LogicVis Project Report

CSE 403 Software Engineering
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1. Motivations and Objectives

Coding can be difficult to learn. As students, we struggled with many of the fundamental coding concepts. Looking back at these experiences, we wish to build a tool that could make learning how to code much easier as our project. An effective method we found put code into the form of a control flow graphs. Beginner students are used to reading and processing information mostly linearly, and did not have much experience reading code, which contains sequences of steps that jump a lot. This method helps students understand code by connecting to the their prior knowledge of reading flow charts and diagrams[1]. Though graphical tools exist, we noticed a distinct trend amongst all the tools we checked, like JavaVisualizer, and InfoVis Toolkit--they do not handle recursive cases well [9, 10]. We found this to be quite odd because we remembered that recursion was one of the most difficult topics to master, yet it is left out in most tools that are built to help beginners. Through research, we found that the major difficulties students have with recursion are [2, 3]:

Students not utilizing functional abstractions

The purpose of abstractions is so that we can work with something without knowing how it works. For example, there are two forms of knowledge associated with learning how to drive a car: (1) knowing how to operate the car (2) knowing how the car operates. Most drivers do not actually know in detail how cars work, but they can still utilize cars in those ways. In the context of recursion, students have similar troubles: they focus on *how* the recursive step works instead of *what* the recursive step does [2]. If we can help them accept that the recursive step just does what the function itself does, the difficulty of understanding the recursive part of the function diminishes.

Lack of a proper methodology to represent a recursive solution

Many students that are new to recursion do not understand how to formulate a solution that uses recursion. They begin to write recursive solutions when prompted but often cannot imagine the solution they drafted in a concrete way. For example, they will think of including a base case and a recursive call, but cannot connect these components together to form a coherent solution.

The goal of our project is to build a tool for Java that can help new programmers learn recursion by visualizing the flow behind programs using arrows to connect subsections of the code. This tool can translate a chunk of recursive code to a flowchart so that it is easier for people to grasp the recursive algorithm and build their own recursive programs. In addition to using this tool on existing code, students can also draft their own solutions and use this tool to check whether

their solutions behave as intended. Because recursion is a difficult subject, we also design this tool to be used as a supplement in addition to instructions by the instructors teaching.

2. Paper Prototype User Study

```java
public static void mystery(int x) {
    mystery(x, 2);
}

public static void mystery(int x, int n) {
    if (n == x) {
        System.out.println(x);
    } else if (x % n == 0) {
        System.out.print(n + " ");
        mystery(x / n, n);
    } else {
        mystery(x, n + 1);
    }
}
```

We conducted a user study to confirm that our product will assist with learning recursion. The code for user study is to the left (prints the prime factorization of x). The code is recursive and somewhat complicated. We have developed a paper-prototype for the code here and used it to test the effectiveness of our ideas (See User Manual for UI reference [11]).

2.1 Choice of Method

The tasks given for the users are to compute the results of functions. We split the study into two similar parts: one part without our tool and one part with it. In each part, we will ask similar questions about the program's output and gauge the participants' understanding of the given piece of code. This way, we hope to find whether our tool helps students follow recursion better. We pick this method to mimic methods often used in beginner programming classes while being practical while using a paper prototype.

2.2 Set-up

We performed our study on a college student with a background of AP Computer Science, which means they have learned recursion, but not extensively and not recently. We let the subject look at two methods, hiding both their names (i.e. we labeled them as mystery). The reason we hid the names was to reduce the chances that the participant used their math knowledge to understand the code rather than their knowledge about recursion. We first used a method we showed returned the nth number of the Fibonacci sequence and did provide our paper prototype on the method. We then used a method that printed out a number's prime factorization and included a corresponding paper prototype on the expected product. For each method, we asked the following questions:

- What does factors(20)/fibonacci(5) output? (mystery(20)/mystery(5), to the participant)
- What does this method do?
- How does this method work?

2.3 Performance

The subject was able to identify the output and functionality for both programs without outside assistance. However, the subject spent a few minutes longer on the second prompt, completely missing the base case (went to fibonacci(-1)), and drew a representation of the method calls while computing it. For factors(20), the subject was able to quickly find the output but had trouble explaining why n was incremented by 1 in the second recursive case.

