Learning how to use the Ancient Chinese Abacus through Tangible Interaction

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ABSTRACT

Our project deals with how to utilize concepts of tangible interaction to design an interactive game with the ancient Chinese abacus, as featured in the Cyrus Tang Hall of China at the Field Museum in Chicago. Our primary learning goal for this exhibit is for an visitor to gain enough familiarity with the abacus to be able to represent numbers. Based on related work in eliciting engagement at museum exhibits, we argue for a tangible model of the abacus in our design, which we believe will help visitors grasp the concepts in arithmetic through abacus number representation as well as push them to appreciate the ancient Chinese culture.

Author Keywords

Abacus; Tangible Interaction; Collaborative Museum Exhibit; Arithmetic; Image Processing.

INTRODUCTION AND MOTIVATION

Calculation in modern times is a simple process we usually take for granted. We can easily type numbers and operations into a calculator and have a result return instantly. While the people of ancient China did not have this luxury, they did have the abacus, a sophisticated device that helped people perform not only simple operations like counting and addition, but also more complicated ones such as multiplication, division, and even cube roots. Its invention in 200 BC played a pivotal role in providing Chinese households and businesses, especially with the expansion of trade along the Silk Road. The ability to quickly perform arithmetic with the abacus made keeping track of transactions and personal finances much easier than earlier alternatives such as piles of stones or sticks.

The abacus was revolutionary for its time, but it has also proved itself to be useful long past its prime on the Silk Road, as it is a useful tool for learning the abstract concepts of arithmetic. With this historical background in mind, we decided to create a project utilizing the affordances provided by the abacus to create an interactive exhibit modeling the arithmetic representations possible on the device and showcasing the context of the abacus in ancient China. A model of the ancient Chinese abacus, our inspiration for this project, can be found in the Cyrus Tang Hall of China at the Field Museum in Chicago.

The exhibit will include a physical abacus accompanied by a screen displaying an unopened treasure chest and a code consisting of numbers represented in Chinese character form. The objective is to crack the code by configuring the abacus to the numbers in the code. A hint is provided in the form of a pool of possible numbers in the code. Once the exhibit system detects that one of the numbers contained in the code has been cracked, the corresponding Arabic numeral is displayed above to the character. The code will include a mix of both single-digit numbers, which are guessed and used to puzzle out the larger numbers whose digits contain them. Once the visitor has cracked the entire code, the treasure chest opens.

Our primary learning goal for this exhibit is for an exhibit visitor to gain enough familiarity with the abacus to be able to represent numbers. People today generally perceive the abacus as a difficult tool because there is a lack of familiar Arabic numeral representations present on the device, but we feel that this conclusion is unjustified. While the abacus can initially seem intimidating to new users due to its unfamiliar construction, it is surprisingly easy to learn with some minimal instruction and interaction. We want visitors to overcome their initial apprehension and learn by doing while interacting with a fun and approachable exhibit. We hope that visitors will walk away from the exhibit with an appreciation of the simple yet effective design of the abacus, particularly in the idea of place value, in which a number's value depends on its position.

Our secondary goal is for exhibit visitors to become acquainted with the Chinese characters that represent numbers. People unfamiliar with the Chinese language can feel intimidated by the thousands of characters that the written language consists of. By presenting a small but essential set of Chinese characters, we hope to make the Chinese language feel more familiar and accessible to visitors, who may become interested in learning more Chinese in a different setting.

In this paper, we argue that a tangible model of the abacus is essential to achieving our primary learning objective of using an abacus to represent numbers. We believe it is important to make this interaction tangible because it makes the process of calculation a physical one instead of virtual, like we experience now with digital calculators. An important concept in number representation is the idea of place value, in which the value of a digit depends on its place within a number. This abstract concept is represented very concretely in the abacus, whose rows of beads correspond to powers of ten. By presenting the idea of number representation and place value in a way that is not only concrete but also physical, i.e. via a tangible device like the abacus, exhibit visitors can learn number representation through sensory-motor interactions that tie into cognitive outcomes. Furthermore, while we do not emphasize the history of the abacus in our exhibit, we do emphasize the tangibility of the abacus, which allows users to feel the beads and helps them imagine themselves in the world of ancient China.

RELATED WORK

We will first discuss how who interacts with collaborative museum exhibits and why these exhibits have achieved success in museums before diving more deeply into how the abacus has been used in learning contexts and how this has contributed to our design.

In order to design our project in such a way to make people have a fruitful experience, it was necessary to see what kind of people our tangible exhibit would attract. McManus (1987) discussed four common types of museumgoers, groups with children, singletons, couples, and adult groups. Her experiments focused on the exhibits that attract certain types of groups by analyzing how long groups stayed at an exhibit, how much they interacted with the exhibit itself, and how much they spoke amongst each other while at the exhibit. Her findings suggested that interactive exhibits work best with groups with children, because children rarely read text and are more engrossed by interactive exhibits they can play with. They also work well with adult groups, as adults value the social interaction they have with their peers when they interact with exhibits together.

