

Steps toward a Digital Ecology

Ecological Principles for the Study of Digital Ecosystems

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STEPS TOWARDS A DIGITAL ECOLOGY:

ECOLOGICAL PRINCIPLES FOR THE STUDY OF DIGITAL ECOSYSTEMS

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Abstract

The notion of digital ecosystems has become a fruitful metaphor for examining the effects of digitalization across boundaries of organization, industry, lifeworld, mind, and body. In business-economic terms, the metaphor has inspired IS research into new business models while, in engineering terms, it has led to important insights into the design and governance of digital platforms. Studying digital ecosystems in these terms, however, makes it difficult to trace and explain those effects of digitalization, which do not materialize predominantly in economic and engineering patterns. Important relationships and their effects may therefore go unnoticed. In response, I draw on the ecological epistemology of Gregory Bateson and others to contribute an ecological approach to digital ecosystems. Such an understanding, I argue, expands the possibilities for tracing and explaining the wide reaching, boundary crossing effects of digitalization and the runaway dynamics they may lead to. I suggest to do this based on three principles: (1) part-of-ness – phenomena are to be observed as always part of a larger ecosystem; (2) systemic wisdom – ecosystems have limits, which need to be respected; and (3) information ecology – ecosystems are not mechanical but informed, cognitive systems. As my contribution, I propose six avenues for future IS research into digital ecology.

Keywords: digital ecosystems, digital ecology, Gregory Bateson, future IS research, ecological thinking, responsible digitalization.

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1. Introduction

In an infamous statement made during an earnings call in 2017, Reed Hastings, CEO of Netflix, declared not YouTube or HBO to be Netflix's greatest competition but sleep (Hern 2017). While the statement may have been tongue-in-cheek, it is indicative of the degree to which digitalization has been able to short-circuit domains of human existence and, thus, make them interdependent. Take, for instance, how money spent for advertisements on Facebook leads to the design of addictive apps, which keep users hooked so that they consume more ads, which, in turn, leads to sleep deprivation (Harris 2016). As we keep on injecting digital technology into things, bodily functions, brain signals, social systems, and lifeworlds, it is becoming challenging to trace these *heterogeneous* relations and their systemic effects, which will only grow in reach and intensity in an emerging digital world (Benbya, Nan et al. 2020, El Sawy, Malhotra et al. 2010).

Digitalization connecting everything with everything is an expression of what media theorist Erich Hörl (2017b) calls the technoecological condition of our time. Diffused into the environment, especially through sensors and algorithms, technology has become ecological and the management of and through technology is increasingly becoming the management, or orchestration, of the organized complexity of the environment (Kallinikos, Aaltonen et al. 2013, Mikołajewska-Zajac, Márton et al. 2021). IS research is engaging with this technoecological condition under the label of digital ecosystems. Used in a metaphorical sense, the term is meant to convey that contemporary information systems are qualitatively different from their predecessors, as they emerge radically complex, unbound, and interconnected, crossing conventional boundaries of organization, industry, and market (Benbya, Nan et al. 2020, Rai 2018). This has been done largely in business-economic and engineering terms, employing the notion of digital ecosystems for the study of new digital business and innovation constellations (Parker, Van Alstyne et al. 2017, Tiwana 2014). Such

approach has proven to be helpful with improving transactional efficiencies and innovation capacities, by, for instance, conceptualizing the environment as a market of voluntary participants (e.g. Airbnb managing a market of hosts and guests) or as a periphery of innovators complementing a product-platform (e.g. Apple managing external app developers) (Eaton, Elaluf-Calderwood et al. 2015, Gawer 2014).

Yet, as illustrated in above examples about Netflix and Facebook, digitalization short-circuits a diverse range of heterogeneous domains that do not stop at boundaries of business and innovation. If this heterogeneity is not accounted for, there is a risk of underestimating the degree to which technology has intensified the organized complexity of the environment, resulting in problematic runaway dynamics, by which an ecosystem ends up exploited and eroded by blitzscaling and disruption (Bateson 2000, Hörl 2017b). There are many examples of such dynamics of digitalization, especially when fuelled by a belief in limitless user-growth and blitzscaling network effects (Mikołajewska-Zajac, Márton et al. 2021, Sterman, Henderson et al. 2007). As Netflix, for instance, pushes the limits of the human need for sleep in order to maintain growth, it inadvertently erodes the capacity of its own audience to pay attention (Terranova 2012). At worst, such dynamics become destructive, as is the case with Facebook. The social media platform, which originated from rating the “hotness” of female college students, has grown to such a size that it is now implicated in the manipulation of democratic elections (Economist 2019). To be able to understand and to counter these kinds of dynamics, one needs to trace their patterns in their *heterogeneity* without stopping at arbitrary boundaries. Society will otherwise miss the wider, systemic effects of digitalization, which, as we are all too aware from climate studies, turn runaway and eventually come back to haunt us with potentially catastrophic intensity, making it ever more difficult to course correct (Meadows 2008, Sterman 2014).

It is against above backdrop that I propose to draw on ecological thinking to study digital ecosystems. As I will discuss in detail, the term “ecological” is not used in this paper in an exclusively biological sense but in the sense of the philosophical tradition that is diametrically opposed to modernistic reductionism (Baecker 2007, Bateson 2000, DeLanda 2016, Deleuze and Guattari 1987); to think ecologically is to focus on patterns of relationships without drawing “an arbitrary line between organism and environment [and] without stopping at species, mechanical or linguistic boundaries, and especially without invoking a reified conception of society” (Star 1995:13). Hence, ecology does not mean to apply biologicistic analogies, comparing, say, a mobile app with a living organism, or a corporation with an animal keystone species. Rather it is to understand organized complexes of *heterogeneous* parts and relationships (i.e. ecosystems) without assuming inherent, natural boundaries between the biotic, abiotic, social, mental, or mechanical (DeLanda 2009, Phillips and Ritala 2019). Ecological thinking, thus conceived, has developed to deal with the kinds of heterogeneous, complex, unbound, and interconnected systems we are increasingly encountering as digital ecosystems (El Sawy, Malhotra et al. 2010, Star 1995:14).