2.4 Feedback

The user responded that, in comparison, our charts did not help understand a specific line of code, but the flowcharts make the execution flow much easier to follow: the flow chart indicates how each recursive step progresses to the next one and helps the user see where each step executes. Furthermore, the user found that there was too much displayed at once; having a reduced flow chart based on which statements execute may make our chart easier to follow.

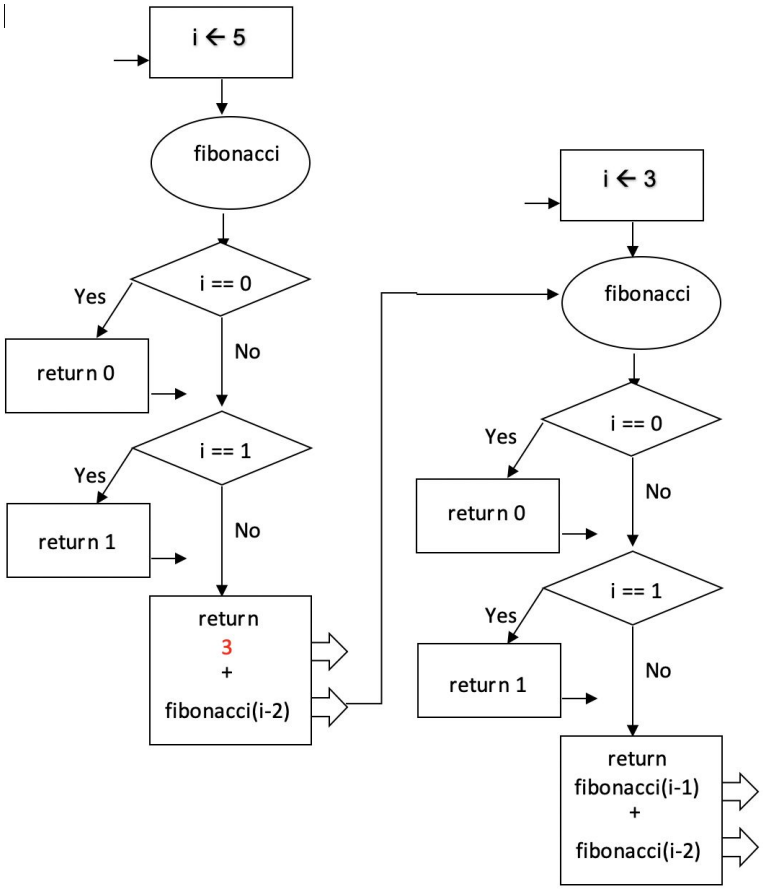
2.5 Analysis and Future Testing

From the fact that the subject made a separate representation for the first method, we found that the prototype we created successfully served as a separate way of understanding in itself. The representation the subject listed the parameters and return values of each call, which overlaps with and is included by our product's functionality. In addition to being able to characterize the program faster, the subject also had no trouble following the execution of code, likely because all the steps are expanded out for the subject. On the other hand, our prototype failed to give meaning to why each and every line of the code existed.

Further testing about user debugging and developing will be necessary to examine other aspects of this project. These will be performed when more features are available. Follow-ups on this are in the later user studies section.

3. Our Approach

LogicVis is a program that takes an input of a Java recursive function code and its arguments and outputs a logic graph of control flow. It reads in the Java code line by line and turns each line into a node representation with the shape indicating the type of command. LogicVis graphs contain different representations for basic Computer Science concepts, including if/else, loops, recursion, etc. This tool will output the logic graph with input and output parameters tracking for each iteration. As previously mentioned, students generally have two problems with recursion, and we seek to help students by solving these problems. Below is the our graph representation of a simple recursive program.



The following sections will discuss how this approach is expected to combat typical problems students have with recursion.

Not utilizing functional abstractions

Our approach to this problem is to attempt to unpack the abstractions that is packed in the recursive function. Here we are building our graph to represent those recursive steps concretely. Our take on the visualization of a recursive function will exhaustively list iterations of recursive calls. If the students can see the results of the code by expanding the graphs, they have the potential to acknowledge and trust that the recursive call will perform its intended function. If students are able to accept this idea, they can recognize *what* the calls do without focusing on *how* it is achieved. This does not directly teach students the concept functional abstractions, but it makes recursion more easily recognizable, and by that familiarize student with abstractions. The extra information on the return values and parameters of each call is also here to help students confirm their understanding of the program.

