MACHINE INNOVATION – A FUTURE REALITY?

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ABSTRACT

As digitalisation and machine intelligence are rapidly emerging towards disruptive status, the question should be asked whether humans will or should remain in control of innovation? Often people think of artificial intelligence substituting humans, but huge value is going to come from the new goods, services and innovations artificial intelligence will enable. The 4th Industrial Revolution; the Internet of Things; smart everything, from wearables to cities; and artificial intelligence are future waves that will change forever the world as we know it today. We tend to think that future "smartness" is only possible through the creative abilities that humans have. But as machines are entering the workplace and our daily lives, not only as static robots on a manufacturing line, but as intelligent systems with the potential to replace lawyers and accountants, doctors and teachers, companions and partners, their role in innovation in complex environments need to be explored. Already, governments are considering introducing new systems for protecting intellectual property that is generated by a non-human entity. This means that the notion of innovation, which up to now has been an attribute of humans only, will have to be redefined to accommodate these new innovators of the cyber world. The evolution of innovation from a human-only initiative, to human-machine co-innovation, to autonomous machine innovation is explored in this paper. An analysis is done on the maturity of machine intelligence and human-machine relationships, to investigate the potential of machines becoming autonomous innovators. Innovation is dependent on the ability to recognise patterns, combine and integrate existing properties and knowledge to represent something that is perceived as new by the user, filling a gap in the market. This is exactly what machines are taught to do and teach themselves to do better in a conceptualisation era that follows the knowledge economy and takes us along into the algorithm economy. This paper presents a mind model to facilitate a better understanding of future innovation systems in the context of the complexity of the future digital world. It introduces a discussion, that should continue, on how individual innovation, enterprise innovation and community-based innovation may be supported by machine innovation and how national systems of innovation could well be replaced by a global machine innovation network in the future.

Key words: innovation, machine intelligence, artificial intelligence, future

INTRODUCTION

This is a conceptual paper, the intention of which is to act as a thought leader, presenting a mind model to aid our understanding of what will be. A literature scan on the issue of machine innovation yields information on innovation to develop intelligent machines, but virtually nothing about intelligent machines that do innovation. Yet, initial hints are there that machines that become increasingly intelligent, will be able to innovate. In approaching the 'research' question: "Will machines be able to innovate in future?", one can find enough evidence in the progress of artificial intelligence application trends, the technologies employed and the way people innovate to reach a conclusion. In theoretical physics, a process is often applied called a “Gedanken” experiment, a thought experiment made famous by Albert Einstein (Perkowitz, 2010). In such an experiment one imagines to be in a position where currently unmeasurable phenomena can be experienced. The research question on machine innovation can best be addressed by doing future thinking that is evidence based. In looking at the future, the author has developed a future thinking space and a future thinking lens (Botha, 2016a) that consist of a spinning triangle with the corners being emerging or disruptive technologies, human behaviour and events. A discussion about machine innovation needs to be based on existing human innovation processes and systems of innovation and how they are applied to support innovation. The question is then extended to whether human innovative capabilities can be transferred to machines and whether intelligent machines will be able to independently innovate or whether it will be a human-machine partnership where co-innovation takes place. This paper will first report on a literature survey on the status of intelligent machines in context of innovation. It will then apply the future thinking lens to intelligent machines and their potential ability to support different forms of innovation. This will be followed by a mind model on machine innovation. This model ties together different innovation regimes and apply them to human innovation, human-machine co-innovation and autonomous machine innovation.

BACKGROUND UNDERSTANDING

The state of artificial intelligence and intelligent machines

Artificial intelligence (AI) is not a new unique technology, but the combination of sensing, comprehending and acting in machines (Purdy and Daugherty, 2016). Its theoretic and technological basis has been developed over a long time. What is unique to AI is that all three its basic capabilities are underpinned by the ability to learn from experience and to adapt over time. The term “Artificial Intelligence” was established in 1956, but the roots go back to Alan Turing’s ground-breaking paper in 1950 in which he poses the question “Can machines think?” (Turing, 1950). Carbonella et al., (2016) write that the aim of AI is to imitate human behaviour and that it has been present in many ancient mythologies and most religions.

Worldview of intelligent machines

The interest of people to create devices that replicate human behaviour fits the metaphor that man is the new creator. Another metaphor that emerged since the 1950s with the advent of the electronic computer is that computational systems are brains. This has led to similar views that the brain is a computer. Mental processes are now equated to computer algorithms. This merging of metaphors has led to the development of science that emulate the human brain (neural networks) and understanding of the human brain to build better computers, e.g. the Human Brain Project (HBP, 2016), a European Commission Future and Emerging Technologies Flagship, aiming to put in place a cutting-edge, ICT-based scientific research infrastructure for brain research, cognitive neuroscience and brain-inspired computing.

