Sustainability and the manager's perception of reality: towards a theory of bounded perception

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Cabiddu F., Watson R,T., Piccoli G. (2020). Sustainability and the manager's perception of reality: towards a theory of bounded perception, in AAVV., Contributi in onore di Gaetano Maria Golinelli, Rogiosi Editore, Napoli, ISBN: 978-88-6950-393-1

Abstract

Obiettivi. *L'obiettivo del presente lavoro è definire un framework teorico in grado di identificare il ruolo dei Sistemi Informativi per il superamento della percezione limitata die manager nei confronti delle problematiche ambientali.*

Metodologia. *Il presente lavoro è di tipo concettuale ed esplora come il concetto di percezione limitata possa portare a scorrette interpretazioni dei problemi ambientali e fornisce un framework teorico in grado di spiegare l'aiuto offerto dai Sistemi informativi per comprendere quali segnali devono essere percepiti e come devono essere trasformati.*

Risultati. *I nostri risultati mostrano come i Sistemi informativi possano alleviare i problemi legati alla percezione limitata del manager estendendo i loro confini e capacità di rilevamento e facendo corrispondere i flussi digitali ai canali di rilevamento analogici. Il paper offre, inoltre, delle proposizioni basate su un'analisi approfondita di tre flussi di letteratura: scienze naturali, sistemi di informazione e gestione.*

Limiti della ricerca. *Il lavoro è esclusivamente teorico, future ricerche potrebbero testare il framework teorico empiricamente e renderlo operativo.*

Implicazioni pratiche. *L'articolo fornisce idee pratiche e tecniche per estendere i confini sensoriali dei manager e per migliorare le loro decisioni manageriali*

Originalità del lavoro. *Ci sono state pochi studi teorici che si sono focalizzati sul ruolo dei Sistemi Informativi per il superamento dei limiti della percezione umana per migliorare la percezione dei problemi ambientali.*

Parole chiave: *processo decisionale; percezione limitata; problemi ambientali; Sistemi Informativi*

Objectives. *The aim of this work is to provide a theoretical framework able to identify the role of information systems in overcoming the bounds of perception of environmental issues*.

Methodology. *This is a conceptual paper that explores the concept of manager's perception of reality and how bounded perception can lead to misinterpretation of environmental signals by providing a theoretical foundation to guide practice on what, trough the help of Information Systems, should be sense and how it should be transformed.*

Findings. *Our findings show how Information Systems could alleviate the problems related to manager's bounded perception by extending their sensing boundaries and capacity and matching digital streams to analog sensing channels. We offer propositions based on in-depth analysis of three stream of literature: natural science, Information Systems and management.*

Research limits. *This is a theoretical paper, future research efforts should be directed towards both empirically testing the framework and operationalizing it.*

Practical implications. *The paper provides practical ideas and techniques for mangers to extending their sensing boundaries and therefore improve managerial decisions.*

Originality of the study. *There has been little formal theorizing about the role of information systems in overcoming the bounds of human perception to enhance the perception of environmental issue.*

Key words: *decision making; bounded perception; environmental issues; Information Systems*

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1. Bounded perception: a problem not perceived

Decision-making is the central activity of any organization (Eisenhardt and Zbaracki 1992; Huber 1984), and the quality of an organization's decisions is affected by its decision makers' perception of the reality surrounding them. In a complex environment, a decision-maker's capability is limited by both bounded rationality and bounded perception. Bounded rationality is the limited capacity of the human mind for formulating and solving complex problems (Simon 1982). Bounded perception, for which we can find no prior definition, is the limited capacity of the human senses to perceive the features of their environment. We can sense only some aspects of environment and then within limited ranges and many other attributes we cannot sense. For example, we can hear sounds within the range of 20 to 20k Hz and a distance of a few kilometers at best. We cannot see, hear, taste, smell, or touch CO_2. While there has been considerable literature focused on bounded rationality since early pioneering work (Simon 1982; 1997; 1956), the limits of humans' perceptive capabilities have been relatively ignored in management and information systems research. A search with Google Scholar using "bounded perception" and "bounded rationality" gives remarkably different results. The first page of each search reports 166 and 15,442 citations, respectively, for each phrase. If it were not for one article (Heifetz et al. 2006), "bounded perception" would have less than 50 citations. As to be expected, Simon's work (Simon 1982, 1991) dominates citations on "bounded rationality." The dominant article (Heifetz et al. 2006) on bounded perceptions is a mathematical model of unawareness that mentions the phrase twice, does not define it nor cite a source for the term. Searches using the terms "bounded sensing" and "bounded perceiving" give similar results.