Lack of a proper methodology to represent a recursive solution

This graph also aims to be the alternate methodology for students to represent the codes that they write. Tracing the steps in a recursive program provides students with a mechanical means to follow the recursive algorithms. In our implementation, we will have made it clear that another function frame has been made every time we descend down the stack. Another utility this graph seeks to focus is on helping to debug their own code. Since students are unfamiliar with drafting solutions to a program, intended use of this program is to represent what the students write themselves into concrete graphs. Though this tool does not focus on individual lines, this tool does point out clearly where each line will take place with the nodes of the graph. This way, students will understand the placements of every line they write, as opposed to putting down lines randomly because they imagine they are supposed to be somewhere due to their inability to comprehend recursion.

The recursion will be handled by adding options to expand recursive calls when they appear in the original function graph. They will be generated on demand and allowed a complete expansion in concrete cases. Our minimum viable product will be designed such that a strict number of recursion iterations will be enforced with a working GUI. For the final product, we are aiming for removing the strict limit on the number of recursion iterations but rather utilize the lazy evaluation approach based on scrolling in the UI.

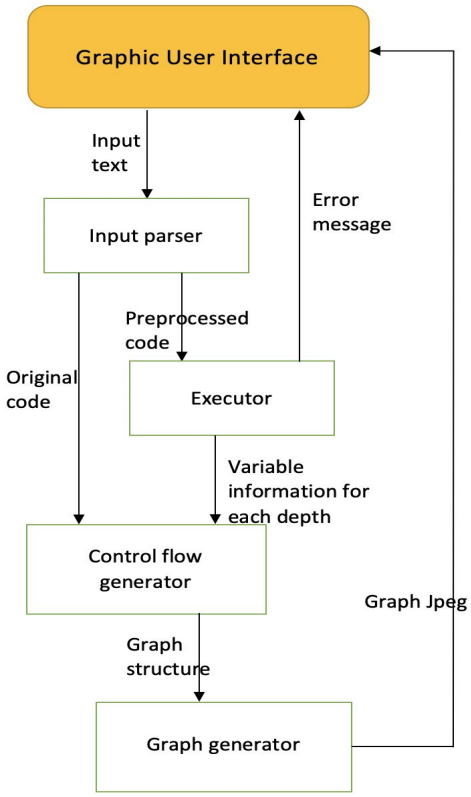
4. Details

4.1 Interfaces

(Refer to the user manual [11])

4.2 Architecture

The architecture is represented by the diagram to the left. The boxes represent components of the architecture and the arrows represent the flow of the data from one component the another.



4.2.1 Graphic User Interface

This layer is the front end part of our project. It will let user type input code and get the parameter value and display the graph.

4.2.2 Input parser

This layer will read the input from the front end software, get the input value, preprocess it and send the code to the executor. By processing we mean modifying lines of code in the input text in order to execute it and obtain the desired output in the executor.

4.2.3 Executor

This layer will execute the input code. If the execution failed, send an error message to front end and display error message. If succeeded, the executor will send the code along with the information such as recursion depth and parameter value of each depth to the control flow generator.

4.2.4 Control flow generator

This layer will generate the basic control flow code of each depth of recursion call with corresponding input value and send the control flow graph information to the graph generator. This layer does not generate any graphs, it only generates the data how the graph is supposed to be constructed.

4.2.5 Graph generator

This layer will visualize the graph and implement the clickable features to the graph, then send it back to GUI and display the graph.

4.3 Technologies

We have chosen to develop this software in Java since we are most familiar with the Java language and its libraries.

Graphic User Interface:
We plan to use the JavaFX library, which provides a clean graphical UI that works as a standalone. The older libraries such as Swing and AWT do not provide as much functionality whereas others like Pivot are used as RIA.

Graph Generator Algorithm:
We plan to build this from scratch. We want to be able to make a parsing and graph generation software that fits our Graphics User Interface, so although we may reference existing flowchart generators, we would have to rewrite most of it if we wanted to use one.

