SeeMore: An Interactive Kinetic Sculpture Designed to Teach Parallel Computational Thinking

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Abstract

Parallel computing is generally perceived to be difficult topic to understand and learn. This paper presents a design case study that was conceptualized and implemented to introduce non-computational savvy audience (e.g. students, K-12, senators, elderly, etc.) to the concepts of parallel computational thinking. In order to visualize and better comprehend the data transmission mechanism and algorithmic patterns of parallel computing, a kinetic computing sculpture comprising of a functional cluster of Raspberry Pi computers has been built by an interdisciplinary group of researchers. To evaluate users' learning experience, a focus group interview with high school students was conducted. Data from the study reveal that students found the sculpture an engaging and effective visual artifact that illustrated parallel computing patterns. After interacting with the sculpture, the participants were able to explain parallel computing to other participants and correctly answer all assessment related questions.

Introduction

Even though parallel computing forms the backbone of most of the technologies that we use every day, and without parallel computing, most modern scientific discoveries would not exist (e.g. sequencing the human genome, confirmation of the Higgs boson), educating people about parallel computing is hard since it is an extremely abstract topic that requires deep conceptual knowledge. Devices used for parallel computing are often "black boxes" in which the only indication of transmission is through limited external cues (i.e. flashing LED lights or the hum of the system).

In the project discussed in this paper we postulated that if we can provide those who are new to the idea of parallel computing a visual and embodied experience, they would find it easier to comprehend the concept. To translate this idea into a designed object, a kinetic computing sculpture comprising of a functional cluster of Raspberry Pi computers (figure1.) has been built by an interdisciplinary group of researchers.

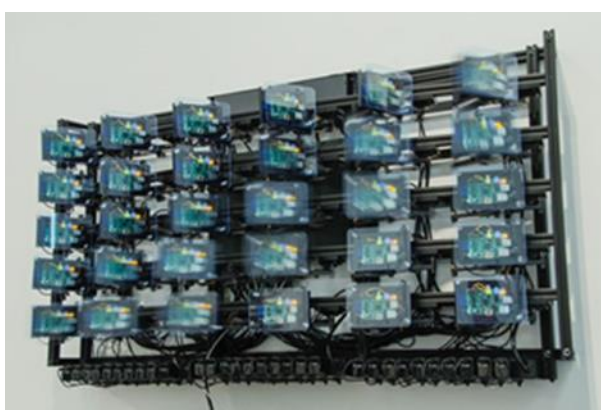


Figure 1. Kinetic sculpture (prototype version consisting 30 Raspberry pi computers), 2014

In this sculpture, each computing device is attached to a compact servo mechanism fitted to an aluminum structure that reacts to both computation and data movement of parallel programs running on the system. The movement of the Raspberry Pi computers corresponds to the underlying computing/data transmission being executed and together these movements emerge as recurring patterns (e.g., wave patterns, butterfly patterns, etc.). These patterns visually demonstrate the underlying algorithmic structures of parallel computing. An interactive touch screen display alongside the sculpture empowers visitors to interactively select and view the effects of various parallel computation choices that computer and computational scientists make every day.

In this paper we provide an overview of the design of the educational exhibit and also share preliminary results of users' learning experiences.

Computational Thinking and Parallel Computing

The pervasive application of computation all around us and its application in almost all our everyday functions have created a need to be able to interact and work with computational technology. In addition to being just users, it has also become important for people to develop the ability to use the computing power at their disposal across different activities. This ability to think and solve a problem using computational concepts and methods has been termed Computational Thinking (CT), and "involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science"[1]. CT is increasingly considered a basic skill required to succeed in the 21st century[2]; similar to the fundamental skills of reading, writing, and arithmetic[1].

CT includes the understanding and use of fundamental computer science concepts [3-5]

- systematic processing of information,
- symbol systems and representations,
- algorithmic notions of flow of control,
- structured problem decomposition (modularizing),
- iterative, recursive and parallel thinking,
- conditional logic,
- abstractions and pattern generalizations (including models and simulations),
- efficiency and performance constraints, and
- debugging and systematic error detection.

