Animation of the Contextual Analysis and Code Generation Phases of a Compiler

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Level 4 Project — January 1, 2000

Abstract

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Contents

Chapter 1

Introduction

With increasing technological advances and furthering levels of software abstraction, some may consider compilation to be a slightly esoteric subject, in that, broad knowledge of compilation theory is unnecessary in a modern environment and required only in a small number of highly specialised industries. Yet, remaining as a cornerstone of a computer science curriculum at many schools and universities is the art of compiler construction, behaviour and optimisation. Why is this?

When questioned on the necessity of teaching compilation, Niklaus Wirth, the creator of the *Pascal* programming language and renowned lecturer of compiler design remarks, "*knowledge about system surfaces alone is insufficient in computer science; what is needed is an understanding of contents*" [7]. Wirth's view is one that many share, in the respect that the most successful computer scientists must have more than a superficial understanding of which approaches to follow in a given situation. They must understand how various components interact and why they behave the way they do. To gain a true understanding of the building blocks of computer science is to gain a greater insight into the scientific and mathematical concepts within the field, which provides the most effective means of making informed technological decisions.

Compilation theory is a foundational notion of computer science, upon which a larger syllabus can be developed. To students, the benefits of learning about compilation are perhaps not in its direct application, but in its ability to act as the stepping stone that facilitates a more comprehensive grasp of other concepts; concepts which themselves are grounded in compilation theory.

1.1 Motivation

Compilation can often be a challenging field to teach effectively. Many components of compilation involve the generation and traversal of complex, abstract data structures. Abstract, conceptual notions such as these are notoriously difficult for students to understand. We desire to find a solution which provides concrete representations of these abstract ideas.

In response to this problem, a common approach employed by educators is to attempt to illustrate the compilation process. The educator typically creates some type of "slideshow", using an application such as Microsoft PowerPoint. The slides contain a pictorial representation of the data structure in question, and each slide demonstrates a distinct step of the traversal over that data structure.

Whilst using a slideshow is currently the only practical way to demonstrate these concepts, it has two main drawbacks. Firstly, to create illustrations in this way is an arduous task for the educator, realistically meaning that the demonstration must remain short. Secondly, and more importantly, the educator is restricted to showing only pre-determined examples. Since there is effectively an infinite number of ways the compilation process may occur depending on the input, pre-determined examples are almost guaranteed to omit certain details, making it difficult for students to achieve a broad and complete understanding.

1.2 Aims

This project aims to alleviate or solve many of the issues currently faced in attempts to create effective visualisations of various compilation concepts. The project will provide a web application in which users will be able to animate the ***contextual analysis*** and ***code generation*** phases of the ***Fun*** compiler. The animation will incorporate a representation of an ***abstract syntax tree*** (AST).

Contextual analysis and code generation are two different stages of compilation which aim to validate certain aspects of the compiler's input and construct some appropriate output. The behaviour of these stages is expressed by traversals over an AST. An AST is a data structure that represents the hierarchical syntactic structure of a section of code. Fun is a simple, educational programming language equipped with a compiler. Chapter 3 introduces all of these concepts in considerably more detail.

The application will allows users to supply programs written in the Fun language as input to the Fun compiler. The application will then animate the contextual analysis or code generation phase of the compiler. The mechanics of each phase will be illustrated by "jumps" over the input program's AST, demonstrating the traversal that is internally taking place within the compiler. In general, the application should:

- Allow a user to input any syntactically valid program written in the Fun language.
- Visualise the contextual analysis phase of a program's compilation.
- Visualise the code generation phase of a program's compilation.
- Augment the animation with explanatory messages that provide insight into the logic of the compiler.
- Augment the animation with any relevant auxiliary data structures.
- Allow the animation to be played, paused or stepped through (backwards and forwards).

