Is Detrimental Unexpected IT Emergence Inevitable?

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Emergence—"a unifying theme for 21st century science"[1]—is 150 years old.[2] It is the name given to new behaviors displayed by complex adaptive systems, specifically those that differ from the behaviors of the systems' individual components.

Emergent behaviors can be expected or unexpected, and although beneficial unexpected emergence can be welcome, detrimental unexpected emergence is not. Given the increasing pace of global IT development, it is important to understand whether detrimental unexpected IT emergence is within organizations' control.

Key Concepts in Emergence

Complex adaptive systems consist of components with their own evolving behaviors that interact with each other to create emergent behaviors.[3] A system is defined as a set of components working together toward a common purpose.[4] In information science terms, the complexity of a system is described by the minimum length of a description of a system, where the length of the description is measured in units of information.[5] The more information needed to describe a system, the more complex it is. The more complex it is, the more likely it is to be unpredictable and to exhibit unexpected emergence.[6]

For example, a doorknob is a technology that integrates multiple parts to solve the problem of opening and closing a door. The growth and transmission of pathogens due to many people touching doorknobs—including some who may be ill and others whose personal hygiene may be lacking—is an unexpected emergence. The subsequent mitigation of this detrimental unexpected emergence comes from doorknobs made from or plated with copper, due to copper's high performance as a bactericidal agent.[7] A doorknob might be described by three units of information: a doorknob may be pulled to open a door, a doorknob may be pushed to close a door and a doorknob may be pushed down or twisted counterclockwise to unlatch a door. Compared to, say, a social media system consisting of hundreds of functional elements, this would make a doorknob a very simple system.

In mathematics, resultant vectors can be considered emergent. In a space consisting of two vectors (each representing the force on an object as its own behavior), the resultant vector behaves differently from the two individual vectors, both in quantity and direction (**figure 1**) and, thus, represents emergence.

Although the representation of a system in **figure 1** is simple, predicting the resultant vector or equivalent—or indeed the behavior of new real-world systems of interacting components—is complex, because:

- Some of the components may not be identifiable or identified, such as E and F in **figure 2**. Making

FIGURE 1
The Resultant Vector in a Vector Space

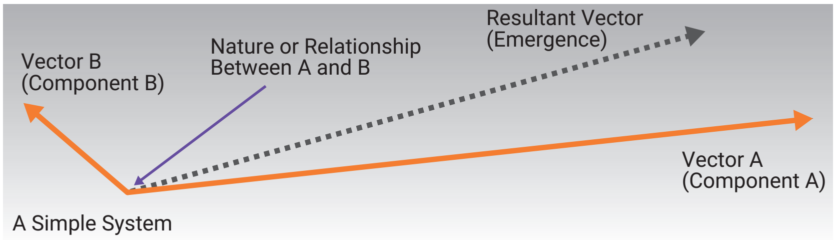

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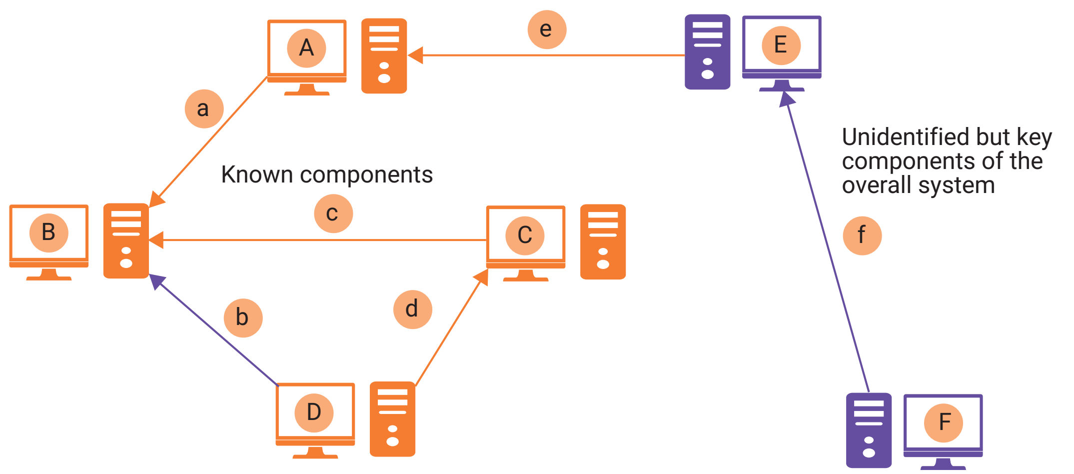
FIGURE 2

