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Entrepreneurial action, creativity, & judgment in the age of artificial intelligence

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ABSTRACT

The rapid advancement of computationally complex systems of artificial intelligence (AI), is the fruit of a decades-long effort to endow machines with cognitive capabilities that equal or even exceed those possessed by human actors. As the growing sophistication of AI algorithms revolutionizes entrepreneurial action in uncertain environments, these advancements raise an important set of questions for future theory-building in entrepreneurial action, creativity, and decision-making research. In this paper, we take up these critical questions by exploring how advancing AI systems provide novel solutions for resolving the fundamental challenges of modal uncertainty in entrepreneurial decision environments. And in doing so, AI algorithms create new possibilities for future forms of entrepreneurial action. We conclude the paper with a robust discussion of future research at the intersection of AI and entrepreneurship.

1. Introduction

The rapid emergence of computationally-complex systems of artificial intelligence (AI) is the culmination of a decades-long effort "… to create and understand intelligence as a general property of systems, rather than as a specific attribute of humans" (Russell, 1997: 57). After many fits and starts, the field is now principally organized around the goal of constructing a systems-based form of machine intelligence (Russell, 1997), yielding impressive results across an advanced range of cognitive tasks previously thought to be impossible for software systems (Shi, 2011). Andrew Ng, former director of AI initiatives at Stanford, Google, and Baidu, suggests that "if a typical person can do a mental task with less than 1 s of thought, we can probably automate it using AI" (Ng, 2016: 4).

This rapid growth in the capabilities of AI is transforming the practice of entrepreneurship. Over the past few years, venture funding for AI startups has grown exponentially. Annual expenditures to advance AI initiatives now exceed $40B, mostly in the form of strategic acquisitions by tech giants such as Google, Amazon, Microsoft, Alibaba, and Baidu, in their continuing battle to access mission critical AI technologies developed by early-stage startups (Bughin et al., 2017). Global revenues generated from AI applications/systems are expected to climb from $12B in 2017 to more than $46B by 2020. Between 2012 and 2017, annual venture funding for AI startups increased from $1.7B to more than $15B (Statista, 2018). In China alone, cumulative investment into AI technologies exceeds $300B, fueled in part by the ambitious plan to build a $1 trillion AI industry by 2030 (Barhat, 2018). A crucial part of this ambitious plan centers on incubating AI startups with more than $4.5B in funding invested in Chinese AI startups since 2012 (Lee and Triolo, 2017). Overall, this fervent interest and escalating investment in AI to mimic, augment, and even replace the cognitive labor of human actors reflects the long-term belief in the transformative potential of AI systems (Makridakis, 2017).

The rapid emergence of AI will also transform entrepreneurship theory (Mitchell et al., 2017). The most important of these

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transformational changes stem from the ways in which AI fundamentally alters the calculus of the actor-environment nexus, particularly as it pertains to entrepreneurial action under conditions of uncertainty (McMullen and Shepherd, 2006). In the field of entrepreneurship, entrepreneurial action, judgment, and decision-making under conditions of uncertainty are central tenets of entrepreneurship theory (Townsend et al., 2018; Packard et al., 2017; Foss and Klein, 2012; Foss & Klein, 2015; Klein, 2008; McMullen, 2015; McMullen and Shepherd, 2006; Alvarez and Barney, 2007; Sarasvathy, 2001; Venkataraman, 1997). These uncertainties range from questions about the effectiveness of new processes, the consequences of key decisions, or even the preferences of customers for novel products and services while new ventures toil with limited resources, amidst social resistance, and against competitive threats (McMullen and Shepherd, 2006). Taken in this context, the emerging wave of AI systems offers transformative technological solutions that hold the potential to mitigate key uncertainties that are central to new entrepreneurial opportunities (i.e., Alvarez and Barney, 2007). This is due in part because "… the new wave of artificial intelligence does not actually bring us intelligence but instead a critical component of intelligence—prediction … (and) better prediction reduces uncertainty" (Agrawal et al., 2018: 2). Since core theories of entrepreneurship were designed to contend with action, judgment, and decision-making under conditions of uncertainty, the advancing capabilities of AI systems offer functionally superior and low-cost means to eliminate uncertainty. This, in turn, has generated challenges to existing entrepreneurship theory but also new opportunities for entrepreneurship theory development (Van Burg and Romme, 2014).

