SENS.AI: How to create affection with technology?

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ABSTRACT

Artificial intelligence (AI) is increasingly applied in products and services, which we use in conscious and unconscious applications in our society. But for the general user, it is often unclear what AI systems are and how they really work, which makes them seem like a mystery. This project aims to serve as an exploration to;

- Designing a prototype that will give users a better understanding of how AI systems work in an unconventional form.
- Application of speculative design in new aesthetics, telling the story that the AI also wants to learn to experience human interaction, in the form of a video to start the debate.
- If physical interaction between user and AI could improve cooperation

This pictorial describes the exploration and concept development of SENS.AI, a shape-changing embodied AI which allows for collaborative human-machine interaction to understand and explore different haptic outputs of affection.

Author Keywords
Aesthetics; Embodied AI; Emotion; Explainable AI; Haptic Tangible Interaction; Humanized-AI; Shape-Changing;

INTRODUCTION

AI becomes increasingly available in online services and electronic products. However, these intelligent models are often seen as a scary black box [1, 2] or science fiction human beings that take over the world. Due to their lack of transparency and shear interaction [2], a major drawback for using AI arises [1, 3]. Transparency links with trust and it is therefore unclear what an AI system can do [4]. The idea of what an AI can do is misinterpreted, which causes it to be applied in appliances where it is not suitable for [5]. In some tasks, AI's are able to exceed human capability [1, 6]. However, these tasks should be very specific and based on the right data. Whenever an AI is confronted with complex and/or contextual tasks or incorrect data, the results would not be useful or as desired [5]. It is important to make concrete what the role of the AI will be and where its appliance will be valuable [3].

It is recommended to have an AI system that is explainable and transparent, where it is clear what the system is capable of doing and how well it can do that [4]. On top of that, giving the user the feeling they are in control and have autonomy of the AI's actions [4].

When interacting or collaborating with an AI, its physicality is an important factor. Within Human-Computer Interaction (HCI) it is known that without a proper interfacing, computers cannot properly be used [7]. With AI systems, this desire is less forthcoming. Keeping the 'scary black box'-idea unintentionally alive. Interfacing computer systems should provide a more pleasurable, easy and satisfying experience [7] and would therefore fit AI systems as well. On top of that, it might give the opportunity to make AI more explainable. Where physicality can help in actively detecting and correcting flaws in the model and biases in the data [1] together with understanding the training loop.

The field of haptic human computer intelligence is growing rapidly over the last years [8, 9]. People use haptic interactions to explore the world around them and to perform certain tasks [8, 9]. By making these sensations artificial, information can be presented to users to help them in e.g. completing tasks and understanding the system at hand, because of the simultaneous exchange of information between the user and the system [3]. However, there are two downsides in the desire to create haptic computer interfaces. Firstly, there is a need for off the shelf components that fit the haptic desire [8]. Secondly, there is a need to understand what kinds of information can be successfully presented in haptic interfaces [9].

An interesting information exchange can be the feeling of touch and emotion. Where humans interact in a haptic and emotional manner to convey their thoughts, intentions and emotions [10, 11], human-computer interaction lacks this due to current complexity [11]. In order to interact and collaborate with AI's, a more human-like system should be offered. Resulting in a more humanized-AI [6]. Where emotion and explainability are two of its core requirements. This way, a shift from human-AI interaction can go to human-AI collaboration [12]. For the reason that a “social” robot or AI that is able to “feel”, “understand”, and “respond” to touch in a more human-like way, will be capable of enhancing a more meaningful and intuitive interaction with humans [11]. Where touch alone is strong enough to convey distinguishable emotions.

In this pictorial, the idea of a more embodied and explainable AI is being explored. To see whether it is possible to create affection with an AI through embodied interaction. And if this results in a more understandable, less scary, AI.

SCOPING

This section discusses four topics which are integrated in, and relate to, the final concept of this pictorial.

Material Aesthetics

The industrial revolution brought a functional approach to design, where the form follows the function [13]. However, to be able to enhance the relation between people and products, together with how products co-shape the human-world relation (postphenomenology: subject and object can only be understood in relation to each other), material aesthetics need to be taken into account. Since the human sensory perception of things and the world, is the basis of our experience and existence [14]. The aesthetics of materials can be found beyond the "standard" material properties (e.g. stretchiness, softness, etc.). A new, additional dimension is shape-change. This can lead to new functions of products and forms of interaction [15] (Figure 1). Adding to the aesthetics of the interaction [16].

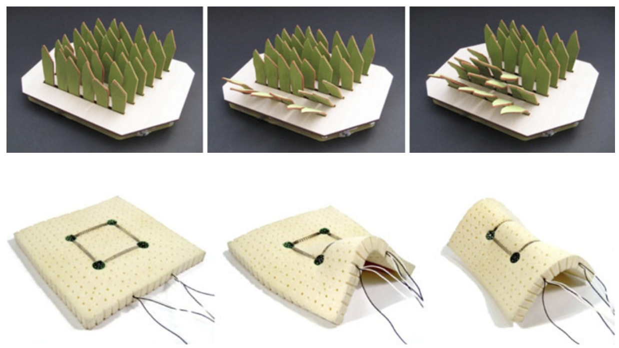

Figure 1. Shape-changing experiments [15]

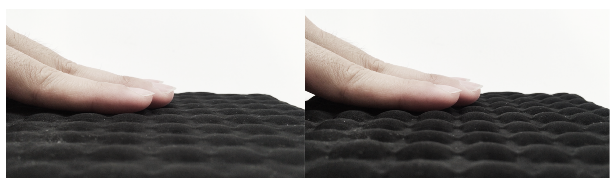

Figure 2. Tactile surface shape-change experience [17]

Ou et. al. [2016] investigated a bending mechanism (Figure 2) that has multiple, programmable shape-shifting behaviors with inextensible materials, including paper, plastics and fabrics. They looked at the possibilities for new applications for products and what happened to the interaction. In a world where technology gets more and more intertwined with our lives [18], we can imagine a future where technology and humanity might be inseparable. The vision on postphenomenology and material aesthetics might be one of the ways humanity can understand the digital world in an embodied manner. Where tangible interfaces might improve the understanding of AI, especially for when it is applied in daily life usage.

New Aesthetics

Material Aesthetics focus on the world around us. However, a new realm of aesthetics arose due to technological and digital development. Aesthetics of the digital world become more and more integrated into our daily physical world. New Aesthetics addresses this integration and blending of the digital and the physical world [19]. It is not a movement, but it can be many things. It can be a critical attitude, for example towards the way we use satellite images and how this influences power relationships [20, 21]. It can be a collaboration between human and machine, for example changing the meaning and interpretation of a piece of text simply by a single typo that occurred through the use of the technology [22]. It can be a project, for example creating designs that opens up the discussion on the use of personal data and how the interaction of technology with technology could regain one’s privacy [23]. How these integrations of technology influence our experience of day to day life, is something that is addressed by New Aesthetic. It is communicated through momentary representations such as image, text, design and more [20]. Furthermore, it is important to note that the word “aesthetic” is not directed necessarily to the visual aspect of these momentary representations, but rather to those things that are invisible. Meaning that it seeks to acknowledge the politics within the relationships between the digital and the physical world and gives space for (self-) critique [20].

Human-AI collaboration

New to our digital and physical world are AI systems. They are already embedded in our daily lives, with a variation in how active or passive it is presented to the user. Siri (virtual assistant that is part of Apple Inc.) is an example of an active system where it is apparent to the user that she is working with a digital assistant with a certain level of "intelligence" [28]. In contrast, Facebook's machine learning system [29] presents the user with a real time newsfeed with the most appropriate post for the user according to the system. But the question with both systems is whether it is a cooperation for the user or whether the user makes use of a tool. This is determined by how the user experiences the interaction. But what is the difference between these two forms of interaction?

Recent research has paid much attention to Human-AI Interaction (HAI) and Explainable AI (XAI) but interaction is not necessarily collaboration [12]. Collaboration includes mutual understanding of goals, pre-emptive task co-management, and shared progress monitoring as humans do every day. In order to integrate AI into the already complicated human workflow, it is crucial to bring the Computer-Supported Cooperative Work (CSCW) perspective [12] into the foundation of algorithmic research and plan for a Human-Al Collaboration future of work. How this interface should function is currently the subject of much research [30].

Whether users experience an AI system as a tool or a collaboration depends on how the user experiences the system. In our view, AI should ultimately be experienced as a collaboration to get the most out of the system, this even applies in the design world. Tim Cook (Apple CEO) once said: "*AI design will allow creatives to concentrate on their real job.*" [31]. One of the desired directions AI should move into if we want to benefit from its capabilities.