Difficulty of Identifying All Component Parts of a Complex System

A more complex system with known (orange) and unknown (purple) components and relationships



assumptions about them or not even knowing they are part of the system can amplify unexpected emergence.

- Individual components can themselves be systems rather than single components.
- All the component relationships are neither necessarily identifiable, identified nor understood, e.g. b, e, and f in **figure 2**.
- Some of the behaviors stemming from each individual component or relationship may not be understood or expected.
- The components are not necessarily limited to IT. They can include users, regulators, funders, skills, experiences, processes, procedures, governance and equipment, as well as access to power and access to telecommunications, sea, air, land, the electromagnetic spectrum and space.

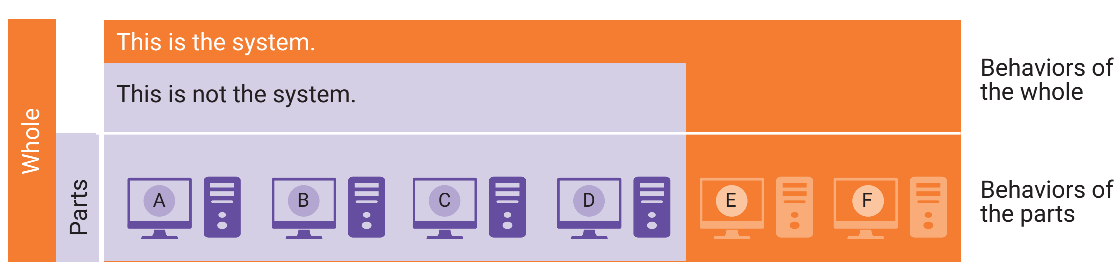
A system can be considered as a whole or as the sum of its parts. Emergence occurs in a whole system, but not in its parts. Describing a system depends on the point of view of the observer. An observer looking at a whole system will see one set of behaviors, and an observer looking at parts will see the behaviors of the individual parts.

Holon is the noun for this dualism (**figure 3**), derived from the Greek "holos," meaning all, and "on," meaning part.[8] The impact of not understanding all components and their behaviors is compromised understanding of the whole and, thus, of the holon. The visible orange section in **figure 3** represents the gap in understanding if the system is only considered to contain the purple components, illustrating the potential for unexplained emergence.

The more complex the system, the more complex the emergence, and the less likelihood of awareness of all possible emergent behaviors under all possible operating scenarios. That some components can themselves be systems gives rise to a system of systems, dramatically increasing the complexity.

FIGURE 3

The Holon



There are three types of emergence:[9]

1. **Simple**—Also known as synergy, it refers to the components and relationships that occur in noncomplex (ordered) systems to create expected emergence, not necessarily in the absence of unexpected emergence.
2. **Weak**—Anticipates and allows for expected emergence, but because the system is complex it cannot predict total emergence.
3. **Strong**—Refers to unexpected emergence (e.g., in systems of systems) when two or more systems integrate to perform a common goal, possibly disruptively. Chaotic or unpredictable emergence is likely with systems of systems.

Emergence is difficult—sometimes impossible—to predict in a real-world system of individual components. Predictability is reasonable only with the lowest of type of emergence—simple emergence.

Note that emergence disguises cause and effect in a system; one cannot understand the system by analyzing the behavior of its individual components.[10] This is referred to as irreducibility.

Examples of Detrimental Unexpected IT Emergence

There are many examples of detrimental unexpected IT emergence, whether from a data or an IT perspective. From a technology perspective, common examples are blockchain and social media, and from a data perspective, common examples come from aspects of data management.