Bounded perception is an important topic because past and current events show that failure to perceive problems can cause societies to collapse (Diamond 2005) and firms to fail (Weick 1993). This happens because leaders and managers who miss important environmental signals are more vulnerable to surprise and unable to take high quality decisions. This lack of perception of environmental issues makes the issue of bounded perception highly salient to current society. We live in a world facing major ecological issues and inundated with industrial chemicals. We lack the perceptual ability to detect in our everyday lives many of these problems accurately because of the bounds of our senses and the related inability to discriminate between relevant and irrelevant data (Starbuck and Milliken 1988).

Over time, however, humans have augmented their perceptual ability with information systems. For example, we have sensors that measure CO_2 levels, and we survey customers to measure their view of service. Prior research has demonstrated that information systems have beneficial impacts on managers' decisions (Nolan and McFarlan 2005). However, there has been little formal theorizing about the role of information systems in overcoming the bounds of human perception to enhance the perception of reality. In this article, we address this understudied area, and identify the role of information systems in overcoming the bounds of perception of environmental issues. In particular, we will address two questions: 1) How does bounded perception condition managerial decisions? 2) How can information systems enhance perception and therefore improve managerial decisions? While there have been a significant number of Human Computer Interaction studies that have analyzed how machines might change or facilitate human perception (Dix et al. 2006; Reeves and Nass 2000) to this date, researchers have not explicitly addressed how bounded perception influences the ability of organizations to make the right decisions when faced with changes in their environment.

Three distinct streams of literature frame our proposed conceptualization. First, both the natural sciences and information systems offer insights about the notion of perception and bounded perceptions. The former gives us the formulaic notion of environmental perception (Chalmers et al. 2009, p. 1102). The latter helps us to extend it to include digital data, represented by discrete, discontinuous binary digits. Next, the management literature offers insights about the manner in which managers perceive the characteristics of the environment and how it is filtered by their bounded perception. Finally, the information systems literature contributes ideas on both bounded perception and decision quality.

This article is structured as follows. We analyze the notion of perception, discuss the bounds of perception, review the limited prior literature on bounded perception, consider the implications of perception in a massively digital world, and conclude with a discussion of the implications for IS research.

2. Deconstructing perception

According to the natural sciences, perception is the process of becoming aware of the immediate environment through the senses (hearing, sight, smell, taste and touch). This means that our sensory perception is obtained through a combination of our five senses, each specialized in decoding specific information, and supplying an overall impression of the environment. For example, sight furnishes information on an object's position, but it is primarily touch that suggests information related to a material's surface properties (Fagiani et al. 2011). Theories on how perception works come from research about the ecological psychology of objects and people in the real world. This literature, provides a view of perception as a relation between the perceiver and what is perceived (Chemero 2003; Gibson 1979).

Based on these conceptualizations, we elaborate a prior formulaic specification of environmental perception, namely:

$$P(\tau,\rho_t)=\sum_{i=1}^{5}\omega_i S_i+\Delta$$

Where

P is the environmental perception

τ is a task

ρt is a person's preconditioning at time t

ωi is the perceptual weighting of sense Si at the time t.

△ is a distraction factor (e.g., another person talking or a car passing) (Chalmers et al. 2009, p. 1102).

The prior original formulation of environmental perception assumes humans receive only analog data, but now, most data are born digital, such as a customer filling in an online form or a probe reporting temperature as a string of bits. In just over two centuries we have shifted from an analog to a digital world in nearly every dimension.

Information Systems researchers have started to explore the role of technology in this dynamic arguing that many information technologies do more than simply transmit or store information. They can transform data into information to improve human perception. In this perspective, technology affordance refers to "an action potential, that is, to what an individual or organization with a particular purpose can do with a technology or information system" (Majchrzak and Markus 2012). For example, computerized medical imaging technologies such as ultrasound and computed tomography enable radiologists to see and diagnose pathology that could not be visualized using human perception (Barley 1988).
As a result, we refine the original formulation of environmental perception to include digital data. Our extension of the prior specification of perception includes the impact of multiple digital streams upon a human. For example, a person watching a 4D-movie has the possibility not only to listen and see the movie in the traditional way, but also to perceive on her own skin the changes that the character in the movie is experiencing, thus feeling, for example, the chill of the wind or the