5. Testing and Results

5.1 Quick lookup of Initial Progress

We are able to produce the frameworks for the UI and the intended data abstractions for given functions that processes non-recursive functions. To see these results, go to the root directory of LogicVis' README.md and following the directions about initial results.

5.2 Evaluation Methodology

Because this product is focused on assisting students with learning recursion, we determined to use user studies to evaluate our product and determine the way forward. The following sections describe how the studies are performed.

5.2.1 Setup

We find computer science students of varying experiences with coding and ask them to perform programming tasks we will evaluate them on. As we have the complete product, we no longer have the restrictions we do previously from the paper prototype. The problems we pick are of the two types: Fill in the blank and Debugging (The actual code and specification are in Appendix C), which are more difficult and comprehensive than mystery output type questions in the previous experiment. In these experiments, we first introduce the problem given. Our product is given to use in some experiments, but for some trials, we evaluated the the test subjects without our tool as the control group. This is to simulate a situation where an instructor tries to teach a student about recursion using this tool.

5.2.2 Metrics

We measure the performance of the test subjects by timing their time to reach the solution and analyzing the processes made by each subject during that time. Two testers will be present

during this process: one provides assistance such as explanations and hints on the questions and one takes notes on the interactions and occasionally provide explanation if the other tester missed some point. This process will conclude once the test subject solves the question.

5.2.3 Restrictions

Due to difficulties in the technical progress, the user studies cannot be conducted exactly as described above. The tool we were provided with only generates the graph for a single iteration of the recursion, rather than being able to expand as we have expected. So, instead of conducting the experiment above, we ran the experiment using the existing tool and let one of the testers generate the arguments and return values of each iteration call by hand. This attempts to simulate the expected product, but is lacking in aspects since the complete graph is not generated. Because the complete effects of changes are not shown, we chose to forgo the fill in the blank question as it does not help students formulate solutions well. We then performed the experiment with the altered setup using the programs odds() and printTwos() (details in Appendix C).

5.3 Results

(Detailed experiment notes is included in Appendix C)
While the subjects were using the tool, a common complaint is that the elements in the graphs are too difficult to see. Because the control flow of the code given are simple, the low graphics quality graph provided very little assistance. The following are observation of each individual test subject.

5.3.1 Almost no Java experience, had Matlab experience (No recursion knowledge)

The subject took 57 minutes to solve odds() without the tool and 32 minutes to solve printTwos() with the tool. The subject showed a lot of confusion regarding the Java syntax and the concept of recursion in both the control and the tool version. The tool was not able to help much in this case: the program uses print lines for output as opposed to return values. The subject used tool to identify parameters over the iterations, but was not able to utilize the tool beyond that. The reduction in the time can be attributed to both the familiarity and use of the parameter calls tool in the second question.

5.3.2 High School Computer Science (Has learned about recursion)

The subject took 24 minutes to solve printTwos() without the tool and 6 minutes to solve odds() with the tool. The subject expressed inability of understanding the Mathematics behind the programming statements of printTwos(). For odds(), the tool proved helpful by providing the participant with the parameters and return values of each iteration. The large reduction in time is likely due to noticing that handling odds and evens separately solves the problem upon looking at the arguments of each recursive call, which is given by the tool.

5.3.3 Foundations of Programming and Data Structures (Has learned about recursion)

The subject took 27 minutes to solve odds() with the tool. The subject once again had difficulties over the Mathematics properties of the problem. The link between editing the integer string and performing Mathematics operations were very difficult to grasp. The subject also started with misunderstandings of the problem and showed problems with debugging rather

than with recursion in general, which extended the time by quite a bit. The subject used the tool but was not able to overcome the misunderstanding until the tester clarified it.

5.4 Analysis

The poor UI and limited information in the graph generated decreased the effectiveness of the tool by a lot. However, our tool showed promise in its ability to display return values and argument values in each recursive call. This demonstrates that the tool does serve as a solution to students often not being able to recognize recursion as an abstraction--seeing the results of each call convinces students to trust the recursive calls to perform its function when writing their own code.

From this, we found that our current priority should be to make the UI look better and be able to expand the graph into following call iterations. Further user testing must be conducted once more features of the product are implemented.

