THEORIZING INNOVATION IN A DIGITIAL FIRST WORLD: STEPS TOWARDS A COGNITIVE ECOLOGY OF DIGITAL INNOVATION MANAGEMENT

ABSTRACT

Digital technologies that operate autonomously, learn, and perform 'cognitive' tasks pose significant challenges to theories of innovation management. It is no longer the case that innovation actors think *with* digital technologies, but rather they think *through* digital infrastructures that compute human experience and shape innovation trajectories. Existing research suggests that we can understand how digital technologies shape organizational innovation by examining the socio-cognitive processes through which they are interpreted, or by elaborating the ways in which material agency intervenes to circumscribe human activity. This paper contends that, while offering important insights, the dominant socio-cognitive and materialist approaches to studying technology in digital innovation, fall short of capturing how digital objects not just interact with humans, but how human experience itself is computed. This paper therefore advances a novel 'cognitive-ecological' approach to the study of digital innovation, that allows us to attend to the digital mediation of human experience and the non-materiality of digital objects. We draw on the work of Gregory Bateson, N. Katherine Hayles and Edwin Hutchins, to conceptualize cognition as an ecological *process of computation* that unfolds through *cognitive assemblages* comprised of conscious (human) and non-conscious (technical) cognizers. We outline how this 'cognitive-ecological' approach might function generatively to reconcile socio-cognitive and materialist perspectives, and elaborate on how future research might employ the cognitive-ecological approach to unpack the cognitive dynamics of human-technology relations.

Keywords: Digital innovation, digital object, distributed cognition, ecology, mobile robotics, algorithmic management, Hayles

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INTRODUCTION

Digital technologies have become infused with almost all aspects of contemporary organization (Alaimo and Kallinikos 2022; Bailey et al. 2022). Networked technologies are fundamentally different from other previous technological developments, in that they demonstrate the ability to learn, the ability to operate autonomously, and the capacity to outperform humans in a variety of skilled cognitive tasks (Bailey et al. 2022). The theoretically disruptive capacity of emerging digital technologies is exemplified in recent debates concerned with digital innovation management, where it is argued that digital technologies pose challenges to assumptions about the boundaries of innovation, the conceptual distinctions between processes and outcomes, and the locus of innovation agency (Nambisan et al. 2017; Yoo et al. 2012). The scale of the theoretical challenges precipitated by digital technologies is such that researchers have called for the development of novel theoretical approaches that might help us get a grasp on the fluid, distributed and dynamic nature of digital innovation (Baygi et al. 2021; Nambisan et al. 2017).

To address the role of the digital in innovation processes, we first turn to existing theoretical configurations of the relationship between technology and innovation, focusing on socio-cognitive and materialist approaches. It is argued that these theoretical approaches offer promising solutions to unveiling the mechanisms through which digital technologies influence, configure and direct digital innovation (Nambisan et al. 2017). Socio-cognitive approaches emphasize the interplay of human cognition and technological developments through the notion of technological frames (Olesen 2014; Orlikowski and Gash 1994; Spieth et al. 2021). These approaches inculcate a focus on the ways in which technological developments unsettle entrenched cognitive frames, and the socio-political processes through which new frame are established and legitimized (Kaplan and Tripsas 2008; Raffaelli et al. 2019). In this way, socio-cognitive approaches may be useful in revealing the social processes and mechanisms (e.g innovation narratives and sensemaking) through which digital innovation may be shaped (Kumaraswamy et al. 2018), but they configure technology only as a passive element that primarily functions to trigger these social processes.

A greater performative role of technology is recognized by IS research informed by 'materialist' approaches (Barrett et al. 2015; Cecez-Kecmanovic et al. 2014; Leonardi 2011; Mazmanian et al. 2014; Orlikowski and Scott 2015). Whilst there are varying ontological positions that are encompassed within the broad notion of materialism (Leonardi 2013), these approaches generally ascribe to material objects varying degrees of agency, and describe the human and material world as more deeply connected and co-related. Here, both human and material agencies are variously seen to 'afford' particular uses, becoming 'imbricated' in work systems, 'entangled', or arranged in sociomaterial 'assemblages'(Leonardi 2013; Orlikowski and Scott 2008). Each of these concepts offers a progressively active account of the role of technological artefacts in relation to the human (social) process of innovation (Orlikowski and Scott 2015). These approaches help unveil the ways in which digital technologies configure innovation processes, and how they are implicated in material discursive practices that are constitutive of organizational innovation (Nambisan et al. 2017). More broadly, they shine a light on the activity of digital technologies in shaping innovation trajectories, for example by highlighting the material-discursive practices through which particular inclusions and exclusions are made (Orlikowski and Scott 2015).

In this paper we argue that while socio-cogntivie and materialist approaches have been useful in advancing understandings of digital innovation, their conceptions of technology do not go far enough to attend to the particularities of the digital object which are non-material and computationally contingent (Faulkner and Runde 2019; Yoo 2010). This ontological ambivalence renders accounts of digital technologies as localized interpretations or enactments problematic (Kallinikos et al. 2013), while socio-cognitive accounts (Kaplan and Tripsas 2008) fall short of capturing distinctive affordances of digital objects that enable the computational mediation of human experience. When digital objects enter into innovation processes they no longer merely trigger human cognitive processes, but their largely invisible participation in shaping cognition means that generating information, developing interpretations, and making determinations in response to these interpretations are tasks that are distributed between human and non-human actors (Baskerville et al. 2020; Murray et al. 2021). It is therefore no longer the case that human innovators think *with* digital technologies, rather they think *through* vast, opaque, non-material digital infrastructures that shape physical reality and *compute* human experience (Baskerville et al. 2020; Yoo 2010). Whilst IS research has systematically elaborated the capacity for digital technology to mediate human experience (Baskerville et al. 2020; Yoo 2010), we currently lack an understanding of how the *cognitive* capacities of digital technologies function to shape innovation processes and outcomes, and this is the challenge that the current paper takes up. Developing understandings of the ways in which digital technologies shape cognition in the process of innovation is a particularly pressing concern in light of emerging efforts to digitize and automate industrial R&D (Accenture Life Sciences 2020). For example, it is anticipated that in the next five years, biopharmaceutical firms will "increasingly use AI models to identify and validate targets, design molecules, synthesize and test molecules in silico, and feed data back into these models to improve their predictive capabilities in order to accelerate the laborious and capital-intensive process of drug discovery" (Deloitte 2020, p. 5).

