots sitting on a chair. Mr. Dukan, an electrical engineer, could not resist. Bending over, he kissed the robot on the cheek. In response the NAO tilted its head, touched his cheek and let out an audible smack.

It is certainly a very French application for a robot, but the intimate gesture by the $16,000, two-foot robot, now being used in academic research labs and robotic soccer leagues, also reflects a significant shift.

Until recently, most robots were carefully separated from humans. They have largely been used in factories to perform repetitive tasks that required speed, precision and force. That generation of robots is dangerous, and they have been caged and fenced for the protection of workers.

But the industrial era of robotics is over. And robots are beginning to move around in the world.

More and more, they are also beginning to imitate — and look like — humans. And they are beginning to perform tasks as humans do, too.

Many of the new generation of robots are tele-operated from a distance, but are increasingly doing tasks independent of direct human control.

For instance, Romeo, a five-foot humanoid robot, will soon be introduced by Aldebaran as a "big brother" to the pipsqueak, kissing NAO robot. Created with the assistance of $13.8 million from the French government, the costly robot is being programmed to care for older people and assist in the home.

To provide useful assistance, it will have to do more than the repetitive work already being performed by commercial robots in factories, hospitals and other settings. Moreover, the new robots are designed not just to replace but to collaborate with humans.

The idea that robots will be partners of humans, rather than stand-ins or servants, is now driving research at universities and industrial laboratories. This year, new United States industry standards for robotic manufacturing systems were published, underscoring the emergence of

the field. The standards specify performance requirements that will permit human workers to collaborate with robots directly, and they reverse manufacturing guidelines from 1999 that prohibited “continuous attended operations” requiring humans to be in close contact with robots that were deemed unsafe by the industry.

Today’s robot designers believe that their creations will become therapists, caregivers, guides and security guards, and will ultimately perform virtually any form of human labor. (Robots that can think on their own — that is, perform with high levels of artificial intelligence — have yet to arrive.)

The key to this advance is the new robots’ form. Their humanlike appearance does more than satisfy science-fiction fantasies. Roboticists say they are choosing the human form for both social and technical reasons. Robots that operate indoors, in particular, must be able to navigate a world full of handles, switches, levers and doors that have been designed for humans.

Roboticists also point out that humans have an affinity for their own shape, easing transitions and making collaboration more natural. Creating robots in humanoid form also simplifies training and partnerships in the workplace, and increases their potential in new applications like caregiving.

It is still unclear how well these new faux-people will be accepted by society, for they raise fundamental questions about what it means to be human. However, rapid improvements in computer vision, processing power and storage, low-cost sensors, as well as new algorithms that allow robots to plan and move in cluttered environments, are making these new uses possible and in the process changing the nature of robotics.

“This is the wave that’s happening in robotics right now,” said Charlie Kemp, an associate professor in biomedical engineering at the Georgia Institute of Technology in Atlanta. “Things are not the same when you’re interacting with people. That’s where we want robots to be; it’s where we see there are huge opportunities for robots; and there are very distinct requirements from what led to the classic industrial robot.”

And so on factory floors around the world, a new breed of robot is being manufactured by companies like Rethink Robotics of Boston, which makes a humanoid robot for simple factory automation tasks, and Universal Robots of Odense, Denmark, which makes a dual robot-arm system designed for doing more traditional factory applications, but without cages.

Rethink Robotics recently released a video of its robot, Baxter, making a cup of coffee with a Keurig coffee machine. The company said the humanoid robot, with tong-like hands and a computer-screen face, was trained to carry out a variety of preprogrammed coffee-making tasks in just several hours.

In Dr. Kemp's Healthcare Robotics lab at Georgia Tech, a five-foot robot named Cody, which is able to sense forces on its arms and has a base that allows it to move gracefully, is being used as a dance partner for both experienced human dancers and patients in physical therapy.

"This is a way that robots can be used for fun, interactive exercise in rehabilitation," Dr. Kemp said. "We can also use it as a tool to understand whole body physical interaction between people and robots."

At Carnegie Mellon University, Manuela M. Veloso, a professor of computer science, has developed a series of mobile robots she calls CoBots to perform tasks like delivering mail, guiding visitors to appointments and fetching coffee. She calls it "symbiotic autonomy," since the robots also rely on humans. For example, because they don't have arms, they can't operate elevators, so they have been programmed to wait and ask for human assistance. If they get lost, they stop, call up a map of the building on their computer screens, interrupt a passing human and say, "I am lost, can you tell me where I am?"

