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The role of sound in infoscapes: human and technological information processing

In our daily life, we encounter many sources of information or sources that are intended as information. In this essay, the autor focusses on environments containing sources of information that are human-made. He refers to these environments generated by products or systems as infoscapes, analogous to soundscape but as a more general term. Furthermore, in this essay the author makes one other important distinction. He considers information as a concept that is emergent from the processing of the sensed data in the physical outside world (Umgebung), both by human and system and the meaning given to it. This distinction is important because it means that not all data or disturbances in this Umgebung may yield information.

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When I studied in Amsterdam (in a time when there were no mobile phones and fancy noise-canceling headphones), I commuted every day by bus from Haarlem to Amsterdam. During part of that ride, a group of hearing-impaired children traveled to their school. They were a loud bunch, they shouted and had fun. Everybody else on the bus knew when the stop was coming when they got out and 'peace' returned. I tell this story because of the following. For the hearing-impaired children, their perception-action loop was impaired. They were producing sound (action), but they could not or only in a very limited way perceive it (perception). Thus, a cacophony of — for the other passengers — 'meaningless' sounds was filling the bus. For the passengers, the perception-action loop was also impaired, such that no action could be taken to silence the crowd of juveniles. Perhaps everybody (including bus drivers) tried once, but they were not able to communicate with these hearing-impaired children (the children communicated among themselves with sign language and vocal utterances). Consequently, the other passengers could only wait for the desired bus stop where the children got out.
This story functions as an example that can be extended to how people and systems perceive things and act upon them. It also exemplifies Von Uexküll (1909) distinction between *Umwelt* and *Umgebung*, in which the latter is the physical outside world and the Umwelt the inner experience of this outside world. Meaning that every individual organism has its own way of giving meaning to the physical outside world. In the aforementioned example, the passengers versus the hearing-impaired children.
In our daily life, we encounter many sources of information or sources that are intended as information. In this essay, I will focus on environments containing sources of information that are human-made. I will refer to these environments generated by products or systems as infoscapes, analogous to soundscape but as a more general term. I am aware that the term infoscapes is also used in different contexts (Skovira, Borkovich, & Kohun, 2022), but with the rise of intelligent connected systems there is a need in cognitive ergonomics for a term that captures the multitude of informational streams. Furthermore, in this essay I will make one other important distinction. I consider information as a concept that is emergent from the processing of the sensed data in the physical outside world (Umgebung), both by human and system and the meaning given to it. This distinction is important because it means that not all data or disturbances in this Umgebung may yield information.

Analogy between human information processing and technological information processing

In a world where the role of intelligent systems becomes larger, the interpretation of the world by these systems (*Umwelt*) will play an increasingly greater role in human interaction. One of the first issues that plays a role in the interaction between humans and systems is that of trust (De Visser et al., 2020). If intelligent systems are not trusted (undertrust), their actions will not be accepted. If they are trusted too much, it can lead to overtrust and accidents. Therefore, in the design of intelligent systems, one should be able to strike a perfect balance between over- and undertrust so that a user can be confident enough to use the system. This process in which humans and systems learn to know each other shortcomings and strengths is called trust calibration. Until now, humans have been more capable of adapting than systems. Consequently, trust calibration is a result of an iterative process between humans and systems. By which the human adapts to the shortcomings or to the better analysis of the world by the system. One could also state that if the different interpretations of the world (*Umwelts*) are not similar, this could lead to miscommunication between humans and intelligent systems. Like two people speaking different languages and both do not know the other language. It is, therefore, worthwhile to come up with a conceptual framework that gives a kind of grip on the different *Umwelts* of humans and systems.

The Human Information Processing model has already been presented by Wickens (1992) and has been elaborated on in the work of Proctor and Vu (2010). This model by itself can be seen as a variation of the perception-action loop. Parasuraman, Sheridan and Wickens (2000) already indicated similarities between Human Information Processing and the processing of information by automated systems. In their paper, they exemplified where automation could take over the role of humans. In their proposition, they indicate that, especially in the stage in which critical decisions are made, human decision-making should prevail. In their terminology, the stage in which decision selection on high-risk functions will be made, humans should make these decisions. This was, of course, 24 years ago, but it is still a relevant and ethical aspect that should play a large role in the implementation of technical systems. Especially at this time when AI enables automatic decision-making on much more complex issues. Such as the life-or-death decisions made by the Lavender-system in the current Gaza conflict (Abraham, 2024). This system points to places that should be attacked and bombed. As far as the military state, the system makes fewer mistakes than humans do in the targeting. However, the implementation of this type of