Blockchain's Ballooning Energy Needs

Technology emergence is related to the novelty, synergy and functionality of a system.[11] For example, almost 30 years before the mythical Bitcoin creator Satoshi Nakamoto published his groundbreaking paper on Bitcoin in 2009, emergence was found to be paramount in distributed computing (a system such as Bitcoin runs off multiple networked computers rather than off a single computer). For the multiple networked computers to stay in sync, reaching what is known as consensus (achieved by proof of work in the case of the Bitcoin blockchain) was determined to be essential.[12, 13] Proof of work is a mechanism that verifies a transaction before adding it to the blockchain. Blockchain functionality is the synergy of many individual components—such as encryption,

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open source software communities and distributed computing—that display distinct individual behaviors.

An unexpected emergent outcome of the Bitcoin blockchain is the huge energy need for proof of work. It consumes 127 terawatt hours (TWh) of electricity annually—as much as Ukraine or Sweden, which are among the top 30 energy-consuming countries in the world.[14] It also produces 38 kilotons of electronic waste and has a carbon footprint of 71 million tons of carbon dioxide[15]—as much as Morocco or Romania, which are among the 60 countries with the highest carbon footprints.[16]

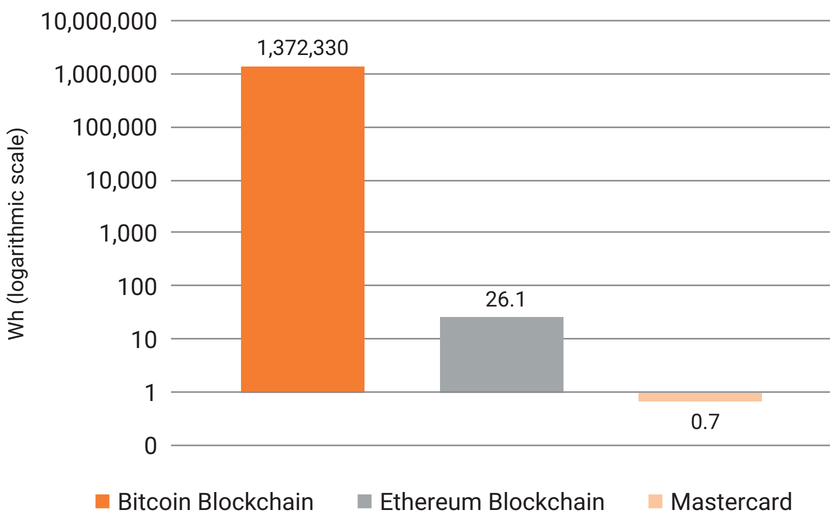
This behavior is different from the individual behaviors of the component systems (**figure 4**). The Ethereum blockchain (using the proof-of-stake validation mechanism rather than the more energy-intensive proof-of-work mechanism) requires significantly less electricity, just 0.01 TWh per transaction.[17] Yet at 26.08 watt-hours (Wh) per transaction, Ethereum is still significantly more energy-intensive than Mastercard, for example, which requires 0.7 Wh per transaction.[18]

Social Media's Human Toll

Another view of detrimental IT emergence is the acquisition and overuse of IT (including smartphones) by individuals, potentially resulting in

FIGURE 4

Bitcoin Blockchain Energy Requirements Compared to Ethereum and Mastercard



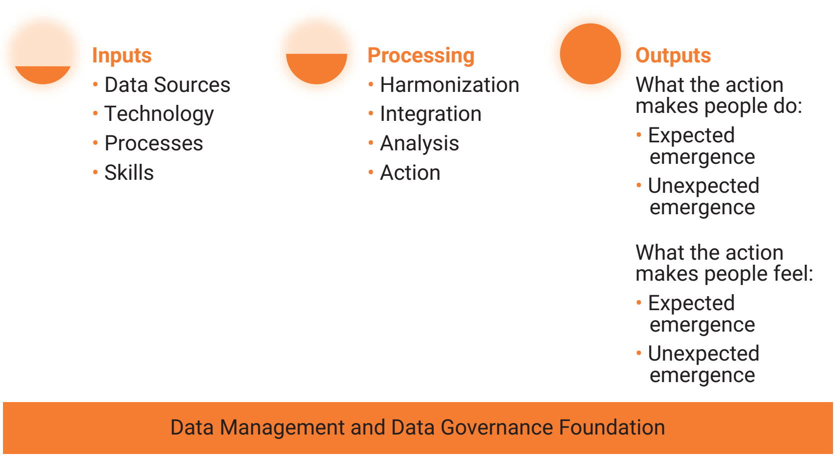
Sources: Digiconomist, "Bitcoin Energy Consumption Index," *https://digiconomist.net/bitcoin-energy-consumption* and Digiconomist, "Ethereum Energy Consumption Index," *https://digiconomist.net/ethereum-energy-consumption*