vibration of the ground during an explosion: all these data streams will be transformed into analog streams that will impinge upon her. The transformation of these digital feeds will influence perception. At the same time, a person can still receive direct analog feeds, such as someone else talking while the movie is in progress. Thus, the perception for each sense, Si, at time t, is influenced by both the direct analog feed, Ai to that sense, and the set of current digital feeds, Dj, impinging on Si, which can be formulated as:

$$S_i = A_i + \sum_{j=1}^{m} D_j$$

In addition, we need to elaborate preconditioning. We propose that a person's preconditioning a time t, putting aside issues such as personality and intelligence, is influenced by what has been perceived in the past (Gibson 1986: 258). These prior perceptions have different weightings, because some events are more traumatic or impressionable than others, they have a higher impact. The weights of prior preconditions will likely decay with time because of a decrease in saliency and the higher influence of more recent perceptions. Formally,

$$\rho_t = \sum_{k=t-1}^{n} \beta_k P_k$$

Where

Pk is the environmental perception at time k

βk is the weighting of perception Pk at time t.

3. Bounded perception

The prior original formulation of environmental perception and its extension to include digital data assumes that individuals have limited perceptual capability to process the sensory information generated by the world. More specifically, humans limit the affordances by "picking up a particular kind of information, leading to the perception of a particular affordance" (Ingold 1992: 46). This happen because our five senses can detect signals within a limited range (hearing and sight), within a limited set of categories (taste), or above a certain threshold (smell and touch) (see Table 1). The colors that individuals can see are only a small part of the electromagnetic spectrum. For instance, many of the animals that eat bananas can see light in the UV range. As a result, they see ripe bananas glowing luminescent blue but not green ones (Moser et al. 2008).

Tab. 1: Sense range or categories

Sense	**Boundaries**
Hearing	20 Hz to 20,000 Hz (Munro 2009) and at most several kilometers
Sight	400 to 700 nm (Gegenfurtner 2009) and hundreds of light years
Smell	There is no equivalent to the wavelength of light, and there is currently insufficient knowledge of the olfactory

	response to identify boundaries (Cometto-Muñiz 2009)
Taste	Five categories: sweet, salty, sour, bitter, and umami (meaty) (Lemon 2009)
Touch	Ill-defined boundaries because touch is experienced from sensors in the skin, muscles, tendons, and joints and effects vary with temperature (Klatzky and Lederman 2009)

Source: our elaboration

A good example of how bounded perception can lead to misinterpretation of environmental signals is offered by the history of the Mann Gulch fire disaster, where 12 firefighters (from a crew of 15) perished. There is no analysis of how the firefighters' bounded perceptions affected the sense-making process of the crew's foreman and the crew, but archival records show a lot of available information and indicate that the bounded perceptions of firefighters influenced their decisions. The smokejumpers saw the fire, but their bounded sight didn't enable them to see the extension of the fire and recognize its danger. They heard the wind but didn't connect it to the spreading fire. When the foreman ordered everyone to lie down in the burnt area, the crew heard him saying something about escaping the fire, but the noise of the fire had become intense by that time. The smokejumpers ignored him, and perished (Weick 1993).

In addition, our ability to process sensory information is also bounded. An orientation on one sensory stream (e.g., vision) causes a shift in attention from one or more of the others (e.g., touch) (Spence 2009). We are primarily limited to handling one sensory input at a time. Selective attention theories, developed in the psychological and organizational behavior area, suggest that bounded perception results from humans' tendency to orient themselves toward, or process information from, only one part of the environment to the exclusion of other parts (Broadbent 1958). This selective attention is a result of people having limited capacity for processing information and relying on simplified mental models of reality to organize their knowledge and make sense of the world (Cyert and March 1963; March and Simon 1958). At any specific moment, only a small level of the information available on the visual field can be processed and used in the control of behavior (Desimone and Duncan 1995). To deal with this perceptual overload, managers focus their attention on those domains that they believe to be most relevant while selectively ignoring others (Bogner and Barr 2000; Fiol and O'Connor 2003; Hambrick and Mason 1984; Nadkarni and Barr 2008).