Alert to these important developments, our study addresses the theoretical implications of advancing AI systems to theories of entrepreneurial action, judgment, and decision-making. To provide a concrete grounding for our arguments, in following sections, we focus attention on how rapidly advancing AI systems provide new tools for entrepreneurs to address key aspects of modal uncertainty, best defined as "uncertainty about what is possible" (Bradley and Drechsler, 2014: 1229), meaning the array of situation-specific outcomes and eventualities that could potentially come to pass. Modal uncertainty is endemic to the types of decision problems entrepreneurs face in the pursuit of new opportunities (Townsend et al., 2018). For this reason, AI technologies have become freshly relevant in providing powerful new tools that are capable of augmenting entrepreneurial judgment and decision-making. This, in turn, is transforming the practice of entrepreneurship (Townsend et al., 2018) and raising new questions regarding theories of entrepreneurial action, judgment, and decision-making. We conclude the paper with an overview of these questions in order to outline and motivate future research on several important issues emerging at the intersection of the fields of AI and entrepreneurship.

2. Artificial intelligence, uncertainty, & entrepreneurial action

2.1. What is artificial intelligence?

The loss by world chess champion, Garry Kasparov, to IBM's Deep Blue computer in 1997, was a watershed moment for AI (Hsu, 2004). Although AI had by that time already become well-established as a central component of serial applications in manufacturing processes and productivity enhancements (Simon and Munakata, 1997), the primacy of human intelligence was still largely unquestioned (Newborn, 2000). In the wake of Kasparov's stunning loss, it became apparent that the capabilities of Deep Blue leveraged an increased capacity for raw computing power to the expert cultivation and application of chess knowledge (Hsu, 2004). In response, Kasparov lamented "I was not in the mood of playing at all … I'm a human being. When I see something that is well beyond my understanding, I'm afraid" (Kasparov, 2017: 215). Program directors at IBM were more circumspect regarding the implications of Deep Blue's victory: "Does Deep Blue use artificial intelligence? The short answer is 'no.' Earlier computer designs that tried to mimic human thinking weren't very good at it. No formula exists for intuition … Deep Blue relies more on computational power and simpler search and evaluation function" (Nilsson, 2009: 32). IBM's cautious claims notwithstanding, AI's progress was unmistakable: while Kasparov could evaluate three chess positions per second, Deep Blue could evaluate over 200 Million – a staggering computational advantage (Nilsson, 2009).

Succeeding generations of AI have built upon Deep Blue's speed and sophistication. In 2017, Alphabet/Deep Mind's system AlphaZero taught itself how to master not only chess but shogi and Go – two games that involve exponentially more complex possibility spaces. Unlike IBM's work on Deep Blue, which required painstaking development of algorithms to anticipate an enormous number of possible contingencies, AI scientists at Deep Mind developed the underlying algorithms with only a basic understanding of game rules. In a very short time (i.e., 9 h to master chess, 13 h to master shogi, and 13 days to master Go), AlphaZero defeated all other algorithms which had already beaten the top ranked human players (DeepMind, 2019). In addition, where Deep Blue required extensive programming and used brute-force methods to evaluate millions of possible chess moves, AlphaZero was developed with minimal programming and evolved in a matter of hours or days, evaluating only 60,000 possibilities per move decisions in chess. Furthermore, whereas Kasparov lamented the pure computational prowess of DeepBlue, he praised the "dynamic, open style" creative play of AlphaZero, learned by competing with itself over countless iterations of game play (Kasparov, 2018). These contrasting reactions to the success of Deep Blue and AlphaZero illuminate several important questions about exactly what AI truly is. According to the New Oxford Dictionary (2019), AI is "the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages."