6. Limitations

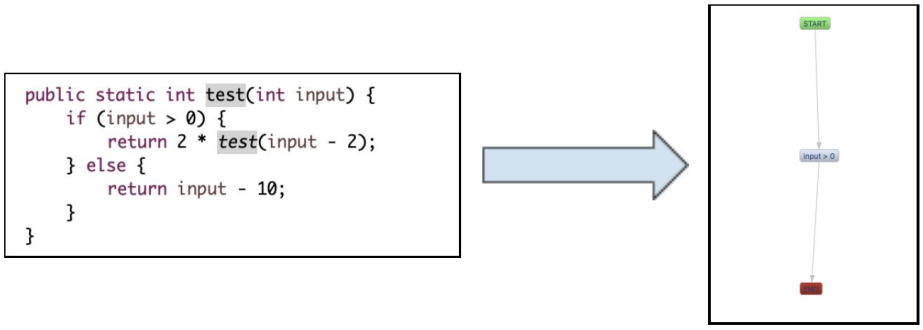
We run risks that our approach is not received well by the intended audience. The reasons for this may be having unintuitive navigation, unclear information, or distracting factors in the final product. To mitigate the harmful impact of such risks, we have been conducting user research and found ways to avoid some issues according to the feedbacks given. More changes will be necessary.

We also have taken limitations in deciding the scope of our project. We have chosen to make this software specifically for Java and best used as a supplement in addition to traditional ways such as being taught in class. We based this on the idea that most students that learn computer science start with Java and in the setting of a typical classroom. Another risk that we will be taking is our decision to not handle Java built-in library functions. Displaying these would introduce a whole new set of problems, such as additional clutter and having to implement it in the first place. Overall, we hope to build our software for a large enough scope of statements to help the user while not also overwhelming them. If we have successfully chosen the correct scope for our product, we will have made the version of our software that will help most people.

7. Related Work

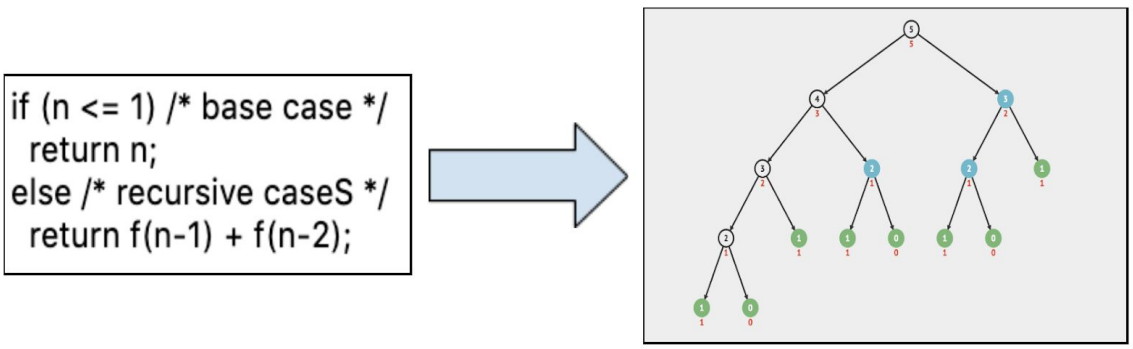
As we mentioned before, there are many visualization tools online, but none of them handle recursion to the amount of detail we hoped for. For example, the Eclipse CFG Generator[4] was designed as an Eclipse plugin to translate a piece of code into a flowchart (See Figure 1). The following graph is an example of how it works. However, the visualization it produces neither shows what each line of code is doing (each line of code are simplified to the category of the code or the name of the variable, like “expression” and “plaintext”) nor it shows a clear logic flow within the code (it only visualizes the if/else condition and ignores all other method calls) which makes it impossible to visualize recursion. Also, the CFG Generator and many other

tools[5][6] fall short in that they do not handle recursion any more than simply noting that the method was called. For example, Eclipse CFG Generator simplifies the function call to "expression" which tells no information about this function call. In other words, though it helps users understand a program's flow in a low level, users will still be unable to understand a recursive piece of code, as it provides no extra help on the abstraction of recursion under the call. In comparison, our approach gives visual representations of every single line of code within the recursive function and we track the parameters and return values of the recursive calls, giving the users of our program, especially students, a better sense of the current iteration of the recursion.



