Voice Programming in Computer Science Education

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1 Introduction

Our goal is to create a voice-enabled platform that uses machine learning to allow anyone to learn the fundamentals of computer science. Currently, we seek to reduce the amount of cognitive load required to introduce programming concepts, which would give more students the opportunity to study computer science.

Programming by voice looks to benefit both new and experienced programmers. We used Google Blockly, a simple visual coding library, and created a robust programming grammar on top of it so that anyone could use it regardless of age. In addition to discovering solutions to voice-enabled programming, our project will help teach computer science concepts to people who are unable to use a traditional mouse and keyboard.

1.1 What are the results or outcome of the project?

2 HCI Principles

Cognitive load, the amount of thinking required to complete a task, was the main focus when making design decisions. According to "The Limits of Speech Recognition" by Ben Shneiderman, certain applications of speech recognition can be successful as long as the designers of the application focus on creating an efficient and reduced grammar. Our grammar is the structure of language that is recognized by our speech recognition and it is built to be as simple as possible. Simplicity for the speech recognition aims at reducing cognitive load by reducing redundancy. In "Cognitive Load Theory" by John Sweller, the redundancy effect is when redundant information causes a user to understand the content less than if the redundant content was removed. Therefore, using a concise grammar for voice-programming, should decrease the cognitive load required for computer science education.

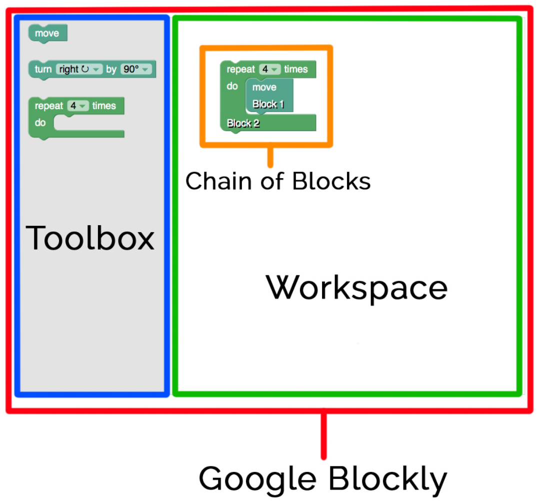


Figure 1: Google Blockly workspace diagram

3 Blockly

Google Blockly is a JavaScript library that creates a visual block programming environment where core computer science logic can be taught, such as conditionals and looping. Blockly is run in the web browser, which allows it to be used on any smartphone. We chose Google Blockly over other block based languages due to its easily extendible and customizable API.

Let us introduce some terminology here that would be used extensively in the paper moving forward. Blockly has the concept of a "workspace"(See figure1). This is the space where all the blocks that need to be executed in the program are located. A "chain of blocks" (See figure 1) is used to refer to a series of vertically-connected blocks in the workspace that are executed sequentially. In Google Blockly, it is also possible to several independent chains of blocks in the workspace. The order of execution causes the topmost chain of blocks to be executed first. The topmost chain is decided based on the highest vertical location of the first block in the chain. Normally, users interact with Blockly by looking at the workspace and adding blocks to the it by using a menu that holds the allowed blocks for a program. We will refer to this menu of allowed blocks as the "toolbox" (See figure 1). In order to move blocks from the toolbox to the workspace, users must click and drag using a mouse in a traditional Blockly setting.

The toolbox is where all the allowed blocks for a particular program can be found. Google Blockly has a large library of blocks, which can be grouped as:

- **Logic**: if statements and equality testing
- **Loops**: while loops, for loops, for-each loops and break statements

- **Math**: incrementing variables, summing numbers, randomizing numbers and other basic math and geometry operations.
- **Text**: displaying text, appending text, searching through text, substring, printing and prompting
- **Lists**: creating a list with variables, length, testing if empty and searching through a list
- **Color**: changing the color and random coloring
- **Variables**: creating a variable, initializing it and modifying its value
- **Functions**: a chain of blocks with a name and a possible return value

4 Speech

To reduce cognitive load, we focused on creating a concise and fixed grammar, i.e. there is only one way to say a command. While speech recognition can be used for a conversational style of programming, we wanted to mimic the standard idea that computer languages have a rigid grammar (or syntax).

To create a rigid grammar, we focused on how to make the grammar as simple and succinct as possible. It was important to use verbiage that came naturally as well. For example, instead of having two commands to either move a block above/below another block, we only supply the user to moving a block below another one. Reducing the grammar by even one command simplifies tasks, because instead of saying, "move block 1 above block 2" the user can simply use the opposite command and say "move block 2 below block 1".

The user has the following commands:

- Add - "get a ______ block"
- Connect - "connect block ___ under block ___"
- Connect inside - "connect block ___ inside block ___"
- Separate - "seperate block ___"
- Change field - "change ___ in block ___ to ___"
- Delete - "delete block ___"
- Run program - "run the program"
- Next level - "go to the next level"
- Stay on level - "stay on this level"

In order to execute the above commands, we use a parser to map interface commands to commands in the grammar. The parser extracts information on which action to execute and which blocks to manipulate if necessary, and passes the structured information to the workspace controller.

