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Book

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1. Introduction

May 11th, 1997: IBM's Deep Blue became the first artificial intelligence (AI) to beat a human World Chess Champion and that after only 19 moves. Garry Kasparov's defeat appeared to numerous observers, inside and outside the chess community, as the beginning of a new age, where the importance and self-perception of humans may clearly have changed, becoming nearer to zero, at least in terms of ego. To a certain extent, it was the death of a centuries-old conception of chess. One could continue to play, but knowing that some algorithm will beat him or her. That was the End of History—of chess—to paraphrase the title of the 1992 book by Francis Fukuyama.

Almost 25 years later, we are chatting, more or less successfully, with Siri, Cortana, and their fellow virtual friends and cannot wait for affordable self-driving cars. Go is usually considered the most abstract and complex board game; nevertheless, the spectacular performances of AlphaGo Zero in 2017 barely impressed the larger public and was definitely not a big surprise for most chess players. Apparently, winning games was over for humans. This realization leads to the question of what happened with the remaining human chess players. Is someone still really playing chess seriously or only out of boredom as chess would no more be the "Game of the Kings" but rather a sort of Monopoly or Cluedo? The reality check is striking; never before have so many humans played chess, and never before have humans played so well! Therefore, this is definitely not the End of the History of Chess.

What happened is that there was a shift from a human *versus* machine paradigm to a human+AI paradigm. This shift allowed humans to get better at chess and AI, discovering new ways to learn. It is not only about human players benefiting from the "teaching" or "coaching" from superior and faster algorithms. Neither is it just AI digging deeper in broader games library fed by better human *versus* machine games. Something very different and very unexpected could be observed. Furthermore, seemingly, this did not only happen in the chess community but "contaminates" progressively more and more fields. We call this the rise of centaurs.[1]

Listen to what Case (2018, p. 2) tells us about AIs, humans, and chess: "*The next year, in 1998, Garry Kasparov held the world's first game of "Centaur Chess." Similar to how the mythological centaur was half-human, half-horse, these centaurs were teams that were half-human, half-AI. But if humans are worse than AIs at chess, wouldn't a Human+AI pair be worse than a solo AI? Wouldn't the computer just be slowed down by the human, like Usain Bolt trying to run a three-legged race with his leg tied to a fat panda's? In 2005, an online chess tournament, inspired by Garry's centaurs, tried to answer this question. They invited all kinds of contestants — supercomputers, human grandmasters, mixed teams of humans, and AIs — to compete for a*

[1] It seems that the idea of centaur chess playing emerged for the first time in the SF novel The Peace War, written by Vernor Vinge and published in 1984. Interestingly Vinge was also the first author to introduce in his novella True Names (1981) the concept of cyberspace, and that, three years before the publication of Neuromancer, the well-known novel by William Gibson, and almost ten years before the World Wide Web was developed by CERN. This information is nevertheless anecdotal, and the fact that since more than a century visions provided by SF writers outsmart almost systematically the predictions of serious foresight analysts only proves that SF writers tend to be very lucky.

grand prize. Not surprisingly, a Human+AI Centaur beats the solo human. But — amazingly ***— a Human+AI Centaur also beats the solo computer.*** " (original emphasis).

The paper aims to provide some speculative thoughts about what the next episodes of this story may be, regarding particularly a field that, like chess, was considered for a long time as the prerogative of humans—innovation. The paper resolutely follows a "What if?" logic. It starts with current knowledge and observation on AI to point to the possible implication of symbiotic learning (section 2). Then the paper investigates in a speculative way what the consequences of the "centaur hypothesis" could be in terms of innovation capacities (section 3). In a third step, a so-far atypical field of realization of innovations is considered as an example (section 4). Finally, the conclusion (section 5) addresses the limitations of this speculative exercise.

2. Understanding Centaurs

2.1 What Are the New Centaurs?

Initially, centaurs were creatures featured in Greek mythology with the upper body of a human and a horse's lower body and legs. What if a "new kind of centaurs," a terminology being inspired by chess vocabulary, was currently rising? A kind of human+AI pair where the computer, or better say the exponentially growing network-based computer resources, is not slowed down by its human component but magnified by it? Or put differently, what if some humans could benefit from an Intelligence Augmentation (IA)? This question sounds like SF, but in fact, it has already happened—and this seems to be only the beginning.

Far away from prophesizing the emergence of omniscient and omnipotent entities, we aim to understand the impact of these humain+AI pairs within different fields of existing activities and investigate how far the development of centaurs would notably affect innovation and cities.

The first question to ask is a very prosaic one: is a "new centaur" something intrinsically different from a "virtual horse" driven and used by a human? For at least 3500 years, humans were successfully using horses for agriculture, traveling, warfare, and the like. Today, even if they are mostly used for leisure activities, our current mental representations of cars, farming, etcetera are still profoundly influenced by the initial way to mobilize an external source of power such as animals. Therefore, if AI is something other than just an additional "horse" like trucks, laser-cutting machines, or computers, such "horses" allow the multiplication of human physical and cognitive resources but remain only tools. This paper is based on the assumption that centaurs are intrinsically different from tools. This assumption is based on the observation of two phenomena: deep learning and symbiotic learning.