Intelligent machines and humans

Fear has always existed in debates of technology vs. labour that humans will be replaced by machines in the workplace. This fear is now extended from blue collared workers that may lose their jobs to robots in factories to white collared workers that may be replaced by a higher from of creative power. The focus has shifted to automatability of tasks from mere automation where humans are replaced by machines. Thus, we should be speaking of human-machine partnerships in the workplace. The paradigms should shift from total task take-over as in automation to co-thinking, co-learning and co-working. In future, machines will increasingly work and behave like humans. This means that creativity, intuition, motivation and ethics may be common to both people and machines. Will machines have a conscience? Human-machine algorithms will be developed and human-machine relationships will be challenging human resource management experts. Autonomous machine decision making will have to be trusted by humans. Human rights and machine rights may co-develop and require creative thinking from legal professionals. When will machines become so human-like that they demand remuneration and time off? Relationships between humans and machines may call for a new industrial psychology (Botha, 2016b).

The learning machine

Nordström (2016) writes "an increasing number of artificial intelligence applications are being developed that make machines more sophisticated in how they learn and make decisions... By gathering and synthesizing vast volumes of data from multiple sources, these intelligent machines can automate complete processes or workflows, learning and adapting along the way. This rapid development of intelligent automation is bringing about a new era of productivity and innovation on an astounding scale, setting new standards for quality, efficiency, speed and functionality". He continues: "The future winners of the digitized economy will embrace intelligent robots as a springboard for new growth and innovation, rethinking what they do across every area of the enterprise".

Machine consciousness

Humans innovate with a consciousness of the impact of their innovations. Will intelligent machines ever have consciousness? The question relates to whether there is a relationship between intelligence and consciousness. Consciousness is the state or quality of awareness, intelligence is the ability to acquire and apply knowledge. To answer this question, one has to look at the dissociation of consciousness and attention in humans. Haladjian (2016) is of the opinion that one can program ethical behaviour based on rules and machine learning, but not reproduce emotions or empathy, but at the same time admits that this may be possible through simulations. There is a deep relation between emotion and cognition in human intelligence. Emotions in machines will thus not be able to be programmed through control systems, but will have to be acquired through learning and simulation. Haladjin argues that machines may develop access consciousness, but not phenomenal consciousness. Block (as quoted by Kriegel, 2006) makes a distinction by defining phenomenal consciousness as what it feels like to be conscious; whilst access consciousness deals with readiness (availability) to reason and control of action and speech. The current state of AI is that it will act on the basis of rationality, but not empathy. Is there a relationship between consciousness and conscience? Conscience generally deals with an inner feeling or awareness of rightness or wrongness of behaviour, based on morality or value systems. Consciousness relates to an awareness of the environment. Machines can be very aware of where they are and in what context. The open question is whether they can distinguish between right and wrong? Does this mean that intelligent machines may be corruptible?

The innovating machine

So often one reads about the "innovation machine", meaning how organisations have perfected innovation and drive their future competitiveness through innovative approaches and products. But will machines be able to innovate? As digitalisation and machine intelligence are rapidly emerging towards disruptive status, the question should be asked whether humans will or should remain in control of innovation? The 4th Industrial Revolution; the Internet of Things; smart everything, from wearables to cities; and artificial intelligence are future techno-economic waves that will change forever the way we work, play, live and transact. We tend to think that future "smartness" is hidden only in the creative and innovative abilities that humans have. Innovation is dependent on the ability to recognise patterns, combine and integrate existing properties and knowledge to represent something that is perceived as new by the user, seeing the gap in the market and intuition. This is exactly what AI and intelligent machines do. David Autor is quoted in (Purdy and Daugherty, 2016): "Often people only think of AI boosting growth by substituting humans, but actually huge value is going to come from the new goods, services and innovations AI will enable".

Inventing machines

Apart from innovating machines, where innovation is seen as something that may not be new, but a combination of existing things that add value to the owner or user, invention has to do with discovery. Will intelligent machines be able to invent? Inventing machines have been demonstrated (Hantos, 2016). Already, governments are considering introducing new systems for protecting intellectual property that is generated by a non-human entity. This means that the "definition of ingenuity and innovation, which up to now has been the provenance of mankind, would be reshaped to accommodate these new inventors of the cyber world". The question remains whether with the "open everything" movement and the increasing trend to open up research data for global use, patenting will still be the norm? Machine invention will be so fast that the patenting processes may fall behind (unless AI lawyers do that). The norm may become the same as what has been applied in the software industry for decades – do not patent, just be first to market. This may become an adopted principle in machine invention and turn the IP world on its head through radical disruption.

How we innovate

Types of innovation

Innovation has been classified in many ways (Lee and Trimi, 2016), such as *incremental* (step-wise), *radical* (abrupt), *ambidextrous* (coupled systematic problem solving and ideation), *disruptive* (game-changing) and *frugal* (removing non-essential features for developing environments). Other forms of innovation include:

Market innovation - improvement of the mix of target markets and the creation of new markets

Sustainable innovation - the creation of new market space, products and services or processes driven by social, environmental or sustainability issues, (Keeble, et al., 2005)

Technological innovation - new technologies are envisaged that will support innovative products and services

Social innovation - the value accrues primarily to society rather than individuals

Integration innovation - finding ways of integrating existing solutions in such a way that they address new challenges

The evolution of innovation includes phases of closed (or proprietary) innovation, collaborative innovation, open innovation and co-innovation. Most of these innovation types are aimed at value creation for individuals, organisations or societies.