The purpose of this paper is, therefore, to make a first step towards a digital ecology as the study of digital ecosystems as actual, not metaphorical, ecological systems; that is *as organized, unbounded complexes of heterogeneous relationships of processes*. This first step is made by drawing primarily on the works of Gregory Bateson (2000) for following reasons. First, Bateson conceptualizes ecosystems as actual information systems, which makes his ecological thinking directly applicable in the IS field, as demonstrated by existing research (e.g. Kallinikos 2006, McKinney and Yoos 2010, Star and Ruhleder 1996). Second, Bateson provides a comprehensive and uncompromisingly relational account of ecology, which allows tracing dynamics and processes in their heterogeneity wherever they lead. Hence, he serves as an IS-friendly representative and stand-in for the rich intellectual tradition of

ecological thought (e.g. Baecker 2007, DeLanda 2016, Deleuze and Guattari 1987, McLuhan 1964).

In more detail, I draw on Bateson's work and complement it with the works of others to derive three ecological principles relevant for the study of digital ecosystems: (1) part-of-ness – phenomena, such as digitalization, are to be observed as always part of a larger ecosystem; (2) systemic wisdom – nothing, including digital ecosystems, can grow forever. Ecosystems have limits, which need to be respected; and (3) information ecology – ecosystems are not mechanical but informed, cognitive systems. Based on these principles, I will then outline six avenues for future research on digital ecosystems (see Table 1), concluding that digital ecology raises new opportunities, as it challenges established principles of market externalities, zero marginal costs, and Neo-Darwinian evolution.

2. Digital ecosystems

In IS research, the term ecosystem refers to a collection of actors and artefacts that organize and coalesce around an integrating organization and/or platform. The notion has been in use in business economics since at least the 1990s to better capture the kind of innovation and value creation increasingly occurring across conventional boundaries of formal organizations, industries, sectors, and markets (Moore 1993). These kinds of constellations differ from market-based arrangements and vertically integrated supply-chains, as they orchestrate complementary niche actors and resources to offer highly complex products and services. Typical examples are Apple's iOS ecosystem (Mukhopadhyay, de Reuver et al. 2016, Sorensen, de Reuver et al. 2015) and TripAdvisor (Alaimo, Kallinikos et al. 2019). In case of transaction platforms, such as Airbnb, the ecosystem contains of the participants on the supply- and demand-side, and the platform owner, matching the two sides (Parker, Choudary et al. 2016, Song, Xue et al. 2018). The more common understanding in IS research pertains to an innovation platform as a particular product architecture, consisting of a stable core and a

periphery of complementary modules (Ghazawneh and Henfridsson 2015, Parker, Van Alstyne et al. 2017). Combined, they form a platform ecosystem, which benefits from the innovation potentials that come with external complementors, resulting in highly flexible offerings (Ghazawneh and Henfridsson 2013, Tiwana 2014) and open innovation (Hienerth, Lettl et al. 2014, Shaikh and Levina 2019).

Adding to above notions of ecosystems, which largely align with the strategic management and industry innovation literature (Gawer and Cusumano 2014, Jacobides, Cennamo et al. 2018, Teece 2007), the IS field also emphasizes the novel aspects that come with digitalization (de Reuver, Sorensen et al. 2018, El Sawy, Malhotra et al. 2010, Henfridsson, Mathiassen et al. 2014). Digital artefacts and, by extension, digital ecosystems, are product-agnostic, because their functionality is not as predetermined as is the case with purely physical products (Constantinides, Henfridsson et al. 2018). This characteristic is due to the openness, editability, and reprogrammability of digital artefacts, as well as the interoperability and distributedness that comes with standard interfaces and homogenizing data (Kallinikos, Aaltonen et al. 2013, Yoo, Henfridsson et al. 2010). As a result, digital artefacts are never per-se finished, nor is there a single owner dictating the design and governance of a digital ecosystem (Eaton, Elaluf-Calderwood et al. 2015, Henfridsson, Mathiassen et al. 2014, Karhu, Gustafsson et al. 2018). This gives rise to generativity and new organizational dynamics. For instance, by moving the locus of digital innovation into the ecosystem, firms drastically change their organizational form (Parker, Van Alstyne et al. 2017, Winter, Berente et al. 2014). Similarly, digitalization blurs product boundaries, allowing digital ecosystems to extend into new markets, envelope competing service providers, and form co-ompetitive relationships (Adner and Kapoor 2010, Clemons, Dewan et al. 2017, Constantiou, Márton et al. 2017).

Given these novelties, the notion of an ecosystem has served as a helpful metaphor (de Reuver, Sorensen et al. 2018), as it captures socio-technical developments that emerge as highly complex and large-scale systems bereft of the clear boundaries and centralized control of traditional information systems (Hanseth and Lyytinen 2010, Henfridsson and Bygstad 2013, Star and Ruhleder 1996). Ecosystems are hence defined and studied as business and innovation constellations, which form to create value for their customers and, ultimately, to make a profit as a value network (Alaimo, Kallinikos et al. 2019, Constantinides, Henfridsson et al. 2018, Phillips and Ritala 2019, Selander, Henfridsson et al. 2013). Such understanding gives preference to digital business models and technical functionalities for the purpose of generativity, scalability, and profitability as well as for maximizing transactional and other efficiencies (Parker, Choudary et al. 2016, Tiwana, Konsynski et al. 2010). Against this backdrop, digital ecosystems are at times conceptualized as a new meta-organizational context, focusing the analysis on their parts and participants (Wareham, Fox et al. 2014), such as on keystone firms (Iansiti and Levien 2004), focal and niche economic actors (Ghazawneh and Henfridsson 2015, Selander, Henfridsson et al. 2013), or core products and peripheral complements (Gawer and Henderson 2007, Tiwana 2014). Their characteristics and behaviours are then explained according to homogeneous descriptors and relationships, such as price, standards, functionality, or control (Constantiou, Márton et al. 2017, de Reuver, Sorensen et al. 2018, El Sawy, Malhotra et al. 2010, Ghazawneh and Henfridsson 2015).

Studying digital ecosystems in above terms has led to a better understanding on how to improve platform business models by maximizing transactional efficiencies and innovation capacities. Yet, as is the case with any approach, there are also blind spots. First, research into the participants of ecosystems provides valuable insights into the *populations* of ecosystems (i.e. app-developers, Airbnb guests, etc.). However, there is a danger that the organized complexity of the ecosystem as a whole and its capacity to change and adapt on its

own terms is underestimated, because the environment is seen as a mere context or “container” within which things happen (Meyer, Gaba et al. 2005, Wang 2021, Winter, Berente et al. 2014). In other words, if the systemic behaviour of the *ecosystem* itself is not accounted for, emergent, non-local phenomena and systemic challenges remain understudied (El Sawy, Malhotra et al. 2010, Phillips and Ritala 2019, Tilson, Lyytinen et al. 2010). These phenomena are of particular importance, as ecosystems are capable to self-organize and self-regulate, making it impossible for an individual part (e.g. a designer, keystone firm, or IS researcher) to know, let alone control, the whole. Indeed, IS research has shown that attempts by individual actors to control large-scale, complex systems can result in its opposite (Ciborra 2000, Star and Ruhleder 1996, Tilson, Lyytinen et al. 2010).