detrimental physical health effects in adults and developmental impairments in children.[19] One-third of the respondents to a Pew Research Center survey expected the detrimental impacts of technology to outweigh its beneficial impacts within the next decade.[20]

Social media has exposed young people to bullying, rumor-spreading and the pressure of unrealistic expectations.[21] The detrimental impacts of IT on analytical thinking, memory, focus, creativity, reflection, mental resilience and dopamine addiction[22] were unforeseen.

FIGURE 5

The Data Value Chain



That social media technology contributed "more than minimally" to the death of a 14-year-old girl[23] is among the worst forms of detrimental unexpected IT emergence. In the words of her grieving father, "it's time to protect our innocent young people instead of allowing [social media] platforms to prioritize their profits by monetizing the misery of children."[24] This was not the first case of its type.

Impact of Individuals

In some cases, a single person's entrepreneurial endeavors can be highly impactful. Consider Elon Musk, for example, the driving force behind Starlink,[25] Tesla,[26] and SpaceX,[27] whose vision and influence have introduced unexpected emergence in a multitude of industries.

Examples of Detrimental Unexpected Data Emergence

Merging data sources with differing lineage can introduce beneficial and detrimental emergence resulting from:

- Timing differences between sources
- Differences in meaning between data elements
- The ways data are stored (e.g., data type and encoding), which, at first glance, may appear comparable but are actually completely different

Further examples of emergence include assumptions that data are accurate when they are not necessarily so, breaches of sensitive data when collected or stored, and uses of data in ways not initially imagined. Compounded emergence can occur in data management and data governance (domains that include privacy and security risk controls), for example, or in such new behaviors as the production and distribution of fake news and deep fakes.

Emergence is generally considered a final outcome, but it can occur at multiple points along the data value chain (**figure 5**). From a privacy perspective, at the input level, emergence may occur when third-party data are acquired without consent, as exposed during a privacy audit. At the processing level, emergence may occur in the form of data being processed in ways not initially agreed upon with the data source, as exposed during an EU General Data Protection Regulation (GDPR) audit.

Detrimental unexpected privacy and security emergence seems to come to a head in the breaches of the personal data that occur around the world. For example, a breach of the personal data of 9.8 million customers of Optus—a major Australian telecommunications organization that experienced the biggest data breach in Australia—shows that organizations "may be forced to dispose of what they don't need, or fined more punitively if they misuse or lose what they have."[28] The Optus breach stressed the high cost of data hoarding.[29]

One reason it is taking so long for Australian organizations to become more aware of data risk is that Australia's Privacy Commissioner is underfunded.[30] This situation is not unique to Australia.[31, 32] Furthermore, organizations have forgotten that customer data do not belong to them and that it is a privilege to be a data steward.[33] Privacy and security need significant investments to stem declining trust in organizations.

Unexpected Detrimental IT and Data Emergence: Primary Risk

If outcomes cannot be predicted and a system cannot be understood, then realizing that the outcome can be detrimental for individuals, groups, organizations or even for society as a whole means that the variance in outcomes compared to expectations—risk—can be so significant that it can compromise an organization's efforts to achieve its objectives or negatively impact society overall. Some factors driving the risk include:

- Unvalidated new technology
- Lack of consideration of cross-domain impact
- Disagreement about what the system is solving or providing
- Conflicts of interest about solutions to problems, such as between surveillance and privacy
- Increasing levels of connectivity between information technologies
- Contradictions and other differences between short-term and long-term values driving a solution[34]
- System unknowns, both known unknowns (for example, known gaps in a system's capabilities for which no adequate response seems to exist) and unknown unknowns
- Increasing system performance expectations (E.g., tight coupling can expose weak links in high performance environments, whereas low performing components cannot be replaced without replacing entire sets of components.)