A smart future

Innovation should, however, be extended to also assist in creating a smart future. Smartness includes intelligent environments, hence the role of intelligent machines. A smart future is more than preparing for the future by visualising it, it is setting up the future with the right technology choices, living conditions, connectivity and business endeavour. A smart future requires smart people; smart leadership; smart governments; smart infrastructure; smart industries; smart healthcare and education systems; smart transport and residences; matching human talent and jobs; creating business opportunity and work, utilising both the youth and elderly; sustainability and designing, beyond our current thinking horizons. This level of smartness reaches a complexity that can best be addressed by employing machine intelligence and with that machine innovation, taking the vast number of variables into account to create our tomorrows.

Human-machine co-innovation

Game changing innovation is emerging from online human collaboration and crowdsourcing (Nesim, 2016). With crowdsourcing and open innovation, the mere volume of ideas can grow so large, that they represent the complexity of social networks. Finding adoptable ideas from the proliferation of ideas from innovators and linking them to each other to form an innovation ecosystem can represent complexity large enough where human cognition fails and it will be necessary to employ artificial intelligence. Swarm optimisation has been applied to this level of innovation (Martinez-Torres and Olmedilla, 2016). Swarm optimisation was inspired by the social behaviour and movement patterns of bird flocking and fish schooling. It is based on the swarm intelligence concept, which refers to artificial intelligence systems where the collective behaviour of individual elements that are interacting locally with their environment create coherent holistic patterns.

This means that well connected communities and human relationships will remain at the roots of innovation, with the exception that intelligent machines will be added to the mix. Innovation in virtual space will be used to design new products and services. Communication is a primary engine for innovation. However, the larger the participant set, the more selectivity is required for new ideas that lead to new solutions and the more complex the interaction becomes. Thus the need for artificial intelligence. Machine cognition will assist human cognition. New ideas and new designs have to be compared with a vast range of existing ones and user requirements need to be dynamically addressed in product and service development. Innovation addresses the synchronisation of product offering and user preference. Given the dynamism of the user market and the fact that the user or customer becomes more selective, sophisticated and customisation oriented, machine intelligence could be a major aid to the innovation process, logging and matching the user requirements, the innovative ideas, the patterns they form and the cross-impact they have on each other (competitiveness) and the market (fulfilling and creating needs).

Machines learn. By doing co-innovation with humans, they will build an inherent capability to innovate on their own.

THOUGHT EXPERIMENT ON MACHINE INNOVATION

The Future Thinking Space (Botha, 2016a) is defined by a triangle where the corners represent emerging technology, behaviour and events (refer to Figure 1). By "spinning" the triangle to simulate inter-parameter interaction, a continuum is created that makes up the future thinking lens. As the emerging technology, behaviour and events are moved through space and time, they influence each other through cross-impacts that are dependent on the direction of spin. For example, a clockwise spin leads to technology influencing events, events influencing behaviour and behaviour influencing technology. An anti-clockwise spin results in technology influencing behaviour, behaviour influencing events and events influencing technology. Future strategic views now emerge in a clockwise spin of the lens or in an anti-clockwise spin, based on narratives for the particular future in consideration.

This future thinking lens is now applied to machine innovation. The technologies considered in artificial intelligence are: complex adaptive systems (intelligent machines interact with and autonomously adapt to their environment); predictive systems (intelligent machines use knowledge gained through experience and machine learning to anticipate effects of different factors); consciousness (intelligent machines can do rational simulation); understanding people (human-machine interfaces and interaction); machine vision (using sensing systems that conduct pattern recognition); self-programming (the ability to change operating algorithms based on learning and desired outcomes).

The human behaviour in the marketplace that will drive machine innovation are: product/service customisation expectations; need for rapid solutions; need for connected products/services; involvement in product/service specification; the need for simplified user interfaces for complex and knowledge-rich products/services; high usability features; and highly intelligent support.

Human behaviour among innovators include: the need for contribution to open innovation; competitive benefits from proprietary innovation; financial and social value creation; empowerment to create a smart future; making sense of complex environments and the desire to remain in control.

Major events that will drive machine innovation are: power balance shifts as a result of renewed nationalism and localisation and the end of globalisation leading to global vulnerability (geopolitical); global recession, currency value stability, failing economic alliances, wealth-poverty divide (economic); climate change and resulting food security, water scarcity, nutrition and health issues (natural); interconnectedness, harmony, cohesion and well-being (social) and migration and cultural shifts (demographic).

These emerging technologies, behaviour and events now yield specific innovation impacts when the lens is spun clockwise or anti-clockwise or when it is put in oscillation.

Spinning the future thinking space anti-clockwise

In this exercise the influences are considered when technology impacts on behaviour; behaviour impacts on events; and events impact on technology.