Bounded perception is also influenced by what we are prepared to see. As Einstein noted, "It is the theory which decides what can be observed" (Heisenberg 1989). This means that people maintain mental representations of expected relations and paradigms, which in turn regulate their perceptions of the world (Bruner and Postman 1949). Thus, building on the earlier part of this section, bounded perception is a limited capacity to detect and process sensory information and an inability to recognize the relevance of some sensory inputs.

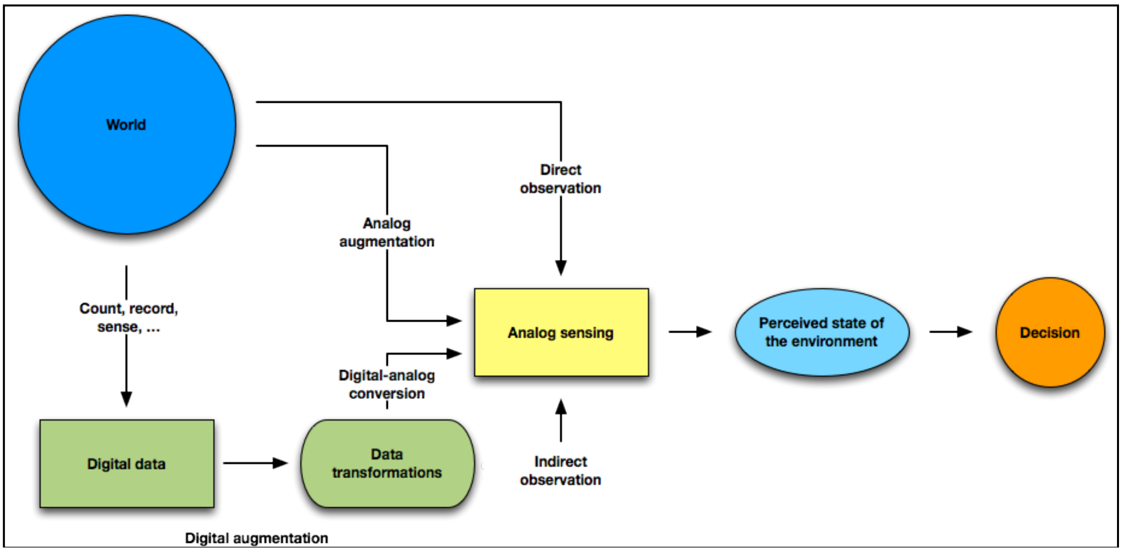
4. The managerial perception of reality

Although several explanations of the manner in which managers perceive the characteristics of the environment have been developed missing in such studies is a micro level account of the problems related to a manager's bounded perception. Two views have been particularly dominant: the positive and the interpretive. The positive view assumes that a single, objective reality exists independently of what individuals perceive (Aldrich 1979; Chandler 1962; Child 1972; Emery and Trist 1965; Thompson 1967). In contrast, the interpretive view denies that one real world exists, that is, reality is essentially mentally represented and therefore perceived (Burrell and Morgan 1979; Daft and Weick 1984).

In recent years, researchers have noted that managers differ in the degree to which they perceive the business environment (Castrogiovanni et al. 2011) and have developed the linkage between management perception and causal ambiguity (Powell et al. 2006). Others posit that the structures of cognition and the scanning and sense making processes may influence the framing of the decision (Narayanan et al., 2011). A new stream of research, ecological materiality (Whiteman and Cooper 2011), suggests that both ecologically embedded actors (i.e., actors that understand the local peculiarities and interactive effects) and actors with expertise in specific process, such as a fire, will be better able to perceive changing ecological conditions because they can access a richer repertoire of information.

Humans have been extending their sensory capability for tens of thousands of years to improve their perception of reality and the quality of their decisions (see Figure 1). Learning from others via indirect observation, which still persists today, provided the first extension. Our elders and peers teach us about the world through devices such as folklore, adages, and theory. We learn that "the grass is greener on the other side of the hill," from others rather than seeing the greener grass. Earlier societies developed myths to explain the world and these influenced the perception of reality. Today, we are taught theories, along with the myths of yore that help us to interpret and explain the world.

Fig. 1: The perception of reality in a digital world



Source: our elaboration

Analog augmentation, in the form of telescopes, stethoscopes, and X-rays for example, extends the perception of reality. With a telescope, astronomers extend their visual ability, and early astronomers were able develop a more exact description of the solar system and dispel the flat earth model.