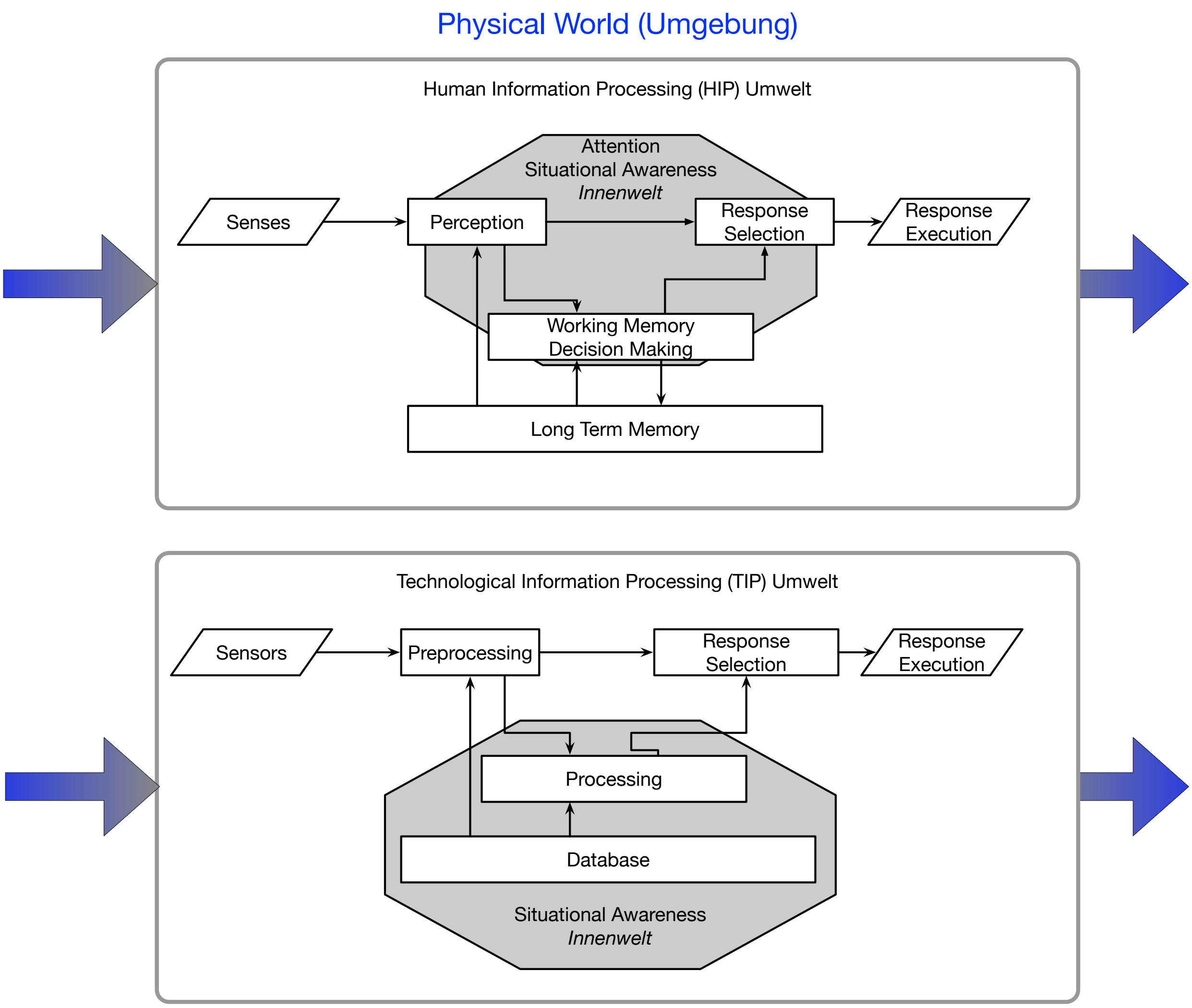

Figure 1. A conceptual framework of Human Information Processing (HIP) and Technical Information Processing (TIP).

system seems to be contradictory, given the implementation of high-risk functions by Parasuraman et al. (2000). Above all, it is an ethical issue if one wants to let a system make death or life decisions. This ethical aspect is not the focus of this paper, and the processing of data that leads to different informational views on the world is the main topic.