(Figure 1: Eclipse CFG Generator)

The best recursion trackers we found online were those like VisuAlgo[7]. VisuAlgo runs a program, such as GCD, and demonstrates a live example of the method call flow as a recursive tree. It lets you step one recursive call at a time and shows the parameter values and return values of each call. See figure 2 for the VisuAlgo example.

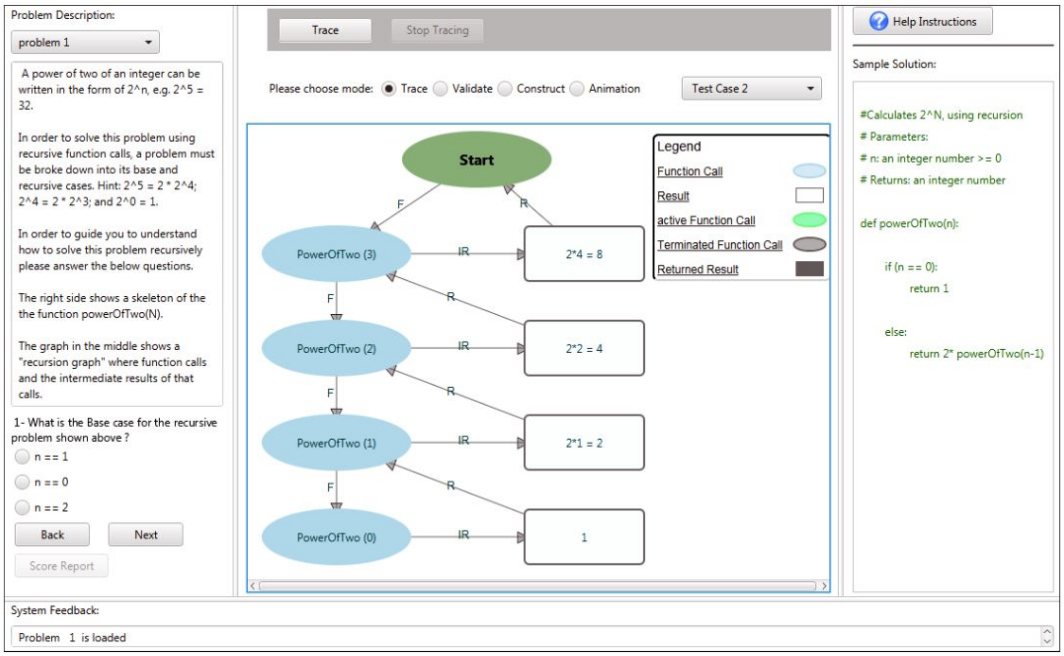


(Figure 2: VisuAlgo)

We are using a similar approach, stepping one recursive call at a time with the parameter and return value visualized. The difference is that VisuAlgo represents each recursive calls as a single node with no information on what happens inside the function. Students struggle to understand the recursive program because they have little to no idea about how the result was obtained. We have looked for many tools that track complicated recursive calls, but no such graphing tools exist. Our approach takes into account every line of code, making the user

completely aware of the program execution without high level uses of abstractions. In addition, when students use LogicVis to examine their own code, they can contrast our outputs to grasp the impact of each specific line, which VisuAlgo cannot do.

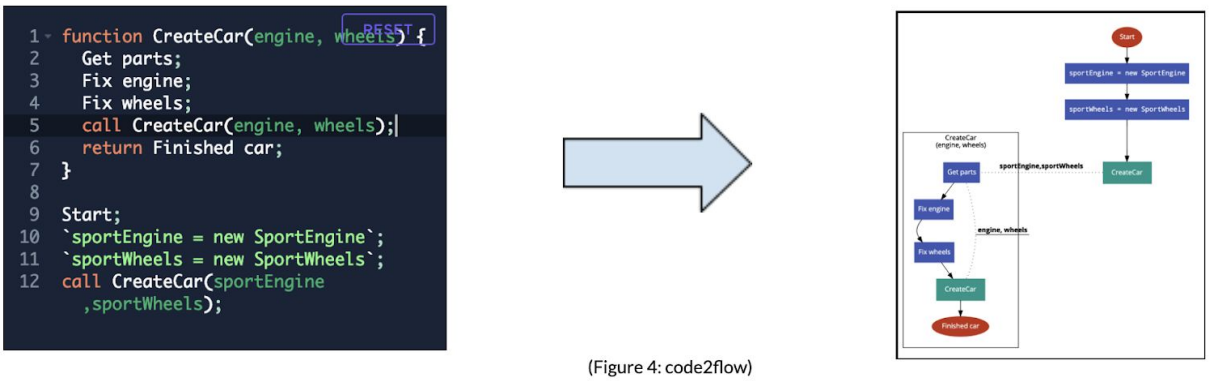
Another approach on helping student learning recursion is ChiQat-Tutor System, a system that helps visualize certain predefined recursive functions[8] (See Figure 3). It is helpful to get students to understand the given recursive function cases by giving students questions and tasks to do about given recursive functions, but it is similar to the previous examples in that they do not generate the details about the recursive call. Since this tool is not able to process non-preset programs, students may also have difficulties with reasoning about their own recursive code during the debugging process. Our approach plans to be able to generalize on all the recursive functions to provide specific graphs on recursive programs for students to compare.