To advance understandings of how the cognitive capacities of digital technologies function to shape innovation processes, this paper develops a novel conceptualization of the relationship between human cognition and digital technology, anchored in ideas concerned with ecological cognition (Hayles 2017; Hutchins 1995, 2010). Specifically, we advance a novel conceptualization of cognition as a distributed process of computation that implicates conscious, as well as non-conscious cognizers, and unfolds across social and technological contexts (Hayles 2017; Hutchins 1995). We then expound how digital innovation emerges as a property of shifting *cognitive assemblages,* that encompass feedback and feedforward relations amongst conscious cognizers and non-conscious technical systems. In configuring digital innovation as an emergent property of malleable cognitive assemblages, our approach foregrounds the cognitive dynamics of human-technology relations, sidestepping thorny debates concerned with the limitations of 'social' and 'material agency' (Cecez-Kecmanovic et al. 2014; Kautz and Jensen 2013; Leonardi 2013). Instead, we highlight how digital innovation is characterized by regimes of punctuated agency amongst conscious cognizers and *cognitive* technologies. In foregrounding cognitive dynamics, our approach attends to the distinctive character of digital objects, namely their computational contingency and non-materiality (Faulkner and Runde 2019). Similarly, by drawing attention to the cognitive activity of digital objects and locating them in distributed cognitive systems, we can explain how the computational mediation of human experience plays out in the process of digital innovation (Baskerville et al. 2020).

We believe that our cognitive-ecological approach to human-technical relations has significant implications for research and practice. First, we offer a novel theoretical approach to digital innovation management, one that attends specifically to the nature of digital objects, responding directly to calls for the development of new theoretical perspectives that explain the intermingling of the human and the technological the process of digital innovation (Nambisan et al. 2017). Second, in elaborating the mechanisms through which digital technologies contribute to human cognitive activity, we are able to explain how the decisions of digital systems function to shape innovation processes and outcomes, in particular the process of invention (Garud et al. 2013). In foregrounding distributed flows of cognition, the activity of digital systems in innovation processes become more transparent and tractable (Baskerville et al. 2020). Third, our cognitive-ecological model of human-technical interaction lays the foundation for a new strand of research concerned with the role of cognition in digital innovation, extending the scope of cognition beyond individuals and groups (Kaplan and Tripsas 2008), to technological artefacts and infrastructures. This line of inquiry may overlap with, and complement approaches that highlight the socio-cognitive aspects of digital innovation (Fraser and Ansari 2020; Nambisan et al. 2017), as well as those that draw attention to the performativity of digital artefacts in configuring innovation processes and outcomes (Barrett et al. 2015; Orlikowski and Scott 2015). The theory articulated here does not contradict, or refute existing socio-cognitive and materialist approaches to digital innovation, but rather functions genratively to reconcile these perspectives, illuminating socio-cognitive processes whilst attending to activity of digital technologies in the configuration of these cognitve processes.

LITERATURE REVIEW

The Digital Object and The Digital Condition

IS research is increasingly attentive to the particularities of the digital object and the digital condition as such (Baskerville et al. 2020; Faulkner and Runde 2013, 2019; Kallinikos et al. 2013; Yoo 2010). Contrasting theoretical approaches embrace different perspectives on the ontological stability of the digital object, with some affirming the ‘thingness’ of digital objects (Faulkner and Runde 2013, 2019) and others emphasizing their ontological ambivalence (Kallinikos et al. 2013). One way to approach digital objects is by distinguishing between data (audio, video, datasets) and their associated the non-material bitstings[1] that encode programs (sets of computational instructions) and so called 'bearers' which can be material (e.g hard, disk drives) or non-material (e.g file formats) (Faulkner and Runde 2019). Unlike material bearers which exhibit spatio-temporal attributes, digital objects themselves have no inherent spatio-temporal properties or features (e.g volume, location, mass). Digital objects "take shape on a screen or hide in the back of end of a computer program, composed of data and metadata regulated by structures and schemas" (Hui 2016, p. 1) and they cannot be directly experienced unless they 'bottom-out' in material bearers (e.g. an LCD screen on a laptop) (Faulkner and Runde 2019). The second essential property of digital objects is their computed nature or computational contingency (Baskerville et al. 2020). Unlike analogue objects that are typically connected to other external referents, digital objects are fundamentally self-referential (Yoo et al. 2010), as they are the products of computation, understood as "real time processes performed by digital computers that involve the algorithmic manipulation of information borne by bitstrings" (Faulkner and Runde 2019, p. 1288). However, these processes are themselves defined by bitstrings that encode instructions and as such "digital actions and digital objects can be indistinguishable" (Baskerville et al. 2020, p. 510). It is this mutually constitutive relationship between computation and digital objects that gives rise to computational congingency, rendering digital objects perennially incomplete, or continuously in the making (Garud et al. 2008; Kallinikos et al. 2013).

The non-material and computed nature of digital objects give rise to a multitude of distinctive technological affordances (Kallinikos et al. 2013; Yoo 2010; Yoo et al. 2010, 2012). For example, the bitstings that lie at the core of digital objects "enable the separation of the semiotic functional logic of the device from the physical embodiment that execute it",

[1] "A type of syntactic object made up of 0s and 1s employed in a binary numbering system, where bits are structured according to an appropriate file format so as to be readable by the kind of computer hardware for which they are intended" (Faulkner & Runde, 2019 p. 1285).

meaning digital objects are reprogrammable in terms of their functional capabilities (Yoo et al. 2010, p. 726). Similarly, this binary coding enables data homogenization, whereby signals are converted into homogenous bitstings that can then be stored, transmitted, processed or displayed by any other digital object[2] (Yoo et al. 2010), thus the degree of modularity afforded by digital technologies runs much deeper than that afforded by traditional technologies characterized by the tight coupling of content and medium (Kallinikos et al. 2013). In contrast to non-digital technologies, digital objects are editable (i.e always open to modification), interactive (i.e enable multiple forms of activity), open (i.e accessible to other digital objects) and distributed (Kallinikos et al. 2013). These attributes enable the development of complex, layered architectures consisting of both material (i.e hardware) and non-material (i.e software) elements, which are spatially distributed and may be largely inaccessible to localized human perception (Baskerville et al. 2020; Yoo et al. 2010).

More radically, it is suggested that the capacity of digital artefacts to change functions (reprogramability), communicate (addressability, communicability), sense and adapt to environmental conditions (sensibility), store information (memorizability), identify and connect with other digital objects (traceability and associability) give rise to a radical new form of computing (Yoo 2010). Specfically, it is argued that computing is no longer a discrete activitiy that takes place in particular organizational contexts or settings, rather human expeirence is increasingly subject to full, or partial digital mediation (Yoo 2010). The notion of experiential computing suggests a much tighter intertwinement of human experience with technological affordances, so much so that technology is not merely an object of interpretation, nor is the experience of technology an end in itself, rather digital technology increasingly shapes our lived expeirence (Yoo 2010, p. 218). Developing this

[2] The homogenization of data enables the separation of the content and the medium, in contrast to analogue devices were heterogenous signals on one medium are converted into heterogenous signals in another medium.

argument further, it has been argued more recently that, the contemporary digital condition is characterized by an ontological reversal, whereby digital objects are no longer tools that model physical realities and aid human decision-making, but actively participate in shaping those very physical realities and experiences (Baskerville et al. 2020). It is a condition in which human actors no longer think with digital tools, but rather think through vast, opaque, non-material digital infrastructures that *compute* human experience and regulate social life (Baskerville et al. 2020).

