Debunking the Myth of the Fourth Industrial Revolution

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University of the Witwatersrand, Johannesburg

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Introduction

The Fourth Industrial Revolution (4IR) is all the rage these days.[1] In ideological terms, it appears to be hegemonic in its construal of our contemporary socioeconomic context, from our day-to-day interpersonal exchanges to the machinations of the global economic order. We often hear appeals to the supposed "magic"[2] of the technology that goes with it, to resolve the economic, political and educational crises and problems of the world (and latterly, its health crises – WEF, 2020). Appeals to a 4IR usually go with a listing of a whole lot of 'new', 'unprecedented' technologies that sound smart, make us feel outdated, and leave us in awe of the future. Technologies like cyber systems, artificial intelligence, delivery drones, the internet of things, and fully autonomous killer robots.[3] But it is around this misleading sense of awe – which I shall later refer to as an ideology – that my argument turns in this paper. None of these technologies necessarily warrants the claim that we are in a technological revolution, let alone a "Fourth Industrial Revolution". I shall examine these and similar technologies, to establish my claim. The argument also runs deeper than that. An industrial revolution, properly conceived, encompasses a complex range of economic, social and cultural transformations, and there is very little evidence to suggest that we are living through a fourth one of these. A careful, deep analysis of the First, Second and Third Industrial Revolutions will make this quite clear. What we discover in these three revolutions, by way of fundamental social transformation, is not taking place in the current context of the digital, networked, information society.

This paper commences with an account of the dispute between Schwab (2016) and Rifkin (2011, 2016) about whether there is such a thing as a 4IR, to provide a context for subsequent arguments. It then moves to start to develop its main argument, that *there is no such thing as a Fourth Industrial Revolution*. First, an account of the First Industrial Revolution (1IR) is provided, based on an examination of historical literature. This establishes analytically that this period of history was one of fundamental, transcontinental change, characterized by complex, interconnected, mutually-dependent social and socioeconomic relations and practices, as well as economic and technical innovations. The significance of the 1IR, of course, is that it is the archetypal *industrial revolution* in historical and theoretical terms. From this history, a framework for the analysis of any industrial revolution can be derived; this is done here to establish the criteria that any social transformation must meet if it is to count as such. Having established this analytic framework, the argument then goes on to examine the Second Industrial Revolution (2IR) and the Third Industrial Revolution (3IR). Again through an analysis of historical literature, it is established that both of these meet the criteria to be considered as industrial revolutions. They did indeed take place, to the full extent of the social, economic and cultural relations that one might expect. The 3IR is also carefully examined in relation to the aggregate of technical innovations that characterize it, because this is crucial in determining whether or not we can meaningfully claim a *revolution* from the 3IR to a 4IR. The resolution reached here is that there is no evidence that we are living in a contemporary, society-wide, technological revolution of any sort. The final substantive section of the paper moves on to the much more important question of whether there is a contemporary *industrial revolution* that is fundamentally transforming society beyond the dominant everyday, economic, social, cultural and geopolitical realities of the 3IR. It argues that it is quite clear, on the basis of all the evidence adduced, that there is no such phenomenon. The last part of the paper is more illustrative. By way of a selection of quotations from a range of sectors, it shows how the ideological frame of the 4IR as a massively converged set of global, technological marvels has spread around the world, despite the fact that it is nonsense.

Background: Schwab and Rifkin

The annual World Economic Forum (WEF) pilgrimage to Davos in the Swiss Alps is often styled as the gathering of the world's economic elites. Corporate heavyweights, heads of state, selected intellectuals, and their entourages gather to discuss and, importantly, strategize "the next big thing" in the exercise of global power. At Davos 2016, Klaus Schwab famously introduced (he would say disrupted) the world to the notion of the 4IR:

> *We are at the beginning of a revolution that is fundamentally changing the way we live, work, and relate to one another. In its scale, scope and complexity,* ***what I consider to be the fourth industrial revolution*** *is unlike anything humankind has experienced before. We have yet to grasp fully the speed and breadth of this new revolution. Consider the unlimited possibilities of having billions of people connected by mobile devices, giving rise to unprecedented processing power, storage capabilities and knowledge access. Or think about the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few. Many of these innovations are in their infancy, but they are already reaching an inflection point in their development as they build on and amplify each other in a fusion of technologies across the physical, digital and biological worlds … The first industrial revolution … [was] Triggered by the construction of railroads and the invention of the steam engine, … The second industrial revolution … made mass production possible, fostered by the advent of electricity and the assembly line. The third industrial revolution began in the 1960s. It is usually called the computer or digital revolution because it was catalyzed by the development of semiconductors, mainframe computing, personal computing and the internet …* ***I am convinced*** *that the 4IR will be as powerful, impactful and historically important as the previous three* (2016: 7 & 11 & 13; my emphases).

He placed a great deal of emphasis on what he proclaimed to be the unprecedented speed, size and scope of the proclaimed 4IR, in relation to previous industrial revolutions. The *velocity* of change, he suggested, is exponential rather than linear; the combining of multiple technologies *broader and deeper* than ever before; and the *systems impact* is now total, across the whole of society and the world economy (2016, pp.8-9). This is why, he said, "disruption and innovation feel so acute today… innovation in terms of both its development and diffusion is faster than ever" (2016, p.14).

Not far away, an expert contributor[4] to the understanding of industrial revolutions, Jeremy Rifkin, was arguing that the WEF was "misfiring" with its 4IR intervention. Rifkin's background is in an extensive 'future of work' literature, which explores the digitalization and automation of work in both offices and factories, attendant job losses, and the consequent 'hollowing out' of the middle classes in society (e.g. Rifkin, 1995; Zuboff, 1998; Gorz, 1999; Beck, 2000; Standing, 2009). He dates the emergence of the 3IR to the post World War II period (1995, p.61), but argues that its most significant impact was being felt only in the nineties – in computers, robots and software taking over strategic thinking and managerial functions, in relation to the production and distribution of goods. However, Rifkin notes how the 'new generation of sophisticated ICTs being hurried into a wide variety of work situations… [replaces] human beings in countless tasks, forcing millions of blue and white collar workers into unemployment lines, or worse still, breadlines" (1995, p.3). So well before 2016, Rifkin was operating on the terrain onto which Schwab descended – but with a notable disagreement. Rifkin does not think that these dramatic changes to business processes, the workplace or society constitute a 4IR.

Rifkin challenged Schwab's claim that the fusion of technologies between the physical, digital and biological worlds is somehow a qualitatively a new phenomenon:

> *The very nature of digitalization … is its ability to reduce communications, visual, auditory, physical, and biological systems, to pure information that can then be reorganized into vast interactive networks that operate much like complex ecosystems. In other words, it is the interconnected nature of digitalization technology that allows us to penetrate borders and "blur the lines between the physical, digital, and biological spheres". Digitalization's modus operandi is "interconnectivity and network building." That's what digitalization has been doing, with increasing sophistication, for several decades. This is what defines the very architecture of the Third Industrial Revolution.* (Rifkin, 2016)

Rifkin went further, rejecting Schwab's argument that an overall rapid increase in the velocity, scope and systems impact of new technologies implies a 4IR. He showed that it is the intrinsic interconnectedness of networked information technologies themselves, and the continuous, exponential decrease in digital technology costs, that produces changes in "velocity, scope, and systems impact", and that this had been going on now for some thirty years. It was a misconception that Schwab saw this as a "new revolution".

So we sit here, in the first instance, inside a debate about contemporary technological innovation. Some have suggested that it does not matter whether or not we call it an extended 3IR or an emerging 4IR – we live in an era of widespread, rapid technological innovation, and this is what matters. This is not contentious (examples of this will be described below). The dispute is supposedly one of "semantics". Unfortunately, though, this misses the point: the question is about whether there is rapid and fundamental social and political change – a revolution – taking place now, from the 3IR to a 4IR, and if so, what the implications of such a claim might be. The core contention underlying this paper is that the notion of a 4IR is ideology, and while it justifies certain practices, it does not exist as a substantive socio-economic phenomenon. As ideology, it functions to naturalize and obscure the deepening exploitation and marginalization of the world's poorer nations and people (for a development of this argument, see Moll, 2022a).

The question is about whether there is rapid and fundamental social and political change – a revolution – taking place now, from the 3IR to a 4IR, and if so, what the implications of such a claim might be.

In the face of the serious possibility that the 4IR is nothing more than a myth, Schwab and his WEF pulled off a major coup at Davos in 2016. From then onwards, the notion that an unprecedented industrial revolution is upon us, has become ubiquitous in social, political and economic narratives around the world. In every sphere of life, the question on virtually everyone's lips is, how can we make sure that we are ready for the 4IR? Alison Gillwald (2019) describes it as "one of the most successful lobbying and policy influence instruments of our time. … the WEF policy blueprints on the 4IR fill a vacuum for many countries that haven't publicly invested in what they want their own futures to look like". Perhaps the important lesson to be learned from all of this is that the most effective communication strategy by far, is to draw world leaders together in lavish and convivial surroundings, give them a free book, and send them back home with a formula that will convince their subjects, constituents, customers or clients that we are on the brink of a brand new world.

The First Industrial Revolution – 1760 to 1850[5]

There are two narratives of the 1IR that one encounters in the popular imagination. The first invokes the fantastical image of the Stephenson brothers driving their steam engine, 'Rocket', down a railway line through crowds of cheering, top-hatted men. In this account, the industrial revolution was "one of the most celebrated watersheds in human history"; it was "a response to the opportunity … of economic growth" (Allen, 2006, p.2). James Watt and his contemporaries invented the steam engine, the mechanical loom, the spinning jenny, and other innovative factory machines. Workers were no longer forced to work by hand, they could now use these machines, driven by water or steam power, to increase production. Labour was saved and productivity dramatically increased, e.g. in 1800, a cotton spinner could spin 200 times as much in a day as she could in 1700 (BBC, n.d.). Products could now be manufactured in factories, instead of just made at home. In this story, the 1IR was "fundamentally a technological revolution [focused on] the sources of invention" (Allen, 2006, p.2). The second narrative is also all too familiar:

> *At the centre of most people's picture of Britain's industrial revolution in the nineteenth century stands the dark, satanic mill, where an exploited and dispirited army of men, women and children is engaged for starvation wages in a seemingly endless round of drudgery: the pace of their labour is determined by the persistent pulse of the steam engine and accompanied by the ceaseless clanking of machines; and the sole beneficiary of their efforts is the grasping, tyrannical, licentious factory master.* (Bythell, 1983, p.17)

Now both of these narratives might appear larger than life, but as Bythell (1983) points out, together they highlight the core of the social and economic transformation that characterized the 1IR, namely *the emergence of the factory*. It is the tension between economic production on the one hand, and the human degradation of broader social relationships on the other, that constitutes the ensemble of economic and social changes that we know as the 1IR. The revolution was not simply, nor fundamentally, technological. The imperatives that drove technical innovations of all kinds, including Watt's famous steam engine, emerged from socioeconomic forces that were pushing the centres of economic production, and therefore people, out of the rural areas of Britain into the cities. A number of historians note that the 1IR in Britain represented a transition out of a feudal economy (Bythell, 1983; Deane, 1965; Heaton 1965; Hobsbawm, 1962; Knox, 1974; Marx and Engels, 1848; Reeve, 1971; Thompson, 1963). While the prevailing political system was a land-based, aristocratic one in which power was in the hands of a small governing class, there had for decades been a developing system of proto industries – styled as a 'domestic cottage system' – which supplied goods to rapidly expanding colonial markets. And it was not the traditional landed aristocracy that benefited most from these conditions. Behind Engels' (1845) observation that, "before the introduction of machinery, the spinning and weaving of raw materials was carried on in the working-man's home" (1845, p.51), lies the dramatic story of rise of the merchant *bourgeoisie* that is the social and political revolution known as the 1IR. "The domestic system, not less than the factory system which replaced it, was a method of mass production which enabled wealthy merchant-manufacturers to supply not only textile fabrics, but also items as diverse as ready-made clothes, hosiery boots and shoes, and hardware, to distant markets both at home and abroad" (Bythell, 1983, p.18).

For some time in the eighteenth century, this network of cottage industries kept up the supply of commodities required by these 'distant markets'. However, greater mass production was increasingly required to supply the Indian, North American and Caribbean colonies, let alone British consumers. Colonial mechanisms, at the centre of which was the rising class of increasingly wealthy, increasingly powerful merchant-manufacturers, were at work. For example, after the conquest of Bengal by the British East India Company in 1757, the massive imports of cheap textiles from England both undermined the home-spinning industry of Bengali village women, and increased the demand for cheaper imported cloth amongst Indians (Maddison, 1971; Heaton, 1965). Colonial markets, in general, were expanding in similar ways: English craftsmen and craftswomen, "were often, all unknowing, supplying the wants of West Indian slaves and North American frontiersman" (Bythell, 1983, p.19). The dependence being produced in the colonies saw British textile exports rising thirty-fold between the 1780s and the end of the Napoleonic wars circa 1815 (Deane, 1965, p. 89).

The revolution was not simply, nor fundamentally, technological. The imperatives that drove technical innovations of all kinds, including Watt's famous steam engine, emerged from socioeconomic forces that were pushing the centres of economic production, and therefore people, out of the rural areas of Britain into the cities.

This global demand for commodities was the death-knell for producers in cottage industries, who simply could not make enough quickly enough. Unprecedented mass production was required by world trade, and large-scale factories soon appeared in the cities, particularly in the north of England. Bythell (1983) points out that the same merchant-manufacturers who had profited from the organized cottage industry system, now turned their backs on it and became the new factory owners of the rising capitalist order. Factories represented major industrial growth, but the social consequences were devastating for the rural people whose livelihoods were now torn out from under them by the industrial revolution. As the famous English historian, Eric Hobsbawm, puts it, "in terms of economic productivity this social transformation was an immense success, in terms of human suffering, a tragedy … which reduced the rural poor to demoralized destitution" (1962, p.48).

Cotton and textiles dominated the international cycles of production, distribution and consumption that constituted the 1IR. The Harvard historian, Sven Beckert (2014), makes the case that cotton was the 1IR's "launching pad." In replacing wool and flax in the manufacture of textiles and clothing, it made the mass production of clothing and textiles possible. Its strong fibres were uniquely suited to hard mechanical treatment by spinning and weaving machinery. Previously, from the sixteenth century, Britain (along with other European traders) had purchased cotton textiles in India for its own markets. Now, as colonization came into line with British manufacturing, the standard colonialist pattern of economic exploitation ensued: raw cotton was extracted from India, manufactured into textiles and clothing in Britain, and sold back into India at a significant profit. The Indian 'homespun' proto industries were quickly undermined. Soon, the cheaper cotton available from plantations in the Caribbean and American colonies undercut raw cotton exports from India. The consequences for India, increasing poverty and economic devastation, should be obvious. Beckert (2014) notes the irony that the British industrial revolution was built on a basic raw material, cotton, which was not produced locally at all.

In the midst of all this industrial transformation, there were of course major technological innovations taking place all the time. It is worth emphasizing that, "for the economy as a whole to switch from manual techniques to mechanized production required hundreds of inventors, thousands of innovating entrepreneurs, and tens of thousands of mechanics, technicians, and dexterous rank and file workers" (Greenwood, 1999, p.8). The 1IR was indeed notable for its inventors and inventions. The steam engine was an iconic innovation of the period: James Watt's invention in 1781 of a new type to power other machines in factories, and Stephenson's Rocket hitting the railway lines in the 1820s. There were many others, especially in the textile industry: Crompton's spinning mule, Hargreaves' spinning jenny, Kay's flying shuttle and Arkwright's water frame. In America, Eli Whitney's cotton gin, a machine that separated cotton fibres from their seeds, added another 1IR technical innovation at the supply end of raw materials for British industry. These machines all contributed to a vast increase in the amount of cotton that could be spun or cloth that could be woven at any one time, thus propelling the expansion of the modern factory system. Kennedy (1993) suggests that, once the spinning mule was harnessed to steam power, the mechanization of manufacturing was inexorable. Technology developed rapidly in all kinds of factory situations. Cort's puddling and rolling technique increased wrought iron production; Wilkinson's gun-barreling machine made cylinders for steam engines; Maudley's heavy-duty lathe went into factories for all kinds of purposes (Greenwood, 1999). It is reasonable to suggest that "no earlier technological breakthroughs produced anything like the rise in output that flowed from the Industrial Revolution" (Kennedy, 1993, p.8).

However, this rapid development of the technologies of production brought with it the appalling, characteristic labour processes of the 1IR factory. Ironically, such conditions have been seen again only in today's sweatshops in the global South, under the regime of the 3IR (or if you like, the putative 4IR) (see Mezzadri, 2017). Workers in British factories at the end of the eighteenth century laboured for long hours in intolerable conditions: "Suffering under awful conditions in factories and mines, they were organized alongside their machines in a strict, time-driven system of labour unlike anything known previously" (Kennedy, 1993, p.8). In contrast to work in the pre-industrial cottage system, factory workers lost autonomy in the work process, subject now to the factory hooter and the requirement that they keep the machinery turning. The exploitation of child labour was a particularly horrific feature of the 1IR. Children often worked in factories and mines in the most exploitative conditions possible; they could get into the nooks and crannies to oil up and maintain machines where no adults could. They were paid the least and forced to work in the most dangerous conditions. By 1841, over 45,000 boys and 60,000 girls in their teens worked in textile factories, and some 22,000 girls were clothing-makers (Tuttle, 2001; Humphries, 2013). 16% to 20% of the total work force in the textile factories were children under 14 (Cruikshank,1981, p.51). One-third of the work force of coal mines was under the age of 18. In 1842, there were some five thousand children *between the ages of 5 and 10* working underground (Falkus, 1987, p.85). Engels (1845) aptly summed up the workers' plight thus: "The industrial revolution has simply carried this [the exploitation of workers] out to its logical end by making the workers machines pure and simple, taking from them the last trace of independent activity".

> For the economy as a whole to switch from manual techniques to mechanized production required hundreds of inventors, thousands of innovating entrepreneurs, and tens of thousands of mechanics, technicians, and dexterous rank and file workers.

With this labour process went, inexorably, an emerging set of labour relations in the workplace. The factory became the crucible of the formation of new social classes. To use the everyday language of the factory floor, a clear hierarchy was set up of *workers and bosses*, in which the interests of these different classes differed from each other fundamentally:

> *Where hundreds labour together under one roof and one direction as the normal type of work unit; it stresses the new importance of complex machine technology in the process of production; and it emphasizes that, because ownership of these machines, of the building which houses them and the engine which drives them, rests with the private capitalist, there exists an unbridgeable gulf between him and his property-less, wage-earning employees.* (Bythell, 1983, pp.17-18)

The English historian, E.P. Thompson (1963), suggests that "the outstanding fact" of the 1IR was the "formation of the working class" (1963, p.194). He shares a common understanding with most historians that the conditions of the factory floor thrust workers into "a competitive, scrambling, selfish system, a system by which the moral and social aspirations of the noblest of human beings are stultified" (1963, p.830). He reinforces the view that with the breakdown of rural proto industries, and the rise of the factory system, any mutuality of interest between employer and employee was lost. However, he is also at pains to emphasize the positive shared consciousness among English working people, who, "as a result of common experiences (inherited or shared), feel and articulate the identity of their interests as between themselves, and as against other men whose interests are different from (and usually opposed to) theirs." (Thompson, 1963, p.11). It is no wonder that the issues surrounding labour in the factories of the 1IR provided fertile ground for the rallying call of the *Communist Manifesto* in 1848: "The modern bourgeois society that has sprouted from the ruins of feudal society has ... simplified class antagonisms. Society as a whole is more and more splitting up into two great hostile camps, into two great classes directly facing each other – bourgeoisie and proletariat" (Marx and Engels, 1848, pp.14-15).

If increased economic exploitation and workplace immiseration were straightforwardly the general conditions of the 1IR workplace, then the situation with regard to its socioeconomic and community-related consequences was more nuanced. If one were preparing a set of these ubiquitous notes on the Web to assist students to avoid reading and research, then one might be tempted to come up with something like Table 1, which describes differences without in any way understanding those differences.

Table 1 *A popular and misleading way to structure a school essay*

Social Impacts of the First Industrial Revolution	
POSITIVE	NEGATIVE
■ increase in wealth ■ cheaper and more plentiful goods ■ increased standard of living ■ rise of professions and trades ■ better housing ■ technology development (machines, tools, vehicles) ■ improved health care (vaccines, pasteurization, medical instruments)	■ low wages ■ urban poverty ■ harsh and unsafe working conditions ■ long working hours ■ urban overcrowding (slums poor sewage contaminated water ■ air and water pollution ■ outbreak of disease (cholera, smallpox, tuberculosis)

Hobsbawm (1962) points out that it was only after the 1830s that literature started appearing about 'the rise of the capitalist society' and the social effects of the industrial revolution. In this historical literature, there are frequent references to 'optimistic' and 'pessimistic' interpretations of the 1IR. The former seems to emphasize the rising prosperity of Britain, the latter the degradation of the British working classes (Hobsbawm, 1963). One of the 'optimists', Allen (2019, p.111-112), argues that England was a highly prosperous country in the eighteenth century, "a long way down the social scale" – the average working class family consumed over three times as much subsistence goods annually as did workers in the rest of the world. Kennedy (1993) reinforces this view: "possessing greater manufacturing efficiency than any other society at that time and enjoying ever-higher standards of living, many Britons became proponents of laissez-faire economics and of an 'open' trading order" (1993, p.9). Many of the 'optimistic' authors write glowingly of the social, economic and technological advances of the period (Deane, 1965; Evans, 1983; Holland, 1968; Knox, 1974). It does indeed seem to be the case that, *as a whole*, Britain prospered at all of these levels during the 1IR, especially in relation to the rest of the world. Amongst other things, it was the dominant colonial power after the mid-eighteenth century, not least on the back of a liberal, free trade economic model that itself was generated by the context of the 1IR (Lange et al, 2006. p.1421).

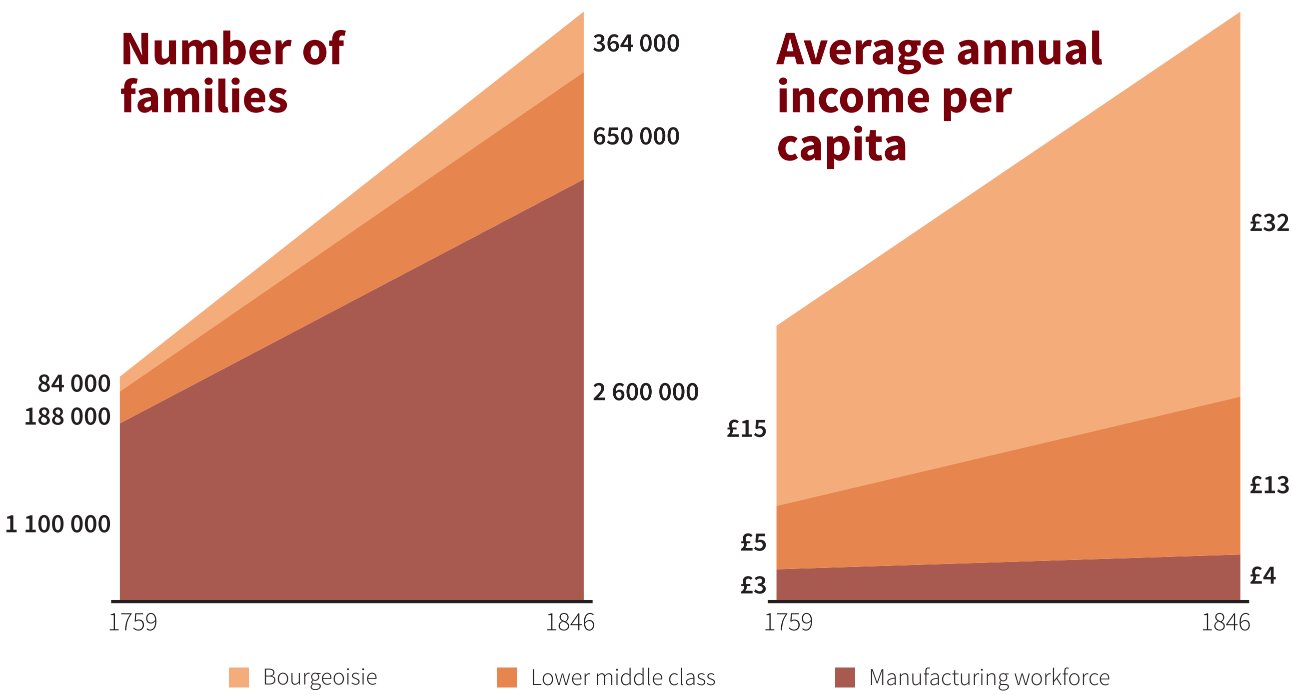
However, it does not take much further digging to discover that the prosperity of Britain *as a whole* was deeply unequal in advancing the entire population of Britain. Kennedy (1993) immediately qualifies his optimism: "this is not to say the material benefits were immediate or, for that matter evenly distributed. Industrialization brought early gains to the entrepreneurs, inventors, mill owners, and their financial backers [as opposed to the 'ordinary person'] who realized the new methods of manufacture would lead to enhanced profits" (1993, p.9). If one examines conventional economic population categories, then it is clear how this social cleavage permeated and consolidated itself in British society in the 1IR. Figure 1 shows starkly how, from 1759-1846, the average annual income per capita rose sharply for the bourgeoisie during the period, but hardly at all for the manufacturing workforce.

The population as a whole grew considerably in this period, but it was the bourgeoisie and the middle classes, and not the labouring classes (about two-thirds of the population),[6] who became wealthy, and benefitted from the improved standards of living, health care, housing and access to commodities that went with this population growth.[7] It becomes clear that the 'optimistic' interpretations of the 1R mask the deepening of socioeconomic inequalities in Britain. As Haines and Walsh put it, "poverty stalked in the midst of plenty. While statistics revealed steadily mounting material welfare and the growth of national and per capita wealth, hundreds of thousands of wretchedly poor filled the slums of the great urban communities" (1941, p. 653).

Evans epitomizes the triumphalist account of socioeconomic development: "The rise in the population of Britain during the eighteenth century… acted as a spur to industrial development… since it provided not only a potential workforce for workshop and factory but also rising demand for industrial goods" (1983, p.104). However, the inescapable truth of this population growth was appalling social conditions in the fast-growing cities and factory towns. Hobsbawm points out that the fact that the conditions of the labouring poor between 1815 and 1848 were intolerable, has not been denied by any reasonable observer (1962, p.205). Social housing provision was at the centre of these conditions. As factories boomed and markets grew, employers were forced to build houses for the prospective workers who migrated to the urban factories. These houses tended to be jerry-built, as cheaply as possible, in terraced rows or 'back to back', with shared, communal, 'earth closet' toilets (Thompson, 1963; Hobsbawm, 1962). The pressure of the population migration meant that, almost as soon as they were occupied, these housing quarters became overcrowded slums:

> *[Everything combined to maximize] … the demoralization of the new urban and industrialized poor … Towns and industrial areas grew rapidly, without plan or supervision, and the most elementary services of city life utterly failed to keep pace with it: street-cleaning, water supply, sanitation, not to mention working-class housing. The most obvious*

Figure 1 *Increase in number of families and income per capita for three classes in British society from 1759 to 1846* (statistics from Allen 2019)



consequence of this urban deterioration was the re-appearance of mass epidemics of contagious (mainly waterborne) disease, notably of the cholera. (Hobsbawm, 1962, p.203)

Obviously, the mass of people who descended on the cities and industrial towns were not only the employed workers. Periodic bouts of unemployment were almost certainly extremely high, and contributed to overcrowding (Falkus, 1987, p.85); "a floating population of tens of thousands of unemployed slept on the ground overnight and poured into the streets the next day" (Kennedy, 1993, p.3).

Health and sanitation deteriorated steadily. Problems with contaminated water, sewage, and garbage and solid waste disposal were widespread. "In the crowded cities ... garbage was thrown into the streets, rivers were polluted, and deaths from diseases such as cholera, smallpox, typhoid, and tuberculosis multiplied (Kennedy, 1993, p.96). Perhaps the most remarkable support for the 'pessimistic' interpretation of the 1IR comes from the fact that it was only "when the new epidemics sprung from the slums began to kill the rich also" (Hobsbawm, 1962, p.203), that something was done to intervene in the steady deterioration of working class housing and habitats. It took the 1842 Sanitary Conditions of the Working Classes inquiry, and the similar 1844 Health of Towns commission, as well as cholera epidemics in 1831 and 1848, to motivate the merchant-manufacturers to undertake systematic urban rebuilding and improvement of working class housing (Thompson, 1963, p.219).

Last, but certainly not least, we must consider the expansion of colonialism and slavery as central features of the 1IR. The Trinidadian historian, Eric Williams, is known for the strong view that slavery funded the industrial revolution in Britain. He builds his thesis on the notion that the transatlantic slave trade provided a triple stimulus to British industry:

The Negros were purchased with British manufactures; transported to the plantations, they produced sugar, cotton, indigo, molasses, and other tropical products, the processing of which created new industries in England; while the maintenance of the Negroes and their owners on the plantations provided another market for British industry … By 1750, there was hardly a trading or a manufacturing town in England which was not in some way connected with the triangular or direct colonial trade. The profits obtained provided one of the main streams of that accumulation of capital in England which financed the Industrial revolution. (Williams, 1944, p.52)

Now subsequent historians have questioned the strong version of the 'Williams thesis', demonstrating in various ways that there were other forms of capital accumulation and sources of profit that also funded the revolution. One of the most recent historians of Atlantic trade summarizes the critical appraisal of Williams' work thus: slavery neither produced nor funded capitalism, but "exchanges with the slave plantations *helped* British capitalism to make a breakthrough to industrialism and global hegemony ahead of its rivals" (Blackburn, 1997, p.573). Whether slavery played a key role in *financing* the industrial revolution or not, the political, economic, social and labour realities of this 'triangular trade' were an integral part of the 1IR. The 1IR was realized through slavery and cotton. We have already seen that cotton became the main raw material of the industrial revolution. Recent writers (Blackburn, 1997; Dattel, 2009; Beckert, 2014) have established how important slaves in the southern American cotton fields were to the British textile and clothing industry. These plantations supplied over eighty percent of its basic raw material. It follows that the dramatic increase in the capture and transport of slaves across the Atlantic in the late eighteenth century was a direct response to British demand for raw cotton. Forced labour on the cotton plantations was very harsh work, and there was a high mortality rate among slaves.

