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Would Archimedes Shout “Eureka” If He Had Google? Innovating with Search Algorithms

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Short Paper

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Abstract

In this paper we investigate the relationship between algorithmic search tools and the innovation process. Today, search algorithms are used for all tasks, yet we know little about their impact on the well-studied innovation process. We suggest a theoretical framework based on centripetal and centrifugal forces that conceptualizes the relationship between the algorithmic design logics of search tools and the innovation process. We use it to illustrate the current challenges with the use of informational search tools based on design principles of popularity and personalization, for innovation. We propose the need to develop and use exploratory search models and tools for innovation.

Keywords: digital innovation, search, algorithmic search, creativity, design logic

Introduction

There is a significant body of literature documenting and theorizing how digitization has shaped the innovation process (Henfridsson et al. 2018; Mendling et al. 2020; Nambisan et al. 2017; Yoo et al. 2012). Studies have investigated how the balance between newness and comprehensibility of new product meanings is created through the interaction of digital and physical product development (Gongtai Wang et al. 2022), how 3D printing tools are shaping and accelerating the creative process (Boland et al. 2007; Lifshitz-Assaf et al. 2021) and how the use of makers technologies enhances accidental innovation (Austin et al. 2012). Others have studied the effect of digital tools on the innovation process: how digital probes cultivate and sustain diverse outputs as possibilities, thus performing as generative mechanisms (Jarvenpaa and Standaert 2018); how using online open innovation platforms to solve strategic R&D problems influences not only the knowledge boundary work but also the professional identity of R&D professionals (Lifshitz-Assaf 2018); and how using remote testing tools invoke challenges in the design process (Bailey et al. 2012).

Today, there is a burgeoning debate about the effect of search algorithms on our society. On the one hand, these algorithms provide user experiences that are consistent with user expectations, allowing users unparalleled access to information (Storm et al. 2017). On the other hand, these algorithms polarize society by exposing individuals to like-minded opinions while obfuscating contradictory ones (Haidt 2022; Pariser 2011). In the scholarly realm, the effects of search algorithms have been studied in the realms of social media and news recommendation (Chitra and Musco 2020; Holone 2016). Still, we know little about the impact of these same algorithms on creativity and innovation. Recent literature has called for further investigation of the use and impact of algorithms on knowledge work and innovation (Wang and Nickerson 2017). Our paper aspires to answer this call by investigating how the process of idea generation is mediated by algorithmic search tools.

Product designers, engineers and other creative professionals consistently use informational search engines during their innovation processes (Barker 2018). We therefore suggest that there is a need to study the effects of the informational search algorithms (ISA's) on the innovation process. In this paper, we theorize why and how algorithmic search impacts the creative heart of the innovation process, idea generation. We

build upon the information systems literature on digital innovation and representation theory and suggest how the algorithmic search is affecting the knowledge search process in ways that are critical for the creative idea generation process. We propose a process model of ideating with search algorithms that allows us to conceptualize the role of algorithmic design logics in terms of their effect on the individual's ideation process.

Ideating with Search Algorithms: A Process Model

We propose a process model of how using search algorithms for creative tasks, over time, influences the new ideas generation process of an individual social actor. We build upon the digital innovation line of inquiry (Nambisan et al. 2017; Yoo et al. 2012) and representation theory (McKinney and Yoos 2010). Underlying our model is the assumption that the focal actor's internal mental representations or referents are shaped by the digital information signs that are returned from the search algorithm (Bailey et al. 2012; Recker et al. 2019; Weber 1997). These internal representations are created by the actor in response to their encounter with the output of search algorithms. Subsequently, these representations shape the actor's meaning-making processes in their ideation process and subsequent innovations (Gongtai Wang et al. 2022; Recker et al. 2019). An assumption of representation theory is that people "desire representation that faithfully represents some domain… because they provide a more informed basis for actions than unfaithful representations do" (Burton-Jones and Grange 2013). We concern ourselves with the faithfulness and effects of search algorithms in representing the space of concepts related to the search problem. Accordingly, we focus on users that are searching for solutions to creative tasks, using digital algorithmic search systems (Weber 1997). The domain we consider is the full domain of the creative task being searched for by the focal actor. In a somewhat recursive fashion, we conceive of the concepts relating to the creative task as the real-world phenomenon that the search algorithm system is representing. Our model level of analysis is the individual social actor in their process of ideating. Our theoretical framework is built upon two main components that we define below: (1) Concept spaces (the overall concept space and the focal actor's concept space) and (2) algorithmic design logics, the logics that drive search algorithms. We specify below our theoretical framework and a model of the forces activated in the process of ideating with search algorithms. We then suggest experimental research design to investigate the important relationship between algorithmic search tools and the innovation process. We test our theoretical model by comparing the common information search algorithm of Google on creative tasks to an exploratory search algorithm and share preliminary results from a user study.

