Deep Automation and the World of Work

Martin Upchurch and Phoebe Moore

Introduction

Recent technical advances in digitalisation, robotics and artificial intelligence (AI) have seen a flush of applications in the world of work. The technologies span interactive web based communication such as social media, as well as 3-D printing, wearable self-tracking devices, autonomous cars, smart phone apps., machine learning (ML) and mobile robotics (MR). These developments are conjoined with an expansion of computer algorithms, which have a triple use of predicting behaviour based on stored data and flow charts, recording performance against targets, and enhancing the flexibility of robots. Various terminologies have been applied to the new developments. Phrases such as 'gig economy', 'app economy', or 'platform economy' are now applied to the re-organisation of work whereby services can be ordered through smart phone apps. which range from delivering food, hiring a taxi, renting a walk for your dog, or booking a night's bed-and-breakfast accommodation[1]. Those who own and control access to the app. provide no service other than linking consumer and worker, while the worker is not employed by the app. but is (albeit controversially) 'self-employed'. Some predictions suggest that the technical advances mean that almost half of all jobs in the USA may be under threat of disappearance in the next two decades (Frey and Osborne, 2013). Therapists, choreographers, surgeons and social workers are recorded among the occupations least likely to lose their jobs, while clerical workers, telemarketers, watch repairers and librarians are most likely. The combined processes have been suggested to be akin to 'deep automation' whereby society is transformed with the introduction of new social classes in a different type of economy (W. Brian Arthur, 2011). The dramatic transformation in work is taken further when considering robotics and AI, with one popular commentary predicting that we are entering an era 'defined by a fundamental shift in the relationship between workers and machines…machines themselves are turning into workers, and the line between capital and labor is blurring as never before' (Ford, 2015: xii). A vision of technological 'Singularity' is apparent, whereby our intelligence, it is argued, would become 'non-biological' and creativity would be unbounded by human limitations. Machines would dominate production through processes of self-improvement, re-writing their own software to outstrip the functional capabilities of the human brain (Kurzweil, 2005).

Many of these visions present a potentially catastrophic vision for human labour, and scholarly analysis of the type of society that digitalisation and associated aspects of 'deep automation' might usher have been widespread. Most prominent, is the view that we are moving towards a society based on immaterial labour, whereby material production has evaporated into the ether of a weightless world. Instead we are becoming bounded by a world where power lies 'both everywhere and nowhere', dominated by service work and immaterial labour embracing universal cultural 'products', knowledge and communication (Hardt and Negri, 2000). It is a new era where accumulation of knowledge usurps accumulation of capital as the driver of the system, and makes computerisation and digitalisation 'different' from other technologies, such as the telegraph, telephone or jet engine, which have similarly condensed time and space in the past. Indeed, the new alleged immateriality challenges the classical Marxist view of value creation through the labour process. For if value creation is now to be both 'free' and a 'weightless' product of culture and knowledge, rather than of the exploitative interaction between the forces of production and the social relations of production, then are we also to move to a world where human labour becomes redundant, where 'knowledge-driven production tends towards the unlimited creation of wealth, independent of the labour expended.' (Mason, 2015: 136).

We also recognise that prospects for resistance to new technology and automation are integral to capitalism, precisely because technology is not a neutral, exogenous factor for change, but is rather a tool for capital that will be utilised in a double dynamic - to boost competitiveness and to control or suppress labour autonomy. Contemporary examples of resistance in the UK illustrate this point. They include the unofficial stoppages by dockworkers in the 1970s against the technology of containerisation which threw them out of work. Prior to containerisation ships spent almost half their time in dock, and the sacks and pallets that contained the goods were taken off ship by crane and hooked ashore by individual dockworkers. Containerisation allowed for mass transit via overhead platforms, onshore storage of goods and direct loading to lorries and trains. It also required deep water ports to accommodate larger ships using economies of scale. Consequently, many small ports closed or work shifted seawards away from river inlets to deeper water. The number of dockworkers in the Port districts of east London, for example, fell by 150,000 in a ten-year period between 1966 and 1976 (El-Sahli and Upward, 2015 p2), and the class composition of the area changed accordingly. A vivid example of the immediate impact of the introduction of new technology also came in the 'old' media in the 1980s as hot metal compositing and typesetting was replaced by computer-based digital input. The Wapping dispute in 1986 followed the defeat of the miners a year earlier and was led by Rupert Murdoch against the traditional print unions (the journalists' union, NUJ, had already voted to support the move to the new plant, the few dissenting voices were also sacked by Murdoch). 5500 men and women, working on Fleet Street, were dismissed as they struck against plans to shift newspaper production (of The Times, The Sun and the News of the World) to the new plant in London's east end docklands. The new plant was fully geared to using new technology and the solidarity picketing at night near the gates of the plant proved unsuccessful in stopping Murdoch as he brought in scab labour with support from the electricians' union EETPU.

Disputes such as this proved to be defining moments in creating new ways of producing and organising work. Spirited resistance from collectivised labour, however, has not always been enough to prevent technological change.

This chapter seeks to explore the technology driving deep automation, but also to critique the academic debates that have arisen in its aftermath. A classical Marxist perspective is employed, first to review the relationship between technology, capitalism and the labour process, and second to explore the evidence for claims that digitalisation and deep automation means we are moving to a weightless world of work. Having briefly reviewed the main perspectives on technology within historical frames in our Introductory chapter, we can also begin to ask a key question. That is to what extent is the contemporary new automation technology, spawned from advances in computerisation and digitalisation different from, or the same as, other technologies? To help provide an answer we first review debates about digitalisation and deep automation, before examining the evidence of change.

The Early Challenge of Digital Automation

The first computers, originating from tabulating machines but with digital technology, began to be developed at the end of the 1940s. It was an incremental development, the adding, sorting and tabulating functions of tabulators were enhanced by electronics and circuits made from vacuum valves. Production in the 1950s was dominated by firms such as International Business Machines (in the USA), who were market leaders in punch card tabulating machines invented by company founder Herman Hollerith in 1890 (see DeLamarter, 1986, for a critique of IBM's market dominance). It was not until the late 1960s that the first computer-based information systems began to enter the workplace. This was spurred by the continuous development of integrated circuits on micro-chips, which entered the mass production stage after being used in the US Minuteman missile and Apollo space programmes. The early workplace computers were confined to a whole room in terms of size, and it was not until 1965 that a free-standing computer the size of a typewriter, the *Programma101,* was developed by the Italian company Olivetti. Olivetti had managed the technological breakthrough with the development of a programmable magnetic card, the forerunner of the 'floppy disk'[2]. Mass production and mass usage of desktop computers did not take place until the late 1980s, spurred by further advances in micro-chip technology and lowering of costs.