Exchanges with the slave plantations helped British capitalism to make a breakthrough to industrialism and global hegemony ahead of its rivals.

There seems to be no doubt that the model of "triangular trade" provides a compelling understanding of just how slavery was implicated in the 1IR:

African people were captured and sold onto ships, and transported across the Atlantic to become slaves on plantations in the Americas. The cotton that they produced was transported across the Atlantic to the burgeoning textile factories in the north of England. Much of the cloth produced in these factories was then transported down the Atlantic coastline, as the most desired currency used by British traders to buy slaves in Africa (Moll, 2020).

The transatlantic slave trade, with its systematic assault on the freedom of people on the west coast of Africa, and its brutal disregard for the lives of slaves on transportation ships and American cotton plantations, was a fundamental element of the 1IR.

The detail and depth of this historical account of the 1IR has been necessary to establish its complexity. What made it a social revolution is to be found in the transformations of socioeconomic, cultural and geopolitical strata that were much broader than mere technology innovations. In many senses, the 1IR was primarily one of industrialised human degradation. This analysis allows us to avoid the tendency of so many writers who illustrate (and believe that they account for) the 1IR by picking out and naming one or two 'iconic' technologies of the time, such as coal-based energy, or the steam engine, or railway transport. The modelling and analysis of industrial revolutions requires that we transcend such technological reductionism.

Methodology: An Industrial Revolution, properly conceived

In the above account of the 1IR, we have encountered a number of claims about what lay at its heart. Its core was large-scale manufacturing driven by machines (Kennedy). It was a technological revolution focused on invention (Allen). It replaced the domestic system with the factory system (Bythell). It was both a successful and a tragic transition from an agricultural to an industrial economy (Hobsbawm). Its launching pad was cotton (Beckert). It sprouted as modern bourgeois society from the ruins of feudal society (Marx and Engels). Its outstanding fact was the formation of the working class (Thompson). Its commodity production was maintained by a continual supply of slave labour from Africa (Dattel). Its three-faced Janus was the commodification of Africans, the brutalization of slaves in the American colonies, and the immiseration of the working poor in Britain (Williams).

So which of these claims about the essence of the 1IR should we take to be correct? The point is, they all are, and that is the paradox of the matter. All of them are strata of the fundamental socioeconomic transformation of the period 1760 to 1850 that was centred in British society, but which had consequences for the whole world. From the preceding historical analysis, we can distill the following key conjunctural features that constituted this era as a distinctive historical phenomenon that took place from the mid-eighteenth century to the mid-nineteenth century:

- A technological revolution, consisting in the multiple innovations of the steam-powered textile factory, and the production and transportation of these commodities;
- Transformation of the labour process – the 'nature of work' – in which workers now operated large machines to enable mass production;
- Changing labour relations in the workplace, in which factory owners made large profits by exploiting workers, and which formed the working class in society at large;
- Changing community and social relations, in rapid, haphazard migration of newly impoverished people off the land into the cities and factory towns;
- Global transformations, related to the centrality of slavery in transatlantic trade and the exercise of colonial power.

Historians regard (or construct) the 1IR as the archetypal industrial revolution (Cannadine, 1984; Coleman, 1992; Hobsbawm, 1997; Stearns, 2012). Falkus (1987) points out that while some economists and economic historians have considered concentrated moments of short-term economic acceleration a revolution, the dominant view amongst historians is that for a period of change to 'count' as a revolution it must be characterized by long-term socioeconomic change at a fundamental, or structural, level:

1. The first view seems to be associated with economists of many persuasions – neoclassical, neoliberal, Keynesian, evolutionary – who consider an 'industrial revolution' to be a rapid, short-term economic change where one or more technologies are replaced by another, novel technology. These thinkers tend to identify the notion of an 'industrial revolution' with a 'technological revolution'. Such a revolution is a concentrated, short period of accelerated technological progress characterized by new innovations, a period when the whole economy moves faster and changes abruptly. There is something of this in the 'optimistic' views of the 1IR discussed above, e.g. in Allen's notion that it was fundamentally a technological revolution focused on invention and opportunities for economic growth

(2006, p.2). More sophisticatedly, these periodic economic accelerations are understood by various evolutionary economists as cyclical technological innovations, repeated from time to time, in a manner similar to the theory of punctuated equilibrium that defended Darwin's classical theory of evolution in the face of apparently cyclical gaps in the fossil record.[8]

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2. The second approach adopts a more fundamental social historical view, suggesting that if, after a longer period of time, the entire socioeconomic context has been transformed, then a revolution has taken place (Falkus, 1987, p.75). I have suggested that the pivotal transformation of the social and economic order that characterized the 1IR was the emergence of *the factory*. However, this idea does not reduce the 1IR to disruptions and transformations in either technology or the economy, although it encompasses both. 'The factory' is the central motif in the historical account of wide ranging transformations at every level, in every nook and cranny of the nascent industrial society. Consider Bythell's two popular narratives of the rise of industry, or Thompson's expansive account of the creation of the working class in and around the rise of the factory, or Hobsbawm's extensive descriptions of 'industrial revolution' as the total ensemble of socioeconomic and macro-social changes that we know as the 1IR. As Knowles remarked 100 years ago, "the term 'Industrial Revolution' is used, not because the process of change was quick, but because when accomplished the change was fundamental" (1922, p.79).

The latter view predominates in the historical literature on the 1IR. The historiographer Lemon cautions us against the lack of depth in the historical analysis of those who want to find revolution in short-term technological changes:

> *Today we are prone to overestimate the pace of some change in earlier history … This is because certain changes, **particularly technological ones**, can have rapid practical effects. But changes in the way people think and behave regarding the larger questions in life take longer to become established, and even longer to work out their full effects"* (Lemon, 2003, p.870, my emphasis).

Historiography, the study of the research methodology of history, makes it clear that the writing of history must make practical sense of human action over long time frames. Ordinary language concepts like 'actors', 'intentions', 'causes', 'consequences', 'past', 'present', together with 'time' itself, must be refigured into a plausible, followable, extended narrative. An historian has a much wider set of statements to process than does an economist, straddling an entire social domain, and so historical explanations are more complex and elusive than those in economics. Paul Ricoeur (1965; 1984), in his account of the epistemology of historical research and writing, makes it clear that the aim of history is *to explain more in order to understand better*: "to explain what happens and to describe what happens coincide … a narrative that fails to explain is less than a narrative" (Ricoeur, 1984, p.125). In this regard, Hobsbawm (2002, p.294) comments that the twentieth century saw two great influences that changed the writing of history – the ideas of Fernand Braudel after 1945, and the influence of Clifford Geertz after 1968.

For Braudel (1958), the writing of history is *longue durée*, and requires detailed narratives that achieve plausibility in their depth (see also Scriven, 1959). It prioritizes long-term historical processes over *histoire événementielle* (histories of events), and seeks to draw out historical trends and patterns in the telling of the story. Historians typically do not spell out a research 'methodology' in the sense that a research design based, at least originally, on the deductive-nomological model of scientific explanation does – aim, purpose, research question, literature review, conceptual framework, methodology, findings, discussion, etc. – although the conceptual frameworks of social theorists in other disciplines clearly influence the historical accounts that they construct. Andrew Abbott usefully distinguishes the "axes of cohesion" of different disciplines: "anthropology is largely organized around a method, political science around a type of relationship, and *economics around a theory of action*" (2001, p.140, my emphasis) – economics is, if you like, a policy discipline. The axis of cohesion of history is clearly *depth narrative*.

A prominent historiographer describes the influence of Geertz's concept of 'thick description' on history as the adoption of "the technique of bringing to bear upon a single episode or situation a mass of facts of every kind and subjecting them to intensive analysis so as to elicit every possible cultural implication" (Himmelfarb, 1987, p.128). The methodological principle of thick description – adopted by Geertz from Gilbert Ryle – is that it is not simply a matter of amassing detail about social reality (observed for ethnographers, recorded or remembered for historians), but an interpretation of the detail in relation to its contexts, circumstances, meanings and underlying causes. This interpretive characteristic of description, built detail upon detail, is what makes it 'thick'. The methodology is simple in concept: describe and describe and describe again, until the evidence is saturated and the social phenomenon under scrutiny becomes explicable in terms of the meaning systems of the people whose practices constitute it – an echo of Ricoeur's point that in depth narratives in history, "to explain what happens and to describe what happens coincide". History is thus able to represent a "full living past reality…in its full complexity" (Berkhofer, 1995, p.31).

Geertz (1973; see also 1990) is clear on the similarities and differences between thick description in history and anthropology. Both disciplines are interpretive, and importantly both are *microscopic*. Methodologically speaking, however, anthropology tends to be concerned with "exceedingly extended acquaintances with extremely small matters" (1973, p.21), whereas history tends more to be concerned with large scale interpretations of whole societies, world events, global neocolonialism, and so on. Despite the rise of 'social history', historians often work with the microscopic methods of thick description towards an overall account of historical epochs, such as industrial revolutions.

One can imagine a critic (perhaps an economist), schooled in the deductive-nomological traditions of the social sciences, or even the building of 'evolutionary', predictive models based on cyclical patterns of the past, being nonplussed by the detailed historical narrative of the three industrial revolutions, and the absence of an explicit, multivariate theory of change, in this paper. They might insist that an analytical model of an industrial revolution, or even a techno-economic revolution, can be succinctly stated with a graphic representation to aid its visualization. Such a criticism misses the point entirely: it is precisely in the detailed, *longue durée*, thick historical description of each of the three industrial revolutions, and a similar treatment of the putative evidence for a 4IR, that it becomes evident that the latter has not come about. This point will be demonstrated as this argument proceeds. The ironic words of Paul Feyerabend come to mind:

> *To those who look at the rich material provided by history, and who are not intent on impoverishing it in order to please their lower instincts, their craving for intellectual security in the form of clarity, precision, 'objectivity', 'truth', it will become clear that there is only one principle that can be defended under all circumstances and in all stages of human development. It is the principle: anything goes* (Feyerabend, 1992, p.19).

Thick description, I would suggest, is the methodological realization of the anything goes principle.[9]

> It is in the detailed, *longue durée*, thick historical description of each of the three industrial revolutions, and a similar treatment of the putative evidence for a 4IR, that it becomes evident that the latter has not come about.

To turn now to the notion of a technological revolution, which I have suggested is only one of the socioeconomic transformations that is necessary for an industrial revolution to occur: The literature on this notion is replete with an impressive array of language signifying fundamental change. It is a terrain of cycles, crises and crashes; bubbles, booms and busts; slumps, stagnations and stagflations; golden ages and global shortages; upswings and downswings; prosperity, recession, depression, and recovery; innovations, disruptions and creative destructions. However, despite the poetic touches, close examination of these concepts shows them to be a series of synonyms that narrow down to a focus on technical innovations and attendant economic fluctuations. I have no doubt that much of this literature provides us with the basis of important explanations, *in their disciplinary context*, of the financial and technological changes that have taken place in the economy over time. However, my concern here is with the much broader, more pervasive matter of how we account for *industrial revolutions*.

The following terms are often used interchangeably in these discussions:

Technological revolution
Techno-industrial revolution
Techno-mechanical revolution
Techno-scientific revolution
Techno-economic paradigm
Information technology (IT) revolution
Digital (technology) revolution

The problem of reductionism comes about when any one, or some, or all of these are equated with an industrial revolution. Each concept is seated within an axis of cohesion – a *discipline* (Abbott, 2001) – that is confined to the terrain of purely technological and value-related economic phenomena. To Abbott's suggestion that economics is organized around a theory of action as its axis of cohesion, we need to add the increasingly common notion that information systems, and even Artificial Intelligence (AI) in its narrow sense, revolve around a "sociotechnical axis of cohesion" (Sarker et al, 2019; Lévesque et al, 2020). The upshot is that none of these concepts, when articulated within their own disciplinary contexts, can account for the transformed labour processes, labour relations, social relations, cultural expressions, and relations of global power and exploitation, that also have to be demonstrated if the phenomenon in question is to count as an industrial revolution. No doubt each term has validity in accounting for 'techno-economic' change, but it simply does not grasp the extent of an industrial revolution.

Wikipedia, which we warn our students against, tells the basic lie: "The most well-known example of a technological revolution was the Industrial Revolution in the 19th century" ('Technological revolution', n.d.) – quite why the latter term is capitalized and the former is not, is unclear. It then goes on to blur the issue even further. The former concept seems to be just about technological and financial market fluctuations:

> *What distinguishes a technological revolution from a random collection of technology systems and justifies conceptualizing it as a revolution are two basic features: (1) The strong interconnectedness and interdependence of the participating systems in their technologies and markets. (2) The capacity to transform profoundly the rest of the economy (and eventually society).*
> ("Technological revolution", n.d.)

'Society' creeps in at the end as a possible dependent variable to be impacted on by the *independent* variable of the technological revolution. Do societies somehow exist independently of technological revolutions or "the economy"? Can society be conceived of in any meaningful way as a 'discrete' statistical variable? The point in referring to this Wikipedia entry is not to endorse its claims, but to illustrate just how crude representations of a technological revolution can be, especially when they come to stand as proxies for putative industrial revolutions. We can dismiss such notions easily enough.

> Do societies somehow exist independently of technological revolutions or "the economy"? Can society be conceived of in any meaningful way as a 'discrete' statistical variable?

However, there is a broad tradition in evolutionary economics that needs much more serious consideration. It draws on 'Kondratieff wave' theory and Joseph Schumpeter's notion of *creative destruction* to construe industrial revolutions as "techno-economic paradigms" (e.g. Freeman and Louçã 2001; Perez 2002; Malecki and Moriset, 2007). Nikolai Kondratieff[10] (1935) posited technology-driven historical cycles of economic prosperity every 50 years or so, and his model of long, techno-economic waves of capitalism has been projected forwards mathematically to suggest a series of ongoing technological revolutions throughout modern history, and, as it were, future history. Some of these projections are particularly fanciful – for example, Knell (2010) imagines that we are currently entering a *sixth* techno-scientific revolution. There is an unfortunate teleology based on Kondratieff's waves at work here. Knell bases his prediction on an extension of Perez's (2002, p.57) retrospective[11] mapping of five technological revolutions – 1771, 1829, 1875, 1908, 1971 – the last of which is the "age of information and telecommunications". However, his sixth turns out to be a damp squib, no more than an echo of Schwab's prophecy of 'unprecedented convergences' of the physical, digital and biological worlds in nanotechnology, biotech, quantum computing and AI. One can see here very clearly, though, how the idea of a 'technological revolution' can expand artificially to become an 'industrial revolution', almost without thinking.

Schumpeter extended Kondratieff's ideas in his notion of "industrial mutations" – in fact, it was he who coined the term "Kondratieff cycles". Industrial mutations are processes in which the economy is "incessantly being revolutionized from within" to make way for innovation (1943, p.31). One commentator describes this as a unique explanation combining development, innovations and cycles:

> *Economic development … has endogenous origins. … In a cyclical manner, innovations are implemented by a herd ["troupe"] of entrepreneurs (the leading inventors, followed by the rest of the herd), which generates a period of prosperity based on the widespread distribution of these innovations. Then, the disturbances in the economic system subside during the next phase (characterized by 'credit deflation' and 'creative destruction'), and the economic system returns to a state of near equilibrium.* (Potier, 2015, p.994, my translation)

Schumpeter (1939, 1943) was interested in modelling business or economic cycles – the rate at which innovations are introduced into the economy. He developed a model incorporating three different conceptions of the waves of capitalism: the Kondratieff long cycles of about 50 years, the Juglar cycles of about eight years, and the Kitchin short waves of up to 40 months[12] (Potier, 2015). These cyclical technological and economic events become the basis in some academic literature for classifying and predicting 'industrial revolutions'. In popular literature, a number of authors use the ideas of Kondratieff and Schumpeter loosely to justify Schwab's claim that there is a 4IR. Besides the technological reductionism, there is an unfortunate teleology here that projects 'long waves' into the future, on a recapitulationist evolutionary logic (although Kondratieff himself was sceptical of such teleology [Mustafin 2018, pp.10-11] and there is a suggestion that Schumpeter may have been too [Papageorgiou and Michaelides 2016]).

Criticisms of both Kondratieff and Schumpeter abound. Wallerstein suggests that they both worked with data about western Europe and the USA, which may not hold for the world economy as a whole (Wallerstein 1984, p.563). Maddison (1991), in a mainstream economic critique of the idea of capitalist waves (he prefers the term 'periods'), suggests that both Kondratieff's and Schumpeter's "treatment of statistical material is illustrative rather than analytic, and is at times rather cavalier". He shows, for example, by means of his own impressive statistical analyses, that they underestimate the impact of World War I, and that Schumpeter also tends to "brush off" the serious economic consequences of the 1929-1933 recession and World War II. He further suggests that Kondratieff offers no plausible causal explanation as to why capitalist development should entail systemic, cyclic long waves, and that Schumpeter fails to explain why innovation should "come in regular waves rather than in a continuous but irregular stream" (1991, p.103). The Marxist, Gintis (1990), accuses Schumpeter of focusing only on the ability of an economic system to generate competent and innovative entrepreneurship, thus eliding issues such as the morality of private property and broader questions of democratic transformation. Moldaschl (2010) suggests that for Schumpeter the idea of innovation is one of "technological insularity" because it pertains only to "commercially exploitable novelty" (2010, p.2). He claims that Schumpeter does not have a theory of innovation, but only a theory "in which the entrepreneur – as a more or less creative subject engaged with 'new combinations' – [is] the most important endogenous driver" (2010, p.12). There are numerous examples of these kinds of criticisms of Schumpeter and Kondratieff in the literature on revolutionary technologies and economic changes, and an equally large number of defenses and extensions of their work and subsequent developments of it, for example in the 'techno-economic paradigm' (Freeman and Louçã 2001; Perez 2002). The point about the vast majority of all this literature, however, is that it is *internal critique*, by which I mean that it operates as theoretical and scientific debate within the boundaries of the concept (or if you like, the conceptual framework) of a technological revolution, conceived as a discipline (Abbott, 2001) or an academic territory (Becher and Trowler, 2001). It is inwardly focused rearticulation and debate concerned to sort out the problems and anomalies faced in the study of 'technological revolutions'. The dissolving of the broader concept of an industrial revolution into the narrower concept passes almost without noticing.

There appears to be very little *external critique* of the same literature. The conceptual problems associated with reducing 'industrial revolution' to 'technological revolution', 'techno-scientific revolution', 'techno-economic' paradigm, or whatever, need much more thorough academic scrutiny. So too do the practical problems and unintended consequences that arise in government, industry, education and the like if this conflation is not corrected. In South Africa, this debate is particularly urgent: a number of progressive thinkers and activists, in correctly eschewing Schwab and the WEF, have leaned towards Kondratieff and/or Schumpeter to provide some understanding of contemporary advances in digital technology and their implications for our society (Gillwald, 2019; Deedat, 2020; Sutherland, 2020; Cooper, 2021; Maharajh, 2021).

Sutherland's (2020) article is, I suggest, particularly salient in understanding the problem associated with this tendency. He is fully aware of the ideology-laden character of 4IR rhetoric, describing it as "an attractive flag around which to spin an elitist and neoliberal vision of the future of manufacturing" (2020, p.246). He also considers the history and implications of the three industrial revolutions in Africa deliberately, which is something that neither 4IR advocates nor Schumpeterians often bother to do (see Moll, 2020).[13] However, his account of the character of the 1IR and 2IR in and for Africa is a sweeping gloss over the entire eighteenth and nineteenth centuries: "the role of Africa was limited to providing agricultural products and raw materials,[14] such as cocoa and coffee beans, cotton, rubber, sugar cane, and tobacco, plus gold and diamonds from South Africa and copper from then Northern Rhodesia" (Sutherland, 2020, p.236). Sutherland's account of this historical period is totally reduced to economic analysis, related to issues like the "extraction of resources", "tiny markets for luxury goods", "infrastructure for resource extraction (e.g. railways)", and economic and industrial path dependencies. The definitive, pivotal character and consequences of the *first two industrial revolutions* in Africa were the issues of slavery, military conquest by European or European surrogate armies, the legal codification of colonialism, and the political, cultural and psychological colonization of its people, in addition to economic subjugation and the extraction of commodities (Amin, 1972; Amin, 1989; Fanon, 1986a; Fanon, 1986b; Memmi, 1965). Sutherland, however, dissolves the notion of an industrial revolution in technological, value-related economic and business-centred conceptions of pseudo-revolutions.

The arguments of W.E.B. du Bois (1935) on economic reductionism in the writing of US history come to mind. Sutherland's elision of slavery from the 1IR, and of imperialist colonialism from the 2IR, are reminiscent of the manner in which US economists treated slavery with "moral impartially", as "a sort of working out of some cosmic social and economic law" (1935, p.585). For Du Bois, in this "sweeping mechanistic interpretation" of history:

> *there is no room for the real plot of the story; for the clear mistake and guilt of rebuilding a new slavery of the working class in the midst of a fateful experiment in democracy; for the triumph of sheer moral courage and sacrifice in the abolition crusade; and for the hurt and struggle of degraded black millions in their fight for freedom and their attempt to enter democracy. Can all this be omitted and half suppressed in a treatise that calls itself scientific?* (Du Bois, 1935, p.585)

The definitive, pivotal character and consequences of the *first two industrial revolutions* in Africa were the issues of slavery, military conquest by European or European surrogate armies, the legal codification of colonialism, and the political, cultural and psychological colonization of its people, in addition to economic subjugation and the extraction of commodities.

This is precisely what the undermining of deep, systematic, historical accounts of the social totality of industrial revolutions (or the absence of such revolutions) by reductionist accounts of 'technological revolutions' does. It is telling, then, that Sutherland conceives of the supposed contemporary information technology revolution as follows:

> *4IR comes not from these historical analyses, but from of a recent tradition of auto-cannibalism of business models – firms re-imagining their businesses before rivals do it for them, in order to capture their revenues. … A central concept is the dynamic capability or the means by which an organisation adapts its resources, used as a framework to understand how corporations respond to disruptions, …* ***Underlying this is the idea of Schumpeter who described a process of creative destruction****… The principal thrust of 4IR is about changing business models, … through the adoption of a [Schwab's] poorly defined set of technologies including 3D printing; artificial intelligence (AI); autonomous vehicles; biotechnology cyber-physical systems (CPS); fifth-generation wireless (5G); internet of things (IoT); industrial Internet of Things (IIoT); nanotechnology; quantum computing; and robotics.* (Sutherland, 2020, p.237, my emphasis)

Et voilà! Despite the progressive intentions of advocates of 'waves' or 'disruptions', the fusion of Schumpeter, Kondratieff and Schwab is upon us (might Schwab say this is an unprecedented technocratic convergence?). The 4IR is recast, and its associated ideological frame legitimated, by Schumpeter's notion of *creative destruction*.

My argument in this paper is that this is a severe mistake, because it rips such technological change out of its deeper social and historical context. However, Hobsbawm makes the interesting observation that "good predictions have proved possible on the basis of Kondratiev Long Waves – this is not very common in economics – [and this] has convinced many historians … that there is something in them, even if we don't know what" (1995, p.87ff). The questions that one might want to put to Hobsbawm, if it were possible, are: Are these *historical* predictions? Why would a historian want to make predictions? If so, are these teleological predictions of changes in a strict periodicity discovered in the past, or simply changes projected on the basis of an analysis of the contradictions of the present? Whatever the answers, this debate must clearly go on vigorously.

The analytic approach in this article treats industrial revolutions as fundamental transformations across multiple social and economic dimensions which impact each other in complex ways and have a global impact – hence the use of the term 'socioeconomic' to grasp this complexity. The social transformation that resulted from the 1IR was a profound combination of material progress and social suffering that was so wide-ranging that it warrants the term 'revolutionary'. It was far more than a period of intense technological innovation or the merging of technologies. While this transformation was centred in a particular society (Britain) over the course of nearly a century, it had ramifications and lasting consequences for the whole world.

Karl Polanyi's (1945) insights in this regard are crucial: prior to the industrial revolutions, the socioeconomic mentality of people was based on communal systems of reciprocity and redistribution; the consequence of industrialization was the institutional construction of a competitive market society regulated by the State. This "great transformation" was established in Britain in the 1IR, and consolidated globally in the 2IR. It was not simply an accumulation and confluence of inventions. By identifying the key elements which constituted the 1IR as an industrial revolution, we can construct an analytical framework that can be applied to other periods of significant change to evaluate whether they legitimately constitute industrial revolutions. These characteristics can be used as criteria for this analysis. An industrial revolution, in its socioeconomic entirety, must exhibit at least the following substantial, conjunctural features over a period of time:

- A technological revolution, characterized by widespread, connected technological innovations;
- Transformation of the labour process, to do with the productive activity of workers in the workplace, or the 'nature of work';
- Changing labour relations in the workplace and class-specific[15] institutions in broader society;
- Changing community and social relations, in the sphere of everyday life and culture (notably in patterns of urbanization);
- Global transformations, related to international trade and agglomerations of power.[16]

The historical analysis of the 1IR above makes it clear that these different strata in society function together in an industrial revolution, and that any one of them cannot be reduced to any other. Hence the injunction that an industrial revolution is far more than just a technological revolution. It is a complex ensemble of technological, economic, social and political changes, not just a merging or emerging of technologies.

We can now go on to assess the notions of the second, third and fourth industrial revolutions against these criteria.

The Second Industrial Revolution – 1865-1914[17]

More than any other industrial revolution, it seems appropriate upfront to highlight the technological marvels of the 2IR. Hobsbawm suggests that, in what he calls the "age of empire", or the industrialized world – the world of factories – "modern technology was not only undeniable and triumphant, but highly visible" (1989, p.27). In the first place, by 1870, technology with roots in the 1IR had established an extensive infrastructure for trade and commerce: a network of harbours, particularly on the northern Atlantic, and railway and telegraph networks in Europe and North America, had shifted "the large technological system from an exception to a commonplace" (Mokyr, 1998, p.2). Furthermore, unlike the 1IR, where the relatively few inventions and innovations were, as it were, out of the public eye, connected in productive ways *inside factories*, the new technologies of the 2IR were all over the place. They became very much the *lifestyle* of people in the industrialized countries of the world. There were many of them: motor cars, electric light bulbs, electrified streets, tall buildings, telephones, radios. Behind these sat the big industrial breakthroughs of the era: steel, electricity, petrol ('gasoline' in American), industrial chemicals, and the 'machine tool revolution' in the USA (for a more thorough discussion of this, see page 45 below). Steel was not invented in the 2IR,[18] but cheap, quality steel was generally available after 1865 when open-hearth, and later electric and oxygen, furnaces enabled large-volume steel production. Neither was electricity discovered in the 2IR, but the large scale generation of power was one of its most significant achievements. Electric machines, and electric lighting in factories, streets and homes, were soon widespread. Petrol *was* a 2IR discovery: the first oil well had been dug in Pennsylvania in 1859, and paraffin (in American, kerosene) distilled for lighting. One of the by-products, petrol, was 'discovered' in the 1880s, with the invention of the motor car. And in industrial chemistry, European nations, especially Germany, took the lead (Mokyr, 1998, p.4), although plastics emerged in the USA. All of these breakthroughs were pivotal to the global industrial expansion of the 2IR.

By 1870, technology with roots in the 1IR had established an extensive infrastructure for trade and commerce: a network of harbours, particularly on the northern Atlantic, and railway and telegraph networks in Europe and North America, had shifted "the large technological system from an exception to a commonplace.

It is worth recalling the better-known innovations of the 2IR. In 1865, the German-French duo of Siemens and Martin introduced the open-hearth furnace to produce cheap steel. In 1867, Nobel invented dynamite in Sweden, which he was later to regret deeply. In 1876, the Englishman Bell invented the telephone. The American Edison perfected the light bulb in 1879. In 1882, the same Edison opened the world's first steam-driven electricity generating stations in London and New York. The first skyscraper was built in Chicago in 1884, using a groundbreaking steel frame. In 1886, Starley built the first modern bicycle, the 'Rover', in Coventry, England. In 1886, two Germans, Daimler and Benz, respectively invented the first prototype of the internal combustion engine, and a pioneering three-wheeled motor car. Another German, Diesel, built the first diesel engine in 1893. The Italian Marconi broadcast the first transatlantic radio signal in 1901. The American Wright brothers flew the first aeroplane in 1903. In 1907, Baekeland invented bakelite, the first fully synthetic plastic, in Washington DC. The first diesel-powered motor ship was built in Denmark in 1912. In Detroit, USA, Ford introduced the automated assembly line in 1913. And then, to temper some of the technological triumphalism that might have crept into this paragraph, we might note that the 'unsinkable' Titanic was built in Belfast in 1911, and that the British soldier Swinton started to build the first military tank in 1914.

Now my purpose in the previous paragraph was not to extol the achievements of great white men (although the significance of that should become clear shortly), but to illustrate two important points about the 2IR: (i) that technological innovation was no longer centred on the economy of one dominant country, as it had been in the 1IR. Now Germany, France, Belgium, Italy, the USA, some Scandinavian countries *and* Britain constituted a global industrial nexus. In the 1880s "no country outside of this 'developed world' (and Japan, which had joined it) could be described as industrial or even on the way to industrialization" (Hobsbawm, 1989, p.21); and (ii) that the range of technological innovations that characterized the period was indeed vast. This geographic spread and diversity of new technology is suggestive of a crucial economic aspect of this industrial revolution: the interaction between the giant industrial corporations in the USA and Europe, who employed only a small fraction of the overall labour force, and small, flexible, localized firms which served specific sections of the market. This maximized innovation: "the great pathbreaking inventions ... were crucial not because they themselves had necessarily a huge impact on production, but because they increased the effectiveness of microinventive activity" (Mokyr, 1998, p.1). This is what made the 2IR pervasive.