2.2 Deep Learning As the Basement of What Centaurs Could Become

Deep learning corresponds in reality to the result of the setting up and activation of deep neural networks, the usual academic name of deep learning. Deep neural networks are networks based on multiple layers between the input and output layers. Moving through the layers allows calculating each output's probability; this, in turn, enables the modeling of complex non-linear relationships. In other words, it can be seen to a certain extent as a form of artificial autodidactic process. For instance, this makes possible an algorithmic self-teaching enabling the recognition of a dog after being fed thousands of labeled images of various animals. Parloff (2016) points out that currently, numerous medical startups claim they will soon be able to use a deep neural network to diagnose cancer earlier and less invasively than oncologists will.

Makridakis (2018, pp. 49-50): "*How far can deep learning go? There are no limits according to technology optimists for three reasons. First, as progress is available to practically everyone to utilize through Open Source software, researchers will concentrate their efforts on new, more powerful algorithms leading to cumulative learning. Secondly, deep learning algorithms will be capable of remembering what they have learned and apply it in similar but different situations (Kirkpatrick et al., 2017). Lastly and equally important, in the future intelligent computer programs will be capable of writing new programs themselves, initially perhaps not so sophisticated ones, but improving with time as learning will be incorporated to be part of their abilities."*

As a result of the rapid increase in the complexity of individual AI, some unexpected consequences are currently pointed. As Rahwan et al. (2019, p. 478) stress: "*Although the code for specifying the architecture and training of a model can be simple, the results can be very complex, oftentimes effectively resulting in 'black boxes.' They are given input and produce output, but the exact functional processes that generate these outputs are hard to interpret even to the very scientists who generate the algorithms themselves, although some progress in interpretability is being made.*"

2.3 Symbiotic Learning as the Core Characteristic of the Nature of Centaurs

Symbiotic learning, according to our understanding, is even more revolutionary than deep learning. Symbiotic learning is not only a human whose capacities are boosted by an algorithm in terms of analytical capabilities, memory size, real-time access to sources, almost infinite information, and the like. In this case, one can refer to the concept of "intelligence augmentation."

Pleading for an interdisciplinary study of machine behavior, Rahwan et al. (2019, p. 483) state that: "*We shape machine behaviors through the direct engineering of AI systems and through the training of these systems on both active human input and passive observations of human behaviors through the data that we create daily."* In their analysis, these authors already consider several of the aspects that will be depicted later in this section in reviewing the following topics: i) mechanisms for generating AI behaviors; ii) functions fulfilled by the emergence of AI behaviors; iii) evolution of AI behaviors (phylogeny); iv) individual AI behaviors; and v) collective AI behaviors. These aspects led them to address the final issue of hybrid human-AI behaviors. In this respect, they stress that: "*Although it can be methodologically convenient to separate studies into the ways that humans shape machines and vice versa, most AI systems function in domains where they co-exist with humans in complex hybrid systems. Questions of importance to the study of these systems include those that examine the behaviors that characterize human-machine interactions including cooperation, competition, and coordination* (...) *as well as which factors can facilitate trust and cooperation between humans and machines.*" (Rahwan et al., 2019, p., 483).

Jennings et al. (2014) call Human-Agent Collectives or HACs: "*HACs are a new class of socio-technical systems in which humans and smart software, agents, engage in flexible relationships* *to achieve both their individual and collective goals. Sometimes the humans take the lead, sometimes the computer does, and this relationship can vary dynamically*." (Jennings et al., 2014, p. 80). Nevertheless, the most crucial difference is that while Jennings et al. (2014) consider HACs as a form of agile teaming where humans and agents will form short-lived teams before disbanding, it is assumed here that centaurs constitute a permanent and symbiotic relationship. This symbiotic relationship between humans and AI is the very core of the nature of centaurs and results from the three steps of the symbiotic learning process displayed hereafter.

In a first step, the human part of the symbiote teaches, guides the AI, encourages it in their curiosity by confronting them with new issues, like parents try to do with their children when raising them. In other words, the human part is schooling the AI to allow the AIs' creativity to flourish.[2] Consequently, two initially identical AIs will rapidly— remember: deep learning is high-speed learning—diverge, depending with whom they are "growing up" like it is the case for human, real, twins separated as they are still very young and are growing up in very different families, social environments, countries, etcetera. Alison Gopnik summarizes the situation this way (quoted by Guszcza et al. 2017, p. 16): "*One of the fascinating things about the search for AI is that it's been so hard to predict which parts would be easy or hard. At first, we thought that the quintessential preoccupations of the officially smart few, like playing chess or proving theorems—the corridas of nerd machismo—would prove to be hardest for computers. In fact, they turn out to be easy. Things every dummy can do, like recognizing objects or picking them up, are much harder. And it turns out to be much easier to simulate the reasoning of a highly trained adult expert than to mimic the ordinary learning of every baby*."