This application will act as a teaching tool, equally useful to educators and students alike. Students are free to use the tool outside of school/university hours in order to further their own learning. Additionally, since any arbitrary Fun program can be compiled, the restriction to educators of showing only pre-determined examples is removed. Finally, the level of automated analysis attainable from the application is considerably greater than anything currently possible by present techniques. It will hopefully provide a better means for those looking to learn but also remove some of the struggle taken on by educators in teaching the topic.

1.3 Outline

The rest of this report is organised as follows: Chapter 2...

Chapter 2

Background & Related Work

Despite the animation of compilers being a considerably novel area of research and development, attempts to visualise computing algorithms date as far back as the 1980s [2]. The vast majority of work in the field up to now has been focused on the animation of complex, yet small and well-defined algorithms, most notably sorting algorithms or tree traversals.

Indeed, compilation is certainly not small nor particularly well-defined (in that the behaviour of the compiler can vary significantly depending on the implementation), however, many aspects of typical algorithm animations (such as tree traversals) can be found in abundance within a potential compiler animation. Ultimately, compilation itself is just an algorithm, and it would seem logical to assume that any lessons learnt during the development and evaluation of existing algorithm animation software should be equally applicable to the area of compiler animation.

The remainder of this chapter considers research done which attempts to evaluate the effectiveness of algorithm animation from an educational perspective. We then explore and critique some modern examples of web-based algorithm animation tools. Finally, we discuss how we might use the results of prior evaluations along with our analysis of existing products to influence our design of a compiler animator.

2.1 Effectiveness of Algorithm Animation

One of the earliest algorithm animation systems was developed by Bentley and Kernighan in 1987 [2]. The system enabled users to annotate sections of an algorithm which were later processed by an interpreter to create a sequence of still pictures; an example of which is shown in Figure 2.1. In the very first line of the system's user manual Bentley and Kernighan confidently state, "*Dynamic displays are better than static displays for giving insight into the behaviour of dynamic systems*". This belief of Bentley and Kernighan is one that many of us would intuitively believe. The intuition being that when attempting to understand any multi-step process, an animation which displays each step of that process is more effective than a single static diagram, or a section of explanatory text. However, it is important to consider whether this belief has statistical backing or whether it is simply an assumption. Certainly, in 1987 algorithm animation itself was still in its infancy and no studies had been carried out that provided the empirical evidence to support this intuition.

Six years later in 1993 Stasko, Badre and Lewis were amongst the first to consider whether algorithm animations assisted learning as much as we might think [3]. Stasko, Badre and Lewis carried out a study which involved attempting to teach students the concept of a "pairing heap", with one group using textual descriptions of the algorithm, the others using an animation. Stasko then repeated a similar experiment in 1999 with Byrne

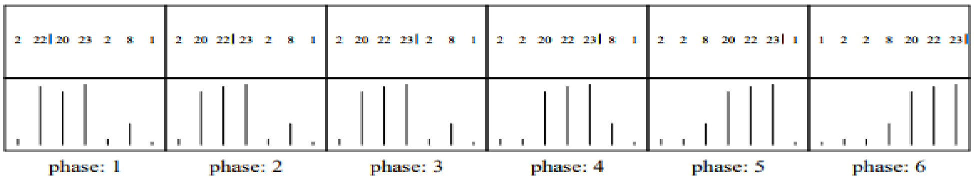


Figure 2.1: A sequence of stills from an insertion sort algorithm

and Catrambone in which one group used an animation and the others used static visualisations (such as diagrams from a textbook), instead of textual descriptions like in the previous experiment [4]. In both studies the researchers found the results to be disappointing. They found that whilst students in the animation group did perform moderately better than their textual or diagrammatic counterparts, the improvement was not statistically significant.