In light of the distinctive affordances of digital objects and ontological reversal implicated in the contemporary digital condition, theoretical approaches to organizational innovation face significant challenges if they locate innovation within the domain of the firm, rely on the concentrated agency of organizational actors for explanation (e.g Crossan & Apaydin, 2010), or propose a sharp distinction between innovation processes and outcomes (e.g Garud, Tuertscher, & Van de Ven, 2013). The distinctive features of digital objects (i.e non-material and computed nature) and their associated affordances mean that organizational innovation no longer be treated as a bounded phenomenon, with pre-defined innovation agents and neatly demarcated processes and outcomes (Nambisan et al. 2017).

To address these challenges, two contrasting theoretical approaches are proposed, one which focuses on the socio-cognitive processes through which digital innovation unfolds, and the other which emphasizes the agency of technology itself in processes of organizational innovation (Nambisan et al. 2017). Below we unpack these contrasting theoretical approaches further and argue that, while each has their merits in attending to aspects of digital innovation, neither adequately attends to the non-material natute of digital objects, nor the computational mediation of human experience.

Socio-cognitive Approaches to Digital Innovation

Socio-cognitive approaches emphasize the interplay of human cognition and technological developments. At the heart of socio-cognitive approaches lie technological frames, which are preunderstandings and interpretive repertoires that determine how a new technology is understood and used (Spieth et al. 2021). Technological frames encompass assumptions about the nature of a technology (i.e what it is and what it can be used for), expectations about performance and beliefs about its importance and value (Kaplan and Tripsas 2008; Orlikowski and Gash 1994). Frames are held at both individual and collective levels, although research tends to focus on the collectively-held frames of distributed innovation actors (e.g users, producers, institutions) (Kaplan and Tripsas 2008). Functionally, technological frames reduce the complexity and ambiguity of novel technologies and direct managerial attention, which support sensemaking by innovation actors (Spieth et al. 2021). It is suggested that technological changes function to unsettle entrenched technological frames, and 'trigger' recurring processes of deframing and reframing until the emergence of a new (provisional) collective frame (Kaplan and Tripsas 2008; Spieth et al. 2021). Thus, it is argued that frames exert a powerful influence over the choices human actors make in the design, adoption and use of technology, and therefore over organizational innovation (Kaplan and Tripsas 2008; Orlikowski and Gash 1994; Spieth et al. 2021).

Building on technological frames, socio-cognitive approaches conceptualize innovation in terms of the beliefs of innovators as the generative forces that shape decisions about technology development, adoption and use (Garud and Rappa 1994). Innovation management describes the process by which technological changes establish or change the collective technological frames held by innovation actors, and how such frames shape organizational responses including R&D investment and technological trajectories (Kumaraswamy et al. 2018). Existing research on the implementation of digital technology in the context of public administration suggests that framing entails a translation process, in which core actors enrol others in support of a shared vision (Azad and Faraj 2008). This process unfolds through cycles of frame differentiation, frame adaption and frame stabilization which enable the translation of incongruent frames amongst diverse stakeholder groups and facilitate a temporary consensus on a 'truce frame' (Azad and Faraj 2008) that emphasizes commonalities in technological frames across groups. Earlier research examining IS delivery highlighted how innovation actors employ discursive strategies (e.g stories, metaphors) to shift frame salience amongst different organizational constituents, and emphasized how such shifts in frame salience can facilitate or inhibit the adoption of novel IT applications (Orlikowski and Gash 1994). Whilst these studies suggest a degree of flexibility in technological frames, allowing space for actors to influence frame salience, others have indicated the relative rigidity of frames that are deeply connected to occupational (rather than organizational) identity (Davis and Hufnagel 2007).

Aside from the process of framing, reseachers employing a socio-cognitive approach to innovation management have focused on the impact frame congruence has on technology adoption and use patterns (Olesen 2014). For example, research suggests that 'problem frames' influence technology use patterns in innovation processes, showing how different frames produce different technology-enabled knowledge replication processes, which in turn engender different approaches to product innovation (Vaccaro et al. 2011). Socio-cognitive approaches are increasingly employed in the study of digital innovation, where researchers have mobilized technological frames to explore how incumbent firms respond to digital disruption (Fraser and Ansari 2020). They find that organizational members develop non-binary framing positions which vary along three dimensions (challenge type, response urgency, firm heritage). The non-binary nature of these frames permits a degree of flexibility that means organizational members may have divergent frames but may reach consensus on responses to digital disruption. Another important finding of this research is that frames are distributed holographically throughout the organization, meaning divergent frames are found within as well as across organizational sub-units (Fraser and Ansari 2020). It is argued that the flexibility afforded by non-binary frames and their holographic distribution allowed incumbents to rapidly cycle through different responses to digital disruption (i.e adaption, differentiation). Others employ the notion of 'digital mindsets' to explain how different beliefs about technological change cultivate different perceptions of digital transformation (i.e opportunity or threat), which in turn influence behavioural responses of organizational members to digital transformation efforts (i.e support or withdrawal) (Solberg et al. 2020).

In sum, socio-cognitive approaches set technological changes and organizational innovation in a dynamic relation, which is undoubtedly helpful for illuminating the processes and mechanisms through which digital innovation unfolds. However, in attributing human innovators the capacity to "shape cognitions, relations and resources" (Kumaraswamy et al. 2018, p. 1031) which create advantages from technological developments, these approaches pay less attention to the role of technology in directly driving (digital) innovation. Within these approaches, the role of technological elements is largely restricted to triggering processes of framing, while the mechanisms by which technology shapes human cognitive activity remain largely unexplored. This is a potentially significant oversight in light of the contemporary digital condition, in which human experience is mediated by digital technologies (Baskerville et al. 2020; Yoo 2010). In light of this, others have adopted theoretical approaches that afford greater room to technology vis-a-via human interpretation in accounts of organizational innovation. These theoretical approaches, grounded in materialist configurations of technology, are outlined below.