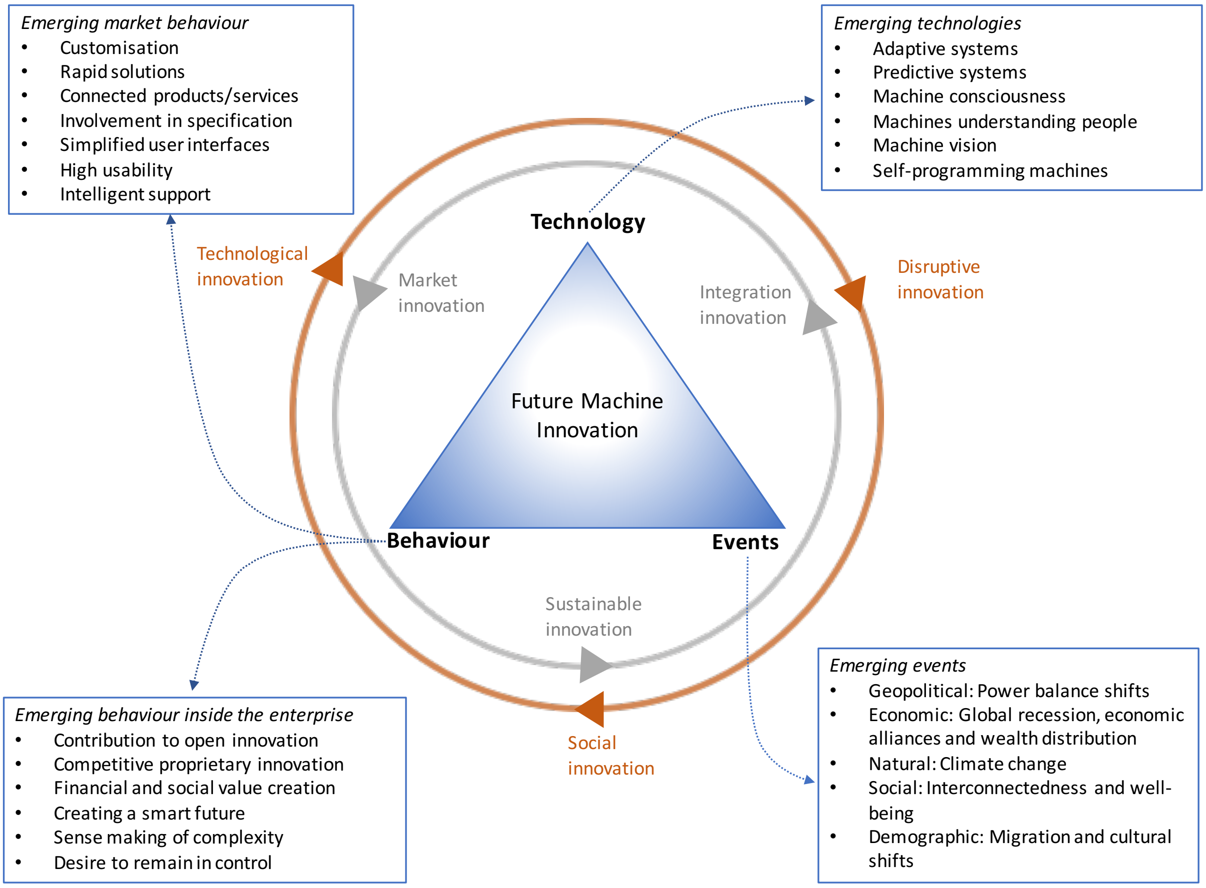

Figure 1: The future thinking lens for machine innovation

Market innovation

Market innovation will result from AI technology in machine innovation influencing human and market behaviour. The application of AI technologies will have a large impact on improvement of the mix of target markets and the creation of new markets. Intelligent machines that can suggest innovation improvements will enable products and services much better tailored for the market. These innovating machines will support market innovation through analysis and learning and modelling that will result in supporting human innovators. Innovating machines will operate either as assistants for human innovators, or independently. They may be customised for innovation from a support system point of view, or may be on the production line, in the environment that is being sensed, part of the control system, integral to life support and safety systems or mobile as part of transport and logistics environments.

Sustainable innovation

Human behaviour in markets or inside the organisation can influence events through sustainable innovation in the creation of new market space, products and services or processes that are driven by social, environmental or sustainability issues. The quest for creating new market space because of the user revolution dictating new demands can lead to economic renewal. Innovative processes on how political choices are made, economies are evolving, social benefit is derived and on the movement of people to find new opportunities are required for sustainability and peace. Intelligent machines will be ideal in supporting sustainable innovation, to take market dynamics into account, and to match the innovations with the complexity of geopolitical, economic, natural, social and demographic events that unfold. Sustainable innovation includes frugal innovation and intelligent machines could contribute to understanding essential products and services in a development context.

Integration innovation

When events determine technology, it usually results in integrating existing solutions in such a way that they address new challenges. Emerging events will require the application of existing AI technology to assist with innovative solutions. In addition, the emerging events may stimulate the development of new AI technologies. Warfare and power balance, as part of the geopolitical sphere, for example, has always driven advanced technology development. Peacekeeping, economic prediction and innovative ways of addressing poverty, climate change mitigation and adaptation, well-being of people and human migrations will eventually all have a major impact on what AI technologies are integrated for the complex solutions required.

Spinning the future thinking space clockwise

In this exercise the influences are considered when behaviour impacts on technology; technology impacts on events; and events impact on behaviour.

Technological innovation

Technological innovation takes place when behaviour in the marketplace or by human innovators demands new technology. The emerging market behaviour identified will lead to the need for new intelligent machines with the ability to support innovation or do it autonomously. Highly dynamic environments ask for more intelligent technologies in supporting machine innovation. Emerging AI technologies will be stimulated and new technology domains such as genetic engineering, neuro-engineering, the Internet of Things, virtual simulation and augmented reality will be integrated with AI to support better technological innovation processes.