Although the usefulness of CT is well established, it is extremely hard to implement its concepts in practice. Computational concepts are considered difficult for novice learners to understand and apply [4, 6]. Similar to other concepts common across the sciences that are inherently abstract and not readily observable (e.g., force, heat), computational concepts are also challenging for students to understand [6, 7]. Even within computer science, some concepts are harder than others as they are more abstract and complex and it is hard to visualize how digits are manipulated; parallel computing is one such concept. In parallel computing, a problem is broken into discrete parts so that it can be solved concurrently[8]. Learning parallel computing involves understanding of a higher level of abstraction somewhat removed from the details of hardware and memory architectures [8, 9]. Thus, parallel computing/programming has the general perception of being difficult to understand and apply. It is generally taught to computer science majors in a single course or as a sequences courses [9]. It is expected that students taking these parallel computing courses already have some basic understanding and experience with computational concepts and programming.

As CT is gaining traction in the educational community, the term parallelization/parallel computing is also being incorporated within general curriculum initiatives. For example, at the K-12 level, the concept of "parallelization" is being introduced to students as they "organize resources to simultaneously carry out tasks to reach a common goal"[10, p. 9]. Suggestive curriculum activities by the Computational Thinking teachers' resources in K-12 are shown in Table1.

Concept	Definition	Grades PK to 2	Grades 3 to 5	Grades 6 to 8	Grades 9 to 12
Parallelization [10, p. 9]	Organize resources to simultaneously carry out tasks to reach a common goal.	Based on a set of criteria, break the class into two groups. Have one group read aloud while the other group provides humming background music. The goal is reached, but the whole is better than the individual parts	Teachers facilitate in planning team project timelines, roles, and assignments and working together to complete components (how do we breakup the tasks, what tasks have to be done sequentially and others simultaneously, check-ins, meeting deadlines?).	Student teams plan production of a video, including script, props, and roles of the team in producing the video. Identify tasks that will be carried out simultaneously, and milestones where they check in, and plan, and put things together	Describe the sequence of activities by each of the armies leading to the Battle of Waterloo. Include both physical activities (e.g., recruit troops) and intellectual activities (e.g., pick troop positions).

Table 1.Suggestive activities for introducing the concept of parallelization in the Computational Thinking teachers resources[10, p. 9]

The activities suggested by the Computational Thinking teachers' resources (Table 1) involve introducing the concept of parallelization, not parallel computing per se. It assumes that students will be in a formal educational setting and that a teacher or facilitator will be present. The activities include introducing students to the broad knowledge of parallelization hoping that the students will be able to make specific connections with parallel computing and to systems that use parallel algorithms. Critically, the activities do not introduce the inherent complexities involved in parallel computing. On the other hand, at the collegiate level, parallel computing is taught within a Computer Science curriculum [11] and require students to have at least some level of programming knowledge. Both the K-12 and the college level approaches of teaching parallelization/parallel computing have been designed keeping a formal educational setting in mind.

Apart from formal settings, informal opportunities e.g. museums, zoos, aquariums, botanical gardens, online resources are also widely considered as environments where one can gain reliable, authentic, and comprehensible presentations of art, history and science objects and ideas [12-15]. These informal institutions of learning are designed to promote understanding, conversation, and positive attitudes about their content [16]. Research studies on learning from museums [12, 15, 17]in particular suggest that interactive exhibits have been particularly effective in intriguing ones interest in science, and engagement in scientific inquiry. The learning that occurs by interacting with such exhibits is considered to be self-motivated, interest driven and contextually relevant[15]. What a visitor learns from an interactive exhibit can be explained in terms of learner's experience with the exhibit, comprehension of the effects, ability to explain and understand the topic being demonstrated etc.[17]. Considering the inherent difficulty in comprehending the concept of parallel computing, an interactive and visually appealing educational exhibit in the form of a kinetic sculpture may facilitate learners to grasp the concept more easily. An interactive exhibit may thus be a tool for learning parallel computing.

Design of the kinetic sculpture

The kinetic sculpture comprising Raspberry Pi computers named '*SeeMore*' is the creation of an interdisciplinary group consisting of computer scientists, educators, and artists. The aim of *SeeMore* is to improve our ability to educate non-computer scientists (e.g. students, K-12, senators, elderly, etc.) as to the importance and sophistication of parallel computation. The transformative approach combines the creation of a parallel or distributed system with mechanisms to visualize computation. The following sections describe the design principles behind the making of *SeeMore*, and the evaluation process.