(Neo)Materialist Approaches to Digital Innovation

A second important literature that considers the nature of technology in innovation emerges partly as an extension or development of socio-cognitive approaches that more explicitly focus on the nature of 'matter'. Such accounts of materiality attribute agency to matter in a wide variety of ways (Leonardi, 2012). One is to emphasize how objects can 'afford' particular uses for instance on the basis of their design and other actionable characteristics, whether visible or not. Such affordances may be interpreted differently according to individuals' circumstances and needs (Gibson, 1979). Therefore, within the affordance lens, technology is seen as bundles of action potentials that delimit the scope of innovation actors' activity (Majchrzak et al., 2013; Nambisan et al., 2017; Yoo et al., 2012). A more interactive way of relating materiality and human work is to conceive of the relation of objects and human action in a *fractical* manner, akin to shingles being stacked upon one another, creating a temporary layer of stability (Taylor 2011). Such 'imbrication' conceives objecthood interactively, emphasizing the temporal nature of stability and the communicative processes involved in bringing objects into being (Taylor 2011). In contrast to socio-cognitive approaches outlined above, materialist accounts see the role of 'matter' and especially technology not as being neutral, but as performative, creating regularity, routines, the possibility for shared accounts, but also responsibility, authority and the possibly for misunderstanding and the legitimization of some practices and communities over others (Barrett et al. 2012). The routines of organizational innovation are therefore intertwined with technological elements and only by studying both in relation are we able to understand the emergence, development and implementation of new ideas (Garud et al. 2013). Studies of digital innovation have demonstrated how the imbrication of human and material agencies functions to create new routines (Leonardi 2011), patterns of communication amongst different occuptational groups (Boland et al. 2007), and knowledge management practices (Majchrzak et al. 2013).

Blurring the lines between human agents and materials even further are 'entanglement' approaches, such as outlined by Orlikowski and colleagues (Beane & Orlikowski, 2015; Orlikowski, 2007; Orlikowski & Scott, 2008; 2015). This approach equally notes the role of discursive practices but elaborates a more radical idea of intertwinement where both, individuals and matter, emerge through and as part of their 'entangled intra-relating' (Barad, 2007). The distinction between human (social) and material agency is relaxed, instead both forms of agency are *entangled* in material-discursive practices (Cooren 2020). Consistent with this view, organizational innovation is always *materialized* in practice, rendering it a fundamentally a technological affair. Existing research has drawn on these ideas to show how service innovation is created by material-discursive practices that draw together human and material agencies, emphasising the performativity of algorithms that make particular inclusions and exclusions (Orlikowski and Scott 2015). Others develop the notion of 'dynamic reconfiguration' to explain how objects of scientific study are (re)configured by software tools that allow human researchers to observe, measure and define celestial objects (Mazmanian et al. 2014). Here, technology plays a much more active role in processes of figuring, configuring and reconfiguring organizational realities, that extend beyond purposive human action (Mazmanian et al. 2014). Thus, entanglement approaches configure organizational innovation not as an output of something accomplished through socio-cognitive processes localized in human actors as elaborated above. Nor does it unfold through the 'imbrication' of distinctive human and material agencies (Leonardi, 2011). Instead, it occurs through the interweaving of bodies, activities and artefacts in sociomaterial assemblages (Orlikowski 2007).

The socio-cognitive and (neo)materialist theoretical perspectives outlined above are configured as viable theoretical foundations on which to develop new insights into digital innovation (Nambisan et al. 2017, 2019). However, we contend that the particularities of digital objects and of the contemporary digital condition present significant challenges to these theoretical perspectives, that impact their viability as theoretical foundations for the investigation of digital innovation. Whilst socio-cognitive accounts are useful insofar as they provide an explicit theorization of the role of technology in innovation, they are limited by the assumptions concerning the primacy of human perception, interpretation and agency in a broader sense. For example, the actor-centric concept of technological frames assumes that (human) innovators' socially mediated constructions of technology can be shaped and influenced through purposive strategic action of skilled entrepreneurs, rendering the process of digital innovation a framing contest amongst different organizational stakeholders (Fraser and Ansari 2020; Kumaraswamy et al. 2018; Spieth et al. 2021). These actor-centric assumptions are problematic in light of the contemporary digital condition, in which human experience is increasingly and pervasively mediated by digital technology (Baskerville et al. 2020; Yoo 2010). If digital technologies are increasingly shaping physical reality and *computing* human experience, then attention to this technological configuration of experience is necessary in theoretical accounts of human cognition. However, as far as we are aware, socio-cognitive approaches have thus far overlooked the computed nature of human experience. It is this oversight that we contend is problematic, since accounts of digital innovation rooted in socio-cognitive perspectives implicitly overlook the functions of digital technology in the constitution of experience, and therefore overemphasize the role and functions of human perception and interpretation in digital innovation processes.

Neomaterialist approaches appear to offer a solution to this issue, particularly 'entanglement' approaches which set human and material agency in a much more symmetrical relationship. For example, the notion of dynamic reconfiguration reveals the ways in which technology actively (con)figures human interpretations of scientific and organizational phenomena. However, as some have recently highlighted, these approaches rely on a notion of material agency that is extremely broad in scope, engendering an analytical emphasis on the tangible and visible aspects of materiality (Cooren 2020; Kautz and Jensen 2013). This emphasis on the tangible and the visible is particularly acute in studies rooted in the imbrication metaphor, where 'material' seems to refer to a particular property of a technology that determines the scope for human action (Kautz & Jensen, 2013; Leonardi, 2011). Importantly, this notion of materiality extends to software (i.e digital objects), which are considered to have definitive material properties (Kautz & Jensen, 2013; Leonardi & Barley, 2010). The distinction between the technological and the material remains ambiguous within entanglement approaches, however the focus on performativity foregrounds the local enactment of material dimensions of technology, which are typically tangible and visible (Cooren 2020; Kallinikos et al. 2013). The emphasis on material agency implicit in neomaterialist approaches is rendered problematic by the fundamentally non-material nature of digital objects (Baskerville et al. 2020; Yoo 2010). A consequence of this is oversight is an analytical overemphasis on the 'material bearers' of digital objects, to the neglect of the wider, distributed patterns of computation (i.e digital activity) that configure organizational processes and activities, including innovation (Beverungen et al. 2019; Faulkner and Runde 2019; Kallinikos et al. 2013).

Based on the arguments outlined above, we contend that existing theoretical approaches to the study of digital innovation are limited by their inattention to the specific features of digital objects, namely their ontologically ambivalent and non-material nature, and their assumptions about the primacy and fidelity of human perception and interpretation. Consequently, a novel theoretical foundation for the study of digital innovation is required, one that attends to the digital mediation of human perception and interpretation as well as the non-material and computationally contingent nature of digital objects. It is precisely this theoretical foundation that is developed in the following section, which articulates an ecological 'cognitive assemblage' approach to digital innovation.

ECOLOGY AND COGNITION

Subsequently, we develop an alternative approach to theorizing digital innovation, based on cognitive ecology (Hayles 2017; Hutchins 1995, 2010), that attends to the computed and non-material nature of digital objects as well as the digital mediation of human experience. To do this, we first elaborate our configuration of cognition as distributed ecological process of computation (Hutchins 1995) before outlining the systemic relations between cognitive elements as they process information, producing complex and flexible 'cognitive assemblages'(Hayles 2016a).