Despite computer graphic capabilities improving significantly since the 1990s, other more recent studies have all shown the same results. The general consensus being that whilst animations do provide a small benefit, it is certainly not as large as our intuition would lead us to believe. However, that is not to say that algorithm animations are without use. Stasko, Badre and Lewis suggest that algorithm animations are not particularly effective when students are trying to learn a concept for the first time, but is likely to be much more suitable when students are looking to refine their understanding of a particular notion. The theory is that students should ideally learn the primitive concepts of the algorithm using conventional methods initially, then transition to using animations when looking to clarify and solidify their understanding of certain aspects.

Stasko, Badre and Lewis also reveal a list of guidelines they believe to be effective advice when building algorithm animations, some of which are summarised below:

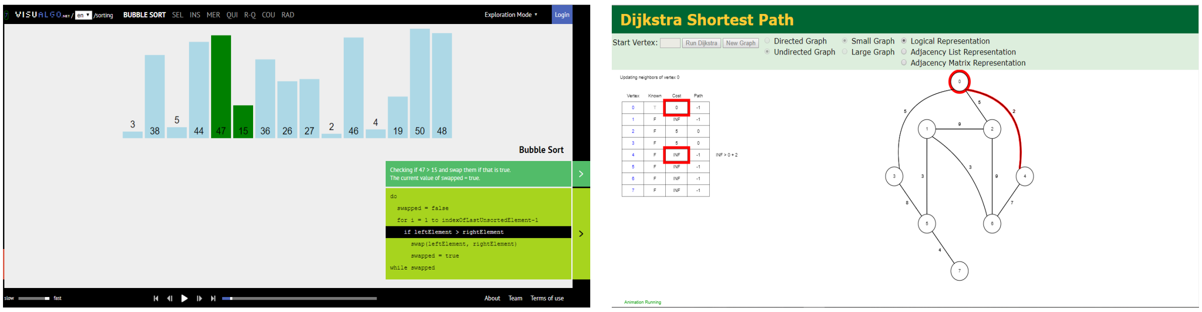
- The animation should be augmented with textual descriptions.
- The animation should include rewind-replay capabilities.
- Students should be able to build the animation themselves.

These guidelines suggest that algorithm animations require accompanying messages that explain the logic of the algorithm at each step. Also, the animation should be interactive in order to engage students in "active learning" over "passive learning". This interactivity would include intricate controls over the playback of the animation and the ability to modify the input of the algorithm.

2.2 Existing Products

Currently, very few existing tools provide even static illustrations of compilation components (such as syntax trees) and virtually no tools exist that create animations of the compilation process as a whole. There are however, an abundance of web applications that animate more straightforward algorithms, such as sorting or searching algorithms.

One of the most popular and well implemented is VisuAlgo [6]. VisuAlgo provides an interface for animating various sorting algorithms, including bubble sort, selection sort, etc. As shown in Figure 2.2a, Visualgo implements many of the guidelines we previously listed. It provides impressive playback controls, the ability to choose the input of the algorithm and displays in-depth descriptions of the current step in the algorithm, in both plain English and pseudo-code.



(a) VisuAlgo (b) The University of San Francisco

Figure 2.2: Animations of different algorithms from different applications

Moving away from pure sorting algorithms, the University of San Francisco developed a small web application which animates Dijkstra's algorithm [5], as shown in Figure 2.2b. Dijkstra's algorithm is arguably more complicated than many sorting algorithms, involving the need to visualise tables and graphs. However, we see that at the expense of this complexity, the application has sacrificed several usability aspects in comparison to VisuAlgo. You cannot define your own input and you cannot pause or rewind the animation. Additionally, whilst some very primitive details are displayed next to the table at each stage, they are far from informative explanations.

2.3 Discussion

Despite studies showing that algorithm animation is not as effective as we might have initially believed, it would seem that the surprisingly poor performance is due to specific circumstances which could be alleviated if the environment in which an algorithm animation tool was targeted for use was selected more carefully.