In a second step, the IA part modifies the way of thinking of the human part of the symbiote, like the human part of a chess centaur tends progressively to play differently, even when not connected to its own, AI. This step means its human view of reality—remember reality is nothing else than a cognitive and social construct—evolves radically over time, even if it is most probably at the same pace as the AI part of the symbiote. In other words, since the human part learns to think differently and progressively sees the world from a different perspective, its personality and identity change. This change would imply a form of psychic plasticity of centaurs in the meaning of Tisseron (2018), who explores the psychological dimensions of future human-machine interactions. This author points to the possibility of two distinct stages. The second stage would see humans and AI entering (from a psychological perspective) in an adult-to-adult relationship, what he calls poetically "*amitié informée et réaliste*" (Tisseron, 2018, p. 13). This stage can be seen as the prolongation of an initial phase (an adult-to-child relationship) during which the AI learns mainly through imitation processes. During this initial stage, the AI would rather (metaphorically) act like a young child sensitive to a reward, i.e., "*un jeune enfant sensible à la récompense*" (Tisseron, 2018, p. 43).

Finally—this may sound more speculative—in a third and ultimate step, it could be envisaged that centaurs will communicate not only with humans and AIs on separate channels. Separates channels mean each element, human or AI, of the symbiote exchanging information exclusively

[2] The analogy with schooling encompasses certain limitations. In the case of human children, teenagers, and young adults, the educational system, from kindergarten to university, is supposed to do the same: improving learning and creative capacities. Nevertheless, empirical observations quite often just show the opposite since educational systems appear as perfectly efficient in killing creativity. Cf. notably an excellent TED conference given in 2014 by the late Sir Ken Robinson: https://www.ted.com/talks/sir_ken_robinson_do_schools_kill_creativity?language=enW

with their counterparts, humans, or AIs. Put in other words, this would mean humans are chatting together in one corner of the party and AIs chatting together in another one[3]. This kind of interaction may even be reinforced by the relationships between centaurs, high-level AIs, and low-level AIs (cf. Kelly, 2016). Again, this type of communication will most probably be resolutely different depending on the interlocutors of low-level IAs—i.e., high-level AIs, humans, or centaurs.

The assumptions related to these three steps may sound surprising, if not exaggerated, or even foolish. When would centaurs become an everyday reality, being, for instance, spread as Watson is today? No definite answer is possible, but it can be reasonably expected that it will take less than 20 years from now. This actuality requires "only" three conditions. The first is reaching a higher level of AI development. The second condition is to render possible a better integration of AI and humans in terms of communication bio-interfaces, leading to a high level of symbiosis. The third condition is to allow some human+AI pairs to grow up together as individual entities for the first time. These three conditions would allow the emergence of shared identity through mutual learning based on real experiences (*e.g.*, surgical operations). It is not possible yet to determine which of these steps will take the most time, notably since numerous feedback loops between these steps are expected. Nevertheless, a horizon of fewer than 20 years from now may seem realistic considering Kelly's predictions (2016).

Things can happen much faster and to a larger scale than optimistic expectations! Interestingly, in a paper addressing what he calls "the forthcoming AI revolution" and its impacts on society and firms, Makridakis (2018) overviews the predictions he made about information technologies more than ten years before (Makridakis, 1995). Besides identifying successes and failures of his predictions, he stresses "*that major technological developments (notably the Internet and smartphones) were undervalued while the general trend leading up to them was predicted correctly*" (Makridakis, 2018, p. 47).

3. Centaurs and Innovation

3.1 Problem Solving and Decision-Making: Playing According to the Existing Rules

Far away from apocalyptic visions concerning the future of work, Chui, Manyika, and Miremadi (2015) suggest that the growing use of AIs in the economy is more likely to transform, rather than eliminate, jobs. Today, there is a growing consensus that it is important to distinguish "task" automation from "job" automation. Markoff (2016) points out that AI technologies will most probably continue to replace routinized jobs and, at the same time, will increase the number of workers whose jobs require problem-solving, flexibility, and creativity. One could imagine that in a near future, the—boring—jobs requiring light-speed computation will be for AIs and the—exciting—creative, innovative, and valorizing jobs for the human. Nevertheless, this vision remains quite "classical" since it depicts a dichotomy: fast and routinized tasks will be for AIs. Human-speed and innovative jobs will remain in the field of highly qualified humans. Reality will most probably be somehow less contrasted in this respect. However, if one

[3] The idea of some AIs chatting together seems very unlikely to most people who believe that, for instance, AIs have no sense of humor. This argument may nevertheless reveal fallacious since numerous humans seem to be totally deprived in this respect and unfortunately do not refrain from chatting.

accepts the hypothesis of the rise of centaurs, the main issue to address is how far centaurs will be able to innovate differently, and what will this difference be?

According to Jarrahi (2018, p. 580): "*AI and other intelligent technologies can assist human decision makers with predictive analytics: (1) they can generate fresh ideas through probability, and data-driven statistical inference approaches and (2) identify relationships among many factors, which enables human decision makers to more effectively collect and act upon new sets of information*." If one comes back to the history of chess centaurs, Cage (2018, p. 5) provides a striking argument: "*There was another shock in store for Garry Kasparov. Remember that 2005 online chess tournament between supercomputers, human grandmasters, and Human+AI centaurs? I forgot to mention who actually won the grand prize. At first, Garry wasn't surprised when a human grandmaster with a weak laptop could beat a world-class supercomputer. But what stunned Garry was who won at the end of the tournament — not a human grandmaster with a powerful computer, but rather, a team of two amateur humans and three weak computers! The three computers were running three different chess-playing AIs, and when they disagreed on the next move, the humans "coached" the computers to investigate those moves further. As Garry put it: "***Weak human + machine + better process was superior to a strong computer alone and, more remarkably, superior to a strong human + machine + inferior process***."* (original emphasis).