The principles behind the design of the sculpture

SeeMore is an ongoing collaborative project that melds art and engineering to distill abstract concepts of computer science into a tangible experience. The collaborative brainchild of artists and computer scientists, *SeeMore* transforms the elegance and significance of parallel computation into visual form. The design is built upon the wildly successful Raspberry Pi (RPi), a small, fully functional computer designed at the extremely low cost of $35. The 256-RPi's cylindrical structure is inspired both by early parallel Cray computer designs as well as the fluid dynamic simulations these powerful computers are regularly tasked with calculating. This project translates data movement through a living sculpture that physically represents computation as it propagates and evolves within the computer.

Figure 2. Cray-1 supercomputer,1976

Figure 3. SeeMore's final framework, 2014

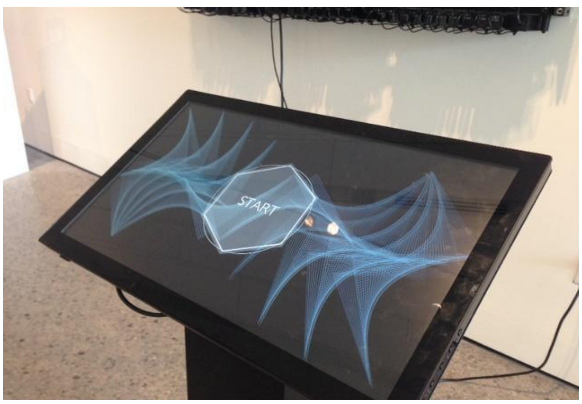
The principles behind the design of the learning experience

According to Miles, Alt, Gosling, Lewis, and Trout, "One of the most active ways of coming to know about things is via the method of interaction. … By the method of interaction, we generate experiences that we can think about and talk about "[18, p. 34-36]. The designed experience of *SeeMore* aligns with the above definition of interaction. In order to help people to perceive parallel computing patterns, the learning experience was aimed to provide interactive ways to know and visualize "parallel computing". The movement of raspberry pi computers and the user interface is intended to provide an interactive learning experience of parallel computing patterns.

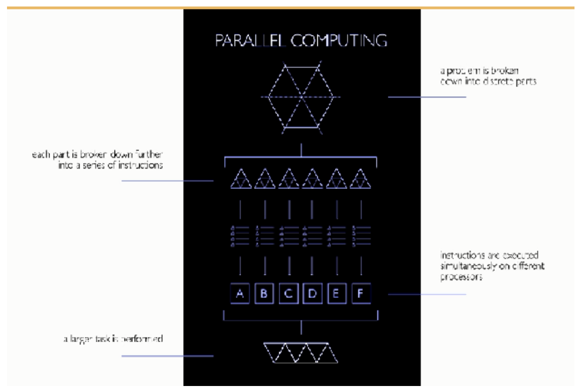
In terms of interaction design, the project took an activity-centered approach[19]. According to Saffer, an activity-centered design project focuses on the tasks and activities that need to be accomplished; the users perform those activities to achieve a certain objective[19]. The designer's task is to create tools such that the users can perform such actions. In this project, the activities of the user interface were designed for the audience to gain better understanding of parallel computing and visualize the associated patterns.

For *SeeMore* it was difficult to define the domain of the users. Being a museum exhibit the audience of the sculpture can virtually be anyone-ranging from kids to adults to senior citizens. From a design perspective it is difficult to design a user interface that should address such a wide audience. Since initially the sculpture would be exhibited at a museum type gallery of a University arts center, the audience was assumed to be of the age of young adults to adults. The surrounding environment of the user interface was considered to be a museum (more specifically, a science museum). Typical interaction time with the sculpture was considered to be no more than 5-10 minutes.

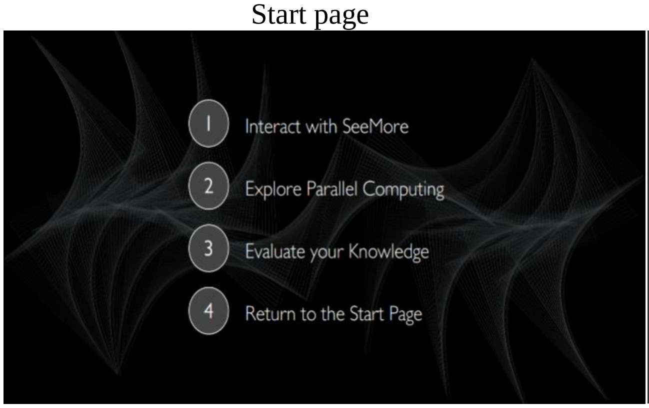
From an educational perspective, the focus was on delivering the concept of parallel computing to the audience in a way that is easy to comprehend and provides an interactive learning experience. The user interfaces included a short video explaining the concept of parallel computing, how it is being used and its importance. The second step of user interface allowed the user to freely interact (e.g. manipulate any particular Raspberry pi of the sculpture). The third step involved gradually demonstrating and explaining a parallel computing algorithm (e.g. MapReduce). Finally, a user could test his/her understanding by answering four multiple choice questions. Figure 4. Provides a few screen shots of the user interface.