Generative Models

From all the different directions AI models can go into, we focussed on generative models. The generative model is capable of generating new plausible examples that come from an existing distribution of a data set [24]. For example a generative model can generate photographs that are similar but different from the photographs of a dataset as can be seen in Figure 3.

Generative models can handle much more complex tasks than discriminative models [25]. If we have a look at this example (Figure 4) of handwritten numbers, a discriminative model models the probability that the handwritten number equals the digit 0 or 1. The discriminative model is using a conditional probability. For example, the probability that the written number is the digit 0 given a certain handwritten number as input (ø), one call this the condition (notated as p(0|ø)) [26]. In other words, the model needs to choose if this handwritten number is the digit 0 or not.

A generative model tries to generate handwritten zeros and ones that lie close to respectively the digits 0 or 1. The generative model is using a joint probability distribution, i.e. it is asking the question “what is the probability that this is a handwritten zero and if it is the digit 0” [26]. Suppose our generative model generates the handwritten number ø. The joint probability of ø and 0 is notated as p(ø,0). For example, the generator generates a ø with the joint probability p(ø,0) as ½ and p(ø,1) as ½ , this is called its distribution. This is a pretty bad distribution. We would like to see that the generator generates something like o with the following joint probability, p(o,0)=0.99 and p(o,1)=0.01. Well known generative models include Generative Adversarial Networks (GAN's), which can be used for image generation, or Bayesian Networks, which can be used for generating new datasets similar to the original. An interesting concept for creative exploration and creation.

Figure 3. Example of generative model in- and output. Left: one of the images from the dataset. Right: output sample from generative model. [27]

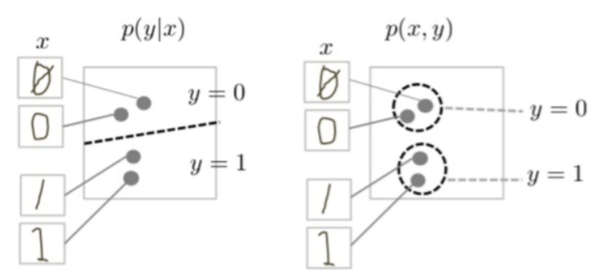

Figure 4. Probabilities of a discriminative and generative model [25]

EXPLORATION PHASE

During the exploration phase of the concept development, the main focus was on exploring the subjects of Material Aesthetics and Human-AI Collaboration (although, later on, the other two subjects mentioned in the 'Scoping' section were integrated into the concept as well). To get more grip on what our own and other people's perception on AI is, information was gathered into two Miro boards (Figures 5 and 6). This exploration confirmed the previous findings from research regarding the need of exploring how AI could potentially be more understandable. Furthermore, based on previously mentioned research on haptics and AI, value was seen in creating this understanding through haptics and embodied interaction as well as humanizing the AI. A focus was put on affection. Design opportunity regarding affection was seen, as many current interaction devices that offer affectionate interactions [32, 33] cater almost solely to humans rather than it being a collaborative interaction. However, we do feel like affection can positively influence human-AI collaboration.

The design of the physical aspect of the prototype, for supporting the embodied interaction, was inspired by projects such as Tactile Orchestra [34], The Compression Carpet [35], and Ripple Thermostat [36]. A dynamic, circular design from Pinterest was the inspiration for the final design mechanism [37] (Figure 7 and 8).

The kind of machine learning (ML) that would fit the embodied interaction and collaboration the most, would ideally be a self-supervised learning approach [38]. Generative models also fall under this approach. Although making such a model fully functioning would be outside the scope of this project, initial steps were taken to translate and categorize the sensor data into input which could be used for the model. This will be further described in the following section.