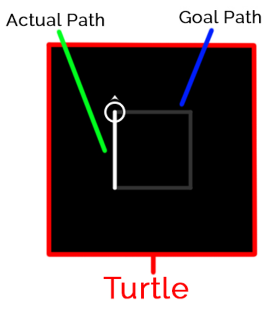


Figure 2: Turtle workspace diagram

4.1 How do the user interface commands described earlier map to the commands in the grammar?

5 Turtle

In order to implement the voice-programming interface using Blockly, we decided to use Turtle. Turtle is a Blockly game, that contains a turtle that can be moved around using a small subset of commands (blocks). The objective of the game is to make the turtle trace a particular path shown to the user, using only the provided blocks in the toolbox. Turtle is one of many Blockly games that we could have chosen in combination with Google Blockly and our speech recognition, but chose it for its simplistic design.

- **move**: moves the turtle forward
- **turn**: turns the turtle, can decide between left or right turning and angle of turning 1, 45, 72, 90, 120, 140 degrees
- **repeat**: repeatedly executes the blocks inside it, can decide to repeat either 2, 3, 4, 5 or 360 times
- **pen**: can decide between up/down, up stops the turtle from drawing a line, down makes the turtle's movements draw lines again

Turtle evenly divides computer science concepts into levels in order to reduce the cognitive load of the learner. Each individual level reinforces previously learned topics, while introducing new ones simultaneously. An example of a couple of consecutive levels would be as follows:

1. User is exposed to how to move the turtle forward and also turn the turtle to make a square. In order to make the square, the user is only give move and turn blocks, meaning they need four move blocks and three turn blocks to complete the task.

2. User is given a repeat block in the toolbox. Now the user is tasked at completing the same task as before, but with only using one repeat block, one move block and one turn block.

A user has now, in two levels, been first introduced to the mechanics of moving and turning the turtle in the Google Blockly environment and then naturally transitioned into loops. Since the task is simply “create a square”, it is not too difficult to utilize the new blocks provided, given the knowledge of previous levels.

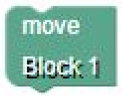
6 Speech recognition

We perform speech recognition using the Webkit Speech API in Google Chrome. The API provides us with the user’s speech, as understood by the speech recognition engine, in text form. We chose this option over CMU’s Sphinx because we wanted to get better recognition and the Google Speech API has been trained on a lot more data compared to CMU’s Sphinx engine which we could train on a limited and non-representative set of data that we would generate. Google’s Speech API is also easier to use and available in other web browsers (since this is primarily a web application).

7 Suggestions

We provide the user a list of suggestions to teach them the grammar. We do this because the grammar is a rigid, fixed grammar. Furthermore, we provide these suggestions because we don’t give any training in the grammar to the user. Instead, we hope that they can pick it up by following the suggestions. The suggestions mechanism provides generic suggestions, not specific to the block IDs or the workspace. We do not suggest how the user should solve the program, as the user might mistakenly believe. Instead, we simply teach them how to use the grammar. However, the appearance of particular suggestions is triggered by certain states of the workspace. For example, when an empty repeat block is on the canvas, we suggest that the user “Connect block 2 inside block 1” with these exact block IDs, regardless of what the block ID of the repeat block is. Finally, we provide an example in Table 1 of the suggestions box with the corresponding workspace before and after adding the first block. We modify the suggestions list when we believe it could be useful for the user. For example, when there is a repeat block on the canvas, we suggest that the user connects a block inside of the repeat block, to make use of the repeat block. However, our current suggestions system is quite limited.

Table 1: Example of suggestions before and after adding the first block to the workspace.

when	workspace	suggestions
before		"Get a move block"
after		"Get a move block" "Delete block 1" "Run the program"

8 Corrections

As previously described, we use the Google speech API built into Google Chrome to capture user commands. However, the API has a hard time understanding commands from our grammar. We hypothesize that the API expects ordinary English, and as a result, phrases like "get a turn block" or "change 4 in block 3 to 5" are often recognized incorrectly by webkitspeechcrecognition. We developed Algorithm 1 to correct incorrectly recognized phrases ("recognitions") to what we hope are the intended commands ("utterances").

The correction algorithm first takes in a recognition r, a workspace W, and a max modification factor (described later) λ. First, the recognition r is converted into a phoneme sequence ρ using a modified version of CMU's pronouncing dictionary [?]. Then we generate a set C of all possible commands that a user can specify given the workspace. For each command c, we convert it into a phoneme sequence γ and compute its edit distance e to ρ. We iterate over C to find the minimum edit distance e^* (breaking ties arbitrarily) and corresponding minimum edit distance command c^*.

Furthermore, if μ is too far from the original recognition sequence ρ, we reject the correction μ and notify the user that we didn't understand their command. We added this feature to avoid using a "correction" from a completely unrelated sentence picked-up or recognized by the speech API. Our notion of "too far" is satisfied when

$$e^* > \lambda * length(\rho)$$

As such, there is no fixed maximum number of edits, as this could give different performance for different string lengths.

8.1 Correction Algorithm Parameters

The correction algorithm requires the following parameters to run:-

- **Recognition**: The recognition of the utterance by the speech API.

