

Creating an interaction with cellular automata for science and technology museums

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Abstract. The development of technology creates a need for more students following science and technology curricula. Enthusiasm for these subjects is being raised for example by modern science and technology museums, and within schools increased attention is given to subjects like programming. This document describes the design process of an interaction with cellular automata. For interaction design, this means dealing with large sets of settings and a difficulty in offering a clear mental model to the user.

Keywords: Cellular automata, Interaction design, Education.

Mathematics Subject Classification: Primary 37B15.

1 Introduction

The development of new technology brings changes to the way people live in multiple ways; current advances in robotics and artificial intelligence cause fears of ever more jobs being lost to a machine or an algorithm that performs better at lower cost. When Jacquard invented his groundbreaking automated loom weavers feared being put out of work and fiercely protested the new technology, not shunning violence and death to protect their interests. Technology and its monetary interests won; some weavers were indeed put out of work while others adopted the invention and became primordial programmers who punched holes in the cards that store instructions for the looms. This particular method of data storage and processing later inspired Babbage's analytical computers, forming the foundation for modern computing[1].

Around the advent of computers, John von Neumann tried to devise a machine that could reproduce itself; his approach contributed to what became known as cellular automata. Variants of cellular automata exist in different dimensions, but they share the attribute of living on a type of discrete grid. A square grid is most often used, but the principle can be used with other grid types such as hexagonal or triangular grids.

The state of each cell on the grid is updated according to the state of its neighbours: a ruleset determines the new state. Wolfram among others performed extensive research into elementary cellular automata which are one-dimensional in operation and whose output can be mapped in two dimensions; they work on a single line and leave a trace in a field. Three adjacent cells are used to determine the state of a cell on the next row. With the minimum two states per cell, this gives $2^3 = 256$ different patterns, a particular instance of which called rule 30 can be used for random number generation[2]. Increasing the neighbourhood size to 5, the number of different outcomes explodes: $2^5 = 4294967296$

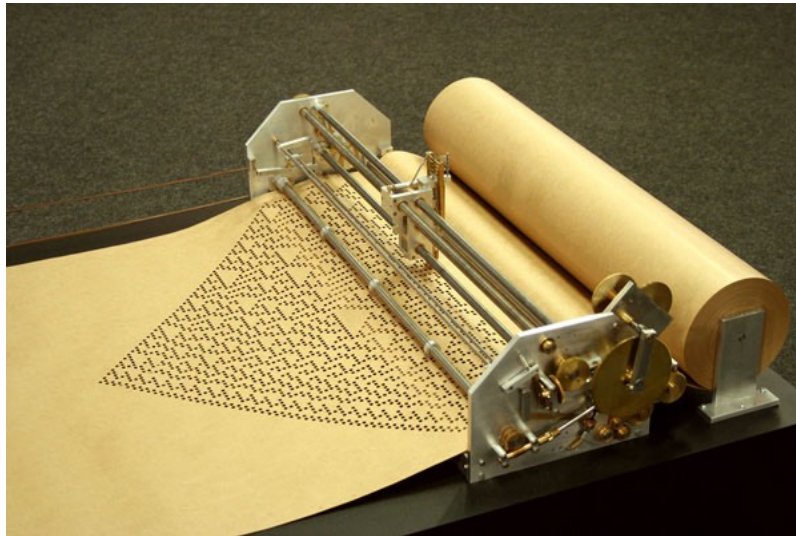


Fig. 1. Installation by K. Myskja that punches holes in a roll of paper according to rule 30.

Cellular automata are applied in science and design, for example to simulate chemical reactions, electrical circuits and traffic, or for generation of patterns[3, 4, 5]. An art display that mechanically recreates the aforementioned rule 30 shows the beauty of complex patterns from simple individual steps, as seen in figure 1.

These fascinating properties give an opportunity to spark interest in people unfamiliar with the principle of cellular automata. The graphical nature of the output lends itself to an interaction where the user influences the outcome; a type of generative design.

The following sections will describe the design process of an interaction with cellular automata within the context of a science and technology museum.

2.1 User interface with cellular automata

A simple starting point was chosen to create a first interaction with cellular automata, namely giving users direct control over the eight rules that govern an elementary cellular automaton. A board with eight switches controls a Processing sketch that iterates the ruleset. Each rule is displayed on screen together with its setting, while the other half shows the resulting pattern when the rule is iterated over a number of rows. Changing a rule updates the pattern to reflect