"The robotics community calls the idea cheating," Dr. Veloso said, "but it's not. It's the secret to real autonomy."

To function in the real world and to be safe, robots must have a radically different design from factory robots, which are based on "stiff" actuators capable of moving with great speed to a precise position. The new robots have "compliant actuators," which respond to external forces by yielding in a natural fashion.

The original research into this area of what is now known as "soft robotics" began in the mid-1990s at the Massachusetts Institute of Technology, with work by Gill Pratt, who was exploring walking robots, and Matthew Williamson, then a graduate student and now director of technology development at Rethink Robotics.

The research was not initially focused on solving the problem of human interaction, but the scientists soon realized the implications, recalled Dr. Pratt, who is now the project manager for the Defense Advanced Research Projects Agency's Robotics Challenge, an upcoming contest that is intended to advance robotics technology to be used in natural disasters and other emergencies.

"It actually started with numerically controlled machine tools," he said — using computer-controlled robots to perform milling tasks.

For those manufacturing uses, what mattered was the precise positioning of the robot limb. However, Dr. Pratt was focused on developing walking robots that could move in the natural world, and force was more significant than precision to meet that challenge: "There the position of the limb didn't matter so much, but what mattered was how hard was the robot pressing on the world, and how hard the world was pressing back on the robot," he said.

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The Zeno R25 is designed as an inexpensive version of the Zeno R50 and RoboKind says that it will retail for US$2,700. However, the company points out that even though it's made to be more affordable, it also enjoys some advances on the Zeno R50.

Though it looks a bit like a supersized toy, the Zeno R25 packs some fairly sophisticated technology in its humanoid form. Its brain is an OMAP 4460 dual core 1.5 GHz ARM Cortex A9 processor with 1 GB of RAM and 8 GB of memory that can be expanded via a MicroSD expansion slot. It runs mainly on open source software to allow for hobbyist work and user customization and the robot also has Wi-Fi and Bluetooth connectivity.

Since the robot is intended to be interactive, it's equipped with a 5-megapixel autofocus camera in its right eye. Backing this up is a battery of visual algorithms for detecting colors, motion, faces, and QR codes. In addition, Robokind's CompuCompassion system is designed to allow the Zeno R25 to identify and respond to emotions.

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The robot that can speak 19 languages (via the cloud)

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Robots in China

Step into the factory of Chinese SUV and truck maker Great Wall Motors, and it's easy to forget you're in the world's most populous country. Swiss-made robots pivot and plunge, stamping metal door frames and soldering them to the skeletal vehicle bodies of a mini-SUV called the Haval M4. The blue-smocked workers in yellow hard hats are few and far between here in Great Wall's largest factory complex, located in Baoding, some 90 miles southwest of Beijing.

"With automation, we can reduce our head count and save money," says Hao Jianjun, Great Wall's general manager, who has invested $161 million into mechanizing four plants with 1,200 robots. The average price of a factory-floor robot is around $50,000 before installation. "Within three years, this cost will be completely paid for in savings from reduced worker wages," says Hao. After the robots were added, the number of welders at Great Wall dropped from 1,300 to around 400.

Last year sales of industrial robots in China reached 22,577 units, up 51 percent over 2011. That puts China just behind Japan and South Korea, but ahead of Germany and the U.S., in the purchase of new robots. With robot sales quadrupling from 2006 to 2011, China is on track to

become the world's largest industrial cyborg market by 2014, predicts the Frankfurt-based International Federation of Robotics.

China's car industry has led the automation wave, particularly at its joint ventures with General Motors (GM), Honda Motor (HMC), and Volkswagen (VOW:GR). Consumer electronics, food and beverage processing, and the plastics and textile industries are following suit. "What we are seeing is robots increasing in a lot of industries where they are already common in the rest of the world," says Yuchan Li, an analyst with economic consultancy GaveKal Research. "For China, there is still a lot of low-hanging fruit when it comes to automation."

China is now an important market for robot makers such as Japan's Fanuc, Germany's Kuka and Siemens (SI), and Rockwell Automation (ROK) of the U.S. Swiss-based ABB (ABB) has chosen Shanghai to base its global robotics business and produce robotic systems for auto and electronics clients.