The second blind spot pertains to tendencies to treat ecosystems as patterns of homogeneous relationships. In contrast to above, here the organized complexity of the environment is acknowledged but homogenized into markets of voluntary participants, architectures of complementing modules, and other transactional and functional patterns (Parker, Choudary et al. 2016, Parker, Van Alstyne et al. 2017, Tiwana 2014). Since such an account of digital ecosystems stops at the boundaries of business and innovation constellations, other patterns, such as hospitality, goodwill, and sleep, and the dynamic complexity they give rise to are underestimated. Sleep deprivation, for instance, cannot be accounted for as sleep deprivation itself, but only as a market failure or side-effect of disruptive innovation. Indeed, homogenizing the heterogeneity of ecosystemic relationships runs the risk of triggering runaway dynamics, as one may not even be aware of other relationships to begin with (Serman 2014). Hence, should Netflix ever “win” the competition against sleep, it would destroy its own environment by depleting the capacity of its customers to regenerate their attention and, by doing so, Netflix would destroy itself.

3. From naturalist ecology to ecological epistemology

The term ecology can be split into two broad streams. The first and more typical stream understands ecology as the biological study of life on earth. Going back to mid-19th century, this naturalist ecology expanded from an ecology of plants and animals to the study of all biotic forms and their non-biotic environments organized into *bioenergetic* ecosystems, ranging from local food chains to the planetary climate (Pickett and Cadenasso 2002). However, it was not until the environmental movement that the impact of human activity was considered. And even since then, human activity has been, to this day, relegated to the domain of the social as an external factor impacting the ecological (Stewart 2000/2011). The relationship between these two domains is the subject of socio-ecological research, which is now, drawing on sociotechnical systems concepts, expanding into the study of socio-technical-ecological systems (Ahlborg, Ruiz-Mercado et al. 2019, Stokols 2018).

The way ecology is understood in this paper is the second and arguably lesser known stream, treating ecology as an epistemological disposition diametrically opposed to modernistic reductionism - typical examples being media ecology and Actor Network Theory (Eede 2019:28ff). In this sense, ecology is not the other from the social and technical, but an interconnected and transversal way of thinking - a *non-modern* eco-logic (Guattari 2000, Hörl 2017a) that opposes the modern treatment of nature as passive and obedient (Heidegger 1977) or as mere reactive to human industry (Beck 1986). Nature, rather, is always turbulent and unruly; it is active not only in an autopoietic sense as biological life but, as argued by new materialism, also in the sense that non-living material systems, be it steel or stone or tissue, are *participating* in the world based on their own patterns of being (DeLanda 2009, 2015). Being is *Teilsein* (being-part-of) not *Dasein* (being-in).

It is against this backdrop that ecological systems are characterized as units of *heterogeneity*, connecting patterns we call biotic, abiotic, social, mental, and mechanical into wider patterns that are without inherent, natural boundaries and dichotomies – including those that artificially and arbitrarily isolate humanity from nature (Herzogenrath 2009, Star 1995).

Indeed, social-ecology, as described above, is not the result of combining two ontological worlds, one social and one natural, but two disciplines, political science and naturalist ecology, brought together to bridge a separation created by those disciplines in the first place (Ahlborg, Ruiz-Mercado et al. 2019). The same argument applies to the expansion of social-ecology by sociotechnical concepts, which resulted from bridging the disciplinary boundaries between organization studies and operations research, extended by recent attempts to bridge social and natural sciences more broadly (Sarker, Chatterjee et al. 2019).

Gregory Bateson (1904-1980) was a preeminent and foundational figure of this second stream of ecological epistemology (Harries-Jones 1995). As he dedicated his life to the understanding of the patterns that connect formal thought and natural history (Bateson 2000:454), he saw the ecological crisis as a crisis in our ways of thinking – a crisis in the *ecology of ideas* (or “ecology of mind”) brought about by Cartesian dualism cutting mind from nature and, by doing so, turning humanity and its environment into enemies (Bateson 2000:468). To avert this crisis, Bateson drew attention to the patterned pathways by which information travels across what would be considered boundaries of the social, technical, and natural; “[those] lines between man, computer, and environment are purely artificial, fictitious lines. They are lines *across* the pathways along which information or difference is transmitted. They are not boundaries of the thinking system. What thinks is the total system which engages in trial and error, which is man plus environment” (Bateson 2000:491; italics in original). For Bateson, ecology was the study of these patterned pathways, organized into

ecosystems that are not bioenergetic and mechanical (i.e. “unthinking”) but cognitive and mindful, *informed* systems (Mikołajewska-Zajac, Márton et al. 2021).

Highly suspicious of any boundaries, Bateson was a truly transdisciplinary scholar and intellectual nomad. His work was influential in anthropology, psychiatry, biology, sociology, and communication studies, including the ecological philosophy of Guattari and Deleuze, the media ecology of McLuhan and Postman, and the sociology of Goffman and Luhmann (Eede 2019, Harries-Jones 1995). For IS research, Bateson’s main influence can arguably be traced back to his contributions to cybernetics.¹ Although he is typically associated with so-called second-order cybernetics (Foerster 2003)², Bateson does not really fit that categorization due to his uncompromisingly ecological understanding of systems. Other notions of second-order cybernetics, most prominently autopoiesis (Maturana and Varela 1992), emphasize the boundary between system and its environment created and maintained by the system itself, such as cell walls or human skin. Bateson’s opposition towards such boundaries was not that he denied that cells have walls or humans have skin but that those were not the only possible boundaries of living systems (Guddemi 2007, Star 1995:19).³ For him, the whole unit of organism *and* environment was systemic; and while cutting this unit into system and environment was obviously necessary, this could be done in a multitude of ways depending on the observer’s purpose.

Without inherent boundaries, a system becomes an ecological phenomenon – a system is always an *ecosystem* (Bateson 1980). And it is this ecological thinking that, I submit, is a

¹ Bateson was a core member of the famous Macy Conferences, which founded cybernetics as the science of steering and control in the 1940s.

² While first-order cybernetics is focusing on questions of how systems steer themselves through negative feedback loops, and thus appear as if they behave purposefully, second-order cybernetics brings the observer of such systems into the picture as yet another system, constituting an epistemological shift from a self-regulating to a self-referential understanding of systems (Froese 2010).