The studies found that algorithm animation was less effective in novice students who were learning the algorithms for the first time, yet could be an effective tool for students who are looking to revise particular concepts. Consequently, any future algorithm animation tool should likely act as a secondary learning resource. Ideally, students should have been taught the concepts using conventional methods to begin with, then the educator can distribute the application to students who can utilise this as a means to refine and clarify understanding.

When considering the previous guidelines proposed by Stasko, Badre and Lewis and how they might affect algorithm animation software, it appears a potential system should:

- Provide supplementary textual explanations that rationalise and justify the logic of the algorithm.
- Include rewind-replay functionality that allows the animation to be restarted, or played step-wise, backwards and forwards.
- Ensure users can create the animation themselves by allowing them to modify the input to the algorithm.

After analysing some examples of current products that are available in the area of algorithm animation, such as VisuAlgo and the University of San Francisco's Dijkstra's algorithm animator, it seems there is a trade-off between complexity and usability. In order to animate a considerably more complex algorithm, the University of San Francisco sacrifices much of the visual support and playback control that VisuAlgo is able to provide.

However, a tool based on compiler animation would need to include both aspects of complexity and usability. The tool would implement an algorithm that is certainly more complex and volatile than even Dijkstra's algorithm, but in order to be educationally effective, it also needs to provide the display of highly input-dependent analytics and implement the usability and interactivity features such as playback control that are embedded within the guidelines of the previous studies.

Chapter 3

The Fun Programming Language & Compilation Theory

This chapter aims to briefly introduce the reader to the main tools and concepts used throughout this paper. This includes a small overview of the Fun programming language, syntax trees and the various phases of compilation.

3.1 The Fun Programming Language

Included in Niklaus Wirth's 1975 book *Algorithms + Data Structures = Programs*, was a language written entirely in Pascal named "PL/0". PL/0 was intended as a small educational programming language, used to teach the concepts of compiler construction. The language contains very primitive constructs and limited operations. Similarly to PL/0, "Fun" is a simple imperative language built using ANTLR [1], developed at Glasgow University by David Watt and later extended by Simon Gay. Its purpose is to illustrate various general aspects of programming languages, including the construction of an elementary compiler. The language is provided as a supplementary aid during the delivery of the level 3 computer science course, *Programming Languages*, at Glasgow University.

The Fun programming language has a ***flat block structure***. A flat block structure means that variables can have either a local or a global scope, and that the same identifier may be used to declare a local and a global variable. [Add more here...].

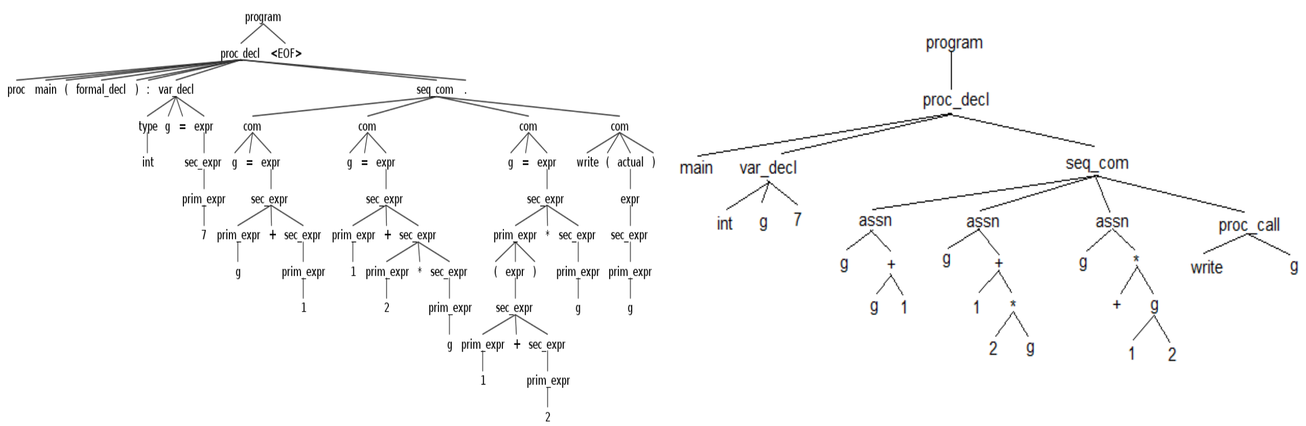
Whilst Fun may differ significantly to other programming languages, particularly in its complexity, it is not the case that the concepts illustrated are exclusive to the Fun language or the Fun compiler. Fun is sufficiently generic that the core concepts can be explained in an easily understandable format (due to the simplicity of the language), which then facilitates learners in applying the same logic to more complex constructs in other languages.