Alongside the rise of computerisation, the immediate post war period also saw the growth of robotics and associated technologies of artificial intelligence (AI). If we define a 'robot' as a machine with flexible moving 'arms' we can record that the first such mechanised mannequins or musical automata were recorded as long ago as the 3rd Century BCE. An early humanoid robot, blowing a trumpet, was made in 1810 by Friedrich Kaufmann in Dresden. However, the construction of more complex and autonomous robots, programmed to mimic human movement and neural responses, is extremely difficult, and is linked to developments in artificial intelligence. The first electronic and autonomous robots were made in Bristol, England by William Grey Walter in 1948, and it was not until 1954 that a programmable and digitally computerised robot – *Unimate* – was made in the USA by George Devol, which was subsequently used by General Motors to lift and stack hot metal in its New Jersey factory from 1961 (Waurzyniak, 2006). The link with AI focuses on the robot's ability to 'think' in increasing degrees of complexity which mimic and even surpass human brain power. We will discuss robot 'thinking' as a form of consciousness later in the chapter but in the early days of development such 'thinking' was measured by the degree to which the robot or computer passed the 'Turing Test' (after the celebrated British computer scientist Alan Turing). The test is based on the proposition that a machine would be able to think if it could hold a conversation that was indistinguishable from one with a human being (Turing, 1950). In purely technical terms, the prospect of a world where machines did all the work (computers, robots, AI and algorithms) has been termed a state of 'technological Singularity' by commentators following the Hungarian mathematician Neumann János Lajos (John von Neumann) from as early as the 1950s. Such a world would envisage not only human-less factories and paper-less offices but also driver-less cars, and homes with robots fulfilling housework and other domestic chores.

As its usage spread through the 1950s and 1960s computerised automation began to be presented as a fundamental break with old technology, allowing for a different world of work based on cybernetics and its associated feedback loops which enabled more efficiency in decision-making. Excitement with new technologies at the time infected political discourse, famously with the speech given in 1963 by the leader of the British Labour Party, Harold Wilson, who called for a new scientific revolution based on computerisation, automation and the 'white heat of technology' so that social democrats could 'replace the cloth cap [with] the white laboratory coat as the symbol of British labour'[3]. Alvin Toffler's (1970) best-selling *Future Shock*, predicted a massive transformation of work, entailing the deconstruction of the 'traditional' job, or the introduction of more leisure time for workers in aggregate as work 'collapsed' and the unemployed drifted into leisure. During the 1970s the fashion for predicting a 'leisure society' embraced sections of the trade unions, with the 1979 publication of *The Collapse of Work* by Clive Jenkins and Barry Sherman of the UK white-collar union ASTMS. In academic circles Daniel Bell's *The Coming of Post Industrial Society* in 1973 predicted a society driven by new 'intellectual' technology with scientists and engineers in occupational ascendancy. Bell's vision was expanded by Jeremy Rifkin two decades later in 1995 who foretold the 'end of work', and by André Gorz's postulations of the end of a ‘wage-based society’. The common denominator in all these studies over a 30-year period was an emphasis on the rise of ‘knowledge work’ and its replacement of manual labour and the ‘traditional’ working class. Manuel Castells, in his monumental trilogy *The Information Age* (1996), reinforced the tendency towards technological determinism and placed information technology as the *root* of modern social change, arguing that the net replaces hierarchies as the dominant form of social organisation, and the individual constructs her self-identity within the same technologically based process.

However, the predictions of a brave new world heralding the end of work or a leisure society did not materialise. Average working hours in the advanced industrial economies fell considerably in the immediate post war period from 1950 to around 1980, but since then, as computerisation has become a widespread feature of work, we find that the downward trend has been reversed and in many countries (such as the United States) has actually shown a tendency to *increase* (Lee *et al* 2007: 32; Pradella, 2015)[4]. Second, any leap in productivity, deemed necessary for digitalised automation to enable the end of work, has also failed to transpire. There will be an increase in organisational and worker productivity after the introduction of newer forms of ICT, as there was in the late 1990s, or from putting more of the business on-line. However, such boosts to productivity appear to be unsustainable (Henwood, 2003). Once the employee has learnt how to use a computer and email, for example, the boost in her ability to process work more speedily subsequently plateaus. As with working hours, the evidence over the last two or three decades would suggest a *worsening*, rather than improving trend. US Conference Board data analysed by the economist Michael Roberts, shows us that between 1960 and 1980 average productivity growth per year in advanced economies was slightly over 4 per cent, it averaged approximately 2 per cent between 1980 and 2000, but fell further to 1 per cent and less after 2000[5].

We can point to reasons for the failure of digitalised automation in its first flush to produce either a leisure society or a great leap forward in productivity. First, capital has no incentive to introduce any labour-saving technology for benevolent reasons that may enhance the public good. Individual employers will need to recoup the cost of investment in new technologies by ensuring the necessary reduction in unit labour costs is achieved. As we have already described, the introduction of technology within an enterprise will also induce a tendency over time to reduce surplus value as capital-bias takes effect, and so to maintain competitiveness with its rivals an individual capital must use countervailing tendencies, such as extending the working day, or intensifying work. The industrial sociologist John Child elaborated on this and concluded in his review of the evidence published in 1975 that computerisation was used by employers *not* to reduce work hours but rather to extend routinisation of tasks by digital means so that the 'logic' of advanced information systems 'would appear to extend the routinisation, indeed bureaucratisation of work to clerical and even managerial levels where this may hitherto have been absent' (Child, 1975: 149). Child's initial findings of de-skilling and routinisation were confirmed by many others within the labour process theory school of analysis during the 1980s and 1990s (see Boreham *et al*, 2008 ch. 2 for a review). Second, it is not the case that there is ever increasing supply and demand for new technological innovations. The 'runaway' scenario, discussed in our Introduction, is severely tempered by the rigours of the market, which can be saturated and constrained by personal income restraints and income inequalities. The ‘adoption’ rate of many new technological innovations aimed at consumers illustrates this perfectly. There is usually a sharp upward curve in adoption rates of new technologies, followed by a plateau effect as demand is saturated and new products, sometimes but not always upgrading the earlier ones, enter the market. So the post war boom in cars, refrigerators, and landline telephones flattened out in advanced western economies by the 1980s. Similarly, the 1970s boom in credit cards and colour televisions lasted just two decades[6]. Is there any reason to expect that consumer behaviour towards smartphones and digital wearables will be any different?