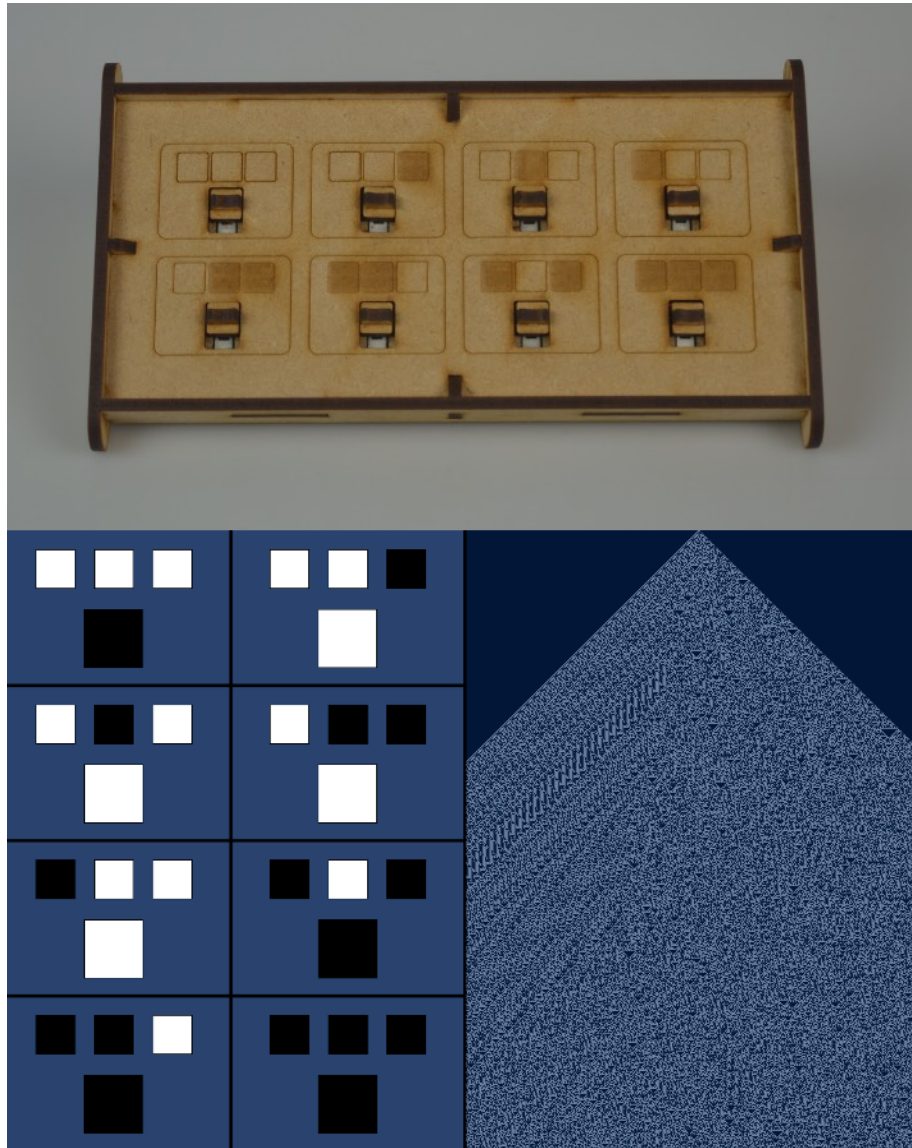


Fig. 2, 3. Switchboard with individual settings for the eight rules of the elementary automaton and the graphical interface showing the setting (rule 30 again) of each rule with the accompanying pattern.

the new settings. Figures 2 and 3 show the switchboard and the graphical interface respectively.

A small demonstration of this interaction was done within a lecture given at the faculty of Industrial Design at the Technical University Eindhoven. The general impression was that the cellular patterns are interesting to play with, but the overall GUI was somewhat confusing especially to people unfamiliar with the concept of cellular automata (CA).

The subsequent iteration should further clarify the principle of CA in a number ways: instead of instantly showing the cellular pattern iterated over hundreds of lines, a step-by-step approach should give more insight in how the patterns emerge.

2.2 Physical embodiment

Embodiment of interactions has been discussed and researched by amongst others Dourish [6]. The embodiment of an interaction determines the user's experience, and designers partly have influence over the embodiment. A substantial amount of an interaction's embodiment is determined by the user themselves: location, time, mood, social setting, and other factors are outside the sphere of the designer's influence.

Different frameworks for guiding the design of the remainder exist. This project undertakes the creation of a tangible interaction with cellular automata.; to make the abstract cellular automata more engaging, the embodiment needs to be brought from the digital to the physical world for both the CA input and output.

Through the aforementioned input device a form of interaction with cellular automata was created. Elements of the interaction could be classified as tangible: the eight rule inputs directly manipulate their digital counterparts. This connection was however not obvious because on the screen, the entire CA pattern was updated and displayed at once, making it difficult to see the individual rules and their characteristics in operation. The Processing sketch used to display the output could be altered to slow down the process and show the individual cell and line iterations, but that would not take the system output out of the digital realm. In order to bring the embodiment of the interaction further into the physical realm, the output would have to follow suit.