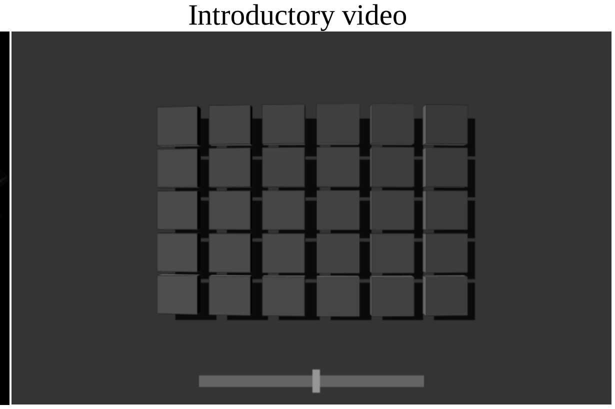
Start page



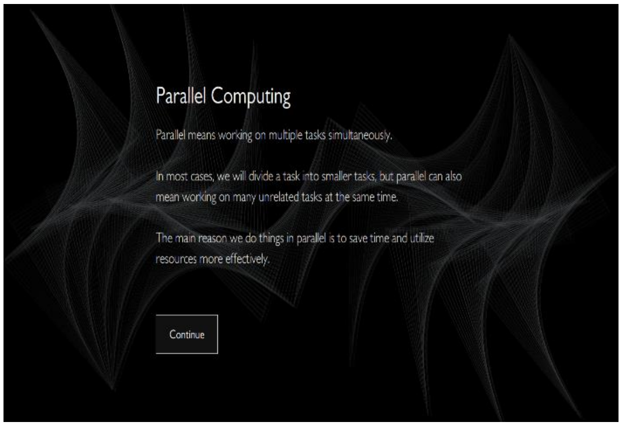
Introductory video



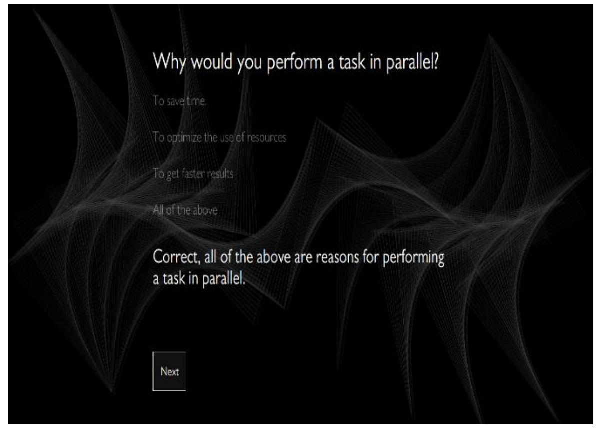
Options



Interact with the sculpture



Explore parallel computing (MapRedue)



Challenge your understanding (Assessment)

Figure 4. User interface images of SeeMore

Assessment

The main concepts (objectives) of parallel computing that the dynamic sculpture intended to illustrate were:

1. How each task of parallel computing is broken down into multiple pieces and how each processor completes a piece of the task
2. The underlying patterns that emerge from such computation

Participants' experience was considered to be naturalistic, allowing them to freely interact with the sculpture similar to the way one learns from museums exhibits. Although it is difficult to measure how people learn in museums, Stevenson suggests that what a visitor learns from an interactive exhibit can be explained in terms of learner's experience with the exhibit, comprehension of the effects, ability to explain and understand the topic being demonstrated etc.[17]. A qualitative research approach provides the means for understanding learner's experiences[20]. This is because, qualitative methods, such as focus group interviews and observations allow researchers to better understand and explore participant's experiences and perceptions of an incident (in this particular case, interacting with an exhibit). Thus, in order to evaluate the effectiveness of dynamic sculpture as a tool for learning parallel computing, the focus group discussion was coded using the objectives of the sculpture and the criterions described (in Table 2) by Stevenson's. At the end of the interaction with the sculpture, the participants were also asked to answer a set of multiple choice questions and explain what they had learned in the focus group interview. The video recording of the focus group discussion was also evaluated by an expert in parallel computing.