Cognition as an Ecological Process of Computation

Ecological approaches to cognition were pioneered in the development of cybernetic theories of mind (Bateson 1972). Whilst it is not feasible to fully elaborate this conception of mind here, there are a number of key features that help characterize the ecological configuration of mental processes. First, mind(s) are configured as aggregates or systems of interacting parts, accordingly, explanations of cognitive processes reside in the organization and interaction of these multiple parts (Bateson 1979, p. 93). Second, mental processes are defined by circular flows of information around the system of interconnected parts, where information is defined as "a difference that makes a difference"[3]. Thus, to explain mental

[3] Bateson's aesthetic conceptualization of information as "any difference that makes a difference" contrasts with Shannon & Weaver's probabilistic conceptualization of information that lies at the core of information theory. The particularities of these alternative configurations of information and the implications for information-theoretical approaches to organization are beyond the scope of this paper.

processes, we must focus on the systemic interconnection of distributed elements, rather than the mental capacities of individual components of the system (i.e cognitive actors). Third, in mental processes (i.e cognition), the effects of difference (information) can be regarded as ‘transforms of difference’, some of which entail consciousness and take place within the human body, but some of which do not entail consciousness and take place outside of the human body (Bateson 1979).

The configuration of cognition as “transforms of difference” finds resonance in cognitive science that invokes the metaphor of computation to describe cognitive processes, whereby “computation is realized through the creation, transformation and propagation of representational states” (Hutchins 1995, p. 65). Ecological cognition assumes that the computations that occur within the bodies of human actors are not ontologically discrete, but that these computations are components of broader cognitive (computational) systems (Hutchins 1995, p. 65). Specifically, ecological approaches to cognition assume that the sort of computation that cognition entails applies to events that are internal to human actors, events that involve humans in interaction with one another, and events that involve humans in interaction with technological artefacts (Hutchins 1995, p. 118). More recently, it has been argued that the context in which cognition (computation) unfolds may extend to technological infrastructures, in which technological artefacts (such as digital objects described above) interact autonomously with one another, in the absence of human consciousness (Beverungen and Lange 2018; Hayles 2017). Therefore, cognition as an ecological process of computation can be defined broadly as “the propagation of a representational state across representational media” (Hutchins 1995, p. 118). Ecological cognition is therefore not an attribute, but “a dynamic unfolding within an environment in which its activity *makes a difference*” (Hayles 2017, p. 25). Importantly, cognition as the propagation of a representational state across representational media (computation) implicates the identification, interpretation and re-presentation of representational states (i.e information) in contexts that connect them with meaning (Hayles 2017, p. 25). According to this definition, meaning is not fixed, but evolves in relation to the particular contexts in which interpretations and re-presentations are performed by cognizers, be they human or technical.

Configuring cognition as an ecological process of computation has significant implications for organizational analysis. First, since any process of identifying, interpreting, and re-presenting difference constitutes a 'cognitive' process, it dramatically lowers the threshold for what may be considered cognition. Second, it delineates cognition from 'thinking', rendering the former a much more capricious activity than the latter, which entails higher level mental processing associated with conscious reasoning (e.g the creation and use of verbal languages). Third, it extends cognitive capacities to non-humans such as digital objects, or simple biological life forms, although it is recognized that there are gradations of complexity involved in the identification, interpretation and re-presentation of representational states (Hayles 2017). This necessitates a re-drawing of analytical boundaries along the dimensions of *cognizers and non-cognizers*, and the various modes of cognition that are implicated in digital innovation. These analytical boundaries are elaborated further below.

Cognizers, Non-Cognizers and Non-Conscious Cognition

Cognizers refer to any biological or technical element that engages in the cognitive process outlined above, this may include humans and digital objects that are comprised solely of bitstrings (e.g optimization algorithms) and those comprised of bitstrings and their material bearers (e.g robots). Conversely, non-cognizers refer primarily to material processes and inanimate objects (Hayles 2017, p. 29) that *do not* identify, interpret and re-present representational states in contexts that connect them with meaning. It is suggested that cognitive capabilities bestow cognizers with distinctive agentive capacities that are unavailable to non-cognizers (Hayles 2017). These agentive capacities are; 'flexibility', which denotes the ability of a cognizer respond to changing environmental conditions, 'adaptability', which denotes the capacity to develop new abilities in response to changing environmental conditions, and 'evolvability', which denotes the capability to change programming that determines the array of possible responses to changes in environmental conditions (Hayles, 2017 p.28). In light of possessing these agentive capacities, cognizers, whether they be human or technical, are considered 'actors' within wider cognitive systems (Hayles 2017). Furthermore, because agency is intertwined with cognition, it is suggested that those actors with higher cognitive capabilities, such as humans whose cognitive activity entails complex conscious reasoning, have greater agentive capacities than non-conscious actors that typically perform lower level computations (Hayles 2017).

For example, high-level cognitive processes such as human thought, entail representations of 'the self' and 'objects in the world that the self has intentions towards' which are connected in mental models and inner narrative monologues (Damasio 2000; Hayles 2017). Conscious thought then is principally concerned with the propagation of complex representational states (mental models, theoretical abstractions) across complex representational media (verbal language, written text, charts, tables, drawings). Technological frames, those abstract models concerning the purpose, value, role and functions of a technological artefact are a good example of representational states associated with higher-level cognitive processing. Similarly, innovation narratives (Bartel and Garud 2009) and the forms these assume, such as strategy documents, journal articles, narratives and rhetoric are good examples of the representational media through which these representational states are propagated (Cooren 2020). High level cognitive process, such as framing, are intertwined with human consciousness and take place in particular contexts (e.g embodied, in wider social milieus) but as we highlight above, ecological cognition extends beyond conscious information processing.

In light of the computational mediation of human experience described above (Baskerville et al. 2020), it is important to recognize that a great deal of cognition occurs beyond the reach of human consciousness. This *non-conscious cognition* refers to cognitive processes, as defined above, that are undertaken by technological devices and that are embedded within technological infrastructures (Hayles 2012, 2017)[4]. Non-conscious cognition operates on a much smaller temporal scale than conscious human thought, and is able to identify, interpret and re-present representational states (i.e differences) that are too dense and too subtle for human consciousness to discern (Hayles 2017, p. 27). Deep learning is a good example of non-conscious cognition that is instantiated in digital objects (Lecun et al. 2015). Deep learning is a form of machine learning in which algorithmic systems accomplish particular tasks (e.g speech detection, image recognition). Deep learning systems are composed of multiple modules that "each transform the representation at one level (starting with raw input) into a representation at a higher, slightly more abstract level" (Lecun et al. 2015, p. 436). For example, an image is analyzed initially as an array of pixel values (a representational state) which may be fed into the first layer of representation that will identify the presence/ absence of edges at particular location (another representational state). Working from this, a second layer might identify the particular angles of (another representational state), which a third layer may identify, and interpret and re-present as larger combinations of angled edges that correspond to particular parts of familiar objects (another representational state). Subsequent layers would then detect objects as combinations of these parts (Lecun et