The major revolution in augmentation, however, has been driven by the digital revolution of the last half-century, particularly in the last decade with the development of low cost sensing devices. Now, much of what manager learn about the world originates as digital data (e.g., camera sensors, digitized text and numbers) that is transformed by computers into an analog stream (e.g., photos and text on a screen) to be processed by our tens of thousands of years old evolved analog sensing capabilities. As a result, an impressive range of information is now digitally created, stored and consumed. Furthermore, types of information that were simply impossible to capture are now routinely captured, stored and analyzed. Digital augmentation has become extremely influential in framing manager perception of reality. They learn the performance of the London Stock Exchange not by going in a physical place, but by consulting an app on a smart phone.

As digital technology continues to expand its influence on everyday experiences, it is imperative that we develop information systems that can transform the mass of digital data into analog formats that humans bounded perceptions can process, the bottleneck in the process of assessing reality. We believe that it will become increasingly important for IS scholars to study how we transform digital data from sensing systems into formats that improve a decision maker's perception of reality.

5. Information Systems research issues to alleviate the bounds of perception

According to the prior discussion, there are two fundamental problems related to managers' perceptions. First, some managers' perceptions are limited by range, threshold, conditioning, and personal selectivity (Hughes 1999). Second, managers have limited capacity to attend concurrently to all the stimuli they receive. The gap between the perceptual ability of the person and the signals that arise from the environment can lead to individual stress (Ragu-Nathan et al. 2008) and organizations to fail (Weick 1993). IS could alleviate the problems related to bounded perception by enhancing managers' perceptions by extending their sensing boundaries and capacity and matching digital streams to analog sensing channels. Given the very limited prior research on bounded perception, we need to initially take a broad approach to the topic and provide an answer to one fundamental question to establish research in this area: How can information systems enhance perception and therefore improve managerial decisions? This first question leads directly to several key IS questions related to what we should sense and how we should present it to human decision makers.

5.1. Extending Individual Sensing Boundaries

Information systems can enhance perception and therefore improve managerial decisions extending individual sensing boundaries and sensing capacity. Sensor networks extend individual ability to sense outside their physical range, and the digital data they capture can be transformed into analog format and processed by our brain. As a result, humans can sense, generate, store and communicate all types of information that were not available in the past. Mangers can detect pollution via a satellite and broadcast the data to scientists in hundreds of laboratories. Sensor networks and scientific instruments enable individual to extend their sensing capability beyond its inherent limits. The combination of sensor networks and the global information infrastructure is creating smart cities (Riva and Borcea 2007). Such embedded computing environments (Lyytinen and Yoo 2002) are likely to change the way individuals perceive the environments.

5.2. Extending Individual Sensing Capacity

By extending their sensing boundaries, humans create the circumstances for massive information overload (Eppler and Mengis 2004). Our capacity to handle stimuli is limited, which can be a problem in a modern world in which we subject a flow of information well beyond the needs of our African ancestors of millennia past. Information systems, again, can help to handle this overload in two fundamental ways. They can be used to amplify or attenuate environmental signals (Watson et al. 2002). Because we have limited attention, we need information systems to sort out what matters and to amplify and bring what is important to the forefront of our attention. Most cars, for instance, alert us with a light when the fuel tank reaches a lower limit and then ping continuously when there is only enough fuel for 25 kilometers or so.

Over the millennia, humans have discovered how to extend their sensing boundaries and capabilities. A tribe's scouting party was its means of extending its sensing boundaries beyond the village, and now we have space probes that can report windstorms on Mars. Furthermore, we have learned to tandem sensing mechanisms and information systems so that they we can magnify the critical and dampen the inconsequential.

5.3. Sensing and decision making

Our senses, ultimately, are the only means by which we can get information about the environment, and this information determines the quality of our decisions. Over the last few decades, we have massively increased our ability to use machines to sense the environment, analyze these data, and transform the results into formats we can perceive (Yoo 2012; Yoo et al. 2012). Humans have augmented their senses because they recognize that more and better information improves their decision-making capability. The physician who orders a series of blood tests and an MRI knows from education and experience that the data she cannot sense directly will enable her to make more accurate diagnosis. We need to consider what we should sense and how we should present it to human decision makers.