³ Such views overemphasise surfaces of organisms, such as cell walls and human skin, as the only possible boundaries between system and environment, while disregarding other, more important exchanges, such as the human gut, whose contents are neither part of the organism nor of its environment (Stewart 2000/2011).

useful approach for the study of the kinds of complex, unbound, and interconnected information systems, we increasingly call digital ecosystems, crossing boundaries of modernistic convention – that is of organization, industry, market, sector, nation, lifeworld, mind, and body (Benbya, Nan et al. 2020, Rai 2018). Bateson’s ecological epistemology is particularly helpful, because it enables addressing the two blinds spots of digital ecosystems research discussed above. First, it conceptualizes ecosystems as information systems, allowing IS research to study digital ecosystems as actual ecological systems. Second, it is uncompromisingly relational, allowing researchers to trace digital ecosystems across any boundary. I will elaborate on this in the following by developing three principles for a digital ecology as the study of digital ecosystems - (1) part-of-ness, (2) systemic wisdom, and (3) information ecology.

3.1 Part-of-ness

Systems are patterns of relationships and cybernetic feedback, which can learn and self-correct (Bateson 2005). A system, in other words, *is* the relationship between, for instance, parent and child or user and designer. This, in turn, means that everything only exists as *part of* a relationship and broader system of patterned interaction and communication (DeLanda 2016, Harries-Jones 2002). Importantly, this sentiment of “part-of-ness”, as I call it, connotes an inextricable intimacy that should not be conflated with observing a phenomenon *within* an environment. Take as an example the difference it makes between thinking that one is stuck in traffic and the realization that one *is* the traffic.⁴ Indeed, as Bateson demonstrated in his double bind studies on schizophrenia (Bateson 2000:194-200), the mere attempt to reduce systemic (i.e. irreducible) phenomena to atomistic, isolated elements, such as an individual human, is not only epistemologically erroneous but a truncation of this intimate part-of-ness,

⁴ I want to thank my colleague [name withheld] for sharing this analogy with me.

which introduces incongruence and can lead to pathological patterns (such as schizophrenia). Rather, one has to appreciate the unbounded ecological organization of processes and the feedback loops they are a part of (Introna 2018, Zundel 2014). This includes digital ecosystems, which themselves are not isolated entities but always part of larger ecosystems (Mikołajewska-Zajac, Márton et al. 2021).

The notion that relations are primordial is not a foreign idea in IS research, as it has been influenced by theories such as already mentioned media ecology and ANT, and more contemporary notions of sociomateriality (Orlikowski and Scott 2008, Schultze, van den Heuvel et al. 2020), some of which were informed by Bateson's ecological thinking (Eede 2019). The most explicit example is information infrastructure studies, which is partly rooted in an ecological, relational take on infrastructures as large-scale, geographically dispersed systems (Bowker, Baker et al. 2010). Case in point is the seminal study by Star and Ruhleder (1996)⁵, who draw on Bateson to observe a large-scale software system as an ecology, identifying double binds as an infrastructural syndrome for incongruent communication between the various participants.

3.2 Systemic wisdom

In Bateson's view, systems are not static structures of connections but dynamic and processual (Zundel, Holt et al. 2013:105). Patterns are to be understood like music, with melody and rhythm, rather than a seamless carpet or arrangement of bricks (Bateson 1980:10). And it is such a focus on the patterns of processes, which allows them to be compared and typified based on their dynamics and not the actants involved (Bateson 1980). Thus, one can account for how *processes themselves change in a patterned fashion* or, in

⁵ The title of the paper - "Steps toward an ecology of infrastructure" – is an homage to Bateson's most famous book "Steps to an ecology of mind".

other words, how change changes.⁶ An important pattern for Bateson is what he calls “schismogenesis”; that is, a continuously intensifying, positive feedback loop (Bateson 2000:68f). For instance, atom bombs do not have much in common with gifts, however a nuclear arms race and reciprocal gift giving can both develop the same runaway dynamic, as the parties involved try to outdo each other. Gift givers, for instance, may start loaning money from a bank, which spawns a new financial industry, specialized in and, therefore, depending on the runaway gifting to continue. In more general terms, a local solution becomes a systemic problem, as an entire ecosystem (gift givers, banks, bank employees and their families, etc.) becomes addicted to the relationship between gift giving and debt (Bateson 2000:309-37). If not counteracted, this erodes the flexibility of the entire ecosystem to adapt and eventually results in systemic collapse, such as the 2008 financial crisis.

What is required is what Bateson refers to as *systemic wisdom* (Bateson 2000:309); that is an understanding of and responsiveness to the systemic patterns of processes and feedback loops. Nothing can grow forever, including the digital. Arguably, this point is closest to the first stream of ecology, as it encourages to think in terms of sustainability and resilience rather than the maximization of profits and efficiencies (Stokols 2018). Likewise, similar notions of systemic wisdom are also prevalent in IS research, such as soft systems methodology (Checkland and Scholes 1990) and complex adaptive systems theory (Tanriverdi, Rai et al. 2010). The closest example is system dynamics, drawing on the same cybernetic language of positive and negative feedback (Sterman 2014). For instance, Ruutu et al. (2017) develop a system dynamic model to simulate various outcome scenarios for platform competition, such as winner-take-all, and suggest points of intervention on how to regulate the systemic patterns rather than individual actors.

⁶ A simple illustration: physics does not only have a concept of the change of position (i.e. velocity), but also of the change of the change of position (i.e. change of velocity or acceleration), of the change of the change of the change of position (i.e. change of acceleration or jerk), of the change of jerk (called jounce or snap) etc. (Bateson 2000: 248).

3.2 Information ecology

Information plays a central role in Bateson's work, as he conceives of systemic behaviour motivated by information (i.e. an ecology of ideas), travelling along patterns of intensifying and balancing feedback loops. Famously defined by Bateson as "a difference which makes a difference" (Bateson 2000:459), information refers to mutual relationships and connections, as differences are not about demarcating the world into isolated entities but about making connections in-between (Cooper 2005, Harries-Jones 2005, Zundel 2014). After all, it is the difference *between* parent and child that connects them into a family, which, as a relational pattern, exhibits the ability to be in-formed and, thus, to learn and adapt (Bateson 2000:458). More recently, new materialism has been expanding upon this notion, arguing that matter has the capacity to participate in ecological patterns (DeLanda 2009, Deleuze and Guattari 1987, Shaw 2015); in other words, matter does not need to be brought into form (or informed) by an agent but is already "equipped with the capacity for self-organization – matter is thus *alive, informed* rather than *informe* ('formless')" (Herzogenrath 2009:6; italics in original). In this sense, information is truly connecting everything with everything (Cooper 2005, Holt and Zundel 2017).

