Making Sense of Digital Information: The Process of Attributing Meaning to Continuous Abstract Information

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***Abstract*— The process of sense-making is one of the most fundamental processes in human cognition; perceiving the world and understanding its meaning. With the progression of technology, one might wonder if humans are able to attribute meaning and make sense of digital information to the same extent as they do with other perceived information.**

At the same time, a clear empirical overview of the sense-making process lacks in current research. Theoretical frameworks exists, but they do not seem to include all different steps and criteria necessary for attributing meaning to information.

This qualitative study evaluates whether people attribute meaning and make sense of abstract digital information when continuously confronted with such information. It provides an analysis of the sense-making process based on the experiences of participants who wore a sixth sense for digital information and tried to understand what it meant.

***Index Terms*— Human computer interaction, Information processing, Intelligent systems , Knowledge discovery**

I. Introduction

HUMANS continuously make sense of the world around them. By perceiving what is called reality and processing it afterwards, humans understand the information that reaches their senses continuously. Ultimately, everything that can be perceived and made sense of is what can be called ‘real’. However, as the digital or virtual world becomes a larger part of life, it becomes a question to what extent the digital can be considered as real or reality, or if humans can make sense of the digital world to the same extent as they can make sense of the physical world.

Making sense of the world around us, or the process of sense-making, has been a topic of study in many different areas of research, such as organizational psychology [1] and human-computer interaction [2]. Overall, it can broadly be defined as a ‘motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively’ [3]. However, while the process has been studied in several areas of application, not much empirical research has been done in evaluating the different steps it contains.

Theoretical frameworks attempting to describe the different steps in the sense-making process exist. One of those that is quite complete is the Data/Frame Theory [4], [5]. According to the Data/Frame Theory, when people try to make sense of something, they always start with some initial ideas about it, called the frame. The frame is shaped by the data that people are trying to make sense of, but the frame also shapes the data as it influences what is considered useful data. It serves as a hypothesis of the connection between different data points, and thus of the meaning of the information. The frame can be questioned and tested, as well as elaborated on when more data is received. If it appears that the initial hypothesis is incorrect, reframing might occur, or a new frame might form. While this theory provides a plausible way of looking at the process of sense-making, and while several aspects of it are supported by empirical evidence, it does not fully cover the process in detail [5]. One might wonder what kind of data is necessary to be able to reframe or elaborate on a frame for example, or how a frame is initially formed in cases where people have no clear prior knowledge.

As technological developments progress, the need for a better understanding of the sense-making process grows. One of the areas in which such an understanding or a framework based on empirical evidence is necessary, is that of cognitive enhancement. Cognitive enhancement can be defined as making people capable of higher mental performance, to have an (competitive) advantage over others in certain situations [6]. One way of providing such competitive advantage, could be to give people more direct access to digital information, to allow them to make more intuitive and faster decisions upon such digital information. Decision making can be seen as an important aspect of sense-making [3], and in order to make proper decisions upon information, such information must first carry meaning.

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An attempt at evaluating how people make decisions and generally deal with new types of abstract information given to them has been done in a study providing people with a sixth sense for the magnetic north [7]. In this study, people were trained to work with a vibration belt that communicated to them where the north was, and their performance as well as subjective experience was evaluated. The results showed that people are capable of using such information, while some participants showed changes in the subjective experience of their environment. However, as participants were deliberately trained, a clear evaluation of how people would try to make sense of new abstract information presented to them without such clear training lacks. Also, the magnetic north is still physical information in a certain way, and one might wonder how this translates to digital information that is not otherwise perceivable to humans.

In the current study, it was evaluated whether people can attribute meaning and make sense of abstract digital information when continuously confronted with such information. A full analysis of the process that they go through in their attempt to do this is provided. The results will hopefully help in the future development of devices that attempt to provide people with information in a more intuitive and unconscious manner. Also, the general analysis of the sense-making process might be of value in the development of intelligent systems. If machines are to truly understand and make sense of the world, it is vital to understand what sense-making is, how people go through the process of making sense of information and what the requirements are for the emergence of meaning.