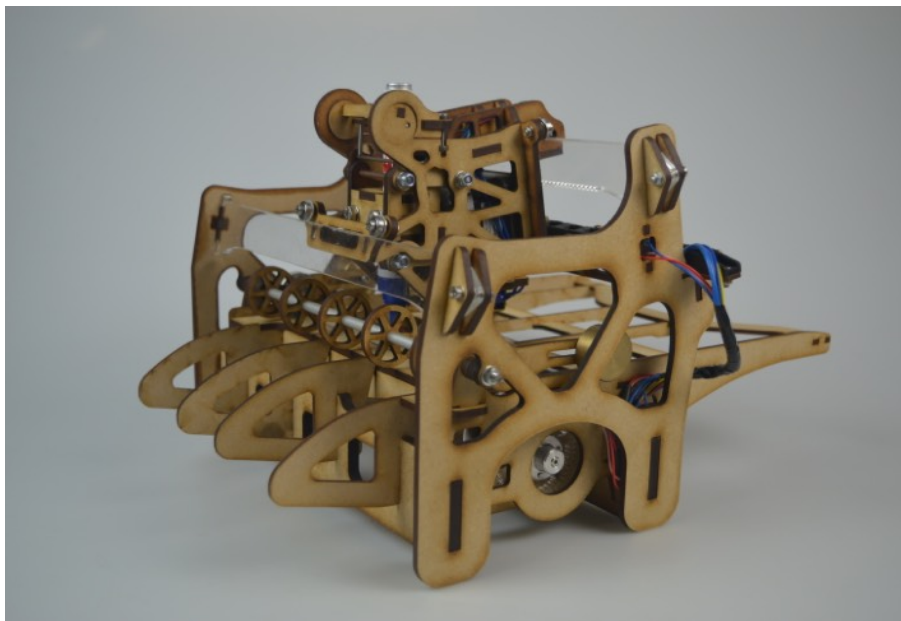


Fig. 4: Plotter designed and programmed to give a physical output to cellular patterns.

A decision was made to design a device with a mix of electronic and mechanical parts capable of creating a physical representation of CA patterns. The choice for this iteration was to create a plotter dedicated to printing CA patterns while enabling user interaction during the process;

figure 4 shows the plotter. A generic marker is operated by a solenoid while two stepper motors position the paper and pen across the two other axes.

2.3 User feedback & feedforward

In addition to the switchboard, serving as a device giving the user direct control over the rules, more interaction modalities were added. In the same vein as the switchboard, an accompanying panel - see fig. 5 - was designed with the following interactables:

- Indication lights of the current CA neighbourhood configuration
- Two-position switch to alter between 3-area and 5-area automata
- Dial to control the process speed.

The indication lights allow additional visual feedback on the process. They enable the user to see how the different rule configurations are applied individually, and follow the contribution each rule makes to the emerging pattern.

Switching between 3-area and 5-area cellular automata is intended to entice the user to try out the different outcome in operation and resulting patterns between the two modes. In this iteration, a random ruleset is generated each time the mode is switched to the 5-area CA. The reasoning behind this decision is that the interaction with eight switches is already challenging to understand. The 5-area CA uses 32 rules - having that many switches would likely be overwhelming, and interaction would become somewhat haphazard experimentation rather than a concerted effort. Later iterations can deal with the larger sized automata.

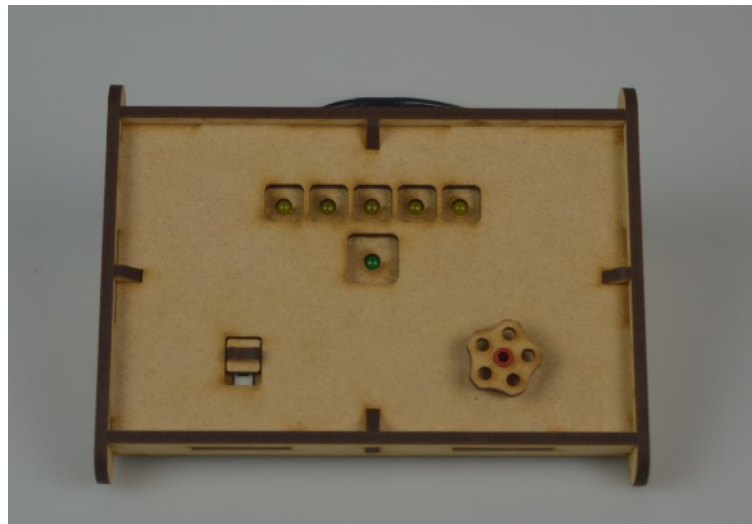


Fig. 5: User in/output in addition to the rule state switches.

A time component is often a part of interaction frameworks [7]. In tangible products, unity of location, direction, modality, and time are described as contributing to the coupling between user input and output. A time component can also influence the experience in a different way: *“Yet art forms with a strong temporal component (...) show that aesthetic experiences are built (...) on how the expression develops in a performance over time.”* [8]

The user is given control over the process speed as the operation of cellular automata have a temporal component. While each individual cell state is determined, the user can slow down the process to gain a better understanding of each rule and the interaction between rules. To see how the rule configuration builds up over many iterations, the process can be accelerated to see the bigger picture.

2.4 Improving overall interaction quality

The first version of the plotter proved to work, but was not reliable enough. A redesign was made for an exhibition during the Maker Faire Eindhoven. The second iteration of the plotter allowed for more precise control over the size of the dots placed on the paper, faster operation due to improved stiffness of the construction and a better presentation in general. A visual comparison of both versions can be found in figures 6 and 7.