Irrespective of the clear miscalculations of the anticipated impact of computerisation and computerised automation in its first wave of development, we have seen new debates and predictions arising from the second wave, associated with the internet and further advances in robotics and AI. It is to these debates that we now turn.

The Second Wave of Digital Automation

The second wave of digital automation places increased use of information networks at the centre of a (new) new transformation of work. This new era of digitalised automation has variously been called Industry 4.0 or the ‘Second Machine Age’ (Brynjolfsonn and McAfee, 2014) to indicate a departure of historic significance such as a fourth industrial revolution. It is worth rehearsing the speed of events. The onset of everyday usage of the internet (at least in the Global North) began as the first text message was sent and received two decades ago. Hypertext enabled web based communication, and was created in 1989, the Google search engine appeared in 1998, Facebook in 2004, and YouTube in 2005. Twitter was launched in 2006, but now records over 600 million daily tweets, while Facebook recorded its one billionth user by October 2012.

This second wave was accompanied with academic analysis which introduced the concepts of digital, immaterial and free labour. Indeed, a new lexicon entered academic discourse on the crest of this wave. The ‘digital’ or ‘gig economy’ has become a mixture of computer-based networks serviced by ‘digital artisans’, producing and distributing information and knowledge for free as part of a ‘shared’ or ‘gift economy’. There is no doubt that such platform -based services, for example, often linked to home-based crowdwork, are expanding. A recent report from researchers at the University of Hertfordshire, for example, found that crowdwork was ‘growing fast’ across its selected European countries, with ‘evidence that this model is spreading to other diverse areas including health services, teaching, legal services and a wide variety of manual and maintenance tasks’ (Huws *et al,* 2016: i).

Much of the driving force for the new discourse and related aspects of ‘immateriality’ came from a theoretical standpoint associated with an autonomist or anarcho-communist tradition. Some of this vision is drawn from the *operaismo* approach of the Italian autonomists of the 1970s, in which society is portrayed as a ‘social factory’ where work has shifted out of the factory, ‘thereby setting in motion a truly complex machine’ (Negri, 1989: 92). Paul Mason (2015: 218), in tangent, links the concept of the network society to the work of the early Russian Bolshevik Alexander Bogdanov. The ideological ties with Bogdanov comes from his philosophical outlook promoting the concept of a society based on knowledge and integrated systems. *Proletkult* was constructed by Bogdanov as an effort to raise the scientific and technical education of ordinary workers to a level whereby a future communist society could be introduced on the foundation of such knowledge-driven inter-linked systems[7]. Michael Hardt and Toni Negri in *Empire*, take the concept further and describe an epoch of ‘postmodernisation’ in which material production has evaporated into a weightless world. In this perspective the ‘cultural’ aspects of labour power become central to the process of accumulation. As Tiziana Terranova (2000: 33) argues, cultural and technical work is integral to the internet, it is free in that it involves ‘the activity of building Web sites, modifying software packages, reading and participating in mailing lists, and building virtual spaces on MUDs and MOOs’[8]. Rather than create a new swathe of leisure, however, as was predicted in the earlier debates, the boundaries between work and non-work might become blurred, as digital communication (e-mails, smart phones etc.) means that we can never ‘switch off’ from work.

Coupled with the blurring of work and non-work is an association between an increasingly digitalised economy and precarious labour. Nick Dyer-Witheford, in *Cyber-Proletariat*, proposes a ‘post post-*operaismo*’ perspective ‘taking as its starting point neither ‘worker’ nor ‘multitude’ but ‘proletariat’ whereby the proletariat, induced by cybernetics, embraces workers beyond the workplace as the key transformative agency’ (Dyer-Witheford, 2015: 12). We find also that mainstream management theorists have leapt upon the rise of networks based on the internet and digitalisation as an opportunity to re-invent organisational decision-making structures in the workplace to the advantage of capital. Thus, Web 2.0 in the workplace offers opportunities to ‘flatten hierarchies and promote open and egalitarian workplace arrangements’ (Attwood-Charles and Schor, 2015). Such arrangements are not, however, designed to challenge management prerogative, but are rather intended to tap into worker creativity under the guise of ‘post bureaucratic’ management and corporate competitiveness.

Proponents of post-modernisation, or post-capitalism refer to Marx's 'Fragments on Machines' in the *Grundisse*. In this work, which is essentially a series of notes recorded by Marx before he produced *Das Kapital*, Marx refers specifically to the potential of mechanisation to dominate the production process. The machine appears as an all-powerful force, both in fragmenting the input of the individual worker and engendering a subservient relationship to technology through division of labour.

> But, once adopted into the production process of capital, the means of labour passes through different metamorphoses, whose culmination is the machine, or rather, an automatic system of machinery (system of machinery: the automatic one is merely its most complete, most adequate form, and alone transforms machinery into a system), set in motion by an automaton, a moving power that moves itself; this automaton consisting of numerous mechanical and intellectual organs, so that the workers themselves are cast merely as its conscious linkages. (Marx, 1973).

Marx, however, foresaw mechanisation of the production process not just as a conceptual end-point of the logic of capital accumulation but also as a driver of alienation, after which liberation could only be achieved by workers taking back power and control of production. Those in the autonomist tradition, however, tend to leap to this end-point without assessing the social upheaval and revolutionary process that Marx insisted upon. Power is assumed without taking power in a utopia of 'fully automated luxury communism'. As such there is an implied chronological inevitability of transformation within the autonomist/anarcho-communist/post-capitalist interpretation. Rather than challenge capital directly through revolution, as Marx argued, the power of capital in this vision is subverted in diffuse forms, either through networks of the dispossessed, or in its reformist version, through processes of state investment in new technologies supported by ever-shorter working hours and a universal basic income (Srnicek and Williams, 2015). Marx's associated premise of 'communal production' is then translated as a progressive outcome of cyber-inspired 'full automation,' rather than as an intended outcome of workers throwing off the shackles of capital and taking control of the means of production.