Nonetheless, it was in large corporations that the most significant transformation of the labour process associated with the 2IR came about. It came to be known as Taylorism. It was essentially the organization and management of workers to maximize productivity in mass production factory environments. In 1911, Frederick Taylor published *The Principles of Scientific Management,* based on his task analysis and study of work methods, as supervisor of machinists at Bethlehem Steel and other engineering companies. Influenced by early behaviourists, his principles included:

1. Select workers specifically for each discrete task in a scientifically determined division of labour. Take this notorious quotation, for example: "a man who is fit to handle pig iron … [must] be so stupid and so phlegmatic that he more nearly resembles in his mental make-up the ox than any other type… the man who is mentally alert and intelligent is … unsuited to … the grinding monotony of work of this character" (Taylor, 1911, p.59).
2. Select and train each worker, as opposed to leaving him *(sic)* "passively" to train himself.
3. Give detailed instructions to and supervise each worker in the performance of his specific task.
4. Increase the number of managers to ensure workers actually perform the tasks. (Taylor, 1911)

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The key innovation that was introduced by Taylor into factories was the *assembly* line. The notion that specific tasks be allocated to specific workers underpinned this transformation of the labour process in large factories. Taylorism was implemented and managed 'scientifically' in the capitalist economy of the USA and the commandist economy of the Soviet Union (Scoville, 2001).

Another part of Taylor's research was on *interchangeable parts* – the precise manufacture of different components of a whole, assembled, manufactured product, so that any component could be fitted by a worker into any such product on an assembly line:

> *Interchangeable parts was not an 'invention.' It was eventually to become a vastly superior mode of producing goods and services, facilitated by the work of previous inventors, especially the makers of accurate machine tools and cheap steel. To be truly interchangeable, the parts had to be identical, requiring high levels of accuracy and quality control in their manufacture.* (Paxton, 2012, p.9)

This led to the famous, perhaps infamous, collaboration between Henry Ford and Taylor (Paxton, 2012). I say infamous because Taylor's critics (e.g. Braverman, 1998) accuse him of dehumanizing workers, of *deskilling* them, by focusing only on the control of labour and the cheapness of products (Webster, 1991. p.55). The Ford Motor Company hired Taylor in 1913 to study its workers to determine the most efficient and time-saving methods to increase productivity, and later that year introduced precision machine tools and assembly lines into its factories. Ford adopted Taylor's methods, taking them further by introducing a moving conveyor belt into each assembly line. Soon, Ford was rolling out up to 10,000 Model T Fords a day. The *automated assembly line* is regarded as a key feature of the 2IR. In this model of the labour process, a product moves along a conveyor belt, and workers install individual components one-by-one. There were numerous examples of assembly lines being introduced in foundries, and engineering, machine tool, motor car, locomotive and clothing factories, in this period. Obviously, some industries did not mechanize in this way (e.g. mining, transport, construction), but there was still evidence of 'the principles of scientific management' influencing the labour process in them (Hobsbawm, 1989, p.115).

The factory system was, by 1865, ubiquitous in the industrialized nations of the world; in the period that followed, large factories became common, and giant factories increasingly evident. With Taylorism's emphasis on management, the hierarchy of the factory floor was now one of *workers – supervisors – bosses*, with the interests of these different classes still distinguishable from each other, fundamentally in the case of workers and bosses, and more ambiguously in the case of supervisors. In the 2IR, these changing relations in the workplace became the norm. The result was the most significant change in the social relations of the workplace in history: the legalization and formal consolidation of the trade union. Thousands of British workers had formed trade unions in the 1IR, but these were repressed by force and curtailed by law. In 1799, the Combination Act was passed, "to prevent unlawful combinations of workmen", banning trade unions and collective bargaining. The ensuing period, well into the 1800s, saw many strikes in England and Scotland which were severely repressed. In the USA and parts of Europe, similar events occurred.

However, factory outputs were also negatively affected, and politicians and capitalists began to consider whether trade unions could not serve their interests as well. A political debate had started amongst them about whether trade unions could be part of ordered society. *Their* ordered society. In 1848 (in a period when rising socialist politics was closely linked to trade unions, and at the time Marx and Engels published the *Communist Manifesto*), the liberal John Stuart Mill wrote:

> *If it were possible for the working classes, by combining among themselves, to raise or keep up the general rate of wages, it needs hardly be said that this would be a thing not to be punished, but to be welcomed and rejoiced at. . . . If they could do so, they might doubtless succeed in diminishing the hours of labour, and obtaining the same wages for less work.* (Mill, cited by Ekelund and Tollison, 1987, p.590)

Mill argued that unionized workers should be thought of as "a protected class of working men" which could be "raised up". But his main problem was that trade unions would push wages up, decrease jobs, and therefore increase the size and political militancy of the broader mass of the working classes. Hobsbawm (1967) engages a debate amongst economic historians about whether the unions themselves, in these debates, shifted towards non-political trade unionism. Was there a "new intellectual ferment within the trade union world in the 1880s reflected in the spread of socialist ideas", or did an increasingly middle-class trade union leadership succumb to "a gradual schooling of the impracticable elements into a sobered and somewhat bureaucratic collectivism?" (1967, p.359). These political debates and dynamics were carried through into the 2IR.

Whatever the case may have been, the general outcome of these political processes was that trade unions were incorporated into the socioeconomic landscape of industrial capitalism by the late 1800s. Britain legalized trade unions in 1872, after a Royal Commission on Trade Unions agreed that their establishment benefited both employers and employees. In France, labour unions were illegal until 1884, but by 1895, the General Confederation of Labour was established and recognized. In Germany, after the repeal of anti-socialist laws, the Free Association of German Trade Unions was formed in 1897. In the USA, the Massachusetts Supreme Court had, already in 1842, ruled labour unions to be legal "provided their purposes and methods are legal"; by 1886, the massive American Federation of Labor was established. The main point, for purposes of this paper, is that the *establishment* of nationally organized trade unions was the major transformation in the social relations of production that characterized the 2IR. By the late 1800s, trade unions were unbanned across the industrial world and 'labour aristocracies' incorporated into the socioeconomic landscape of industrial capitalism (McLennan, 1981).

Just as the assimilation of the trade union into the labour relations order was distinctive of the 2IR, so paradoxical stabilization was part of the revolution in the sphere of social and community life. With the growth of capitalism and industrialization since the 1IR, social relations between the rich and poor had obviously become more complicated, often more antagonistic. Yet the 2IR does seem to have improved aspects of social life somewhat, especially in regard to urbanization.

Mokyr (1998) is very helpful in understanding the situation in the 2IR, as compared with the rising wealth of the middle classes and the impoverishment of the working classes in the 1IR. He suggests that it is not easy to determine the overall effect of technological progress on livelihoods in the 2IR:

> *Technological changes increased the well-being of the populations of Western Europe and North America, in particular. Yet Industrialization led to urbanization, to the concentration of large numbers of workers in dangerous and unpleasant factories and mines, to alienation, the breaking-up of traditional communities compounded by large waves of emigration… [However] it is clear that until 1914 life was getting better, incomes were rising, work-hours slowly declining, some forms of social insurance emerging, nutrition and housing slowly improving.* (Mokyr, 1998, pp.13-14)

Mokyr provides compelling demographic and statistical evidence for this claim. Between 1870 and 1914, across Europe and the USA, infant mortality declined significantly, life expectancy increased, working people received somewhat higher incomes, they lived in less congested housing, and had access to running water, sewage, and medical care. And the rich got richer, and prospered even more.

The 2IR was often styled by those living the upper and middle class good life as *la belle époque* ('the beautiful era'); many historians have adopted the term to describe its social and cultural aspects, as they have Veblen's (1899) notion of the 'leisure class' – a social class displaying conspicuous consumption – and Pettigrew's (1921) description of 2IR America as a 'plutocracy", a society ruled by people of great wealth. These concepts capture well the social contradictions of the time: rising prosperity on the basis of all kinds of technologies, and yet an increasing resentment on the part of the working classes about their social situation. It seems no accident that the socialist and labour political parties that have formed the government or chief opposition in most countries since, were formed at the height of the 2IR. Hobsbawm sums up the contradictions of the 2IR thus:

> *It was an era of unparalleled peace in the western world, which engendered an era of equally unparalleled world wars. It was an era of, in spite of appearances, growing social stability within the zone of developed industrial economies, which … [conquered and ruled] over vast empires … It was an era when massive organized movements of the class of wage workers … suddenly emerged and demanded the overthrow of capitalism. But they emerged in highly flourishing and expanding economies … at a time when capitalism offered them slightly less miserable conditions than before.* (Hobsbawm 1989, pp.9-10).

These contradictions can perhaps best be tracked in relation to the planning and definition of cities in the 2IR. Hobsbawm observed that the haphazard migration to cities that characterized the nineteenth century was "a gigantic process of class segregation, which pushed the new labouring poor into great morasses of misery outside the centres of government and business and the newly specialized residential areas of the bourgeoisie" (1962, p.203). The industrial cities had expanded rapidly, with a proliferation and style of building largely dictated by factory owners. As one might imagine, public health concerns increasingly came to the fore. This, plus a growing social movement focused on poverty and housing, brought about the first concerns with urban planning (Hall, 2014).

Hall (2014) suggests that the origins of urban planning lay in the anarchist movement, which placed great emphasis on ideal cities in ideal societies. There were also notable activists, such as the clergyman Andrew Mearns, who published the influential pamphlet, "The bitter cry of outcast London", in 1883; and Jacob Riis, who in 1890 published *How the other half lives*, early photojournalism which exposed the squalid living conditions in New York's tenement slums. The former described inner city London in these terms:

> *pestilential human rookeries … where tens of thousands are crowded together amidst horrors which call to mind what we have heard of the middle passage of the slave ship … reeking with poisonous and malodorous gases arising from accumulations of sewage and refuse … dark and filthy passages swarming with vermin … dens in which these thousands of beings who belong, as much as you, to the race for whom Christ died, herd together.* (Mearns, cited by Hall, 2014, p.15)

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Urban planning, seen officially as the restoration of order, was now central to the 2IR agenda. In Britain, the Royal Commission on the Housing of the Working Classes was established in 1884 for the purpose, as was the House Commission of 1894 in the USA. Commentators generally date the origin of the urban planning movement as being around 1900 (Hall, 2014). The definition of the city, the stabilization of urban life, the provision of basic amenities to curtail the spread of disease, the consolidation of neighborhoods and who lived in them, the zoning of sections of cities for different functions, all of this was now on the public agenda. Such planning originated in Germany, and spread to the USA, Britain, and the rest of Europe. Public health was the most frequently cited rationale for keeping cities organized (Duhl and Sanchez, 1999). Hobsbawm describes the stabilization of the cities that was achieved as "the almost universal European division into a 'good' west end and a 'poor' east end of large cities" (1962:203).

As to the relations between the wealthy and the poor on a more global scale, the 2IR (despite the abolition of slavery) simply deepened the colonial relations evident in the 1IR. "The major fact about the nineteenth century is the creation of a single global economy…. an increasingly dense web of economic transactions, communications and movements of goods, money and people linking the developed countries with each other and with the undeveloped world" (Hobsbawm, 1989, p.62). It is no historian's accident that the period of the Second Industrial Revolution and the Age of Imperialism are conventionally dated as being from the 1860s to 1914. The economic and technological prosperity of the 21R was intimately bound up with the subjugation and economic exploitation of the colonized world. Rather than using Hobsbawm's term, the 'undeveloped' world, we should perhaps be using Frank's (1971) term, 'underdevelopment', to recognize that the industrialized nations of the 2IR systematically *underdeveloped* the people and communities of the rest of the world, creating and maintaining in them a state of dependency. Hobsbawm implies as much:

> *We are therefore in 1880 dealing not so much with a single world as with two sectors combined together into one global system; the developed and the lagging, the dominant and the dependent, the rich and the poor… Even this description is misleading. While the (smaller) first world, in spite of its internal disparities was united by history and as the common bearer of capitalist development, the (much larger) second world was united by nothing except its relations with, that is to say its potential or actual dependency on, the first.* (Hobsbawm, 1989, p.16)

Industrialization and its attendant 'civilization' had developed in a manner that relied on the extraction of commodities from exotic places The burgeoning economies of the west now depended on raw materials which were to be found in 'remote' places of the world. Rubber, indigenous to and first extracted from the Amazon forests, was now grown in colonial plantations in the French Congo and Malaya; copper, essential to the electrical industry, was colonized in northern Rhodesia and the Belgian Congo;[19] gold and diamonds came primarily from South Africa. Although oil came mainly from the USA and Europe in the 2IR, the industrial nations were already competing for control of the Middle East oilfields (Hobsbawm, 1989, p.63). Furthermore, 'colonial goods' such as sub-tropical fruits, rice, sugar, tea and coffee were demanded by the food markets of Europe, let alone the grains and meat that could be produced more cheaply in the colonies. The reason for that had much to do with exploitable, cheap, often coerced labour (Pollard and Holmes, 1972). And then, of course, colonies provided markets for the purchase of commodities produced at the centre: "the search for and consolidation of markets was a natural by-product of an international economy based on the rivalry of several competing industrial economies, intensified by the economic pressures of the 1880s" (1972, p.67). For example, 45% of 2IR English clothing and cotton exports went to India alone (1972, p.69). All in all, colonial expansionism was very much on the agenda of the industrialized nations at this time.

Between 1876 and 1915, about one quarter of the world was colonized by Britain, France, Germany, Belgium, Italy and the USA, "the global industrial nexus", between them. In south-east Asia, the period was characterized by ongoing military actions, in which the colonial powers effectively competed with each other for territory. In 1867, the French annexed Cochin China (southern Vietnam) and Cambodia. They then moved northward, seizing Hanoi in 1882. After a war with China (1883–1885), colonized French Indochina was established, across a territory 50 percent larger than France itself. From 1873, the Netherlands engaged in a protracted war with the Sultanate of Aceh, to eventually consolidate Dutch rule over modern-day Indonesia by 1904. In 1898, at the onset of the Spanish-American war, Philippine rebels declared independence from Spain, but the USA refused to recognize it and annexed the territory in 1899. The bloody Philippine-American War (1899–1902) eventually established American colonial authority. By 1913, from its military bases in the long-established colonies of India and Burma, the British had consolidated its colonial occupation of Malaya and Borneo.

However, it is the 'scramble for Africa' that establishes, beyond doubt, the historical case to place imperialism at the economic centre of the 2IR. The colonial presence in Africa had for the most part been in small coastal enclaves, to serve as ports for the transatlantic slave trade, points of trade, 'refreshment stations' for shipping, and the like (the British colony of South Africa was the notable exception). By the 1880s, 80% of Africa remained under traditional and local control. But by this time, the interest amongst industrial powers in the raw materials and potential markets of Africa was growing rapidly. To preempt conflicts amongst themselves that might have led to war (specifically, the military conflicts between colonial powers that had taken place in south-east Asia), the Berlin Conference of 1884 to 1885 was convened, initially to discuss "the problem of the Congo". The countries represented included Belgium, France, Germany, Britain, Italy, Portugal, all with existing colonial enclaves in Africa, the fading colonial power Spain, the Netherlands which had previously held a colonial enclave in the south of Africa, and countries with strong economic interests in Africa, like Denmark, the Swedish-Norwegian Union, and the USA.

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Reading the declaration signed at the conference (Berlin Conference, 1885), it is notable that its overwhelming content is about "free trade" for the colonial powers in Africa. Despite brief gestures to combatting slavery, and the "wellbeing of the native populations", most of it is about the movement into or out of Africa of goods, merchandise, and cargo. It declares freedom of navigation "for the merchant ships of all nations equally" of the Congo River (Article 13) and Niger River (Article 26), and a free trade zone stretching eastwards from the Congo Basin to the Indian Ocean (Article 1.3). It ends by requiring "any power" that might take possession of tracts of land on the African continent "outside of its present possessions" or anew, to abide by the freedom of trade conditions agreed upon (Articles 34 and 35).

Of course, what happened then, almost before the ink of the signatories had dried, is that the colonial powers parceled out virtually the rest of Africa between them. Belgium, France, Germany, Britain, Italy and Portugal all acquired new colonies. Notably, while no new colonizers got on board, the USA, Denmark and the Swedish-Norwegian Union fought for and achieved their strategic interest of giving the agreement "a commercial definition, as opposed to a geographical one" in the opening up of free trade on the Congo and Niger rivers (Munene, 1990, p.76). The delegates in Berlin drew the future boundaries of Africa, and "apart from some localized detail, paid scant regard to Africa, let alone to Africans. Prior to the Berlin Conference few of the present boundaries of Africa existed. Those that did were limited to settler territories" (Griffiths. 1986, p.204). The political map of Africa that they produced was a mishmash of rivers and straight lines that divided Africa up into fifty arbitrary colonies with little in common with the indigenous cultures and regions of the continent. The Berlin Conference established imperialism in Africa, and the agreement that it reached was a central legal mechanism of the 2IR.

The above account of the years 1865 to 1914, in all of its complexity, makes it quite clear that we can legitimately call the 2IR an industrial revolution. The period meets all the criteria to allow us to give it this historical significance:

- *Technological revolution:* widespread technological novelty and invention, arising in the development of steel, electricity, petrol and industrial chemistry;
- *Transformation of the labour process:* the assembly line and interchangeable parts transformed work in factories;
- *Changing work relations in the workplace:* the competing interests of factory owners and workers intensified, leading to the recognition of trade unions and the emergence of socialist political parties;
- *Changing community and social relations:* social cleavages between the rich and poor were consolidated, for example in the management of cities;
- *International/global transformations:* colonialism was systematized, and the economic exploitation associated with it intensified.

The absence of Industrial Revolution – 1915 to 1965

It would not do to fast forward to the late 1960s, without pausing to wonder about the years 1915 to 1965, and why no one seems to posit any industrial revolutions in that period. It is striking how many historians, particularly military historians, seem to be itching to find an industrial revolution in this period (e.g. Hobsbawm, 1995; Miller, 1998; Mindell, 2000; Palazzo, 2000; Hacker, 2005). It was after all four decades of dramatic world history: a deep economic depression between two world wars, and the 'golden age of capitalism' of the fifties and sixties; the achievement of formal independence by most colonized nations (if not the ending of colonization); the Cold War with its arms and space races, and of course the World War I and World War II themselves. It is a truism that war accelerates the pace of technological innovation. So why, in these intense forty years, was there no industrial revolution? Hobsbawm's answer in relation to the technological innovations of war seems generalizable to the whole period:

> *The modern industrial economy was built on constant technological innovation, which would certainly have taken place, probably at an accelerating rate, even without wars … Wars, especially the second world war, greatly helped to diffuse technical expertise, and they certainly had a major impact on industrial organization and methods of mass production, but what they achieved was, by and large, an acceleration of change rather than a transformation.* (Hobsbawm, 1995, p.48)

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There were indeed many technological innovations in this period: World War I, most notably, accelerated aeronautics and chemistry (related particularly to chemical weapons – Palazzo, 2000; Fitzgerald, 2008). The size and influence of the German chemical and pharmaceutical industries, which persist to this day, was enhanced significantly by these initiatives. World War II produced rocket technology, enhanced radio technology (radar and sonar), improved plastics (nylon parachutes, plexiglass, etc.), magnetic analogue tape recording (apparently plundered from Germany at the end of the second world war – Hardisty, 2015), and then the one that perhaps nobody would dare to contemplate as sparking an industrial revolution, nuclear fission. The motor industry produced many innovations, such as hydraulic brakes (1919), the synchromesh gearbox (1932), coil spring suspension (1934), power steering (1951), catalytic converters (1956) and anti-lock braking systems (1966). In 1947, the transistor was invented by the American physicists, Shockley, Bardeen and Brattain, and accelerated the field of electronics, leading to the first transistor radios and a new generation of computers in the 1950s. The first computers, which used vacuum tubes, had appeared in the 1940s, weighing in the order of one gigagramme.[20] Transistors made it possible to build smaller and faster computers. The examples go on. Yet there was arguably no technological revolution, let alone an industrial revolution. It seems true that the technological innovations of the period, with the possible exceptions of the transistor and nuclear fission, tended to be very much the technology of the 2IR in continuing industrial development. It was an acceleration of change rather than a transformation.

The most obvious reason why is that the various social contexts which relate to technological transformation did not show much by way of revolution in these years. The factory floors, trade unions, social and community contexts, and life and death in the colonies, tended to be in something of a holding pattern over two world wars and the deep economic depression between them. Hobsbawm (1995) shows, by drawing on various economic indicators, that the world economy stagnated until after World War II: by 1948, world trade was not significantly higher in volume than before 1915. The USA, which emerged from the war as by far the most powerful world economy, tended to be self-sufficient, barring a few raw materials. Socially and economically, other states tended to isolate themselves against threats from outside. The world economy was visibly in crisis, leading these states to try to consolidate socially and politically, rather than change. One social indicator of this is that trade unions lost half their membership from 1920 to 1932 (1995, p.89). Furthermore, the 'golden age' following the 1950s capitalist boom brought with it socioeconomic and political rebuilding, without much evidence of technological transformations inspiring social change (Toniolo, 1998; Marglin and Schor, 1992; Milberg and Winkler, 2009). While "the core countries of western capitalism … traded with the overseas world, … what really exploded was the trade in industrial products, mainly between the industrial core countries" (Hobsbawm, 1995, p.269) – evidence of socioeconomic consolidation, and no suggestion of revolution of any kind. In colonial contexts, the 1950s were dominated by anti-colonial struggles, and the 1960s by transitions to independence. Fanon's lament in 1961 that the new leadership of African nations "possesses neither industrialists nor financiers. The national bourgeoisie is not geared to production, invention, creation or work" (1961, p.37), gives us some sense of why industrial revolution did not have any colonial impetus in those times.

This section commenced with the claim that a pause to consider the years 1915 to 1965 would be worthwhile. It has been worth it because it gives us a good sense of how, despite numerous episodes of significant technological innovation in a particular era, there may be no grounds for declaring it to be an industrial revolution. My argument in this paper, of course, is that this is precisely what is happening now in relation to a putative 4IR.

The Third Industrial Revolution – 1969 to the present

The 3IR is variously known as the 'computer revolution', the 'digital revolution', the 'informational age', the 'information society', or the 'network society'. All of these descriptions are accurate in some way, and between them capture the complexity of the social, economic and cultural transformations that this era has witnessed. There is no question that these transformations constitute an industrial revolution.

The iconic technological events of the 3IR have been the invention of the Internet and the World Wide Web (WWW, or simply 'the Web'). The Internet was a 1969 project supported by the US Department of Defense (DoD) that aimed to link computers via standard telephone connections at a number of universities working on DoD-funded research. According to Castells, it was this "revolutionary electronic communication network, that would grow during the 1970s to become the current Internet" (1996, p.54). I differ with Castells about giving it the tag 'revolutionary' at that stage. It was serious technological innovation, yes. But it remained a relatively unknown platform until Tim Berners-Lee built a document-linking structure on it, and most importantly, defined open standards for defining and exchanging information via the Internet. This structure consisted of three computer codes, HTML, URL and HTTP[21] (acronyms that we see every day), which he had defined to find a way for scientists from all over the world to collaborate on research at the European Organization for Nuclear Research (CERN).

In 1991, Berners-Lee went live with the first browser that used these standards to exchange hyperlinked data via the Internet, and inaugurated the WWW. At about the same time, Marc Andreesen started to develop Mosaic, which became the first popular, widely available browser after its release in 1993. So, to the extent that we talk about the Web and the Internet interchangeably, it seems fair to say that, thirty years ago, the Internet was 'switched on', thus consolidating the fundamental social revolution that we know as the 3IR. This is not to say that the Internet or the WWW caused the 3IR; rather they emerged from and became the vehicle for the socioeconomic transformations of the time.[22]

Most of the other technological innovations of this time would come to have some kind of relationship with this globalized computer network. Microelectronics has expanded exponentially since the 1960s, building on transistor technology, notably in the development of integrated circuits and microprocessors. These made possible the personal computers of the 1980s, and later the cell phone and laptop computer technology of the 1990s and beyond. Programmable logic controllers (PLC) originated in the late 1960s in the automotive industry in the USA, and are central to 3IR industrial transformation. A PLC is a digital computer built to control manufacturing processes, such as assembly lines or robotic devices, or any activity that requires high accuracy and repeatability. It is digitally linked to all machinery and production data sources, and 'manages' the production process continuously by analysing real time data. The Ethernet, a networking system that enables communication via a protocol (a 'network language', a programmed set of rules) between computer workstations and other digital devices, was invented in 1973. Among other things, Ethernet enables interconnected local office networks in wired, local area networks (LAN) or more widespread business networks in cabled, wide area networks (WAN). Robotics, the development of computerized machines that replicate human action, is an area of major 3IR technological innovation. The first digitally programmed robot was installed in a Connecticut factory in 1961 to shift and stack hot metal (Engelberger, 1985, p.7), and robot technology has progressed steadily since then. By 2000, there were some 750 000 industrial robots in the world (UN, cited in "History of robots", n.d.).

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Underlying all of this is the technology of *digitization*, which is the technical process of encoding analogue information (documents, objects, images, sounds, etc.) into computer readable binary data (zeroes and ones). In this format, information is organized into discrete *bits* of data that all devices with computing capacity can process. This is why we call them 'digital technology'. The 'interoperability' that is produced is the crucial technical phenomenon that makes the networking of machines possible, and hence the network society. Many other areas of technological progress in the 2IR have been increasingly dependent on computerization:

> ***Modern** biotechnology (bread making is, after all, biotechnology) dates to gene splicing experiments by Paul Berg at Stanford University in 1971, but bioinformatics came into genetic research only by 2000. However, computational drug design – "the use of computers to literally design drugs atom by atom" – first occurred in the 1970s* (Maulik and Patel, 1997, p.109).

Nuclear energy has developed all over the world in the 3IR. Control systems required to maintain stability in a reactor are necessarily computerized. The disasters at nuclear power stations in Three Mile Island in 1979 and Chernobyl in 1986 were both substantially, but not wholly, attributed to programming faults in the computer systems that managed their reactors (Neumann, 1995).

Space technology, another significant 3IR feature, is obviously heavily reliant on digital communications and other computer technology. Once the Soviet Union narrowly beat the USA in their ideologically charged space race in the late 1950s, with Sputnik 1, satellite technology rocketed into the 1960s.

Globalization is a term often used to describe the socioeconomic transformations of the 3IR. We should be careful here; we have already seen that the 1IR was in some sense globalized by 'triangular' transatlantic trade (particularly the slave trade), and the 2IR likewise by systematic colonialism. However, the term globalization has particular significance in relation to the 3IR:

> *a global economy is a new reality, different from processes of internationalization in previous times, for one simple reason: only at this point in history was a technological infrastructure available to make it possible. This infrastructure includes networked computer systems, advanced telecommunications, information based technology, fast transportation systems for people, goods and services, with a planetary reach, and the information processing capacity to manage the complexity of the whole system.* (Carnoy and Castells, 2001, p.3)

It is generally accepted that it was the networking of digital technologies that drove capitalism into a globalized economy, *willy nilly*, in which productivity and competitiveness is based on information processing (Castells, 1999; Greenwood 1999; Milberg and Winkler, 2000; Witt and Gross, 2020). In the pursuit of profit, "the most critical distinction in this organizational logic is to be or not to be in the network … everything that counts is organized around a worldwide web of interacting networks" (Castells, 1999, p.6).

It is generally accepted that it was the networking of digital technologies that drove capitalism into a globalized economy, *willy nilly*, in which productivity and competitiveness is based on information processing.

Speaking less abstractly, networked technology allowed, indeed compelled, large corporations to trade outside national borders to maximize profit, reduce costs of production and better serve local markets. They did this in two ways: (i) by *offshoring*, which is the relocation of a factory or other operational process to a foreign country to take advantage of lower costs; or (ii) by *outsourcing* services to a foreign company, again to lower costs, e.g. the farming out of call centre operations by American or South African banks to companies in India (most *outsourcing*, by the way, is 'in country', and much of it is, more recently, outsourcing to 'the cloud'). From the 1970s, the now "multinational" corporations started to move their manufacturing facilities "from the developed to the developing world" (Levy, 2005, p.686). *Offshoring* became an increasingly prevalent practice in response to the lure of low-cost labour in the poorer countries of the world. "While labour remained a major factor of production, … industry [shifted] from its old centres in the rich countries with high cost labour to countries whose main advantage, other things being equal, was cheap hands and heads" (Hobsbawm, 1995, p.571). Among the earliest factories to move abroad *en masse* were low-skill assembly operations that migrated to Mexico and Asia in the 1980s. For example, in 1985, AT&T moved the assembly of home telephones from its only USA plant in Louisiana, to Singapore. Ford and GM started moving motor plants to Mexico and other "low cost countries" in the 1980's (Moavenzadeh, 2006, pp.35-36); as one of their senior executives justified it, "in Mexico, an engineer costs ten times a manufacturing employee. In the United States, an engineer costs about the same as a manufacturing employee" (Moavenzadeh, 2006, p.42). And it is well-known that many multinationals in the garment industry moved their manufacturing operations to 'sweatshops' in countries like India, Bangladesh and Honduras. Some of this was offshoring, but most became outsourcing, the other means that multinational corporations use to move manufacturing operations 'out of country'. Ironically, many 'manufacturing' firms often do not manufacture anything at all (Milberg and Winkler, 2000, p.14).

By the 1990s, not only manufacturing, but also services like software programming, call-centres and database administration, were regularly being outsourced to underdeveloped countries. Offshoring practices from the 1980s on represent not just a quantitative shift, but a major structural shift in which a networked information technology infrastructure is used to coordinate an intricate and dispersed set of economic activities, from supply chains to production processes to distribution networks to financial transactions, at sharply lower costs (Milberg and Winkler, 2000; Levy, 2005). These take the form of digitally dispersed Global Value Chains (GVCs) in which the production, trade and marketing of a final goods are spread over several countries, with each one undertaking a discrete good or service. The consequence is the global fragmentation of trade across countries, and an increasing emphasis on finance and the concealment of wealth, rather than on production per se (Keane, 2014; Seabrooke and Wigan, 2014). GVCs "hide, obscure and relocate wealth to the extent that they break loose from the location of value creation and heighten inequality" (Seabrooke and Wigan, 2014: 257), which ramifies into structural consequences at every level of society.