3.2 Syntax Trees

A syntax tree is simply a hierarchical representation of a source program; with global statements towards the root, and more deeply nested statements towards the leaves. We typically consider two types of syntax tree: the concrete syntax tree (often called a parse tree) and the abstract syntax tree (AST). A parse tree contains an exact representation of the input, retaining all information, including white-space, brackets, etc. Conversely, an abstract syntax tree is a smaller, more concise representation of the parse tree. An AST usually ignores words and characters such as white-space, brackets and other redundant details which are derivable from the shape of the tree.

During compilation, the compiler will traverse one or sometimes both types of tree, depending on the language implementation. The compiler usually visits each node in the tree in a "depth-first" manner, perhaps with some small variations. These traversals constitute the contextual analysis and code generation phases of a compiler, which validate certain aspects of the input and produce the output of the compilation.

From a visual point of view, ASTs are considerably easier to read and understand. Any information that is lost from the conversion of a parse tree to an AST is purely semantic and does not affect how the tree is evaluated. Consequently, when attempting to demonstrate the data structures built during compilation to students, it is much more productive to show an AST, as opposed to a parse tree. Figure 3.1 illustrates the visual differences between a parse tree and an AST of the same hypothetical Fun program. We can immediately observe how large and difficult to read Figure 3.1a is, in comparison to Figure 3.1b. There are many unnecessary tokens, such as EOFs, brackets and colons which obfuscate the diagram. The parse tree also contains many paths consisting of multiple unary branch nodes, which could easily be collapsed into a single edge. Beyond visualisation, it's worth noting that there can also be large computational advantages of using an AST within the compiler's implementation as they are usually much easier to manipulate and require less memory; however, the compiler of the Fun language does not happen to take advantage of this.



(a) Parse Tree/Concrete Syntax Tree

(b) Abstract Syntax Tree

Figure 3.1: The ANTLR generated parse tree and the theoretical AST of the same Fun program

3.3 Compilation Phases

Compilation is the process of automatically translating high-level code into low-level code. The most common case is to convert a program whose source code is written in some programming language, into an executable program. This compilation process can usually be decomposed into three distinct phases:

a) *Syntactic Analysis*

b) *Contextual Analysis*

c) *Code Generation*

If either syntactic analysis or contextual analysis encounters an error (as specified by the language) during its

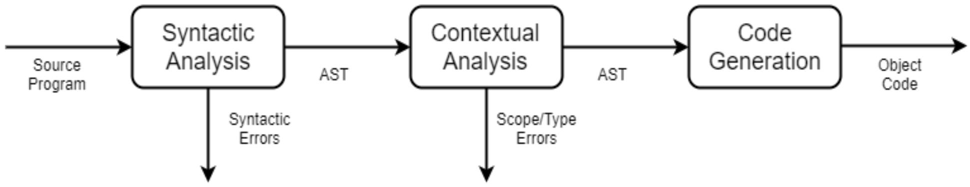


Figure 3.2: Compilation Pipeline

execution, that particular phase completes, the remainder of the compilation process is halted and the errors are reported to the programmer. See Figure 3.2 for a diagram of a typical compilation pipeline.