Van Egmond, De Ridder, and Bakker (2019) extended this way of thinking, combining the earlier models of Wickens (1992) and Rasmussen (1983). Figure 1 presents a conceptual framework for Information Processing by humans and systems. The physical world (*Umgebung*) is presented in the blue frame around the grey boxes of HIP (Human Information Processing) and TIP (Technological Information Processing). This conceptual framework is a graphical representation of the infoscape. Of course, this is an oversimplification, but I think it gives nice handles for designers and ergonomists to understand why certain interactions take place. The arrows coming out of the HIP and TIP models change color from grey to blue, indicating that the output of the models undergoes perturbations in the outside world, whereas the blue arrow changes from blue to grey to indicate that the data from the physical world undergo interpretations by Information Processing systems. The HIP system consists of three main stages: perceptual encoding, cognitive encoding, and responding (Proctor & Vu, 2010), in which the perception-action loop is extended by a cognitive stage. An elaborate variation of these stages is shown in Figure 1.
The stages in Figure 1 for HIP and TIP are quite similar: (1) sensing the visual world (senses and sensors); (2) creating structure (perception, preprocessing); (3) a cognitive stage (decision making, memory, attention, response selection); (4) action (response execution). The grey blob captures the *Innenwelt*, which could be considered as situational awareness. In this stage, the attribution of meaning and information generation takes place. Although the similarities between HIP and TIP can be readily seen in Figure 1, there are some important differences that need explaining, especially because these differences are the underlying misfit between the *Umwelt* of both systems.
We are familiar with human senses and their capabilities, whereas sensors for the TIP system are different. Although the outside/physical world is the same, the internal representation in HIP and TIP is different. This means that actions taken by both systems will be based on different views of the world. I will focus on three differences: the sensing stage, the perception/preprocessing stage, and the cognitive stage. The human senses consciously used in our daily lives are vision, hearing, tactile-haptic, and smell/taste. A sense like proprioception is subconsciously active. Note that physical events that enter the system via the senses are already preprocessed by the senses (e.g., thresholds, critical bands). In the perception stage of the HIP system, further preprocessing occurs and creates structural information. In my view, the TIP system preprocessing is one specific stage, and the actual structural processing occurs in the TIP's cognitive stage.
In Table 1 I list a number of (human-like) sensors that are used in the automotive industry. Of course, this is not an extensive overview, there are many technical sensors (temperature, position sensors) and sensors that are outside our perceptual range, such as ultrasonic waves (distance), infrared, and radar sensors. Note that these latter sensors are often a combination of omitting and receiving.
I briefly touched upon HIP and TIP's perception and processing stages. I will leave a further elaboration for another time and place. There is one important aspect that needs to be discussed in the cognitive stage of the HIP and TIP system, which is the retrieval and input to the long-term memory or database in the model. As can be seen in Figure 1, the HIP model has two arrows, one for retrieval and the other one for input. Thus, in the HIP model, knowledge generated by information processing will be put into long-term memory in some form. Conversely, the TIP system only supports retrieval. The reason for this is as follows: Currently, AI chip makers like Nvidia put knowledge in their chips generated by external computer systems using deep machine learning algorithms that take considerable time to run. Thus, actionable knowledge on an AI chip of a system can only be internally updated by more powerful external computers that run deep learning algorithms. This is an external process, not an internal process, in the current AI-driven systems. That is the reason that the arrow going from processing to database is missing in the TIP system. In the

Table 1. Human-like Sensors in Automotive.

Modality	Sensor	Event
Auditory	Microphone	Speech, noise detection
Visual	Camera	Interior, fatigue detection Exterior, lane-keeping
Touch/Haptic	Pressure sensor	Steering wheel, Fuel tank - using buoyancy
Smell	Smell sensor	Interior smell
Proprioception	Camera	Lane-keeping

next section, the role of sound will be discussed in relation to the introduction example and the role of sound in an environment like an Intensive Care Unit (ICU).

