UNTANGLED - An Interactive Mapping Game for Engineering Education

Gayatri Mehta, Xiaozhong Luo, Natalie Parde, Krunalkumar Patel, Brandon Rodgers, Anil Kumar Sistla
University of North Texas, Denton, TX, 76207
gayatri.mehta@unt.edu

Abstract—Retaining students poses a huge challenge in the field of engineering, as many students become discouraged while working on their degrees and switch majors or leave school entirely. Our key observation is that it is extremely important to introduce students to real-world problems early on in their studies. Too often, students become confused and dissatisfied by abstract theories in their early engineering courses, and fail to see any practical importance to what they are learning. This paper presents the idea of using an interactive game, UNTANGLED, to introduce real-world problems related to chip architecture and design in the early stages of engineering education, thus generating enthusiasm and helping students connect the theories they learn in classes to applicable problems. We believe that doing so will help elevate future engineering student retention rates.

I. INTRODUCTION

It is well-known that many engineering students leave the field before completing their degrees. Seymour and Hewitt [1] and Matthews [2] disclosed that the number of students leaving engineering is between 40 and 50 percent, with some students switching majors and others leaving school entirely. To exacerbate this high rate of departure, diversity in the field is notoriously low, with women and minority students leaving at even higher numbers than average [3], [4]. Reasons for such low retention rates are varied, but some of the common reasons include the fact that students in introductory engineering courses are often left confused about the purpose and practical applications of an engineering degree, as well as the reality that underrepresented students are apt to feel like outsiders in the field, leading them to eventually switch majors [5], [6].

Greater measures need to be taken to retain all students, and especially those from underrepresented groups, by renewing their interest and assuring them that they are capable of succeeding in engineering. To approach this problem, we recommend several actions to be taken to increase student confidence and enthusiasm about engineering degrees.

Our key observation is that it is extremely important to introduce students to real-world problems early on in their studies. Too often, students become confused and dissatisfied by abstract theories in their early engineering courses, and fail to see any practical importance to what they are learning. Students should be presented with a big picture of how the basic concepts that they are learning fit together to form the origin of solutions to many unique, exciting problems in engineering.

Presently, most engineering programs offer courses dealing with real-world problems only at advanced levels. We recommend that engineering curriculum be enhanced by bringing these real-world problems to introductory courses. These problems should be presented at a level that students can understand without prerequisite background and skills in the field, and this will in turn lead to an increase in student enthusiasm for studying engineering. Furthermore, when these concepts are presented without any background knowledge requirement, students will have a higher confidence in their ability to succeed.

Recently, scientific games, also known as Games With A Purpose (GWAP), have experienced an explosion in popularity [7], [8], [9], [10]. In these games, computational tasks are transformed into more entertaining activities. We have developed an interactive game called UNTANGLED [11], [12], [13] in which users compete to create the most compact, visually appealing arrangements of circuit elements onto a grid. The game is presented to players abstractly, with circuit elements shown as blocks in bold colors that must be untangled and arranged, but it actually consists of real algorithms that players are mapping onto different chip architectures which could conceivably be manufactured in silicon. UNTANGLED was designed to be accessible to anyone, so it does not require any electrical or computer engineering background to play, and it has been played by people from diverse backgrounds. We have made several observations from our user studies and the worldwide online game competition that was held for ten days in August 2012. In addition to learning human strategies to create efficient placement and mapping solutions (which will be presented in our forthcoming paper), we have observed that the game has promoted computational thinking [14] among players. More details are discussed later in Section IV of the paper.

UNTANGLED has the potential to provide a great avenue for students in introductory courses in Electrical Engineering (EE) and Computer Engineering (CE) to understand the critical design issues in real-world problems related to chip architectures. Students can compare multiple architectures using our interactive framework, and they can also discover which strategies yield more compact designs. In doing this, they get a big picture of how these compact designs can lead to low-power, light-weight chip designs that can be used in the next generation of portable electronics. We firmly believe that presenting real-world problems using this type of game-driven
The approach can be very promising in attracting and retaining students in the field of engineering. We describe our game, UNTANGLED, in Section II. Observations made from user studies and the online game competition are presented in Section III. In Section IV, we discuss how UNTANGLED can promote computational thinking. Section V describes how UNTANGLED can help improve retention of all students in the engineering field, and finally conclusions are presented in Section VII.

II. UNTANGLED - THE MAPPING GAME

UNTANGLED [11], [12], [13] was designed to be accessible to anyone, so that it does not require any electrical or computer engineering background to play. Our user interface has evolved over time based on extensive player feedback. We performed numerous think aloud experiments [15], conducted exit interviews, and encouraged players to give us feedback through emails. We are using the iterative approach of designing, testing and evaluating our game repeatedly. Current interface features include:

- **Drag and drop nodes within the game grid.** Users found it most intuitive to click on nodes and drag them to where they wish them to go. Dragging a node on top of another one causes the locations of those nodes to be swapped. Nodes can be dragged outside the painted boundaries of the game grid, which causes the grid to resize itself.