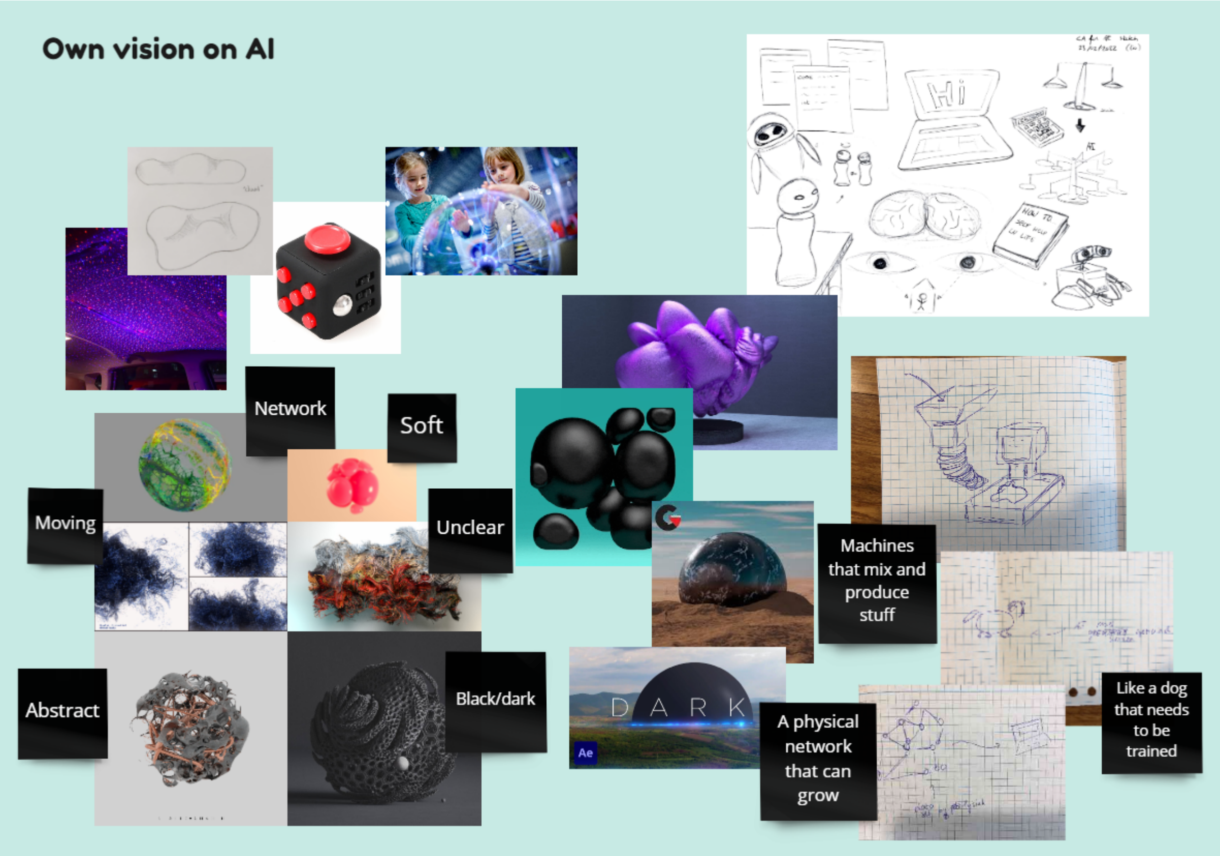

Figure 5. Exploration map of what we think AI should look like physically

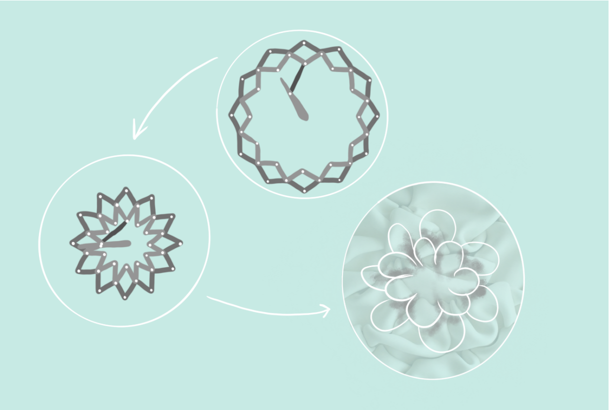

Figure 7. Initial mechanism and fabric movement sketch

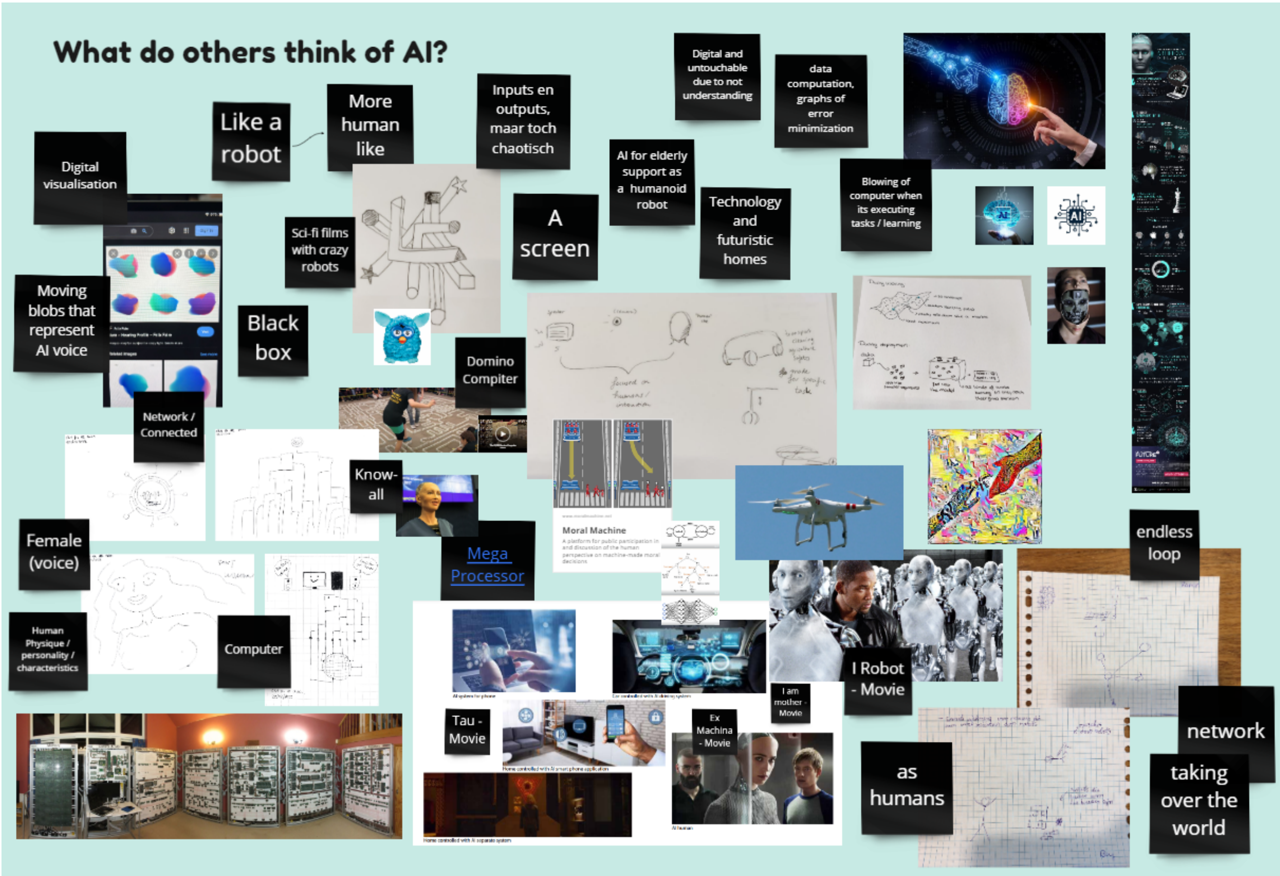

Figure 6. Exploration map of what other people think of AI

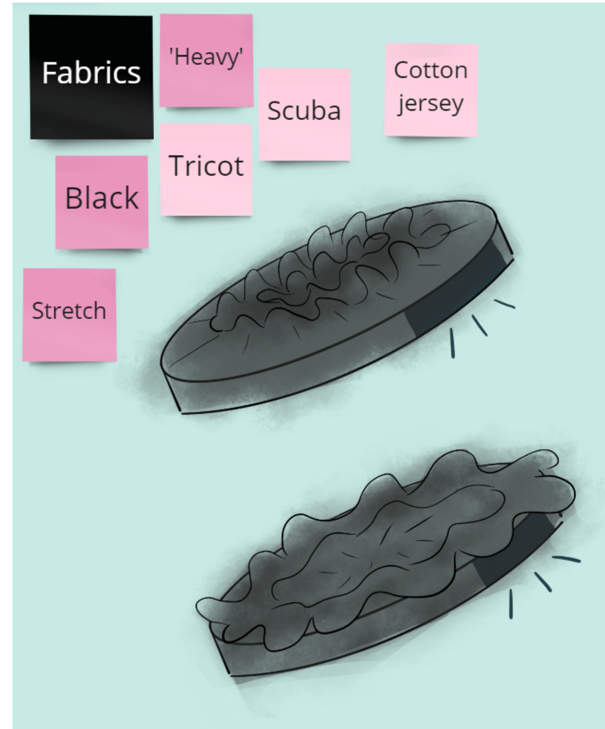

Figure 8.Fabric selection to fit the desired sketch

SENS.AI

SENS.AI is a shape-changing embodied AI (Figure 9) which is aware of the human-human interaction and wonders whether it is able to have this interaction with humans as well. And through this, creating a more meaningful human-computer interaction.

The user is able to teach the AI how humans interact, through following the multiple learning loops (Figure 10). Which are designed to make the AI less scary and more understandable. Through the intense training loops, the user is able to understand the AI's need for correct data and correction to be able to create a desired output.

Figure 9. SENS.AI in its physical and embodied shape.

SENS.AI aims to strengthen the connection between user and AI by enriching the interaction and giving the AI more human characteristics. This is by involving the tactile senses in the interaction, one of our basic ways of communicating. In current AI systems, this is normally ignored. In addition, the system also gets the "urge" to learn these human agencies, it wants to learn to stroke and tickle as well.

The purpose of this installation is to ultimately explore whether adding these features to an AI system can make the user experience the interaction more like a collaboration.

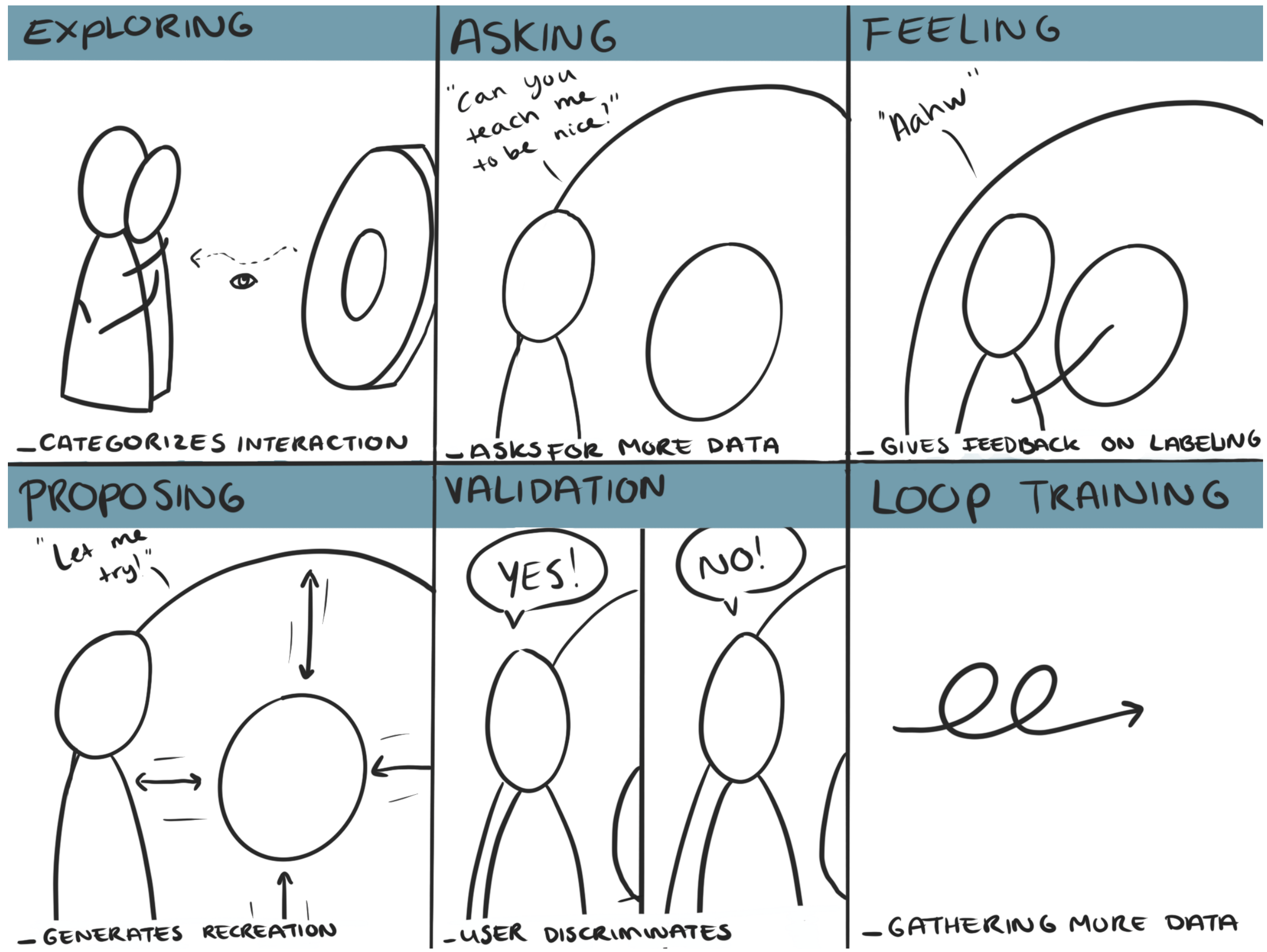

Figure 10. User journey storyboard of SENS.AI.