Disruptive innovation

Disruptive innovation may take place when technology influences events. Disruption can be positive or negative. When intelligent machines have the ability to suggest or effect innovation that will solve the global challenges represented by geopolitical, economic, natural, social and demographic events, they can make a major positive contribution to the state of the world. These positive innovations will become possible because intelligent machines will deal with large complex datasets much faster; see emergent patterns easier than humans; apply their acquired consciousness to consider a multitude of cross impacts, good and bad; present objective support to humans through humanitarian conflict solution; and improve themselves through algorithm adjustment to be more effective. On the other hand, machines that are intelligent and autonomous may make the wrong decisions or get out of control when they reject the sense of consciousness and even a conscience they simulate themselves. Recently, well-known scientists and business leaders (Stephen Hawking, Elon Musk, Bill Gates, Steve Wozniak and others) have joined up and expressed their concern about the proliferation of AI, mainly in smart weapons systems (Sainato, 2015 and Gibbs, 2015). Such technologies could have a negative disruptive effect on the world and initiate new emerging events that may get out of control (nuclear war, biological warfare, climate disruption, human injustice, etc.). Evolution has given humans their strongest instinct, that of survival. Instinctively then, we will try to eliminate the threat that artificial super-intelligence may have on us. The down-side of this lies in the fact that many of the good impacts of super-intelligent machines aimed at our survival will be eliminated as well. It is a matter of choice and risk.

Social innovation

Social innovation takes place when events determine the behaviour of people. Social innovation primarily accrues value to the collective (society) rather than the individual (human or organisation). The emerging events identified will shape market behaviour and the way people innovate for new solutions and value. In the neo-liberal world order, openness has led to globalisation. Sharing of information, the right to be informed and participate, ownership of capital and the right to create an own future are accepted benefits of neo-liberalism. Global conflict and interference over these rights, however, remain to exist and ideological, religious and commercial drivers perpetuate the conflict and human suffering in some parts of the world. The use of human-machine co-innovation or autonomous innovation by machines could resolve many of the issues that humans have found so difficult to address over the past century and more. Machines are apolitical, unbiased, have no need for greed (yet) and could apply their advanced technologies and fast learning to impartially address so many of the social innovation needs that have emerged. It is often said that you cannot innovate *for* someone, but you can only innovate *with* someone. In social innovation, co-innovation between humans and machines may just be the right approach.

MIND MODEL ON MACHINE INNOVATION

It was argued that intelligent machines, utilising AI technology that is available or emerging today, can most definitely contribute to a broad base of innovation. This implies the existence of three innovation agents: humans innovating on their own; intelligent machines assisting humans to innovate (human-machine co-innovation); and intelligent machines innovating autonomously.

Innovation regimes for humans

Innovation regimes are defined as a combination of innovation modes (grassroots innovation; systematic innovation) and innovation domains (open innovation; closed or proprietary innovation).

Figure 2 shows the characteristics of the innovation regimes for humans.

Grassroots innovation refers to innovation by individuals that normally do not have any formal training in innovation. It is thus the natural capacity that human beings have to innovate. The term is often used in context with bottom-up solutions for developing communities, but does include any defined society, also focus groups in modern marketing. *Systematic innovation* refers to innovation processes that have been studied, documented and can be transferred and adopted. *Open innovation* involves the sharing of ideas at a precompetitive phase in a highly participative way and *closed innovation* is that innovation which is considered as leading to proprietary solutions. Moving from grassroots innovation to systematic innovation, knowledge is normally formalised, and captured in a retrievable form.