The role of sound in the infoscape

In the introduction, the HIP systems of bus passengers and hearing-impaired created clearly a different auditory Umwelt of the same physical world. In the ICU, an analogous situation can be observed. A patient monitoring system is equipped with sensors to monitor patients and uses auditory signals to alert the medical staff. However, patient monitoring systems do not have the capability to listen. Thus, they do not experience the sounds that they emit into space (they have no listening sensor). This means that a self-correcting mechanism is not there. The infoscape is, therefore, filled with a multitude of sounds. Furthermore, the medical staff is often busy with other things, and the actual cause of the alarm is not always clear. Thus, for the HIP system of the medical staff, there is often no attribution of meaning to the alarm signal. In this case, the medical staff becomes tired and annoyed by these alarms, which is called alarm fatigue. Therefore, it is not directly obvious which action needs to be taken. Another important aspect that causes alarm fatigue can be derived if one considers the stages of this information processing. In the past, research has focused on the sensory quality of the sounds. The quality can be linked to the perception stage (sensory pleasantness). Although the quality of sounds has improved, medical staff still suffer from stress and alarm fatigue. Bostan, Özcan, Gommers, and Van Egmond (2022) suggested that this aspect is due to task interruption, which is part of the cognitive stage in the HIP system. Consequently, it means that a solution for the reoccurring problems with alarm sounds is not perceptual (sound quality) in nature but cognitive. This means that designers should focus not on improving sound quality but on making the radiating systems more intelligent in order to manage the number of events. In conclusion, an infoscape is filled with many multimodal sources that each are analyzed and interpreted by human and technological systems, resulting in different Umwelts. These are often not similar, resulting in confusion and an unsuccessful calibration process between human and technological systems. In order to understand each other, both technology and humans should understand each other's representation in order to be complementary or supplementary. This will lead to trust and acceptance. The challenge is of course to design systems such that they become as adaptable as humans.

Future steps

What are the implications of the above for future research and design? First, research needs to develop insights how the representations of the world for AI based intelligent systems are similar but also different from the human representation of the world. Note that also humans may use among themselves a different representation of the world which is also often neglected in design. Without this knowledge there will be difficulties with trust in and acceptance of these systems. For example, if a car with automation decides to slow down given a decision made on the interpretation of the sensors and this decision is incongruent with the decision a human would make, this will evoke distrust and an unwillingness to accept this decision. Consequently, humans switch off the automated systems, something that is often observed in automated driving. Second, one of the major challenges will be to develop research paradigms that enable researchers to gain insights in human behavior with AI based intelligent systems. Especially in the design phase of such a system, one would like to know what possible reactions of human users would be. We employed in the Horizon 2020 Mediator project (unpublished) enactment as a possible paradigm, which functioned above expectations. Thus, one participant was the driver, one participant the automated sensing system and a third one made the decisions on the information received by the other two participants. This information could then be infused in the design cycle. Now to return and end with the examples when sound is radiated in the environment without the radiating system sensing what it actually produces. In other words, the feedback loop of the system is not present. One could now imagine intelligent systems that with sensors (e.g., microphone) 'sees/hears/feel' its environment in the same way as humans. In this way, correcting itself by switching of sound/alarms if the noise pollution becomes too high. Does this sound futuristic? If one notices the very fast developments of AI perhaps not.

Samenvatting

Geautomiseerde en intelligente systemen maken een steeds groter deel uit van ons bestaan. Al deze systemen produceren signalen waarvan een mens informatie moet maken. Deze artificiële ruimte van signalen wordt hier aangeduid als *infoscape*. Het probleem is dat niet alle signalen als informatie verwerkt worden. Dit leidt tot een verlies in vertrouwen, acceptatie, et cetera, met als gevolg dat geautomatiseerde systemen worden afgezet. Het is daarom essentieel dat ontwerpers begrijpen wat de verschillende interpretaties van de fysieke wereld zijn en die kennis gebruiken om de communicatie tussen (intelligent) systeem en mens te verbeteren. In de huidige wereld wordt de mens gevraagd om te adapteren aan het systeem, het zou processen verbeteren als de adaptatie tweezijdig zou zijn. Een voorbeeld wordt gegeven en besproken van de situatie in intensive cares waar een kakofonie aan geluiden wordt geproduceerd, die vanuit het 'denken' van het systeem noodzakelijk zijn maar tot frustatie van de medische staf leiden.

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Contribution to the human factors criteria

The *Tijdschrift voor Human Factors* lists three criteria taken from Dul et al. (2012) to evaluate this essay. The presented conceptual framework has a *system approach* because it offers an integrated view of the information processes among intelligent systems and humans, which may lead to a more balanced infoscape. It is *design-driven* because the understanding of how systems and humans represent the 'real' world is essential in the design of systems in order to have a complementary division of tasks. It can lead to *better performance and well-being* because the way of thinking affords the incorporating of both worlds and considering their strengths and weaknesses.

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