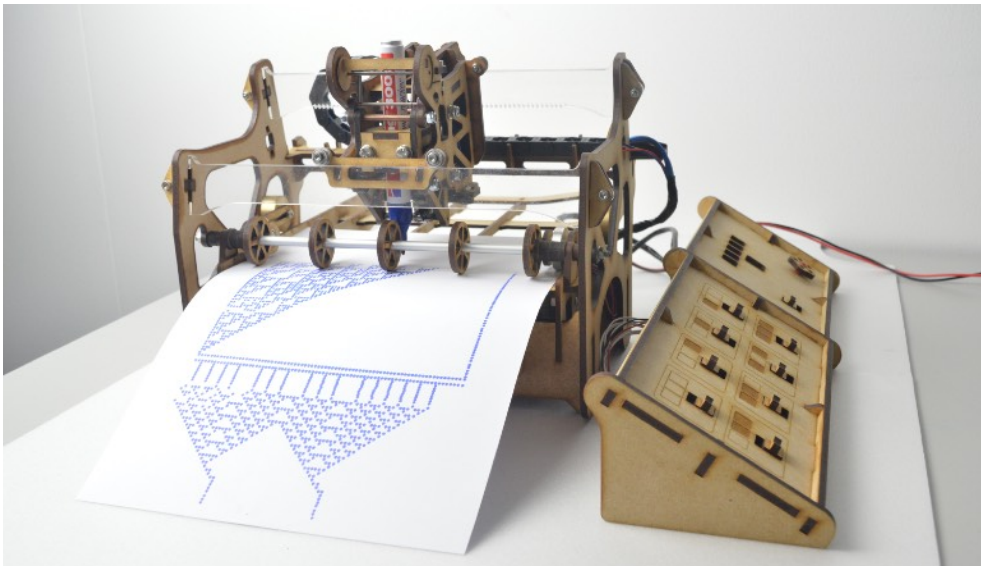
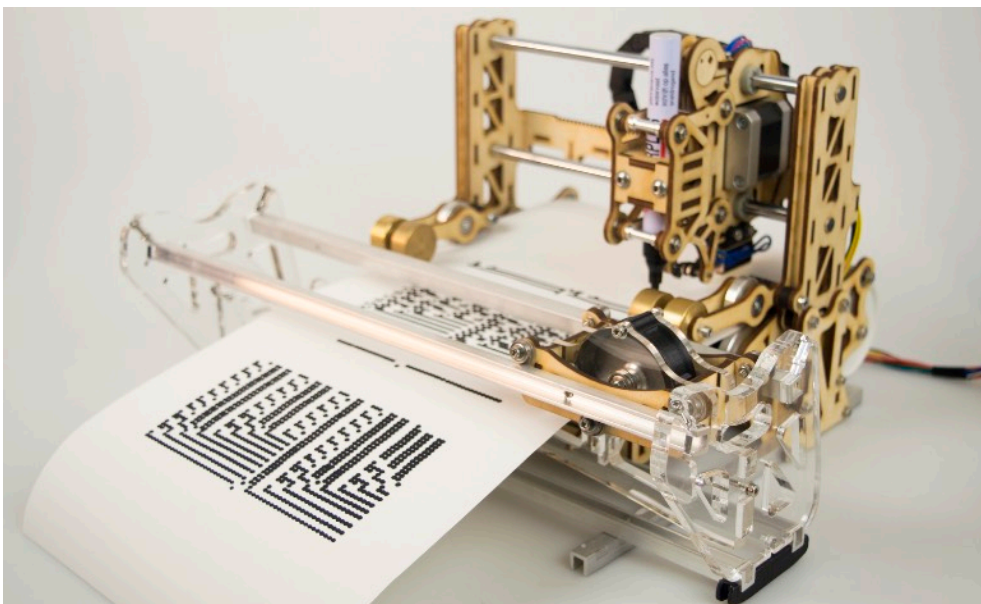


Fig. 6, 7: The first and second iteration of the cellular plotter.



During the exhibition of the second iteration at the Maker Faire Eindhoven, it became clear that the project had potential and at the same time needed improvement, especially on the interaction side. Visitors were generally interested in the machine as well as the patterns, showing this combination of mathematics and technology has the ability to interest or even captivate both young and old visitors. It also showed the working of cellular automata was not necessarily clarified by the interaction, only what their output patterns are like.

The most important remark made by users was their expectation of an immediate impact when changing the automaton rules. Another important observation was that the additional feedback and controls did not necessarily improve the user's understanding of how cellular automata operate. On the contrary, the flashing lights were seen as a nice distraction, but not contributing to their understanding of cellular automata without additional explanation. Switching between the 3 and 5 area automata also proved confusing as it takes some time for a new pattern to be take shape; there was too much of a disjunction between providing input and seeing output.

2.5 User interface for a large number of settings

Switching each individual rule as done with the elementary automaton does not translate well to automata with increased neighbourhood sizes; the switchboard with eight elements already proved to contain unpredictable or surprising results.

Taking into account the context of a museum, the 256 patterns offered by the elementary cellular automata are simply not numerous enough to provide sufficient variation for the amount of guests. Increasing the neighbourhood size to the next logical size of 5 suddenly solves this problem by offering over four billion different patterns with the comparatively low, four-fold increase in the number of rules.

From the observations of users interacting with the switchboard for the elementary CA, it didn't seem to be feasible to extrapolate this concept to the larger CA. A board containing 32 switches would most likely devolve to an interaction without meaning; research into interaction design within this context recommends taking a different approach.