For an exhibit to effectively convey information, it must be engaging and interesting to the visitor each step along the way in order to prevent them from losing focus. Allen (2004) discusses how museum exhibit designers first achieved this balance through the Exploratorium based design, or hands-on exhibits. While Exploratorium based design promotes self-driven learning and personal engagement with the phenomenon being studied, it also has the potential to exhaust mental faculties at a quicker rate than exhibits that are less mentally demanding. At any given time at a museum, multiple exhibits compete for a visitor's attention, and it becomes easy for a visitor to lose focus on the current exhibit and move onto a different one without having absorbed what the exhibit was meant to portray. To prevent such mental fatigue, Allen suggests that museum exhibits must emphasize ease of access through utilizing design principles such as use of affordances and interactivity.

We now must understand how the affordances of the abacus can help children learn the abstract concepts of mathematics and how to utilize this in the context of a museum. Unfortunately, since the invention of the modern-day calculator, there have not been many recent articles that address the advantages of using the abacus in learning environments. Spitzer (1942) focuses on how the usage of the abacus in learning environments highlights how the abacus helps to convert abstract mathematical concepts into a concrete visualization. He argues that the abacus has five characteristic that allow children to gain a more explicit understanding of arithmetic, which include the idea of the place value, the concept of collection, and the function of zero. Elaborating upon the last characteristic, if elementary-aged children are asked to explain the function of the placeholder number 0, they would probably not be able to coherently explain it, but if they are shown the number 107, they most likely would not have trouble understanding the function of 0 in that number (Spitzer, 450).

Furthermore, our abacus interaction incorporates elements similar to videogames since the participants to our exhibit, or the "players", are asked to crack a numerical code through arranging numbers on the abacus. Our design is goal oriented, utilizing an imaginary scenario (cracking the emperor's code) and a challenge (representing the numbers on the abacus) in order to inspire interest and engagement. Griffith (2002) highlights the educational benefits of video games in his paper discussing their use for educational purposes. Video games tend to attract participation across several demographics, including age, gender, ethnicity, and educational status. Video games also serve as useful tools for providing immediate feedback, reinforcing intellectual habits, and keeping records of behavioral change, and therefore, the player's learning. Perhaps most relevant to our interactive design, videogames are often stimulating for the player, therefore making it easier to maintain the player's attention for longer periods of time. When utilized for educational purposes, they can serve as an effective means to stimulate learning.

THEORETICAL BACKGROUND

Based on McManus's findings that interactive exhibits work best with groups containing children, we decided that we want to target groups with children and adult groups through hands on interaction with the abacus. This is a large audience base, as 75% of all museumgoers are groups (McManus, 1987). We will therefore create an interface that has simple, child-friendly graphics that will encourage younger museum goers to approach our exhibit, but also an intriguing puzzle that will draw adults into the exhibit as well.

Taking Allen's suggestion that museum exhibits emphasize ease of access through affordances and interactivity, we will emphasize the main affordance of the abacus: the ability to move its beads. The beads make a satisfying clack when moved and can be shuffled about quickly and easily, which has the advantage of drawing in groups with children. This physicality of the beads will also provide a concrete representation of arithmetic concepts by grounding them into a physical representation. Our design will also have a simple code-breaking game on the screen that responds in real-time to the museumgoers' actions to the abacus, which promotes the interactivity of the exhibit.

Drawing upon Spitzer's identification of the place value as a key idea in arithmetic, we design our exhibit so that children can approach it with little to no experience with the abacus but still quickly learn how the device functions. After several interactions, they will have a richer understanding of arithmetic. Through the challenge of representing larger numbers, they may even come to understand the motivations for why the people of ancient China chose to represent and calculate numbers with the abacus for so many centuries.

Lastly, our exhibit incorporates a game-like scenario where the participant is given the task of cracking a code through arranging particular numbers on the abacus. The computer provides immediate feedback for the current number represented on the abacus. As players attempt the challenge, they can utilize the visual feedback in order to guide them towards representing the candidate numbers for cracking the code. Even without any prior knowledge of the abacus, one can move beads around to see how the numerical representation of the abacus changes with each action, allowing for the player to learn how the abacus functions as they play the game. Potential participants will hopefully be drawn by the fact that our tangible interaction exploits the characteristics of video games that make them popular among many demographics. While many interactive challenges run the risk of feeling daunting, we believe that the majority of individuals will not feel daunted by our task by not imposing any time restriction or competition.