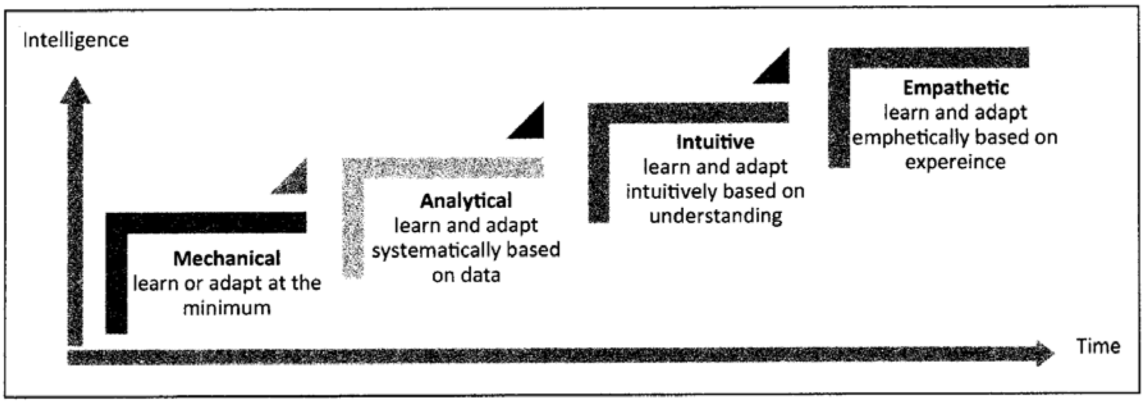
What DeepBlue, AlphaZero, and all their friends have in common is that they did develop radically new ways of playing and winning, respecting strict fixed rules. For instance, a 64 squares world where every "actor" functions and possibilities are perfectly known. However, this relates only to decision making, finding the best way to "win the game" according to a given set of rules. In decision-making processes, most of the options are relatively well known even if specific options may, for instance, encompass a high level of uncertainty. Consequently, it can be assumed that in a situation where "innovating" consists of improving something already existing, *i.e.*, incremental innovations, centaurs appear as much "efficient," *i.e.*, faster and more exhaustive than humans alone.

3.2 What Can Centaurs Achieve that AIs cannot?

The next logical step is to ask the question: what about AI+human symbiotic playing "real-life games"? Games without fixed rules? Alternatively, with changing rules, either resulting from a stochastic process or from the results of previously "won or lost games." Or even games with contradictory rules? What about situations consisting of exploring the unknown or situations that imply being creative? In other words, what could centaurs achieve that neither humans nor AIs alone could achieve?

Reviewing the literature on AI, Huang and Rust (2018) distinguish four types of "intelligences" where machine intelligence mimics human intelligence dimensions, such as knowledge and reasoning, problem-solving, learning, communicating, perceiving, and acting. As a result, these authors propose to classify in the order of their developmental history in AI (cf. fig 1).

Figure 1: the four intelligences of AI according to Huang and Rust (2018)



Source: Huang and Rust (2018, p. 15)

The analysis of Huang and Rust (2018) is mainly focused on the potentials and threats in job replacement in the service sector. Nevertheless, if one considers the hypothesis of the emergence of centaurs, it must be stressed that these authors do not assert that only the "worst-case scenario" will take place. Total replacement is not the only logical final step since integration is also thinkable. In particular, they point to what they describe as "*machine-enhanced humans. In this possibility, humans are physically or biologically integrated with machines, and AI becomes a technological extension of humans. (...) one possibility for AI is "beyond human," which adds human bio-enhancements, prosthetics, or implants*." (Huang and Rust, 2018, p. 165).

Jarrahi (2018, p. 579) states that: "*By employing an analytical approach, individuals can engage in methodical, laborious information gathering and analysis, and develop alternative solutions in an attentive fashion. An analytical approach often involves analyzing knowledge through conscious reasoning and logical deliberation. The problem-solving ability of AI is more useful for supporting analytical rather than intuitive decision making.* (…) *However, much of cognition and human decision making is* ***not a direct result of deliberate information gathering and processing, but instead arises from the subconscious in the realm of intuition****.*" (emphasis added).

In the academic literature, such capabilities—particularly when linked to the issue of innovation—are often summarized under the "conceptual umbrella" of creativity. Sternberg and Lubart (1999, p. 3) proposed what became one of the most widely accepted definitions of creativity in this respect: "*the ability to produce work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints).*" Regarding creativity, there are at least three attributes related to innovation processes for which centaurs may be superior to AIs alone. The conception of these attributes is partly inspired by reflections proposed by Dewhurst and Willmott (2014). They address the issue of the role senior leaders should still play with the emergence of Ais, implying that they can only play such roles better than AIs. These three attributes are: asking questions, tolerating ambiguity, employing soft skills, and considering ethical aspects.

First Attribute: Asking Questions

Starting not only with a willingness to improve processes, cutting costs, expanding markets, and the like but with a willingness to ask good questions, or at least new questions. This generation may be seen as having new problems rather than the production of new solutions. It goes beyond deep learning. It is not a matter of advanced analytics but a matter of "deep curiosity."