The field of AI is centuries old (Brooks, 1999; Buchanan, 2005), emerging in its modern incarnation in 1956, at a conference organized by John McCarthy at Dartmouth College. After numerous false starts and a long series of prominent disappointments (Brooks, 1999), the field has evolved rapidly and is principally organized around the goal of constructing a systems-based form of intelligence (Russell, 1997) based on six different sub-disciplines: natural language processing, knowledge representation, automated reasoning, machine learning, computer vision, and robotics (Russell and Norvig, 2016). Collectively, the growing computational complexity derived from the system-level organization of these sub-disciplines continues to yield impressive results across a variety of tasks previously thought to be impossible for software systems to handle (Luger, 2005).

Although many impressive breakthroughs are still occurring in relatively narrow application areas (Agrawal et al., 2018), akin to IBM's successful deployment of Deep Blue, rapidly evolving AI systems with more ambitious technical aims are channeled towards what researchers have termed human-level AI (HLAI). Here, AI systems of intelligence are instantiated in "machines that think, that learn, and that create" (Herb Simon quoted in Russell and Norvig, 2016: 27). Although many AI scholars remain skeptical AI will replace the creativity, ingenuity, and imagination of human actors in the near term (Atkinson and Wu, 2017; Dreyfus, 2007; Searle, 1980), work is coalescing around an "augmentation thesis" whereby AI technologies extend, enhance, and complement the capabilities of humans (Jarrahi, 2018; Lemaignan et al., 2017; Epstein, 2015).

2.2. Modal uncertainty & entrepreneurial action

The fundamental problems of organizing and acting in ill-structured information environments, where the future is opaque and largely unpredictable (Townsend et al., 2018), are central to the foundational theories of entrepreneurial action (Sarasvathy, 2001; McMullen and Shepherd, 2006; Alvarez and Barney, 2007; Klein, 2008; Foss and Klein, 2012). The crux of the problem created by uncertainty under these conditions lies in the degree to which the "actual future" state of world exists only as an undefined and unbounded set of possible futures (Shackle, 1974). Under these conditions, uncertainty is the absence "… (of) a complete description of the world which we fully believe to true. Instead we consider the world to be in one or another of a range of states … our uncertainty consists in not knowing which state is the true one" (Arrow, 1974: 33). According toKnight (1921: 221), this indeterminism is the source of future opportunities for entrepreneurs to pursue novelty and innovation: "If there is real indeterminateness, and if the ultimate seat of it is in the activities of the human (or perhaps organic) machine, there is in a sense an opening of the door to a conception of freedom in conduct" (Knight, 1921: 221). In later work, Knight (1942) defines these "human activities" of innovation and adaptive judgment[1] as the primary "problem-solving activities of the entrepreneur"; that is, those activities that are essential to identify "correct manipulation of means" to achieve success in innovation through error reduction and adaptation.

However, because these indeterminate decision environments are ill-structured, the relevant information is only partially known by actors attempting to enter these markets. As such, entrepreneurs are forced to contend with weak and incomplete signals and sparse data structures in order to identify opportunities. Identifying opportunities under these conditions requires imagination and creative approaches to decision-making (Kier and McMullen, 2018; Klein, 2008). Pattern-matching capabilities are at a premium, challenging entrepreneurs to link highly fragmented data from disparate sources in order to identify the underlying patterns that can serve as the basis for action (Baron, 2006). Under these conditions, modal uncertainty creates enormous challenges for entrepreneurial actors since there are virtually unlimited possible future states of the world (McGrath and MacMillan, 2000). Furthermore, since actors engage these possible future worlds with only partial knowledge and cannot simultaneously pursue opportunities in multiple possible worlds, the opportunity costs of action are high under these conditions (Shackle, 1955). In the face of such "non-divisible, non-seriable experiments" (Shackle, 1955: 8), modal uncertainty is one of foundational challenges entrepreneurs face in pursuit of new opportunities (cf. Langlois, 2007).