II. Methods

A. Case Study: type of digital information

To research the topics mentioned above, a specific case of digital information had to be used. Digital information of course comes in many different forms. However, for this specific research question, it was important to use digital information that is not otherwise easily accessible, to truly provide participants with new information they would not otherwise encounter. The information chosen for this study is the presence of digital devices in the surroundings of a participant, measured through probe requests.

Each digital device that has the possibility to connect to Wi-Fi networks (smartphones, laptops, etc.) is constantly looking for such networks to connect to. They do this by sending out probe requests: a request for access points to send them information to ensure a connection. The probe request contains information about the device that send the request, such as the brand of the device, the name of a specific access point it might be looking for and its unique MAC (Media Access Control) address. The MAC address is sometimes also called the hardware or physical address, as it is a unique address that is hardcoded within every digital device. It has the form of FF:FF:FF:FF:FF:FF, of which the first six digits correspond to the brand of the device or the Wi-Fi chip.

By catching the probe requests of digital devices in the environment, the unique MAC address of these devices can be read out, allowing us to see which unique devices exist in our surroundings. Since nowadays smartphones can almost be seen as a representative for people, sensing the presence of such devices as smartphones enables someone to indirectly sense the presence of people.

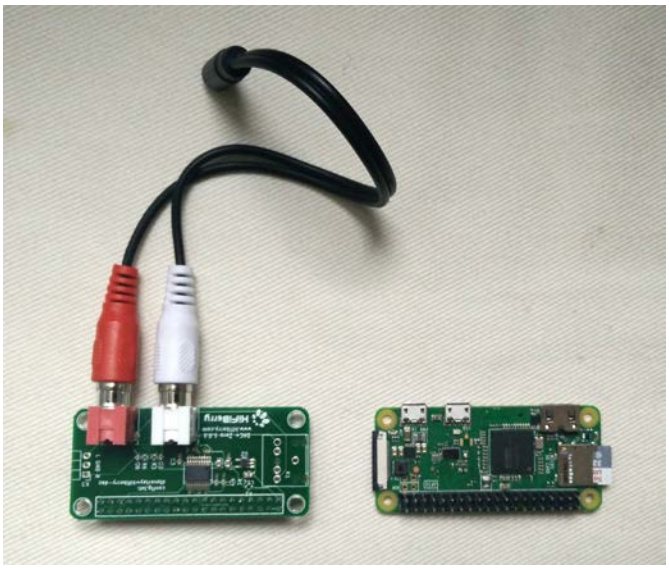

Fig. 1. The electronics the prototype was made of, consisting of a Raspberry Pi Zero W (right) and an attached HiFiBerry DAC shield.

B. The Research Prototype

A device was developed that detects probe requests of digital devices in its surroundings, translates the MAC addresses of such devices into sequences of sounds and communicates these sounds to the wearer of the prototype.

A Raspberry Pi Zero W was used as a processor and sensor (Figure 1). The build-in Wi-Fi chip of the Raspberry Pi was set to monitor mode, allowing it to monitor for and catch probe requests within the range of the Raspberry Pi. The device monitors in different rounds. A round starts with a monitoring period of 10 seconds, looking around and waiting for probe requests of nearby devices to come in. After that, the program iterates through the list of found MAC addresses. If a specific address was detected the round before, it does nothing. If this is not the case, it creates a new sound sequence for the specific MAC address and plays it back, or it plays a previously saved sound file for this address.

While there has not been a lot of research into making new senses, there is a lot of work on sensory substitution that explains how people might use information given to them through one modality to process information about another modality. In these papers, two modalities are mostly used: haptics [8], [9] and sound [10]–[12]. Both seem to be quite effective, but as for this specific study quite detailed information needs to be communicated, sound seemed like a better option, as it allows for more detailed communication [13]. Therefore, it was decided to decode the MAC addresses of the sensed devices into sound sequences. The Python