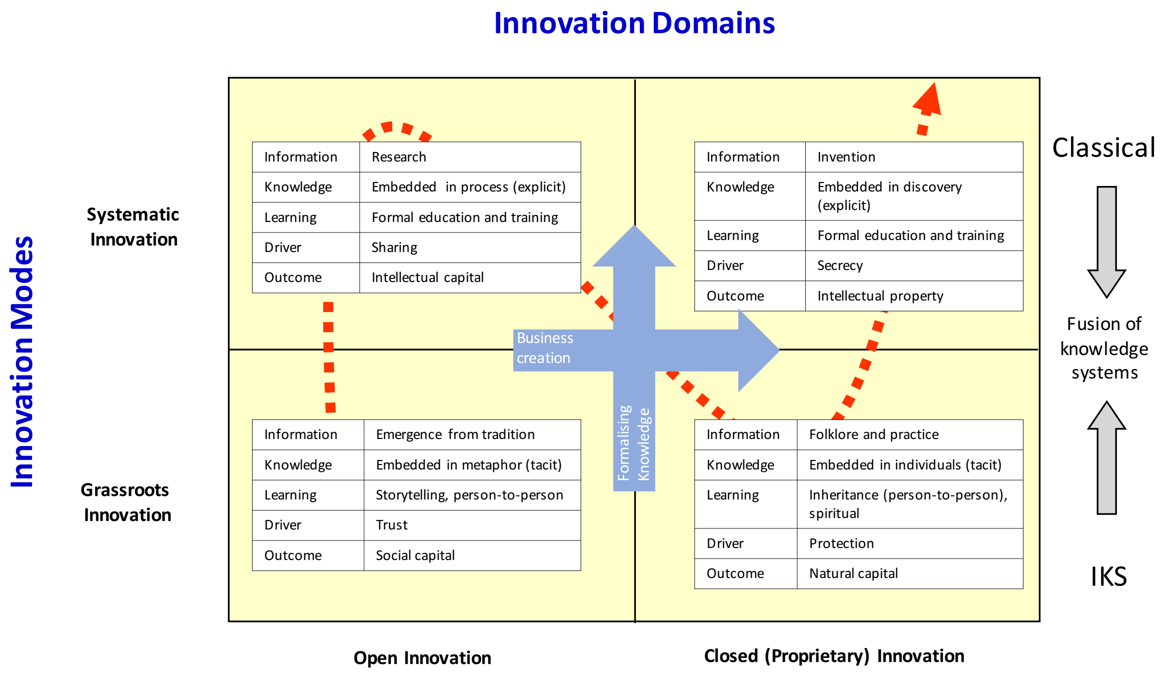

Figure 2: Innovation regimes for humans

It represents the fusion of classical and indigenous knowledge systems (IKS). Moving from open innovation to closed innovation normally refers to business creation and ownership. Each of the innovation regimes are characterised by the information that feeds innovation, working with knowledge, learning, its primary driver and the main outcome of the innovation.

Open grassroots innovation

In open grassroots innovation information emerges from tradition. Knowledge is embedded in metaphors, typically found in storytelling. Learning takes place through storytelling and knowledge is passed from person-to-person in narrative form over very long time periods. The driver to make innovation work is trust among people. The main outcome is the development of social capital, defined as the networks of relationships among people who live and work in a society, enabling that society to function effectively.

Open systematic innovation

Information for this innovation regime normally originates from research done on specific topics. Knowledge is embedded in explicit processes. Learning is based on formal education and training in innovation systems. The driver for this innovation is the sharing of knowledge at a precompetitive level. The outcome is intellectual capital that includes the people that innovate, their networks and the potential for proprietary gains.

Proprietary grassroots innovation

Information to use in innovation originates from folklore and practice that has been demonstrated in successful application of the innovation, usually without a sound base of scientific proof or understanding. Knowledge is embedded in individuals and is normally tacit and uncodified. Learning is through inheritance and normally passes from the practitioner to a very close relative or from one small specialist group to another. The knowledge is often deemed as a spiritual gift. The driver for this type of innovation is protection of practices that are not formally described and codified. The outcome is most likely value-addition to natural capital, since the knowledge is often linked to natural resources.

Closed (Proprietary) innovation

This type of innovation is the best known in the business environment and normally includes intellectual property protection such as the registration of a patent. The information feeding the innovation is based on invention. The knowledge lies in discovery and is of an explicit nature. Learning on how to do this type of innovation takes place through a formal education and training process. The driver is secrecy until disclosure after intellectual property protection has been secured. The outcome is intellectual property that has monetary value.

The fusion of knowledge systems

These regimes are juxtaposed to represent a flow of innovation practices that may also be linked. The innovation can, however, exist only in one regime. Alternatively, it can start, say, at open grassroots innovation, progress to open systematic innovation, develop into closed grassroots innovation and finally end up as formally protected proprietary innovation. The innovation process can start in any domain. In this way, Indigenous Knowledge Systems (IKS) or traditional knowledge that include the natural ability of humans to be innovative, and classical knowledge systems that are based on a sound academic understanding, can both contribute towards the innovation process. The adoption of IKS based approaches in the corporate environment has been known to yield very good innovation results.

Innovation regimes for machines

The same landscape can now be used to describe innovation regimes for machines. The innovation modes and domains used for describing human innovation are maintained and the envisaged characteristics when machines are applied to innovation are discussed with reference to Figure 3.

Open grassroots innovation

When intelligent machines are employed to assist with innovation in this innovation regime, information will now be obtained from a database built from community inputs or machine sensing and surveillance. The knowledge that the intelligent machine will work with will originate from data mining and synthesis processes. Machine learning will include audio-visual recording and sensing of the environment. The driver will be privacy, which may encourage individuals to share their knowledge, thus addressing the trust issue when humans innovate in this innovation regime. The outcome will be social capital as part of innovation for inclusive development ensuring that all marginalised and excluded groups are stakeholders in development processes.

Open systematic innovation

In this connected and shared regime of innovation, information will originate from big data and social networking. Knowledge will be extracted through pattern recognition and applying complexity algorithms. Machine learning will be through simulation and modelling and result in complex data visualisation to communicate results with humans. The driver is access to humans and other intelligent machines and objects connected to the Internet of Things. The outcome is intellectual capital that could be further developed into proprietary intellectual property.