One factor driving the switch to robots is demographics. Next year China's labor force will peak at 1 billion before starting to shrink, in part because of the nation's one-child policy. Labor shortages are already common and are driving wage inflation, up around 20 percent annually in recent years. Beijing is encouraging automation by forcing up minimum wages. A rise in labor costs "ups the ante for manufacturing companies so they change their production processes and move up the value chain," says Louis Kuijs, chief China economist at Royal Bank of Scotland (RBS) in Hong Kong.

Finally, the level of precision required to make many high-end consumer electronics and other products now lies beyond the abilities of most humans. Mistakes can be very costly, points out Raymond Tsang, a partner at consultant Bain & Co. in Shanghai.

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To some economists, stubbornly high unemployment rates in the U.S. and Europe are at least partly attributable to the rise of machines. "There's no question that in some high-profile industries, technology is displacing workers of all, or almost all, kinds," wrote Paul Krugman in the *New York Times* on Dec. 9, adding that "many of the jobs being displaced are high-skill and high-wage." Massachusetts Institute of Technology professor Erik Brynjolfsson, co-author of *Race Against the Machine*, says: "Robots are becoming more capable and skilled, and people with the same sets of skills are not as much in demand." According to this view, robots aren't change agents. They're destroyers of worlds.

Yet the robot revolution doesn't have to cause panic. While robots can claim some technological superiority over humans, even the most sophisticated machines have limitations. Automation will inevitably displace jobs, but it's already bringing fresh economic opportunities as well. The last two decades have shown how technology can create industries even as it turns whole cities into has-beens. The ratio of jobs created to jobs eliminated by robots and where all

the newfound wealth ultimately winds up are entirely dependent on how workers, businesses, and policymakers prepare for this new era.

All that said, it's too soon to write dirges for the humble human worker. In today's workplace, there are still things that robots just can't do. At Quiet Logistics, an order-fulfillment center for online retailers in Devens, Mass., 64 robots are used to move merchandise around the warehouse, but 330 humans are required to fold, package, and ship the products. Why not have robots do the whole thing? "People are really good at picking up things," says Bruce Welty, Quiet Logistics' chief executive officer. "It's very difficult to get a robot to make the decisions required that a human makes to pick something out of a bin—particularly if there are many different things in that bin."

Humans continue to have another advantage over robots: They remain a more flexible workforce. To handle this year's holiday shopping season, Amazon.com (AMZN) hired 50,000 part-time workers. While seasonal, part-time labor is not something you can necessarily build an economy on, it's worth noting that Amazon didn't buy more robots, because you can't hire a robot part-time (yet). What would additional robots do when demand receded? "Come January," says Jim Tompkins, a supply-chain consultant, "all that automation's going to be staring you in the face."

This is the state of the robotic arts today: a point where humans and robots share labor, with robots handling the simple and repetitive and humans taking care of the complex and dynamic. Some robotics designers and engineers would like this to be a blueprint for the future, where increased automation does not necessarily displace human beings. Rodney Brooks, a former MIT robotics professor, is an optimist. To Brooks, who is also founder and chairman of robot maker Rethink Robotics, these machines are going to help workers, not compete with them. He points out that personal computers didn't get rid of office workers, they changed the jobs people did. When it comes to robots, "it's not a one-for-one replacement," he says. "People are so much better at certain things."

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Reshoring jobs

They may only be six employees in a small warehouse outside of Danbury, but the technicians at Practical Robotic Services L.L.C. are playing a vital role in the movement to bring manufacturing back to the United States.

While the lure of cheap labor costs in Asia and elsewhere has moved manufacturing facilities offshore for years, many company executives are now finding it cheaper to move back home and use robotics to do the job.

“Manufacturers have been paying $1 per person, per day (in Asia),” said Glenn Sahlin, PRS technology manager. “That’s what we have to compete with. That’s not politics. That’s the way it is and the best way to compete is with automation.”

With better technology available amid raising labor costs in China, there’s been a sharp increase in the number of manufacturers moving back to the U.S. In fact, more than half of large manufacturers are now planning or considering “reshoring” from China, according to a recent survey by the Boston Consulting Group.

Using technicians and programmers like those at PRS, manufacturers are better able to program robots to assemble products and move them along the supply chain faster. By completing this process in the U.S., survey respondents said they’re also able to save on transportations costs, produce higher quality products and be closer to their customers. About 200 manufacturers nationwide responded to the August survey. The group estimates between 2.5 million and 5 million manufacturing-related jobs will be created in the United States by 2020.