The international socioeconomic consequences of offshoring have been, and continue to be, dramatic. Hobsbawm sees globalization as the continued prosperity of the developed market economies – "perhaps twenty countries inhabited by about six hundred millions" (1995, p.571) – and the increasing impoverishment of others:

> *Globalization and the international redistribution of production would continue to bring most of the world's six thousand millions into the global economy. Even congenital pessimists had to admit that this was an encouraging prospect for business. The major exception was the, apparently irreversible, widening of the chasm between the rich and poor countries of the world … and the pauperization of many ex-socialist countries.* (Hobsbawm, 1995, p.571)

There has indeed been significant socioeconomic progress for *some* countries in the globalized 3IR, those that have adapted to the demands of the global information economy. Mauritius, the Baltic states, Singapore, China and India spring to mind (although the latter two display deepening internal inequality between economic elites and the poor). But the critical role of networked ICTs in stimulating economic expansion is a double-edged sword (Castells, 1999. p.3). While some countries accelerate economic growth by introducing digital production systems, for those not able to realize the new technologies, "their retardation becomes cumulative" (1999, p.3). They either become increasingly marginalized, or they become the labour reservoirs for the offshoring practices of multinational corporations. In the worst traditions of the slavery and colonialism of the 1IR and the 2IR, the severe oppression and exploitation of the marginalized people of the neocolonial world continues in the 3IR. Beckert (2014) describes the offshoring and outsourcing of manufacture as a "giant race to the bottom" by global industry always on the look out for cheap labour; for example, having destroyed the cotton cloth industry in India in the 1IR, the global garment industry shifted cotton plantations and clothing manufacture back to Asia in the most exploitative way. Castells and Portes (1989) make an insightful point in this regard: "It is often argued that uncontrolled, exploitative relationships … [are not part of] advanced capitalism. But it is precisely the development of sweatshops and of other unregulated activities after a long period of institutional control that causes old forms of production to become new ones" (1989, p.13). These exploitative, some might say neocolonial, economic relations of globalization are an integral part of the 3IR.

The 3IR is often described as a shift beyond mining and manufacturing economies, to a *service economy*. This obviously does not mean that the miners and factory workers somehow conveniently disappear from the scene. But what happens in the 3IR is that the operations of, say, an iron ore mine in Carajas, Brazil, an iron ore mine in Kathu, South Africa, a steel plant in China, and a shipping company operating under a Panamanian flag of convenience, are not each managed as an entity on its own, or even as part of a national company, but rather together as a globalized network of the production and distribution of steel. Each of them is, as Castells (1996) would put it, a *node* on a massive global information system networked into every part of the manufacturing process and distributed all over the world. The operations of each one of them, on a day-to-day basis, are determined globally. The production process is thus primarily dependent on the management, flow and utilization of information rather than on raw materials and energy. This has major implications for the way that work is organized in large corporations.

In the worst traditions of the slavery and colonialism of the 1IR and the 2IR, the severe oppression and exploitation of the marginalized people of the neocolonial world continues in the 3IR. Beckert (2014) describes the offshoring and outsourcing of manufacture as a "giant race to the bottom" by global industry always on the look out for cheap labour.

First, it tends to replace low to moderate skilled work tied to a particular place with the highly mobile knowledge work required to coordinate geographically dispersed networks of activities (Beck, 2000; Carnoy and Castells, 2001; Levy, 2005). So it places at risk middle-wage, middle-skilled jobs that can be outsourced to localities with cheaper labour costs, or can be replaced by technology. Jobs such as office managers, human resource practitioners, office workers, call-centre operators, and the like. It places a premium on high skilled jobs requiring expertise and knowledge that cannot be substituted by technology. Its defining feature is that different localities, regions and nation states have become networked in globalized, systematic capitalist production.

Second, it has a similar effect on jobs in factories, particularly in the labour process known as 'just-in-time' manufacturing, pioneered by the Japanese motor car and electronics industries in the 1970s (Kaplinsky, 1989; Hobsbawm, 1995). In the background, assembly line workers have been continually replaced by industrial robots in these industries since the 1960s. But the transformation of the labour process runs deeper than that. Digitally networked technologies enabled computerized inventory control and quicker transport, and thus allowed factories to move away from supply-driven production systems to demand-driven ones. It brought an end to the "old mass production which produced enormous stocks 'just-in-case' they were needed at times of expansion, and then stopped dead while stocks were sold off in times of contraction" (Hobsbawm, 1995, p.404). 'Flexible specialization' now means factories need to produce only enough to supply dealers 'just-in-time', and can reset machinery and change outputs at short notice to meet changing demands and allow product innovation. As a consequence, there is a move away from the 2IR trends to deskill workers and increase the division of labour on assembly lines. The much more flexible labour process requires fewer but more highly skilled workers to operate and reset machines across different settings. Some sites no longer even require factory floor workers at all: 'lights-out production' environments are on the increase in high-tech manufacturing, managed entirely by off-site engineers using digital networks (Ware and Grantham, 2003, p148). So in these factories labour is either upskilled or discarded.

Third, it leads to job-cutting in a number of ways. Low-level service jobs *in the company* (like cleaners, security personnel, maintenance workers and canteen staff) tend to be outsourced (or 'contracted out') to suppliers who specialize in low paid, part-time labour, itself deemed 'flexible' by the exigencies of the new economy. Internally provided services cost more than services bought outside the firm, partly because the workers involved often have 'benefits' and are unionized, but largely because they are no longer needed *on a constant basis* in scaled-down, 'smart' workplaces. So these outsourced workers, along with the factory workers replaced by robots and digital PLCs, and the mid-level office functionaries who are being displaced by information technology systems operated by experts, are all released ("let go" is the going terminology) into an already large *services sector* to try to find further employment. This phenomenon developed exponentially in the latter part of the twentieth century (Castells, 1996; Kalleberg, 2000; Witt and Gross, 2020), to the point where the service economy has become by far the largest global economic sector. Economists deem it the 'service' sector because it does not create primary value, as do the no longer dominant mining and manufacturing economies (Hill, 1987). The service economy is 'non-standard labour', consisting predominantly of *precarious*, part-time, temporary, contract, migrant, short term, quickly assembled for projects, kinds of work. Sometimes, it can be very lucrative, but on the whole it is associated with declining wages, less job security and often itinerant living conditions. Kalleberg reports that numerous economic studies have shown that service sector jobs tend to offer lower wages, even after controlling for education, experience, etc. (2000, pp.342-345).

All of these processes have led to what is known as the 'hollowing out of work' in the industrialized countries. At the top end of the economy are the expert, highly-skilled, very highly paid jobs that steer the networked digital economy; at the bottom end are the unstable, low-wage, low-skills jobs in transportation, cleaning, banking, wholesale and retail trade, childcare, maintenance of property, computer support, accommodation, food services, personal services, amusement, recreational services, and the like. In the middle is the systematic demise of midlevel, middle-wage, 'blue collar' jobs. The rise, from the 1970s onwards, of the services economy is a critical feature of the globally networked 3IR.

The nature of the workplace and its relationship to society has changed radically in the 3IR (Zuboff, 1988; Rifkin, 1995; Castells 1996; Gorz, 1999; Beck 2000; Huws, 2014). Obviously, there has been "a leap in the state of technology" – new digitally enabled machines make work faster and more efficient (Greenwood, 1999, p.2). Digital connectivity means that the manufacturing process tends to be dispersed across localities and national borders. As work and labour are increasingly automated, the organization of a 'workplace' concerned with the production of a particular commodity – ranging from airliners to toothpaste tubes – becomes virtual in character. At the level of technology, this distributed automation simplifies work processes, enhances efficiency and reduces the time taken to complete tasks (Zuboff, 1988). Work teams are smaller, supplemented from time to time by transient 'consultants' or 'temps' (the terms designate different skill levels and social statuses) brought in on contracts in 'non-standard' employment.

In the OECD countries, from the mid-1980s to the mid-1990s, between one-third and half the labour force comprised such employees (Carnoy and Castells, 2001, p.7). Since 1975, the typical household employment profile has been one of dual earners (couples, extended family) and single parents, rather than the mythical single male head of household (Potter, 2003, p,78). Beck (2000, p.3) characterizes the workplace flexibility of the 3IR as a transition from a "work society", in which reliable, paid work is the norm, to a "world risk society" where activities are more fluid and the labour market has become more insecure.

It becomes clear that what is considered to be increasing efficiency and manufacturing output by global corporate elites – they tell this story purely as one of technology and financial gain - "is the outcome of a particular social order and the interests it accommodates and renders legitimate. Even within the bounds of the legitimate order, what is gain for some may turn out to be perceived as a loss by others" (Kallinikos, 2010, pp.1098-1099). In 1995, Rifkin warned of the deepening tendency of the 3IR to require "fewer and fewer workers … to produce the goods and services for the global population" (1995, p.xvi).

The new organization of work entails the individualization of workers directly into labour markets and the structure of production (Carnoy and Castells, 2001). The effect is to bring an end to the tradition of 'permanent', full-time jobs in stable businesses, thus dissolving the identities that workers developed within industrial organizations such as the corporation and the trade union. Work relations have changed dramatically, as the relationship of workers to supervisors and employers becomes individualized. 'Core' work is narrowed down to specific tasks, as jobs get intermittently redefined and allocated to individuals, who are often short-term contract workers. Gorz (1999) notes a peculiar feature of this in the labour market, the increasing emphasis placed on "the sale of self". A freelance provider of professional services effectively becomes a self-promoting commodity, continually sold in the marketplace. People come to identify themselves as 'working commodities', which leads inevitably to conformism. 'Knowing how to sell oneself' is the greatest virtue in the 'personality market' (1999, p.43). Workers are individualized in the 3IR, separated from their 'traditional' identities built over more than a century, and from the social networks that enabled them to find economic security (Carnoy and Castells, 2001 p.8).

The nature of the workplace and its relationship to society has changed radically in the 3IR … As work and labour are increasingly automated, the organization of a 'workplace' concerned with the production of a particular commodity – ranging from airliners to toothpaste tubes – becomes virtual in character.

The power of trade unions has declined in the 3IR. Castells (1996) is pessimistic about organized labour in the network society, which seems at odds with traditional forms of worker organization. Since increased production in some economic sectors is based on automation, and the reduction of the 'labour component', trade unions encounter an increasingly diversified and polarized labour market. There is a decline amongst workers of a collective identity *as a working class*, in the face of the individualization and dispersion of work. This presents difficulties for trade unions in addressing 'non-standard' or 'precarious' workers, beyond issues that appeal to the traditional membership. However, the labour market remains the conduit through which the distributional and poverty outcomes of globalization are shaped. So Gorz (1999), for example, remains optimistic that trade unions can rethink their role in opposing globalization and its disastrous effects on workers. This would necessarily involve more *networked* resistance and large-scale mobilization, in alliance with other opposition groups, and a strategic shift in the traditional focus of the union on only narrow workplace interests. As Gorz puts it, "there can be no effective trade unionism which remains exclusively focused on the workplace and on defending that section of the workforce which is in stable employment" (1999, p.42).

The fundamental social transformations of the 3IR have been enormously complex, permeating every aspect of people's lives. I cannot do justice to that complexity here. Perhaps it can be "simply put, [as] the process of world shrinkage, of distances getting shorter, things moving closer, [pertaining to] the increasing ease with which somebody on one side of the world can interact, to mutual benefit, with somebody on the other side of the world" (Larsson, 2001, p.9). However, it is important to recognize the social complexity of the 3IR, encompassing identity and diversity, social inclusion or exclusion, urban life, media and communications, consumer culture, social movements, and the cohesiveness of families and communities. As Cohen puts it, "all the dimensions of globalization – economic, technological, political, social and cultural – appear to be coming together at the same time, each reinforcing and magnifying the impact of the others" (2006, p.183). To stop here would also beg the question of what the 'mutually beneficial interactions' are that Larsson refers to, and for whom they work. The implications of globalization for the life and work of people, their families and their societies, have been contradictory.

In their defining works, sociologists like Castells (1996, 1997, 1998), Beck (2000), Gorz (1999) and Standing (2009, 2017), while all severe critics of the inequalities produced by the globalized information economy, have nonetheless expressed optimism about the ability of information technologies to foster progressive social change. Each wants to turn the network society on its head, as it were. Castells is perhaps the most realistic of the four: he recognizes that the source of productivity and growth in the 3IR lies in the generation of knowledge, extended to all aspects of economic activity, through information processing (1996, p.219). It is thus strategically necessary to take steps to ensure that all countries develop this capacity in order to enter the global economy and access global markets (Castells, 1999). Beck (2000) draws on German debates on *civic labour* to advocate a 'third way', in which there is a minimum income guarantee, and the networking and communication possibilities of ICTs are employed to allow citizens to develop their own formal employment, community activity and entrepreneurship. Gorz's (1999) and Standing's (2009) visions are is similar: for the former, the knowledge driven on the Web should encompass "exemplary experiences which explore other forms of productive cooperation", which can turn commitments to change in the head and in the heart "into a common project, into the *general will*" (1999, p.102, my emphasis). Standing (2017) makes a simple point, that the digital age means that we have the institutional and technical means to put in place a basic income grant. ICTs (of the 3IR, let us emphasize), provide a basis "to build a good society rather than one that facilitates the aggrandizement of a privileged elite who knowingly gain from the insecurities of others. … That is what basic income is about" (2017, p.50).

Castells (1998, 1999) suggests that *networks* constitute the new social morphology of the information age. Because society is distributed on a network of digitalized nodes, it has a hierarchy, but it has no centre, no single articulating or organizing principle. A modern city, for example, is "a space of places and flows … a multicentred metropolis" (1996, p.xxxiii) that exhibits contradictory social status and defines social relationships. The urbanized hierarchies of modern society tend to take the following form (distilled from a reading of Beck, 2000, and Castells, 1996):

- At the top are the global elites, very well-paid, living lives that tend to be time-poor. They live in wealthy enclaves, linked electronically on networks of decision implementation; however, "meeting face to face to make financial or political deals is still indispensable" (Castells, 1996, p.xxxvi).
- Beneath them are precariously employed skilled people, whose lives oscillate between intense work and 'downtime'. They live in 'the suburbs', distanced from the masses, and connected digitally to potential workplaces and major metropolitan regions and their areas of influence.
- Then there is the working poor, often in even more precarious 'piece jobs' or short term employment. They live in social housing, within reach of work centres and transport systems, and while digitally connected via cell phones, do not use this connectivity in their work.
- At the bottom is a growing unemployed underclass, whose lives are directionless, but time-rich. They live on the margins, in inner city slums or informal settlements on the outskirts of cities.

It strikes me that one way to broadly characterize the central contradiction of the globalized, information society is this: half the people do twice as much work as they should, and the other half can't find jobs (the maths is perfect). Some economists write euphemistically about "heightened economic insecurity" in the advanced countries. In 1996, in Denmark, France, Germany, Japan, Britain and the USA, almost 35 million people were jobless, and even more were in insecure, low wage jobs. "In most developing countries … poverty [was] widespread and chronic underdevelopment [meant] that millions of workers [were] destined to eke out a living in physically onerous, low-productivity tasks" (Härtl, 1996, p.3).

But perhaps the most significant social tension of the 3IR is that between cultural uniformity and cultural diversity. The former is often known as 'McDonaldization', scores of young people eating the same fast food, wearing the same brands, 'supporting' the same English soccer team, and connected together in social media friendships by means of the same rules of personal display, "alone together" in Sherry Turkle's apt phrase (2011). The latter, cultural diversity, is seen for example in intensified expressions of race, gender and religious solidarity, carried on the Net, such as #BlackLivesMatter, #womenpower, #gaypride, #BDS, #jewsforjustice and #rhodesmustfall. Beck (2000) emphasizes that global processes must have roots, a place, origin, locality, and that the global-local tension on the information highway is therefore paradoxical: "globalization does not mean globalization automatically, unilaterally or one-dimensionally" For Beck, "the West" appears now to be "a social structure of ambiguity and multiple activity that has hitherto been more characteristic of the developing world" (all 2000, p.46). In the context of globalization and the network of multiple information, social identity can be fragmented in unprecedented ways.

Just as with the previous two industrial revolutions, the complexity of the 3IR that has been discussed here makes it quite clear that we can legitimately call it a complex industrial revolution. It too meets all the criteria to give it this historical significance:

- *Technological revolution:* the Internet of digitally networked, global information technology.
- *Transformation of the labour process:* the individualization and global dispersion of work.
- *Changing work relations in the workplace:* the hollowing out of the workforce and the dwindling of mid-level, mid-skill jobs; the growth of the service sector.
- *Changing community and social relations:* the rupturing of local community boundaries, and the emergence of contradictory cultures of uniformity and diversity.
- *International/global transformations:* the international redistribution of production, and the structural deepening of the gulf between the richer and poorer regions of the world.

Together, in all of their complexity, these phenomena came to be known as globalization.

The technologies of the Third Industrial Revolution

Each account of the industrial revolutions that have been considered up to now has included a survey of the prominent, often radical, technological innovations of the period. Now, as we consider the myriad claims that are made around us about a 4IR that is supposedly upon us, it is worth drawing up a similar list of contemporary innovations. One listing of these technologies comes from Xing, Marwala and Marwala:

> *4IR unveiled artificial intelligence (AI), machine learning, robots, intelligent machines, 3D printing, bioscience technologies, Internet of Things (IoT), and cyber-physical systems (CPSs). These developments are shaping a new data economy. … these data resources, though abundant and ubiquitous, constitute the 4IR inputs.* (Xing et al, 2018, pp.171-172)

Given the prominence of robotics, machine learning and the Internet well back in the twentieth century years of the 3IR, the brevity and bluntness of this statement of course raises questions. Below, I report on two surveys of academic literature and popular media that I conducted to arrive at a broader understanding of the distinctive technologies of the 4IR as it is construed around the world. The first survey was conducted in July 2020, and the second in August 2021.

The methodology I used to compile the list is a very basic form of an inductive approach in grounded theory. I entered the search terms, "fourth industrial revolution", on those two wonderful 3IR technologies, the *Google* and

Google Scholar search engines. A number of examples of the kinds of sources that I encountered are set out in the final section of this paper (pages 55-59). I noted down every 'technology' that was held up to be an exemplar of the 4IR in the content of the web pages that were presented to me, until the data was clearly saturated. The notion of 'saturation', in relation to qualitative research data, refers to a judgment made by the researcher. It is the moment "when no new information seems to emerge during coding, that is, when no new properties, dimensions, conditions, actions, interactions, or consequences are seen in data" (Strauss and Corbin, 1998, p.136). As I proceeded, I used a basic coding procedure to classify into four groups the people (or institutional personas) who declared the technologies – the general public / scientists and technologists / social scientists / other academics and professional intellectuals. I had no 'deductive' reason to do this, but did so largely because I was curious to see whether the surveys would throw up any substantive differences. In the process I surveyed well over 300 websites, and scanned some 150 digitized journal articles.

Table 2 lists all the 'technologies' mentioned, usually strung together in chains of up to 15 items, and declared to be *merging* in some way to constitute the 4IR. There were 59 '4IR technologies' declared. I categorized these terms as shown in Table 2. Leaving aside the obvious problem that a number of them are either synonyms or substitutes for each other (e.g. robotic process automation = robots = robotics, or voice-activated virtual assistants = speech recognition = natural language generation = natural language processing), there were a handful of 'technologies' that clearly emerged as the most stated exemplars of a 4IR. I should note here that the coding analysis revealed no differences between the standard utterances of the four categories of people described earlier, academic and non-academic alike. The technologies that they all described were pretty much the same.

The items in capitalized letters in Table 2 were by far the most frequently mentioned items that came up in the Google searches. Most people, I suggest, will recognize how often proponents of a 4IR mention these, to try to convince us of its existence. During the first search in July 2020, the

Table 2 *Terms claimed to be '4IR technologies' in Internet searches*

NEW INNOVATIONS (7)
Autonomous vehicles
Molecular informatics
Nanotechnology
Quantum computing
Self-driving motor cars
Semantic web
Socio-technology

NOT TECHNOLOGIES (14)
ARTIFICIAL INTELLIGENCE
DIGITALIZATION

Organizing frames (5)
Ambient computing
Converging technologies
Fusion of technologies
Merging technologies
Ubiquitous computing

Others (7)
Big bang disruptions
Factories of the future
Genetics
Genomics
Industry 4.0
Manufacturing 2.0
Utility computing

TECHNOLOGIES ORIGINATING IN THE 3IR (38)	
ROBOTICS	
AUTOMATION	
MACHINE LEARNING	
INTERNET OF THINGS	
CYBER-PHYSICAL SYSTEMS	
BIG DATA	
BLOCKCHAIN	
3D PRINTING	
3D graphics	HTML5
5G technology	Intelligent machines
Advanced wireless technologies	Local game saving
Analytics / big data analytics	Machine learning platforms
Augmented reality	Mixed reality
Autonomous safety robots	Natural language generation
Bioinformatics	Natural language processing
Biotechnology	Robotic process automation
Cloud computing	Robots
Computer integrated manufacturing	Smaller and more powerful sensors
Deep learning platforms	Smartphones
Digitization	Speech recognition
Drones	Techno-materials
Gene sequencing	Virtual reality
Genetic engineering	Voice-activated virtual assistants/ chatbots

categories *internet of things, machine learning, robotics, automation, 3D printing* and *big data* were dominant (as reported in Moll, 2021a). By August 2021, the categories *blockchain* and *cyber-physical systems* had joined the list of the most frequently mentioned.[23]

Now the question must be, as it was for examples of technological advances in the two World Wars and the Cold War, do these innovations represent a technological revolution, or just an acceleration of change? My argument here will be that they are for the most part the technology of the 3IR in continuing industrial development. Hence, the subheading of this section (which you may have wondered about). Space does not permit me to make the case for each of the 38 items on the right-hand side of Table 2, that we are in an acceleration of change in the 3IR rather than a 4IR. However, I will attempt to do so in relation to each of the eight most frequently declared 'technologies'. It seems that a similar argument would hold for the rest of the items.

Do these innovations represent a technological revolution, or just an acceleration of change?

Let me start, though, by addressing the declared 'technologies' in the left-hand column of Table 2. The seven in the top left-hand cell of the table are, I believe, revolutionary technologies in their own context. They do not, however, constitute technological revolutions. I shall return to this matter later.

There are 14 concepts in the first column that I categorize as not, in fact, technologies. Of these, five are merely collective nouns used to describe groupings of technologies. However, two of them – *digitalization* and *artificial intelligence* – are often spoken of as 'technologies', which is somewhat misleading. They are very prominent in discussions of and justifications for the alleged 4IR:

- **Digitalization** (not to be confused with digitization, discussed earlier) is a sociological concept, operating at a macro-sociological level to describe society at large, but also at various micro-sociological levels, such as accounts of business practices. It refers to the way in which most domains of social life are transformed around the digital technology (i.e. 3IR) infrastructure that is now at the centre of society.

  In this paper, it denotes the fundamental socioeconomic transformation associated with the 3IR, namely the transition to what Castells calls a network society: "a society whose social structure is made of networks powered by microelectronics-based information and communication technologies" (2004, p.3). At the policy level, it signifies the responsibility of governments to create enabling social environments related to technology development. In the sphere of business, digitalization means the process of changing workplaces and business models in the light of the new, global technology order.

  So digitalization is not a technology; in any event, it is a concept that describes the pivotal transformation phenomenon of the 3IR.

- **Artificial Intelligence** (AI) is a field of knowledge and research that originated in the 1950s, which seeks to conceive, and sometimes to build, artificial animals and humans. It brings together such disciplines as cognitive science (some would argue that AI is a component of cognitive science), philosophy, cognitive psychology, neuroscience, computer science, and information engineering. Among its central questions are, "can a machine think?" and "can a machine act like a human being?" In seeking to answer them, AI hypothesizes a functional equivalency between human cognition and a computer programme. It tries to understand the nature and limits of this putative identity between machines on the one hand and primate intelligence and action on the other. For example, AI researchers investigate whether information processing in a person and a machine are governed by the same kinds of rules in accessing, storing and retrieving information in memory processes. Or they ask if the 'cognitive' schemas that produce action in machines and humans can be understood to be equivalent (Floden, 1981, p.95). Often, AI researchers either build actual machines (such as robots) or write symbol-processing algorithms – there is a debate in the field about the extent to which either, or both, is necessary – to help them find answers to their research questions.

  However, it is not the technology as such that interests AI researchers, but rather the 'virtual machine' (expressed in the form of an algorithm) that *in principle* runs inside it or is formulated by it. A 'piece' of AI is the mental model of an information-processing system that a programmer has in mind when writing a program that could run inside a machine (Boden, 2016, p.4). Unresolved controversies in AI include whether a machine can make decisions, have consciousness, be self-reflexive, and make ethical decisions ('moral AI') (see Searle, 2014).

AI is not technology *per se*, but some of the knowledge it produces is continually applied in various technology fields, including software engineering, computer design and – most notably – machine intelligence. It is very much of the 3IR, having commenced with the advent of modern high-speed digital computers in the 1950s (Turing, 1950; McCarthy, 1955). To recognize that AI is a scientific field that has progressed rapidly in the past three decades does not warrant the claim of a fourth technological 'revolution'.

AI is very much of the 3IR, having commenced with the advent of modern high-speed digital computers in the 1950s.

The eight highlighted terms on the right of Table 2 refer to technologies that originated before the new millennium – during the period that was undisputedly the 3IR. While all of them continue to be developed in exciting, complex ways right now, they are all rooted in the digital revolution that commenced in the previous century. When we examine them carefully in their historical context, we discover that they are all sustained, rapidly developing technologies of the 3IR:

- **Robotics** is the development of computerized machines that replicate human action. We have already seen that it has technological roots way back in the 3IR. As regards *automation* (which is the displacement of human workers by robots in manufacturing), the first digitally programmed robot, as noted earlier, appeared in Connecticut in 1961 (Engelberger, 1985, p.7). In 1969, the Stanford Arm, a six-axis articulated robot was invented, able to follow arbitrary paths in space and widen the potential use of robots in industry. 1974 saw the world's first electric, microcomputer-controlled, industrial robot installed in a Swedish factory. IRB6, as it was known, carried out welding, grinding and polishing functions in steel pipe production.

  It must be emphasized that the vast majority of industrial robots are relatively 'unintelligent', fixed machines that carry out rudimentary manufacturing functions on assembly lines. We have already seen that by the new millennium, there were some 750 000 of these working in factories around the world. By 2021, the International Federation of Robots (IFR, 2021) documented a record three million industrial robots operating in factories globally. China had the highest number, with just over one million units, and Japan the second highest – 412,000 units. Most of these operated in motor car and electronics manufacturing.

  At the other end of the spectrum, there are relatively few anthropomorphic (or 'humanoid') robots, mostly found in research and technology development contexts, rather than the workplace. This is despite the science-fiction like projections of the coming of robots that we often find in 4IR hype. WABOT-1, the first anthropomorphic robot, appeared in Japan in 1973. Its technological focus was mainly on a limb control system enabling it to walk. It was also fitted with sensors to enable gripping and transporting of objects, measuring distances to objects, and speech recognition. However, the most valuable research outgrowths from it were related to implementing bipedal walking functions in robots, from the end of the 1970s into the 1980s (Takanishi, 2019). Freddy I (1969–1971) and Freddy II (1973–1976) were Scottish experimental robots using an object-level robot programming language, which allowed them to handle variations in object position, shape, and sensor noise. They both used video cameras and bump sensors to recognize objects, and Freddy II was augmented with a large vertical 'hand' that could grip objects once recognized. By 2020, the robot that is widely regarded to be the world's most advanced (even "the most socially developed" – Staple, 2021) humanoid, ASIMO,[24] still uses sensor, actuator, bipedal, and language processing technologies that have a lineage straight back to WABOT-1 and other predecessors, along with up-to-date machine learning that has a similar technological 'ancestry' (more about this in a moment) (Sakagami et al, 2002). Honda Corporation's ASIMO (Advanced Step in Innovative Mobility) appeared in 2000, and ceased production in 2018. It (he?) is able to walk, hop, run, jump, serve food and drinks, recognize moving objects, respond to human gestures, and similar (YouTube, 2011). However, ASIMO is not as advanced as it (she?) sounds. Perhaps this is best illustrated anecdotally. Following the 2011 Fukushima nuclear power plant meltdown, when a 15-metre tsunami disabled the power supply, robots have been used extensively in cleaning up the mess (YouTube, 2019). However, ASIMO was not up to the task:

  > *… there was surprise that this triumph of Japanese robotic engineering wasn't deployed in the reconnaissance and clean-up operation. Instead, [much more primitive] US-made military robots [that look more like the tiny offspring of*

fork-lift trucks and military tanks than humanoids] were drafted in. Perhaps that's because Asimo is primarily a PR device …" (Staple, 2021)

So robots, it turns out, are indisputably one of the defining technologies, still evolving, of the 3IR. This much is also clear in the manner in which the literature of the time reflects technological developments – the iconic robots of science fiction are surely Isaac Asimov's Cutie and Speedy from *I, Robot* (1950), and Philip Dick's (1968) Nexus-6 Androids from *Do Androids Dream of Electric Sheep?*

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- **Machine learning** refers to the ability of computers to learn and act automatically as humans do, without explicit programming. The goal is a computer that can learn 'from experience', and improve its information-processing ability over time in autonomous fashion by running algorithms to access and process data. The most 'intelligent' computers can be fed data, access it themselves (think Big Data) and 'experience' it via sophisticated sensors. These developments have a history deeply rooted in the 3IR. The term 'machine learning' was coined by Samuel, who invented a computer programme to play draughts in the 1950s. In 1957, Rosenblatt combined Hebb's psychological model of brain cell interaction with Samuel's programme to create the game Perceptron, which was the first artificial neural network able to learn patterns and shapes. In 1959, Widrow and Hoff created such a programme to detect binary patterns. After that, there was a bit of a lull in developments in machine learning, partly because neural network research was abandoned by computer science and AI researchers (Boden, 2016).