[4] Non-conscious cognition also unfolds within embodied contexts, for example the integration of somatic markers such as chemical and electrical signals into body representations (Hayles 2017, p. 27). However, the primary concern of this paper is the non-conscious cognition that is 'exteriorized' into technological objects and infrastructures.

al. 2015). The outputs of non-conscious cognition may be ‘fed forward’ to human conscious perception through reverberating circuits (Hansen 2014), for example when we are presented with recommended products from online retailers (Hayles 2016b) or, even more imperceptibly in form of navigation software that continually recalculates optimal routes, or the gamified interfaces of multimedia platforms or video games that directly address human senses, prompting near direct bodily reactions (e.g., scrolling or clicking). While interacting with the human, these processes operate at microtemporal scales are too fast to reach the level of conscious thought and yet they do directly affect human thinking and action. It is precisely this form of *non-conscious* cognition that “generates a host of presuppositions about the way the world is and how it works” (Thrift 2004, p. 177). In other words, when the outputs of non-conscious cognition are fed-forward for conscious deliberation (as in the example of TripAdvisor), the ‘raw’ data we work with in the development of technological frames and innovation narratives has already been *computed* by the cognitive nonconscious (Hayles 2017). Figure 1.0 provides an overview of conscious and nonconscious cognition, indicating the representational states and representational media associated with more and less complex forms of cognitive activity.

INSERT FIG 1.0 ABOUT HERE

In parsing cognition in this way, ecological cognition makes a crucial distinction between cognition and material agency, understood broadly as “the capacity for nonhuman entities to act on their own, apart from human intervention” (Leonardi, 2011, p. 148). Specifically, it is no longer the case that *all* non-human entities have agentive capacities, but rather only those nonhuman entities that are *cognitive*. Material processes may be explained by reference to the physical forces acting upon them, they do not identify, interpret and re-present representational states in contexts that connect them with meaning. This is not to say that material processes (e.g respiration, evaporation, alternating current conversion) are unimportant, since these often provide the foundations from which cognitive activity can emerge, but it is to suggest that these processes do not involve interpretation and choice, which are foundational to cognition (Hayles 2017). Consequently, it is important to consider the nature of interactions between conscious human thought and technical non-conscious cognition.

Cognitive Assemblages

In light of the ecological view on cognition outlined above, it is important to emphasize that conscious human cognition and technical non-conscious cognition are systemically intertwined, such systems may be termed 'cognitive assemblages' (Hayles 2016a, 2017). Cognitive assemblages are flexible arrangements constituted by interactions amongst conscious and non-conscious cognitive actors, "they operate through contextual relationships at multiple sites and levels, as conditions and contexts change" (Hayles 2016b, p. 33). In contrast to 'networks', the Deleuzian notion of 'assemblage' indicates arrangements that are not too rigid such that constitutive elements cannot (cognizers) leave or move (Hayles 2016a). Similarly, 'assemblage' also places analytical emphasis on the *relationship* between constitutive elements, in contrast to networks which focuses attention on nodes and edges (Hayles 2016b). The interpenetration of human and technical cognition in cognitive assemblages means that their decisions affect one another, such that non-conscious cognitions may be 'fed forward' for conscious human deliberation, the products of which may then feed back into technical systems, affecting their operations (Hayles 2016a, p. 34). Importantly, it is cognitive assemblages that perform the functions associated with cognition, namely attending to new situations, incorporating knowledge into adaptive strategies, and evolving through experience to create novel conditions, behaviours and activities (Hayles 2016a, p. 33). Therefore, we contend that cognitive assemblages provide a useful concept for the analysis of digital innovation, allowing researchers to map and articulate the evolutionary cognitive trajectories through which new products, processes and services emerge. Accordingly, innovation, understood as “the invention, development and implementation of new ideas” may be conceptualized an emergent property of cognitive assemblages comprised of conscious (human) and non-conscious cognizers (see Fig 1.0).

DISCUSSION: IMPLICATIONS FOR INFORMATION SYSTEMS AND DIGITAL INNOVATION

Understanding the role and functions of digital objects, and their interactions with human actors, is an ongoing concern for IS research, particularly the stream of research concerned with digital innovation (Baskerville et al. 2020; Nambisan et al. 2017). At the beginning of this article, we suggest that the non-material nature of digital objects, and the ubiquitous digital mediation of human experience pose challenges for existing theoretical approaches to digital innovation. Specifically, we argued that socio-cognitive approaches perhaps overemphasize the role of human perception, interpretation and agency, neglecting the degree to which human experience is technologically mediated. Whilst this issue is addressed to a degree by materialist approaches, which position human and material actors in more symmetrical relationships, the reliance on a broad notion of ‘material agency’ cultivates an analytical emphasis on the tangible and visible aspects of technology, which may be problematic in light of the fundamentally non-tangible, ontologically ambiguous nature of digital objects (Faulkner and Runde 2019; Kallinikos et al. 2013). To address this theoretical lacuna , we introduced ideas from cognitive ecology, which allow us to reconceptualize digital innovation as a distributed process of computation across conscious and non-conscious cognizers. Novel ideas are generated and diffused as cognitive assemblages, comprised of conscious and non-conscious cognizers, flexibly respond to new information which is interpreted in particular contexts that connect it with meaning. The primary contribution of this paper therefore is an alternative theoretical approach to digital innovation, which we term a 'cognitive ecological' approach, that allows us to conceptualize digital innovation in a way that is attentive to cognition, the digital mediation of human experience, and the non-materiality of digital objects (Baskerville et al. 2020; Faulkner and Runde 2019).

Our aim is to offer an alternative theoretical approach to IS scholars researching digital innovation, that sits alongside socio-cognitive and neomateiralist approaches. Socio-cognitive approaches to digital innovation emphasize socio-cognitive processes in driving innovation processes (Kaplan and Tripsas 2008; Raffaelli et al. 2019; Tuertscher et al. 2014), rendering technology a 'trigger' for such processes. Conversely, materialist theoretical perspectives highlight the performativity of technology in organizational innovation, drawing attention the intertwinement of social and material agencies that drive innovation processes (Bailey, Leonardi, & Barley, 2012; Garud et al., 2013; Leonardi, 2011; Orlikowski & Scott, 2015). Whilst both of these approaches are undoubtedly helpful in unpacking the 'relational complexity' that characterize digital innovation (Garud et al. 2013), the insights each approach afford remain disconnected, thus understandings of the interplay between human cognition and technological performativity within innovation processes remain underdeveloped. The cognitive-ecological approach advanced here shares points of convergence and divergence from existing socio-cognitive and neomaterialist approaches to digital innovation which are outlined in Table 1.