Instead, an interaction was created using fewer controls. As an exploration a prototype was designed that contains three potentiometers and two switches. The analog to digital converter in Arduino boards is an 8-bit device, meaning it has a resolution of 1024 values. Combining the read-outs of three such potentiometers and two switches gives the exact amount of patterns that can be generated by a cellular automaton of neighbourhood size 5 while using five distinct settings.

$$2^{32} = 1024 * 1024 * 1024 * 4$$

A preview of the currently selected pattern is shown on an LCD, allowing users to scroll through the nearly endless variations; this immediate feedback is included to increase engagement through responsiveness.

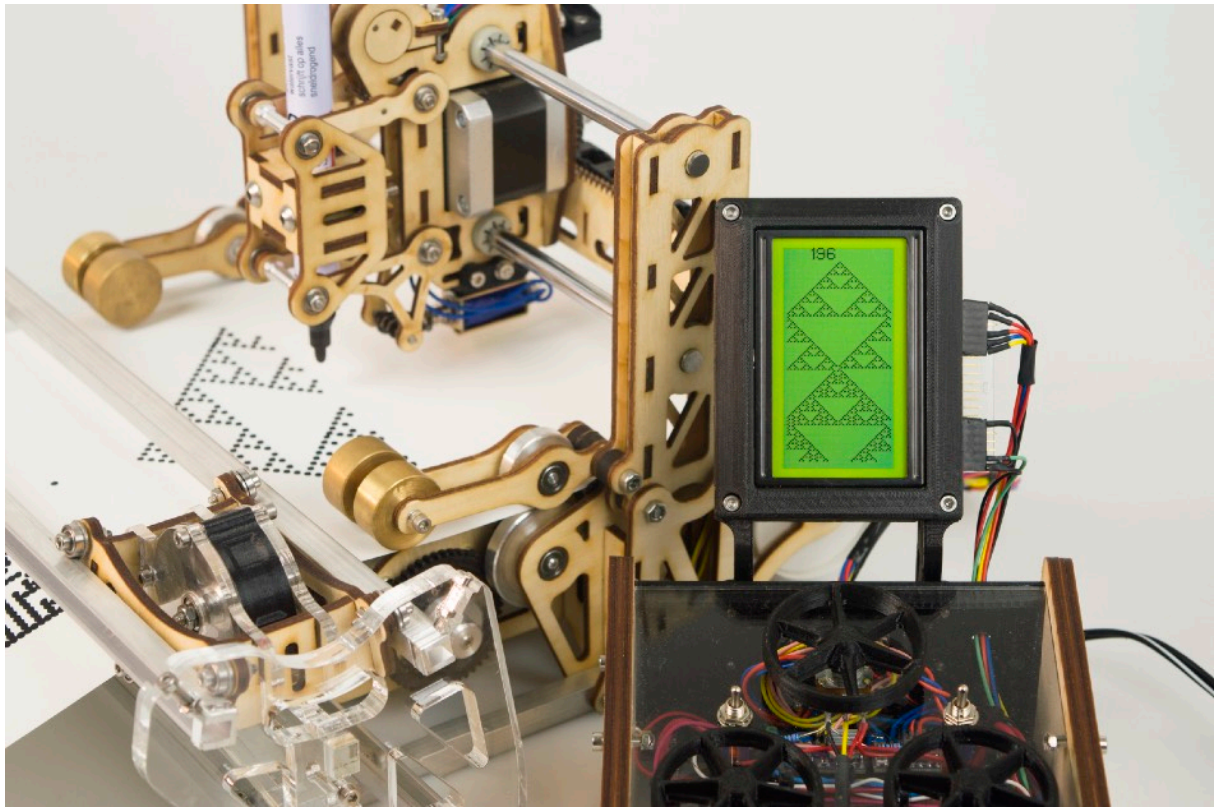


Fig. 8: First iteration of an interaction with size 5 cellular automata.

This iteration of the project was exhibited during the Dutch Design Week; two modifications were made to the plotter. Instead of individual sheets of paper, the machine is fed by a roll of paper, making the machine more suitable for unattended expositions. Sections of paper can be cut off; this addition was made to give visitors the opportunity to take a souvenir of their experience.

3.1 Interaction design for museums

A non-exhaustive list of recommendations for interaction design within the context of a museum is given below. As the field of interaction design deals with sometimes subjective or hard to measure parameters, there is some disagreement on the best practices across different researches. Interacting with an artefact in a museum can be described as a sequence of steps, each with their particular recommendations. The final interaction design for this project is based on the previous iterations and these sources, arranged into sequences.

3.1.1 Trigger curiosity

One of the primary goals of an exhibit is attracting visitors. A sense of curiosity increases the likelihood a visitor engages with the exhibit [9]. If an exhibit does not invite visitors to further investigate, it can't be successful within the context of a science museum.

What constitutes a visually attractive exhibition differs across cultures and individuals; in order to make the object's attraction universal one can try to find a common ground, or one

can make the decision to tailor their design to a specific user group. For example Hornecker and Stifter [10] recognise that older age groups have an interest in objects that evoke a nostalgic feeling, whereas the younger generation is more interested by an opportunity to play a game. Museums that promote technology among children will often have parents accompanying their children, so it makes sense in this context to create a design that appeals to both age groups.