  However, an explosion in machine learning research and development took place in the 1980s, on the basis of research programmes that had started in the previous two decades, like that of Marvin Minsky at MIT (Kuipers, 2008; Alpaydın, 2016; see also Minsky, 1967; Minsky & Papert, 1969):

> *The fact that neural network research, which later led to the field of machine learning, started in the 1980s is not accidental. At that time, with advances in very-large-scale integration technology, we gained the capacity to build parallel hardware containing thousands of processors, and artificial neural networks was of interest as a possible theory to distribute computation over a large number of processing units, all running in parallel.* (Alpaydın, 2016, p.28)

The evolution of 'parallel hardware' – parallel distributed information processing (which, by the way, is modelled on discoveries about the neural networks of the human brain that encode our knowledge and explain how the excitation or inhibition of underlying cognitive schemata generate our everyday actions and the awareness we have of them [Rumelhart, McClelland *et al.*, 1986:9]) – in computers was important in the development of machine intelligence. It led to the evolution of *deep learning*, which creates an 'artificial neural network' that can learn and make decisions on its own. In the early years of deep learning research, 'recurrent neural networks' were developed that processed sequential data such as text and speech with some success, and were then able to repeat such processes. Conventional machine-learning techniques were more limited in their ability to process data from images (such as pixels in a photograph). The introduction of the 'backpropagation algorithm', however, in the mid-1980s (Rumelhart, Hinton and Williams, 1986) brought major advances in machine intelligence. This is a method in which processing errors are recognised by the machine at the point of output (not input), and then distributed backwards to change its internal parameters so that the same mistakes are not repeated – the machine is 'trained by', it 'learns' from, itself. This led to the development of 'convolutional neural networks', in which computers simultaneously detect different patterns – say shapes, textures, objects and colours in an image – at different levels. In the nineties, for example, Yan LeCun and his colleagues trained a computer to recognize handwritten postal codes on mailed envelopes (LeCun et al, 2015).[25] While there have been significant 'breakthroughs' in machine intelligence in the new millennium – facial recognition software circa 2015, and many of the surveillance technologies that Zuboff (2019) identifies in her book on *surveillance capitalism*, are good examples – the basics of the technology date back to at least the 1980s.

It seems that, also in the 1980s, the confluence of machine learning and robotics started to take shape. It should be emphasized that not all machine learning is about robots, and most industrial robots (like those on motor car assembly lines) are not learners. The vast majority of such robots are still 'unintelligent' mechanical arms that weld or screw on certain parts of a car or a household appliance, in some factory or other. However, two things should be clear from the review of the history of Robotics above: (i) whereas robots had to be tediously hand-programmed for every task they performed up to about the late 1970s, the burning intellectual questions of Robotics by the 1980s needed machine learning technology to inaugurate learning robots; and (ii) the merging of the two technological spheres was inherent in the evolving technologies of the 3IR. Since the 1980s, there has been increasing demand for robots more capable of identifying parts from a random selection, or maintain a high degree of repeatability or 'positional accuracy' when objects shift about on assembly lines (Yerkey, 1984).

So there was a converging of the two domains of technology approaching the turn of the twenty-first century. For Kuipers, the serious questions of machine intelligence became: "How can a robot learn a cognitive map from its own experience of the environment?" and "How can an agent learn, not just new knowledge within an existing ontology, but a new ontology it does not already possess?" (Kuipers, 2008, p.243 & p.261). The confluence of robotics and machine learning (Van de Velde, 1993; see also the various chapters in Apolloni et al, 2005) signals the height of the 3IR. One picks this up, for example, in academic and general debates about 'machine vision' in robots, in which sensors (cameras, lasers, lidar, radar, etc.) are placed in robots to detect and categorize aspects of their environment. 'Assistive robots', for example, were developed to be able to process sensory information, and then act to help disabled and elderly people with everyday functions. 'Machine learning' algorithms in robots enabled 2D and 3D object searches and 'object learning', where the robot makes and acts on predictions derived from probabilistic reasoning.

Then there are *chatbots*, these robots with apparently female human voices 'inside' our cell phones, that answer endless questions we put to them. From a technological point of view, a chatbot is only the latest phase in the evolution of *natural language processing* dating back to the 1960s, but she (whoops, *it*) is nonetheless impressive. There is also *robotic process automation* to consider – this is continually evolving office automation technology, again dating back deep into the 3IR, in which 'robotic software' emulates human interactions with digital systems to carry out business processes. These last two examples are perhaps the most ubiquitous forms of robot technology today.

In a notable review of the state of robotics and machine learning towards the end of the last century, Van de Velde (1993) describes a learning robot as "an autonomous system: equipped with sensors and effectors, it moves around and interacts with its environment in order to achieve some goals". Such robots are autonomous, because they "can learn for themselves what is best for them, without their designers having to figure if all out beforehand". Van de Velde goes on to suggest that, by the nineties, "this claim [was] more than [just] programmatic talk" (1993, p.1). Let us not forget that, in 1997, the IBM computer 'Deep Blue' beat the world chess champion.

From a technological point of view, a chatbot is only the latest phase in the evolution of *natural language processing* dating back to the 1960s, but she (whoops, *it*) is nonetheless impressive.

- An **Internet of Things** (IoT) is a system of networked mechanical and digital devices with the ability to transfer data amongst themselves without any human intervention.

An example of an IoT might be the 'converged intelligence', triggered by the arrival of your digitized German sedan, that welcomes you home from work by booting up your favourite sound tracks to soothe your tired soul, assesses climactic conditions and switches on a heating system or air conditioner as necessary, pours you a double Irish whiskey and soda, checks the weather for the following day and suggests an outfit from an inventory of clean clothes, also reminding you of the online reading you need to do for your appointments for the next morning, prompting you to use your cell phone to choose your supper menu, ensuring that the refrigerator will restock itself via its connected grocery delivery app, and letting your hard-working, late-departing factotum in the kitchen know what he should start cooking (or perhaps sending him an SMS giving him the night off, and ordering in using a take-away delivery app), *all connected via the Internet* (for a similar, proverbial case, see Moll, 2022b).

Networks and devices and data. It does sound revolutionary, but the question is, is the technology and its organization new? It would appear not.

The important point here is that an IoT is customized to particular workplaces or living spaces. It combines old analogue technologies and newer digital technologies in pragmatic combinations via Internet networks. In relation to any particular machine or device, all that the Internet does is "provide us a way to attach it". To construe it as some kind of revolutionary super-machine that will effect dramatic, future technology enhancements, as Kumar et al (2019) do, is ICT hubris.

The core technology of the IoT is indeed the Internet, which we have already seen dates back to 1969, and then its global explosion with the WWW from 1991. Analogue to digital, and digital to analogue converters (ADC; DAC), which link mechanical devices via sensors and actuators into the IoT, first appeared in the 1960s, with Pastoriza's electronically switched ADCs and DACs (Kester, 2005, pp.10-20). The first IoT was reputedly built in the early 1980s, when techies at Carnegie Mellon University installed micro-switches in a vending machine to check cooldrink availability from their desks (Teicher, 2018). Perhaps the most significant piece of technology in the evolving IoT was Trumpet Winsock in 1994, which made it possible to attach PCs to Internet networks (Zittrain, 2008, p.29).

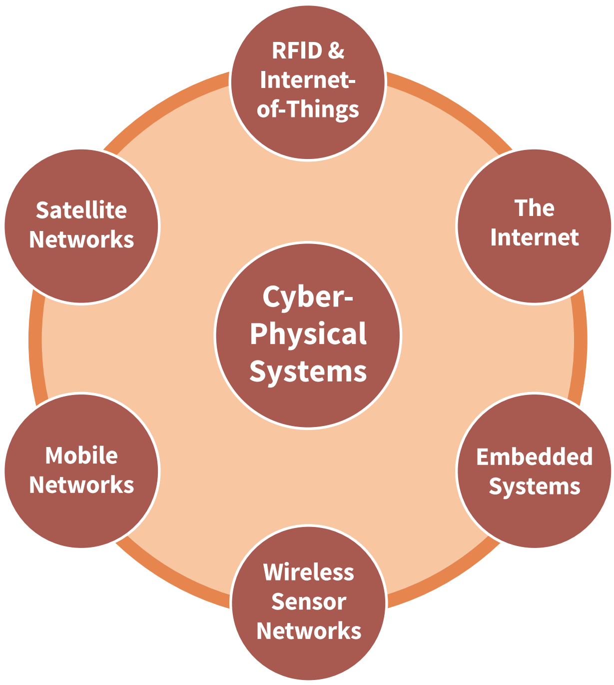
In the 2020s, it is clear that IoTs can radically beef up businesses and governments, by networking things like inventory control, transportation, shipping, security, energy conservation and urban waste management, but their technology is definitively that of the 3IR.

- **Cyber-Physical Systems** (CPSs), at first glance, appear to be a strong candidate do be described as twenty-first century technology. The term itself was coined in 2006 by scientists at the US National Science Foundation to describe their work on software engineered, interactive digital, analogue, mechanical and human components. And in the contemporary world, CPS technology sits at the centre of everyday life, in manufacturing, electricity supply, health care, transport, traffic control, water management, and security systems, to name but a few. It is also prominent in urgent, establishment global change agendas, such as decarbonization (Inderwildi, 2020, p.744). While it has obvious continuity with IoTs, as Figure 2 suggests, a CPS is distinctive in that it is all about integrative models. It sits in the software programmes that integrate the components, rather than the components themselves. As Edward Lee puts it:

> *CPS connects strongly to the currently popular terms Internet of Things (IoT), Industry 4.0, the Industrial Internet, [etc.] … All of these reflect a vision of a technology that deeply connects our physical world with our information world. … [But] it does not directly reference either implementation approaches (e.g., the "Internet" in IoT) nor particular applications (e.g., "Industry" in Industry 4.0). It focuses instead on the fundamental intellectual problem of conjoining the engineering traditions of the cyber and the physical worlds.* (Lee, 2015, p.4838).

So it looks very much like CPSs might be one of Schwab's revolutionary disruptions.

Figure 2 *A representation of Cyber-Physical System components* (from Pervez et al, 2016, p.32)



However, this sense of what a CPS is, is beguiling, as becomes clear when we start to unravel its technological roots.[26] The key point is that *a CPS is all about computational models*. In this, its history goes all the way back to Norbert Wiener's work during World War II, designing technology to aim and fire anti-aircraft guns automatically. Although he employed analogue control circuits and mechanical parts, and not digital computers, his mathematical principles were precursors to the digital feedback control loops found today in CPS. Wiener consolidated this control logic in his 1961 book, *Cybernetics*.[27] From the 1960s, the development of the mathematical principles of cybernetics is evident in the history of what are known as *embedded* and *hybrid* systems in computer programming. In the 1960s, researchers at MIT developed the guidance system for the Apollo spacecraft, which employed the first example of a modern, concurrent, embedded computing programme (Trageser and Hoag, 1966). The notion of hybrid systems, the interaction of digital controllers, sensors and actuators in dynamic physical systems, was widely researched in the 1990s (Koutsoukos and Antsaklis, 2003).

All of these developments were concerned with the intellectual problems of how to write programmes to be embedded inside digital devices and digital technology systems (here, there is an obvious connection with AI). A core principle of this field in the 1960s, the Golomb principle, makes it clear why we must date the evolution of the technological aspects of CPSs well back into the 3IR of the previous century – "do not conflate the model with the thing being modelled" (Golomb, cited by Lee, 2015, p.4839), i.e. do not conflate speculative models of contemporary, cyber-physical systems with the long-standing, evolving solution of programming problems in this terrain. In the latter part of the twentieth century, cybernetics research was dominated by the problem of representing temporal constructs in programming algorithms (Orgun and Ma, 1994; Lee, 2015, pp.4844-4848). In general, these concerns have continued until the present:

> *As an intellectual challenge, CPS is about the intersection, not the union, of the physical and the cyber. … these models and methods do not combine easily … Models play a central role in all scientific and engineering disciplines. However, since CPS conjoins distinct disciplines, which models should be used? Unfortunately, models that prevail in these distinct disciplines do not combine well.* (Lee, 2015, p.4838)

It would seem that the character of CPSs puts paid to any suggestion that it has much to offer that has been revolutionary in the twenty-first century.

It would seem that the character of CPSs puts paid to any suggestion that it has much to offer that has been revolutionary in the twenty-first century.

- **Big Data** storage, and associated analytics, is technology that enables a massive coming together of information in extensive, global networks, based on 3IR technology that has evolved over the past sixty years (Arutyunov, 2012; Hurwitz et al, 2013). The phrase refers to the massive amounts of data that large organizations, like companies and governments, must process in a meaningful way to be able to plan and make strategic decisions. However, while the amount of data – unstructured, structured, continuously generated by Internet communication systems – is unprecedented, the technology of data storage and analysis in fact evolved in waves over many years:

> *It would be nice to think that each new innovation in data management is a fresh start and disconnected from the past. However, … most new stages or waves of data management build on their predecessors. … Data management has to include technology advances in hardware, storage, networking, and computing models such as virtualization and cloud computing. … The data management waves over the past five decades have culminated in where we are today: the initiation of the big data era."* (Hurwitz et al, 2013, pp.10-11)

The history of the emergence of 'data' as storage and analytics makes it quite clear that the ongoing emergence of what we now term 'big data' is a technology of the 3IR.

In the 1950s, the first computer systems, provided data storage on magnetic disks. Data was stored in flat files with no structure. To understand information, say about customers, 'brute-force methods', had to be applied. Then, in 1961, the silicon chip (or 'integrated circuit', still the basic building block of 'big data') was invented. This miniaturized technology provided for much larger, more efficient data storage and retrieval, and much smaller computers to do the job! Later in the 1970s, Codd's "relational model of data for large shared data banks," brought about *relational databases*, in which structure was imposed on data. This added a level of abstraction – an 'ecosystem' of analytic tools – that helped organizations classify and compare histories of complex transactions in decision-making, Then, in 1976, Chen produced the graphical *entity-relationship model* of database design to enable related data elements to be defined for any software system, thus adding deeper analytics to increase data usability. This model defined data elements in such a way that new relationships between data sources could be defined without complex programming. By the 1990s, as the sheer volume of data grew out of control, the *data warehouse* was developed. In the new millennium *cloud computing* evolved as the warehousing was taken off-site (Arutyunov, 2012, p.173). Cloud computing is innovative, contemporary, on-demand data storage and computing power, without direct active management by the user (see page 54 below regarding the recent trend of 'outsourcing to the cloud'). One of the most important attributes of cloud computing is the bringing together of diverse data sets, e.g. climate records with social media messages.[28] But it is the words, not the evolving technology, that are twenty-first century: *Big Data* has a long history but a short past!

- **Blockchain** is a digital information database with a distinctive structure, distributed across the nodes of a computer network. A blockchain stores information in discrete 'blocks' that are linked together, hence 'chained'. This moves beyond the way databases have usually structured information into tables, with no boundaries between data elements. When filled, a block is sealed digitally, and linked to a previously filled block, thus forming a chain of data. This produces a *secure*, shared, distributed ledger. An irreversible data timeline is constructed, where each block receives a timestamp and a *hash* (a digital fingerprint, or unique identifier). Hashes prevent any block from being altered, or the insertion of any new block between existing ones. In this way, data security increases, as subsequent block verify previous blocks.

Schwab and the WEF's narrative about blockchain is that it is one of the biggest innovations of the twenty-first century. Similarly, Gupta (2017) says, "we're now in the midst of another quiet revolution: blockchain, a distributed database that maintains a continuously growing list of ordered records, called 'blocks'." He presents us with a range of contemporary innovations that supposedly establish the claim:

- Bitcoin and other "revolutionary" cryptocurrencies of the twenty-first century – he describes Bitcoin as "the first blockchain" – function as the public ledger for all transactions on these networks;
- Blockchain more broadly, that is the extension of underlying Bitcoin technology into inter-organizational cooperation globally;
- *Ethereum*, second-generation blockchain programming that builds "little computer programs" to provide financial instruments in the system;
- "Scaled blockchain" in which the technology itself selects, deploys and regulates the computers necessary to carry out its work, without sacrificing security.

Add to this the progress in blockchain technology from the trading of *fungible tokens* (digital tokens like Bitcoin that function in a similar way to the textiles used to buy slaves in the 1IR, or plastic casino chips around a roulette wheel) to *non-fungible tokens* (like the integrity of a Ferrari Daytona SP3, an artwork or 'a piece' of intellectual property), then surely we must be living in a technological revolution, even a 4IR?

Like cyber-physical systems, this supposed revolution is beguiling. The 4IR prophets usually tell us that blockchain originated in the period 2008–2009 when 'Satoshi Nakamoto' (this is a pseudonym used by a person or group of people) conceived and implemented the Bitcoin cryptocurrency. At their most honest, they might admit that its technology dates back to the specification of conditions for a cryptographically secured chain of blocks by Haber and Stornetta (1990). If they bothered to read these authors, they would realize that blockchain technology was first described way back in the previous century, and (once again) is clearly an evolving technology of the 3IR.

The information and software engineering community recognizes this fact. In 2018, the BBVA[29] Foundation bestowed its *Frontiers of Knowledge Award* in the ICTs category to Shafi Goldwasser, Silvio Micali, Ronald Rivest and Adi Shamir for their "fundamental contributions to modern cryptology, an area of a tremendous impact on our everyday life." The citation went on, "Their advanced crypto-protocols enable the safe and secure transmission of electronic data, ranging from e-mail to financial transactions. In addition, their work provides the underpinning for digital signatures, blockchains and crypto-currencies. … [The corpus of their work] is crucial to the fabric of our connected digital society" (BBVA, 2018). Now here is the point: The Goldwasser–Micali (GM) cryptosystem was first proposed in 1982. The award they received recognizes that history. GM is an asymmetric data encryption algorithm that they proved to be secure under standard cryptographic assumptions. The subsequent work of Goldwasser, Micali and colleagues went on to develop more efficient, more secure cryptosystems for much longer digitized texts (see for example Goldwasser and Micali, 1984; Goldwasser, Micali and Rivest, 1988).

Another major line of continuity that blockchain has back into this 3IR milieu relates to the classical Merkle-Damgård (M-D) hash function This was first formulated by Merkle (1979, pp.3-15), and formally specified and validated in the 1980s by Damgård (1987; 1989). It is clearly part of the technological history of blockchain, specifically its iterative structure, where the value of a previous block's hash is the input for the next block, and so on. Again, there are good reasons to pour cold water on the claim that blockchain is a radical new technology of the new millennium: "blockchain as a new technology has created a great amount of hype and hope for different applications. There is a promise of a better, decentralized trust based on strict guarantees from cryptography. However, there is a great similarity in the structure of blockchains and classical iterated hash functions of the M-D type" (Halunen et al, 2018, p.1).

- **3D Printing** – Here it is clear that much the same historical argument applies. 3D printing, or *additive manufacturing*, is a family of technologies that use photopolymerization to build solid objects from digital models. The 'printing' machines all embody the same principle, that of using a light source – a laser or UV projector – to cure a liquid or powder into hardened plastic. The technique can be described as the structured fabrication of an object, in that it lays down successive, multiple strata of a material to construct a final product. The Japanese inventor Hideo Kodama, in 1980, created a solid object by using ultraviolet light to harden polymer plastic. This was a precursor of stereolithography (SLA), invented by Hull in 1984, in which a laser beam is focused on light-reactive "resin", forming polymers to construct the body of a three-dimensional solid. Deckard and Beaman's laser sintering (SLS), also of the mid 1980s, is another advanced form of additive manufacturing, in which layers of a powdered polymer – normally nylon – are fused together to create objects. Fused deposition modelling (FDM), invented by Crump in 1989 for everyday commercial use, allows one to create virtually anything simply by creating a digital model of it. FDM has been dubbed 'desktop 3D printing' because it is the most commonly used form of the technology today. To construct an object, the 'printer' melts a cable of thermoplastic, then delivers it layer-by-layer, directed by a computer model. SLA, SLS, and FDM make up the history of 3D printing, and clearly constitute an enduring, innovative technology of the 3IR.

The conclusion from these preceding discussions of proclaimed 4IR technologies is clear. None of them is a radical, ground-breaking invention of today. All of them were, and are, gradual evolutions of technology rooted back into the defining technological transformations of the 3IR. The claim made about a host of new 'revolutionary technologies' that are bringing about a contemporary social revolution starts to crumble. There are a number of authors who write 'top-10'-type lists about such technologies – Bernard Marr (2019, 2020a, 2020b) is one of the most prominent. The vast majority of candidates on his lists not only drop off the podium when subjected to the above kind of analysis, they are also disqualified from all future events. Marr, however, remains a prominent 4IR ideologue.

The conclusion from these preceding discussions of proclaimed 4IR technologies is clear. None of them is a radical, ground-breaking invention of today.

Revolutionary technology and technological revolutions

Now don't get me wrong here – I do not claim that there are no technological innovations in our time that are revolutionary in their own context. One example of such a development that is without doubt revolutionary, and is indeed a revolutionary fusion of technologies, is the first real-life 'shadow hand'. I was quite surprised during my Google searches not to find any commentators who listed it specifically in their string of technologies supposedly proving the existence of a 4IR. The terrain is Bionics, or Brain Robotics if you like, and the technology is the first bionic hand. It is a consciously animated, sentient, dexterous and clinically viable prosthetic hand. It amplifies and translates electrical impulses from the human nervous system into digital information that allows a person to control and use her robotic hand (Wits University 2019; McNamara, 2020).

This is truly revolutionary stuff – it goes way beyond, and transcends, the ADC and DAC converters of the 3IR. However, we need to be cautious about claiming that it constitutes an overall 'technological revolution', let alone a 4IR.

Even Marr, who seems to struggle to avoid the language of ICT hubris, becomes cautious, speculative, when he gets onto technological innovations of this kind. Take for example his account of quantum computing (QC):

> *[It] will completely redefine what a computer is and could give us computing power that is millions or trillions times more powerful than supercomputers today. Although conventional binary computing is likely to be all we will need for many tasks we carry out on computers in the near future, incomprehensibly quick quantum computing is likely to have a variety of applications.* (Marr, 2020b)

Perhaps he is not struggling to avoid 4IR talk, because he knows this is what his followers want to hear? Nevertheless, there is no sense here of an overall technological revolution that is upon us. Marr knows very well that a revolutionary technology does not necessarily constitute a technological revolution. This is evident in the ambivalence shown across different claims about QC in the quotation immediately above (my emphases):

"*could* give us computing power that is [exponentially] more powerful than supercomputers"	**vs.**	"*completely redefine* what a computer is"
"*conventional* binary computing is likely to be *all we will need* for many tasks"	**vs.**	"*incomprehensibly* quick quantum computing is likely"

Speculative soothsaying, indeed. I have replaced the "millions or trillions" with "exponentially", because the former is just rhetoric. Does he mean 2,000,000 times or 999,000,000,000,000 times, or something in between? Human beings still have more 'positional accuracy' than robots, and a margin of error of 499 trillion either way seems a bit much even for an expert futurist. Expert scientists, by the way, project that QC computing power will increase exponentially by a factor of one million (Möller and Vuik, 2017, p.255), and then only if the very high construction and maintenance costs, enormous use of electricity, and the tendency towards a "blind trust in simulation results" can be overcome (p.263).

It is difficult to take an incipient technology of the immediate twenty-first century that is revolutionary, and construe it as a broader 'technological revolution', simply because such technologies are generally found *in their own contexts of discovery and emergence*, that is to say in the research contexts in which they appear. Even an accomplished 4IR ideologue like Marr finds this difficult. It can only be done glibly, in the way that Schwab does.

In the top left corner of Table 2, there are seven items that do indeed appear to be revolutionary technologies of the new millennium, *in their own contexts*. QC is one of them, as are self-driving motor cars and nanotechnology. The significant thing about all of these is that they are, at this stage, mostly thought experiments or speculative algorithms, or very early prototypes of the envisaged technology that has not yet been shown to work.

To go back to QC: currently, the vast majority of it is carried out by analytic or simulation procedures, because existing quantum computers are not widely available. The problem is that these are extremely expensive, fill an entire room in a specially designed building, and are difficult to construct and maintain (Möller and Vuik, 2017, p.263; de Avila et al, 2020, p.223; Wilkens, 2021). Yet their computing capabilities are still all small-scale (less than 100 qubits) – many QC researchers argue that only millions of qubits will enable useful quantum computing applications. Claims about QC by scientists are therefore modest and tentative: "it has gone from science fiction to foreseeable reality" (Wilkens, 2021); "when sufficiently mature", QC "*could* tackle problems … beyond the reach of conventional computing (de Avila et al, 2020, p.223, my emphasis); "the turning point for science, when research about quantum computers shifts towards research using quantum computers draws closer" (Johansson et al, 2021, p.19); "It has taken more than three decades, but we are now at the cusp of moving from scientific theory to commercial reality" (Morgan Stanley, 2020, p.1).

In the case of nanotechnology, there is similar scientific caution. It is most advanced in medical applications. Astruc (2016, p.4) tracks seminal works on nanoparticles in the last three decades of the previous century, which "included liposomes, DNA-drug complexes, polymer-drug conjugates, antibody-drug conjugates, polymer nanocapsules, polymer-protein conjugates, albumin-drug conjugates, block-copolymer micelles, anti-arthritis gold nanoparticles, and anti-microbial silver nanoparticles." These establish that the present generation of nanomedicine has roots back in the 3IR, although the emphasis now is on implants, microscopically tiny devices inserted into the body to enable diagnosis or treatment delivery without any contact with the patient. Medical nanotechnologists envisage a unified device able to carry out imaging inside the body, diagnose a disease, release the appropriate drug, and monitor the success of the intervention.

One example of contemporary nanomedicine in development is a graphene-based brain implant that can record low-frequency electrical activity. Potentially, it will allow neuroscientists to measure these signals to deepen our understanding of the brain. It might also be used as a carrier for drug delivery, and a substratum for tissue engineering. However, the state-of-the-art of this particular technology is described by researchers as needing "accurate theoretical modelling of the interface between graphene and biological material" in order for it to advance (Bromine et al, 2018). Neuralink (which has popular 4IR appeal in South Africa because of its connection to Elon Musk) is an envisaged brain-machine interface device. It is hyped (not least by Musk himself) as being able to decrease the restrictions imposed by brain and spinal cord injuries: the aim is to implant devices in paralyzed humans to enable them to use phones and computers. The view of the scientists working on it, however, is clear: "further research studies are needed to move forward beyond speculation" (Fiani et al, 2021).

Self-driving motor cars have been prominent in the rhetoric of the '4IR technological revolution'. The Volvo XC90 SUV, a collaboration between Uber and Volvo that commenced in 2016, is reputedly the most advanced 'autonomous vehicle'. It was presented in June 2019 as "the first production car that in combination with Uber's self-driving system is capable of fully driving itself". However, there is still great circumspection on the part of all the companies researching experimental autonomous vehicles about claiming that they can drive on all roads, anywhere, especially after the vaunted Volvo killed a pedestrian in 2018 (Pelmets, 2021). When Volvo presents its vehicle as "capable of fully driving itself", what they mean is that it is ready to be programmed to connect with a wealth of data about routes, roads, regulations, robots,[30] traffic signs, other vehicles, pedestrians, weather conditions, and the like. One imagines this might be possible in a small, ordered neighbourhood, with clearly marked roads and road signs, roadworthy vehicles, well-tempered children, and well-behaved citizens – *and* meticulously maintained digital data about all of these things. Living in Johannesburg, I often wonder how an autonomous vehicle can be programmed to drive in places where the opposite conditions often prevail, and drivers and pedestrians seldom obey the rules of the road (most notoriously, our minibus taxi-drivers, who are well known for shooting red robots, driving in lanes against oncoming traffic, and generally finding ways of forging unimaginable routes through traffic to get to their taxi ranks as quickly as possible). I cannot imagine that such algorithms would be possible. Be that as it may, the general view around the world still seems to be that autonomous vehicle technology is not ready for deployment on public roads (Chadha and Bhatia, 2020). An experienced motoring journalist characterizes the current situation as follows:

> *Self-driving cars are already on the road, [but] operating only at lower speeds within small geofenced areas … Hands-free driving assistance is improving, but drivers are still required … don't make any plans to let your driver's license lapse just yet.* (Wardlaw, 2022)

The general view around the world still seems to be that autonomous vehicle technology is not ready for deployment on public roads.

It is not difficult to make the case that each of these technologies is revolutionary in its own context. It is partly because of the careful way that the innovators (the scientists, not Musk, in the case of Neuralink) talk about the 'revolution' associated with their technology that this notion makes sense. This stands in stark contrast to the kind of speculative, reductionist, futuristic texts – such as Kurzweil (2005), Menzel and D'Aluisio (2001), Marr (2020a) and, one daresay, Schwab (2016) – that conjure up technological revolutions where there are none.

We would do well to do some careful conceptual analysis in this regard. The use of the concept 'revolution' is often so slippery (it is a massively open, floating signifier, if you like) that it undermines clear discussion about the so-called 4IR. In order to understand fully what the role of technological developments has been in industrial revolutions (and what their putative role is in a 4IR), it is important to affirm an important conceptual distinction that has been at work in this article up to now – that between a 'technological revolution' and a 'revolutionary technology'. Because a particular technical invention is revolutionary in its own context of use, does not mean that it constitutes, or is part of, a broader technological revolution – the bionic hand, for example. There are obvious, well-known examples of technology innovation that make this distinction clear:

1. *The wheel* (or more specifically, wheels with fixed axles): Perhaps the most famous technological innovation, the wheel appeared in Mesopotamia around 3500 B.C.E. (Rao, 2011, p.2). There was no identified, broader, system-wide technological revolution taking place at that time, but the wheel was clearly revolutionary in its own context.
2. *Concrete:* Bedouin builders in the Levant around 700 B.C.E. discovered hydraulic lime, which *revolutionised* defensive capabilities of clay fortresses because it could harden their walls (these Bedouins may not have been the first). Concrete then evolved and was used intermittently, in various ways, in construction for many centuries. However, only by the seventh century was it part of a technological revolution in the construction of houses, floors and underground storage chambers (Jaren and Sui, 2018).
3. *The short, stabbing assegai.* In the early nineteenth century, the Zulu king Shaka kaSenzangakhona invented a short spear, 'iklwa', which was used like a sword in close-quarters combat (Ivey, 2019). This *revolutionary* weapon gave his warriors military superiority in battles with other ethnic communities in southern Africa during the period of Zulu expansionism known as iMfecane (circa 1815 to 1840). But iMfecane was not a 'technological revolution'.
4. *The beer can.* Beer was first canned in 1935 in Virginia, USA (Maxwell, 1993). This was in the immediate aftermath of the 'great depression', with no technological revolution, let alone an industrial revolution, in sight. It was regarded as revolutionary because it dealt with two of "the three biggest enemies of beer" – light, oxygen and heat. Did I hear someone object that beer does not belong up there with the wheel, the assegai, or concrete? Oh well, it was at least "rEvolutionary" in its context (Petro, 2014).