Concept Spaces: Scholars have previously noted the connection between information encountered during the innovation process and the variety of ideas iterated upon by the focal actor (Austin et al. 2012; Jarvenpaa and Standaert 2018). As we are theorizing a process model of ideating with search algorithms, we start our model with defining ideas and the process of generating new ones. According to the creativity and innovation literature, ideas can be defined as "*provisional* and *communicable* representations… that are identifiable, discrete entities, such as specific mental representations or mental states, propositions or proposals, concepts or solutions." (Hua et al. 2022) This definition aligns with representation theory which defines a representation as "a sign[that] represents information about an object for a particular observer." (McKinney and Yoos 2010) Our focal actor has their own concept space, which is the space of ideas that they have generated and accumulated over their lifetime, activated during their ideation process. Beyond this individual actor, there is a mass concept space of humanity, composed of the totality of human knowledge instantiated in concepts, including various forms of knowledge such as tacit, embodied, implicit and explicit forms of knowledge (Nonaka 1994). Over time, various domains accumulate, modify, and diffuse these knowledge core concepts. While most of the knowledge production and problem-solving takes place within disciplinary boundaries, innovation usually takes place by importing or combining core concepts from a different domain than the original one (Henfridsson et al. 2018; Jeppesen and Lakhani 2013). For instance, the invention of the pillcam uses concepts from missile technology to innovate in the domain of gastroenterology imaging (Kneeland et al. 2020). In our framework, overall, humanity's concepts are in the same representational units as ideas, albeit richer and more numerous. We bring this highly abstracted space to demonstrate the interaction between the focal actor's concepts and humanity's concept space.

Search algorithms: To elucidate the search process and connection between the search algorithms and humanity's concept space, we define the digital data space that search algorithms act upon. The units of the

digital data space are digital information units or signs (Burton-Jones and Grange 2013). These signs include text, images and any other information that is digitized and accessible to the search algorithms. Each information unit may represent one or multiple concepts in the overall concept space. Search algorithms take in a subset of the digital data space (signs) as input and return an output that is a series of digital information units as well, termed algorithmic search output in our model. As stated above, the actor interprets the output of the search algorithm, representing it in their concept space.

Information systems scholars have long investigated search algorithms and recommendation systems (Marchionini 2006). Although scholars have theorized about multiple types of search algorithms, over the years ISA's have risen to prominence both inside and outside the realms of academia. Informational search is primarily focused on "question answering" or "fact retrieval" and is usually undertaken with precise queries that yield specific results. Today, the dominant ISA is Alphabet's Google search. It is used for all types of tasks, in all ages, levels of education, professions, disciplines, and most countries in the world today, dominating the search market, with over 90% of all searches done today being on Google. We now turn to discussing the algorithmic design logic of search algorithms, defined as the motivating factors for their output (Gongtai Wang et al. 2022).