Furthermore, *en route* to the new epoch of post capitalist utopia, it is also suggested that the accumulation of knowledge usurps the Smith/Ricardo/Marx view of the accumulation of capital as the driver of the system. Such a world, Richard Barbrook (1998) argues, allows many workers to 'escape from the petty controls of the shop floor and the office'. Rather than being dependent on a single employer, office space may also be shared in new co-working spaces, where digital artisans, developers, designers and translators hire a space to conduct their work activity that is marketed across the ether. Capitalism, in this view, shifts from the factory and the collective workplace for its wealth creation to one based on the accumulation and dissemination of knowledge of individuals through the internet. Hence a shift from 'material' to 'immaterial' labour. Of course, such a concept of 'immateriality' remains open to question. Rather than see a dispersal of power associated with the networked digital economy we have seen a *concentration* of digital capital. Microsoft and Google dominate the industry through processes of exclusivity and buying-up smaller competitors. The smartphone app. company Uber has sought to assume market dominance at the expense of small taxi companies dependent on a switchboard and short band radio rather than an app. Facebook are now owned by venture capitalists and have swallowed WhatsApp, while Google has bought YouTube[9]. More tellingly, rather than being 'weightless' or 'immaterial', the production of services and products remains rooted in the material circumstances of the workers that produce them. This is no more apparent than in the case of the ultimate example of 'weightlessness', that of cloud computing, which rather than being ether-based is housed in energy-hungry mainframe computers owned by corporate giants such as Google. As Cook

(2012) pointed out in a report prepared for Greenpeace: 'If the cloud were a country it would have the fifth largest electricity demand in the world'. Neither is the concept of 'free labour' without its problems. As Diane van den Broek has argued in her critique:

> digital labour is neither free or immaterial, because it is not the content of labour itself, but rather its relationship with capital that gives it 'weight' and value…., labour remains heavily bound by an employment relationship and a labour process, whether work is performed in cyberspace or other more 'grounded' locations. Indeed, given the mutual dependency between wage labour and capital, both concepts become meaningless without the other. (Van den Broek, 2010 p 123-124).

This was only too well recognised by cyclists employed as part of the 'platform economy' when working on food delivery in London for Deliveroo. It was by collectively organising and taking strike action in 2016 that the cyclists forced a decision by Employment Tribunals that they should be considered as 'employees' rather than as self-employed contractors. A similar legal decision judged that the 40,000 Uber taxi drivers in the UK are also workers and not self-employed. The tribunal ruling in October 2016 came despite the Uber employers arguing their case that the company was merely a technology platform and not a transport business[10]. Workers in 'shared' labour spaces, often utilising their creative labour, also suffer similar material and exploitative treatment from capital, prompting German unions to begin to organise such 'crowd workers' in Berlin (Knaebel, 2016). However, it is not only in the field of digital labour that deep automation has occurred in this second wave. Progress has also been made in the field of robotics and artificial intelligence. It is to this that we now turn.

Robotics, 3-D printing, AI and Algorithms

In his book *The Rise of the Robots* author Martin Ford depicts:

> a new era that will be defined by a fundamental shift in the relationship between workers and machines. That shift will ultimately challenge one of our basic assumptions about technology: That *machines are tools* that increase the productivity of workers. Instead, machines themselves are turning into workers, and the line between the capability of labor and capital is blurring as never before. (Ford, 2015).

The reasons for the great leap forward in robotics and other computer based technology such as 3-D printing identified by Ford are twofold. First, is the technical progress made in computing the algorithms necessary to enable robots to recognise shapes and images in both two-dimensional and even three-dimensional form. This enhancement in visual perception allows for the robot to determine the position and shape of a box, for example, to be better able to handle and stack the box. It allows for an expansion in the ability of a robot to work in a warehouse or at the front end of retailing or services such as fast food serving. Second is the advances made in 'cloud robotics' which allow for robots to remotely access computer programmes and images from a central computer location without having to carry a programmable pack. This will make the robot lighter and more mobile and more speedily adaptable to new tasks guided by the cloud computer. These two advances go alongside mechanical innovation which allows for robots to imitate the precision of the human limb, enabling a robot to perform such precise operations as laser eye surgery.

Combined, these innovations have led to an impressive growth in the number of robots made for industrial, agricultural and domestic purposes. Indeed, so much is suggested of the potential for robots' advance that MEPs in the European Parliament commissioned a report (European Parliament, 2016), and consequently called for comprehensive rules for how humans will interact with artificial intelligence (AI) and robots. The fear expressed by the politicians is that advances in AI could elevate robots to the status of an electronic ‘person’ with rights and privileges in law. In terms of numbers, the International Federation of Robotics (IFR), report that more than a quarter of a million industrial robots were supplied in 2015, with China operating 27 per cent of the total[11]. Robot sales have increased in the Asian markets at a great rate, with the highest robot density recorded in South Korea, but also at a lesser rate in the USA and Europe. The only country in Europe which saw a decrease in sales in 2015 was the United Kingdom. Within manufacturing they have been used in China on an increasing scale in batch production as an alternative to a diminishing pool of labour. As robot costs decline, and real wages rise in the Chinese industrial districts, the ‘payback’ period for capital for investment in robots has fallen (Bland, 2016).

In the western industrialised nations, both robots and 3-D printing have allowed for increased factory automation and lower unit costs in more advanced mechanical operations such as automobile assembly, leading some companies to consider ‘re-shoring’ production after decades of ‘off-shoring’ to cheaper labour areas of the global economy.

Advances in robot technology might lead us to the conclusion that predictions of ‘Singularity’ is near. In this world, our intelligence would become ‘non-biological’ and creativity would be unbounded by human limitations. Machines would dominate production through processes of self-improvement, re-writing their own software to outstrip the functional capabilities of the human brain. A parallel phenomenon to Singularity would be the rescheduling or even destruction of Marx’s labour theory of value. This is because of an assumption that the marginal cost of production will be driven towards zero, as ‘stuff that can be made with tiny amounts of human labour is probably going to end up being free, shared and commonly owned’. (Mason, 2015: 164). This ‘post-capitalist’ utopia (or dystopia), challenges the permanency of the labour theory of value (whereby all added value is created by human or 'living' labour) by suggesting that the organic composition of capital (enhanced in this instance by the absolute amount of capital enshrined in robot and AI form) can rise so much and to such an extent that human input is negligible or even absent from the production process and surplus value then shrinks towards zero. An orthodox economic explanation is offered for this phenomenon by Carl Shapiro and Hal Varian (1998) who suggest that information is costly to produce but subsequently cheap to reproduce. The cost of producing the first copy of information may be substantial, but the cost of producing (or reproducing) additional copies is negligible. It is in this 'reproduction' phase that the marginal costs associated with digitalisation may tend towards zero as 'economics of abundance'. The scenario of Singularity does, of course, signal a complete collapse of human employment, a possibility that has excited the imagination of many commentators in both the academic and journalist communities. Few jobs or occupations would escape the ravages of computerised automation. While most routine jobs would disappear, the destruction would also overlap into professional work. Doctors, for example, may be replaced by smart phone apps. that diagnose a patient's symptoms and robots that perform operations (Kirkup, 2016). The collection of big data and its processing by algorithms (machine learning) may enable correlations of behaviour, genetic disposition, or symptoms to predict a person's health. Even IT specialists would not be safe, as much of the 'knowledge' which enables them to hold down employment may be transferred to a central cloud computer accessible by all from any location.