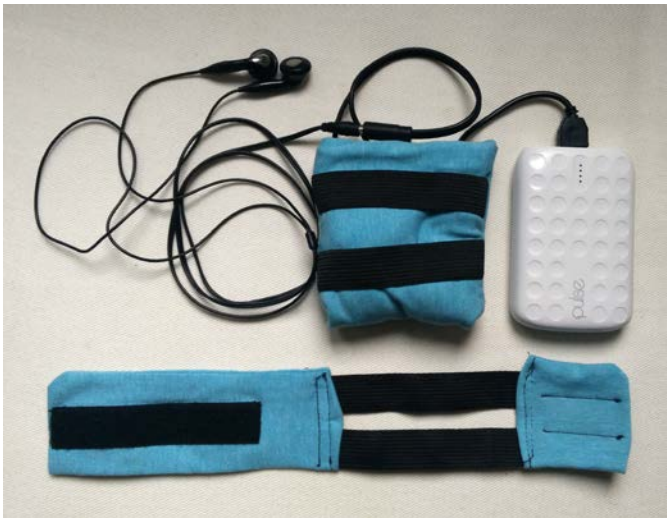

Fig. 2. The research prototype as presented to the participants, including a pocket containing the electronics, an attached powerbank, attached earphones and a band to attach the prototype to an arm or belt for wearing comfort.

synthesizer script PySynth [14] was used for decoding. Each character in the MAC address is given a specific tone, creating a unique sound sequence of twelve tones for each sensed device.

These unique sound sequences are saved as WAV files on the SD card of the Raspberry Pi, creating a database of previously sensed devices from which the prototype can sample, to make the process faster.

To make the prototype easy to wear and carry for a long period of time and to protect the electronics, a soft bag was made around it. A powerbank battery can be attached to power the device and earphones can be attached to listen to the sounds (Figure 2).

C. Participants

A total of six subjects participated in this study, divided into two groups of three. All participants were students, and their ages ranged from 21 to 27 with a mean of 23.8. In each group there were two males and one female. The participants in the two groups were allowed different levels of prior knowledge about the workings of the prototype and with it the aim of the research. The first group did not get any prior knowledge about the workings of the prototype or the research question. The second group was told that the device was 'aiming to become your new sixth sense for digital data. It senses the presence of all digital devices around you and communicates the identity of these devices to you.' The purpose of this division was to be able to see if prior knowledge might influence the performance of participants in finding out what the signals meant, as well as to be able to observe possible differences in the process of attributing meaning to the signals.

D. Experimental Period

The research methods used are similar to those used in anthropology. The aim of any anthropological study is to understand connections and similarities between humans, as well as their differences and to conceptualize these [15], which is highly related to the aim of this study. In order to achieve this in a qualitative manner that is authentic, it is important that multiple methods are used to observe participants. Also, in general, the process starts in an open way to see hypotheses and concepts emerge, in a more speculative way rather than through statistical methods. From these, eventually a theory can be developed [16]. For these reasons, both a diary study and interviews were used, to generate rich and personal data about each participant.

Participants were instructed to wear the prototype continuously during waking hours for fifteen consecutive days. If there occurred any situation during which wearing the prototype would be inappropriate they were allowed to take it off, as long as they would wear it for at least six hours a day. Such periods of not wearing the prototype were allowed to make it easier for the subjects to participate, as well as to keep up their motivation for participation. They were instructed to document the times at which they put it on and took it off.

During the study, participants were supposed to evaluate on the experience of using the prototype by keeping a diary. This could be done in a physical notebook, digital notetaking app, audio recordings or any other means of documenting they preferred. This freedom was provided to stimulate them to document rich and qualitative data. They were instructed to keep this diary with them at all times, such that they could document it immediately when they noticed something particular or had new insights related to the device. Attention had to be paid to information about the context they would be in at that specific moment, such as the location, the amount of people around them and the date and time. Participants were also supposed to reflect on the experience by the end of every day they wore the device in a similar fashion.

While keeping the diary, participants were instructed to pay attention to some specific topics:

- Specific strategies they might use to find out what the signals mean;
- Patterns they might recognize in the signals;
- The annoyance of the signals;
- The meaning of the signals.