Algorithm 1 Correction Algorithm

```
procedure CORRECT(r, W, $\lambda$)
    $\rho \leftarrow stringToPhoneme(r)$
    $C \leftarrow generatePossibleCommands(W)$
    $e^* \leftarrow \infty$
    $c^* \leftarrow r$
    $\gamma^* \leftarrow \rho$
    for $c$ in $C$ do
        $\gamma \leftarrow stringToPhoneme(c)$
        $e \leftarrow findMinEditDist(\rho, \gamma)$
        if $e < e^*$ then
            $e^* \leftarrow e$
            $c^* \leftarrow c$
            $\gamma^* \leftarrow \gamma$
        end if
    end for
    if $e^* \leq \lambda * length(\rho)$ then
        return $c^*$
    else
        return $r$
    end if
end procedure
```

- **Workspace**: The state of the workspace that contains information about the numbers and types of blocks currently present on the workspace.
- **Maximum Modification Factor**: The maximum percentage of modification (i.e. correction) allowed to the original recognition. The methodology to get calculate this number, is described in section 8.2.

8.2 Calculation of Maximum Modification Factor

8.2.1 Data Collection

The data was gathered manually by speaking into the speech engine and recording the utterance, recognition and correction (if it exists) in text form. The correct and incorrect utterances, along with their recognitions and corrections were stored as CSV files.

8.2.2 Statistical Procedure

The data containing the accuracy corresponding to each threshold value from 0.00 to 1.00 (with a step size of 0.01) was collected by running the analysis on both positive and negative data examples.

For the correct examples, the accuracy was obtained by counting the total number of correct corrections. In other words, we need to count the total number of times the recognition was corrected to the original utterance. For the incorrect examples, the accuracy was obtained by counting the total number of times corrections were not made - since corrections are always valid, mapping an incorrect utterance to a valid command is not correct.

Lastly, the maximum modification factor was calculated by using the threshold value that corresponded to the maximum average accuracy of the positive and negative examples. It is important to note that the average was calculated by weighing the categories equally, and not the examples.

8.2.3 Limitations

1. We had approximately 100 positive examples and 200 negative examples, and this is not the expected distribution of real-world data. In practice, we would expect a lot more positive examples than negative.
2. The negative examples were mostly random utterances that might be picked up by the microphone in a loud environment. In other words, these utterances didn't even come close to being recognized as a valid speech command. While this data might be useful when a lot of vocal activity is going on around the user, this does not serve any purpose in adapting the speech recognition to a user that is using the speech interface in a quiet environment (which is the expected behavior).
3. Sample size of approximately 300 examples is low.

8.3 Give an example of a common case that the corrections algorithm, as currently implemented, fails on

9 Layout

As the user writes a program, certain locations on the workspace fill with blocks. This presents a challenge: what should happen when blocks overlap with one another? For our system to be practically useful, it must avoid introducing such visual impairments, which may prevent the user from issuing commands (e.g. if they cannot see a block ID) or which may introduce unnecessary cognitive load.

Blockly by default places new blocks at the top left of the workspace, even if the new block will overlap an old block. Similarly, when Blockly connects one block to another, the resulting chain might overlap another chain.

We devise simple layout algorithms for each case. To make this formal, we view the workspace as a 2D plane W where the origin is the top left corner, the x axis ranges from 0 to $\textsc{Width}(W)$, and the y axis ranges from 0 to $\textsc{Height}(W)$. Let B denote the set of blocks on the workspace and let m denote a small, constant margin. In our implementation, we choose $m = 20$ (pixels) because it is small enough to preserve space on the workspace, and large enough to prevent Blockly from automatically connecting nearby blocks.

Adding Blocks We place new blocks by finding the vertically lowest free position on the workspace and placing the new block there, exactky m pixels right of the toolbox. This is summarized by Algorithm 2.

Moving Blocks Suppose the user has just connected one block to another, and the resulting chain now overlaps n chains. We repair the layout by moving the n conflicting blocks individually via Algorithm 3.

Algorithm 2 Place New Block

```
procedure PlaceNewBlock($B, m$)
    $\ell \leftarrow m$                                ▷ stores lowest $y$ on the workspace
    for $b \in B$ do
        if $y_b + \text{HEIGHT}(b) \geq \ell$ then
            $\ell \leftarrow y_b + \text{HEIGHT}(b) + m$
        end if
    end for
    return $(m, \ell)$
end procedure
```

Algorithm 3 Relayout Existing Block

```
procedure Relayout($b, B, W, m$)
    $x \leftarrow m$
    while $x < \text{WIDTH}(W)$ do
        $y \leftarrow m$
        while $y < \text{HEIGHT}(W)$ do
            if CanMoveWithoutConflict($b, (x, y)$) then
                Move($b, (x, y)$)
            end if
            $y \leftarrow y + m$
        end while
        $x \leftarrow x + m$
    end while
    Move($b, (m, m)$)
end procedure
```

10 Related Work

10.1 What is the related work in speech interfaces for programming?

10.2 What is the related work in speech interfaces for computer science education?

11 Future Work