3.3.1 Syntactic Analysis

Syntactic analysis takes a source program as input and upon success, produces an AST. The purpose of syntactic analysis is to verify whether the source program is well-formed in accordance to the source language's syntax rules. Syntactic analysis can be broken down into ***lexing*** and ***parsing***.

Lexing is the process of breaking down an input program into a stream of ***tokens***. A token is simply a single element of the input program. For example, a token could be an individual identifier, operator or keyword. How the compiler chooses to define tokens is dependent upon the implementation of the language. The token stream is then passed as input to the parser. Figure 3.3 shows how a small excerpt of Fun code may be decomposed into a token stream.

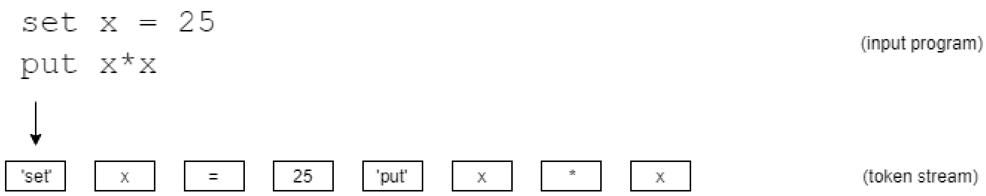


Figure 3.3: Lexing of Fun code into a token stream

A parser converts a token stream into an AST using some parsing algorithm. The Fun compiler uses ***recursive-descent*** parsing. Recursive-descent parsing involves "consuming" the token stream from left to right. At each token, the parser checks whether the next sequence of tokens are of the correct type, as determined by the language's syntax. The parser carries out this check for every token in the stream. If any checks fail, a syntax error is reported to the programmer. If all tokens are consumed successfully, the parser outputs an AST representing the parsed program.

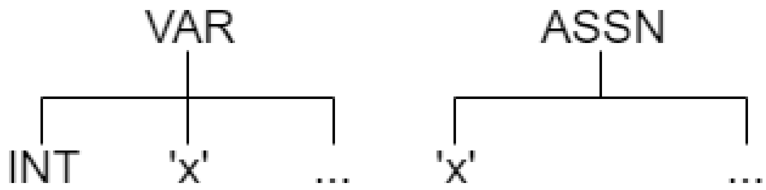
3.3.2 Contextual Analysis

Upon successful completion of syntactic analysis, the generated AST is traversed by a contextual analyser. A contextual analyser checks whether the source program represented by the AST conforms to the source language's scope and type rules. Contextual analysis utilises an auxiliary data structure called a ***type table*** in order to help carry out these checks. Each row of the type table contains three fields of information about a declared variable: its scope (which as discussed in Section 3.1 can be local or global), its identifier and its type. Figure 3.4 demonstrates a small example. The identifier "x" is used twice to declare an integer in both global and local scope and the identifier "main" is used to declare a function which takes no parameters and returns no value. Contextual analysis can be broken down into ***scope checking*** and ***type checking***.

Scope	Identifier	Type
global	'x'	INT
global	'main'	VOID -> VOID
local	'x'	INT

Figure 3.4: Type Table

Scope checking ensures that every variable used in the program has been previously declared. If the contextual analyser encounters the *declaration* of an identifier as it is traversing over the AST, it inserts the identifier along with its scope and type into the type table. If the contextual analyser finds that there is already an entry in the table with the same scope and identifier, then a scope error is reported to the programmer. Similarly, if the contextual analyser encounters the *usage* of an identifier during the traversal, it checks that the identifier is already in the type table (i.e., has been previously declared). If the identifier cannot be found in the type table, then a scope error is reported to the programmer. Figure 3.5 shows snippets of an AST which illustrate the declaration and usage (assignment) of the same variable. Assuming global scope, in Figure 3.5a we would insert an entry with identifier “x”, type “INT” and scope “global” into the type table. In Figure 3.5b, we would lookup “x” in the type table to ensure it has been previously declared.