3. Artificial intelligence & entrepreneurial action

Given the centrality of modal uncertainty to entrepreneurial action, AI's escalating capacity to deliver assistive, enhanced decision-making under uncertain conditions is simultaneously transformative but also problematic for extant entrepreneurship theory. On the one hand, the ability to leverage the benefits of AI into an entrepreneur's decision-making processes increases the capacity of individuals and organizations to make headway in reducing modal uncertainty (Agrawal et al., 2018). Information costs that are insurmountably large for individual actors are potentially rendered *de minimis* for intelligent machines equipped with high processing speeds and deep learning algorithms (Bughin et al., 2017). On the other hand, these developments have a direct and lasting impact on the meaning, function, and influence of modal uncertainty in theories of entrepreneurial action, judgment, and decision-making. Accordingly, we now turn our attention to discussing how emerging tools in AI research are fueling the development of practical applications and tools designed to augment human judgment in addressing the problem of modal uncertainty.

3.1. Modal uncertainty & generative algorithms

In recent years, numerous applications have emerged in the AI literature (e.g., Singh, 1998) on the effectiveness of generative search algorithms enacted by AI systems to search over massive possibility sets to identify alternative opportunities (Agrawal et al., 2018). The functional effectiveness of these algorithms has been aided by complementary advances in data storage and computing speed, to deliver novel solutions to various decision problems. Enterprise-level success stories to resolve modal uncertainty are also emerging, such as Autodesk's pioneering, AI-powered design tools that enable designers to explore massive possibility sets to identify novel and innovative designs.[2] For applications geared towards topological optimization, these tools

[1] Knight (1942) also argues that "uncertainty bearing," which he defines as the passive acceptance of residual indeterminism, is the least important function of entrepreneurship.

[2] See https://www.autodesk.com/solutions/generative-design for more information.

utilize algorithms to discover "the most efficient design based on a set of constraints or characteristics, often by removing material from the design" (Autodesk, 2019). The assistive value of this technology is potentially transformative. Since the possibility space of the design search is subject to closure based on the design constraints, the algorithm is coded to find an optimal solution bounded by those constraints. Human designers can then alter these search parameters by altering the range of possibilities (Autodesk, 2019).

Startup companies such as Insilico Medicine, an AI-powered pharmaceutical venture, incorporate deep learning algorithms (e.g., generative adversarial networks) to generate novel molecules that researchers can investigate for potential new therapeutics. Research published by the company estimates that there are 10^{30} potential "drug-like" therapeutic molecules, a sprawling possibility space of new drug candidates of which only a tiny fraction has been explored through established drug discovery practices (Putin et al., 2018). To address these challenges, Insilico is pioneering new generative adversarial networks that weave together a set of sophisticated generative algorithms to identify possible new therapeutics with various "adversarial" algorithmic filters to eliminate candidates that do not meet certain criteria (Insilico, 2019). The startup combines these drug candidates with predictive algorithms to determine the likelihood that these drug candidates could successfully make it through the clinical trials process. Across these and many other examples, the convergence of rapidly improving generative algorithms such as those developed by Insilico enable entrepreneurs to rapidly and efficiently identify latent means-ends combinatorial patterns and possibility sets (Russell and Norvig, 2016). Collectively, these AI-powered tools facilitate the exploration of massive possibility sets will continue to advance to mitigate the problems of modal uncertainty in the pursuit of opportunity (Zyt et al., 2002).

3.2. *Modal uncertainty & creative AI*

In addition to improving search algorithms, AI-powered learning systems are enhancing the emergence of creative AI (Boden, 1998). An example of these developments is described by Cully et al. (2015) in reports of their experiments training robots to walk, based on the assumption the machine's legs were damaged. One of the decision constraints imposed on the machine was to figure out how to walk using the lowest percentage of contact between the robot's feet and the ground. After canvasing a vast array of possible solutions and assessing the relevant outcomes, the machine quite surprisingly reported it could walk with 0% contact between its feet and the ground. Cully et al. (2015) presumed that this seemingly impossible result was a calculative glitch of some sort. With no foot contact, there could surely be no movement. However, when the team evaluated the machine's solution, they discovered that the machine had eschewed framing assumptions regarding the robot's ambulatory capabilities. Reaching to an imaginative frontier of possible solutions, the machine quite creatively flipped the robot onto its back so it could walk – with full functionality – on its elbow joints, an inventive and unprogrammed solution to the problem.