The IS field is familiar with the term information ecology used with different meanings in innovation ecosystems studies (Wang 2021), information management (Davenport and Prusak 1997), and HCI (Nardi and O'Day 1999); the field has also embraced materialist thinking (Orlikowski and Scott 2008, Schultze, van den Heuvel et al. 2020). Bateson, in particular, impacted the field with his definition of information, which was identified as one of the four main IS concepts of information (McKinney and Yoos 2010). A telling example is Kallinikos (2006), drawing on Bateson (among others) for his concept of an information habitat, by which he captures the complex environment of distributed and networked functionalities interweaving technological and organizational operations.

4. Implications for digital ecosystems studies

Following these three principles, it is now possible to provide an ecological response to the two blind spots of digital ecosystems research. The first blind spot refers to the focus on the populations of ecosystems, underestimating ecosystemic behaviours and dynamics, while the second refers to the prioritization of business-economic and engineering patterns, disregarding other patterns and, thus, risking to trigger runaway dynamics without noticing. In case of the former, the blind spot can be mitigated by describing digital ecosystems as unbounded relational patterns of processes (patterns in the sense of music rather than carpets). Such description, equivalent to how a musician talks about melodic themes and rhythms, does not require natural, self-evident boundaries that contain a system (like a skin). Rather it accounts for the inextricable intimacy of taking part in the world (Teilsein) and for the systemic wisdom to jive with dynamic patterns of change, which have boundaries in the sense of limits of how much stress they can carry. The second blind spot can be mitigated by describing digital ecosystems as patterns of information, which can be followed regardless of how a difference “travels” across an ecosystem – be it a difference in price, standard, symbolic capital, goodwill, sleep, and so on, connecting across conventional, modernistic boundaries of organization, industry, market, nation, lifeworld, mind, and body. The challenge is then how to approach digital ecosystems as unbound wider patterns of information without carelessly truncating them. And it is here that I turn to possible avenues for future IS research.

Table 1 about here

4.1 Digital ecosystems have no “outside”

Observing an ecosystem as one ecological unit puts primacy on the part-of-ness connecting the part to the whole (Selander, Henfridsson et al. 2013, Wang 2021, Winter, Berente et al.

2014). This has concrete implications for the IS field with regards to the notion of “externalities” (that is, the effects of a market transaction on those who are not part of the transaction), as a key concept for digital business models (Liebowitz and Margolis 1994, Parker, Choudary et al. 2016, Stabell and Fjeldstad 1998). From an ecological perspective, there is no such thing as an externality, because there is no outside, to which effects (such as pollution or social inequality) could be externalized (Ahlborg, Ruiz-Mercado et al. 2019, Baecker 2007, Sterman 2014). This point is well understood, when it comes to industrialization, such as pouring chemical waste into rivers (Bithas 2011). When it comes to digitalization, however, it is not only accepted but praised as an innovative business model to believe in a place called “away” one can throw one’s trash at (Meadows 2008); consider how corporate social media platforms crowdsource the filtering of violent and otherwise disturbing imagery to thousands of taskers around the world, thus externalizing the mental stress (including panic attacks and PTSD) that comes from labelling such imagery (Ekbia and Nardi 2017, Newton 2020). The AI, which is trained by this collective labelling, remains the property of the corporation, keeping the benefits and profits, while those who trained the machine are left to their own devices. According to Schultze et al. (2020:825), IS research is partly accountable, when it favours and, thus, legitimates the interests of already powerful actors, while “[o]thers’ interests are largely ignored.”

In response, the IS field can draw on ecological economics, presenting an alternative to the neoclassical theory of externalities (Kapp 1950). In brief, the argument is that social costs, that is all direct and indirect losses incurred by unrestrained economic activities, are “to a large extent a non-market phenomenon, because the relations between production, the environment, and the individual, are not voluntary market relations, but involuntary one-sided relationships forced on the individual [...] usually too weak to defend themselves” (Berger 2008:245). This does not only apply to marginalized people but also to future generations

forced to pay for the consequences of present economic activities.⁷ It is against this backdrop that ecologists are calling for a more fundamental change away from one-sided, exploitative action towards a relationship of reciprocity and responsibility in order to “render visible the social and material relationships that enable the displacement/relocation of negative impacts (the often mentioned ‘externalities’)” (Ahlborg, Ruiz-Mercado et al. 2019:14) as part of rather than external to an ecosystemic whole (Kimmerer 2017). Particular attention needs to be paid to technology, as it is the main driver of the Anthropocene and increasingly used to intervene in the inner workings of nature itself (as is the case with AI solving complex protein structures). For IS research, this would mean to systematically catalogue the displacement of the negative impacts of digitalization and digital business models without assuming a posited outside – be it as a market externality or side-effect of disruptive innovation.

RQ1: What are the relationships that enable the displacement/relocation of the negative impacts of digitalization and how can they be rendered visible?

Not assuming an outside has also implications for the design and governance of digital ecosystems, as one needs to strive for systemic wisdom, cultivating resilience and *regenerativity* (Rasmussen and Vicente 1989), and to be considerate towards heterogeneous, ecological patterns rather than only direct, transactional partners (Selander, Henfridsson et al. 2013, Tiwana 2014). Considering holistic patterns, rather than individual parts, requires a different design sensitivity than the conventional approach based on the works of Herbert Simon (1969), which is to decompose systems into as-simple-as-possible, loosely coupled modules for purposes of analysis and mass-production. This approach faces considerable limits, when dealing with complex, systemic behaviour and non-local, distributed

⁷ The conventional solution to “internalize” externalities through regulation (e.g. carbon credits) or taxation (e.g. tax deduction for electric vehicles) does not apply, as it still does not give voice to the demands of individuals, who have not even been born yet.

phenomena, as is the case with distributed digital technology (Kallinikos, Aaltonen et al. 2013) and, even more so, with neural networks, which, by definition, are non-decomposable (Smith 2019).