It should also be said that there have been revolutionary technologies that appeared at the height of the industrial revolutions, but which had no particular relationship to the attendant technological revolution. Good examples are the invention of *carbon paper* in 1801 in Italy by Pellegrino Turri (Polt, 2019); the *Brownie camera* designed by Brownell and released in 1900, which was the first compact camera that could be used by ordinary people to take photographs of daily life (Lothrop, 1978); Maclaran's *collapsible baby pram*, known as the 'umbrella stroller', patented in the UK in 1965 (Hann, 2002); and the contemporary *airfryer*, which uses high speed, hot air circulation – "rapid air technology" – to 'fry' food in unprecedentedly healthy ways (Vanhaverbeke, 2011, pp.83-86). All of these are revolutionary technologies in their own context; their relationship with the prevailing technological revolution of their time was, or is, contingent at best.

Because a particular technical invention is revolutionary in its own context of use, does not mean that it constitutes, or is part of, a broader technological revolution.

The concepts of revolutionary technology ('technological innovation') and technological revolution are, however, closely coupled to each other in 4IR rhetoric. If we look for example at those exponents of a contemporary information society revolution who put forward a 'positive' account of entirely technology-driven, prosperous, radiant future for all – we might term this happy-clappy 4IR – then it is easy to see why so many people think of 'the 4IR' as a purely technological revolution, and a technological revolution as a whole long list of revolutionary technologies.

Take for example two books by Diamandis and Kotler (2012, 2020) that extol a future that is "better" and "faster" than their readers think. The first predates Davos 2016; the second surprisingly never mentions it.[31] However, between them they read like the hymn books of Schwab's ideological intervention. The order of service across the two texts is all revolutionary technology, technological innovation and technological revolution, innovation and revolution, round and round. We are continuously assured that accelerating technology will ensure that employment, education, healthcare, and, "one thing's for certain, shopping" (2020, p.99), *for everybody*, will never be the same again. Besides recycled notions of accelerating technology, exponential and disruptive innovation, revolutionary tipping points, and the like, these authors add the following technological change metaphors in what they describe as a "wild ride" (2020, p.xi):

- "turbo-boosted" speed and scale of change (2020, p.xi);
- "infinite computing" (2012, para 3531);
- "a disconnect between the local and linear wiring[32] of

our brain and the global and exponential reality of our world" (2012, para 765);

- "tsunami-sized behemoths" of exponential technology (2020, p.8) that fly around in "swarms" (2020, p.10);
- "overlapping waves of change that threaten to wash away almost everything in their path" (2020, p.69), "historically unrivalled in their capacity for disruption" (p.210);
- "a blitzkrieg of technologies" (2020, p.117).

Wow! Who would not want to become a worshipper in the face of such a cargo cult? The conflation of concepts makes us want to stand up on a pulpit at a revivalist meeting rather than engage in a rational conversation about technology.

Armed now with a better understanding of how the concepts 'innovation' and 'revolution' work, we can go back to consider the list of proclaimed 4IR technologies in Table 2. I have suggested that none of those in the right-hand column is a revolutionary innovation of contemporary times. All of them were, and are, gradual evolutions of technology rooted back into the defining technological transformations of the 3IR.

The convergence of technologies

To be fair to the 4IR ideologues, most of them do not limit their notion of a contemporary, new revolution to a list of proclaimed technological innovations. They are careful to make the point that it is not so much a collection of revolutionary technologies that constitute a technological/industrial revolution (although these are necessary), but rather the unprecedented converging of technologies. The term 'convergence' was first used by the historian of technology, Nathan Rosenberg, to delineate the coming together of technologies from "sequences of parallel and unrelated activities" (1963, p.423ff).

For Schwab, a 4IR is evident today in "the *staggering confluence of emerging technology breakthroughs*, covering wide-ranging fields such as artificial intelligence, robotics, the internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few" (2016, p.7). For Marwala (2020b), a 4IR is "the current that *blurs the lines between the physical, digital and biological spheres* through AI, automation, biotechnology, nanotechnology and communication technologies … contrary to the earlier industrial revolutions, 4IR is based not on a single technology, but on *the confluence of multiple developments and technologies*." For McGinnis (2018), it is a "*fusion of advances* in artificial intelligence, robotics, the Internet of Things, 3D printing, genetic engineering, quantum computing, and other technologies" (all my emphases).

The general sense that one gets from claims like these is that a 4IR is generated by technology convergences of a kind that is unprecedented historically – Schwab's "velocity, scope, and systems impact" hypothesis springs to mind. Two questions arise from this:

(I) Is it indeed the case that a revolutionary convergence of technologies did not characterize the technological transformation stratum of any of the 1IR, 2IR or 3IR?

(II) Is there such a revolutionary convergence of technologies in the current era that would go towards warranting the claim of a contemporary industrial revolution?

Before I attempt to answer these questions, some reflection on the notion of the convergence/confluence/fusion[33] of technologies as the 'driver' of change is required. Jamie Morgan (2019, p.374) points out that the core of "fourth industrial revolution material [is] that it is the *confluence* of technologies that is considered socially significant." He goes on to suggest that this means that it is technologies in combination with each other that create the *potential* for change. They "represent an *anticipated* fundamental transformation. However, this anticipation … is in so far as *individually* all of the technology is either available in initial form or is something particular groups are working on somewhere in the world" (2019, p.374) – in other words, *new* technological innovations are the constitutive elements of the potential for change. In critical realist terms, we might say that configurations of emergent technologies are the generative structures or mechanisms that produce the technological revolution (or in the WEF's reductionist view, the 4IR). In Schumpeterian terms, the *innovators* are then the agents who actualise ('trigger off', if you like) these generative mechanisms – Schwab also believes this, but in much less clear theoretical terms.

It seems to me that Morgan is correct that this is the view of Schwab and other enthusiasts regarding the confluence of contemporary technologies as the driver of a 4IR.

Unfortunately, this is an overblown notion of technology convergence(s) and attendant technological revolution, which does not do justice to the way these actually work most of the time.

Edgerton (2008) calls this view "innovation-centric futurism". He suggests that technocratic accounts of technology convergences are misleading, because they attempt to identify the coming together of new technologies at a single point in historical time. Axiomatically, *new technologies* are taken to be central to the way technology convergence occurs. In actual practise, however, human beings work with old and new tools and machines, with hammers and electric drills, knives and graters and electric blenders, computerized (IoT) kitchens and outdoor, wood-burning ovens, in constantly shifting patterns and productive relationships with nature. "Technologies appear, disappear and reappear, and mix and match across the centuries" (2008, p.xii). Only a nuanced, extended historical account of specific technology convergences can grasp their complexity. This seems to be what Morgan is getting at when he suggests that "the development of technology is subject to the values and principles and mechanisms of societies. … it is limited by the very nature of material reality … [and so] any confluence of technologies will be contingent and varying" (2019, p.375).

Edgerton (2008) suggests that technocratic accounts of technology convergences are misleading, because they attempt to identify the coming together of new technologies at a single point in historical time.

History dictates that our standard conception of the nature and significance of convergences of technologies must change:

> *Present visions of the [technological] future display a startling, unselfconscious lack of originality. Take the extraordinary litany of technologies which promised peace to the world. Communications technologies, from railways and steamships, to radio and the aeroplane, and now the internet, seemed to make the world smaller and bring people together, ensuring a perpetual peace. … [However] A history of how things were done in the past, and of the way past futurology has worked, will undermine most contemporary claims to novelty. …* ***These questions become much easier to answer if we stop thinking about 'technology', but instead think of 'things'****. Thinking about the use of things, rather than of technology, connects us directly with the world we know rather than the strange world in which 'technology' lives. We speak of 'our' technology, meaning the technology of an age or a whole society. By contrast 'things' fit into no such totality, and do not evoke what is often taken as an independent historical force.* ***We discuss the world of things as grown-ups, but technology as children.***
> (Edgerton, 2008, pp.xvi-xvii, my emphases)

It is a truism to say that technologies converge, at many points in time and in any era. The important general point to make is that a convergence of technologies is not necessarily revolutionary, in technological terms or otherwise. For the most part, multiple, interacting things (including tools and machines) are part of life and work. They are contingent and vary in relation to material social contexts (Morgan, 2019, p.375).

However, when technology convergences can be considered 'revolutionary' in some sense or another, the judgement is one based on historical specificity. Some historical examples of actual convergences of technology make this clear:

1. In recorded history, the dating of the medieval 'agricultural revolution' is contested. Idrisi dates the Muslim agricultural revolution to the seventh century, while "Europe stagnated" – it was characterised by notable irrigation technologies (2005, p.3). In Europe, Verhust suggests the period is best considered as "a slow process lasting from the late Middle Ages to the eighteenth century" (1990, p.17). Be that as it may, there was a convergence of technologies early on that is considered one of the most important transformations in the history of agriculture – the advent of horse drawn, heavy-duty ploughing (White, 1962; Thomas, 2005; Andersen et al, 2016). The wheeled, heavy iron plough, which could make deeper cuts into the soil than ever before, was invented in the eleventh century. It was innovative in bringing together existing plough technology, the wheel, and more sophisticated iron-making. However, it was hardly revolutionary at that time. The plough was drawn by teams of oxen (previous generations of lighter ploughs were drawn by only one or two oxen), and therefore proved difficult to use for many decades – the hooves of oxen broke easily

under the new work regime, and did not cope well with wet fields; and the turnaround time at the end of a ploughing run required that the oxen be outspanned and inspanned each time. Horses, although they were stronger, more mobile, and easier to communicate and work with, could not be used because the existing yolks suffocated them and cut off blood supply to their brains. The technological revolution occurred early in the twelfth century, with the invention of a new padded horse collar that shifted traction from the neck to the shoulders.[34] This was a major technological breakthrough. Along with inline hitching and horseshoes that made horse power independent of field conditions, the new collar now made horse drawn ploughing viable (White, 1962, pp.57-64). Over about five decades, a *gradual* convergence of iron-making innovations, plough technology, the wheel, horseshoes, inline hitching and the new horse collar radically transformed ploughing and increased agricultural yields. It contributed substantially to the medieval agricultural revolution.

2. Rosenberg (1963) describes the *horizontal* convergence of different kinds of machine tools across industries that took place in the USA over a 30-year period, from about 1880 to 1910. These economic events 'fused', especially, those machine tools that were themselves involved in the manufacture of machine tools, in a technology development programme that contributed significantly to the USA becoming the leading industrial nation in the 2IR. By 1880, there were substantial numbers of machine tools deployed in US factories. A major problem, though, was that their cutting edges were not hard enough to work on previously-hardened steel. So parts for various mechanical technologies – machine tools, locomotives, sewing machines, typewriters, bicycles, and early motor cars – were machined using soft steel, and then put through a hardening process. This, in turn, held back the drive to manufacture interchangeable parts for factories (Taylor, amongst others, was involved in this in this period), because hardening changed the shape of each part to some degree (Paxton, 2012, pp.77-78). Heavier, more rigid, faster automated tools were required to cut, shape and drill hardened metal with absolute precision. US companies achieved this by collaboration *across industries* between the machine shops of different factories (Braverman, 1998, p.135). The production of distinct commodities throughout the economy was all based on a relatively small number of production processes, using a relatively small number of machine types (Rosenberg, 1923, p.423). The development of any particular machine tool required the "adaptation of a special apparatus to a single operation in almost all branches of industry" (1923, p.417). So a system of *technology convergence* (Rosenberg, 1923) was set up across industries that drove forward the improvement of machine tools faster than anywhere else in the world – it meant, for example that by the time Ford set up a production line in 1913, high quality interchangeable parts were available, as were heavy-duty, precision machine tools required for the production of motor cars. The "machine tools revolution" contributed to the broader technological revolution that characterised the 2IR. Braverman thinks that its centrality in accounts of industrial progress at the time is "a veritable technological determinism: the attributes of modem society are seen as issuing directly from smokestacks, machine tools, and computers" (1998, p.11).

3. Contemporary, state-of-the-art indoor agriculture seems to be built on an accumulating convergence of technologies that straddled all three industrial revolutions. These technologies include: 1IR greenhouse innovations (iconically, the greenhouse built at the Palace of Versailles in 1789); the development of soilless cultivation by the German botanists von Sachs and Knop towards the end of the 1IR; solution culture (advanced commercial soilless cultivation techniques) introduced in the 1930s by Gericke in the USA; the introduction of plastic growing beds and drip irrigation/fertilization systems, inaugurating modern hydroponics in the 1940s; customized environmental-control systems (heating, ventilation and air conditioning – HVAC) in the1950s; computerization and automation of HVAC in the 1970s; and the introduction of LED (light-emitting diode) lighting systems in the 1990s – the closest ever approximation to sunlight indoors. These technologies converged over some 180 years to enable modern indoor agriculture routines and operations (Hussain et al, 2014, p.834; Venter, 2017; Mitchell, 2022, p.252).

These are nuanced, historical accounts of technology convergences that stem from thick description of the actual use of *things* over time. It is not so much the moments of *invention* of technologies, as the way that people put them together over time, that allows to understand the transformative significance of these events.

Edgerton suggests that a formulaic, innovation-centred account of technology convergence, "for all its claims to universality, is based on a very few places" (2008, p.xii). I want to suggest further that it produces, simultaneously, an ontological blindness (in that we fail to identify the real, generative potentials of actual combinations of technology as they are used in the work and everyday lives of human beings) and a methodological mistake (in that empirical evidence of the invention of new technology is forced into an associationist [nomological-deductive] economic model of convergence). Rather, we should flesh out a "use-centred history" (Edgerton) of really existing technological convergences over time. This might be considered to be a critique of the 'techno-economic' Schumpeterian account of technology innovation and convergence discussed earlier.

In a technology-in-use perspective, a different notion of technology convergence appears. It will lead, argues Edgerton, to us having to rethink our concept of technological time, which tends to be mapped on an innovation-based timeline. Edgerton points out that steam power in the UK was more important in 1900 than in 1800, and so its status as the iconic technology of the 1IR might be questionable. It was *invented* then, but it has been *innovative* at many points in time, in many different places. Its convergence with other technologies was equally various. Similarly, England consumed much more coal in the 1950s than in the 1850s, more bicycles are now produced globally each year than are motor cars, and the production of books continues to increase significantly in the era of ICTs (blended learning, anybody?) (2008, p.xii).

I return now to the first question on page 43 above, in relation to the Schwab, Marwala and McGinnis claim that there is currently a radical convergence of technology breakthroughs that fuse physical, digital and biological realities in a confluence of fields like AI, robotic automation, the IoT, autonomous vehicles, nanotechnology, biotechnology, quantum computing, and 3D printing: Is it the case that a revolutionary convergence of technologies did not characterize the technological transformation stratum of any of the 1IR, 2IR or 3IR?

Let us get the most obvious misconception out of the way first, in regard to this question. When Marwala (2020b) claims that, "contrary to the earlier industrial revolutions, 4IR is based not on a single technology, but on the confluence of multiple developments and technologies, he is plainly wrong:

1. The transatlantic *convergence* of the cotton gin, the spinning mule, the mechanical loom *and* Watt's steam engine constituted the technological revolution associated with the 1IR.
2. The *systematically planned convergence of technologies* in production lines was decisive in the transformation of the 2IR factory.
3. The Internet was (and is) *the technology of the convergence of technologies* that we know as the digitally networked 3IR. (Moll, 2021a)

Is it the case that a revolutionary convergence of technologies did not characterize the technological transformation stratum of any of the 1IR, 2IR or 3IR?

When we adopt a *technology-in-use* perspective on convergence of the kind considered earlier, then it is clear that a revolutionary convergence of technologies does indeed characterize the technological transformation stratum of each of the 1IR, 2IR and 3IR.

First, recall Kennedy's (1993) suggestion that, in the 1IR, once the spinning mule was harnessed to steam power, the mechanization of manufacturing was inexorable. The revolutionary character of this convergence, and that with crop harvesting, weaving and garment-making technologies, lay in the fact that it created "innovation inside an industrial chain" (Aït-El-Hadj, 2017, p.30). It was, in other words, a convergence of technologies established *in-use*. As these technologies were invented in the context of the drive for mass production, their emergence and development depended on each other. The flying shuttle demanded faster spinning operations; innovations in spinning (the spinning mule and the spinning jenny) demanded more efficient preparation of raw cotton, which was achieved across the Atlantic by the invention of the cotton gin. The increase in the output of cotton thread put pressure back on weaving capacity, eventually leading to the introduction of the power loom. And of course, behind all of this was increasing demand for new innovations in steam engine power and the pulley-belt energy transmission system – themselves facilitating more and bigger looms, and so on (Rosenberg, 1976, p.112).

Second, economic historians tend to consider essential breakthrough of modern industrial society to have been establishment of automated assembly lines (Jevons, 1931; Schön, 2007, p.226). Again, there was a revolutionary convergence of technologies here. Jevons gives the example of a 2IR match factory:

> *From the moment the logs are placed in the veneer-cutting machines, [the material] goes through a continuous series of automatic machines, drying ovens and packing machines which have merely to be regulated, and adjusted and supplied with material."* (1931, p.5)

Taylorization envisaged assembly lines as deliberately, carefully, "scientifically" organized convergences of machines *both old and new* (Edgerton, 2008), with the new energy source, electricity, to maximise production. A complex technological system was put in place to manage the spatial organization of all production apparatuses, the working speeds and temperatures of machines, the properties of materials, machining precision, and (if one regards the human worker as a technology, as Taylor did) the performance of labour (Aït-El-Hadj, 2017, p.36). The fact that these processes were designed in relation to the particular conditions of each production process, and to the skills and character of each labourer, is testimony to way in which the *use* of technology, rather than its moments of invention, brought about any specific production line.

Third, in the very way that it is used and incorporated into their work and everyday lives (for good or for bad) by the users of ICTs, the Internet has brought about the fusion of multiple digitized technologies from its very beginning. This situation continues until the present (e.g. in the IoT and cyber-physical system programming). As has been seen above, an IoT is not some kind of magical, technological entity, but a pragmatic combining of selected technologies in contexts of work or everyday life. Every single one of the technologies of the 3IR discussed above can – at least in principle – be connected with any or all of the others via satellite and Internet technology. These convergences are affordances inherent in the technology;[35] but they are actualized only by the living, breathing, decision making of people using the technology for particular purposes. There is no doubt that the digital convergences of the 3IR have been, and continue to be, revolutionary when considered in relation to the 'industrial age' brought about in the 2IR. The placing of machine learning in WABOT-1 and Freddy I, or the digitized Internet connection of my cell phone to big stock exchange databases, https://www.iwillteachyoutoberich.com/, and the latest Mercedes-Benz catalogue, are not isolated incidents of convergence. They are defining aspects, amongst many, of a socioeconomically pervasive transformation of society that we have no problem thinking about as a technological revolution. The digital convergences of the 3IR, as they consolidate and deepen themselves in ongoing productive and cultural activity, are what sustain the current socioeconomic era.

This brings us then to second question on page 43 above: Can we identify a pivotal, grand confluence of technologies to warrant the claim of a contemporary industrial revolution that leaves the 3IR behind? On the strength of my arguments about specific technologies in the previous section, it seems unlikely that we will find evidence to support this notion. If it is the case that a revolutionary technology convergence can occur only if, individually, "all of the [new] technology is either available in initial form or is something particular groups are working on somewhere in the world" (Morgan, 2019, p.374), then a 4IR is not even on the horizon.

Can we identify a pivotal, grand confluence of technologies to warrant the claim of a contemporary industrial revolution that leaves the 3IR behind?

Why do 4IR advocates believe that there is unprecedented convergence of new ICT innovations at this time? Part of the reason, surely, is that the ontological blindness built into the way that 'information technology' organizes, distorts and presents us with information, reinforces the misconception that there were no significant technological convergences before the current millennium. If you had googled the search term "technological convergence" on Friday 11th February 2022 and scanned the first ten screens, you would have seen nothing to suggest otherwise. You would have seen a lot of language that equates the concept with 4IR-like (mis)understandings of technological innovation and revolution. For example:

[screen 1]
"Technological convergence, also known as digital convergence"
https://en.wikipedia.org/wiki/

[screen 2]
"Technological convergence is the combination of computing, communication, and content around networked digital media platforms"
https://leverageedu.com › Blog

[screen 3]
"Technological convergence is the integration of several technologies into a *single device*"
https://www.dsxhub.org/

[screen 4]
"Technological convergence is a manifestation of technological innovation"
https://www.ncbi.nlm.nih.gov/

[screen 5]
"The case of information and communication technology (ICT) industry is used to highlight this convergence phenomenon"
https://www.worldscientific.com/

[screen 6]
"Technological convergence: Autonomous driving, 5G, IoTs, data centers and power applications"
https://www.smart-energy.com/

[screen 7]
"Critical philosophy of technological convergence: Education and the Nano-bio-info-cogno paradigm"
https://www.jstor.org/stable/

[screen 8]
"Buying up tech businesses in order to embed technological capabilities in their offering has become so normalized, it has a name: technological convergence"
https://www.business-sale.com/

[screen 9]
"Unexpected convergent consequences … when eight different exponential technologies all explode onto the scene at once"
https://www.diamandis.com/

[screen 10]
"Technological convergence is the merging of technologies. When more and more different kinds of media are transformed into digital content"
https://saylordotorg.github.io/

There is nothing here about medieval ploughing breakthroughs, or transatlantic textile machinery in the 1900s, or machine tools at the dawn of the twentieth century, or even WABOT-1 50 years ago. Knowledge of technological convergences gets replaced by the most frequently repeated information (or misinformation) on technological convergence.

There is no shortage of proclamations that there is a here-and-now revolution unlike anything humankind has experienced before, based on the unprecedented convergence of new technologies of the moment. Think back to the prophecies of Diamandis and Kotler (2012, 2020) discussed above.[36]

Another example comes from Young (2020): writing for the Forbes Technology Council, an "invitation-only community for world-class CIOs, CTOs and technology executives", she produces an iterating circle of metaphors about a *converging* smart new world, unprecedented revolution, the overwhelming pace of change, disruptive technologies, exponential growth, continuous and accelerating innovation, raised incomes, digital efficiency, liberated employees and unleashed creativity. My favourite is her idea that "millions of petabytes of data" engender "a new way of life" (2020, para 5). Besides the momentary aside, "how [do we] deal with the disparity of an equitable [sic] society?" (para14), there is no mention of the downside of the digital revolution, and of escalating unemployment in particular. The fact that messages like these are so anecdotally dismissive of widespread, systematic statistical evidence of global job losses associated with digitalization and automation (e.g. ILO, 2016; 2017; 2018; 2019b; 2021 – see also Moll, 2022a, pp.55-56), and do not mention issues like rising poverty, precarious work, offshoring, global inequality, widening wealth gaps inside and between countries, etc. at all, seems not to matter.

It must be said that neither Klaus Schwab (the leading global 4IR advocate) nor Tshilidzi Marwala (the leading South African 4IR advocate) can be accused this kind of happy-clappy 4IR convergence talk. Both are aware of the dangers of the so-called 4IR (i.e. the acceleration and deepening of the 3IR) and the social degradation that it is producing, although in the end they both seem to downplay it (I have suggested elsewhere that this is done for ideological reasons: Moll, 2022a). For example, the WEF says that while Schwab thinks technology convergences reveal "the potential [of the 4IR] "to connect *billions more people* to digital networks, dramatically improve the efficiency of organizations and even manage assets in ways that can help regenerate the natural environment, potentially *undoing the damage of previous industrial revolutions*", he "also has grave concerns: that organizations might be unable to adapt; governments could fail to employ and regulate new technologies … inequality may grow; and societies fragment." (WEF, n.d., para 4-5, my emphases).

Marwala, too, warns strongly that "4IR" technology has "been exclusionary. If the pandemic has shown us anything, it is that inequality in access is a challenge we must overcome to be successful in the 4IR" (2020c, para 23). He acknowledges that "the computerization of jobs will leave a large proportion of human labor unemployed', and that in the "world of 4IR, there is a looming gap between truth (how data resources are being exploited) and fact (how human resources are managing to adapt)" (Xing et al, p.175).

Sometimes Marwala's tone is exclusionary, brutally so: "those who master the means and ways of the 4IR shall thrive. Those who fail to master this revolution shall be thrown into the dustbin of backwardness" (quoted in Wits University, 2018). At other times, it is much more aware of the problem:

> *Discovering the optimal solution to potential job displacements requires a reorientation of our approach to education, science and innovation. Inequities and inequality in communities can be overcome by levelling the playing field to ensure that technological inequality does not become a new exclusionary barrier. While some would have us believe that the 4IR spells doom,* ***it could be*** *the key to finding solutions to some of our most deep-seated problems.* (Marwala, 2020a, p.115, my emphasis)

Whatever the tone, at the end of the day Marwala emphasizes the familiar web of triumphant technological metaphors – notions such as unprecedented workplace disruption, tipping points, innovative computational intelligence, exponentially evolving technologies and the fast approaching *singularity* (the complete convergence of humans and machines) permeate his writings (Marwala, 2020a; 2020b; 2020c; Moloi and Marwala, 2020; Xing et al, 2018). His clanger is, "AI machines assume responsibilities in society that require them to be designed as moral entities" (Xing et al, p.189). In the disciplinary terrain of AI, this has arguably (I think convincingly) been shown to be impossible in principle by the 'Chinese room experiment' (Searle, 1980; 2014; Cordio, 2008).

Where is the evidence for this grand technological revolution? If one examines actual technologies discussed by Schwab and Marwala themselves, then it is clear that there is sparse evidence of a contemporary, widespread, socially pervasive fusion of new technologies that transcends the digital revolution in some way. In any case, the vast majority of their writing is 4IR hype, with very little concrete evidence being provided.

If one examines actual technologies discussed by Schwab and Marwala themselves, then it is clear that there is sparse evidence of a contemporary, widespread, socially pervasive fusion of new technologies that transcends the digital revolution in some way.

In Schwab's (2016) book, there is an absolute disconnect between the rhetoric on the one hand, and examples of actual technology adduced on the other. Bear in mind that what he is proclaiming:

> *[A] staggering confluence of emerging technology breakthroughs … reaching an inflection point in their development as they build on and amplify each other in a fusion of technologies.* (2016, p.7).
>
> *The scale and breadth of the unfolding technological revolution will usher in economic, social and cultural changes of such phenomenal proportions that they are almost impossible to envisage.* (2016, p.31)

Actually, the few instances of "the shift in action" that he mentions are much more low key events, more in the order of a gradual evolution of things. None of them are more than current iterations of 3IR technology. Examples are the Uber app (pp.60-61); "the internet of pipes … employ[ing] sensors in the water system to monitor flows" (pp.75-76); a shirt that can measure breathing, sweating and heart rate (p.116); the Apple watch (p.123); a robot capable of "picking up a part, holding it in front of an inspection station and receiving a signal to place it in a 'good' or 'not good' pile" (p.142); 3D-printed jet engines and spine implants (pp.149-150); and pet-tracking implants in human children (p.110).

More insight into this dualism in Schwab comes from Skilton and Hovsepian's (2018, p.29) report on a conversation one year later (Jan 2017) in which Schwab marveled at the "new technologies" that had materialized in the interim 12 months. These included commercial drone deliveries, nanosensors, carbon nanotube transistors, reusable rocket technology, and a one terabyte SD memory card:

- In 2016, the first commercial drone deliveries took place in the USA, Japan and the UK (Hern, 2016). Why Schwab was surprised is a mystery – major online shopping companies had decided in 2013 to start drone delivery.

In any case, the key innovation had been provided in 2010 by a French drone manufacturer, in the form of a smartphone app making a drone fit for consumer use (Johnson, 2010). This kind of drone technology dates back to military use in at least the 1980s (Bousquet, 2018).

- Schwab enthused about nanotechnological, "dust-sized sensors". It is not clear exactly what 2016 event he was referring to, but at this time the "third way of analytical nanoscience" (Cayuela et al, 2016; López-Lorente and Valcárcel, 2016) had emerged, focused on the use of carbon nanomaterials in the diagnostic process. However, the scientists working on this did not see it as major technological transformation, describing it rather as "a new and promising route to extract reliable information" within a relatively stable, enduring research programme (López-Lorente and Valcárcel, 2016, p.1). Within the research-intensive 50-year history of nanomedicine (Astruc (2016, p.4 – see page 41 above), 2016 seems like it was another good year of progress. Another recent innovation, biodegradable silicon sensors (Penn State, 2020), can be spoken of in a similar way. And we have already seen that number of current research programmes concerned with brain technology are very speculative indeed.
- Materials engineers created carbon nanotube transistors in 2016 that outperformed state-of-the-art silicon transistors for the first time (Malecek (2016). Publications on Google Scholar, however, reveal that this was the outcome of an extended 15-year research programme investigating the electronic properties of carbon nanotubes, carried out by the Advanced Materials for Energy and Electronics Group at the University of Wisconsin-Madison.
- Schwab was keen on the SpaceX Starship and Blue Origins' New Shepard reusable rocket landings in 2016. However, technologically speaking, these were ongoing events in the development of reusable rocket technology going back at least to NASA's space shuttle programme in the 1980 – Columbia in 1981, Challenger in 1983, Discovery in 1984, and Atlantis in 1985. Although the Russian Soyuz-7 rockets are not reusable, there has been some degree of cooperation on this since the mid-1990s in the International Space Station project, between the participating space agencies – Russia, Japan, Europe, Canada and the USA. What *was* new in the early to mid-2010s was the emergence of private spaceflight companies, but this has more to do with the neoliberal ideology of contemporary globalization than it has to do with technology (Moll, 2022a).
- In 2016, SanDisk unveiled a prototype of the first one terabyte memory card. However, this was not particularly momentous – the storage density of memory cards had been increasing significantly throughout the early 2010s, so it would have happened around about then, in the broader scheme of things. Much more significant events in the evolution of memory cards were the secure digital extended capacity (SDXC) format, announced in January 2009, and the proprietary non-volatile memory card format developed by the Secure Digital Association in 2010 for use in portable devices.