INSERT TABLE 1 ABOUT HERE

Consistent with socio-cognitive perspectives, our model suggests digital innovation is a fundamentally cognitive process that unfolds across distributed networks of cognizers. However, our model diverges from socio-cognitive approaches in that cognitive capacities are extended to non-conscious, digital objects. Drawing on cognitive ecology (Hayles 2017; Hutchins 1995), we argue that nonconscious cognition that occurs within technological artefacts and infrastructures, whose outputs are fed forward for human consideration, play an important role shaping innovation trajectories. In this way, our configuration of innovation overlaps with materialist approaches that draw attention to the activity of technological artefacts and infrastructures, manifest in the process of imbrication or in sociomaterial entanglements, that shape innovation processes and outcomes.

The major differences between our cognitive-ecological model and materialist approaches to digital innovation concern configurations of agency. Whereas materialist approaches either delineate between social and material agencies and focus on their imbrication (Cecez-Kecmanovic et al., 2014; Leonardi, 2011, 2013) or on the agential cuts performed by sociomaterial entanglements (Barad 2007; Orlikowski and Scott 2014, 2015), our cognitive-ecological approach draws distinctions between cognizers and non-cognizers, and vests agency with cognizers, whether they are conscious or nonconscious (Hayles 2017). Non-cognizers, such as material forces, possess the capacity for action but they do not perceive difference, make interpretations and selections, they are not active in the propagation of representational states across representational media. Whilst the centrality of interpretation and choice as a condition of agency resonates with Leonardi's (2011; 2013) imbrication approach that differentiates social agency from material agency on the basis of intentionality, our approach suggests that intentionality need not be intertwined with consciousness, technical systems. Learning algorthms excerise intentionality by propagating representational states across representational media, identifying differences (representational states), making interpretations and selections (i.e transforming representational states) in contexts that connect them with meaning.

Our configuration of agency also resonates with the more radical sociomaterial perspectives that emphasize the 'agential cuts' performed by sociomaterial entanglements (Orlikowski 2007; Orlikowski and Scott 2014, 2015). Specifically, since cognitive assemblages collectively exhibit the functionalities of cognition, assemblages themselves have the capacity to shape innovation processes and outcomes as cognition unfolds and reconfigures relations amongst cognizers and contexts. However, in conflating agentive potential with cognitive capabilities, we are no longer forced to discriminate between human decisions and technical implementations, or 'social agency' and 'material agency'. The notion of a cognitive assemblage foregrounds both human and technical cognition and affords them analytical equivalence in the explanation of digital innovation processes (Hayles 2016a, p. 50). Unlike the 'agential cuts' of sociomateriality, cognitive assemblages are not localized apparatuses, but "operate at multiple levels and sites, transforming and mutating as contexts and conditions change" (Hayles 2017, p. 117). Thus our approach presents a response to calls for the development of theory that is sensitive to the ontological ambivalence of digital objects, that aids "comprehension of a complex ecology to which they belong and their internal dynamics" (Kallinikos et al. 2013, p. 387).

Furthermore, the conflation of agency with cognitive capabilities offers a more nuanced treatment of 'material agency' which is broadly configured as "the capacity for nonhuman entities to act on their own, apart from human intervention" (Leonardi, 2011, p.

148). It is argued that such conceptualizations are so broad that they perhaps overlook the distinctive agentive capacities of digital technologies, which are anchored in their openness, reprogrammability, and interactivity (Faulkner and Runde 2019; Kallinikos et al. 2013; Yoo et al. 2010). Here we argue that a more functional configuration of material agency focuses on the agentive capacities bestowed by cognitive capabilities (Hayles 2017). This, we suggest, allows for the development of more fine-grained understandings of how layered systems of digital objects intervene in innovation processes through their computational activity, that is through their screening, filtering, sorting, ranking, optimizing and filtering of information that is fed forward for conscious human interpretation.

These alternative configurations of innovation and agency necessitate shifts in our unit of analysis and have methodological implications. Specifically, a cognitive ecological approach to digital innovation foregrounds flows of cognition, the locus of which is cognitive assemblages, those distributed, flexible cognitive systems comprised of conscious and non-conscious cognizers. In contrast to sociomaterial approaches, which engender a focus on localized material-discursive practices through which the social and technological are constituted, a cognitive ecological approach entails following lines of cognition, that span social and technological contexts, conscious, and non-conscious cognizers (Baygi et al. 2021). This invites a 'genealogical' approach to empirical enquiry, in which trajectories of cognition are traced through the identification the computations implicated in emergence of organizational novelty. Adopting this approach, IS researchers might ask how innovation emerges out of the propagation of representational states across representational media? What are the states, media and contexts implicated in distributed cognitive assemblages and how are these reconfigured through conscious and non-conscious cognition? To address such questions, researchers need to attend to the localized cognitive processes (e.g interactions of robots and AI in the lab) as well as the wider cognitive ecologies in which these cognitive processes are enmeshed (e.g the scientific framing processes that prefigured experimental work, the construction of innovation narratives and technological frames). Such an approach to digital innovation addresses recent calls for the development of novel theory that embraces a processual account of IS phenomena, in particular digital innovation (Baygi et al. 2021).

The cognitive ecological approach advanced here also provides a way of theoretically accommodating the challenges associated with digital innovation, namely the dissolution of boundaries between innovation actors, the intertwinement of innovation processes and outcomes and the distribution of 'innovation agency' (Appio et al. 2021; Nambisan et al. 2017). First, our approach makes no assumptions about the boundaries of innovation (i.e outcomes and processes), rather innovation (new ideas, inventions, products, services, processes) features as an emergent property of cognitive assemblages. Second, by foregrounding flows of cognition, the cognitive ecological approach makes no assumptions about 'pre-defined innovation actors'. Rather, different (conscious and non-conscious) actors become implicated in innovation as they propagate representational states across representational media and these change as cognitive assemblages shift to accommodate computational (cognitive) complexity. Third, the cognitive ecological approach makes no assumptions about innovation processes and outcomes, both of which are instantiated in the propagation of representational states across representational media. Whether particular acts of cognition assume the form of 'process' or 'outcome' is contingent on their temporal position within a cognitive assemblage. Specifically, a cognitive-ecological model implies that a change in any one aspect of an assemblage may be regarded as a cause for change at a later point in time (Bateson 1979, p. 73). For example in automated R&D (Burger et al. 2020), a learning algorithm is at one moment an output of the cognitive activity of its designers, it becomes a 'process' at another moment when it guides experimental search, it becomes an 'outcome' after cycle of experimentation after which it optimizes itself, updating search procedures based on the experimental data generated, it becomes a 'process' again in the synthesis of a novel photocatalyst, which is an 'an outcome'. Collectively, these assumptions concerning the boundaries of innovation address some of the challenges that existing innovation management theory, which make more rigid assumptions about actors, processes and outcomes (Crossan and Apaydin 2010) face in encounters with the digital.