Sensor

It would be desired to have a multi touch input for our physical AI, because of the multi-layered data you can gather. The goal being that the sensor could sense different human interactions, like stroking or tickling. Most importantly, the data of these sensed interactions needed to be distinguishable from each other (with ML). It was therefore desired to have position and pressure data that would vary over time. For example, tickling is a light touch with multiple fingers and punching someone is a short but hard touch.

As can be seen from Figure 11, a pressure sensor matrix was made (based on the open-source project O-mat [39]) from copper tape and velostat, a material that is pressure sensitive. The resistance of the velostat reduces when the material is pressed. A matrix of 15x15 was made with the copper tape in order to locate where the velostat is compressed.

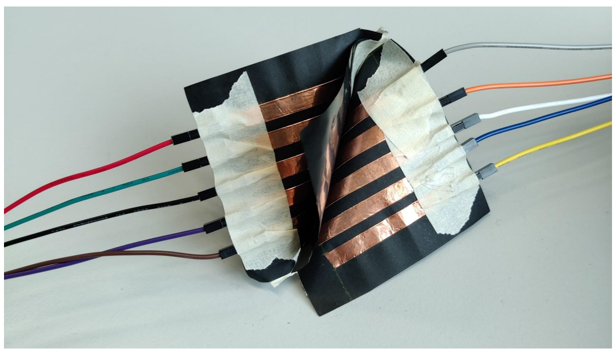

Figure 11. A 5x5 matrix try-out of copper tape with velostat

Sensor data

Processing was used to visualize the matrix data [39]. As can be seen in Figure 12, each square of the 15x15 grid represents an intersection of the copper tape matrix. A black square means that this intersection has not been touched. If an intersection of the matrix is touched the representing square will become white. The amount of pressure that is used on that specific intersection determines the opacity of the white. A light touch is a high opacity (one can easily "look" through it) and hard touch is a low opacity.

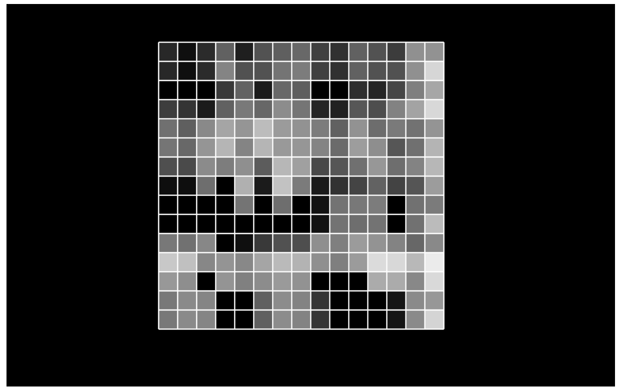

Figure 12. Translation of sensor input into an image. Tickling behavior

To visualize the movement over time, these images were stacked on top of each other. If the same intersection is touched multiple times the square will become whiter by layering the whites with different opacities corresponding to the amount of pressure over time.

Implementation of AI

Our data would have been rather complex if we used the raw data from the Arduino. Arduino printed a sequence of the 15x15 matrix filled with integers. To make everything much simpler, we came up with the visualization in Processing. As the sensor input is now translated into an image, it gives the opportunity to use an Generative Adversarial Network (GAN) [40] (Figure 13 and 14). The model would then be able to generate its own images that could be categorized into different interaction possibilities (Figure 15).

Because of the lack of time, a classification model of the google Teachable Machine tool [41] was used to train the model. Although successful for some categories (including 'Stroke' and 'No Interaction') other categories were almost indistinguishable ('Punch' and 'Tickle'). Tweaking the training data helped with the accuracy of the model, however optimizing the translation of sensor input into image and improving the training data could lead to more accurate outcomes.

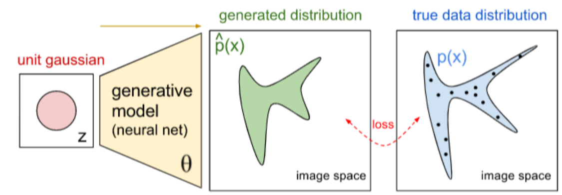

Figure 13. Generated distribution of GAN model [40]

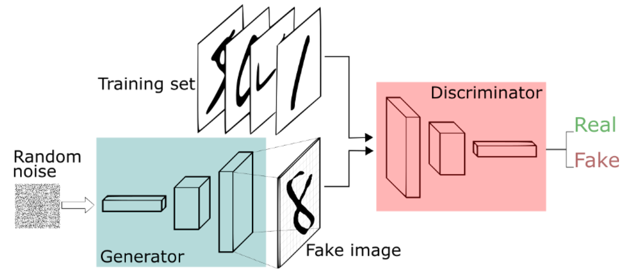

Figure 14. Description of the GAN model [42]

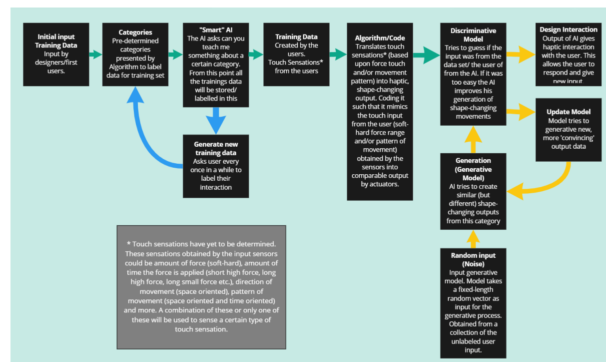

Figure 15.Schematics of Ideal Model for SENS.AI

Kinetic Movement

The system's output is defined to be a movement of material (black fabric). Underneath the fabric, a movable skeleton is built which serves as the construction. Which consists of linked pyramid structures in which all the ends of the ridges can hinge off each other (Figure 16, 18, 19, 20). The movement is realized by 4 stepping motors that can move in two directions with variable speeds and accelerations. The motors are attached to toothed belts that allow four nodes on the skeleton to be moved separately in a linear direction (Figure 17). Due to the geometric shape of the skeleton, the linear displacement of the knot points between the time belt and the frame causes a 3D change in the shape (Figure 18). The concept idea of this movement is that by linking the triangle structures, a coherent movement is created with a steering in 4 individual points. The end goal of this system is to create a construction that is relatively easy to manipulate in a rhythmic movement, making it a metaphor for a mysterious black box system that is attractive due to its appearance.