This is not an anomalous outcome of an isolated experiment. For decades, creativity studies have been a small but vibrant sub-field in AI research. Boden (1998) crafted an early overview of the state of AI creativity research in which she discerned three main types of creativity in the generation of novel ideas: novelty through combinations of familiar ideas, exploratory creativity that generates novelty through the "exploration of structured conceptual spaces" to find unexpected solutions, and transformational creativity that generates novelty through altering specific structures or constraints of the decision environment (Boden, 1998: 348). The achievement of these types of creative AI is reflected in emerging products developed by companies such as Autodesk. In addition to its topological optimization tool described above, Autodesk is also pioneering AI-powered design tools that enhance and augment the capabilities of human designers to explore massive possibility sets to identify novel and innovative designs (Autodesk, 2019). Autodesk is also developing novel generative design algorithms that augment the transformational creativity of human designers (Autodesk, 2019).

Startup companies like Stitch Fix are leveraging similar types of algorithms to enhance the identification and development of innovative new designs in the fashion industry. "We approach this opportunity with inspiration from genetic algorithms: we use recombination and mutation along with a fitness measure … to (create) new styles by recombining attributes from existing styles and possibly mutating them slightly" (Stitch Fix, 2019). The company goes on to note that since "the number of possible combinations is very large" the company augments the model with the work of "human designers to vet and refine this collection, and ultimately to produce the next generation of styles" (Stitch Fix, 2019). Throughout the business model, Stitch Fix blends the work of algorithmic and human ingenuity to power the venture's business model, and in doing so, is pioneering a new model of retail fashion (Wilson et al., 2016).

As these examples illustrate, AI researchers have made significant advances in the past several decades to enhance the creative capabilities of AI systems to resolve modal uncertainty (Boden, 2014). And yet, while these breakthroughs are of unquestioned importance, contemporary discourse is often still based on an outdated view of AI – colorfully described as GOFAI, Good Old-Fashioned AI (Haugeland, 1985) – which emphasizes the symbolic, procedural rationality of these systems. Since these older systems rely upon brute-force computational methods they are, at best, a modest simulacrum of human intuition and creativity. In contrast, new methods are emerging which blend together sophisticated generative algorithms with deep learning tools are providing powerful tools for developing novel and creative solutions that can serve as the basis for entrepreneurial opportunities. In light of these developments, we now turn towards discussing the implications of AI for theories of entrepreneurial action, judgment, and decision-making.

4. Directions for future research

Our central premise in this paper asserts that emergence of AI will transform both theory and practice in the field of entrepreneurship, offering powerful new tools for resolving the modal uncertainties endemic to the processes of innovation and opportunity pursuit. By rendering moot many of the obstacles that thwart systematic search through seemingly infinite possibility spaces, AI systems are poised to improve the range of actions and opportunities new ventures will pursue even while driving the marginal costs of search towards zero (Agrawal et al., 2018). This transformational role of AI constitutes a watershed moment for scholars and practitioners alike to reflect upon the implications of AI for extant theories of entrepreneurial action, judgment, and decision-making; Plainly stated: what is the role of entrepreneurs and entrepreneurship in the age of AI? We now turn our attention to exploring this question.

4.1. Implications for theories of entrepreneurial action, judgment, and decision-making

Almost a century ago, Frank Knight (1921) thesis on the specialized role of entrepreneurs in bearing uncertainty set forth many of the foundational arguments that shaped the development of entrepreneurship theory in recent years (Sarasvathy, 2001; McMullen and Shepherd, 2006; Alvarez & Barney, 2007; Klein, 2008; Foss and Klein, 2012; Townsend et al., 2018). Yet, as we have briefly outlined in this paper, the rapid advancement in the form and function of AI systems is creating powerful tools and new solutions for solving the problems of modal uncertainty. In Table 1 we briefly outline critical assumptions across several core theories of entrepreneurial action: effectuation (Sarasvathy, 2009, 2001), entrepreneurial action theory (McMullen and Shepherd, 2006), creation theory (Alvarez and Barney, 2007), and judgment-based analysis (Foss and Klein, 2012). We then conclude the paper with three critical implications of AI for future theory development in these streams of research.

Table 1
Uncertainty, entrepreneurial action, and artificial intelligence.