During the experimental period, they were contacted once about halfway through the process (on the 7th or 8th day), to remind them to keep the diary and to check if they were following the instructions. During this short conversation, they would be reminded to search for repeating patterns in the sounds.

E. Interview

At the end of the fifteen-day period an interview was scheduled with every participant. Each interview lasted about half an hour and was conducted in a semi-structured manner. The interview consisted of roughly four parts:

1. General questions about the experience of wearing the device. Questions were mainly related to the domains of unconsciousness and fading to the background, repeating patterns the participants might have heard, the meaning of the

signals and strategies they used to find out what the meaning of the signals was;

2. Some questions related to the diary of the participant to gain more in-depth insights from the data already given by the participant;

3. A detailed explanation of the workings of the prototype followed by some questions about how the actual meaning of the signals related to their experience of wearing the prototype;

4. Looking up the MAC address of the phone of the participant and playing it back to them, to see whether they would recognize this specific sound sequence.

Afterwards, the diaries and transcriptions of the interviews were analyzed with a Grounded Theory method [15].

III. Results

A. Group without Prior Knowledge

1) Feeling like Sounds Changed over Time

Participants tend to recognize the first (few) sounds when starting up the device are the same every day. They reported the following: *"The things you hear in the first hour just really sounded like the things I'd heard in the first hour previously,"* (condition 1, participant 1) and *"I feel like the starting-thing was always the same, maybe the two or three after that as well."* (c1, p3) Because of this, they feel that the sounds are either connected to it being morning, or to starting up.

Related to that, participants have the perception that sequences of sounds become longer and sometimes more complex over time. Usually they believe this is the case over the course of a day, sometimes they also feel this is the case over the course of the whole study. Also, they sometimes believe the breaks between sequences become smaller. As one participant mentioned: *"I realized that at least multiple times, the longer I was listening to it, the longer the sounds would become."* (c1, p2)

2) Background Noise

Sounds quickly became background noise as participants start losing their interest in the meaning of the sounds when they cannot find it quickly enough. Usually this is after about one or two days. However, the sounds seem to attract attention when repeating patterns are heard. Often the attention comes slightly too late to consciously recognize the patterns. As one participant reported: *"Because it was already to the background, I was not concentrated on it as much."* (c1, p3) Also, in general participants paid attention to the sounds when starting up, truly listening to see if the prototype was starting up right. After the first few patterns had sounded they stopped paying attention to it. Sometimes they try to concentrate on the sounds more, but they find it hard to do this: *"I actually was trying to pay attention to them at one point, but I was only able to do it when for example I was walking, or like not doing anything that required concentration."* (c1, p2)

3) Describing the Sounds

When describing their experience, participants often had difficulties coming up with the right words. They seemed insecure and mentioned that they could not find the right words.

Some participants tried to overcome this difficulty by giving names to specific patterns. One participant used onomatopoeias that very clearly made a distinction between different sequences: *"So like it starts out with this 'bloopbloopbloop' and then by the end it's like 'bloopbloopbleepbloopbloop' and then it gets into this longer sequence."* (c1, p1) Another participant used more descriptive names for certain sound combinations: *"You know when the wave of the sound was like the lowest one, the real deep ones, I think. There was like two of them, and I for example called them Fatty and Barrel."* (c1, p2)

Giving sounds names helped them to remember specific sounds and pay more attention to them as well. It enabled them to personify the sounds or the device as well as to describe the experience in a more natural way.

4) Insecurity

While participants started recognizing patterns quite early in the process, they were often not sure of this. They found it hard to consciously confirm that they had heard a repeating pattern or in general something they had heard before, as shows in this quote: *"I think I maybe like thought it, but then I was like, nah."* (c1, p1) Only at the end of the test period or when we started discussing it did they usually allow themselves to confirm this. Another participant stated slightly more clearly: *"Often when I was restarting or when I was not thinking for a moment, I had a feeling like, okay, I think I heard this before."* (c1, p3) They also did not really try to prove or falsify interpretations they might have had, mostly because they did not feel it would help and they did not know how to approach proving theories.

Participants usually blame their own way of thinking for not finding the correct meaning. They do not feel like the signals could have been different to make it easier.