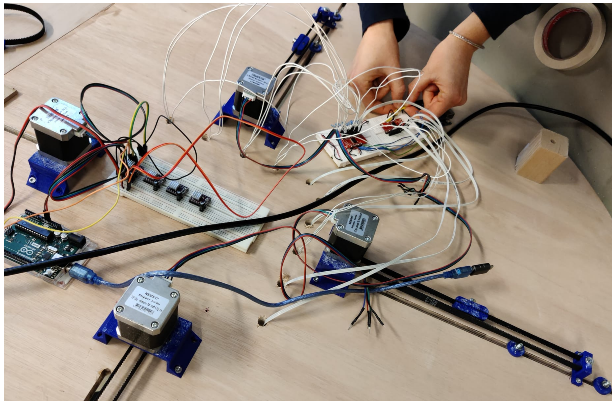

Figure 17. Picture of back-end prototype

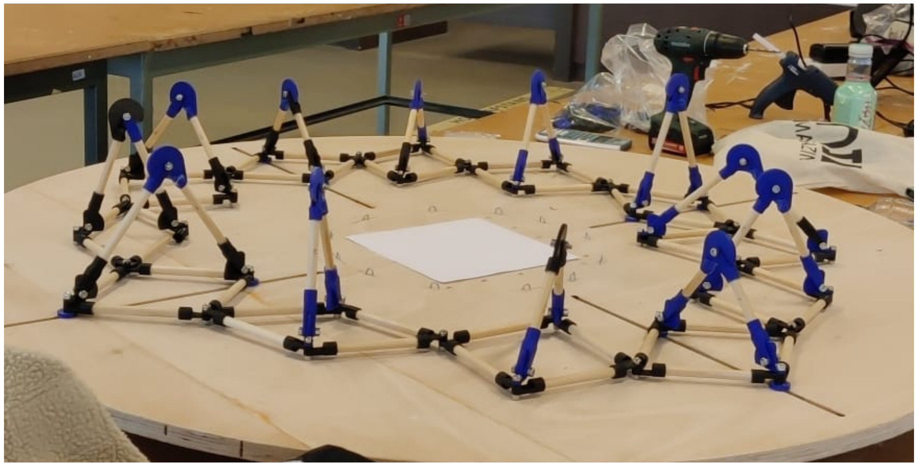

Figure 16. Picture of perspective view of skeleton

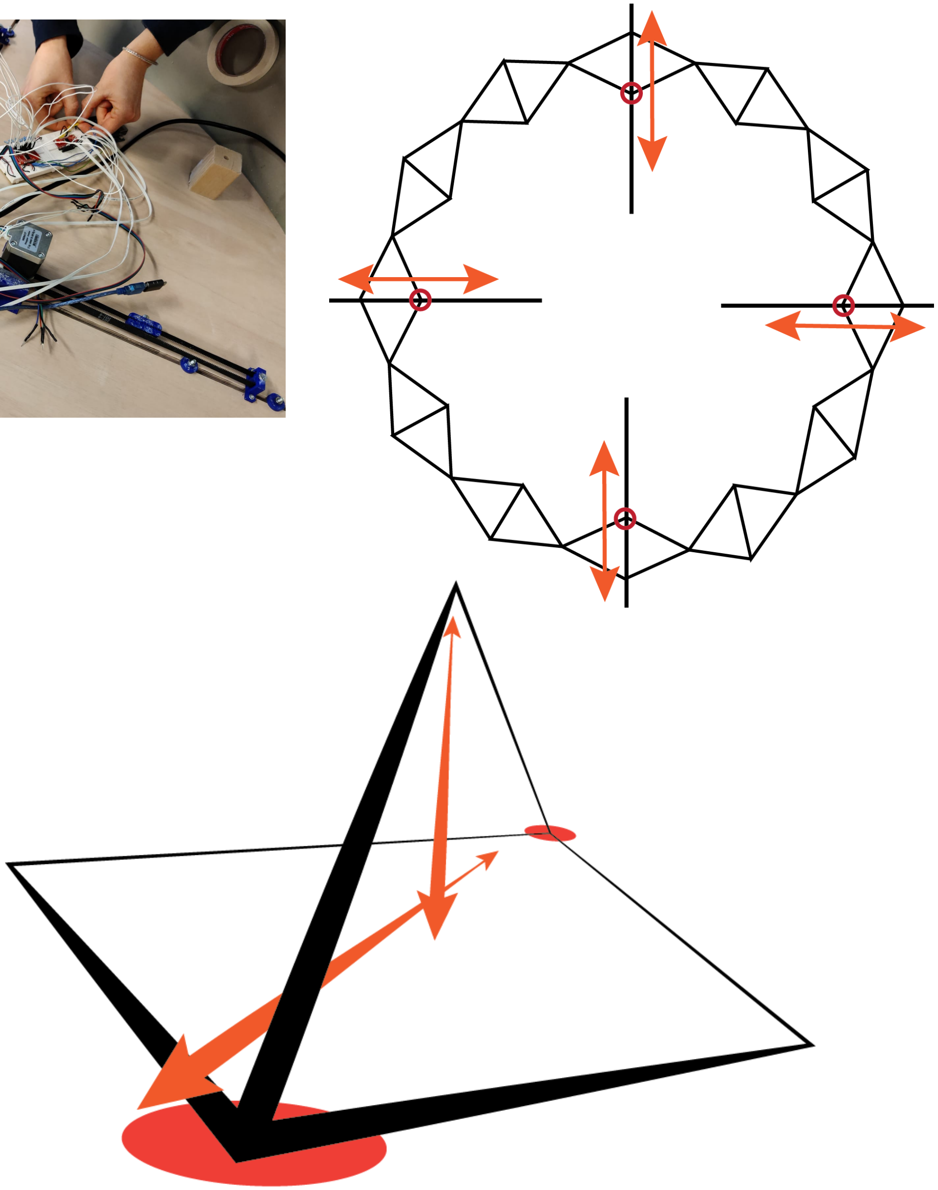

Figure 18.

Illustration movement skeleton. Top: upper view. Bottom: detailed side view.

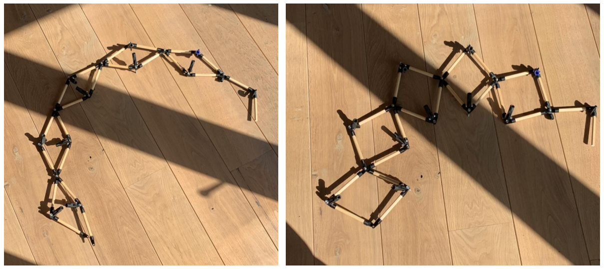

Figure 19. Picture part-skeleton pulled out (Left) and pulled in (Right)

Figure 20. SENS.AI in use

Sensor data translation to actuators

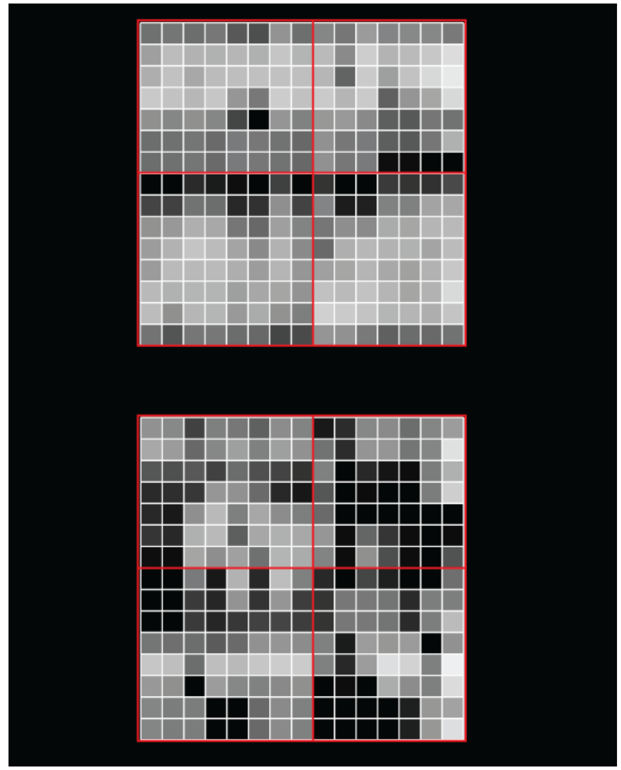

Figure 21. Potential division of matrix for the actuator output. (Top) Similar opacity of neighboring cells. (Bottom) Sporadic opacity of neighboring cells.

The sensors measure the pressure, the location and the changes over time. For the actuator output, stepper motors are used. A stepper motor has 3 variables, speed, direction and the time that is moving. Ideally, the amount of pressure would be mapped in relation to the speed of the stepper motor. The time that someone touches the sensor is mapped to the runtime and direction of the stepper motor. Currently this is set to the amount of loops as described earlier. This translation will be the hard part. One potential solution would be to look at the neighboring cells (See Figure 21). The division of the matrix should relate to the amount of stepper motors. The overall intensity of the cells in that region determine the speed of the motor. The similarity of neighboring cells (are they very similar such as with a 'Stroke' movement or more sporadically as a 'Tickle' movement) determines the smoothness of the speed. If this would be a suitable method would need to be explored in future work.

DISCUSSION & REFLECTION

Sensor data and Machine Learning (ML)

There are a few flaws in the sensor data. First, the sensor is measuring a lot of noise. We experienced that working with copper tape is difficult. And it isn't accurate enough for what we envisioned. The difference between being touched and not touched wasn't big enough to get all the noise out of the visualization. As you can see in Figure 22.