Whereas Schwab's view of these *things* is that,

> *we are looking at technology as threatening our present thinking and interpretation of how the world evolves, [therefore] we need new thinking to define meaning, new concepts to define what humanity is, and what is the purpose of our lives"* (quoted by Skilton and Hovsepian, 2018, p.30),

these authors' wry comment is, "it is perhaps surprising that historically many of these breakthrough technologies have origins well before the present decades and began in the middle to early part of the last century" (2018, p.31).[37] One cannot help recalling Edgerton's comment, "we discuss the world of things as grown-ups, but technology as children" (2008, pp.xvi-xvii).

> "It is perhaps surprising that historically many of these breakthrough technologies have origins well before the present decades and began in the middle to early part of the last century".

In a remarkably similar way, Marwala mixes 'revolutionary' 4IR hyperbole with mundane examples of everyday 3IR technology-in-use. In his most expansive piece on the 4IR, *Closing the Gap* (2020a), he ranges across a large number of activity sectors in society, seeking to provide his reader with evidence of a 4IR. His juxtaposition of the two strands of argument seem unrelated to one other: talk of 'unimaginably rapid, never-seen-before convergence' (2020a, pp.9-10 et passim) and 'unprecedented, exponential economic growth" (2020a, p.116 et passim) on the one hand, and accounts of everyday digital technology at work on the other. Examples of the latter include:

- The Mercedes-Benz feature, Attention Assist, that warns drivers of possible fatigue (2020a, p.82);
- The Facebook app that allows people caught up in a disaster to notify family and friends that they are safe (2020a, p.95)
- The shopping feature on Instagram that "allows consumers to try on products digitally before buying them" (2020a, p.97).
- Calculators on bank and estate agent websites that enable clients to calculate interest, home loan repayments, eligibility for credit, and the like (2020a, p.122).
- The 'tap-and-go' facility on Gautrain to allow commuters to pay for their journey using their credit cards (2020a, pp.125-126).
- Machine learning technology that creates 'life-like' 3D characters or creatures in movies, such as the dinosaurs in Jurassic Park (2020a, pp.187-188).
- Digital 'wearables' that monitor hearth rate, breathing, or 'my number of steps for the day' to help increase fitness or sports performance (2020a, p.210).

Elsewhere, Marwala describes how engineers in big construction firms "deploy Big Data analytics to optimise the vehicle routing strategies at the coalface", how "smart Rockbolt" uses sensors to measure both vibrations and strain in deep underground mines (Xing et al, 2008, p.192), and how the University of Johannesburg developed a "smart machine" to predict the failure of a transformer before it breaks (Marwala, 2019). Marwala mobilizes all of these examples in seeking to warrant his claim that there is a 4IR. However, without exception, they are all developing 3IR technologies.

We are in same situation that Hobsbawm was when he considered the technological progress engendered by World War II, and concluded that "what they achieved was, by and large, an acceleration of change rather than a transformation" (1995, p.48). It seems that Ray Kurzweil's (2005) *singularity* (the time when all intelligent machines will merge with each other, and with human intelligence) is not so near.

In the next section of this paper, it will become clear that the influence that technological convergences have on society depends a great deal on how they are related to other social mechanisms that contribute to the generation of evolutionary or revolutionary progress.

There is no Fourth Industrial Revolution

Apart from the question of how revolutionary current technological developments are, if the 4IR has arrived, we should find evidence of deep transformation of the labour process, labour relations, social life and international socioeconomic relations as was the case in the 1IR, 2IR and 3IR. We know what the criteria are for us to be able to make such an historical judgement, and it soon becomes evident that there are nothing like the deep transformations of the labour process, labour relations, social life, and international socioeconomic relations, that we would expect to find if there were a 4IR. In this section, I demonstrate why.

Work tends increasingly to be individualized and atomized, either globally dispersed for high skilled experts, or localized in mundane service sector activities. Fracturing of occupational identities associated with the 3IR continues, with the erosion of clear boundaries of the workplace and the workday, and spillover into the home and other locations, leading to what Beck and Beck-Gernsheim (2002) call the double face of individualization – "precarious freedoms" – and Huws terms precarious, "delocalizable" work (2014, p.30). The 'future of work' literature in general suggests that future transformations of work beyond the 3IR will combine *universal*, meaningful work, community activity, and increased leisure time. This process could perhaps be based on a universal basic income guarantee (Gorz, 1999; Beck, 2000; Standing, 2017; Paus, 2018), a significant reduction in working hours and working life to slow down and halt unemployment (Rifkin 1995; Granter, 2009; West, 2018), and/or the transformation of the increasingly "isolated, remote, routine and perfunctory" jobs of the digital economy into purposeful, *sentient* work with machine systems (Zuboff, 1998, p.6). However, the same literature shows that, insofar as this restructuring of the relationship between work, leisure and engagement is happening, it remains the province of elites, and is not distributed across society, *across all continents*. A 4IR, in this regard, is some way away.

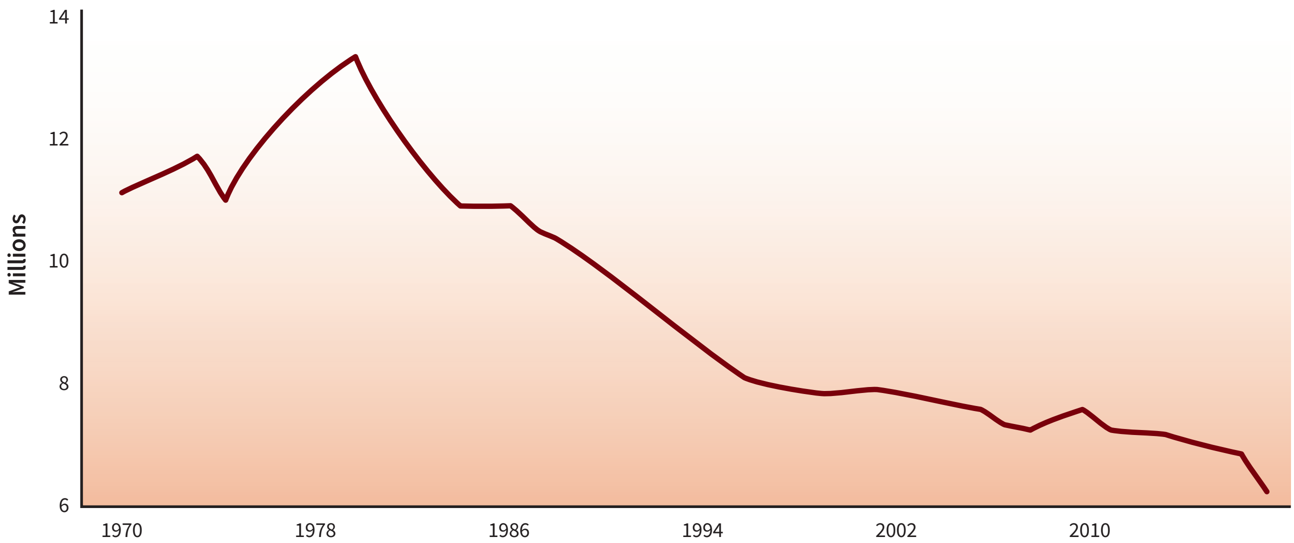
The international hollowing out of the labour market continues. The evidence is unequivocal: the continuing automation of factories and, particularly, businesses continues to deepen the 3IR (OECD, 2019a, 2019b). In the OECD countries, the proportion of middle-skill jobs dropped from 42% in 2000 to 32% in 2019, while high-skill employment increased some eight percentage points and low-skill 2% (OECD, 2020a, p.224). The OECD estimated (prior to the Covid-19 pandemic) that this "hollowing out" will continue, with 14% of middle class jobs expected to disappear as a result of automation in the next 15 to 20 years, and another 32% likely to change radically as individual tasks are automated. While employment in services is likely to increase concomitantly, this will be largely "lower-quality and precarious jobs" (OECD, 2019a, p.3). In non-OECD countries (such as Brazil, Russia, Africa as a whole) the situation is even more stark – for example, in South Africa less than one third of the workforce is in mid-skill jobs (OECD, 2019b, p.17), and about one-third of 14 million jobs in South Africa face an 80 to 90% probability of being automatable (le Roux, 2018).

One of the consequences of individualization and the transient 'team work' that goes with it, is the breakdown of collective structures and solidarity in the workplace and beyond (Huws, 2014, p.40; Visser, 2019a). Precarious work is inherent in the very preconditions of 3IR labour process, and workers are disconnected "from [their] structural and traditional position within the institutional framework of labour" (Allvin, 2004, p.2). In this situation, the decline of the influence and membership of trade unions continues into the twenty-first century. In countries with deep, long-sanding trade union traditions, the continuing decline in trade union membership is dramatic: in the US, for instance, unions represented 20% of workers in 1983, but represent only 10% in 2020 (Rosenberg, 2020); in Britain, similar decline is evident from the 1980s to the present (Figure 3). OECD statistics in general reveal a decline in union density rates – the proportion of union members among employees – from 30% in 1985 to just 16% in 2019 (OECD, 2020b).

These declines have been most pronounced in "advanced industrial countries" – the global industrial nexus that has been tracked historically through this paper. However, in "developing countries" only a minority of workers have formal employee status, which inflates the union density rate in poorer countries (Visser, 2019b, p.14). In South Africa, for example, unions tend to rely on the traditional "model of organizing and bargaining … to defend the interests of permanent workers", and neglect forms of organization that would address the struggles of the increasing numbers of precarious workers (Webster and Forrest, 2019, pp.68-69). Generally speaking, then, the hollowing out process has ramified globally into the "disappearance of the working class as a collective social force, accompanied by the decline of a socialist culture" and of progressive social movements (Virdee and McGeever, 2018, p.1815).

Socially, a broader hollowing out of the middle classes persists, in a dialectical relationship with the context of labour. As Dow points out, the digital economy generates the social phenomena of unemployment at a much faster rate than it generates income, wealth and prosperity (2017, p.34). Castells' "double-edged sword" of the 3IR – economic prosperity on the one hand, and rising urban poverty, inequality and environmental degradation on the other – is continuous. The erosion of the 'political and cultural middle' continues in the evolution of large cities, where intra-urban inequalities and residential segregation develop in a reciprocal relationship with digital inequality (Gilbert, 2010; Nijman and Wei, 2020; UN, 2020). Gilbert has modelled the complex ways in which technological and social capital associated with ICT access and use correlates significantly with urban contexts of residential location, employment and educational history, and with everyday

Figure 3 *Declining trade union membership in Britain* (after Topping 2017)



social networks (Gilbert, 2010, pp.1006-1007). The digital economy, "for all its vigor, growth and contributions to aggregate prosperity, has forged new spatial inequalities in and between cities … disparities have grown, suburbs have been re-sorted into a wide array on the basis of class and race" (Nijman and Wei, 2020, p.2).

There is obviously widespread disillusionment with this growing inequality globally, which threatens the basic legitimacy of political systems. There is general consensus, for example, that this deep social crisis explains the votes for Trump and Brexit, and against Italian reforms, witnessed in recent times: "Thumbing their noses at party establishments, [voters] have repudiated the arrangements that have been hollowing out their living conditions for the last 30 years" (Fraser, 2016, p.281). This 'left behind' identity, and the loss of faith in institutions, go a long way to explaining the growth of socio-cultural politics uncomfortable with the social *status quo* (Wahl-Jorgensen, 2018; Virdee and McGeever, 2018). The 3IR's contradictory patterns of social life continue, with various expressions of nationalism, fundamentalism and chauvinism clashing (or sometimes cohering), with various expressions of group identity, internationalism, diversity and global solidarity.

Finally, globally, the 3IR geopolitical patterns of the marginalization of the South continue, whether by continued offshoring, or onshoring back to automated factories, or simply by discarding the "people (or places [mostly the poorer countries of Africa]) who are not, or are not any longer, considered valuable, even if they are still physically there" (Castells, 1999, p.9). All the evidence of offshoring and foreign outsourcing suggests a deepening of the exploitative patterns of the 3IR, likely to continue for some time into the future (ILO, 2019a). The terrain is like a cynical gaming environment in which multinational corporations continually shift production and business systems around the globe in search of the cheapest labour and infrastructure costs.

Earlier, I pointed out the ironic parallel between the plight of textile workers in the burgeoning factories of late eighteenth century England and those in the sweatshops of the current era of 'globalized manufacturing' (see page 6). Again, Mezzadri's poetic description of a present-day, offshored Indian sweatshop shows that the exploitation of these workers is an echo of the experiences of factory workers in the 1IR. It also strongly emphasizes the point that the sustained patterns of the globalized 3IR economy remain the dominant characteristics of the global economy today:

> *trapped inside the regime of [the factory], their own bodies are turned into commodities – yet another crucial input of production, like threads and cloth. … the body is the first machine used, and also the first machine depleted, and relentlessly so, by the process of production. …They create the soundtrack of labouring, which merges with the steady rhythmic pace of the machines, and that of cloth endlessly pouring from the press.* (Mezzadri, 2017)

All the evidence of offshoring and foreign outsourcing suggests a deepening of the exploitative patterns of the 3IR, likely to continue for some time into the future.

The offshoring trends that began in motor car and garment factories in the later twentieth century continue in an expanded range of industries until the present. Furthermore, there is an emerging pecking order, in which high skill operations continue to be shifted into the 'dominant players' like China, India, Indonesia and eastern European countries, and low skill operations are offshored/outsourced into poorer countries. Western European multinationals now frequently offshore production into countries like Poland and Hungary, significantly in the motor industry (Warda, 2013). Rising labour costs in China and India have led to a steady shift in production into low cost suppliers in countries like Bangladesh, Cambodia, Nicaragua and Vietnam, and most recently into Ethiopia and other African countries (ILO, 2019a, p.8). Ironically, even as they continue to be destinations of choice for high skill services, China and India are themselves offshoring their garment factories into Africa.

There is an increasing view that some African countries, as their infrastructures improve and their cheap labour costs are maintained, "may be set for recognition" (Omoju, 2017; see also Anon, 2018; Lago, 2019). The situation is a destructive paradox for the poorest countries in the world: Ethiopia, for example, somewhere between the 20th and 30th poorest (World Bank, 2020; Ventura, 2021 – there are slightly different criteria used in different ranking systems), is forced to provide the cheapest labour in the world in order to compete in the offshoring market. Multinational clothing factories now offshore to Ethiopia to manufacture favourite fashion brands like H&M, Lee, Levi, Wrangler, JC Penny, New Look, Guess and Calvin Klein, and employ the lowest paid garment workers in the world (Barrett and Baumann-Pauly, 2019).[38] While these wages are no doubt welcome in impoverished families, this deep exploitation has to be recognized as symptomatic of the digital 3IR economy.

Having noted the sustained, exploitative 3IR practices of offshoring and outsourcing up to current times, a word is necessary about the more recent practice of 'outsourcing to the cloud'. Over the past decade, a number of 'multinational' corporations, notably in the garment industry, have backed away from past offshoring practices, and started to *onshore*[39] their manufacturing and business processes back home (Dhar, 2012). Holz describes this as "the geographic relocation of a functional, value creating operation from a location abroad back to the domestic country of the company" (2009, p.156). The reasons for this appear complex, ranging from financial incentives (such as those implemented by the anti-globalization Trump administration in the US) to cost savings produced by shortening GVCs under the global lockdown conditions of the Covid-19 pandemic. However, most onshoring seems to be related to the cost-cutting and increased business efficiency made possible by local 'outsourcing to the cloud' associated with developments in *cloud computing* (Damodaram and Racvindranath, 2010; Dhār, 2012; Zhong et al, 2013).

Cloud computing provides remote data analytics, computational power and storage space, enabling the outsourcing of production management and business functions to a flexible pool of computing resources in the cloud. Dhār (2012) contends that a sophisticated manufacturing process arises from this, which builds on services provided by on-demand access to a shared collection of diverse and distributed manufacturing resources. Furthermore, users are billed for actual usage, shifting costs from capital expenditure to operating expenditure. Whereas in the recent past, responsibility for these information systems was outsourced to "a foreign partner", it now often turns out to be cheaper and more efficient to outsource this internally to a cloud computing provider. Now of course, sitting between the global outsourcing and local outsourcing to the cloud is the process of onshoring – closing down foreign factories and ICT facilities, and reopening them domestically. However, *both of these consolidate and intensify the job loss patterns of the 3IR*. Workers in the offshored facilities lose their jobs, while most of the workers back home do not get their jobs back, because the functions are now outsourced to the cloud. There lies the rub of cloud computing in broader social terms, and it is hardly revolutionary.

Earlier on, I adduced five criteria by means of which we can judge whether any historical period constitutes an industrial revolution. I also showed in the previous two sections that one of these, the criterion that there must be a technological revolution, is not met once we explore the histories of the most prominent digital technologies. Claims that things like intelligent robots, radically networked multiple devices, or large-scale data storage and analytics make up the revolutionary vanguard of a techno-industrial utopia turn out to be less about machines, and more about the machinations of the false prophets of a 4IR. There is very little evidence of a socially pervasive, 'grand' convergence of new technologies that transcends the digital revolution of the 3IR.

Now that the remaining criteria have been considered, the notion of a contemporary *industrial revolution* turns out to be nonsense. There are evidently nothing like the deep transformations of work, the workplace, social life, culture or geopolitics that would be present if there were a 4IR. The realities of the world are still those of the 3IR, and not much change is in sight. These realities are about globalization, and the tensions between those who drive it and benefit from it, and those who are marginalized by it and often resist it. Those of us, from different generations, who were filled with wonderment by Isaac Asimov's three laws of robotics in our distant youth, or *Star Wars* in 1977, or the robopet Poo-Chi in the early 2000s, or *Black Panther* in 2018, find it difficult to shake off the idea of 'the 4IR'. Nonetheless, history compels us to do so.

Recycling 4IR ideology

Despite all of this, the ideology, or if you like the 'discourse', of a 4IR seems to be ubiquitous and hegemonic (Moll, 2022a). In the quotation from Klaus Schwab on page 3 that sets out his belief in and conviction about the existence of a 4IR (pp.4-5), a number of key metaphors are put forward to describe the alleged revolution. In the absence of evidence that there is any such phenomenon, we need to demonstrate how these metaphors function as an *ideological frame* – symbolic representations and cognitive heuristics that constitute the 'common sense' of a political and socio-economic system (Lakoff and Johnson, 1980, p.236) – that is continually replicated by hundreds of enthusiasts to narrate and reiterate a 4IR.

Box 1 sets out this frame, distilled from Schwab's 2016 text, that functions as a formula or recipe to sustain the ideology of the 4IR (Moll, 2021b; 2022a). This section sets out numerous examples that illustrate how this ideology multiplies across the globally digitalized world.

Box 1

The metaphorical frame of the 'fourth industrial revolution'

(distilled from Schwab, 2016)

1. List between 7 and 15 technologies, mostly digital, that sound smart, make us feel outdated, and leave us in awe of the future.

2. Even if they are not of the 21st century, declare them to be so.

3. Declare that there is amazing, unprecedented convergence between these technologies.

4. Suggest that they produce changes that will disrupt and transform every part of our lives.

5. Appeal to each of the previous industrial revolutions as an exemplar of the current one.

Together, these moves will establish your authority in the matter of the 4IR. If possible, in relation to point 4, name one or two core technologies or energy sources in the previous industrial revolutions. Proven suggestions are the steam engine for the 1IR; the internal combustion engine, petrol and/or electricity for the 2IR; computers, smart phones and/or nuclear energy for the 3IR (you would have mentioned the Internet in point 1, so try to avoid that here).

Schwab himself establishes the standard:

> *The 4IR is unlike anything humankind has experienced before. … think about* ***the staggering confluence of emerging technology*** *breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few. … they build on and amplify each other in a fusion of technologies across the physical, digital and biological worlds. … I am convinced that the 4IR will be as powerful, impactful and historically important as the previous three* (2016, p.7 & p.13; my emphasis).

Other advocates of a 4IR replicate the message recipe quite closely:

- "Technologies are emerging and affecting our lives in ways that indicate we are at the beginning of … a new era that builds and extends the impact of digitization in new and unanticipated ways. … The First Industrial Revolution is widely taken to be the shift from our reliance on animals, human effort and biomass as primary sources of energy to the use of fossil fuels and the mechanical power this enabled. The Second Industrial Revolution … brought major breakthroughs in the form of electricity distribution, both wireless and wired communication, the synthesis of ammonia and new forms of power generation. The Third Industrial Revolution began in the 1950s with the development of digital systems, communication and rapid advances in computing power, which have enabled new ways of generating, processing and sharing information. The Fourth Industrial Revolution can be described as the advent of 'cyber-physical systems' involving entirely new capabilities for people and machines. While these capabilities are reliant on the technologies and infrastructure of the Third Industrial Revolution, the Fourth Industrial Revolution represents entirely new ways in which technology becomes embedded within societies and even our human bodies. Examples include genome editing, new forms of machine intelligence, breakthrough materials and approaches to governance that rely on cryptographic methods such as the blockchain." (Davis, 2016)

- The 4IR is "the current that blurs the lines between the physical, digital and biological spheres through AI, automation, biotechnology, nanotechnology and communication technologies… contrary to the earlier industrial revolutions, 4IR is based not on a single technology, but on the confluence of multiple developments and technologies." (Marwala, 2020b)

- "The 4IR is a visionary plan for countries around the world to adopt game-changing technologies like artificial intelligence and robotics. Most importantly, the 4IR does not consider any of these technologies in isolation. Instead, it encompasses a fusion in which these high-powered tech tools integrate with our physical and biological worlds. Think ubiquitous computers, interconnected digital devices, intelligent robots, autonomous vehicles, gene editing, printing of organic matter, and even brain enhancements. An effective way of understanding what the 4IR is about is to consider it in the context of the previous three industrial revolutions." (Getsmarter, 2019)

- "Cloud and mobile computing, big data and machine learning, sensors and intelligent manufacturing, and advanced robotics are among the main types of technology that are leading this transformation. … Industrial revolutions have always been characterized by technological leaps, ever since the very beginning of industrialization: The First dates back to the end of the 18th century with the advent of mechanization based on water and steam; the Second occurred at the beginning of the twentieth century with the intensive use of electrical energy to enable mass production; after World War II, the Third Industrial Revolution introduced electronics and information technology to automate production. The 4IR is mainly characterized by the advent of Cyber-Physical Systems the blending of hardware and software that can interact with humans to complete work, artificial intelligence and machine learning." (Ghislieri et al, 2018)

- "The first three industrial revolutions were characterized by technological advancements but not at the rate of current times. ... The new revolution encompasses new ideas, new possibilities, new creations, and new inventions. This new revolution is about breaking frontiers. … [it is] characterized by a much more ubiquitous and mobile internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence [AI] and machine learning … includes gene sequencing, nanotechnology, renewables, and quantum computing. … It is the fusion of these technologies and their interaction across the physical, digital, and biological domains that make the 4IR fundamentally different from the previous revolutions." (Kayembe and Nel, 2019, pp.81-82)

In discussions of the prospects of Africa in relation to a 4IR, the Schwab messaging frame is often replicated, even as the messengers express concern about whether it might be relevant to the continent (on this see Moll, 2000):

- "The 4IR – characterized by the fusion of the digital, biological, and physical worlds, as well as the growing utilization of new technologies such as artificial intelligence, cloud computing, robotics, 3D printing, the Internet of Things, and advanced wireless technologies, among others – has ushered in a new era of economic disruption with uncertain socio-economic consequences for Africa. … However, Africa has been left behind during the past industrial revolutions. Will this time be different?" (Ndung'u and Signé, 2020)

- "The unprecedented convergence of cyber, physical and biological technologies … 4IR technologies such as IoT and AI enable … [enable] customised products and services. Firms that would emerge as leaders are those that reconfigure their production processes through cyber-physical technologies … and a workforce skilled in 4IR technologies. Africa has the youngest population with a potential to spur an accelerated economic growth … [It is] a potential economic powerhouse, [in which] the 4IR promises socio-economic development through better access to technologies and increased productivity. …. The first industrial revolution mechanised labour through … steam power, bringing about massive improvements to manufacturing facilities; the second industrial revolution significantly increased capacity of manufacturing facilities through the discovery of electrical power … the third industrial revolution developed computers and other electronic devices that enabled automation of factory repetitive tasks, thus improving efficiency and the speed of production During these three industrial revolutions, Africa was largely a supplier of low cost labour in extraction of its minerals and precious metals … and inversely an importer of expensive manufactured goods… However, the promises of the 4IR for Africa are often told alongside concerns that the 4IR might render the continent's workforce obsolete and reinforce already existing inequalities." (Mamphiswana and Bekele, 2020, pp.3-4, omnibus quotation).

In the terrain of commerce and industry, it is obvious that this 4IR messaging will be found throughout the corpus of public statements, and advertisements produced by this sector:

- "The 'fourth industrial revolution' captures the idea of the confluence of new technologies and their cumulative impact on our world. Artificial intelligence can produce a medical diagnosis … Robots can manufacture cars faster and with more precision … 3D printing will change manufacturing … in almost inconceivable ways. Autonomous vehicles will change traffic flows … The first industrial revolution spanned 1760 to 1840, epitomized by the steam engine. The second started in the late

19th century and made mass production possible. The third began in the 1960s with mainframe computing and semi-conductors. The argument for a new category – a fourth industrial revolution – is compelling. New technologies are developing with exponential velocity, breadth and depth." (Harvey, 2017)

- "The Fourth Industrial Revolution is the fourth iteration of the famous Industrial Revolution. It is a massive overhaul of production and industry standards using breakthrough technology; vogue new features and products like 3D printing, robotics, nanotechnology, data mining and bio-tech… So far, there have been three easily quantifiable and studied Industrial Revolutions, all taking place in the span of 200 years. The First Industrial Revolution … was a period where the iron and textile industries were empowered by the power of the steam engine. … agrarian and rural societies were forced into a more industrial mindset ... Just before World War I, the Second Industrial Revolution came into full swing. … Thanks to the birth electricity, mass production and its subsequent implementation was born. Also referred to as the Digital Revolution, … [3IR] was the moment when analog electronics and mechanical devices were made outdated by digital technology. … We reach the hear [sic] and now [4IR]. The new technologies that are being created and sparked by the digital age have the capacity to enhance every facet of life, not just the workforce. ... Everything is being melded together through digital connection. The Internet of Things let appliances and cars and security systems talk to each other. Virtual reality systems allow humans to enter into artificially created worlds. Machinery in manufacturing plants is controlled by artificial intelligence and automated bots." (Senat.me, 2018).

- "The industry 4.0 also referred to as the Fourth Industrial Revolution is characterised by a 'fusion of technologies that is blurring the lines between the physical, digital, and biological spheres'. Industry 4.0 is not a prolongation of the third industrial revolution, but it is a new revolution different from the third. The 4IR is unique due to the scope, velocity and systems impact of the breakthroughs which do not have any historical precedence. The industry 4.0 is coming in with huge disruptions in every sector of the economy, however, the ability to connect billions of people buy mobile devices with unprecedented power, storage capacity and access knowledge make the revolution more unique … [it] is characterised by emerging technology breakthrough in artificial intelligence, robotics, the internet of things, internet services autonomous vehicles, 3-D printing, nanotechnology, materials science, energy storage and quantum computing. … the early 1950s marked the foundation of the third industrial revolution, which was influenced by the advances in technology through the first and second industrial revolutions." (Mhlanga, 2020, pp.14-15)

- Figure 4 is a graphic representation of how the Schwab messaging frame is translated graphically into an advertisement for a 'business solutions' company.