At a certain point, most participants felt like there was no meaning at all. They started coming up with meta-interpretations of what the research could be about.

5) Day to Day

Participants mostly just wanted to go about their normal day. They felt like the prototype or figuring out what it means should not interfere with their normal activities. As one participant explained: *"No, I just tried to go about my day. And then, you know… Just do the things I had to do. I wouldn't like wave my arms, or like go towards a group of people, or go outside, I figured all those things would just happen over the course of my day."* (c1, p1)

In general, they thought the prototype was uncomfortable or uneasy to carry around. They were however not very annoyed by the sounds. Participants did feel detached from social situations while wearing the prototype: *"I didn't wear it during dinner and things like that, because I just feel like that's a bit antisocial,"* (c1, p3) *"I feel a bit removed from a social situation when it's going, almost like I'm in a private*

social situation with the kebouter and not in my immediate surroundings." (c1, p1)

6) Implicit Recognition

Some participants mentioned that they felt like they could predict certain sounds sometimes, or at least that they tried to, even though they were slightly unaware of recognizing repeating patterns. Sometimes they were correct, sometimes not: *"But sometimes you were like, (…) yeah, it's coming again. And it would come, sometimes it wouldn't come, so."* (c1, p2) Humming or singing along was part of trying to predict the sounds*: "Sometimes I heard something, and then I thought, I have heard this before, and then I would sort of sing along in my head, or try to, but sometimes that didn't really work out."* (c1, p3)

All participants immediately recognized the sound sequence of their own phone's MAC address when played back to them. They were surprised that they knew it that well, and all acknowledged that they had heard this pattern very often. One participant immediately said: *"Yes! It would often start with this!"* (c1, p3) Another one started humming along: *"Yes, that's it. 'Tingting ung'. That is it. (…) 'Tingting ung'."* (c1, p2)

B. Group with Prior Knowledge

1) Travelling and Listening

Participants use their daily activities and the places they go to, to get new insights and listen carefully: *"That is something I tried very consciously, while I was cycling, look around who passes by and what that has to do with it."* (condition 2, participant 1) Travelling seems like an activity that is good for this, whether in the car, in the train or on the bike, as it brings people into varying circumstances with different amounts of people around. Participants are very aware of this*: "When I was walking through the station I thought, let's listen, there are so many people here, of which many are on their phone."* (c2, p2) Also, usually they do not have anything else to do except listening to the sounds. Because of this they actually get many new insights while travelling.

Participants usually are not bothered by the sounds while travelling. This is one of the few moments where they actually enjoy the sounds quite a lot. One participant also mentioned she felt connected to the outside world. Even though she did not really know how it worked, it felt to her as if she was constantly making links to something out there: *"It feels a bit as if you're cycling through the city and make connections with something all the time."* (c2, p1) Another participant said that the sounds became inspiration for new song melodies while he was travelling: *"While cycling I think a lot about songs that pop up in my head, I think about making music. Sometimes it was an inspiration for a new melody."* (c2, p3)

2) Making Perfect Theories

Participants want to make perfectly fitting interpretations. They come up with several very clear interpretations along the way. However, if an observation does not perfectly fit an interpretation they have, they will throw that interpretation away quite easily. Some quotes by participants are the following: *"There was always something that could contradict it"*(c2, p1), *"I thought, I have to switch now, it can't be one bleep per device"* (c2, p2) and *"I did not have the feeling that I could test it."* (c2, p3)

In the end, all participants felt like the final explanation made a lot of sense and was logical. There was no real feeling of surprise, even if their theories didn't match at all.