However, claims of total singularity may well prove to be a false dawn. To begin to tackle this question we need to examine the limitations of the technologies and return to our socio-technical analysis. First, on the *technology* itself, we find that despite the impressive technical progress in robotics and associated algorithms, the moves to 'conscious' robots are constrained. Returning to the 'Turing Test' the ability of robots to 'think' as humans do is only a remote possibility. Turing also identified a 'halting problem' whereby a computer using AI may never 'know' when it is 'right', and so will continue to compute (Walsh, 2016: 34). For more complex tasks, robots still need to be minded by humans lest they break down or miscalculate precision movements, which reduces their potential contribution to productivity enhancement and hence investment by capital. Efforts by a leading robotics manufacturer to create an affordable 'plug and play' robot capable of mimicking human movement for widespread use in industry also appear to have stalled. The company producing the new robots, *Rethink Robots*, announced redundancies of nearly a quarter of its staff in 2013 (Tobe, 2013). A simple way of understanding the problem is to imagine a robot attempting to catch a tennis ball in flight. Not only the speed and angle of flight need to be finely calculated in a split second, but also the weight of the tennis ball (which a human would have remembered from previous experience) will determine how hard the robot needs to grip the ball once caught to avoid the ball bouncing back out of the hand. Such a seemingly simple task for a human is a logistical nightmare for a robot. Mercedes-Benz, which is a lead player in developing autonomous cars, has now begun replacing its robots with humans in its factories due to this very lack of flexibility in the robotic machine (Gibbs, 2016). Problems of robot inflexibility in the auto industry (a key player in robotics) are confirmed in a study published in 2016 by Sabine Pfeiffer of German automotive factories. She found that the use of robots meant that humans performed extra work which involved constant monitoring of the robots:

> During a normal and otherwise smooth shift, a worker responsible for the ballet of eight welding and handling robots intervenes 20 to 30 times per shift—not because of technical incidents but in order to prevent them. Although human work declined

quantitatively over the years, its qualitative role increased with automation (Pfeiffer, 2016: 16).

Moves are now afoot to develop ‘cobots’ as an alternative to robots, which operate side-by-side with humans to enable flexibility and creativity to flourish.

The robotics industry is attempting to overcome these problems of inflexibility by researching ways in which a robot can mimic the human thought process by understanding and utilising artificial neural networks. These robotic ‘deep learning systems’ are now able to recognise speech patterns. Big data can also be used in algorithms to map employees’ behaviours, both physically and socially (in terms of emails and correspondence etc.) so that a robot, once fed this information, may be able to ‘behave’ like a responsible employee. However, while algorithms might replicate past human behaviour in robotic form they are a long way off from ‘consciousness’ and the ability to ‘think’ at the level of a human. The algorithms they feed from remain subject to human input in programming and coding and repeat the mistakes and false assumptions that humans may have made in the past, but may *consciously* check against in the present. So, for example, the algorithm-fed robot *Beauty.AI* only chose women of light skin when asked to judge an international ‘beauty contest’, suggesting an unconscious (or even conscious) racist agenda among those humans creating the algorithm (Levin, 2016). The main hurdle, therefore, remains the problem of consciousness, which enables a human to reflect and to understand context before deciding. This is where Turing’s second test, the ability to know when a ‘right’ decision has been made and to stop further computing, comes into play. This may be near to impossible to replicate in AI. A robot may be programmed to perform new tasks, but it cannot transfer knowledge gained in one task to another. The robot has no imagination, emotion or consciousness and remains a machine. Daniel Dennett has explained the conundrum well in *Consciousness Explained* (Dennett 1991: 431) when suggesting that computers work very differently from the human mind – computers process increasingly large numbers of information serially, while the mind involves the simultaneous interaction of different mechanisms and processes. When a human looks into a mirror she sees herself, when a monkey looks into a mirror it sees a monkey. But what does a robot ‘see’ and what does it ‘recognise’? In fact, the robot does not ‘see’ unless it is pre-programmed by human intelligence to record a specific image in distinction from other images.

The further obstacle to full automation and singularity we need to address is that of *economics* and the related political implications of choices made by capital. Even where the upgrades include robotic innovation directly replacing human labour the overall impact on productivity, growth and jobs appears less dramatic than might otherwise be assumed. While the last few years have seen a considerable growth in the use of robots the actual density of robot implantation in manufacturing remains small. Data from the International Federation of Robotics shows that even in the highest density country of South Korea, there are less than 500 robots for every 10, 000 manufacturing workers. While there are approximately 1.5 million industrial robots in the world in 2014, this has to be compared to a worldwide workforce of over 3 billion (IFR, 2016).

On productivity, key evidence published in 2015 from a dataset of companies in 17 countries gathered between 1993 and 2007, suggests that while productivity increases with robotic innovation and some semi-skilled and lower skilled jobs are abandoned, ‘there is some evidence of diminishing marginal returns to robot use – ‘congestion effects’ -so they are not a panacea for growth……this makes robots’ contribution to the aggregate economy roughly on a par with previous important technologies, such as the railroads in the nineteenth century and the US highways in the twentieth century.’ (Michaels and Graetz, 2015). In terms of economics we must consider, as the Marxist economist Michael Roberts reminds us, that robots remain a machine, and as such:

> Robots do not do away with the contradictions within capitalist accumulation … a capital-bias or labour shedding means less new value is created (as labour is the only form of value) relative to the cost of invested capital. There is a tendency for profitability to fall as productivity rises…. So an economy increasingly dominated by the internet of things and robots under capitalism will mean more intense crises and greater inequality rather than super-abundance and prosperity (Roberts, 2016: 10)

Furthermore, *if* it were possible to move to a world of 'full luxury automation' where robots reproduced themselves (robots making robots making robots) then we *would* have a world of zero profits (as there would be no value creation through human labour), combined with super abundance and leisure with robots akin to slaves (or masters). However, the implications for a contest between capital and labour *en route* to this *nirvana* would be enormous. As we have stated earlier in the chapter, there is a dialectical interplay between society and technology, and in this case worker resistance to the capitalist dystopia of permanent joblessness would surely ensure that the road to 'full automation' if it is ever constructed, would be a very rocky one.