To date, search algorithms have been predominantly designed for informational search purposes, seeking to achieve search effectiveness. Larry Page, Google's founder, stated their search design vision, 'The ultimate search engine… would understand exactly what you mean and give back exactly what you want… Google didn't want to return thousands of links, it wanted to return one, the one you wanted." (Pariser 2014)

Algorithmic Design Logics: Most search algorithms' filtering functions are based on semantic similarity between the user's query and the digital information unit. However, as there are frequently a very large number of results that are similar to the user's query, there are usually algorithmic design logics that narrow down and prioritize the results that are presented to the user. Google's developers design its search algorithm according to popularity and personalization design logics. Google originally relied on PageRank, an innovative internet-indexing algorithm that crawled the web and indexed results by **popularity**. Throughout the last decade, Google has bolstered the **personalization** of results, providing context-sensitive, user-specific results (Pariser 2011). In our paper, we wish to center the design logic of popularity and personalization and their critical impact when used for creative tasks. Each of these logics acts in a recursive, time-amplified fashion. As the personalization algorithm learns more about the user, it can provide more personalized results. Similarly, as the popularization algorithm pushes popular results to the top of users' results, these results become more popular. It is therefore worthwhile to consider not only the immediate, but also longer-term effects of search algorithm use on the actor's idea generation and subsequent participation in the innovation process.

The Centripetal & Centrifugal Forces Model

The search intent of the focal actor undertaking a creative task is to perform "exploratory search" (Fleming 2001; Kneeland et al. 2020), to embark on their innovation journey (Van de Ven 2016), to find new ideas, to inspire their creative thinking. As Fleming stresses, investigating the exploratory search process is central to understanding how inventors explore uncharted technological space, as unknown domains are likely to have more untried technological combinations and thus offer more opportunity for breakthrough discovery and radical innovation (Fleming 2001). Still, the literature has demonstrated that actors usually conduct "local search" (Levinthal 1997), individuals and organizations tend to search for potential solutions close to their domain and prior knowledge. Individuals are often look for ideas close to their expertise, their organization, their industry, their country and/or culture, using their own knowledge sources and social networks (Burt 2004). The ability to use algorithmic search that works on a massive, comprehensive, and ever-growing digital database counteracts the tendency to perform local search. Instead, the actor can learn about ideas and concepts that are distant from their concept space and their social networks. This suggests that using search algorithms in the ideation process can enhance individuals' creativity and overall innovation. We propose that the extent to which search algorithms are conducive to innovation depends on their design logics. ISA's, such as Google's are designed for search effectiveness, for finding accurate and relevant information using the design logics of popularity and personalization. We claim that using algorithmic search tools driven by such design logics has detrimental effects on the creative process.

To describe the effects of the design logic on the actor's concept space, we use the analogy of physical forces. In physics, a centripetal force acts on a rotating system tending toward the center of its curved path. In our model, the focal actor resides in their concept space. As they start their ideation process, they are interested in leaving their concept space to learn about new concepts that exist in the overall concept space, to ignite their own creative ideation process. We suggest that repeated use of ISA's based on popularity and personalization design logics creates centripetal forces that act upon the actor. The actor is pushed into a concept funnel that narrows over time, constraining their very ability to *be creative*, to recombine and build upon indirect concepts. A visual illustration of our forces model is presented in Figure 1 below.