In this purview, Henfriddson, Mathiassen et al. (2014) suggest that IS research should draw on the works of architect Christopher Alexander to develop a “network-of-patterns” design frame, which, they argue, is better attuned to technological change in the digital age. In contrast to concrete things, patterns are abstractions, focusing on general properties of solutions learned over time and applicable across settings. This, however, needs to be taken one step further in ecological terms; if we take the notion that there is no outside seriously, that also means that the “network-of-patterns” design frame is itself an abstract solution or pattern, as it is part of that which it itself describes. “No outside” inevitably leads to self-referentiality; when design and governance are part of that which is designed and governed, there cannot be an outside leverage point, from which to decompose, determine, control, or regulate a digital ecosystem (Ciborra 2000, Eaton, Elaluf-Calderwood et al. 2015, Ghazawneh and Henfridsson 2013, Márton and Mariátegui 2015). Indeed, IS research has shown that actors, trying to strategically control digital infrastructures, are caught up in paradoxes and double binds (Star and Ruhleder 1996, Tilson, Lyytinen et al. 2010), as the whole can only be influenced but never controlled by its parts. For IS research, this means to account for self-referentiality in the design and governance of digital ecosystems.

RQ2: What are the principles of self-referential design and governance of digital ecosystems and how can they be put to practice?

4.2 There are ecological limits to digital growth

Further implications derive from the systemic wisdom that also digital ecosystems have limits of growth, which constrain their developments albeit not in ways that are amenable to our

control. Such limitations do not only refer to bandwidth or electricity, which are, of course, important, particularly in cases such as Bitcoin, reportedly requiring as much electricity as the Republic of Ireland (Economist 2018). Other limitations, however, are just as important. Consider the attention economy and its constant efforts to keep users hooked. Rather than respecting human limitations, such as the need for sleep, they are pushed in an attempt to grow the platform. As mentioned in the introduction, some apps are designed based on the same addictive principles as those used for the design of slot machines, all so that users spend more time consuming more content (Harris 2016). In this context, the term “user” certainly receives a sinister meaning, as we are now carrying personalized slot machines in our pockets rather than the bicycles for our minds once promised by a young Steve Jobs (Krainin and Lawrence 1990).

Brought into a larger frame, ecosystemic limits call for renewed attention to the marginal costs of scaling the production of digital goods (Kapp 1950, Shapiro and Varian 1999). For instance, as Airbnb is aggressively expanding its operations, it erodes the hospitality of entire communities (Hill 2015). What begins as a side-hustle, leads to higher rental prices and, eventually, hosts *have* to rent out on Airbnb in order to make ends meet or move somewhere else, thus eroding the local flair Airbnb is marketing to its users (Lindeman 2019). The cost is a loss of flexibility, expressed in the diminishing diversity, hospitality and goodwill of a community (Mikołajewska-Zajac, Márton et al. 2021). Hence, notions of limitless growth in a near zero marginal costs society can become incongruent, or even dangerous, when they invoke a rush to blitzscale digital platforms no matter the consequences (Rifkin 2015, Wachsmuth and Weisler 2018). When, for instance, Facebook scales from millions to billions of users, it is not just more of the same but a qualitative change in the intensity of the marginal costs paid by its environment. Consider how Facebook’s quasi-monopolistic dominance of the public debate in Myanmar amplified hate speech about the Rohingya

minority until polarization became so intense that all flexibility to solve rising tensions peacefully was depleted and the only possible outcome was genocide against them (Economist 2019).

Respecting ecosystemic limits requires a significant shift in perspective, as it challenges a digital economy that revolves around assumptions of limitless user-growth and scalability, which eventually kick in autocatalytic dynamics (such as network effects), constantly accelerating the rate of growth (Parker, Choudary et al. 2016, Song, Xue et al. 2018).

Unhindered growth will eventually become toxic, as it pushes the limits of an ecosystem, eating away its resilience and health (Folke, Carpenter et al. 2010, Holling and Meffe 1996).

This ecological understanding of health in terms of resilience has been translated into engineering robustness in open source ecosystems (Jansen 2014) and expanded by productivity measures, such as return on investments, in business ecosystems (Iansiti and Levien 2004). As reported by Shaikh and Levina (2019:8), healthy innovation ecosystems are, at times, even understood as “corporate-friendly communities that consistently produced highquality, innovative products and services”.

A resilient system has the capacity to change the way it functions in response to a perturbation and, thus, to learn how to cope with similar perturbations in the future (see the network-of-patterns discussed above); robustness, by contrast, is the capacity of a system to resist change by “bouncing back” to the way things were before (Walker 2020). In other words, a robust system is the opposite of a resilient system. This distinction matters, because robustness means brittleness and is the sign of an unhealthy ecosystem bereft of the flexibility to cope with unforeseen change, which is the norm in hyperturbulent times such as our digital present (Benbya, Nan et al. 2020, Meyer, Gaba et al. 2005). For IS research, this opens up avenues for research into what makes a digital ecosystem “healthy”, drawing on an ecological understanding of resilience.

RQ3: What is a healthy, resilient digital ecosystem and how can it be preserved?

Respecting the limits of digital growth has also implications for digital strategy to move away from an image of generals meeting their competitors as enemies on the battlefield of the marketplace towards an image of ecologists concerned with the health of ecosystems (Nan and Tanriverdi 2017, Shaikh and Levina 2019). Indeed, strategic thinking itself, be it businesses or organizations more broadly, is required to change its first principles derived from the modernistic ideologies of technological progressivism and infinite economic growth, as these ideologies have met their ecological limits. In this context, Mitchell, Lemon et al. (2020:7) call for organizational strategy to incorporate “into their planning the amplification and dampening effects of influences moving at different rates and across scales”. The prime strategic goal has to be to preserve the long-term health of the ecosystem one is a part of rather than just one’s own competitive advantage.

The same point can be made about digital strategy. Take, for instance, Uber and its strategy to get as many cars as possible out on the streets at all times in order to reduce waiting times and prices (Hill 2015); this, of course, means maximizing congestion and pollution as a logical conclusion of this ultimately self-defeating business model. IS research is already arguing for more adaptive, digital strategizing to face the challenges posed by the increasing organized complexity of business ecosystems (El Sawy, Malhotra et al. 2010, Tanriverdi, Rai et al. 2010). To expand these arguments in ecological terms, however, requires to include the impact of digital strategy at different rates and across scales other than businesses and markets, ranging from individual users, getting addicted to their phones, to the entire digital information ecology of the internet (Holling 2001). Crucially, this requires championing an ecologist’s attitude that it is not only inevitable but, in fact, desirable for growth to flatten out before it breaches the limits of an ecosystem – an important message particularly for venture capitalists.

RQ4: What is an ecologically informed digital strategy and how can it account for the effects of digitalization moving at different rates and across scales?