Second Attribute: Tolerating Ambiguity

Algorithms are designed to seek answers. Deep learning is about producing an almost infinite number of mistakes to get better answers. Tolerating ambiguity means considering or even keeping solutions that prove not to be the right ones. Nevertheless, these solutions might provide a good, or at least an acceptable, answer to another question, which may not even be formulated or to the current question, but not under the given conditions, in terms of resources, design, aims, and the like.

Third Attribute: Employing Soft Skills and Considering Ethical Aspects

Due to their human part, centaurs may prove more efficient than AIs when it comes to motivating investors, improving project partners' creativity, or empathizing with recalcitrant clients. Introducing a human touch in critical and sometimes not entirely rational situations may generate a real difference, which also applies to ethical issues. It should not be expected from an AI to act in full consciousness—in the philosophical meaning–like a human should act. For instance, a centaur interacting in a crucial project with a human using harmful substances to improve his creativity, which may be a wrong statement, faces an ethical dilemma. Whereas an AI alone would most probably focus exclusively on the project results and not care about the user of harmful substances, a centaur's reaction might be very different.[4]

Summarizing, these three attributes may enhance creativity in the meaning given by Sternberg and Lubart (1999), creativity is the ability to produce both novel and appropriate work. Nevertheless, this does definitively not mean that centaurs would become "all-mighty" and "omniscient." Cognitive biases would still hamper Their abilities, e.g., "slow thinking/fast thinking in the sense given by Kahneman (2011). Nevertheless, these cognitive biases would most probably be different from the ones hampering AIs taken alone. In their paper nicely entitled "Lessons for artificial intelligence from the study of natural stupidity," Rich and Gureckis (2019, p. 179) point out that "*Science and technology often advance through inspiring metaphors. Some of the recent interest in machine learning and AI stems precisely from the comparison between machines and humans and the idea that machine-based systems implement aspects of human cognition but improve on human abilities. (...) A healthy attitude towards recent advances in AI would be to recognize that rather than being free of bias, certain biases are likely to be fundamental to what it means to be an intelligent adaptive agent operating in a vague and uncertain world.*"

[4] Thanks to its human component, the centaur would, for example, empathize with the concerned human; suggest to him to take more cocaine in order to achieve the project, and report him to the authorities only afterward, which would allow the centaur to remain fully ethical, especially if the considered drug addict appears to be antipathetic and/or useless in the future.

3.3 Expanding the Playbook: Innovation as the Invention of New Rules

The core question can be expressed as follows: Can centaurs innovate differently from humans alone, even supported by powerful computers, or from AIs, i.e., when humans set the goals and "explain the rules"? In other words: Can we talk about symbiotic innovations that can be performed exclusively or at least mainly by centaurs? Or would centaurs appear to better innovate in fields where non-centaurs, i.e., humans or AI, have taken alone, seem limited?

The opportunity for a partnership was already pointed by Jarrahi (2018, p. 581): "*AI has the advantage of brute force, making it a rigorous tool for retrieving and analyzing huge amounts of data, ameliorating the complexity of a problem domain.* (…) *One way to materialize the synergistic relationship between AI and humans is to combine the speed of AI in collecting and analyzing information with humans' superior intuitive judgment and insight*."

The primary argument pleading in favor of a supremacy of symbiotic innovations is to consider situations where "new rules" must be invented for "real-life games," which do not exist so far. This argument may apply to products, services, or processes. Depending on how different the existing ones are, the new rules are incremental, slightly modified rules or radical, significantly different rules innovations.

In how far can centaurs' abilities to "win games" be extended to real-life settings where not only the rules are not fixed, but where rules can change over time or depending on the context? How far can capabilities such as creativity and sensing emotions, the core to the human experience, be automated?

Centaurs inventing "new rules" could also be interpreted as new ways to find creative solutions, resulting from what one could call augmented serendipity. Yaqub (2018) proposes a typology describing four serendipity processes leading to creative solutions: i) targeted search solving unexpected problems; ii) targeted search solving problem-in-hand via unexpected routes; iii) untargeted search solving an immediate problem; and iv) untargeted search solving a later problem.

For each of these four types, it appears clearly that symbiotic learning - being the core characteristic of centaurs - would constitute a tremendous accelerator of serendipity. Yaquab (2018, p. 173) states that: "*Observations are usually mediated by instruments, and the development and use of instruments themselves play an important role in serendipity. This is not necessarily the testing of theories nor the replication of experiments, but rather the trying out of new practices. (...) Instruments can be developed and used quite free from theory, playfully even*." Centaurs would, thanks to their dual nature, play at the same time the role of the instrument and the role of the observer with high velocity.

4. Centaurs and the City

4.1 Municipal Innovations: Unspectacular But Crucial

Cities appear as major economic and political actors of the twenty-first century. This development is due to demographic factors and the concentration of geo-strategical and environmental issues in cities, particularly climate change. Moreover, cities seem to be the place *par excellence* of innovation; Wolfe (2014) names cities "Schumpeterian hubs." In parallel, the term 'smart cities' emerged progressively in the 1990s. The concept has become increasingly popular in scientific literature and international policies. According to Albino et al. (2015), the California Institute for Smart Communities was among the first to focus on how communities could become smart and how a city could be designed to implement information technologies. Over the past 20 years, the smart city concept has had many definitions, with smart cities being places where information technology is combined with infrastructure, architecture, everyday objects, and our bodies to address social, economic, and environmental problems. More recently, authors started even to investigate AI clusters in cities. See Doloreux and Savoie-Dansereau (2019) for the case of Montreal.