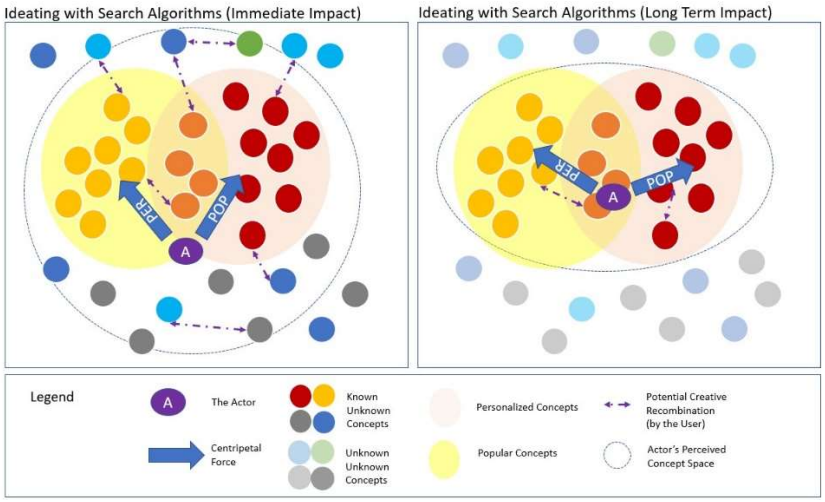

Figure 1. Ideating with Search Algorithms: Centripetal and Centrifugal Forces Model – In the right panel, we show the popularity (POP) and personalization (PER) forces being exerted on the actor in the concept space, pushing them toward average, concepts similar to ones already in their concept space. In the left panel, we show the effects of the *centrifugal force* (the actor's concept space is shrunk), the *comprehensive illusion* (concepts outside of the user's concept space are faded and the weakening of the actor's creativity (they are able to conceive of connections less).

Popularity centripetal force and its effect on the ideation process: The popularity algorithm design logic uses already extant attributes of the internet to index web pages. For instance, Google's original algorithm, PageRank, used backlinks to direct popular pages to the top of its search results. Today, even though there are other search logics involved, popularity remains a major factor in determining the order of search results (Google, 2022). We propose that when ideating with the ISA that is based on popularity, a **popularity centripetal force** (POP) is created, pulling the actor in the concept space toward widely accepted knowledge concepts. This popularity centripetal force is self-reinforcing, acting in a *convergent* manner on the actor's ideation process, converging them onto known, popular concepts. This convergence is caused by a feedback loop: over the last 30 years, PageRank has surfaced popular websites. These websites were clicked on by users who then produced content backlinking back to the clicked site. The algorithm would then up rank the original sites again (Pariser 2014). From an innovation theory perspective, this centripetal force contradicts the search intent of "exploratory search" and the main theoretical tenets of innovation. According to the "long tail" theory of innovation, innovative ideas are found at the "long tail" of the distribution of ideas and not in the popular area where most ideas are (Fleming 2007). Information scholars have also noted the inherently "average" quality of the results produced by Google's search: "The efficiency-based approach to analyzing information used by these systems means we are only presented with the average of this material. Googling 'chair' may not bring you images to inspire new ideas; you might just get a collection of pictures that look similar." (Mothersill and Bove 2019)

H1: Actors that use informational algorithmic search tools that are based on a popularity design principle for a creative task will be ideating mostly based on widely accepted knowledge concepts, thus decreasing the level of novelty of their generated ideas.

The Personalization Centripetal Force and its effect on the ideation process: The personalization design logic uses data about the actor's preferences to tailor the search results to the actor.

Personalization algorithms, in general, construct a simplified model of the user's preferences modifying the search results presented to the user based on those preferences. Typically, personalization algorithms are based on a variety of data sources that the search algorithm has access to; for instance, geolocation and social networking metadata (Provost 2011).

We propose that when ideating with the ISA that is based on personalization, a personalization centripetal force (PER) is created, pulling the actor in the concept space toward concepts like those that they have previously encountered, acting in a priming, *confirmatory* manner. The algorithm preferentially presents websites that it predicts will conform to the model's approximation of the user's personality and taste. A feedback loop is created as the actor clicks on the link and may indeed find the link compelling, increasing their preference for the specific website. Thus, the user is increasingly directed to both concepts that they are being predicted to like by the algorithm. Pariser clearly describes the confirmatory bias created by the filter bubble: "You click on a link, which signals an interest in something, which means you're more likely to see articles about that topic in the future, which in turn prime the topic for you. You become trapped in a you loop." (Pariser 2014)