5.4. What to sense digitally?

The design of an information system starts with establishing requirements, and the field has developed techniques for capturing and recording requirements (e.g., data modeling). We need to extend information requirements' determination to identifying the supply chain from sensed data to decision making. As well as determining what needs to be sensed, IS needs to develop techniques for determining the frequency of sensing and the density of sensors. For example, for optimizing an electrical grid, how often should residential and commercial energy usage be measured and at what level (e.g., building or type of device)? This is also known as the information granularity problem (Watson et al. 2010).

5.5. How to transform what is sensed digitally?

Sensor networks can potentially create a deluge of data that will overload our already bounded perceptions. Given the relatively high bandwidth of our visual processing system, how are data transformed to enable visual analog processing that maximizes the understanding of reality and leads to high quality decisions? There may be, however, occasions when the other senses need to be engaged to process data. For example, when might it be more effective to transform a digital signal into a specific sound to get immediate attention about an important change in reality that needs to be factored into current decisions?

The transformation of digital data into analog formats is likely to become a critical area for IS scholarship because of the vast volume of data that will soon be generated and the need to push these through a finely meshed electronic sieve to extract the essential information that should be communicated to decision makers. In addition, IS scholars will need to help discern which data can be transformed and diverted to other computers for automated action. The sheer volume and velocity of data are likely to give IS scholars an opportunity to become involved in designing solutions. We can expect an increase in research in the areas of business intelligence and predictive analytics.

6. Sensing and bounded rationality

Our ability to sense, particularly in the world of sensor networks, soon confronts our bounded rationality. Our forebears of tens of thousands of years ago suffered bounded rationality when their senses received more information that they could handle. We, their descendants, are immersed in an information tsunami and our senses can easily become overloaded and attention has become a scarce resource. The bottleneck of bounded perception precedes that of bounded rationality. Information systems can perform two critical tasks for humans: they can amplify and attenuate environmental signals (Watson et al. 2002) so that we are alerted to handle the necessary and let information systems handle the mundane. Thus, we arrive at two key research questions.

6.1. How to determine from what is sensed digitally that which should be amplified and how?

Information Systems can be seen as a powerful tool to support the economic system managing information or, conversely, a development that creates a more complex and difficult to manage environment. A clear indication of the first perspective is found in IS studies based on the transaction cost approach (Malone et al. 1987). Such studies argue that IS supports the economic system, providing a more efficient information flow that facilitates the interaction among economic agents under complex and uncertain circumstances, and reducing transaction costs. On the other hand, the literature addressing the problem of 'information overload' underlines the negative effects of IS due to a greater level of complexity faced as a consequence of the increased quantity of information created (Grise and Gallupe 1999). Not all data are of equal value to a current decision, and their value will vary as the context and problem changes. Given that humans cannot process all the data from the analog and digital streams they receive currently, let alone the coming sensor flood, how do we use information systems to determine what matters for the current decision and then how do we ensure that the decision maker pays attention to the most essential data?

6.2. How to determine from what is sensed digitally that which should be attenuated and how?

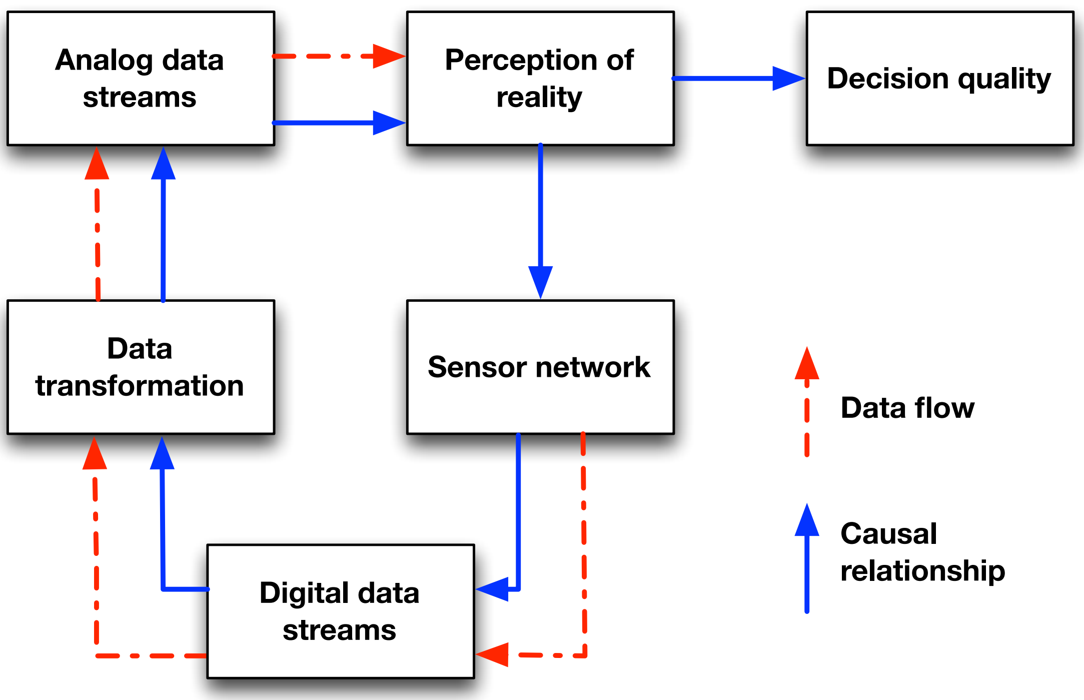
IS researchers will need to build decision models for deciding how to handle data under a variety of circumstances so that the decision maker is not overloaded by irrelevant data or decisions that could have been made by software. We need to be able to determine what data should be effectively bypassed for certain decisions. This sidelined data could be handled in two ways, ignoring or automating the response. A key research question is to determine what data can be ignored at a particular time for a specific location and thus needs no further processing. Another central question is, if certain data need attention, how can they be processed and handled automatically?