3) Annoyance and Fading into the Background

When at home, participants usually don't get a lot of new insights, they only get confused. Participants reported several times that they were confused about hearing a lot of sounds when home alone, while their environment was not changing. One participant wondered: *"I thought, now I'm at home on my own, how can there constantly be new [sounds]?"* (c2, p1) The sounds also annoy them quite a lot, as it interferes with their normal activities at home such as studying: *"While I was studying, when it happened (…), it was a bit annoying. I was pulled out of it and thinking about what happened around me."* (c2, p1)

In general, however, participants felt the sound faded into the background easily, also because the sounds were very regular. If they were working on something in another environment than home, with other people around, they would forget they were wearing it and stop listening to the sounds. As one participant explained: *"I tried to pay attention, especially after you said I had to look for patterns, and then I did that for a while, but it is not continuous, so I paid attention the first few times, but then I started doing something else, and I forgot it after a while."* (c2, p3)

4) Missing the Sounds

While participants in general do not feel like they miss the sounds, they do sometimes encounter situations where they felt it would be fun or interesting to hear what kind of sounds the prototype would make: *"When I was not wearing it, I would think, oh, there are many devices around here, it would be funny if I could hear them now."* (c2, p2) Participants sometimes felt like the sounds became a logical, comforting background noise. It made sense in some way that the sounds were there. They also quite clearly and consciously notice silence and the general absence of the sounds.

Also, one participant did still think of the sounds every once in a while after the research, feeling like they should be there: *"In the beginning I several moments during the day when I thought, oh, it would have been logical to hear something now."* (c2, p1)

5) Feeling of Recognition

Participants vaguely have a feeling that they heard some repeating sounds, but it is quite unclear if they mean just the tones or actual sequences. As one participant explained: *"I did start recognizing the tones after a while, but not that I thought, oh, I have heard this sequence before."* (c2, p2) It feels like this is unclear to themselves as well. They do feel like they

would maybe recognize at least the tones when hearing them again: *"Yes, I think I would recognize them if I would hear them again. But it's not that I can remember them now, no."* (c2, p1)

However, participants do not recognize the sound sequence made by their phone when played back to them during the interview. After listening to it a few times, they start suggesting that it might be similar to some sequence they heard at some point, or that part of the sequence sounds familiar. However, there is never a clear feeling of recognition: *"In the last part might have been a bit of recognition… I can imagine that the sound starts and I'm not paying attention yet, and then there is the end."* (c2, p3)

6) Flaws in the Prototype

Participants generally thought there were some aspects that could be improved about the prototype to improve their ability to develop a sense for digital information. For example, they clearly recognized the delay and general slowness of the prototype as a problem, making it hard to test interpretations: *"It isn't really testable, for example because of that delay."* (c2, p3) Also, they were unsure that the fact that devices from previous rounds would not sound again every time was a good aspect of the prototype. One participant felt that the sounds could have been catchier to remember them better.

Also, both before and after the explanation participants feel that for developing it as a true sense, they would have needed the full information about the workings of the prototype. Now there were too many unknown variables to determine what it all meant, and they could not make connections between sounds and devices well enough to fully use it as a sense: *"Now I miss the prior knowledge to listen to a signal and recognize it as my phone."* (c2, p3)

IV. Discussion

A. Making Sense

When looking at the collected data, several aspects or phases within the sense-making process can be identified amongst all participants. While wearing the prototype, every participant started off by trying to find a way to direct their attention away from the sounds. The sounds were slightly annoying and distracting in the beginning of the process, but all participants learned to move the stimuli to the periphery of their attention within two days.

After that, the process of truly trying to make sense of the sounds started. However, the fact that the information now existed in the periphery of their attention rather than in the center sometimes made it more difficult for the participants to concentrate on the sounds and find out what the meaning was. Still, all participants managed to at least gain some insights about the sounds. How they approached this was however very different for the two groups, showing that there are two aspects of the sense-making process that might have different requirements.

The group without any prior knowledge quickly started recognizing recurring sequences in the stream of sounds. They were however unable to connect a clear meaning to the repetition. The group with some prior knowledge did not recognize repeating sequences, but went into a process of developing possible interpretations into theories and after that develop strategies to test these theories.

While none of the participants were able to actually make sense of the sounds, all the above mentioned aspects will be discussed in more detail, to discuss their role in the sense-making process and the requirements for each of the steps.