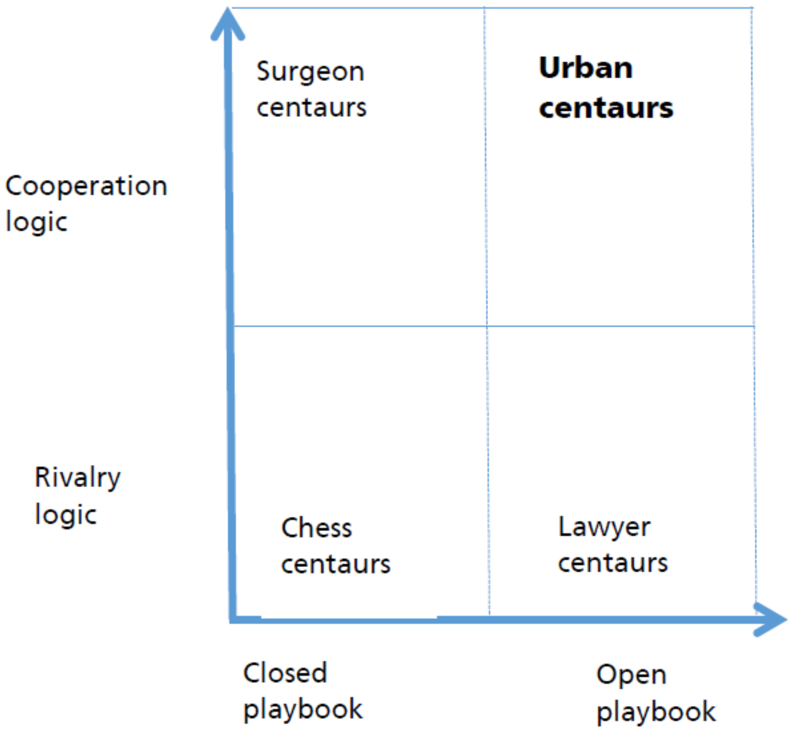
Municipalities are usually not considered initiators of innovation. Consequently, one dimension of the interrelationships between innovation and cities was given relatively little attention so far: cities themselves, or more precisely municipal teams, being the innovators. Shearmur and Poirier (2016) were the first to attempt to conceptualize this specific form of innovation. They see municipal innovations as "non-market Schumpeterian innovation processes." Shearmur and Poirier (2016) state that "(...) *municipalities* (...) *introduce incremental product, process, and service innovations, which we call everyday innovations as they are in response to issues that arise out of municipalities' everyday service and management responsibilities*" (Shearmur and Poirier, 2016, p. 3).

Shearmur (2020) provides numerous examples of recent municipal innovations in investigating the field of sustainability, stressing "(...) *a variety of innovations that illustrate how the proximity of municipalities to everyday material and social problems can make them key actors in altering procedures and habits in view of increasing sustainability*" (Shearmur, 2020, p. 12). The broad spectrum of municipal innovations' examples displayed stretches from biomethanation to environmental patrol through waterways management.

4.2 A Specific Contribution of Urban Centaurs to Municipal Innovations?

This section aims to link, focusing on municipal innovations between different concepts developed above. In this respect, the following statement by Shearmur and Poirier (2019, p. 1) can serve as a starting point for imagining what future contributions urban centaurs could deliver for municipal innovations: "*We find that municipalities' internal capacity determines their innovativeness, that learning occurs, and that the motivation and evaluation of everyday municipal innovation are not market-based.* "The central elements are learning, motivation, and evaluation. In this respect, two dimensions of centaurs' behavior are particularly relevant for learning, motivation, and evaluation. The first dimension concerns how centaurs act and respond to their environment, i.e., following a rivalry or a cooperation logic. The second relates the type of playbook upon which centaurs rely. Figure 2 illustrates the differences resulting from the combination of these two dimensions.

Figure 2: Characterization of Urban Centaurs Along Two Main Dimensions



Chess centaurs are typically following a rivalry logic related to humans, AI, or other centaurs and using a closed playbook, i.e., acting in a limited and well-defined universe. They aim to win against others in respecting given exceptionally well-defined rules. Surgery centaurs are supposed to follow a cooperation logic with other actors to improve their patients' state of health. On the opposite, legal centaurs, acting for instance as lawyers, consider an open playbook to interpret law following a rivalry logic.

Comparatively, urban centaurs could be characterized as:

- following a cooperation logic: They intend to improve through municipal innovations, the situation of the concerned cities in which there are involved, ultimately attempting to increase the level of well-being of the inhabitants.

- considering an open playbook: Their actions are not limited to specific fields, nor must they strictly follow rules which were defined *ex-ante*.

Consequently, and at least hypothetically, urban centaurs could reinforce cities' innovativeness more than humans or AIs alone. In particular, when considering the incremental product, process, and service innovations, as Shearmur and Poirer (2019) do, one may state that urban centaurs could support the emergence of quantitatively more numerous municipal innovations. Urban centaurs could also qualitatively sustain more creative municipal innovations. Both effects would strongly reinforce municipalities' internal capacity to innovate in the meaning given by Shearmur and Poirer (2019).