4.3 Digital ecosystems are the evolutionary unit

Digital ecosystems have the ability to learn and adapt, which is essential for their viability. The main cause for destroying the adaptive capacity of an ecosystem is the attempt to maximize predictability and reliability (i.e. robustness), because it reduces the range of natural variation in the system. Holling and Meffe (1996) call such attempts pathologies of command-and-control management; examples range from stabilizing rivers through dams and monocultural agriculture to rigid bureaucracies and hyper-efficient, zero-redundancy supply chains. Sooner or later, such management always leads to crises, because it erodes the adaptive capacity of an ecosystem and, hence, adaptation needs to be done through human governance, which, as a part, is incapable to control the whole (see the point on self-referentiality above). Indeed, increasing reliability by domesticating ecosystems is a cause for the rise in the propensity of catastrophic events to occur. Making water flow hyper-efficiently in a river causes more floods and operating digitally enabled, just-in-time supply chains around the world causes more virus infections to become global pandemics (Wieland 2020).

The key ingredient of the viability of an ecosystem is diversity, as it increases the pool of potential solutions for unforeseen problems. Such ecological thinking is a clear break from Neo-Darwinian approaches and its focus on the species as the unit of survival. A species is a class and, therefore, marked by homogeneity (its members are the same). An ecosystem, by contrast, survives, because of heterogeneity; a forest, after all, is more likely to survive systemic shocks, when it has diverse flora and fauna. In other words, organism *and* environment are co-evolving together and for each other rather than caught in a battle of organism *vs.* environment (Bateson 2000:454-71). Brought into an organizational context,

this contradicts Neo-Darwinian notions of the heroic entrepreneur or CEO, whose success is explained as the result of their own clever adaptation, but also notions of institutional forces, selecting those organizations for survival that fit societal expectations (Chia 1999, Tiwana, Konsynski et al. 2010).

Mechanical, unilateral approaches to selection and adaptation downplay the complex relationships and co-dependencies between organization and environment (Márton and Mariátegui 2015), which are crucial for an ecosystem to be adaptable and, ultimately, to thrive (Mikołajewska-Zajac, Márton et al. 2021, Tiwana 2014). Going back to the radical relationality of ecological thinking discussed further above, this is a crucial point; heterogeneity does not merely refer to a diverse population but to *diversity of relationships and patterns* (Ghazawneh and Henfridsson 2015, Harries-Jones 1995, Parker, Van Alstyne et al. 2017, Zundel 2014). For instance, even if we assume that a digital ecosystem has a diverse population (such as a variety in the types of app developers), if they are only related through competition, the digital ecosystem itself has little resilience, because, on a systemic level, the only pattern available to solve new problems is a pattern of competition (Henfridsson, Mathiassen et al. 2014). Indeed, recent research into technological interaction has shown that in addition to competition and complementation (or symbiosis), and their hybrid form of co-competition, there are four more types of technological interaction (neutralism, parasitism, commensalism, amensalism) (Sandén and Hillman 2011). For IS research, this opens up new avenues for casting a more complex picture of the dynamics of technological change (El Sawy, Malhotra et al. 2010), which leads to the next research question.

RQ5: What are the types of relationships in a digital ecosystem and how do they impact its adaptive capacity?

The notion of *relational variety* opens up opportunities for IS research to expand upon data homogenization, price signals, and standard APIs as core mechanisms and relationships of digital ecosystems (Constantinides, Henfridsson et al. 2018, de Reuver, Sorensen et al. 2018, Tilson, Lyytinen et al. 2010, Tiwana 2014). From the perspective of a digital ecologist, an overemphasis on standardization in an attempt to *maximize* efficiencies, revenues, control, user growth, and so forth results in a domesticated ecosystem. Because such a system is overspecialized with a single operating objective, it is becoming less and less capable of taking care of itself, as its flexibility and adaptive capacity is undermined (Holling and Meffe 1996). In the digital economy, this pattern of deficiency can be seen in the increasing centralization and domestication of the internet into the “walled gardens” owned and operated by corporations, specializing the internet to serve the single operating objective of marketing (Karhu, Gustafsson et al. 2018, Zuboff 2019). Against this backdrop, it is quite ironic that those walled gardens are called “ecosystems”, as one ecosystem (e.g. Apple’s iOS) is posed to compete against another ecosystem (e.g. Google’s Android) for market shares (Parker, Van Alstyne et al. 2017, Tiwana, Konsynski et al. 2010). If one, by contrast, thinks of a forest and a neighbouring lake, it would be an odd choice to consider them to be in competition with each other rather than entangled in a co-evolutionary relationship with the planetary biosphere.

Responding to the increased domestication of the internet, there is a concerted effort to push for its (re-)decentralization (Shadbolt, Berners-Lee et al. 2006, Verborgh 2020). Central to these efforts are distributed architectures, facilitating heterogeneity of technology, standards, practices, and so forth to find a more sustainable and balanced internet (Musiani and Méadel 2016). The IS field has much to contribute to these efforts, drawing on its substantial research into open source and open information infrastructures (Hanseth and Lyytinen 2010, Karhu, Gustafsson et al. 2018, Lindman 2014, Shaikh and Levina 2019). Ultimately, there are

promising opportunities for the IS field to develop a new narrative of responsible digital management in the digital economy; this includes big-tech superstar firms, as it is in their own interest not to destroy the digital information ecology by eroding the variety of ideas, goodwill of the public and the attention of their users. This requires an appreciation of the importance of redundancies and smaller niches, which may not be profitable short-term but essential for long-term viability (Mitchell, Lemon et al. 2020), as they counter the negative effects of too much homogenization.

RQ6: What are the principles of responsible digital management and how can they be applied to digital ecosystems?

4.4 Broader discussion

An ecological take can be applied more broadly to contemporary information systems, described to be self-referential (Yoo, Henfridsson et al. 2010), ambivalent (Kallinikos, Aaltonen et al. 2013), and instrumental in the making of reality rather than just in its representation (Alaimo and Kallinikos 2017, Baskerville, Myers et al. 2020, Orlikowski and Scott 2015). Case in point, the current, so-called second wave of AI, such as machine learning and neural networks (Ekbia 2008, Smith 2019), are designed to be irreducible, evading management by decomposing their complexity into functional modules (Henfridsson, Mathiassen et al. 2014, Simon 1969). Similarly, large scale databases, such as Facebook's social graph, display properties of systemic complexity that far exceeds mere computation of binary code. Indeed, technology historian George Dyson (2019) sees these systems developing analogue computing capabilities, which, like biological neural systems, emerge on top of digital code, like DNA. An ecological perspective is useful, because it provides a conceptual language to account for systemic, non-local, and, most importantly, unbounded phenomena (Ekbia and Nardi 2017, Tilson, Lyytinen et al. 2010).