	Effectuation Theory (Sarasvathy, 2001, 2008)	Entrepreneurial Action (McMullen and Shepherd, 2006)	Creation Theory (Alvarez and Barney, 2007)	Judgment-based Analysis (Foss and Klein, 2012)
Nature of Entrepreneurial Action	Processes enacted by expert entrepreneurs to leverage existing means under conditions of goal ambiguity to establish new means-ends relationships into new possible states (i.e., effects) of the world.	Action in the face of partial and incomplete knowledge through a two-stage process of identifying and then personalizing possible entrepreneurial opportunities.	Emphasizes the generative actions of entrepreneurs to create new opportunities (i.e., bring agency to opportunities).	Emphasizes action as the use of human judgment to deploy resources in pursuit of core organizational objectives.
Strategies to Address Modal Uncertainty	Expert entrepreneurs *"transform current means into co-created goals with other who commit to building a possible future"*	Uncertainty-bearing thesis: Modal uncertainties in the forms of state and effect uncertainties are addressed through the active "bearing of uncertainty"	Modal uncertainty, instantiated in the concept of evolutionary realism, which presupposes a modal, branching-tree structure to the processes of opportunity emergence requires iterative engagement among actors in the environment (i.e., act and see)	Entrepreneurial judgment is cast as a key mechanism for resolving modal possibilities of which resources to exploit, which employee(s) to hire, which courses of action to pursue when no clear decision rules exist.
Role of Human Actors	No matter how sophisticated of a set of technical tools are at the disposal of human actors, effectuation emphasizes the importance of the "pilot in the plane" to guide the design and actualization of potential futures.	Filtering of third-person to first person opportunities emphasizes the personalization of opportunities whereby possible futures are selected based on their correspondence with an entrepreneur's goals, preferences, and objectives.	Theory eschews the role of search and assumes that the emergence of novel pathways (i.e., novel modalities) emerges from the complexity of the strategic interactions of human actors.	Entrepreneurial judgment is a "cognitive faculty that is applied to those unique situations where no obvious or clear decision rule exists … the exercise of judgment (is) a skilled activity … (that is accumulated) through experiential learning (pp. 94)."
AI Research Opportunities	Generative search tools provide novel solutions for solving the problems of isotropy through a more robust classification of relevant information in entrepreneurial decision environments. Creative AI augments human design of artifacts, including product/solutions, firms, and markets.	Generative search tools facilitate identifying "third-person opportunities" through detection of anomalies and discontinuities in information environments. Creative AI facilities the identification of novel modalities and yet the decision to pursue an identified opportunity still hinges upon the perception of personal fit with the entrepreneur (i.e., "first-person opportunity).	Generative search facilitates systematic search across branching tree, possibility spaces emerging from strategic action. Creative AI tools facilitate identification of novel modalities which might be outside the scope of entrepreneurial actors (i.e., opportunity identification under conditions of ignorance).	Generative search tools facilitate more systematic analyses of decision environments to identify critical resources and possible opportunities for combining and/or recombining resources to create value. Creative AI impacts the degree to which human judgment is needed in unstructured decision environments.

4.2. Critical implication #1: generative algorithms and augmented search

One of the key points of differentiation across the four core theories of entrepreneurial action we discuss here centers on the role of search as the means for navigating through entrepreneurial decision environments. Effectuation and Creation theories explicitly reject the role of search in entrepreneurial decision environments, assuming instead that probabilistic assessment of these environments is stymied by Knightian Uncertainty. "The term 'search' has little or no meaning in creation theory. 'Search' implies entrepreneurs attempting to discover opportunities … that already exist. In creation theory, entrepreneurs do not search … they act, and observe how consumers and markets respond to their actions" (Alvarez and Barney, 2007: 15). Instead, the assumption is that the informational structure evolves based on iterative engagements between entrepreneurs and consumers/markets but that these ongoing strategic interactions are not predictable or computable. This evolving structure of the informational environment is encapsulated in the concept of evolutionary realism, which Alvarez and Barney (2007) argue cannot not be analyzed *a priori.*