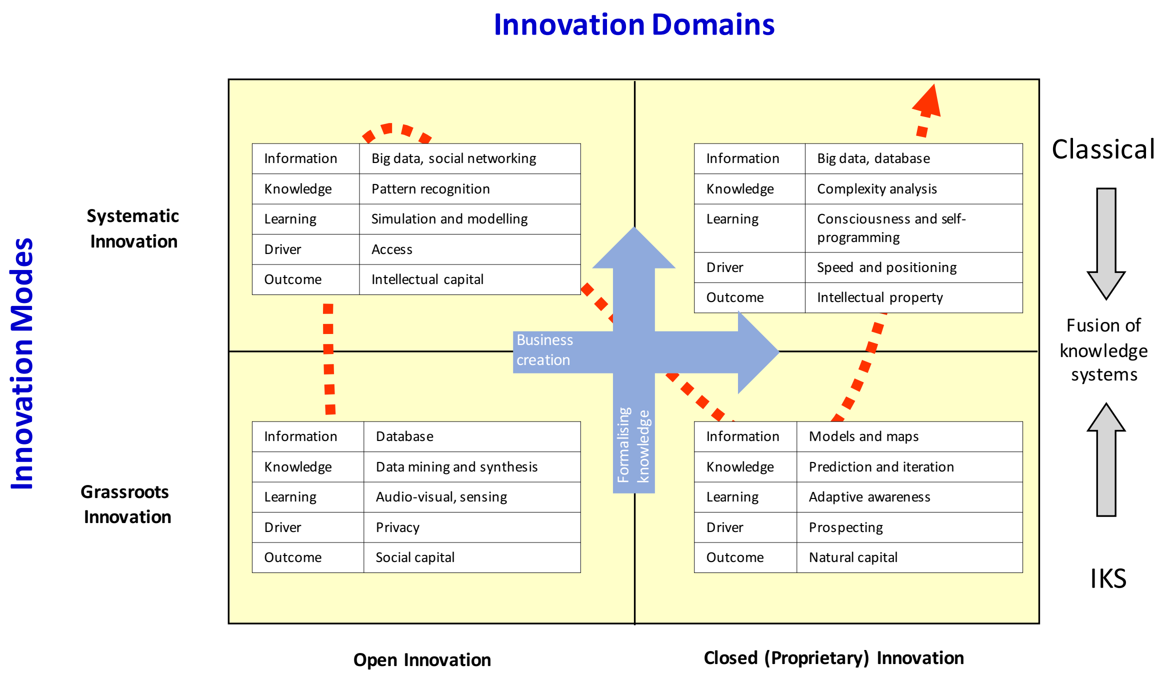

Figure 3: Innovation regimes for machines

Closed grassroots innovation

Information available to machines could be in the form of processes, operating procedures, models and maps that have been acquired from humans or other machines. Knowledge extracted from this information would lead to prediction and iteration of, say how an indigenous product will do in a specific global market. Machine learning will be through adaptive systems approaches shaped by the awareness through sensing of the predicted impact of innovations under development. The driver may be prospecting for new applications or new markets and optimising community offerings in a business context. The outcome will be adding value to natural capital, since products are often related to indigenous knowledge of natural resources as well as increased monetary gain for the community.

Proprietary systematic innovation

Information available to machines that may be employed in this innovation regime originate from big data on markets and proprietary data from databases inside the innovating enterprise. Knowledge on how the product or service may do in the marketplace will be generated from complexity analysis, taking a multitude of parameters that could influence the product or service into account. Machine learning may be through applying machine consciousness of the factors at play and by changing competitive approaches by self-programming and improving market selection algorithms. The driver is speed to market and timing and positioning of the product or service in the market. The outcome is formally registered intellectual property and direct monetary gain.

Innovation regimes and innovation agents

Figure 4 shows how the innovation regimes and innovation agents come together. The basis of the comparison is the most important reason for applying a specific agent/regime combination.