An ecological understanding of digital ecosystems has clear connections to digital infrastructure studies, which, as mentioned above, has some roots in Bateson's work as well (Star and Ruhleder 1996). Both are helpful in conceptualizing the sprawling, interconnected information systems that defy the boundaries of formal organizations (Eaton, Elaluf-Calderwood et al. 2015, Henfridsson and Bygstad 2013). However, there are also differences, warranting future research. For instance, the term ecosystem is agnostic with regards to scale, as anything from a bacteria colony to planet Earth can be seen as an ecosystem (Pickett and Cadenasso 2002). There are also linkages between ecological thinking and sociomateriality, as they share some common roots with regards to their interest in relationality and materialism (Leonardi, Nardi et al. 2012, Orlikowski and Scott 2008). Future research could develop a language to capture the materiality of the relationships themselves that make up an information system as well as to create awareness for systemic wisdom and the wide-reaching, ecological implications of IS research (Schultze, van den Heuvel et al. 2020).

On the level of social theory, this paper also refers to modernistic conceptualizations of society and the impact the ecological crisis had on their reformulation. In particular, the notion of the risk society captures an important transition in societal structure away from industrial modernity, marked by control, towards a reflexive modernity, marked by risk (Beck 1986). Such approach has made significant contributions to social-ecology, demonstrating how ill-equipped industrial modernity is for dealing with global crises (Ekberg 2007). Yet, this approach is better understood as the social science of the discourse *about* "the ecological" – or, to put it more bluntly, "the ecological" is studied as a topic of communication (Luhmann 1993). What is meant by ecology in this paper, however, is different (Hörl 2017a). Indeed, it is exactly those modernistic attempts to capture the essence of a society by focusing on one, defining characteristic, such as risk, that is opposed by

ecological thinking, as it reduces a heterogeneous complex to a single operating system (DeLanda 2006).

Indeed, modern society as a functionally differentiated society, as Luhmann (1998) calls it, may in fact be waning, as digitalization increasingly transverses not only the boundaries of formal organizations, industries, markets and so on, but short-circuits functional social systems (and increasingly biological, psychological and abiotic systems), integrating them into a datafied, digitally mediated habitat (Kallinikos 2006). Society's structure is transforming from functional differentiation to *ecological integration*, calling for a discourse that focuses on connections and dynamics rather than on boundaries and things that move (Cooper 2005, Zundel, Holt et al. 2013). To better account for this transformation, a conceptual language and empirical sensibility is required that have self-referentiality and recursivity at the centre (Hofstadter 1999, Kallinikos, Aaltonen et al. 2013, Márton 2009, Tilson, Lyytinen et al. 2010, Yoo, Henfridsson et al. 2010), and allow for the observation of everything being connected to everything in increasingly rhizomic structures (Deleuze and Guattari 1987). Developing such language begins with a systematic, integrated understanding of core concepts, particularly of "information" and "system", as first principles of IS research.

The final point pertains to the core understanding of information systems as digital maps of a territory. As contemporary information systems are increasingly observed to be constructing or making reality, they call into question the classical notion of information systems as purposeful representations of the real world (Alaimo and Kallinikos 2017, Baskerville, Myers et al. 2020, McKinney and Yoos 2010, Orlikowski and Scott 2015). Brought into an ecological frame, this epistemological shift from a representational view of IS towards a constructivist view of reality-making is understandable. As I briefly mentioned above, because there is a patterned, circular, informational (rather than one-way, mechanical)

interrelationship between territory and map, observations are fundamentally self-referential. Observations (or maps) are *part of* what they observe (territory), leaving no posited, absolute position “outside”, from where accurate representations can be created. This has fundamental epistemological implications. We can only understand or make meaning by comparing descriptions with descriptions within an ecology of maps within maps ad infinitum (Bateson 2000:460). An ecological approach can provide a conceptual point of departure into such non-representationalist accounts of information systems (Hofstadter 1999).

5. Conclusion

The purpose of this paper was to conduct an ecological critique of digital ecosystems in order to explore new possibilities for IS research. Viewed against this backdrop, I proposed three ecological principles. The first concept of part-of-ness postulated that nothing is isolated but only exists as part of its unbounded environment of dynamic relationships. The second concept of systemic wisdom called upon IS researchers to consider wider patterns of change to put preference on ecosystemic viability. The third concept of information ecology established that digital ecosystems are actual ecological systems, if one observes ecosystems as informed rather than mechanical. With these principles, digital ecosystems can be studied by following information as an ecological phenomenon wherever it leads regardless of arbitrary boundaries of organization, industry, lifeworld, mind, and body. Thus the IS field can contribute to a broader understanding and sensibility, so that society does not end up missing the runaway dynamics brought about by digitalization until they feed back with potentially catastrophic intensity. In this regard, I postulated six avenues for future IS research.

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Table 1: Steps towards a digital ecology

Ecological principles	Explanation	Examples from Bateson	Other examples	Implications for digital ecosystem studies
Part-of-ness	Relations are primordial, as everything only exists as part-of a relationship and broader system of patterned interaction and communication.	Double bind and schizophrenia	<ul style="list-style-type: none"> - Information infrastructure studies; - Media ecology; - ANT. 	Digital ecosystems have no “outside”: <ul style="list-style-type: none"> - RQ1: What are the relationships that enable the displacement/relocation of the negative impacts of digitalization and how can they be rendered visible? - RQ2: What are the principles of self-referential design and governance of digital ecosystems and how can they be put to practice?
Systemic wisdom	Ecological limits are to be respected by being responsive to the systemic patterns of	Schismogenesis	<ul style="list-style-type: none"> - Soft systems methodology; - Complex adaptive systems; 	There are ecological limits to digital growth: <ul style="list-style-type: none"> - RQ3: What is a healthy, resilient digital ecosystem and how can it be preserved?

	processes and the change of change.		- System dynamics.	- RQ4: What is an ecologically informed digital strategy and how can it account for the effects of digitalization moving at different rates and across scales?
Information ecology	Ecosystems are informed, cognitive systems – their behaviour is motivated by differences and information, travelling along patterns of heterogeneous relationships of processes.	Information defined as a difference that makes a difference; ecology of ideas	- New materialism; - Innovation ecosystems studies; - Information management; - HCI; - Information habitat;	Digital ecosystems are the evolutionary unit: - RQ5: What are the types of relationships in a digital ecosystem and how do they impact its adaptive capacity? - RQ6: What are the principles of responsible digital management and how can they be applied to digital ecosystems?