- **Select and move clusters of nodes.** Players frequently wish to select groups of nodes and move them as a unit. Our interface supports direct selection and movement of user defined clusters, along with rotation and mirroring.

- **Add and remove pass gates.** Players can add and remove pass gates, which are often required to route data within constraints of the architecture. Creating an efficient mapping requires thoughtful decisions about where to place such elements.

- **Painting nodes.** A paint tool allows players to color nodes as desired.

Standard interface features such as save, reload, undo, and redo are provided, as are zoom and scroll of the game grid. A player’s score is displayed, and violations are highlighted.

Our game includes in-depth tutorials which not only provide players a hands-on experience with the tools used in the game, but also basic knowledge about mapping and placement of blocks. To motivate players, we arrange benchmarks in order of complexity and stage tutorials to introduce concepts at each level. Incentives such as medals are given to encourage optimizing scores at individual levels, and the website for the game includes a leaderboard where players can track their scores in comparison to other players around the world. The introductory video is available at https://untangled.unl.edu.

The current version of UNTANGLED supports stripe and mesh-based architectures, and it allows customization of interconnect arrangements and placement of dedicated vertical routes. Interconnect patterns for the six architectures are shown in Figure 2. The architectures are Stripe, StripeDR, 8Way, 4Way, 4Way1Hop, and 4Way2Hop.

UNTANGLED presents a succession of problems where a data flow graph (DFG) must be mapped onto a specific architecture. To construct winning mappings, players optimize their scores by moving nodes of the DFG within a game grid to create compact arrangements where parents are close to their children, where “close” is defined based on the interconnect structure of the architecture.

Figure 1(a) shows an example of a DFG used in our game. This is our H1 benchmark, which is the inverse discrete cosine transform of MPEG II video compression. Here, nodes are arithmetic operators, logical operators, multiplexors, or pass-throughs. The DFG is presented to players in an abstract manner, with ALUs in red, pass-through elements in pink, and outputs in green (Figures 1(c) and 1(d)). This representation was adequate for our examples. A game designed with tighter scheduling requirements or floating point resource constraints, for example, would require a different solution.

An architecture for our purposes is a specification for where nodes may be placed and how they may be efficiently connected. Nodes could be ALUs or other functional elements
(e.g., pass-throughs), and these elements are connected in a prespecified interconnect topology. Figure 1(b) shows an abstracted example of a stripe-based reconfigurable architecture where functional elements are arranged in rows, and adjacent rows are connected by a full crossbar interconnect.

In game play, our players are presented with an architecture definition, which is abstracted as an icon showing legal connections between a node and its neighbors. They are also given an initial mapping of a DFG onto the game grid (Figure 1(c)). Their task is to rearrange nodes within the game grid until they arrive at a compact, efficient arrangement. Figure 1(d) shows a final result for one of our players, mapping H1 onto the Stripe architecture.

The Stripe architecture consists of nodes arranged in horizontal stripes, each of which is connected to all nodes in the stripe below them using a full crossbar interconnect. We assume that inputs can be supplied to any ALU, but outputs (shown as green ovals) must be routed off chip, blocking all nodes below them from performing computation. The StripeDR architecture is Stripe with dedicated routes (DR) within which only pass-through nodes can be placed.

8Way is a mesh architecture where nodes can connect to any of their 8 neighbors. We assume that inputs can be loaded and outputs read from any ALU. 4Way is the same as 8Way except that diagonal connections are not considered. 4Way1Hop is a generalization of 4Way where horizontal and vertical connections that skip one node are also allowed. Finally, 4Way2Hop is a generalization of 4Way1Hop that also allows horizontal and vertical connections that skip two nodes.

The seven benchmarks for our study included the Sobel (E1) and Laplace (E2) edge detection benchmarks, as well as GSM (E3), ADPCM decoder (M1), ADPCM encoder (M2), IDCT row (H1), and IDCT col (H2) benchmarks from the MediaBench suite. Basic statistics are shown in Table I. The benchmarks varied in the density and arrangement of interconnections, with the simplest graphs being easy to lay out in an efficient manner and the hardest graphs quite difficult.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>BASIC INFORMATION RELATED TO THE BENCHMARKS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>E1</td>
</tr>
<tr>
<td>Edges</td>
<td>24</td>
</tr>
</tbody>
</table>

III. USER STUDIES

We performed several user studies during development of our game. The experimental protocol for all studies was determined to qualify for an exemption from the Institutional Review Board of the University of North Texas. IRB protocols were followed in all cases. Several formal in-house studies were conducted. We also held a worldwide online game competition, which took place for a period of ten days from August 10th through August 20th, 2012. Giftcard incentives were provided to winners of each architecture and overall competition. Rankings were visible on the UNTANGLED leaderboard throughout the competition and can still be viewed on the game website https://untangled.unt.edu.