(Figure 3: ChiQat Tutor)

There is one tool that helps code visualization extremely well, which is code2flow[6] (See Figure 4). It takes text input and generates control flow based on it. It also visualizes function calls with details by having a box containing details of the function outside the main graph. The following

graph is an example.



(Figure 4: code2flow)

Our approach plans to generate a control flow graph similar to this because it makes each step of the execution clear and easier to understand. However, this tool only gives a static graph with no parameters and return values indicated in the output. In the case of understanding recursion, parameters and return values helps students a lot on understanding the current fields of the execution and the result of each iteration. Our approach enables users to formulate their own code by demonstrating the details of their code based on customized inputs and stepping each iterations of the recursive call to have a better awareness of the overall iterations of the program execution.

8. Conclusion

Throughout our research, our initial motivation has been reinforced: recursion is indeed difficult to understand. The visualization of recursion has helped our research participants solve problems, but it still remains difficult to measure an increase in understanding after using our tool, given our current technical limitations.

Our tool shows promise in the implemented parts just as what we expected it to do. However, the visual aspects look to be poor and many components of the product remains unimplemented. Once the product is complete, we expect to see more correlations between our motivation and the effects of it on students.

Hours spent: 50 hours

Appendix A: Schedule

We plan to split major sections of the projects into work done for each week. For each week, we will begin planning the specifics of what each goal entails. After reaching the goal of implementation for every week, we start testing the programs to ensure its correctness. This means that testing will be involved in every week, so we chose to omit it in the schedule below.

Time	Goals
Week 4	- Project proposal and Planning - Write the initial specification - Design visual components of graphs
Week 5	- Finalize the implementation directions and formal proposal document - Assign roles and methods of communication
Week 6	- Design the GUI - Write the user manual - Implement function parsing: Identify the different type of lines in Java - Implement recursion parsing: recognize keywords and represent the flow
Week 7	- Build a data structure to represent the code - Visualize the data structure into a readable graph - Evaluate the performance of the graph using testers
Week 8	- Complete the frame of the UI - Complete processing basic codes excluding recursion and showing initial results
Week 9	- Finish the UI - Finish processing recursion - Research on effectiveness of the tool
Week 10	- Finish the GUI - Link relations between existing functions - Research on effectiveness of the GUI
Week 11	- Final testing - Prepare for presentation

If we have time left over for extra development, we can consider implementing:

- Parsing class structures
- Handling a class with recursive methods

- Making it a plugin for Eclipse
- Supporting modification on generated graphs being reflected in the code

A good “midterm exam” for this project would be checking to ensure that the base visualization of the graph we are building matches our expectations at week 7. This milestone was reached at week 8, and the resulting graphs of the inputs were up to standards. A good “final exam” for this project would be looking at the final product to see whether we are handling multiple functions correctly at the end of week 11. At that point, we would also test everything else to see that they are robust and optimal rather than just its correctness according to the specification.

Appendix B: Roles

Implementation Team: in charge of programming the software so that it runs.

- Andrew Liu
- Candice Miao
- Leo Gao

Evaluation Team: in charge of designing the product and testing its effectiveness.