One of Djajadiningrat's guidelines for interaction design[11] states "Don't hide, don't represent: show.", which is particularly applicable within a technology museum. Functional parts should be celebrated; the design of the plotter tries to adhere to this principle by being as transparent as possible about its working. This can be interpreted as an agreement with Simondon [12] who proposed the term techno-aesthetics for the beauty in forms or structures that are designed primarily from an engineer's perspective. Lattice bridges for example derive their structure from formulas describing loads and stresses instead of aesthetic considerations, but as it turns out this method of design has its own aesthetic merits. This design methodology is arguably more universal in its appeal; it also fits well within the theme of creating an interaction with a mathematical principle.

3.1.2 Engage in interaction

After the initial attraction visitors should be invited or persuaded to interact with the device. A classical approach would be to make use of clear affordances as popularised by Norman [13], something Djajadiningrat contradicts by proposing the affordances to be replaced by 'irresistables'. This step is strongly related to the first and sets apart art made purely to be thought-provoking and artefacts that offer an (educational) interaction. Djajadiningrat further argues for beauty in interaction and not in appearance. One could argue that beauty in appearance contributes in part to the 'irresistible' factor - however it's clear the interaction should be attractive in its own right to keep visitors engaged. The first few moments should provide incentive to continue or to capture the attention by offering a rich interaction instead of pressing buttons. Ease of use should take a backseat to enjoyment of the experience.

Giving immediate or direct feedback to the user is paramount; already during the Maker Faire exhibition this was noted as users expected an immediately visible effect when changing the automaton rules, and this was confirmed during the exhibition at the Dutch Design Week. Initial versions of the software only updated the LCD after a line was completely printed (for archaic reasons) and this turned away a substantial part of visitors who got the impression their input did not have an effect. Users were much more likely to try out different settings once their input was immediately processed and shown on the LCD.

3.1.3 Create experience

Once a visitor's interest is piqued, a longer interaction can be encouraged in different ways. Offering openings for their own creativity, following a story or narrative, and sharing ideas keep visitors engaged. Supporting information can be employed, but research recommends avoiding labels and large amounts of text as much as possible and instead design more around objects and artefacts. Enabling social interaction is also recommended as most museum visitors arrive in groups; visitors that are eager to learn more can achieve this goal by

collaboration. Accommodating groups should not exclude visitors who interact by themselves however.

3.1.4 Closure

At some point the interaction will end, either because the user loses interest or the interaction scenario or narrative comes to a close. In the latter case users might choose to restart the interaction, perhaps with the intention to achieve a different outcome.

Interaction designers have the opportunity to define an end point or keep an open end, leaving it up to the user to decide on a moment to move on.

Within this design, a choice for an open end makes sense considering the context of free discovery. Had the design been made for a workshop or elective, it would be better to define a narrative or scenario and design the interaction with a clearly defined learning goal in mind.

After leaving, the visitor's experience becomes a memory that makes up part of the museum visit. Souvenirs can be offered in the gift shop or at individual exhibits. The latter works well when visitors can personalise the output of the exhibit - in this case, visitors are encouraged to take a piece of the paper they personalised.

4.1 Final interface

The final iteration of the user interface with the cellular pattern plotter combines experiences with the previous iterations and available literature. The design encompasses cellular automata with neighbourhood 5, and makes use of objects rather than switches or dials. The objects can be manipulated and represent the different combinations of cells that form the input of each iteration of a cellular automaton. Collaboration and social interaction is enabled, although an increase in scale would emphasise this aspect.

Each combination of states, a maximum of 32 in total, relates to a rule that can be switched 'on' or 'off' through an action inspired on the rich interaction paradigm [14]. The resulting pattern is updated on an LCD; when the user is satisfied with their setting of the rules, they can send it to the plotter and see the pattern emerge in a physical sense, taking home the printed version if they wish to do so.

Three distinct modes of operation are present in the interface:

- Altering the ruleset
- Printing the ruleset
- Transitioning between setting and printing

Figure 9 shows the final controller; a total of ten black and white tokens can be placed in the receptacle and scanned by pushing down an array of five infrared sensors that determine the current rule configuration. Holding the array in place for a short amount of time switches the rule state between on and off (see fig. 10). When a rule state is changed the pattern is updated on the LCD. This immediate feedback shows the rule has been read by the system, even if changing that particular rule has no effect on the pattern.