Our competition attracted 161 players, who contributed a total of 1623 completed games. At the time of this writing, our game overall has 577 players and 6046 total games, and these numbers continue to increase. Players contributing to the competition played an average of 4 hours over the course of ten days, with 37 players (23%) exceeding 3 hours of game play and 21 players (16%) exceeding 10 hours of game play. The competition saw a spirited battle between two top contenders for overall winner.

Figure 3 shows that a player has identified a critical path in the graph and is aligning nodes in this critical path to make the graph implementation more compact.

IV. PROMOTING COMPUTATIONAL THINKING

UNTANGLED has been played by players from a diverse range of backgrounds, and quotes from players give us information about their individual thought processes. In particular, we observe that players are employing computational thinking to solve their graphs [14]. Some example quotes from players include: “It sometimes helped to separate out portions of the puzzle to try and untangle something.” “Early on I would figure out which blocks had the most connections, and then try to get those ones as close to the center as I could and work on them first.” “I tried to keep track of how many points I got for putting a block in one spot, and then I would switch the blocks and see if it resulted in more points.” “I started my graph by organizing it first, meaning expanding my graph area and then using the cubes to act as a border for the entire thing. I then chose the piece with the most strings attached to it, put that in the middle and went from there,” and “I painted them [the nodes] to help show which areas of the graph needed improvement. Like say there were three pieces that could have been organized differently, I'd paint those one of the colors to show it as a weak area that needed improvement on, and then come back to it later.”

V. IMPROVING STUDENT RETENTION

Currently, the engineering field is beleaguered by low student retention rates. Seymour and Hewitt [1] cited dissatisfaction with curriculum as one of the primary reasons for this problem. Engineering students can often become
dissatisfied with their curriculum because although there are many interesting and beneficial applications to engineering, introductory courses typically do not mention any practical real-world applications [5]. Instead, they tend to focus on tedious theory which, despite its importance, can easily lead to boredom or disappointment.

We suggest that engineering curriculum be enhanced by bringing these real-world problems to introductory courses. The problems should be presented at a level that students can understand without prerequisite background and skills in the field, and this will in turn lead to an increase in student enthusiasm for studying engineering. UNTANGLED facilitates an excellent platform for students in the introductory courses in EE and CE to understand the critical design issues of the real world problems related to chip architectures. The problems are presented to students at a level they can understand without having any special engineering skills or background knowledge. For example, learning modules based on the critical design concerns of chip architecture and the insights gained from the placement/mapping game can be presented in classes such as Digital Logic Design. Students will have a good understanding of the design issues of the chip architecture from these learning modules. Using our interactive framework, they can compare several architectures and can also find out what strategies give them more compact designs. In doing this, they can get a big picture of how these compact designs can lead to low power, light-weight chip designs that can be used in the next generation of portable electronics. Our game-driven approach can be very promising in attracting and retaining students in the field of engineering, especially with respect to those interested in EE and CE.

In addition to this, UNTANGLED also provides great opportunities for students to explore a variety of architectural options, and to study trade-offs between power, performance, and area while using an exciting interactive game environment in advanced EE and CE courses. For example, in a hardware design sequence with courses such as Digital Integrated Circuit Design, VLSI Design, and System-on-a-Chip Design, UNTANGLED could allow students to perform a detailed cross-architectural study for various application domains.

VI. ATTRACTING STUDENTS TO ELECTRICAL ENGINEERING AND COMPUTER ENGINEERING

One outreach event that we created to increase student interest in EE and CE was a freshmen game night. At this event, members of our research team visited one of the dorms at the University of North Texas (UNT) campus. We discussed the purpose and real-world applications of UNTANGLED at a level that was basic and accessible to freshmen. We then walked students through the game’s tutorials, and the students instantly began a friendly gaming competition, each of them attempting to create the most efficient, highest-scoring graphs. Our team remained available to answer any questions throughout the game night, and by the end of the evening we witnessed students comparing strategies, improving their own graphs with experience, and even making plans to continue playing the game after the event was over. UNTANGLED has also been highly appreciated by high school students. Generally, all of the comments we receive from players are positive and enthusiastic.

VII. CONCLUSION

We have presented the idea of using an interactive game known as UNTANGLED for use in engineering education, with the intent to promote computational thinking and increase engineering student interest and retention. This game provides a great platform to introduce real-world problems related to chip architecture and design in the early stages of engineering education, and it gives students a better idea of the problems that they will be solving as they advance in academia and industry.

ACKNOWLEDGMENT

We would like to thank the National Science Foundation for supporting this work with grants CCF-1117800, and CCF-1218656. Special thanks also to all who voted for our contribution to the 2012 International Science and Engineering Visualization Challenge conducted by Science and the National Science Foundation, which earned UNTANGLED a People’s Choice award in the Games and Apps category.

REFERENCES