DESIGN

Our initial design imagined the museum goer as a merchant on the Silk Road, where the abacus was popularized in ancient China. The museum goer, referred to from now on as the user, would then be in charge of calculating transactions on the abacus and keeping the records of the merchant's sales. However, this design had too large of a learning curve, as there was addition, subtraction, and multiplication involved, and would have difficulty keeping people's attention because of the advanced mathematics.

Our next design simplified the interaction between the user and the abacus by creating a code-breaking game (described below). In order to incorporate collaboration and attract our target demographic of adult groups and groups with children, we wanted to have two abaci on two wooden mounts with mounted webcams that connected to a web program. However, for our prototype, we only have one abacus and webcam mount.

Our current design is a code-breaking game connected to an abacus and webcam on a wooden mount. The game involves cracking a code consisting of four independent numbers in Chinese character form. A list consisting of numbers will give users hints on which numbers to guess. All characters represented in the code will be contained in this hint list, but not all numbers in the hint list are guaranteed to be in the code to be cracked. The code is cracked when each of the numbers in the code has been configured on the abacus. If the number that the abacus currently represents is in the hint list, that number will be crossed out in the list. If that number is also contained in the code, then the corresponding number will appear above the Chinese representation contained in the code. This interaction will give players an introduction to Chinese numerical characters and help make connections between Chinese characters and the numbers they represent. Another main component of our game is displaying immediate feedback to players of the current numerical representation of each respective abacus. This immediate feedback will allow players to learn as they play and dynamically pick up how to use the abacus.

The webcam on the mount is connected to a computer program. The program works as follows: A continuous video stream of the abacus is monitored throughout the running of the program, which was developed using the OpenCV Python SDK, an image processing library that can extract useful data from the pixels on screen. Upon initialization, when the abacus represents the number zero, the program draws a line through the center of each bead. Each line created upon initialization corresponds to the location of each bead when the abacus represents zero. Next, when the user moves the beads around to make a new configuration, we can see which horizontal lines still have beads overlapping them in the image by calculating the average color of the center line. If the average color value of the image at the location of each line exceeds a certain threshold, then there is a bead at the location of the horizontal line. Furthermore, knowing where the beads are allows the program to know what number the abacus currently represents.

After having the ability to find where each bead is located, we use this information to calculate the current numerical representation of the abacus. To make this calculation, we found the maximum numerical value the abacus can represent. In our case, this is 16 trillion, when all beads are oriented towards the middle, horizontal rod. Since our program first assumes that all beads are oriented towards the middle rod, we look for beads that are out of place, and subtract out a missing bead's value from the sum when found. After all beads are accounted for, the updated sum is collected and sent over to the client-side AngularJS application using a library called Pusher. Pusher is used to provide a real-time data feed from the server-side to the client-side through the use of a Pusher channel. Even though traditional applications are designed using RESTful API principles where clients initiate communication to a business logic server via HTTP, we felt that this type of design was not appropriate for our needs. Building a typical client-server architecture would require a constant stream of HTTP requests being sent out from the AngularJS event loop, which is not only extremely inefficient for the client-side, but also bombards our server with unnecessary requests. Pusher utilizes a different design pattern, where instead of the client-side initiating communication, the server-side initiates, and "pushes" updates to the client-side when certain events occur. For our case, every time our sum is fully updated after all beads are processed, the final sum is passed through a Pusher channel, which is bound to a $scope variable in the AngularJS application. This allows us to display the current representation of the abacus to users in nearly real-time, as updates are almost constantly being pushed by the server. Putting all of this together gives us the immediate, dynamic feedback which we believe is key to our exhibit.

CURRENT IMPLENTATION

Link to demo video: https://drive.google.com/file/d/0B6S-AG3LaPgWb2tTZ2wzT3MxQk0/view?usp=sharing