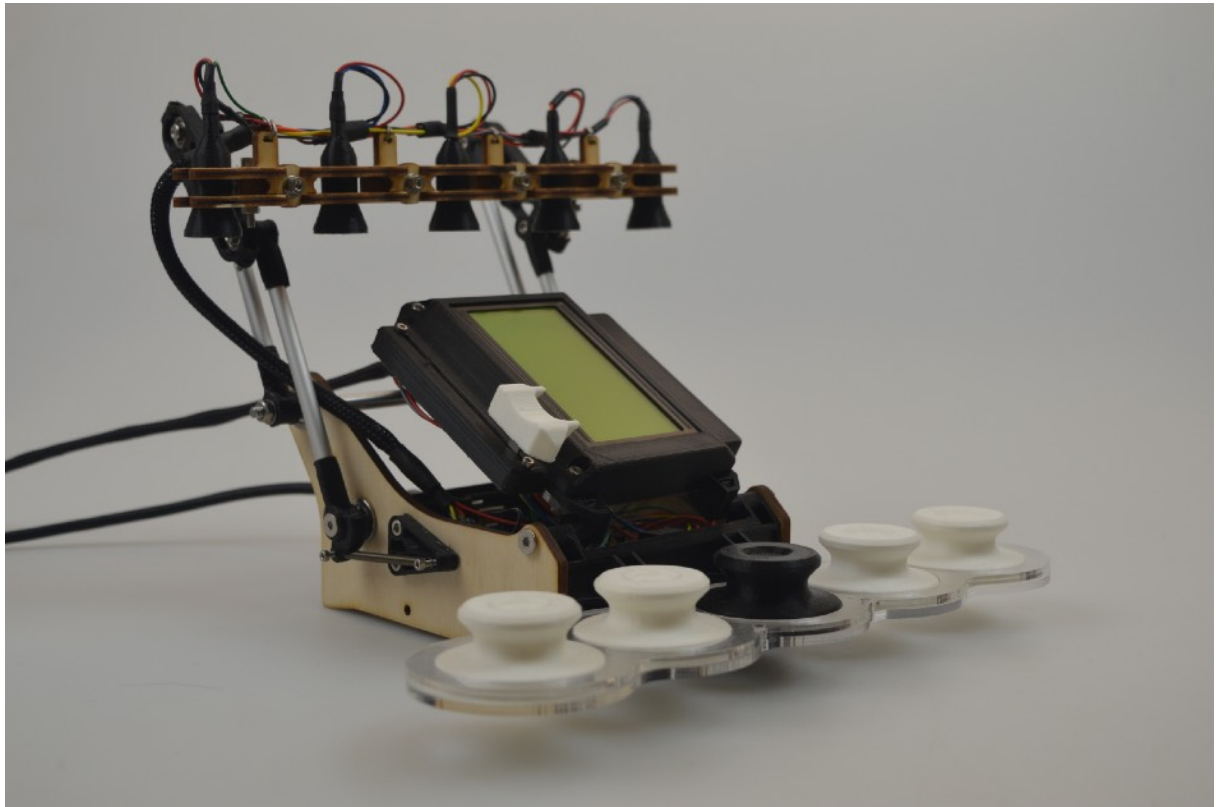


Fig. 9: Final iteration of the controller for interaction with cellular automata.

When the user is satisfied with the pattern they can instruct the plotter to print it on paper by pushing a knob mounted on a sliding potentiometer. Moving the knob upwards pushes the pattern out of the screen and into the printer; a section of whitespace is left between each printed pattern.

In previous iterations the ruleset was printed as long as no changes were made; following feedback from user tests the pattern matches exactly with what is shown on the LCD - after 124 lines the process is stopped. Users can cancel the printing and retract the pattern at any point by moving the slider back down: the pattern reappears on screen and can be altered

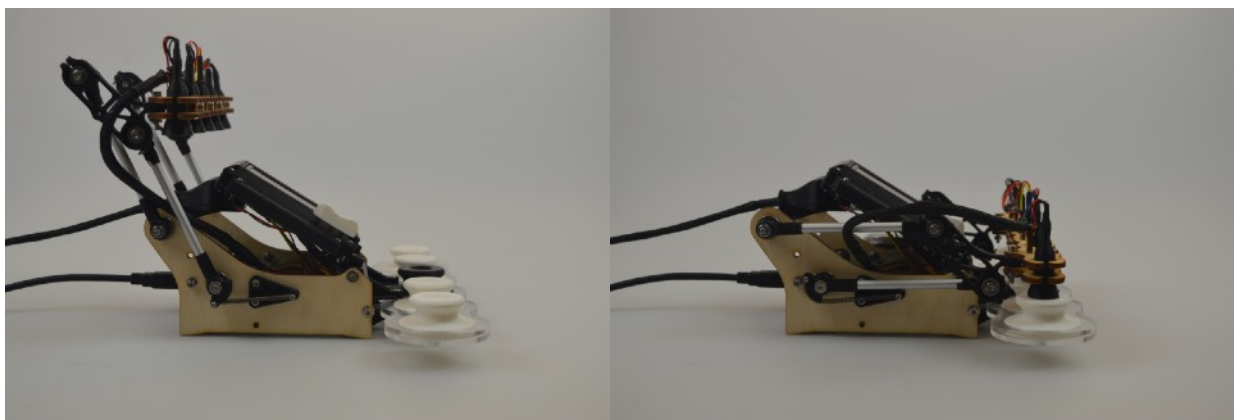


Fig. 10: The configuration of tokens is scanned by holding down the infrared sensors.