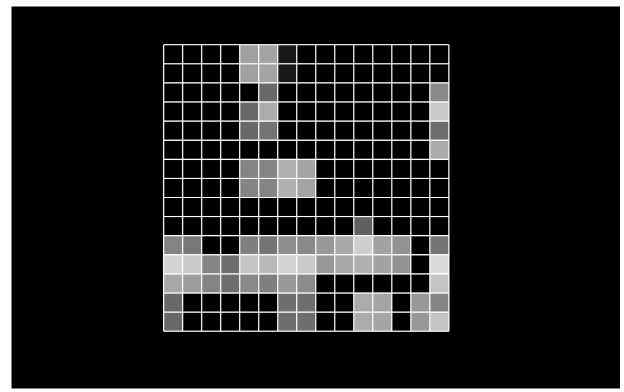

Figure 22. Visualization of the "noise"

The visualization of a punch was very similar, which influenced the accuracy of the ML model. Secondly, we lost some of the data. The opacity of the white depends on the pressure of the touch. If an intersection of the matrix is touched multiple times, these whites with different opacities were layered over time. However, through stacking the images we lost some valuable differences in the data. As a single short, hard, touch will generate the same image as a soft touch for a longer time on the same spot. A solution for this problem could be that we would not layer the output data, but we put them next to each other (Figure 23). This could make the pattern recognition by the AI better.

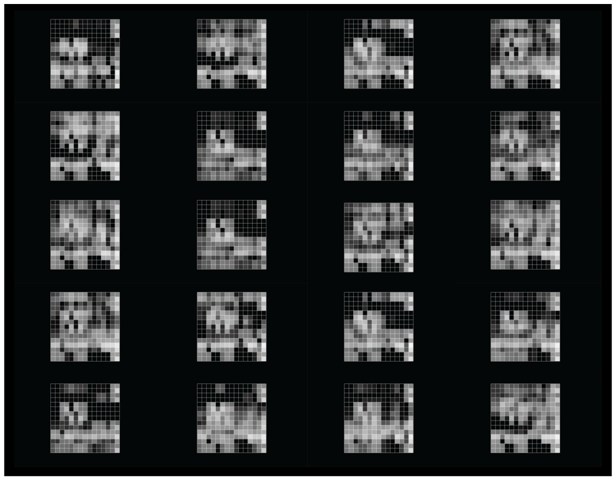

Figure 23. Visualization of multiple sensor readings next to each other

Due to the lack of time, we used a classification model to train the model. As discussed in the previous section, the "bad" quality of the sensor data influenced the accuracy of the machine learning. However, for future research we would like to exchange the classification model for a GAN, as it suits the concept better. The user will show the AI what affection is by touching the sensor. This will be used as training data for the GAN. The GAN can then generate new outputs deviating from the input of the users. The user will be the discriminative model. With the users feedback the GAN can improve its generated outputs. The GAN will probably generate surprising outputs in the beginning, but it gets better after a few training loops. The user will be a part of the learning curve of the GAN. If this indeed makes an AI less scary and more understandable is yet to be investigated.

Kinetic Movement

The kinetic system was designed from a vision without a broad exploration of different possibilities in the execution due to time constraints. By means of exploration, the movement that the installation creates is sufficient. However, for further research in this area it should be redesigned. The current linear movement together with the tensioned fabric is not a right fit. If this reaction caused more displacement in the X, Y and Z direction, the movement would be more noticeable and therefore more distinguishable. In addition, in the current construction there is a lot of friction in the movement, which means that the motors do not always have enough torque to move the system. This would be a hindrance during the execution of a user study.

A major translation between the data takes place from the sensor input to the actuator output. The translation is complicated, which inhibits the communication of the AI to the user. If the actuators are more correlated with the input data, this can be remedied, and the system can be better understandable.

Design expression and aesthetics

As a view of the design towards the user, the choice was made for a design that looks mysterious, a metaphor of a Black Box. It generates an anxious noise due to the electric motors, which amplifies this feeling. The question with this design aesthetic is whether it is the most appropriate one for achieving our goal. In this project, the common design goal was not always clear to the researchers and also varied during the project. This was a result of new acquainted knowledge on AI. As a result, not all design choices were in line with each other, which created friction in the concept. On the one hand, the purpose of the design was to explain the working principle of ML to the society by letting them train the system themselves, which is in contrast to the secrecy. On the other hand, we wanted to broach the subject of new aesthetics by keeping it secret. As a result, the concept has contradictory elements that make it interesting, however conflicting with the idea that an AI is clear on what the system is capable of doing and how well it can do that as mentioned in the introduction.

Future works

When the installation functions as it was intended to do (modification of the aesthetics, mechanics and the ML algorithm), the research question can be investigated with the following setup: "Does giving human emotions to an AI and applying physical interaction enhance the cooperation between human and AI?" Here, it is necessary to investigate when the form of interaction feels like a tool to the user and when it turns into a feeling of collaboration.

CONCLUSION

This pictorial describes the concept development of SENS.AI, a shape-changing embodied AI which allows for collaborative human-machine interaction to understand and explore different haptic outputs of affection. Not only will the machine learn about human affection, the user will be able to better understand the learning process of the AI through the embodied interactions. A copper tape matrix was used as sensor input data which is then translated into an image for categorizing the interactions. Further explorations need to be conducted on the translation from image to actuator output data.

The concept visually plays with the previously established stigma of AI being a 'black box', although its goal is to move away from this idea. It shows the duality of the general perception of AI and the richness that can occur when opening up for interaction with the technology. It can give new meaning and form to everyday interactions of affection by the way it is physically designed as well as having the room to learn with the user rather than solely cater to them.

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Appendix 1 - Background and Roles

Yvonne Bruin

Yvonne was already familiar in the field of data physicalization together with shape change. Throughout her studies she has worked a lot with different materials to explore their effect on the interaction. She wanted to implement this knowledge into this project as well.

During this course, Yvonne also wanted, next to working on the aesthetics of the design, to do more on the technology and realization side. At the beginning this task was mainly given to Leanne and Lio, who were in charge of the code. This way, the process was equally divided, since Jules and Yvonne were mainly working on the shape. When the shape was getting together, Yvonne could spend more time together with Lio and Leanne on the coding, sensor and machine learning aspects. She helped figure out some issues through troubleshooting. Usually, Yvonne does not take a lot of technology tasks upon her. Although this time she wanted to learn more in this field, and therefore tried her best to help and learn where possible.

For the aesthetics aspects, Yvonne took the lead in the usage of the fabric. As a team, the mechanism was decided upon and tasks were divided so each team member could put their skills to use.

Yvonne has been searching for background literature and tried to position the work in there as well. After the literature research, she explained her findings to her teammates, with all literature and notes available for them to see as well.

The whole process was a group effort. Where in some parts some were more busy and in other parts the others. The tasks were divided as equally as possible between all team members. And this was done for the report as well.

Lio Huntjens

Lio is currently an Industrial Design Master student at Eindhoven University of Technology (TU/e). Her interests lie in the creation of tangible designs through the use of innovative technologies (from 3D printing to Artificial Intelligence) which address developments within the sustainability narrative and/or create meaningful haptic interactions. The expertise areas that fit the development within these interests include Technology and Realization (TR) and Creativity and Aesthetics (CA).

During this project, Lio mostly focused on the electronics, code and translation of sensor input to image for the machine learning model. These were some of the skills she wanted to develop during the course. Furthermore, Lio did research on the subjects New Aesthetic, Generative Models, types of machine learning, state-of-the-art projects, and haptics. She used this new gained knowledge as input for the development of the concept. She supported in putting together and exploring the size of the skeleton from the physical prototype. For the report, she (co-)wrote the new aesthetics section, exploration phase, part of the sens.ai section on sensors and actuators, and the conclusion.

Jules Sinsel

Jules is currently working on his M2.1 of the master of industrial design at Eindhoven University of Technology (TU/e) and has a bachelor in mechanical engineering. He uses the two fields of knowledge to create new possibilities. Currently, the focus is oriented on rich /tangible interaction, data visualization/physicalization and AI systems in relation to the user.

The purpose of taking this course was to become better in combining the domains of creativity and aesthetic with math data and computing. To this end, he has taken on the role of the designer and the realizer of the kinetic system in this project. Meaning designing this system in CAD and 3D print the necessary parts, building the assembly and programming the step motor controller in Arduino.

In addition, he delved into the expertise area of user-AI collaboration, what the difference is between working together and using a tool. This was an interesting area of reflection as it now correlates to the experience the product gives to the user.