The center toward which the user is pulled by the PER is concepts related to the algorithm's model of the actor's personality profile and preferences. This personalization centripetal force is also self-reinforcing and acts in a *convergent* manner on the actor's ideation process. From an innovation theory perspective, this centripetal force reinforces known cognitive forces that work against creative ideation. The innovation literature has demonstrated how individuals develop socio-cognitive fixation over time and with experience that leads them to see problems in a similar way, and blocks them from creative problem-solving (Dane 2010; Foster and Kaplan 2001). This socio-cognitive fixation has been shown to result from prevalent industry-shared beliefs (Benner and Tripsas 2012), professional "epistemic cultures" (Knorr Cetina 1999), organizational identity, or past successes (Tripsas and Gavetti 2000). An algorithmic search tool that tailors the search space to that of the individual's past work, profession and industry can work as a force multiplier to the socio-cognitive fixation. In particular, as specialization has been rising in many scientific and technological fields in recent decades (Brusoni 2005), the tendency toward a high degree of cognitive inflexibility increases (Dane, 2010). As Google search is designed to present results within the field of interest and specialization of the specific actor, it can be viewed as deepening the cognitive fixation of what an individual already knows, creating "innovation blindness" (Leonardi 2011).

H2: Actors that use informational algorithmic search tools that are based on a personalization design principle for a creative task, will be ideating mostly based on concepts that are similar to their pre-existing concepts and familiar ones, thus decreasing the level of novelty of their generated ideas.

The long term effect of the centripetal forces: We suggest that the centripetal forces create a long term effect that is negatively influencing the creative ideation process by weakening the actor's ability to *generate creative ideas*. Due to the self-reinforcing nature of the centripetal forces, repeated use lowers the likelihood of exposure to new concepts. When individuals are confronted with new concepts, they search for connections between the new information and their existing knowledge network (Nonaka 1994). The creative work process encompasses meaning-making of these new concepts (Gongtai Wang et al. 2022), and attempting to recombine new concepts with their prior concepts or cumulatively build on other concepts. As Koestler noted, creativity "uncovers, selects, re-shuffles, combines, synthesizes already existing facts, ideas, faculties, (and) skills." (Koestler 1964) The process of recombinant innovation often relies on analogical thinking processes, abstracting the search problem, searching for analogies across a variety of domains and applying them to generate solutions to the original problem (Gilon et al. 2018). We suggest that as the centripetal forces pull the actor away from unfamiliar and indirectly related ideas, the actor's ability to connect indirect concepts, to recombine ideas, and therefore to generate *creative ideas,* is weakened. A recent study on navigation abilities showed that repeatedly using a GPS "negatively impacts spatial memory during self-guided navigation." (Dahmani and Bohbot 2020) Similarly, we posit that consistently using ISA's for creative tasks can lead to an atrophy of the actor's recombinant innovation abilities.

H3: The more often actors use informational search for creative tasks, the less likely they are to recombine and connect indirectly related concepts in creative ways in their ideation process.

The Centrifugal Force

We suggest that using ISA's in the ideation process also creates centrifugal forces. In physics, the centrifugal force is an imagined force that points in the opposite direction of the centripetal force. We propose that the centrifugal force acts as a force that leads the user to perceive that they are searching across a broad, comprehensive space of concepts aligned with their search intent for an exploratory search. This perception is created by the fact that when they use the search engine for informational search, for non-creative tasks, the actor does indeed get a sufficient and significant number of results returned to them. Using algorithmic search, the user sees themselves as surveying the significant subset of the knowledge domain that is relevant to their query, whereas their domain in fact remains quite limited. This *comprehensiveness illusion* is risky as the search algorithms cut out indirectly related concepts that would otherwise inspire the user for creative solutions. Burton-Jones (2019) defines the faithfulness of representations as the ability of a system to "represent certain real-world phenomena, allowing users to reason about these phenomena more cost-effectively than if they were observed directly." (Recker et al. 2019) The comprehensiveness illusion forms an illusion of a faithful representation of the concept space relating to the actor's problem; in reality, however, the actor is presented with only a constrained, skewed, and unfaithful representation of the concept space. Using the navigation analogy, we suggest that a longer-term effect of using ISA's for ideation is that the actor's conception of the world is smaller than it is. That the overall concept space as imaged by the actor is, in fact more limited than in reality.

H4: The more actors use ISA's for creative tasks, the smaller the amount and type of "known unknown" concepts that they perceive as relevant to their ideation process.