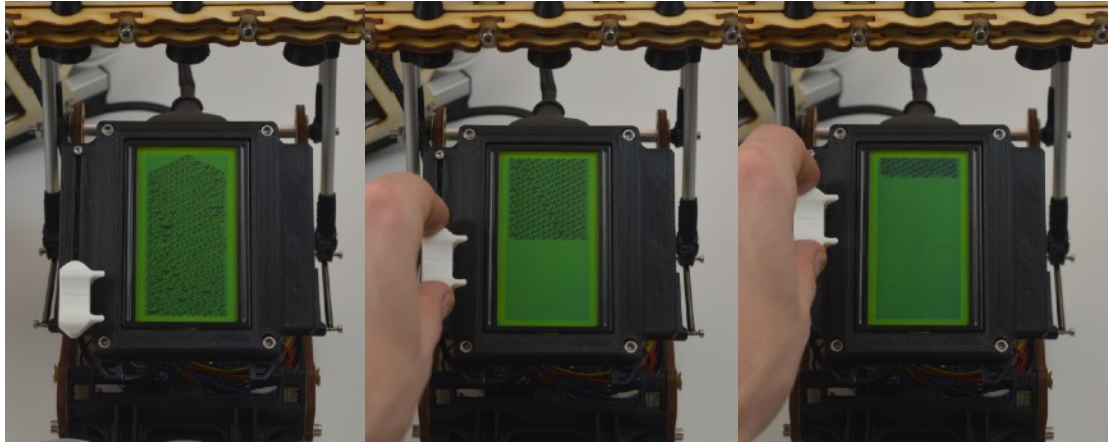


Fig. 11: photographs showing the transition from altering the ruleset to printing.

again by arranging and scanning tokens when the knob is fully lowered - fig. 11 shows the transitioning of the pattern between altering and printing. Figure 12 shows the arrangement of tokens to alter specific rules.

4.2 Conclusions

This projects attempts to create a meaningful interaction with cellular automata with the goal of increasing interest in STEM-related disciplines, in particular the elements of mathematics and engineering.

Different frameworks for interaction design are incorporated throughout iterations of the interface, starting out with a simple tangible interaction where users can directly manipulate the eight rules of an elementary cellular automaton. This iteration showed the need for a physical embodiment of the output, resulting in the creation of a dedicated plotter. In an attempt to make the automata clearer to the users, more feedback elements were added in the shape of rule indication lights and a control over the process speed, but trying these functions out with users lead to the conclusion that more feedback does not necessarily mean improved conceptual models.

These experiences lead to an iteration for slightly larger cellular automata with fewer controls.

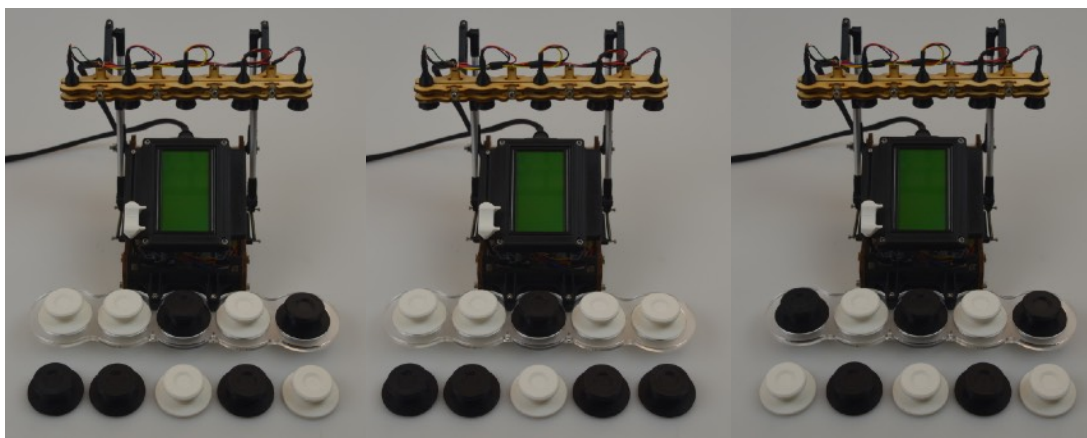


Fig. 12: photographs showing arrangement of tokens - each of the 32 possible arrangements alters a rule of the automaton.

Users had indicated their expectation of receiving immediate feedback upon altering the ruleset; therefore an LCD was included to show the pattern resulting from iterating the current ruleset. Bluntly stated the version discussed in section 2.5 is a glorified scrolling function; the final interaction would have to be more meaningful as users were observed whizzing past many patterns without spending effort in trying to understand how the patterns are generated.

The final iteration combines experience from earlier explorations and a final literature research on interaction frameworks and research directed towards the context of a museum. Tangible interaction still forms the base of the interaction, but following research recommendations the switches operating the rule settings have been replaced by objects representing the automaton rules. In this way the 5-area automaton can be controlled without resorting to a switchboard containing 32 interaction modalities. Scanning the tokens is done in a way inspired by rich interaction - instead of pressing a button, the construction hints towards its functionality by transparently displaying the hinges and the resulting freedom of movement of the sensors. Another control from this framework is the transition slider: the wiring harness is located at the top of the screen, suggesting to the user that sliding the knob upwards transfers the data to the plotter, as if pushing the pattern from the screen into the printer.

From conversations with users, the most important feedback is that an interaction needs to have (nearly) immediate feedback on input; an unresponsive system is abandoned rather quickly. Printing the patterns has certain 'hypnotising' or 'fascinating' properties, lending credibility to the idea of placing a version of this prototype in a museum for science and technology. The resulting product shows the promise for object-based interactions with mathematical principles; the ten tokens can be combined to create over four billion different patterns, a compact and accessible way to navigate a large space of possibilities.

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