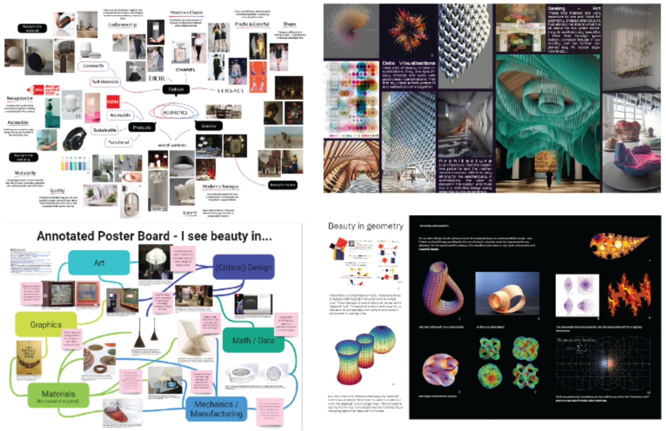
The overall picture of this project is truly a group process, all the decisions were made together and everyone informed each other with the knowledge gained.

Leanne Vis

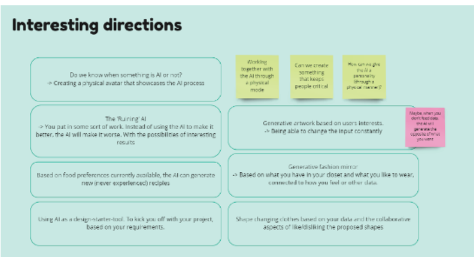
Leanne is currently an Industrial and Applied Mathematics Master student. She has a bachelor in Industrial Design and Applied Mathematics. She is interested in how to apply mathematical concepts into real life. As mathematical concepts are very abstract most of the time, she is interested in exploring more concrete applications. Her expertise areas are Math, Data and Computing (MDC).

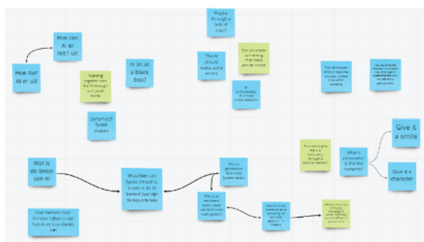
In the beginning of this project, Leanne focussed on the sensor, the data and the code with the help of Lio and Yvonne as well later on in the project. For the poster assignment she did research in Generative models. She used this knowledge for the implementation of AI into the project. Together with Lio, she developed different models for the AI that could be used in the project, because she was interested in possible applications of AI in real life. In the end, she helped Jules to get the stepper motors running.

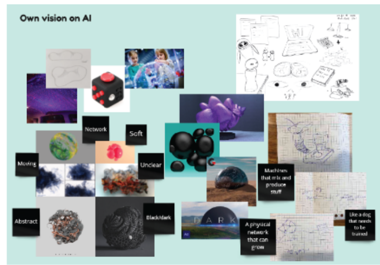
Appendix 2 - Visual overview Design/Research process



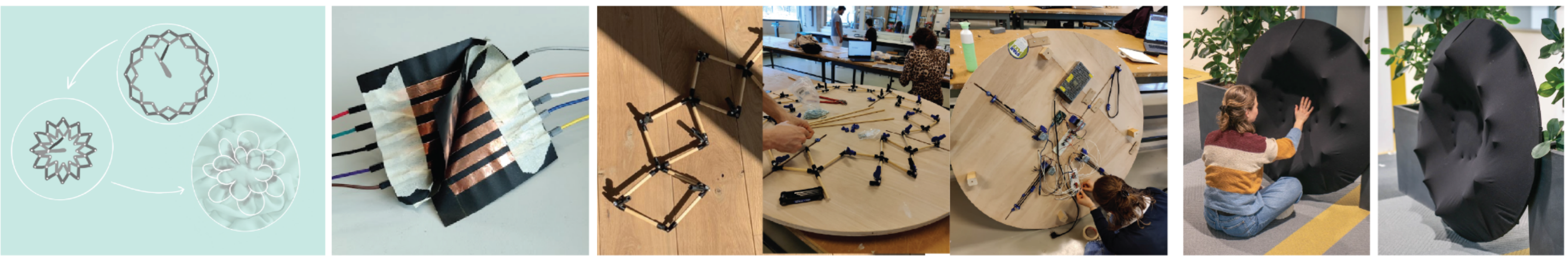
PHASE 1 At the beginning of the course we did a deep dive into our personal aestetic preferences and four different theories







PHASE 2 After the theoretical deep-dive we tried to combine the different theories into an interestic direction for our visionary demonstrator. Together with the exploration of our vision on AI and how other people (outside of the technical field) see AI. Next to that we made a theorethical framing and a slight benchmark.



PHASE 3 Eventually, we decided upon our design direction and started testing the sensor and mechanism. When these were tested we put both of them together into our final design SENS.AI. In the meantime, the codes and electronics of the several elements were made. On the right the visionary experiential prototype of SENS.AI is presented.

Appendix 3 - Math, Data & Computing (arduino code)

```
//Arduino Code from the open-source project "O-mat" https://www.instructables.com/O-mat/
//Code used and partially adjusted for the SENS.AI project for the course DCM210 - Creativity and Aesthetics of Data a


//Mux control pins for analog signal (SIG_pin) default for arduino mini pro
const byte s0 = A1;
const byte s1 = A2;
const byte s2 = A3;
const byte s3 = A4;//Mux control pins for Output signal (OUT_pin) default for arduino mini pro
const byte w0 = 2;
const byte w1 = 3;
const byte w2 = 4;
const byte w3 = 5;//Mux in "SIG" pin default for arduino mini pro
const byte SIG_pin = A5;//Mux out "SIG" pin default for arduino mini pro
const byte OUT_pin = 6;//Row and Column pins default for arduino mini pro
const byte STATUS_pin = 13;
const byte COL_pin = 12; const boolean muxChannel[15][4] = {
  {0, 0, 0, 0}, //channel 0
  {1, 0, 0, 0}, //channel 1
  {0, 1, 0, 0}, //channel 2
  {1, 1, 0, 0}, //channel 3
  {0, 0, 1, 0}, //channel 4
  {1, 0, 1, 0}, //channel 5
  {0, 1, 1, 0}, //channel 6
  {1, 1, 1, 0}, //channel 7
  {0, 0, 0, 1}, //channel 8
  {1, 0, 0, 1}, //channel 9
  {0, 1, 0, 1}, //channel 10
  {1, 1, 0, 1}, //channel 11
  {0, 0, 1, 1}, //channel 12
  {1, 0, 1, 1}, //channel 13
  {0, 1, 1, 1}, //channel 14
  // {1, 1, 1, 1} //channel 15
};
//incoming serial byte
int inByte = 0; int valor = 0; //variable for sending bytes to processing
int calibra[15][15]; //Calibration array for the min values of each od the 225 sensors.
int minsensor = 254; //Variable for staring the min array
int multiplier = 254;
int pastmatrix[15][15];
int numberOfSamples = 1;
int output[15][15]; //Output arrayvoid setup() { pinMode(s0, OUTPUT);
pinMode(s1, OUTPUT);
pinMode(s2, OUTPUT);
pinMode(s3, OUTPUT); pinMode(w0, OUTPUT);
pinMode(w1, OUTPUT);
pinMode(w2, OUTPUT);


digitalWrite(w3, LOW); digitalWrite(OUT_pin, HIGH);
// digitalWrite(STATUS_pin, HIGH);
// digitalWrite(COL_pin, HIGH); Serial.begin(115200); Serial.println("\n\Calibrating...\n"); // Full of 0's of initial matrix
for (byte j = 0; j < 15; j ++) {
  writeMux(j);
  for (byte i = 0; i < 15; i ++)
    calibra[j][i] = 0;
} // Calibration
for (byte k = 0; k < 50; k++) {
  for (byte j = 0; j < 15; j ++) {
    writeMux(j);
    for (byte i = 0; i < 15; i ++)
      calibra[j][i] = calibra[j][i] + readMux(i);
  }
} //Print averages
for (byte j = 0; j < 15; j ++) {
  writeMux(j);
  for (byte i = 0; i < 15; i ++) {
    calibra[j][i] = calibra[j][i] / 50;
    if (calibra[j][i] < minsensor)
      minsensor = calibra[j][i];
    Serial.print(calibra[j][i]);
    Serial.print("\t");
  }
  Serial.println();
} Serial.println();
Serial.print("Minimum Value: ");
Serial.println(minsensor);
Serial.println(); establishContact(); for (int j = 0; j < 15; j++) {
  for (int i = 0; i < 15; i++) {
    output[j][i] = 0;
  }
} // digitalWrite(COL_pin, LOW);
}
void loop() {
  //Loop through and read all 16 values
  //Reports back Value at channel 6 is: 346
  if (Serial.available() > 0) {
    inByte = Serial.read(); if (inByte == 'A') {
      for (int j = 14; j >= 0; j--) {
        writeMux(j); for (int i = 0; i < 15; i++) {
          valor = readMux(i); //Saturation sensors
          int limsup = 450;
          if (valor > limsup)
            valor = limsup; if (valor < calibra[j][i])
            valor = calibra[j][i]; valor = map(valor, minsensor, limsup, 0, 254); if (valor < 150)
            valor = 0;
          if (valor > 254)
            valor = 254; Serial.write(valor);
          // digitalWrite(COL_pin,!digitalRead(COL_pin));
        }
      }
    }
  }
  // Calibration
  for (byte j = 0; j < 15; j ++) {
    writeMux(j);
    for (byte i = 0; i < 15; i ++) {
      output[j][i] = 0;
      for (int s = 0; s < numberOfSamples; s++) {
        output[j][i] = output[j][i] + readMux(i);
      }
      output[j][i] = output[j][i] / numberOfSamples;
      if (output[j][i] < calibra[j][i]) {
        output[j][i] = calibra[j][i];
      }
      if (output[j][i] < minsensor) {
        minsensor = output[j][i];
      }
    }
  } //delay(100); //Print averages
  for (byte j = 0; j < 15; j ++) {
    for (byte i = 0; i < 15; i ++) {
      Serial.print(output[j][i]);
      Serial.print("\t");
    }
    Serial.println();
  }
}
int readMux(byte channel) {
  byte controlPin[] = {s0, s1, s2, s3}; //loop through the 4 sig
  for (int i = 0; i < 4; i ++) {
    digitalWrite(controlPin[i], muxChannel[channel][i]);
  } //read the value at the SIG pin
  int val = analogRead(SIG_pin); //return the value
  return val;
} void writeMux(byte channel) {
  byte controlPin[] = {w0, w1, w2, w3}; //loop through the 4 sig
  for (byte i = 0; i < 4; i ++) {
    digitalWrite(controlPin[i], muxChannel[channel][i]);
  }
} void establishContact() {
  while (Serial.available() <= 0) {
    Serial.print('A'); // send a capital A


    delay(300);
  }
}
```