Neither is it automatically the case that capital will choose to invest in technology even when it is available. As reported by the OECD (2016:3) '…the introduction of new technologies is a slow process due to economic, legal and societal hurdles, so that technological substitution often does not take place as expected'. Thus, the development of autonomous or driverless cars is subject to regulatory concerns over insurance liability, which will act to slow down or even impede development. A major point to consider is that computers are a relatively small proportion of capital stock, and furthermore, investment in computers has been declining since the height of the 'IT Revolution' of the 1990s (Goodridge, Haskel and Wallis, 2012: 34: Mishel and Shierholz , 2017). While upgrades in software and hardware are always likely to occur, the aggregate effect of such upgrading is likely to be small compared to the initial investment. Individual capitals must also consider what Marx described as the 'lifespan of fixed capital', whereby an individual capital, and capital in aggregate, may delay purchasing of new technology until they can be sure of a sufficient rate of return on investment. In the meantime, individual capitalists will attempt to extend the physical life of pre-existing fixed capital (including both computer hardware and software) as a way of reducing costs (see Weeks, 1981 p186 for a full explanation of this particular contradiction). Indeed, the technological and competitive advantage produced from ICT investment may be a one-off event, not sustainable over time. As the management specialist Michael Porter (2001: 62) suggests, 'as all companies come to embrace internet technology, the internet itself will be neutralised as a source of advantage.' The US-based economist Robert J. Gordon is a long-term and mainstream critic of the position that ICT has substantially raised overall productivity. In his latest major study (2016) of the US economy *The Rise and Fall of American Growth* he pours cold water on any claim that ICT had a fundamental effect in raising productivity in the decades since computerisation entered the workplace. Gordon's argument is directed at the 'techno-optimists' and states that the IT revolution led to less significant changes in productivity than a host of other technologies including the telegraph, the electric light, or indoor plumbing and urban sanitation.

The final point to consider is that of the economics of supply and demand for 'full automation' within the real economy. The 'full automation' and post-capitalist schools of thought assume an ever-increasing thirst for new digital technology and a limitless supply of the necessary hardware and software. Yet these assumptions need to be questioned.

Predictions of the coming of Singularity have been based on extrapolations from co-founder of *Intel* Gordon Moore's 'law', by which the number of transistors that can be inserted into a computer doubles every two years, both lowering the cost and vastly increasing computing power. However, this depends on a finite supply of rare earth metals, and Moore has himself acknowledged that there will also be a physical limit to how many transistors you can squeeze into an integrated circuit[12]. Efforts to stack microchips one by one to form a 'slab' or cube may prolong Moore's Law, but only at the expense of decreasing efficiency of battery life in smartphones and tablets as ever more powerful fans are needed to cool the chips[13]. Despite these physical limitations, the prospects of a 'last ultraintelligent' machine ever being constructed, which will 'surpass all the intellectual activities of any man however clever……..(so that) the intelligence of man would be left far behind' (Good, 1965), have continued to fascinate many. A sober analysis, however, has been undertaken by William Nordhaus at Yale University. Using econometric methodology on both the supply and demand side for digital technologies and AI he attempts to predict when singularity might occur. He argues that two 'accelerationist' mechanisms could develop, either from accelerating supply or from accelerating demand, and then applies a series of time-linked tests to both hypothetical scenarios, focusing on the key input variables such as wages, productivity growth, prices, intellectual property products and R&D. Five of his seven tests for the likelihood of singularity proved negative (including that for 'accelerating productivity growth' and 'rising wage growth') while the two that proved positive (including a 'rising share of capital') indicated that singularity, if it did occur, would be at least 100 years away (Nordhaus, 2015). And as we have previously positioned, a rising share of capital may simultaneously lead not only to decreasing rates of productivity growth, but also trigger a crisis of profitability for capital in the long term. The dream of Singularity would thus be faced with a simultaneous collapse of the underlying dynamic of capitalism. The only surviving ‘human’ industrial sectors might be defence and space exploration, to guard against terrorist or foreign hostile cyberattack, and against attack on humans by the super intelligent machine![14]

Some Conclusions

In this chapter we have traced controversies on the history of technology and then reviewed the academic debates on computerisation and digitalisation that first arose in the 1960s and 1970s and their revival in amended form in the new millennium. The first wave produced predictions of the ‘end of work’ or the ‘leisure society’ premised on a massive increase in productivity. The debates from 2000 onwards introduced new concepts of digital, immaterial and free labour, alongside claims, predictions or prescriptions (in varying degree) of the coming of a new era of full automation or post capitalism. The second wave debates borrowed from autonomist theory made popular in the 1970s by the Italian *operaismo* tradition, supplemented in the new millennium by a focus on Marx and his musings on the ‘Fragments of Machines’ in the *Grundrisse*. The theoretical strands connecting the first and second wave assumed an optimism towards the benefits of automation, by heralding a better society brought about by the benefits of digital automation. The more pessimistic predictions of the surveillance society, the perils of big data, or digital de-humanisation (alienation 2.0), are accordingly given less prominence. The optimistic scenarios evident in both waves were predicated in the first wave by an assumption that digitalisation would release workers from work as productivity continued to rise. However, as we have illustrated in this chapter there was no generalised increase in productivity during the heyday of the first wave, rather there was a decline. Secondly, there was a misreading of employer motive for introducing technology, which was not benevolent, in that leisure was offered as an alternative to work, but was repressive, in that workers were squeezed ever more as employers needed to recoup the cost of investment in technology.