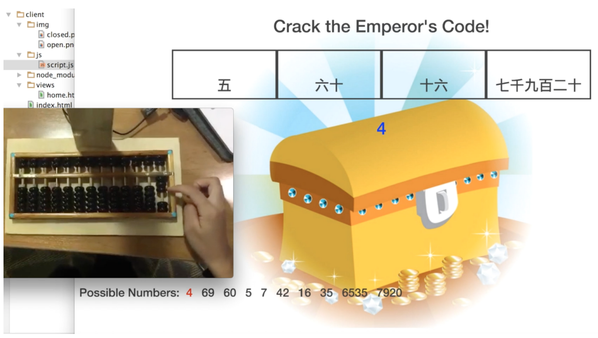

Figure 1: Design of the Code Cracking Game with the Abacus

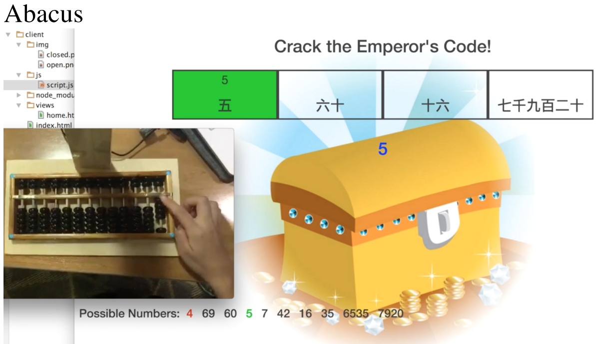

Figure 2: When one part of the code is cracked

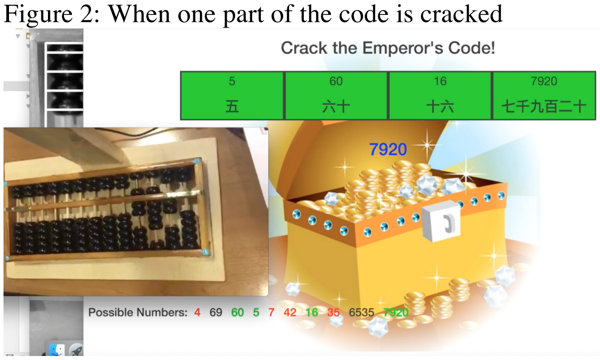

Figure 3: When the whole code is cracked (treasure chest is now open).

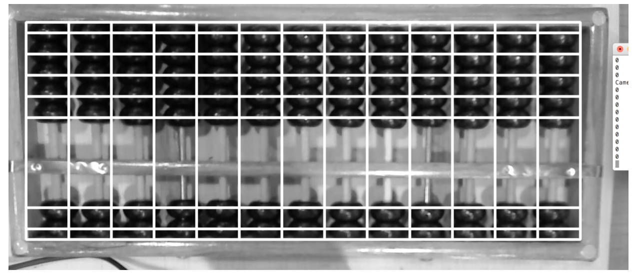

Figure 4: Abacus representing 0

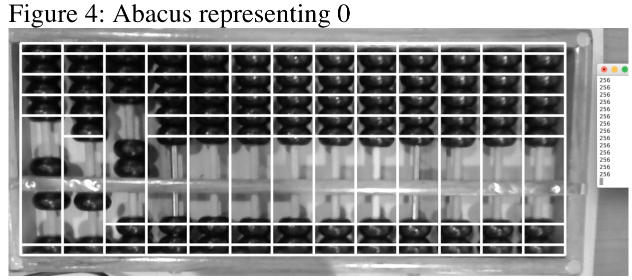

Figure 5: Abacus representing 256

CONCLUSION AND FUTURE WORK

We believe that the tangible nature of our abacus exhibit is essential to our learning objectives of gaining experience in using an abacus to represent numbers and growing more familiar with Chinese characters. The physicality of the beads—touching them, sliding them, hearing them slide around and clack against each other—provides a sensorimotor experience that visitors can then connect with cognitive processes. The affordances of the abacus, which has a row of beads

In future work, we would like to extend our design to accommodate multiple exhibit visitors. Heath (2005) identifies a major problem within computer-based interactive exhibits in science museums: highly structured systems that ask the user to achieve a particular goal often do not provide opportunities for other nearby visitors to participate. He argues that it is inevitable that other visitors will arrive at an exhibit at a time when someone is already interacting with it. Therefore, it makes sense to design an exhibit so that these newcomers can participate in the interaction rather than simply queueing and observing. In future work, we would like to design our exhibit in a way that can facilitate not only individual interactions but collaboration as well: an individual can interact with a single abacus to crack the code, but multiple people can also work together using both abacuses to crack the same code.

Furthermore, we would like to evaluate our design arguments that we provide visitors with a more engaging and effective learning experience by 1) using a tangible abacus, as opposed to a digital, non-tangible abacus, and 2) using a more exploratory exhibit design, in which the visitor starts by playing around with the abacus on their own rather than by following instructions or a tutorial.

We propose testing the first design argument by conducting a between-subject user study in which each participant is presented with the code-breaking task of our current design. The experimental group will interact with this task using the physical abacus and screen displaying the number. The control group will interact with a digital abacus on a screen rather than a physical one. In this study, we will measure three things: rate of learning, by timing how long it takes to break the code; visitor enjoyment, by asking people to rate their enjoyment of the exhibit on a 5-point Likert scale; and engagement, by asking people to rate their likelihood of seeking out more opportunities to learn about abacus use and to learn about Chinese culture.

To test the second design argument, we will conduct a second between-subject user study in which each participant is presented with the same code-breaking task as above. The experimental group will interact with the task using the physical abacus and screen displaying the number. The control group will interact with a physical abacus and a tutorial, instead of simply having a screen that displays the current numerical representation of the abacus. By providing a tutorial that walks the player through the task of cracking the code, we impose more restrictions on the interaction while gaining the benefit of making the task more clear. In this second study, we will measure the same metrics as in the first.

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