1. *A set of 'experiences' (or memories).* These memories can be considered to be divided into three categories: what they did; how they felt; what they thought. 2. *A set of 'effects'.* If a visitor notices, for example, that when spinning round on a turntable a person goes slower when leaning out, then the visitor is considered to have discovered an 'effect'. 3. *A set of 'explanations'.* These are explanations for the effect which the visitor has observed. 4. *A set of 'applications'.* Some of the effects which a visitor observes may be seen by him or her to have a practical application. 5. *More 'understanding' in a general sense.* 6. *A change in attitudes.* It is generally hoped that a visitor may feel positively disposed towards science after a visit

Table 2. Stevenson's summarized version of learning from interactive exhibits[17, p. 523]

Six senior high school students (1 female and 5 male) were observed and interviewed together. The focus group interview was both audio and video recorded. The students were first asked about their basic understanding of computing concepts. Table 5. Shows the questions asked. Question 1 and 2 were asked before students interacted with sculpture. Questions 3 and 4 were asked after the students had interacted with the sculpture and user interface. Table 6. Shows assessment questions presented in the user interface.

Question 1	Would you please list computing concepts that you are familiar with?
Question 2	Where did you learn these concepts from?
Question 3	What do you think about the sculpture?
Question 4	Would you please describe your experience with the sculpture?

Table 3. Focus group questions

Questions 1.Why would you solve a problem in parallel? ● To save Time ● To optimize the use of resources ● To get faster results ● All of the above
Question 2. The design of SeeMore (this sculpture) has been inspired by ● Bill Gates ● Seymour Cray ● Steve Jobs

Question 3. Which of the following is/are TRUE during parallel computing • Multiple processors coordinate computations • A big problem is reduced to smaller problems • Processors exchange partial and completed tasks • Parallel tasks can display different patterns • All of the above
Question 4. Which is <u>NOT</u> an example of parallel computing? • Searching for something on the internet • Computing weather forecast • 3D graphics rendering • Reading a book

Table 4. Assessment questions presented in the user interface

Analysis of the student responses to questions no.1 “Computing concepts you are familiar with” and questions no. 2 “Where did you learn these concepts from?” suggest that this particular group of students were fairly familiar with computational concepts. However, parallel computing did not appear as a basic computing concept in any of their answers or discussions. The students had either taken a computer science course or had someone in their family who has a computer science background. Most of the students had self-taught themselves computing concepts. After a brief introduction given by one of designers of SeeMore, the students were allowed to interact with the sculpture on their own. Figure 5. Shows how students interacted with sculpture. The students interacted with sculpture for approximately 6-7 minutes.