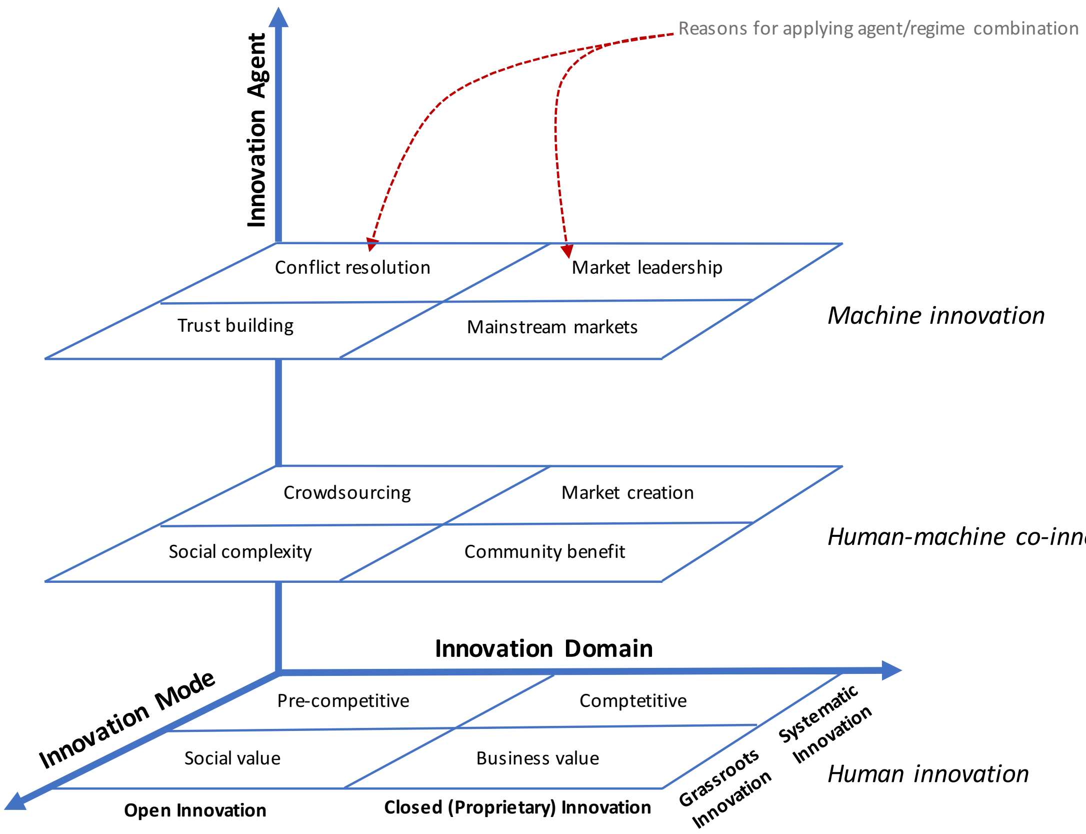

Figure 4: Innovation regimes and agents

Human innovation

In human-only innovation, the description represents the status quo in innovation. Open grass-roots innovation is aimed at generating social value, open systematic innovation is about pre-competitive advantage that can be exploited further, closed grassroots innovation brings business value to communities and proprietary systematic innovation leads to competitive intellectual property and products and services.

Human-machine co-innovation

When humans co-innovate with machines, open grassroots innovation benefits from the unravelling of social complexity by intelligent machine application. Open systematic innovation benefits largely from applying machine intelligence to complex social networking in the crowdsourcing environment and the ability to quickly select those innovations with the best business potential. Closed grassroots innovation will lead to well-modelled prospecting of business opportunities that the community at large can benefit from. Proprietary systematic innovation will benefit from human-machine co-innovation in the competitive advantage fast decision making can bring, the creation of new markets and in matching products and services with the dynamism of the markets.

Machine innovation

When machines will eventually innovate autonomously, their application to open grassroots innovation may initially be limited as trust is being built. The fact that humans are very often not trusted in this innovation regime, may make the intelligent machine the preferred independent and objective innovation agent for communities. Open systematic innovation will largely benefit from conflict resolution or avoidance in the open innovation domain. The complexity of crowdsourcing and the potential for confusion or malicious contributions may be revealed easily by machine intelligence. When machines become the innovation agent for closed grassroots innovation, products and services emanating from this innovation regime may be released on the mainstream markets much faster due to custom fit of need and demand by intelligent machines. Finally, machine innovation applied to the best-known innovation regime, that of proprietary systematic innovation, may improve the chances of market leadership through first-to-market strategies and redefining the intellectual property regime.

CONCLUSION

This concept paper reports on the advantages of possible future innovation conducted by intelligent machines. The technologies required for the machine intelligence are available or emerging. When combined in dedicated innovation support systems, applying these technologies may have beneficial impacts on the behaviour of people and on certain large events. Market needs exhibited by the consumer of today and tomorrow, and the way innovators are addressing them, call for advanced innovation processes that are fast and lead to products and services that are customised and effective. In this complex environment, intelligent innovating machines can play a major role in future. The impact of emerging events that have the potential to change the world of work and living could be mitigated by machine innovation, or humans could be assisted to adapt to these changes.

A thought experiment utilising the future thinking space and constructing a future thinking lens on machine innovation revealed that many different forms of innovation could benefit by employing machine intelligence. The evolution of machine innovation is likely to move from humans as innovation agents, to human-machine co-innovation and eventually autonomous machine innovation. All three innovation agent scenarios will prevail in future.

A mind model was developed to position the role of machine innovation in future. This model is based on known innovation regimes described by the open and proprietary innovation domains and the grassroots and systematic innovation modes. These were characterised for human innovation and machine innovation separately in terms of information required for innovation, the knowledge that lead to contextualisation, learning modes, innovation drivers and main outcomes for each innovation regime. This mind model assists in the understanding of how innovation conducted by the three innovation agents (human innovation, human-machine co-innovation and autonomous machine innovation) align with primary reasons in each innovation regime to choose a specific combination of innovation agents.

Humans will not be the sole custodians of innovation in future. They will find themselves in partnership with intelligent machines that will make innovation more powerful. Sometimes humans will have to stand back and let intelligent machines do innovation that is too complex for the human mind or innovation that has to take place too fast for conventional innovation processes. National systems of innovation, linking physical innovation infrastructure and the organisation of innovative people will be replaced with virtual innovation networks consisting of machine relationships, shared codified knowledge and experience, and connectivity. This may solve the problem that some existing national systems of innovation have of not being very efficient. This inefficiency often results from the focus being too much on connecting the right organisations and structures and not on doing the real innovation. Intelligent machine innovation may rectify this.

The whole world of innovation management, national systems of innovation and business model innovation will be disrupted. The challenge is to let this happen to the advantage of humankind and the earth.

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