H5: The more actors use ISA's for creative tasks, the stronger their beliefs that they have found the necessary concepts for ideating on their creative tasks.

Counteracting the centripetal forces

Algorithms can be designed in various ways: there is no technological determinism on how they are designed and used (Bijker and Pinch 1987). Recent research on algorithms and innovation has started exploring building algorithmic tools that can enhance innovation. For instance, algorithmic tools to find new combinations of knowledge entities to produce innovation, including chemical and biological entities from academic papers (Foster et al. 2021), and patent databases (Youn et al. 2015) as well as building algorithmic tools that search for analogous knowledge components across knowledge domains (Hope et al. 2017; Sun et al. 2016). With this spirit, we argue that the way to counteract the centripetal and centrifugal forces is by purposefully designing exploratory search algorithms or exploration functions/modification on the ISA's. The search literature has broadly described exploratory search algorithms, as "more open-ended, persistent and multi-faceted" search that is needed when "searching for inspiring ideas about new products or services" (Taramigkou et al. 2017). We believe that there could potentially be multiple ways to design an exploratory search algorithm that will enhance creativity and overall create an augmented innovation process. In this paper, we suggest focusing on forces with design logics that specifically counteract those of informational search of popularity and personalization, namely: diversity and universalism.

Diversity: To counter the centripetal force of popularity, we propose a diversity design logic. This logic aims to inspire the user with a variety of concepts by diversifying the set of digital information units that they are exposed to. We note that there is a need to balance this logic with the baseline relevance logic (as complete diversity would essentially be randomness). Therefore, a diversity logic balances relevance and variety.

The underlying mechanism of exploratory search is enhancing the **diversity of information** and knowledge that goes into the innovation process (Fleming 2001; Page, Scott 2007). Exposure to concepts from a wide variety of knowledge domains offers substantial potential for innovative output (Levina and Orlikowski 2009; Majchrzak and Malhotra 2013). We propose that when ideating with the search algorithm that is based on diversity design logic, a force is created, pushing the actor in the concept space toward concepts different to those that they have previously encountered, acting in a *divergent* manner. We postulate that repeated exposure to a wide array of concepts that are indirectly related to each, leads the actor to practice their creative recombinant abilities of finding connections that in turn enhances their creative output (Hargadon & Sutton, 1997; Henfridsson et al., 2018).

H6: Actors that use exploratory algorithmic search tools that are based on a diversity design logic for a creative task will be ideating based on a broad set of concepts, increasing the level of novelty of their ideas.

H7: The more often actors use exploratory algorithmic search tools for creative tasks based on a diversity design, the more likely they are to recombine and connect indirectly related concepts in creative ways in their ideation process.

Universalism: To counteract the centripetal force created by the personalization logic, we propose a search algorithm with a universalism logic that presents the same results to each user regardless of who they are and their past searches. The algorithm does not learn anything about the user, and therefore does not tailor results over time, not biasing the user towards their prior searches or ideas. Implementing a universalist logic involves basing results solely on the underlying digital information units and the user query without using metadata about the user. This logic has been gaining traction; DuckDuckGo, a privacy based search engine has been growing exponentially in popularity in the last few years (Barry 2021) and other competitors, such as Qwant, are entering the field.

This design logic of universalism mitigates the individual actor's confirmation bias. We suggest that when ideating with a search algorithm that is designed according to a universalism logic, actors will get exposed to concepts that are unfamiliar to them. This exposure should have an immediate effect as well as a long term effect encouraging actors to recombine new, indirect concepts with theirs, increasing the novelty of their ideas and enhancing their recombinant capabilities over time.

H8: Actors that use exploratory algorithmic search tools that are based on a universalism design logic for a creative task will be ideating based on concepts that are less familiar to them, increasing the novelty of their ideas.

H9: The more often actors use exploratory algorithmic search tools for creative tasks based on a universalism design, the more likely they are to recombine and connect indirectly related concepts in creative ways in their ideation process.

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