Figure 4 *Schwab's metaphorical frame in graphic form* (Aguru BS, 2021, my emphasis)

- The 4IR is the "fusion of advances in artificial intelligence, robotics, the Internet of Things, 3D printing, genetic engineering, quantum computing, and other technologies... this perfect storm of technologies … is paving the way for transformative changes in the way we live and radically disrupting almost every business sector. It's all happening at an unprecedented, whirlwind pace. While it is set to change society like never before, it builds on foundations laid by the first three industrial revolutions". (McGinnis, 2018)

Shifting our attention now to the terrain of education, it seems equally obvious that we will frequently find the Schwab messaging mythology there. Indeed, we are told things like the following, amongst many, many equivalent examples:

- "The 4th Industrial Revolution will dramatically change the way we relate to one another, live, work, and educate our children. These shifts are enabled by smart technologies, including artificial intelligence, big data, augmented reality, blockchain, the Internet of Things, and automation. These technologies are disrupting every industry across the world at unprecedented speed. For our children to be prepared to engage in a world alongside smart machines, they will need to be educated differently than in the past." (Marr, 2019)

- "The fourth industrial revolution builds on the third revolution but combines multiple technologies from the digital, physical and biological worlds. The two were preceded by the 1st industrial revolution which saw the invention of the steam engine and second revolution which saw the invention of the internal combustion engine. … operating in the current industrial revolution requires higher education levels and cognitive skills. If the 4IR is really to deliver … South Africa has to rapidly and immediately change its education focus and delivery model to be responsive." (Khathu, 2019)

To round off this section, here is a series of quotations that not only replicate the 2016 Davos formula faithfully, but borrow exactly the same language from each other to do so, over and over again. A university plagiarism committee would have a field day here, but this does not seem to bother these 4IR advocates:

- "The first industrial revolution … witnessed the emergence of mechanization, a process that replaced agriculture with industry as the foundations of the economic structure of society. … The *genesis of the fourth and current industrial revolution is situated at the dawn of the third millennium with the emergence of the Internet. This is the first industrial revolution rooted in a new technological phenomenon – digitalization – rather than in the emergence of a new type of energy. This digitalization enables us to build a new virtual world from which we can steer the physical world.* The industries of today and tomorrow aim to connect all productive means to enable their interaction in real time. Factories 4.0 make communication among the different players and connected objects in a production line possible thanks to technology such as AI, Cloud, Big Data Analytics, and the Industrial Internet of Things." (Morris, 2018, my emphasis)

- "Industry 4.0 – 1999. *Here we are ... The fourth revolution unfolding before our eyes. Its genesis is to be located at the dawn of the third millennium with the appearance of the Internet.* It would also be the first industrial revolution *not to take root in the emergence of a new energy but in the potential of a new technological phenomenon: the digitization. A digitization that allowed the construction of a new world, virtual, from which it is possible to control the physical world.* The industry of today and especially of tomorrow tend to connect together all the means of production and to allow their interaction in real time. The 4.0 industry makes communication between all the different actors and connected objects possible within a production line thanks to the technologies of Cloud, Big Data Analytics, Internet Industrial Objects … Applications for the industrial sector are already numerous". (Zarka, 2019, my emphases)

- "Nearly a century later at the end of the 19th century, new technological advancements initiated the emergence of a new source of energy: electricity, gas and oil. ... Nearly a century later, in the second half of the 20th century, a third industrial revolution appeared with the emergence of a new type of energy whose potential surpassed its predecessors: nuclear energy. *Here we are. The fourth revolution is unfolding before our eyes. Its genesis is situated at the dawn of the third millennium with the emergence of the Internet. This is the first industrial revolution rooted in a new technological phenomenon—digitalization—rather than in the emergence of a new type of energy. This digitalization enables us to build a new virtual world from which we can steer the physical world.*" (Parametric Design, n.d., my emphasis).[40]

- "The First industrial revolution was about the mechanization of production using water and steam. The second used electric energy to create mass production, The Third used electronics and information technology to automate production. Now a Fourth Industrial Revolution is building on the Third, the digital revolution … *this is the first industrial revolution rooted in a new technological phenomenon – digitalization – rather than in the emergence of a new type of energy*. These innovations and improvements are gradually optimizing production tools and creating possibilities for the … The industry of today and tomorrow aim to connect all production means and processes to enable their interaction in real time. Factories 4.0 make communication among the different players and connected objects in a production line possible thanks to technology such as Cloud, Big Data Analytics and the Industrial Internet of Things." (Chowdhury, 2019, my emphasis)

- "*Here we are … the fourth revolution is unfolding before our eyes. Its genesis is situated at the dawn of the third millennium with the emergence of the Internet. This is the first industrial revolution rooted in a new technological phenomenon – digitalization – rather than in the emergence of a new type of energy. This digitalization enables us to build a new virtual world from which we can steer the physical world.* At Fortress HSE Pro, we understand the demands and frustrations it takes to effectively manage auditing, contractors, and remote location management; we get it!" (Fortress HSE Pro, 2020, my emphasis).[41]

- "[W}e accelerated the pace of our evolutionary journey, going through four industrial revolutions that deeply transformed the way we live and operate in all fields. And *here we are … in the middle of the fourth revolution which genesis is situated at the dawn of the third millennium with the emergence of the Internet. This is the first industrial revolution rooted in a new technological phenomenon – digitalization – rather than in the emergence of a new type of energy. This digitalization enables us to build a new virtual world from which we can steer the physical world* thanks to technology such as Cloud, Big Data Analytics, the Internet of Things … and, yes … Artificial Intelligence, … a technology that strives to mimic human intelligence. … [However] let's stay pragmatic and try to learn more about what is going on, what Pragmatic AI can actually do for us today, what are the basic algorithms that allow machines to learn, where we stand with BMI [brain-machine interface] technologies and much more …" (Vaccaro, 2018, my emphasis).

- "*Here we are… Living in the core of the Fourth Industrial Revolution*, witnessing the very best and worst of it. Industry 4.0 at its finest, *unfolding before our eyes. This is the only Revolution deeply rooted in a new technological phenomenon – digitalization*. Moreover, this Revolution will change industries, individuals, and institutions rapidly. With new technologies and the use of machines, new forms are made, including: 3-D printing, genome editing, artificial intelligence, Robotics, and augmented reality. … The Fourth Industrial Revolution is the time that we are living right now. Every trend, every tech-development, and everything around you is the Fourth Industrial Revolution. This Revolution is different from others. How? With this Revolution, everything is about development – personal and technological. … The best way to understand what the Fourth Industrial Revolution really is and what are its benefits, you need to understand better its part. Moreover, you have to understand technology. Like any previous revolution, the Fourth one is set on specific pillars that enable the human potential, and overall global development. These pillars are: Artificial intelligence (AI), Blockchain, Virtual reality (VR), Robotics, 3D printing, The Internet of Things (IoT). With the Fourth Industrial Revolution standing for opportunities and challenges, it is essential to use needs and every need of all stakeholders are met." (Belyh, 2020, my emphasis)

- "It witnessed the emergence of mechanization, a process that replaced agriculture with industry as the foundations of the economic structure of society. … at the end of the 19th century, new technological advancements initiated the emergence of a new source of energy: electricity, gas and oil. … the steel industry began to develop and grow alongside the exponential demands for steel. Nearly a century later …. a third industrial revolution appeared … [that] witnessed the rise of electronics—with the transistor and microprocessor—but also the rise of telecommunications and computers. *[Now] Here we are…the fourth revolution is unfolding before our eyes. Its genesis is situated at the dawn of the third millennium with the emergence of the Internet. This is the first industrial revolution rooted in a new technological phenomenon – digitalization – rather than in the emergence of a new type of energy. This digitalization enables us to build a new virtual world from which we can steer the physical world.*" (Nembai, 2020, my emphasis)

The examples above are but some among hundreds, even thousands, of similar relays in the ideological messaging chain of a 4IR that go on and on. There is deep irony here: Schwab wants us to believe that the technologies of the 4IR permeate and disrupt every sector of our society and every aspect of our daily lives. This is not the case. However, the technologies of the 3IR that spread *the idea* of a 4IR mechanically (or electromechanically if you prefer) as hegemonic ideology do indeed permeate and disrupt everything (Moll, 2022a).

Conclusion

The argument in this paper is that there is no substantive evidence to support the idea that we are currently living in a 4IR. There is no fundamental transformation of the world in any of the technological, socioeconomic, social, cultural or geopolitical strata that make it up, as there demonstrably have been in the three industrial revolutions to date. Instead, we need to understand the current context as one of the acceleration of the changes of the 3IR, rather than a new industrial revolution.

So, given that there is no 'Fourth Industrial Revolution', why do so many people seem to believe that there is one? Why do the prominent ideologues of a 4IR, like Klaus Schwab and Tshilidzi Marwala, declare so boldly that there is such a revolution? The only possible answer is to be found in a consideration of ideology:

> *Globalization contains important ideological aspects in the form of politically charged narratives that put before the public a particular agenda of topics for discussion, questions to ask, and claims to make. … The social forces behind these competing accounts of globalization seek to endow this concept with norms, values, and meanings that not only legitimate and advance specific power interests but also shape the personal and collective identities of billions of people.* (Steger, 2009, p.vii).

It is not within the scope of this occasional paper to carry out a detailed analysis of the ideology of a 4IR, how it has emerged, the social interests that it represents, and how it functions across the different sectors and domains of our society. I have started to do this elsewhere, in relation to schooling and political economy (Moll, 2021b; 2022a). 4IR ideology clearly operates in the terrains of academic knowledge production, education, commerce and industry, politics and government, and the media and popular culture. It is also quite evident in the global exercise of economic and political power, and in the patterns of inclusion and exclusion that characterize the world today.

Suffice to say here that this situation seems to have arisen because, from the contradictory perspectives of diverse agents and interest groups across society, the digitalized, information-driven, international order is in trouble. As Johan Muller recently cautioned, current world events "have not been kind to globalization" [and, by implication, to the 3IR]:

> *[By 2016] the optimistic message that globalization could be a powerful positive force if it was managed correctly… had been mauled in dramatic fashion, though some would say its dark side could have been predicted if not averted had we paid more careful attention. What is unequivocally clear is that a wave of anti-technological modernization and anti-globalization is sweeping through the traditional West, and a virulent populism is everywhere on the rise.* (Muller, 2017, p.17)

Given that there is no 'Fourth Industrial Revolution', why do so many people seem to believe that there is one?

Castells' notion that the network society could develop into "a virtuous circle of development" faces increasing evidence to the contrary. Countries on the periphery of the international economic consensus face "a downward spiral of underdevelopment" (1999, p.4), and those at its centre (the 'global industrial nexus' dating back to the 2IR) face challenges to that central location from within, in the form of local, anti-global, populist political agendas. In this situation, it is obvious that those who seek to mobilize political, social and economic forces to try to regain the virtuous circle (contested as it is) of the digitalized socioeconomic order, are much better served by a clarion call that there is a bold, new industrial revolution. A whimpered appeal that we revive and repair the actual one that we live within will not do. This is where the myth of a "fourth industrial revolution" arises. It is an ideological strategy driven by the World Economic Forum (Schwab, 2016) and by governments which have shaped economic interventions using language that invokes a 4IR.

None of this is to suggest that a fourth industrial revolution will not emerge at some time in the future. This seems likely, although we do not want to get into a naïve teleology that suggests that this will necessarily be case, or that we understand its content in advance. Nor do not want to succumb, when we start to question Schwab's vison of a brave new world, to the tendency to talk about essentially the same 4IR in the future rather than the present tense. Equally, we do not want to cling to the idea of a 4IR by dressing it up with a claim that we are in a second, or later, or culminating stage/phase/period/wave (delete whichever is not applicable) of the 3IR. I suggest that the situation is more complex than this.

The myth arises as an ideological strategy driven by the WEF and by governments which have shaped economic interventions using language that invokes a 4IR.

Castells' "double-edged sword" comes into the picture once again. There are positive and negative potentials in the current social conjuncture, regarding a future industrial revolution. To focus on the negative first: such a revolution could have the consequence of further deepening global inequalities, the marginalization of the regions and peoples of the South by the North, and wealth gaps within and between nations. How such a process would relate to technological innovation is not clear. Earlier, we saw Hobsbawm drawing our attention to the manner in which the countries of the global industrial nexus became inward-looking, more isolationist, more 'self-sufficient' and economically conservative, in the years after World War II. This in relation to "a world economy that was visibly in crisis, and internal tendencies to consolidate socially and politically, rather than change" (Hobsbawm, 1995, pp.89). It seems that something very similar may be happening in the context of the Covid-19 pandemic. Even before 2020, economic and political isolationism was increasing, as seen for example in support for Trump and Brexit, already discussed (Fraser, 2016), and rising xenophobia in countries like South Africa (Muluadzi et al, 2021). These tendencies seem now to be deepening (James and Hardy, 2021; Hardy et al, 2021; Waldman, 2021). I have already drawn attention to the 'multinationals' of the North that are starting to *onshore* operations back to their domestic countries, a phenomenon that has deepened under global Covid-19 lockdown restrictions (Kajjumba et al, 2020; Swango, B, 2020). This negative edge of the sword seems to be the way we will go if we stay on course with the 4IR notion driven by Schwab and the WEF. It is, after all, an intensification of the patterns of the 3IR.

On the other hand, we come to the rather interesting mixed metaphor of the virtuous circle of the positive edge of Castells' sword. The twenty-first century has seen growing debate about another kind of possible new industrial revolution, in which a transformation in the way we live and work can be to the overall benefit of the human species, and (in terms that have been emphasized in the current argument) to Africa (Morgan, 2018; Moll, 2020). Technology will no doubt continue to be related to the changing nature of work, and lead to new varieties of work. However, such a revolution must necessarily take place as broader social, cultural and geopolitical transformations that can dismantle the prevailing inequality of the global social order. Of course it will be rooted in the technological breakthroughs associated with the digitally networked society, but not driven by them. I am aware of two prominent strands that emerge from this debate, both of which arise from an extensive 'end-of-work' literature that envisages a coming industrial revolution producing fundamental, egalitarian, socioeconomic transformation:

- First, there is the theorization of a laterally scaled, decentralized, environment-friendly social dispensation, reliant at the technological level on the convergence of green energies and the IoT (see inter alia Rifkin, 2011; Strietska-Ilina et al, 2011; Pollin, 2018).
- Second, there is a growing social movement that envisages a more egalitarian organization of work and leisure, based on a guaranteed minimum wage for all (a basic income grant) (see inter alia Gorz, 1999; Beck, 2000; Standing, 2017; Morgan, 2019). Digital technologies make such a dispensation possible.

One problem with these 'visions' of a 4IR, however, is that they both seem to arise in the well-resourced economies of the North (although there is vigorous debate about a basic income grant in South Africa presently). Be that as it may, these revolutions are not inevitable, nor are these the only way to think about what might emerge from the present.

As Aslam Fataar (2019) points out, in a situation in which the WEF plays a key role in framing the ideology of the 4IR as primarily about digital skills related to "the world of work, work disruption and job losses", it requires activism "in the belly of the beast" if a more transformative agenda is to come about. In the guts of that belly, so to speak, we find Schwab's myth of the 4IR.

Notes

1. Early on, I was smacked hard by academic reviewers from a couple of Information Systems journals, alleging that this is "not scholarly language" that it is "polemical, not academic", or that "this is journalistic writing, not what we expect from a serious contributor to this journal". I resisted the temptation to respond to their editors by pointing out that Google Scholar lists over 900 scholarly papers that employ the phrase "all the rage these days", and over 30,000 that use "all the rage" in their arguments. I am grateful that the editors of Theoria were not constrained by this old, Anglo-Saxon notion of what counts as an academic register, when they published a shorter version of the current paper (Moll, 2021a). However, it soon became clear that these adverse comments, when read alongside all the others from the reviewers, were part of a deeper gatekeeping function. It is fascinating to realise how often rejections of manuscripts by particular journals – even those that appear to welcome critical debate – are motivated by defense of the boundaries and interests of an academic field or discipline (Becher and Trowler, 2001, pp.84-89; Abbott, 2001). In this case, the identity of journals in the field of information systems seems to have become so closely bound up with a belief in the 4IR, that an argument such as the one in this paper cannot be contemplated.

2. Iyinoluwa Aboyeji: "This for the first time, and that's the magic of the 4IR, is the only time where the critical factor of production is labour … talent that is able to absorb these concepts, and leverage them to create change in the society … to level society and to leverage the start-up innovation capacity to be able to skill very quickly innovations that give everyday access to a life that is both going to guarantee them purpose and prosperity" (WEF, 2019, 06'30"- 08'05'). Forgive me, I thought Adam Smith and Karl Marx showed us that the first time labour was a critical factor in production was at least in the sixteenth century. But this is what is said about the 4IR in the polemics that surround it.

3. In *Madame Secretary*, Season 6 episode 3, entitled "Killer Robots", the following exchanges occur:

   SECRETARY FOR DEFENCE: Fully autonomous unmanned ground vehicles.

   Mme PRESIDENT: You mean killer robots.

   SECRETARY FOR DEFENCE: Not the preferred nomenclature, but yes. … AI can operate at a scale and speed far beyond even the most capable trained human soldier. It's a quantum leap forward.

   ETHICS ADVISOR: That's the problem, isn't it? …

   SECRETARY FOR DEFENCE: This technology is inevitable. … To make sure that we develop ethical versions before the unethical versions come out.

   ETHICS ADVISOR: Ethical killer robots, really? …

   Mme PRESIDENT: Artificial intelligence holds great promise for humanity in medicine, transportation and a host of worthy endeavours. …Technology is not the enemy unless we allow it to substitute its judgment for our own.

4. Schwab dismissed a number of global experts on these matters: "I am well aware that some academics and professionals consider the developments that I am looking at as simply a part of the third industrial revolution" (2016, p.8). Alongside Rifkin, the massive contribution of Manual Castells is virtually (if that is the right word) ignored by Schwab. Following the publication of his famous trilogy on the networked, digital society (Castells, 1996, 1997, 1998), the Spanish sociologist is acknowledged in the academic world as the primary theorist of the globalized, network society (White, 2016). It is obvious that Schwab has been heavily influenced by Castells. In the 2016 text, most of his substantive claims about the global information economy are neatly repackaged, albeit sanitized, versions of the latter's arguments. Yet there is only one citation of Castells, in a throw-away comment on p.86 about how overwhelming the 4IR can be. The problem for Schwab is that Castells does not deal in the currency of 'industrial revolutions', nor does he date the fundamental digital transformation of society in the contemporary era, nor does he lend support to the 'unprecedented' speed-scope-system change hypothesis. In more practical, political terms, Castells does not help Schwab very much with his ideological project, which is to declare a bold, new industrial revolution in the 2010s and 2020s, rather than to concede that globalization and the information society is in trouble.

5. The periodization of a social transformation like an industrial revolution is a debatable historical judgment in itself. Toynbee (1884) first dated the 1IR as 1760-1840. The dates used throughout this paper are rough averages from across all sources consulted.

6. Allen (2019) defines these population categories as follows: "bourgeoisie" – factory owners, state officials, lawyers, merchants, ship owners, etc.; "lower middle class" – shopkeepers, tradesmen, school teachers, clerks, publicans, tailors, engineers etc.; "manufacturing

workforce" – builders, traders, miners, labourers, servants, soldiers, sailors, etc. These are just some of the population categories Allen employs.

7. A number of authors make frequent reference to the enormous wealth accumulated by owners of factories, banks and ships, so one can reasonably assume substantial wealth differentials within this category. Allen mentions one Massie, who at the time produced "a breakdown by income of manufacturers, so those who were large-scale employers could be separated from the handicraft workers" (2019, p.96), but he does not seem to specify those differentials anywhere.

8. Classical Darwinian theory posited that evolution proceeded evenly and gradually. However, gaps in the fossil record present anomalies that challenged this view. Steven Jay Gould and Niles Eldredge put forward the idea of "punctuated equilibrium" to defend evolutionary theory against this challenge, proposing that evolution consists of long periods of stasis, in which there are few extinctions or emergences of new species, punctuated by periods of intense evolutionary change (Eldredge and Gould, 1972; Gould and Eldredge, 1977).

9. I am not sure Feyerabend would agree. But then, as a radical sceptic, should he be invoking a *principle* at all?

10. Alternatively translated as Kondratiev in English, French, etc.

11. This raises the question as to whether Perez's retrospective mapping of capitalist waves can be used (as it has been by others) to warrant Schwab's current or immanent 4IR. However, this is not an issue that I take up here.

12. Why Schumpeter worked with these three in particular does not seem clear. Wallerstein (1984) comments: "a whole panoply of presumed cycles, of varying presumed lengths, has been elaborated: the Kitchin (2-3 years), the Juglar (6-10 years), the Kuznets (15-20 years), the Kondratieff (45-60 years), and the 'logistic' or 'trend séculaire' (150-300 years)" (1984, pp.559-560). One might add to these more recent accounts of such waves: Rostow (1978; Rostow & Kennedy, 1979); Mandel (1995); Maddison (1991). The latter describes these as: I: 1870-1913 – 'Liberal Phase'; II: 1913-1950 – 'Beggar-Your-Neighbour Phase'; III: 1950-1973 – 'Golden Age'; IV: 1973 onwards – 'Phase of Cautious Objectives'- almost thumbing his nose at the other theorists. Is this a case of too many theories leading to too little understanding?

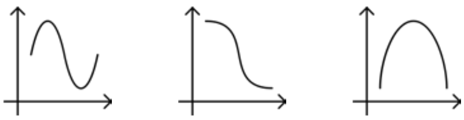
13. Schumpeter (1939, p.52) mentions Africa only once, in a reference to the trading activities of the British South Africa Company, Cecil John Rhodes and the Boer War.

14. It is deeply ironic that Sutherland should source his claim, that the "role of Africa" *was confined to providing agricultural products and raw materials*, in Samir Amin's article, "Underdevelopment and dependence in black Africa" (1972). Amin's conclusion in that article is that, after colonization, there are "no traditional societies in modern Africa, there are only dependent peripheral societies". He commences his argument with a distinction between the view of colonialists from outside Africa, from "London, Paris or Lisbon", that the continent appeared to be homogeneous with regard to the extraction of raw commodities, and "the opposite point of view, from inside … [that] Black Africa, like Latin America, appears extremely variegated" (1972, p.177). So, he suggests that, from the perspective of the colonizer ("the receiving society"), this transfer of commodities served as the principal basis of the wealth and power of the ruling class. However, for colonized people, the experience of the industrial revolutions could "not be reduced to a mode of production", but was variously about the consolidation of slavery, legalized colonization, feudal economies, resistance by village communities to the extraction of surplus, the taxation of peasants and commercialization of the tribute to traditional leaders, shifting political alliances based on support by colonizers to social strata who appropriated tribal lands, internal migrations from impoverished regions, and above all else, the rupturing of traditional cultures (1972, p.193). Sutherland's notion that 'Africa's role' was to *provide commodities* seems to be, as Amin (1989, p.78; see also Satya, 2005) would make clear, a good example of a Eurocentric account of the 1IR and 2IR.

15. One does not want to insist here that this conception should be based on any specific theory of class, such as that associated with Weber, Marx or Bourdieu. Weber conceives of class as related to economic position in society (a notion deployed, for example, by Allen in relation to Figure 1). Marx considers class to be determined by relationship to the means of production, hence the antagonism between lords/chiefs and peasants under feudalism, and the bourgeoisie (ruling class) and proletariat (working class) under capitalism. Bourdieu (1984) puts forward a more distributed conception of class, as agglomerations of personal, economic and cultural capital that are expressed in symbolic boundaries between different status (lifestyle)

groupings in society. My view is that a Marxist theory of class is the most plausible in relation to the economic stratum of society, and that other conceptions of class need to be deployed in relation to other social strata. Obviously, these need to be theorized as being related to each other.

16. One scathing response (I hesitate to call it a criticism, because it is so shallow) to an early version of this paper said of this bulleted representation of the criteria to determine whether any epoch can be classified as an industrial revolution, “this is not a model, but a list”. The implication is that these are five random bullet points, not held together in any principled theoretical way. To be honest, I am not really sure what to make of this criticism, because the model has been built up carefully in the preceding historical analysis of the 1IR. The five points represent the complexity, interconnectedness and depth of each of the strata of an industrial revolution that has been established analytically. It is almost as if the critic has not bothered to read the historical narrative, and would like to be presented instead with an iconic or ‘picture-theory model’ that will directly represent that aspect of the world that it describes (along the lines of the ‘picture-theory of language’ exposed by Wittgenstein). It is immediately clear that the criticism comes from someone who does not understand the ontology of models (see Frigg and Hartmann, 2006). From other comments made, it is clear that she/he is an economist. Economists like descriptive or iconic models, which usually look something like these examples:



Is this critic seriously suggesting that a rigorous account of the 1IR would be better achieved by such a descriptive economic model than by a thick historical narrative of the kind that Hobsbawm offers in his writings? My view is that it would not, and that the five bullet points constitute a much better analytic model of criteria for an industrial revolution. One wonders what this critic would make of (i) Piaget’s (1995) modelling of epigenesis, which is achieved entirely by careful discussion of the relationship between causal events, stages, emergence and complexity, and has no picture-theory of any kind to offer; (ii) the kinetic theory of gases, which is a semantic model that often uses a billiard ball analogy to represent the movement of particles – it doesn’t seriously suggest that gases have balls; (iii) the Newtonian model of a mass on a spring that consists of an ordinary differential equation to represent periodic motion; and (iv) Crick and Watson’s DNA double-helix, which models a theory rather than very tiny bits of a body?

17. All historians seem to regard 1914 as the definitive cut-off point of the 2IR. This is strange, in the sense that the devastation of World War I was in large part produced by the technologies of the time – steel, chemicals, armaments etc.

18. As is well-known, the ‘problem’ of how to make cheap steel was solved by Henry Bessemer in 1856.

19. Hesitantly, I use the names of these colonies at the time, precisely to emphasize that state of colonial domination in the 21R. These nations are today, respectively, the Congo Republic, Malaysia, Zambia and the Democratic Republic of the Congo.

20. One million kilogrammes. The weight of four Boeing 747 jumbo jets.

21. HTML: HyperText Markup Language. The formatting language used on the WWW.
URL or URI: Uniform Resource Identifier/Locator. A unique ‘address’ that identifies each resource on the WWW.
HTTP: Hypertext Transfer Protocol. An ‘application’ procedure consisting of rules for the retrieval of linked resources across the WWW.

22. My thanks to Barry Dwolatsky for helping me understand the details of this complex set of events. Any historical error or technological misunderstanding is, obviously, still my own.

23. It seems that the reason for the increase in mentions of *blockchain* may be growing interest in the online trading of Bitcoin and other cryptocurrencies. I find it odd that it is so ‘popular’ (Moll, 2022b). It is not as clear to me why *‘cyber-physical systems’* has increased in frequency of mentions, although the term does seem to be being used more prominently by academics, at least at my university. It is also frequently used to describe *cybersecurity*, for example by ‘tech gurus’ in popular television programmes, but Lee (2015, p.4838) warns us that this connection is tenuous.

24. ASIMO was allegedly named after the science fiction writer, Isaac Asimov. However, I choose not to believe this, because it would be an insult to Asimov – ASIMO is

nowhere near being the kind of robot that could obey "the three laws of robotics":

First law: A robot may not injure a human being or, through inaction, allow a human being to come to harm.

Second law: A robot must obey orders given it by human beings except where such orders would conflict with the First Law.

Third law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law. (Asimov, 1950; 1964).

25. Deeply ironic, given the destruction of letter writing culture by the 3IR/ 4IR.

26. I use the word beguiling in it strong sense, to mean attractive or enchanting, but not to be trusted because it deceives us and plays tricks with our understanding of what the actual state of affairs is.

27. The prefix 'cyber-', when Wiener (1961) coined it, did not mean 'ICT-related', as it does now. But this latter meaning is of course the way it is used in 'cyber-physical systems'.

28. In one sense, cloud computing is not a technology, but a computing model. In it, users connect into 'the cloud' to access digital infrastructures, operating systems or software apps, rather than relying on institutional outsourcing to achieve this. All computing requirements related to a data centre are available to IT end users via the Internet.

29. BBVA is the Banco Bilbao Vizcaya Argentaria, the second largest bank in Spain.

30. Of course, I mean traffic lights, in any country other than South Africa.

31. The fact that these authors and Schwab do not cite, support or argue with each other at all is strange. Diamandis and Kotler, for example, do argue with McKinsey (albeit just a little bit) when they suggest that the digital revolution has not produced job losses (2020, pp.227-228). Perhaps it is a case of the top prophets not wanting to cede any limelight to the other, where prophecy has become "competitive behaviour in an open market or free market"? (Ramantswana and Sebetseli, 2021, p.2).

32. The neuronal and synaptic structures and functioning of our brains are by no means "linear and local", even in the most linear of imaginations.

33. These three terms tend to be used interchangeably in the history of technology literature. "Technology convergence" was coined by Rosenberg (1963, p.423), "technology confluence" by Jantsch (1967, cited by Granstrand and Holgersson, 2014, p.119ff), and "technology fusion" by Kodama (1992).

34. This horse collar was probably invented in China centuries before, and somehow made its way to Europe (Satya, p.2051).

35. I use the concept of affordances here in its strict realist sense, as intended by the primary theorist of affordances, James Gibson:

> *There has been a great gulf in psychological thought between the perception of space and objects on the one hand and the perception of meaning on the other. … The meaning or value of a thing consists of what it affords. Note the implications of this proposed definition. What a thing affords a particular observer … points to the organism, the subject. The shape and size and composition and rigidity of a thing, however, point to its physical existence, the object. But these determine what it affords the observer. The affordance points both ways. What a thing is and what it means are not separate, the former being physical and the latter mental.* (Gibson 1982, 407-408).

36. For another cynical ideological distortion of the digital economy, see the spin that Diamandis and Kotler (2020) put on the history of urbanization. They know full well that in the 1IR people flocked to the new factory cities to escape poverty induced by the destruction of the feudal economy. One might say they were driven to the cities by the prevailing state of the capitalist economy at the time. Diamandis and Kotler know as well that this was the case when desperate people moved to cities during the great depression of the 1930s, and that it is the case now as people migrate to the urban *favelas*, slums and squatter camps within the global South, or northwards across Trumpian walls and the Mediterranean Sea. Yet the story they tell us is this one of urban good cheer: "Three hundred years ago, 2 percent of the world's population lived in cities. Two hundred years ago, it was 10 percent. But the *Industrial Revolution's steam-powered punch* forever altered those numbers. Between 1870 and 1920, 11 million Americans left the country for the city. In Europe, 25 million more crossed an ocean to settle, predominantly, in US cities. By 1900, 40 percent of the

United States had urbanized. By 1950, it was 50 percent. By the turn of the millennium, 80 percent. … The *rest of the world wasn't far behind*. Over the past fifty years, in low- to medium-income countries, urbanization has doubled, sometimes tripled—think Nigeria and Kenya. By 2007, the globe had crossed a radical threshold: Half of us now lived in cities. Along the way, we got *cities on steroids*. In 1950, only New York and Tokyo housed 10 million residents, which is the figure required for 'megacity' status. By 2000, there were over eighteen megacities. Today, it's thirty-three. Tomorrow?" (2020, p.243, my emphases)

37. I find Skilton and Hovsepian (2018, p.29) a bit baffling: while they are strong advocates of the 4IR (conceived as a technological revolution) in business practices, much of their book provides detailed, insightful accounts of the rootedness of most of the proclaimed 4IR technologies deep in the digital revolution of the previous century.

38. In South Africa in June 2020, a pair of men's Wrangler Texas Stretch Jeans sold for ZAR 680 (about US$ 40); a Calvin Klein Monogram T-Shirt sold for ZAR 320 (about US$ 20); a Guess Monique handbag sold for ZAR 1140 (about US$ 70). In the same period, Ethiopian garment and apparel workers earned on average less than US$ 30 monthly. This is the stark reality of offshoring to an African country in the contemporary world economic order. It must be said that if 4IR ideologues want to talk about this 'new industrial revolution' overcoming inequalities in Africa, then this is what they need to address explicitly (Moll, 2020).

39. There are a number of terms in the emerging literature that are, more or less, synonyms for 'onshoring'. These include 'inshoring', 'reshoring', 'backshoring', 'reverse-shoring', 'international reconcentration' and 'reverse-globalization'.

40. The Parametric Design website is odd, to say the least. This is a design company seeking to convince clients that it can offer novel, innovative, 'disruptive' expertise to solve engineering and business problems. Yet it plagiarizes every word of its 4IR pitch from other websites! Hardly novel or innovative, perhaps disruptive?

41. Fortress HSE Pro has the gall to copyright this content copied directly from others on the Internet: "© 2020 BY FORTRESS".

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