Suppose one accepts the idea that potentially soon urban centaurs may be part of municipalities' staffs. In that case, it is essential to consider their contribution to cities' innovativeness from an organizational perspective. Urban centaurs will interact with humans—co-workers, citizens, and the like. These centaurs will also interrelate with external organizations—suppliers, different administrations, other municipalities, and so forth. Also, centaurs will cooperate with other AIs, different types of centaurs, etc.

Put in other words: urban centaurs embedded in municipal organizations would mean at the same time more innovations and better innovations.

From an organizational perspective, several arguments can be found which support the hypothesis of reinforcement of both quality and quantity of municipal innovations by urban centaurs. In the following, three reasoning lines dealing with the generation of new) knowledge and innovations are presented. For each argumentative set, elements of reflection related to urban centaurs are introduced.

The first argumentative line is based on the combination between the exploration/exploitation trade-off proposed by March (1991) and the definition of creativity proposed by Sternberg and Lubart (1999, p. 3). Creativity is defined as the ability to produce work that is both novel, i.e., original, unexpected, and appropriate, i.e., useful, adaptive concerning task constraints. Two types of municipal innovations increase can be identified; first, a quantitative increase of municipal innovations—which would mean better exploitation in the meaning given by March—and a higher level of appropriateness regarding constraints in the meaning given by Sternberg and Lubart. Second, a qualitative increase of municipal innovations would constitute a more in-depth exploration of the meaning of March combined with a stronger originality of problem solutions in the meaning given by Sternberg and Lubart.

The second set of arguments follows the concept of phronesis in organizations developed by Nonaka et al. (2014). Phronesis is sometimes presented as the "third type of knowledge" since it is a form of practical wisdom, which goes beyond explicit and tacit knowledge since it cannot be taught in Socrates and Plato's views. Phronesis can only be generated by dialectic processes and, according to Nonaka et al. (2014), from an organizational perspective. One hypothesis would be that centaurs, due to their dual nature as symbionts, could reinforce the development of practical wisdom within municipalities, strengthening the ability to generate what Shearmur and Poirier (2016) stress as "everyday innovations."

The third argumentative line concerns the Spatio-temporal knowledge creation processes, as presented by Hautala and Jauhiainen (2014). According to them: "*Knowledge is inseparable from the temporal processes of creation, interaction and interpretation as well as from contexts, or spaces, of creation*" (Hautala and Jauhiainen, 2014, p. 655). In this approach, knowledge creation appears as profoundly interactive, as other people and the environment affect individuals' thoughts and actions. Besides, Hautala and Jauhiainen (2014) state that, when it comes to knowledge creation, considering space only as a material background and time only as universal linear sequences is misleading. In their view, knowledge creation results from a reorganization of spatiotemporal processes. This reorganization is the key to reinforced innovativeness *"(...) in academia, art, business, and local communities*" (Hautala and Jauhiainen, 2014, p. 656). In this respect, urban centaurs may appear, due to their symbiotic nature, as "anchored" in different places and time frames simultaneously. This type of anchoring makes a vast difference with humans alone—one place at a time and own perception of time different from that of one of

AIs, and AIs alone— virtually "present" at several places at a time and with their computational speed resulting in the apprehension of time different from human experience. As a result, the possible answers to the very questions of "where" and "when" in knowledge creation by urban centaurs are profoundly modified. This result, in turn, leads to a reorganization of spatiotemporal processes for the municipalities embedding urban centaurs in their innovation-related activities.

Urban centaurs, summarizing, from an organizational perspective, may foster at the same time more innovations, based on more efficient exploitation of knowledge, and better innovations—based on a more profound exploration of knowledge. In other words, the innovativeness of municipalities embedding centaurs may reinforce both in terms of incremental innovations as well as in terms of radical innovations. Here, it is necessary to stress what "incremental" and "radical" innovations mean for municipalities. Municipal innovations are distinct from companies' innovation since their non-market nature (Shearmur and Poirier, 2016). Incremental innovations may be easier to develop since adaptation from other municipalities' experiences is supported by a degree of willingness to disclose knowledge through cooperation that cannot be found when it comes to firms in a situation of competition. Simultaneously, radical innovations are strongly context-specific for municipalities and may appear modest compared to radical innovations performed by firms acting in a global market. The following section proposes examples of municipal innovations supported by urban centaurs.

4.3 Some Examples of Possible Contributions of Urban Centaurs to Municipal Innovations

The development of municipal innovation supported by urban centaurs could correspond mainly to situations where solutions are found for problems corresponding to a contradiction. In other words, urban centaurs would contribute to distinguishing within the existing corpus of knowledge what could belong to problems and what could belong to solutions in order to ensure possible matches. The issue is then not only to "generate good solutions" but to a certain extent also to "find good problems." The ground hypothesis is that this is quite often difficult to realize using only limited human computational abilities or some limited, or even inexistent, AIs contextualization capacities or intuition.

The following table depicts a few examples of fields in which such municipal innovations could be implemented or supported by urban centaurs. These fields are displayed along two dimensions: the objectives of the concerned innovations and their nature.