In the second wave, the theoretical critique of the coming of the good society is more complex. Both the full automation and post capitalism scenarios challenge the labour theory of value, and suggest that the marginal cost of production will shrink towards zero as robots, computers and AI move further towards technological singularity. However, we have suggested that such a scenario may also prove to be a false dawn. In preferring caution, we have returned to a socio-technical appreciation of technology, and argued that while digitalisation, AI and robotics is a *different* form of technological input in the production process, it is *still subject* to technical, economic, social and political barriers and constraints to its implementation. The technical limitations of both digitalisation and robotics suggest a finite rather than infinite future. For digitalisation Moore's Law may be near its limit. For robots, the problems of inventing a 'conscious' robot able to 'think' and to pass two crucial Turing tests remain remote. In terms of economics, we reject the concept of immaterial or free labour, and recognise that however 'shared' or 'free' such labour may be, it is still rooted in the material sweat and blood of real people undertaking real work for others to exploit. Neither is it the case that demand or supply of digital technology is totally elastic, a condition necessary for full automation to evolve. Intervening factors, of wage inequality, lagged investment decisions, and the negative effects of capital-bias on profit are all real. In terms of politics (or political economy), our historical overview indicates that there is a dialectical relationship between technology and society. Tension and resistance are inherent, and the place of technology within society is subject to social forces which act to shape and reshape society in the light of technical innovation.

All this is not to say that we reject that ‘deep automation’ is not a feature of modern industrial society. Capital will for ever it exists seek to enhance labour productivity, reduce unit labour costs, and increase profit ratios with the help of new technologies. Digitalisation, robotics and AI are part of that on-going process, with the attached negative side effects of big data lack of privacy, extra monitoring and surveillance in the workplace, and a new sense of alienation from each other in the cultural sphere. But these processes are still subject both to the logic of capital accumulation and its associated contradictions and pitfalls, meaning that the ‘full automation’ is only a very distant prospect.

References

Attwood-Charles, Will and Juliet Schor (2015), ‘The Tyranny of Levelled Workplaces’, *Blog of the American Sociological Association*, http://workinprogress.oowsection.org/2015/08/17/the-tyranny-of-leveled-workplaces/#more-3152

Barbrook, Richard (1998), ‘The hi-tech gift economy’, http://www.firstmonday.org/ojs/index.php/fm/article/view/631/552

Bhaduri, Amit (1973) ‘A Study in Agricultural Backwardness under Semi-Feudalism’ *Economic Journal* 83 pp120-137

Bell, Daniel (1973) *The Coming of Post Industrial Society* New York: Basic Books.

Boreham, Paul., Rachel Parker, Paul Thompson and Richard Hall (2008) *New Technology @ Work*, London: Routledge.

Brian Arthur, W. (2011) ‘The second economy’, *McKinsey Quarterly*, October accessible at http://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-second-economy

Brynjolfsson, Erik and Andrew McAfee (2014) *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies*, WW Norton & Company: New York, NY, USA.

Bland, Ben (2016) ‘China’s Robot Revolution’, *Financial Times,* June 6th accessible at https://www.ft.com/content/1dbd8c60-0cc6-11e6-ad80-67655613c2d6

Castells, Manuel (2000) [1996], *The Rise of the Network Society, The Information Age: Economy, Society and Culture* London: Blackwell.

Child, John (1975), ‘Technical progress’, in Brian Barrett, Rhodes Beishon and Joseph Beishon, eds, *Industrial Relations and the Wider Society* Milton Keynes: Open University Press.

Cook, Gary (2012) *How Clean is Your Cloud?*, Greenpeace International (April).

DeLamarter, Richard (1986) *Big Blue: IBM’s Use and Abuse of Power*, London: Macmilla

Dennett, Daniel (1991) *Consciousness Explained*, London: Penguin

Dyer-Witheford, Nick (2015) *Cyber-Proletariat*, London: Pluto.

El-Sahli, Zouheir, and Richard Upward (2015) ‘Off the Waterfront: The long-run impact of technological change on dock workers’, *Working Paper 2015:11*, Department of Economics, Lund University.

European Parliament (2016) Draft Report with recommendations to the Commission on Civil Law Rules on Robotics, available at http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML%2BCOMPARL%2BPE-582.443%2B01%2BDOC%2BPDF%2BV0//EN

Ford, Martin (2015) *The Rise of the Robots: technology and the threat of a jobless future*, New York: Basic Books

Frey, Carl and Michael Osborne (2013) 'The Future of Employment: How Susceptible Are Jobs to Computerisation?' Oxford University accessible at http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pd

Gibbs, Samuel (2016) 'Mercedes-Benz swaps robots for people on its assembly lines', *The Guardian*, 26th February accessible at https://www.theguardian.com/technology/2016/feb/26/mercedes-benz-robots-people-assembly-lines?CMP=share_btn_fb

Good, Irving J. (1965). 'Speculations Concerning the First Ultraintelligent Machine', *Advances in Computers*, (6) 99, 31-83.

Goodridge, Peter, Jonathan Haskel and Gavin Wallis (2012) 'UK Innovation Index: Productivity and Growth in UK Industries', *Nesta Working Paper No. 12/09*.

Gordon, Robert (2016) *The Rise and Fall of American Growth* Princeton, NJ: Princeton University Press

Hardt, Michael, and Antonio Negri (2000), *Empire* Boston MA: Harvard University Press.

Henwood, Doug (2003) *After the New Economy: The Binge….and the Hangover That Won't Go Away*, New York: New Press

Hobsbawm, Eric (1994) *The Age of Extremes*, London: Michael Joseph

Huws, Ursula, Neil Spencer and Simon Joyce (2016) *Crowdwork in Europe,* Foundation for European Progressive Studies/University of Hertfordshire/UNI Global Union Europa

IFR (2016) *Industrial Robot Statistics*, International Federation of Robotics, http://www.ifr.org/industrial-robots/statistics/

Kirkup, James (2016) 'Strike all you like, doctors – technology will soon take away your power', *Daily Telegraph* (12 January), http://www.telegraph.co.uk/news/nhs/12093232/Strike-all-you-like-doctors-technology-will-soon-take-away-your-power.html?fb_ref=Default

Knaebel, Rachel (2016) 'Germany looking for ways to defend the workers of the digital age' *Equal Times* 9th May accessible at http://www.equaltimes.org/germany-looking-for-ways-to-defend?lang=en#.WCIZbPmLTIX

Kurzweil, Raymond (2005) *The Singularity Is Near* London: Viking.