APPENDIX 4 - MATH, DATA & COMPUTING (PROCESSING CODE)

```
matrix_code_v3
//Processing Code from the open-source project "O-mat" https://www.instructables.com/O-mat/
//Code used and partially adjusted for the SENS.AI project for the course DCM210 - Creativity and
Aesthetics of Data and AI
// This example code is in the public domain.


import processing.serial.*;
import processing.opengl.*;
import gab.opencv.*;
import org.opencv.core.Mat;

OpenCV opencv;

int colrow = 15;
float x;
float y;
int ruis;

int bgcolor; // Background color
int fgcolor; // Fill color
Serial myPort; // The serial port
int[] serialInArray = new int[colrow*colrow]; // Where we&apos;ll put what we receive
int[] pastInArray = new int [colrow*colrow];
float[][] colorTarget = new float[3][255];
float[][] currentColor = new float[3][255];
PVector[][] vertices = new PVector[colrow][colrow];
float[] verticesTZ = new float[colrow];
float w = 30;
float ease = 0.75;

int serialCount = 0; // A count of how many bytes we receive
int xpos, ypos; // Starting position of the ball
boolean firstContact = false; // Whether we&apos;ve heard from the microcontroller
int tiempoant;
int render=0;
int dif=0;
int maxAmount=0;
int number=0;
int stoploop = 0;



void setup() {
size(960, 600, P3D); // Stage size
noStroke(); // No border on the next thing draw
background(0);
colorMode(RGB, 255, 255, 255, 255);

// Print a list of the serial ports, for debugging purposes:
println(Serial.list());

// I know that the first port in the serial list on my mac
// is always my FTDI adaptor, so I open Serial.list()[0].
// On Windows machines, this generally opens COM1.
// Open whatever port is the one you&apos;re using.

myPort = new Serial(this, Serial.list()[0], 115200);

for (int j = 0; j < colrow; j++) {
  for (int i = 0; i < colrow; i++) {
    vertices[i][j] = new PVector( i*w, j*w, 0);
  }

}

}



void draw() {
 if (stoploop < 10) {
  if ((render==1) && (maxAmount < 10)) {

    translate(width/4, 60);

    for (int j=0; j<colrow-1; j++) {
     beginShape();
     println("Row"+ j);
     for (int i=0; i<colrow; i++) {
      stroke(255);

      fill(255, 255, 255, (serialInArray[j*colrow+i]/5));
      x = i*width/colrow;
      y = j*height/colrow;
      //verticesTZ[i] = serialInArray[j*colrow+i];

      println(serialInArray[j*colrow+i]);
```

```
      rect( vertices[i][j].x, vertices[i][j].y, w, w);
      rect( vertices[i][j+1].x, vertices[i][j+1].y, w, w);
     }
     endShape(CLOSE);
     // println();
    }
    render=0;
    maxAmount++;
  } else if (maxAmount >= 10) {
    save("image"+number+".png");
    println("image saved"+number);
    number++;

    background(0);
    stroke(0);
    fill(0, 0, 0, 0);

    render=0;
    maxAmount = 0;
    stoploop++;
  }
 } else if (stoploop >= 10) {
  noLoop();
 }
 delay(500);
}


void serialEvent(Serial myPort) {
 // read a byte from the serial port:
 int inByte = myPort.read();
 // if this is the first byte received, and it&apos;s an A,
 // clear the serial buffer and note that you&apos;ve
 // had first contact from the microcontroller.
 // Otherwise, add the incoming byte to the array:
 if (firstContact == false) {
  if (inByte == &apos;A&apos;) {
    myPort.clear(); // clear the serial port buffer
    firstContact = true; // you&apos;ve had first contact from the microcontroller
    myPort.write(&apos;A&apos;); // ask for more
  }
 } else {
  // Add the latest byte from the serial port to array:


  if (inByte < 50) {
   inByte = 0;
  }
  serialInArray[serialCount] = inByte;

  serialCount++;

  // If we have 3 bytes:
  if (serialCount > colrow*colrow-1) {
   //println(millis()-tiempoant);
   tiempoant = millis();

   render = 1;

   // Send a capital A to request new sensor readings:
   myPort.write(&apos;A&apos;);
   // Reset serialCount:
   serialCount = 0;
   //println("New Array");
  }
 }
}
```

Appendix 5 - Math, Data & Computing (training model code)

Working Files

- index.html
- ml5.min.js
- sketch.js — ImageModel_TM_2022_
- model.json — tm-my-image-model
- model.json — tm-my-image-model
- sketch.js — ImageModel_TM_202:

Getting Started

- screenshots
  - quick-edit.png
- index.html
- main.css

```
// Copyright (c) 2019 ml5
//
// This software is released under the MIT License.
// https://opensource.org/licenses/MIT

/* ===
ml5 Example
Webcam Image Classification using a pre-trained customized model and p5.js
This example uses p5 preload function to create the classifier
=== */

// Classifier Variable
let classifier;
// Model URL
let imageModelURL = 'https://teachablemachine.withgoogle.com/models/bXy2kDNi/';

// Video
let video;
let flippedVideo;
// To store the classification
let label = "";

// Load the model first
function preload() {
  classifier = ml5.imageClassifier(imageModelURL + 'model.json');
}

function setup() {
  createCanvas(320, 260);
  // Create the video
  video = createCapture(VIDEO);
  video.size(320, 240);
  video.hide();

  flippedVideo = ml5.flipImage(video)
  // Start classifying
  classifyVideo();
}

function draw() {
  background(0);
  // Draw the video
  image(flippedVideo, 0, 0);

  // Draw the label
  fill(255);
  textSize(16);
  textAlign(CENTER);
  text(label, width / 2, height - 4);
}

// Get a prediction for the current video frame
function classifyVideo() {
  flippedVideo = ml5.flipImage(video)
  classifier.classify(flippedVideo, gotResult);
}

// When we get a result
function gotResult(error, results) {
  // If there is an error
  if (error) {
    console.error(error);
    return;
  }
  // The results are in an array ordered by confidence.
  // console.log(results[0]);
  label = results[0].label;
  // Classifiy again!
  classifyVideo();
}
```