Table 1: Nine Examples of Municipal Innovations Possibly Supported by Urban Centaurs

Nature of the Innovations / Objectives of Innovation	Monitoring and Detection of Patterns	New Combinations of Resources, Actors, Experimentation and the Like	Identification and Adaptation of Solutions Existing "Elsewhere"
Improving Sustainability and Solving Environmental Issues	*Waste management and recycling*	*Drone fleets based enhanced data collection made acceptable to citizens*	*Air pollution tracking and epidemic detection*
Improving the Efficiency of physical and Intangible Infrastructures	*Detection and prevention of leaks (e.g., water)*	*Implementation of data squads and maintenance of data islands*	*Dynamic management and improvement of multi-modal transportation systems*
Improving citizens' well-being and solving social issues	*Urban and architectural design supporting inclusive tourism*	*Real-time homeless supervision and psychological care*	*The conception of urban solutions likely to meet the expectations of bored teenagers*

The nine fields are given as examples to address issues to which almost all cities are or will be confronted regardless of their size, location, or socioeconomic profiles. In each field, it can be assumed that the efforts currently deployed at the municipal level are insufficient. One may assert that the shortage of financial resources or lacking political constitute potential obstacles but the inherent complexity of the issues addressed strongly hampers the emergence of solution. It is mainly the contradictory nature of those problems that constitute the core difficulty. In this respect, urban centaurs—being at the same time animated by a cooperation logic and following an open playbook—are liable to favor the emergence of solutions.

These solutions can be pointed when detecting some common patterns of the nine fields given as examples. At least five common characteristics can be highlighted.

First, partial solutions already exist, being technology-based or not, and are deployed at different scales with divergent degrees of success. Simultaneously, the partial elements of the solution are difficult to reproduce since contexts are different from one city to the other, which is, for instance, the case for the detection and prevention of leaks.

Second, the combination of high computational velocity and perceived likelihoods in population willingness appears to be the key to success. In particular, this willingness in the case for the development of drone fleets-based enhanced data collection seems problematic in terms of citizens' acceptance.

Third, the need for initial creativity followed by numerous experimentations, showing possibly contradictory results. The deployment of such innovations would require numerous trial and error sequences and would elsewhere reveal too time and cost consuming. For instance, this would concern air pollution tracking and epidemic detection

Fourth, the resolution of conflicts is carried inherently by the emerging solutions, conflicts being financial resources, legal obstacles, ideological settings, and the like. Real-time homeless supervision and psychological care could provide an example.

Fifth, the ability to identify and motivate different types of actors that do not know each other, are unwilling to cooperate, or are not familiar with the concerned field of innovation. This innovation could concern, for instance, urban and architectural design supporting inclusive tourism.

The selection of the fields contained in table 1 is naturally extraordinarily subjective, and the examples provided are not intended to constitute proofs, nor may be interpreted as the results of a foresight exercise. This choice was led by the willingness to explore a broad scope of issues that a municipality is potentially confronted with daily, encompassing various degrees of urgency and complexity.[5] The exercise aimed to illustrate the diversity of the problems that may be addressed and hopefully solved in a not too far future with urban centaurs' help.

5 For instance, the crucial issue of bored teenagers for municipalities (as pointed by Shearmur and Poirier 2017, p. 23) reveals the high degree of complexity to be addressed in certain situations. Confronted withs with this species' behavior that defies the capacities of both humans and AIs, one may hope that centaurs will be able to ensure some signs of progress regarding teenagers. One optimistic view would be to state that being able to understand them better could, in the end, improve the ability of humanity to communicate with further hypothetical alien forms of intelligence. In this respect, the author is grateful to his son Marc for the provision of empirical material.

5. Conclusion: Who Would ever Want to Be a Centaur?

This paper is highly speculative and resolutely optimistic. The ideas developed above were ignited by discussions with chess players and strongly influenced by the well-known statement by Kelly (2016) stressing that we should not start a race "against the machines" but a race "with the machines." Speculations about a hypothetical rise of centaurs may raise numerous issues, depending on if and how this would at least partly happen. If the hypothesis would prove to be even only partially true, then numerous challenges would appear both for managers and policymakers. In particular, how to favor the emergence/the retention/the attraction of centaurs in a given company or geographical area?

Nevertheless, as long as empirical investigations are not possible, one must keep in mind the strongly speculative character of the above-developed ideas. The "centaur hypothesis" presented here carries voluntary some fictional and even hazardous features. As Hermann (2020, p. 654) stresses in a paper perfectly entitled "Beware of fictional AI narratives," it seems evident that "*Taking the SF representation of conscious and autonomous machines seriously as a critical technology assessment gives a distorted impression of the capabilities of AI in reality*."

Consequently, it is essential to consider the limits of what can be expected in terms of the development of AI capacities and not become overconfident in what may mainly result from imagination. Nevertheless, in the novel "The Salmon of Doubt," Douglas Adams proposes a somehow alternative way of thinking (Adams. 2003, p. 95):

"I've come up with a set of rules that describe our reactions to technologies:

1. Anything that is in the world when you're born is normal and ordinary and is just a natural part of the way the world works.

2. Anything that's invented between when you're fifteen and thirty-five is new and exciting and revolutionary and you can probably get a career in it.

3. Anything invented after you're thirty-five is against the natural order of things."

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