In summary, the four questions tackle the fundamental issues raised by the phenomenon of bounded perception. We need to develop a theoretical foundation to guide practice on what should be sense and how it should be transformed. Of course, such a theory should be contingent on circumstance because decision-making is highly contextual. In a world experiencing environmental degradation across many dimensions, the issue of determining what to sense is extremely important.

The final two questions can be considered as aspects of the second transformation oriented question. The first state of data transformation is to decide whether the data should be transformed into a format supportive of human information processing to support decision-making or be converted into a series of commands to instruct computers to take automated actions. Hence, we can reduce the questions to basic issues of sensing, transforming, and acting.

To guide initial research on bounded perception, we present the following model (Figure 2) that intermingles data flows and causal relationships. Our extended formulation of perception of reality discussed in the previous section is the dominant causal force. We are the product of our perceptions of reality, which has been shaped by our perceptual boundedness and conditioning processes such as prior experiences and education. A CIO, for example, has had a quite different stream of perceptions from that of a marketing executive because of education and experience. Two CIOs in similar companies will also likely have different perceptions because of variations in their experiences and background.

Fig. 1: Titolo della figura o del grafico



Source: our elaboration

Perception will determine what decision makers think should be measured, thus influencing the design of sensor networks and what data are extracted from such networks. It will also influence data transformation and the interpretation of the resulting analog data streams. For example, an executive concerned with water pollution will invest in sensor network technology and associated information systems differently from one focused on energy efficiency. Thus we put forward the following three propositions:

P1. The perception of reality influences the design of a sensor network.

P2. The perception of reality influences which data streams are extracted from a sensor network.

P3. The perception of reality influences transformation of data streams into analog streams.

Generated analog data streams can modify perceptions of reality. Thus, despite the caveats discussed, we propose that:

P4. Generated analog data streams modify the perception of reality extending our perceptual ability.

Thus, for completion of the causal model and consistency, we state one more proposition.

P5. The perception of reality determines decision quality.

7. Conclusion

The bounded nature of human perception has been almost completely ignored, especially when considered in light of the emphasis given to bounded rationality. We are now entering an era of mass sensors where there will be the capability to generate avalanches of data every few moments.

This same deluge, if processed appropriately by information systems, can create a perception of reality more precise and deeper than ever before. This promise can be achieved with the help of IS scholars because the transformation of data to meaningful information to be processed by one of the five human senses is the critical bottleneck between sensing and the perception of reality. Scholars have effectively ignored our bounded perception, but now we are entering a world where the size and diversity of human organization and the complexity of problems we face means that we must address this phenomenon directly. It has become imperative for IS scholars to learn how to use information systems to address this human limitation that directly affects the quality of decision making. In an age of profound human problems, IS scholars can contribute to helping humans overcome the bounds of their bounded perception.

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Cabiddu F., Watson R,T., Piccoli G. (2020). Sustainability and the manager's perception of reality: towards a theory of bounded perception, in AAVV., Contributi in onore di Gaetano Maria Golinelli, Rogiosi Editore, Napoli, ISBN: 978-88-6950-393-1