- Glenn Zhang
- Jed Chen

Appendix C: Supplementary Information of User Studies

Fill in the Blank question:

```
/**
 * Remove all the digits in the argument that
 * are 1s and return it as an integer.
 */
public static int removeOnes(int n) {
    if (_____) {
        // Base Case
        return n;
    }
    // Recursive Case
    if (n % 10 == 1) {
        return ____________________________;
    }
    return ____________________________________;
}
```

odds debugging question:

```
/**
 * Get rid of all the digits that are even in the string.
 * Examples of this function are:
 * odds(323) = 33
 * odds(13524) = 135
 * odds(12345) = 135
 */
public static int odds(int x) {
    if (x == 0) return 0; // Base Case

    // Recursive Case
    int res = odds(x / 10) * 10;

    if (x % 2 == 1) {
        res += x % 10;
    }
    return res;
}
```

printTwos debugging question:

```
/**
 * Prints an expression equivalent to n by multiplying an odd number by two.
 * The twos will be around the odd number. For example:
 *      printTwos(10) prints "2 * 5"
 *      printTwos(24) prints "2 * 2 * 3 * 2"
 *      printTwos(4) prints "2 * 1 * 2"
 */
public static void printTwos(int n) {
    if (n % 2 == 0) {  // if n is even
        System.out.print("2 * ");
        n = n/2;
        printTwos(n);
        if (n % 2 == 0) {
            System.out.print(" * 2");
        }
    } else {
        // n is an odd number
        System.out.print(n);
    }
}
```

Notes of the Restricted Experiments:
User 1: M. Inouye
Experience: Nearly none in Java. Asked a lot of Java-related questions
Q1: odds
Process:

- Tried printing out multiple cases
- Read through each line of code
- Ran through odds(1)
- odds(101) next, had trouble keeping track: 101, 10, 1, 0 with returns 101, 10, 1, 0
- 40:55 Understanding
- Removed *10, identified what was going on: Sum of odds
- Solution after a hint: want an answer in between these two
- 16:41 Solution (after understanding)

Difficulties:

- Integer permanence (confused about the parameter value not changing after calls)
- Trouble following return statements

Q2: printTwos (with tool)

Process:

- Tried a few numbers to see how it worked: Worked out that there were too many 2x's
- Tried n / 4 and n % 4: Saw that should only divide by 4 when n%4==0
- Tried printing 2 * twice instead of once
- Got answer, but flipped (Technically correct according to spec)
- 32:01 Solution

Difficulties:

- Trouble doing it recursively
- Got stuck after dividing by 4
- Had too many 2's at front

User 2: M. Lin

Experience: AP Computer Science

Q1: printTwos

Process:

- Drew out the print statements per call (on printTwos(24))
- Started doing random things
- Tried switching n /= 2 and printTwos call: Switched a few other calls to see what they did
- Began constructing solution from scratch
- Identified it as a %4 division
- 24:04 Solution

Difficulties:

- Too hard to think about it
- Math is too difficult (?) for this problem
- Found that the recursive case is too hard to implement around

Q2: odds (with tool)

Process:

- Went through tool with odds(12345)
- Identified a difference between evens and odds
- 5:53 Solution

Difficulties:

- Trouble separating evens and odds at first

User 3: M. Zhao
Q1: odds (with tool)
Process:

- Read through the code a few times
- Uses tool as a way of keeping track of values on the stack
- Identified the problem pattern, but not location quickly
- Removed the * 10 eventually
- Multiply by 10 “when it’s odd”
- 27:04 Solution

Difficulties:

- Wasn’t sure where to start

Overall takeaways:

- Tool has severe readability issues
- Problems may have relied too much on participant’s knowledge of math
- Overestimated the participant’s ability to understand recursion
- Participants had hesitations about changing any part of code: Perhaps a debugging issue, not a recursion issue?

Citations

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[9] JavaVisualizer.
https://cscircles.cemc.uwaterloo.ca/java_visualize/

[10] InfoVis Toolkit.
http://ivtk.sourceforge.net/

[11] LogicVis User Manual
https://github.com/orenjina/LogicVis/blob/master/User%20Manual.pdf

Feedback

Rashmi: Put a link to the user manual every time you mention it.

Response: We will put this by including the manual in our citations, and referring to the citations every time. This may not be exactly what was meant, but we figured it is cleaner this way.