In contrast, the uncertainty problem in effectuation theory stems not from too little *a priori* information but from too much information. Here the assumption is that entrepreneurial decision environments are isotropic and therefore "there are no *a priori* limits to the properties of the ongoing situation that might come into play" (Fodor, quoted in Sarasvathy, 2009: 70). Despite these seemingly conflicting assumptions, both sets of assumptions reflect the inherent challenges of modal uncertainty: In creation theory, modal uncertainty stem from the seemingly infinite contingencies and possibilities of human interactions; In effectuation, modal uncertainty also stems from "what organizational actors pay attention to helps enact their environments (therefore) human action generates isotropy in the environment" (Sarasvathy, 2009: 70).

The ability of AI systems to navigate the complexities of human interactions are improving exponentially. In the case of Deep Blue, IBM scientists had to formally program an enormous number of scenarios into the system in order to anticipate various possible contingencies of human decisions (i.e., 200 Million + calculations per move – Nilsson, 2009). The game of Go presents a more difficult computational problem since the number of branching possibilities in each game exceeds the estimated number of atoms in the universe, but AlphaZero's algorithms could defeat the world champion by calculating approximately 60,000 possibilities for each move and with minimal programming (DeepMind, 2019). AlphaZero's reinforcement learning algorithms enable the system to "learn" at an exponential rate, improving the performance of the system without requiring human judgment to anticipate all of the future possibilities the system might encounter.

Our argument here is not that AlphaZero is ready to "defeat" human entrepreneurs; But at the same time, it is crucial to recognize that AlphaZero's algorithms are designed to solve exactly the computational problems inherent in addressing the problems of modal uncertainty in entrepreneurial decision environments. And as similar algorithms are adapted into companies like StitchFix and Insilico Medicine to augment the decision-making capabilities of entrepreneurs to anticipate the actions of customers, competitors, and other stakeholders, the abilities of AI-powered startups to solve the problems of modal uncertainty that are unique to entrepreneurial decision environments will improve exponentially.

4.3. Critical implication #2: automating decision-making & entrepreneurial judgment

In contrast to effectuation and creation theories, both Entrepreneurial Action Theory (McMullen and Shepherd, 2006) and Judgment-based Analysis (Foss and Klein, 2012) do not explicitly reject the role of search in entrepreneurial action and decision-making. For EAT, the process of searching through uncertain decision environments is important for the identification of possible, "third-person" opportunities. The logic in JBA is similar as the ability to search through uncertain environments is described as a unique skill or capability of entrepreneurial actors that requires creativity and superior judgment (Foss and Klein, 2012).

Where the theories appear to differ slightly centers on the rationale for why human judgment and agentic-choice is essential to the process. In EAT, whereas search processes might solve the knowledge problems inherent in entrepreneurial environments, the decision to act still requires agentic choice since it ultimately is a not a problem of knowledge – *what should I know?* – but rather is a problem of motivation – *what should I do?* In these cases, simply knowing which possibilities [i.e., what McMullen and Shepherd (2006) refer to as state uncertainties are equivalent to modal uncertainties] are available to entrepreneurial actors resolves the problems of identifying "third-person opportunities."

In JBA, the necessity of human judgment and agentic choice in entrepreneurial action is constructed upon a different set of assumptions about the relative incompleteness of entrepreneurial decision environments. "(W)e maintain that judgment is the cognitive faculty that is applied to those unique situations where no obvious or clear decision rule exists" (Foss and Klein, 2012: 94). Here the assumption is that clear, systematized decision rules would eliminate the necessity of human judgment. Instead, the capabilities of entrepreneurial judgment are developed through experiential learning but the inherent indeterminism of the decision environment still requires the use of "entrepreneurial creativity (in) exploring, defining, and redefining the problem space in the pursuit of new opportunities" (Foss and Klein, 2012: 95).

The growing capabilities of AI-algorithms to address the problems of modal uncertainty raise key questions for both EAT and JBA, although for EAT, the emergence of AI systems is less problematic for the core assumptions of the theory. This is because the knowledge problems inherent in identifying what is possible (i.e., third-person opportunities) is less important to the theory than the motivational problems inherent in the choice of whether a perceived opportunity is something the entrepreneur desires to pursue. For JBA, however, the advent of creative AI (e.g., Autodesk's generative design algorithms) and the emergence of sophisticated learning algorithms like those developed in AlphaZero raises critical questions about the necessity of human judgment in entrepreneurial decision environments.