Finally, a cognitive-ecological approach to digital innovation opens up questions about how agency is distributed among cognizers, the contribution of different actors to the dynamics and trajectories of assemblages, and the apportion of responsibility for digital innovation (Hayles 2016a). Regarding the distribution of agency among cognizers, future research might explore how the distribution of cognitive activity between conscious and non-conscious cognizers influences the features of innovation, for example the pace of innovation and the radical/ incremental nature of the novelty produced. Future research might explore the relationships between the distribution of consiocus/ non-conscious cognition and innovation speed, as well as the dynamics of interactions between conscious and non-conscious cognizers in more detail. For example, it is well-established that algorithms enact the rationalities of their designers (Lindebaum et al. 2020), but we know little about how the activity of non-conscious cognizers functions to shape the goals, intentions, and perceptions of conscious cognizers. Research might explore the 'framing' activity of non-conscious cognizers and how this functions to shape innovation trajectories, in the form of searching, screening and selection activities of conscious cognizers (Spieth et al. 2021).

The implications of *punctuated agency* require further exploration. According to the cognitive-ecological model advanced here, agentive potential corresponds to cognitive capabilities. This places humans, with their capacity for complex cognition, in a privileged position when it comes to directing the trajectories of cognitive assemblages, while recognizing that the lack the capacity to fully control their evolution. This limited capacity for control is likely to become more pronounced as the organizational spaces in which non-conscious cognizers operate increase in scale and scope (Beverungen and Lange 2018; Lenglet 2011). The limited capacity to control trajectories of cognitive assemblages raises questions for theories of responsible innovation, which are underpinned by notions of ethical agency (Pandza and Ellwood 2013). Future research might look to address this by exploring alternative ethical frameworks in which ethical agency is no longer localized in human actors (Stahl and Markus 2021), but that locate ethical and moral judgements in the systemic relations between conscious and non-conscious cognizers. Specifically, research concerned with the ethics of IS might draw on the cognitive ecological approach to explore the ways in which non-conscious cognizers interact with and transform ethical and moral concerns.

Similarly, the distribution of cognition across conscious and non-conscious cognizers also poses challenges to literature concerned with intellectual property strategy (Somaya 2012), which tends to assume that intellectual contributions to innovation can be localized within particular (conscious) cognitive actors. The configuration of innovation as an emergent property of cognitive assemblages suggests that these assumptions are problematic and this calls for the development of alternative approaches to the management of intellectual property, perhaps based on logics of control rather than ownership. Specifically, future research might explore the legal and technical means by which flows of cognition may be directed, restricted or otherwise protected and the wider implications of this for organizational innovation.

Future research might also focus on elucidating the dynamics of cognitive assemblages, for example by exploring the cultural practices through which conscious and non-conscious cognizers are brought into coordination. The temporal dynamics of cognitive assemblages also require further elucidation, since conscious and non-conscious cognition operate according to different temporal regimes (Beverungen and Lange 2018). Specifically, future research might examine how the temporal structuring of cognition functions to shape innovation trajectories and outcomes, emphasising the active role of temporality in innovation (Ellwood and Horner 2020; Hernes et al. 2021). Alternatively, future research might explore the evolutionary dynamics of particular cognitive assemblages, examining how specific *kairotic meshworks* (Baygi et al. 2021) function to structure flows of cognition and the implications for innovation trajectories. The cognitive assemblage approach might also be utilized to explore the complex, recursive chains of causation that connect innovation micro-processes (e.g invention) to macroprocesses (e.g development, implementation) (Garud et al. 2013).

CONCLUSION

This paper provides an answer to the call for the development of new theories that attend to the particularities and challenges associated with digital innovation (Nambisan et al. 2017). More specifically, we attempted to develop a theoretical approach to digital innovation that is attentive to the particularities of digital objects, and the contemporary digital condition in which human experience is increasingly *computed* (Baskerville et al. 2020). To do this, we elaborate a cognitive-ecological approach that aims to complement insights derived from socio-cognitive and sociomaterial approaches to digital innovation (Orlikowski and Scott 2015; Spieth et al. 2021). We attempted to show how this framework affords the development of novel insights into digital innovation, which we hope can be developed further in future empirical research. To this end, we articulate a research agenda, highlighting the directions future research may take if IS research is to develop a greater sensitivity to the ways in which we think with, and through, digital objects in the pursuit of innovation.

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Complexity of cognition	***Representational State***	***Representational Media***
Conscious	Dispositional beliefs, concepts, cognitive/ technological frames, theoretical models	Documents- plans, articles, drawings, charts, graphs Rhetoric- narratives, metaphor, analogy
Non-Conscious	Data, metadata, data structures, rules and schemas	Non-material bearers- Bitstrings Material bearers- screens, hard disk drives, servers, sensors, actuators

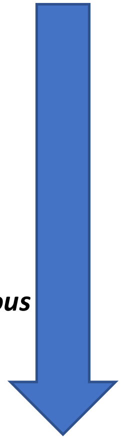

Fig 1.0 Conscious and Non-Conscious Cognition

	Socio-Cognitive (Rappa & Garud, 1994)	Imbrication (Leonardi, 2011)	Entanglement/ Sociomateriality (Orlikowski & Scott, 2015)	Cognitive Assemblage
Innovation Process	Framing supported by narrative	Purposive, teleological process of melding technological capabilities with desired ends	Materialized in practice through intra-actions and agential cuts	An emergent property of flexible, distributed cognitive assemblages.
Role of Cognition	anthropomorphic innovation actors construct and contest frames	Interpretations of technological capabilities in light of goals give rise to perceptions that inform action	Emerges through intra-action of social and material elements. Material-discursive practices assume primacy	Cognition-as-computation lies at the core of innovation processes as they move across human (conscious) and technical (non-conscious) contexts
Role of Technology	Functions as a trigger for framing processes.	Inform perceptions of affordance/ constraint in light of desired ends.	Enacted in localised material-discursive practices	Digital objects and infrastructures engage in cognitive activity which may be fed forward for conscious processing.
Agency	Anthropomorphic innovation actors	Social and material agency. Social differs with regards to intentionality (asymmetrical)	Social and material agencies are symmetrical and entangled. Determined by agential cuts.	Cognizers have agency. Can be human (conscious) or technical (non-conscious). Cognitive assemblages exhibit properties of cognition- agency distributed across cognitive system.
Unit of Analysis	Social (Human) actors	Human and Material actors	Practices	Cognitive Assemblages
Epistemology	Distinguish between actors and frames	Distinguish human and material agency	Distinguish social (human) and material agency	Distinguish cognizers and non-cognizers

Table 1.0 Theoretical Approaches to Digital Innovation