> Since expected detrimental emergence should already have been considered by project risk management, it is specifically unexpected detrimental emergence that remains worrisome.

Although all emergence is a risk, it is detrimental emergence that causes the most trouble. However, since expected detrimental emergence should already have been considered by project risk management, it is specifically unexpected detrimental emergence that remains worrisome (**figure 6**).

A system (the holon) is defined not only by its technologies, but also by stakeholders, the solution space, enabling systems, interoperating systems (represented by E and F in **figure 2** and **figure 3**), internal influences, and external influences including political, economic, social, technological, environmental and legal factors across the entire system's life cycle.[35] This is supported by a principle of systems engineering: "Decision quality depends on knowledge of the system, enabling system(s), and interoperating system(s) present in the decision-making process."[36] All this dramatically increases the scope of considerations required to understand the full risk profile of the holon.

FIGURE 6

Detrimental Unexpected Emergence

Emergence	Beneficial	Detrimental
Expected	Simple emergence expectations	Predicted and engineered out
Unexpected	Positive surprise	Problematic

Source: Adapted from Kopetz, H.; A. Bondavalli; F. Brancati; B. Frömel; O. Höftberger; S. Iacob; "Emergence in Cyber-Physical Systems-of-Systems (CPSoSs)," *Cyber-Physical Systems-of-Systems (CPSoSs)*, 18 December 2016, *https://link.springer.com/chapter/10.1007/978-3-319-47590-5_3#rightslink*

Given this complexity, unexpected emergence or unintended consequences should actually be expected. The problem lies in not knowing what they might be or when they may present themselves.

If something as simple as a doorknob can produce detrimental outcomes, what about machines claiming to think as humans do or the maintenance of immutable records that requires increasing electric power for their sustenance?

Often missing in detrimental unexpected emergence is the acceptance of accountability for the outcomes experienced by the affected parties due to the actions of human progenitors—whether an individual or a group. If and when there is a response, there is also hope that the progenitor's response to negative outcomes is ethical.

While enterprise risk management is always a factor in organizational IT, the risk of a technology to the social fabric that keeps people and communities connected as human beings is of greater concern. Think of the negative impacts of social media. It falls to human beings to identify technology-driven risk to the social fabric and to raise the alarm by any means possible. It cannot be expected that enterprises or organizations will do this given their potential or perceived conflicts of interest. Furthermore, regulators will be slow to respond while they wrestle with understanding the technology, and declining trust in government may compromise its ability to safeguard its citizens' best interests.

Conclusion

The question is whether detrimental unexpected emergence in a holon is predictable—whether the risk can be identified, analyzed and at least partly controlled. The argument made is that detrimental unexpected emergence in holons is not necessarily identifiable, much less controllable, given the holon's almost incalculable complexity, and that what is unknown is unknown.

This is, perhaps, a word of warning for the deployment of emerging systems such as blockchain and artificial intelligence (AI). Humans do not really know what is in store with these technologies. If something as simple as a doorknob can produce detrimental outcomes, what about machines claiming to think as humans do or the maintenance of immutable records that requires increasing electric power for their sustenance?

There is a great deal more uncertainty to come in the growing ecosystem of emerging technologies that break new ground in a particular field; converging technologies, which develop from different technologies with similar goals; and disruptive technologies, which displace earlier technologies.[37]

Therefore, more detrimental outcomes should be expected as society's development of and dependence on IT grows. One way for humans to challenge the potential growth of detrimental outcomes is to highlight issues through the various channels available, such as by means of digital media and the municipal and regional channels of governments. If humans do not, the cost may, ultimately, be greater than what society has the capability to address.

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