In a sense, key differences in the application of AI algorithms by Stitch Fix and Insilico Medicine are instructive. In the case of Insilico Medicine, the founders are constructing a largely automated system whereby the algorithms powering the company's unique approach to drug discovery largely advance through the process with human judgment and intervention at key stages in the process. In our view, the decision to automate the process in this manner makes sense because the perceived value of various therapeutic modalities is already well established by industry practices. This allows Insilico to set up filtering mechanisms to sort through all of the possible solutions generated by the AI system and automate the decision process. In contrast, Stitch Fix utilizes human designers as the "filter" for the possible solutions generated by their algorithms. The company uses human "filters" because what is "valuable" in fashion and design cannot be formalized into decision rules and requires human judgment. By implication, the necessity of agentic choice and human judgment is important where the "value" ascribed to any particular set of modal possibilities cannot be specified with formal rules. Under these conditions, AI systems augment the search capabilities of entrepreneurial actors to address the problems of modal uncertainty but would still require human judgment to address the very human problems of taste, preferences, and motivation.

4.4. Critical implication #3: ambiguity, ignorance, & modal possibilities

As we have discussed, emerging AI systems provide powerful new tools for searching massive possibilities sets to uncover new opportunities. In this sense, AI tools provide powerful tools for addressing the problems of ignorance in entrepreneurial decision environments stemming from a "lack of information or lack of awareness that an opportunity exists within the environment" (McMullen, Shepherd, & Jennings, 2007: 77). However, even while augmenting entrepreneurial decision-making to address the problems of ignorance about what is possible or feasible within a given choice set, these AI tools are still limited in their abilities to solve the problems of the desirability of these possible modalities of action. This remains largely the purview of human actors.

For both AlphaZero and Deep Blue, the computational problem largely centered on identifying the feasibility of various modalities of action. In each case, the systems could compute superior solutions to the problems of modal uncertainty because the desirability of the outcome of the decision task was fixed – namely, to win the game. In this sense, clear value preferences to "win" enhance the "computability" of possible solutions. Entrepreneurs, however, face a more complex set of knowledge problems than simply addressing the problems of modal uncertainty (Townsend et al., 2018). These problems include resolving the problems of ambiguity in determining the tastes and value preferences of customers, which as the example of Stitch Fix illustrates is still a decision problem that requires human actors to resolve (March 1978; Townsend et al., 2018).

The core theories of entrepreneurial action discussed here all address the problems of ambiguity through filtering the desirability of pursuing specific opportunities through self-assessment (e.g., McMullen and Shepherd, 2006; McMullen et al., 2007) or even through stakeholder engagement (Sarasvathy, 2001, 2009; Alvarez and Barney, 2007). This raises important questions for the application of AI tools to the practice of entrepreneurship. Since many AI decision tools are notoriously "unexplainable," both practicing entrepreneurs and entrepreneurship scholars face important questions about whether similar highly inventive moves in entrepreneurial environments that overturn centuries of conventional wisdom would be trusted by entrepreneurial actors? Simply put, would entrepreneurs be willing to stake the future success of their ventures on such unconventional moves?

5. Conclusion

In the opening paragraphs of this paper, we asserted that unbridled progress of AI research over the past few decades is the culmination of years of work "… to create and understand intelligence as a general property of systems, rather than as a specific attribute of humans" (Russell, 1997: 57). We further asserted that the application and use of these tools within the field of entrepreneurship provides powerful new tools for resolving modal uncertainty in the emergence and identification of entrepreneurial opportunities. However, the growing recognition of the power of AI-tools to amplify the creativity and imaginativeness of entrepreneurial actors to identify novel means for addressing the question of "*what is possible?*" does not negate the fundamental importance of human actors to design these systems to address the questions of *what is desirable?* For these questions, human actors will still play a foundational role in the age of Artificial Intelligence.

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