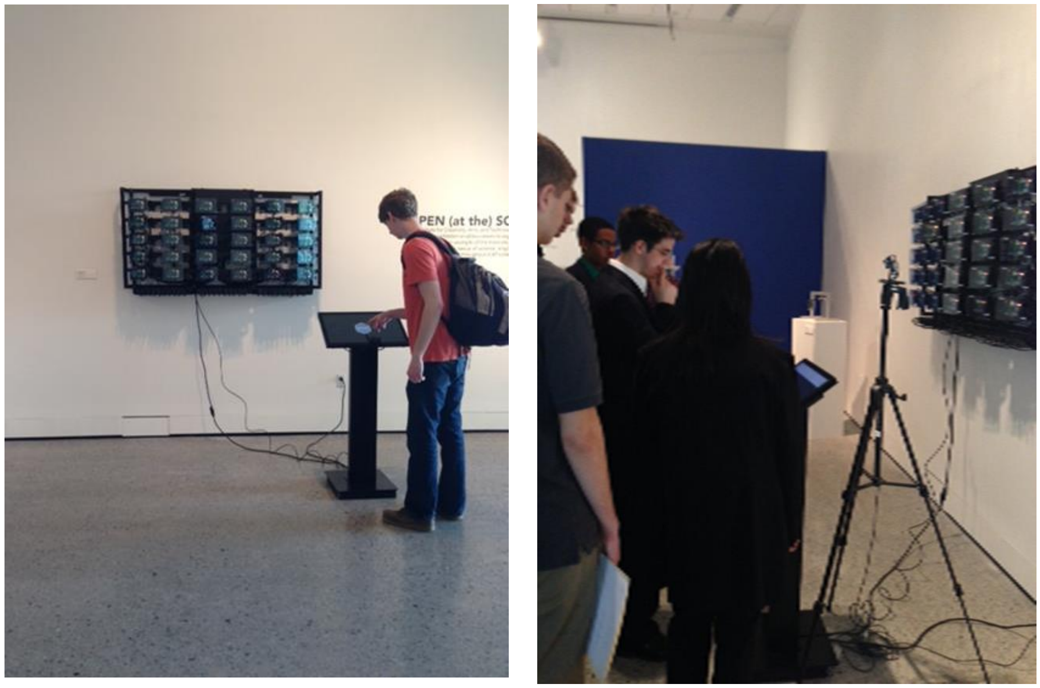


Figure 5. Students interacting with kinetic sculpture

Analysis of video recording indicates that the students were engaged while interacting with the sculpture, found the user interface fairly easy to use and answered all assessment questions (Table 6. includes the questions) correctly. The qualitative analysis further suggests that students were able to describe parallel computing in their own words, had learned something new, gained a better visual understanding of parallel computing and how super computers work. Table 5. Illustrates some excerpts from student discussions during focus group session and aligns them to the objective of sculpture and Stevenson's criterions.

Student excerpt	**Aligns with sculpture learning objective no.**	**Stevenson's criterions**
"I knew how it (parallel computing) worked but never saw it visualized"… "Really cool, the visualization was really helpful in describing how computers work together"[*Student 2*]	Meets objective 1,2	Effects Explanation More understanding
"I knew super computers worked together but I did not know they worked in that way…never so that visualized before. I kinda had an idea, never saw how it works, how many phases…"[*Student 3*]	Meets objective 1,2	Explanation More understanding,
"The patterns are interesting – it was pretty awesome" [*Student 4*]	Meets objective 2	Effects More understanding

"I feel like I learned how super computers work in more visual way" [*Student 6*]	Meet objective 1,2	More understanding
"Is it a multithreading in separate computers? I kinda had an idea but this helped…"[*Student 1*]	Meets objective 1	More understanding
" breaking up a task and all done rapidly, instead it (SeeMore) gives the other option where it sticks out for 8 seconds and twitches around, it does all at once but it makes it sweep" [*Student 6]*	Meets objective 2	Effect More understanding,

Table 5. Sample student quotes and associated codes applied

Student 3 in the focus group discussion stated

"I knew super computers worked together but I did not know they worked in that way… never saw it visualized before. I kinda had an idea, never saw how it works, how many phases …"

In the above excerpt we see that the student is able to identify parallel computing and that he is acknowledging the patterns involved in it. This illustrates the sculpture's ability to illustrate parallel computing and the fact that the student has more understanding on the topic after interacting with it.

When asked about the movements of the kinetic sculpture Student 6 explains the patterns of parallel computing as

"(in parallel computing) a task is broken up and all is done rapidly, instead it (SeeMore) gives the other option where it sticks out for 8 seconds and twitches around, it does it all at once but it makes it sweep"

Here we see the student is being able to describe the process (the effect of parallel computing) in which SeeMore demonstrates different patterns involved in parallel computing.

For further assessing students' understanding of parallel computing by interacting with the sculpture, video recording of the focus group session was shared with an expert in parallel computing. The expert stated that,

"*My concern was that they interpreted the mapreduce example as how all parallel computation was performed. They could describe the mapreduce algorithm fairly accurately, but they were under the impression that they were describing how all parallel tasks were performed.*

I think that misconception will be cleared up once there are multiple example algorithms to explore." [Expert in parallel computing]

The above quote from an expert in parallel computing illustrates that it is necessary for the design team to incorporate more than one example of parallel computing in the final version of the exhibit or else audience members may walk away with the impression that all parallel computing algorithms function in the same manner.

Conclusion

Preliminary user evaluations of the parallel computing sculpture suggest the kinetic sculpture to be an effective learning exhibit that visualizes parallel computing patterns. Participants of the study were first asked about their basic understanding of parallel computing and their background in computer science. The participants were fairly familiar with computational concepts, they had either taken a computer science course or had someone in their family who has a computer science background. By interacting with SeeMore the participants gained more understanding of the concept of parallel computing, were able to explain the concept to others, and appreciated the visualization of computing patterns. The participants enjoyed their interactive experience with the sculpture and explicitly mentioned that they had learned something new.

Acknowledgments

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