B. Periphery of Attention

For all participants, the sounds faded into the background and thus the periphery of their attention quite quickly. People are quite good at filtering out information they cannot use directly, even if this information is presented in a very unnatural and abstract manner, as were the sounds in this study. However, the level to which the sounds fade to the periphery of attention depends highly on the context that people are in and the activity they are engaged in. For all participants in both groups, if they had to do a task that required high concentration in an otherwise quiet environment (such as studying or reading at home), they were insufficiently able to filter out the sounds made by the prototype. The sounds were highly distracting and pulled them away from their activity. However, if they were engaged in activities in more noisy environments with more people around, even if those activities were cognitively demanding tasks, the sounds seemed to fade away completely. While being engaged with the activity, people would completely forget they were wearing the prototype at all.

Furthermore, for both groups, the sounds interfered highly with social situations, especially when directly trying to communicate with others. Of course this is not surprising, since the prototype was literally blocking their hearing, creating noise over conversations.

In general, it can be said that whether people have knowledge about information presented to them or not, they are very good at filtering out stimuli that are not directly necessary to attend to. These abilities do vary depending on the cognitive load that is necessary for a current task and on the amount of information received through the specific sense. In the design of systems providing people with information these factors need to be taken into account. Also, in the design of intelligent systems, a system of peripheral and central attention might be important for functioning in the complex real world, especially when limited cognitive resources are available.

C. Pattern Recognition

Remarkably, the ability to recognize recurring sequences in the stream of sounds differed greatly across the two experimental groups. Whereas the group without any prior knowledge started implicitly recognizing sound sequences after a few days and explicitly recognizing them towards the end of the testing period, the group with some prior

knowledge only slightly started implicitly recognizing some of the sounds towards the end of the testing period. They never explicitly recognized a full sequence. While this might be due to personality traits or simple coincidence, it is remarkable that there is such a clear-cut split between the two groups on pattern recognition. It suggests that the amount of knowledge that is given to a person prior to an unsupervised learning process determines how the person listens to the stimuli.

The difference between the two groups might be highly related to the way the participants deal with the stimuli. The oblivious group did not have any clues as to what they should be looking for, except that they should be listening for recurring patterns. Even though they mostly did not pay attention to the sounds as they faded to the periphery, when they paid attention it was usually at the beginning of the day, when most recurring patterns would be heard. Also, as they did not know at all at which level of detail they had to listen to the sounds, clues that helped them with this such as breaks and the general lengths of the sequences must have stood out. Interestingly, the use of language to describe the sounds supported them in remembering as well as recognizing recurrent sequences.

The group that did have some prior knowledge was constantly looking around to find digital devices with their other senses, to be able to connect that to the sounds they heard. For this reason, they probably paid less attention to the pure sounds itself, and did not pick up on the patterns in them.

In learning processes like these, people might be better at pattern recognition without any prior knowledge. While prior knowledge can help them to connect information from one modality to information perceived through other modalities, it clouds and biases their ability to purely recognize patterns. In the development of intelligent systems, when a choice must be made between some kind of unsupervised learning versus supervised or reinforcement learning, this should be kept in mind. It might be beneficial for the emergence of meaning to start off with a purely unsupervised approach.

D. Developing Strategies and Theories

Developing theories about the meaning of the sounds and developing strategies to test these theories is an important part in the sense making process. The way the two groups approach this differs in several ways, and shows that some prior knowledge might be necessary for developing proper theories, whereas clear links to the environment might be needed for the development of testing strategies.

The oblivious participants tried very hard to come up with interpretations about what the sounds might mean, but never came any further than guessing. The most complete interpretations they came up with were that the sounds changed over time or that they were in fact random, they did not truly believe any other ideas they had. The participants that had some prior knowledge came up with interpretations that were clearer and more complete, to the point that they became testable theories, even if they were wrong.

However, when moving to the next step, developing strategies for testing their theories, participants with prior knowledge had some difficulty as well. They started off by moving around, moving themselves to different contexts with different amounts of people, and tried to observe what happened in these different situations. In that sense, they made a very good first step towards trying to understand the different variables connected to the sounds. However, when their first strategies did not provide them with satisfying results, they were unsure how to continue. Also, while they did actually test several of their interpretations, they felt like they did not know how to do this.