Lang, John and Graham Dodkins (2011) *Bad News: The Wapping Dispute*, London: Spokesman Books

Lee, Sangheon., Deidre McCann and Jon C. Messenger (2007) *Working Time Around the World:Trends in working hours, laws and policies in a global comparative perspective*, Abingdon: ILO/Routledge

Levin, Sam (2016) 'A beauty contest was judged by AI and the robots didn't like dark skin' *The Guardian*, 8th September accessible at https://www.theguardian.com/technology/2016/sep/08/artificial-intelligence-beauty-contest-doesnt-like-black-people

MacKenzie, Donald and Judy Wajcman (1985) (eds.) *The Social Shaping of Technology*, Milton Keynes: Open University Press.

Marx, Karl (1859), *Preface to A Contribution to the Critique of Political Economy*, accessible at https://www.marxists.org/archive/marx/works/1859/critique-pol-economy/preface-abs.htm

Marx, Karl (1973*) Grundrisse: Foundations of the Critique of Political Eco*nomy , London: Penguin translated by Martin Nicolaus, at https://www.marxists.org/archive/marx/works/download/Marx_Grundrisse.pdf

Mason, Paul (2015) *PostCapitalism: A Guide to Our Future* London: Allen Lane.

Michaels, G. and Graetz, G. (2015) ' Industrial robots have boosted productivity and growth, but their effect on jobs remains an open question' available at http://blogs.lse.ac.uk/politicsandpolicy/robots-at-work-the-impact-on-productivity-and-jobs/?utm_source=feedburner&utm_medium=email&utm_campaign=Feed%3A+BritishPoliticsAndPolicyAtLse+%28British+politics+and+policy+at+LSE%29

Mishel, Lawrence and Shierholz, Heidi (2017) 'Robots, or Automation, are not the problem: too little worker power is', *Economic Policy Institute*, February 2017 available at http://www.epi.org/publication/robots-or-automation-are-not-the-problem-too-little-worker-power-is/

Negri, Antonio (1989) *The Politics of Subversion: A Manifesto for the Twenty-first Century*, London: Polity.

Nordhaus, William (2015) 'Are we approaching an economic singularity? Information technology and the future of economic growth'. *Cowles Foundation Discussion Paper No. 2021*, Yale University

OECD (2016) ‘Automation and Independent Work in a Digital Economy’ *Policy Brief on the Future of Work*, May, OECD accessible at file:///C:/Users/MRU/Downloads/Automation-and-independent-work-in-a-digital-economy-2016.pdf

Pfeiffer, Sabine (2016) ‘Robots, Industry 4.0 and Humans, or Why Assembly Work Is More than Routine Work’, *Societies*, 6(2), http://www.mdpi.com/2075-4698/6/2/16/htm

Porter, Michael (2001) ‘Strategy and the Internet’, *Harvard Business Review*, 79:3

Pradella, Lucia, 2015, ‘The working poor in Western Europe: Labour, poverty and global capitalism’, *Comparative European Politics*, 13

Roberts, Michael (2016) ‘Can robots usher in a socialist utopia or only a capitalist dystopia?’, *Socialist Review*, (July/August) accessible at http://socialistreview.org.uk/415/can-robots-usher-socialist-utopia-or-only-capitalist-dystopia

Shapiro, Carl, and Hal Varian (1998), *Information rules: A strategic guide to the network economy* Boston, MA: Harvard Business School Press.

Smith, Adam (1776) *The Wealth of Nations*, Glasgow edition of Volumes, Oxford: Oxford University Press partial access at http://oll.libertyfund.org/quote/316

Snricek, Nick and Alex Williams (2015*) Inventing the Future: Post Capitalism and a World Without Work*, London: Verso.

Swan, Trevor W. (1956). ‘Economic growth and capital accumulation’. *Economic Record* 32 (2): 334–361.

Terranova, Tiziana (2000) ‘Free Labor: Producing Culture for the Digital Economy’, *Social Text*, 63; 18, 2.

Tobe, Frank (2013) 'Rethink Robotics is downsizing', *Robohub*, December 14th accessible at http://robohub.org/rethink-robotics-is-downsizing/

Turing, Alan (1950), 'Computing Machinery and Intelligence', *Mind*, LIX (236): 433–460

Van den Broek, Dian (2010) 'From Terranova to Terra Firma: A Critique of the Role of Free Labour and the Digital Economy', *The Economic and Labour Relations Review*, 20: 2.

Walsh, Toby (2016) ''What if..We create human-level artificial intelligence?', *New Scientist*, 19 November.

Waurzyniak, Patrick (2006). 'Masters of Manufacturing: Joseph F. Engelberger'. *Society of Manufacturing Engineers*. 137 (1)

Weeks, John (1981) *Capital and Exploitation*, Princeton, NJ: Princeton University Press.

---

[1] Food delivery comes through companies such as Deliveroo, Uber is the most prominent taxi app., Tailster is a dog walk app., and AirBnB dominates the app. market for accommodation.
[2] http://royal.pingdom.com/2012/08/28/the-first-pc-from-1965/
[3] http://nottspolitics.org/wp-content/uploads/2013/06/Labours-Plan-for-science.pdf
[4] See also FRED, Economic Research, Federal Reserve Bank of St. Louis accessible at https://fred.stlouisfed.org/series/M08354USM310NNBR
[5] https://thenextrecession.wordpress.com/2014/01/20/productivity-deflation-and-depression/
[6] See research from http://marketrealist.com/2015/12/adoption-rates-dizzying-heights/
[7] Bogdanov was expelled from the Bolshevik Party in 1909. Lenin supported his expulsion on the basis that the 'systems theory' proposed by Bogdanov was at odds with the dialectical materialist approach of classical Marxism.
[8] Note: MUDs and MOOs are online virtual reality systems to which multiple users (players) are connected at the same time
[9]See http://whoownsfacebook.com/ to be updated on corporate ownership of the dot.com giants
[10] https://www.berwin.co.uk/blog/when-is-a-worker-not-a-worker
[11] http://www.ifr.org/industrial-robots/statistics/
[12] See the interview with Gordon Moore in 2015 at http://spectrum.ieee.org/computing/hardware/gordon-moore-the-man-whose-name-means-progress

[13] http://gizmodo.com/5981195/scientists-have-made-the-first-truly-3d-microchip
[14] See also the warnings given in https://www.theguardian.com/technology/2015/jan/28/artificial-intelligence-will-not-end-human-race