The results show that in order to develop first ideas and interpretations into testable theories, some prior knowledge or feedback helps, as it provides people with a direction and a frame of reference. When developing strategies for further testing theories, more feedback or input is necessary to move on.

E. Limitations and Future Research

While many interesting insights can be gained from this qualitative study, there are some limitations which also provide opportunities for future research. First of all, while the prototype used for this study did provide the participants with real information about their environment, technical limitations caused a severe delay in the communication of this information. Therefore, it was almost impossible for the participants to find out what the true workings of the prototype were. For this reason, all main insights are about the beginning of the sense-making process and do not say anything about the final emergence of meaning. Also, the amount of time necessary for the steps identified in the above discussion cannot be reliably estimated. In future research, with more time and means a better prototype might be developed, to evaluate the full sense-making process in a realistic timeframe.

Next to that, this is of course a small study with only a few participants. While it serves as a good first exploration into how humans make sense of information they are confronted with, no statistical inferences can be made. Therefore it is necessary to conduct a larger study on the different aspects identified, to truly evaluate the criteria necessary for reaching the different steps in the sense-making process. Once this can be done, clear implications for the development of intelligent systems that can truly understand meaning can be seen.

Last, one could argue that the results gained in this study are due to human biases or superstitious beliefs, as research has shown that people are prone to rely on superstitious beliefs when they do not have control over a situation, meaning that they generate irrational beliefs about the situation. These superstitious beliefs can appear unconsciously [18], and could have been used by the participants to understand the stimuli even though they could not really. However, when looking at the results, it can be observed that participants generally accepted it if they did not have a proper explanation for the sound signals. Also, conclusions that they did draw are mostly based on real observations they made and theories they tried to test. Therefore, it is unlikely that unconscious superstitious beliefs played a large role in participant's behavior.

V. Conclusion

In this study, participants carried a prototype that communicated to them the identity of digital devices around them through sound signals. Through a diary study and interviews, the process of attributing meaning to abstract digital information was evaluated. One group of participants had no prior knowledge about the workings of the prototype, one group had some minor prior knowledge.

The results show that there are four important aspects or steps in a sense-making process:

- Learning to differentiate between conscious and unconscious perception (or peripheral versus attentional). It takes participants less than six hours to achieve this;
- Recognizing recurring patterns and understanding the length of sequences. It takes participants about two days to start implicitly recognizing patterns and between seven and fifteen days to explicitly recognize them;
- Forming testable theories about the data;
- Forming strategies for testing the theories.

The latter two clearly correspond with Klein's framework [4], [5], as participants who started with some prior knowledge (the initial frame) went on to develop strategies for testing this initial frame and adapt their frame to create new testable theories. However, the first two steps are a missing aspect of the framework. Klein does not mention how people might generate frames from perceived data, and as the results show, this is less trivial than one might expect. It appears that without prior knowledge about abstract data, people are better at pattern recognition than with (limited) prior knowledge. Prior knowledge makes people bypass good listening and simple pattern recognition as they hurry into theories they want to test immediately. It biases their judgement of perceptions as well. Apparently, people who have a prior knowledge 'frame' are not good at collecting the data that builds up the frame, but without prior knowledge the recognized patterns cannot easily be summarized in a frame.

From this it can be said that to make sense of the world, unbiased and unsupervised pattern recognition must be allowed first. After that, feedback about the connection to other perceptions is necessary for building feasible theories or indeed for building a 'frame'. Also, to continue creating strategies for testing, feedback about the connection to other perceptions should not be contradictory. This information could be used to extend Klein's framework to explain the process of generating frames more extensively.

Next to that, it was clear that people are good at filtering out information that is unnecessary. They are able to move the information to their periphery of attention, but they can also attend to it when primed by familiar sounds. Sensory overload is however a problem that must be taken into account. Also, some form of conscious attention at some point is necessary for the recognition of patterns.

In general, this can be summarized as a requirement that, in order to make sense of the complex world, it must be possible to direct attention, to avoid constant processing of all information available.

Appendix

A. Personal Reflection
B. Coded Diaries and Interviews
C. Python Code of the Prototype.

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