(a) Variable declaration (b) Variable usage

Figure 3.5: AST snippets demonstrating the declaration and usage of a variable “x”

Type checking ensures that every operation has operands of the expected type. The rules the contextual analyser uses to determine if an operation has the “correct” operands vary from construct to construct. For example, referring back to Figure 3.5b, we see the usage of a variable. In this case, we are assigning the value of some expression, represented by “...”, to the variable “x”. When the contextual analyser encounters this construct during the traversal, it will retrieve the type of “x” from the type table, then traverse the expression to determine its type. The contextual analyser will then check that the type of the expression is the same as the type of “x”. For example, if we assume that “x” is an integer, “x = 5 + 10” would be a valid assignment, whereas “x = ‘hello world”’ would result in a type error.

3.3.3 Code Generation

Upon successful completion of contextual analysis, the generated AST is traversed by a code generator. A code generator translates the source program into a lower level language, such as assembly language or object code. Code generation utilises an auxiliary data structure called an ***address table***. Each entry in the address table contains three fields of information about a declared variable: its scope, its identifier and its address. Figure 3.6 demonstrates an example similar to Figure 3.4. The identifier “x” has been allocated an address of 0 in the address space allocated to global variables and an address of 2 in the address space allocated to local variables. The identifier “main” has been allocated an address of 7 in the address space allocated to object code instructions. Code generation can be broken down into ***address allocation*** and ***code selection***.

Scope	Identifier	Address
global	'x'	0
code	'main'	7
local	'x'	2

Figure 3.6: Address Table

Address allocation decides the representation and address of each variable in the source program. If the code generator encounters a variable declaration as it is traversing over the AST, it determines a suitable address for that identifier and inserts both values along with the corresponding scope into the address table.

Code selection selects and generates the object code. Upon successful completion of this final phase, the compiler will have often produced an executable program.

Chapter 4

Requirements

This chapter initially discusses the methods via which the requirements of this project, which we will henceforth refer to as the *FunCompiler*, were collected and established. The remainder of the chapter lists the FunCompiler's user stories, functional requirements and non-functional requirements.

4.1 Methodology

The requirements of the FunCompiler were elicited through two main techniques. Firstly, through multiple interviews with Simon Gay. Simon is the current lecturer of the Programming Languages course at Glasgow University. Since both the Fun language and the compilation of Fun programs are delivered during the Programming Languages course, students enrolled in this course will naturally be the target user-base of the FunCompiler. Thus, Simon clearly has the expertise and the experience to offer valuable recommendations on the function and operation of the FunCompiler.

The second technique was to simply utilise the insight gained from performing background research. In particular, we strive to ensure the requirements meet the three guidelines we saw in Section 2.1, proposed by Stasko, Badre and Lewis. Below, the three guidelines have been rephrased to apply directly to the FunCompiler:

- Guideline a) Provide supplementary textual explanations that rationalise and justify the logic of the compiler as it visits each node in the AST.
- Guideline b) Include rewind-replay functionality that allows the compilation animation to be restarted, or played stepwise, backwards and forwards.
- Guideline c) Ensure users can create the animation themselves by allowing any arbitrary Fun program as input to the compiler.

4.2 User Stories

After conducting the interviews and the background research, a set of user stories was devised. User stories are short and simple descriptions of a feature, told from the perspective of a potential user:

User Story	Description
1	As a user, I want to read details of the Fun language, so that I can write valid Fun programs as input and better understand the compilation animations.
2	As a user, I want to be able to input any Fun program, so that I can learn about the compilation process in the general case, not just for specific examples.
3	As a user, I want to be able to view the animation of the contextual analysis phase of my program, so that I can understand how the compiler carries out this task.
4	As a user, I want to be able to view the animation of the code-generation phase of my program, so that I can understand how the compiler carries out this task.
5	As a user, I want to be able to play different sections of the compilation animation independently (i.e., contextual analysis or code generation), so that I can focus my learning on specific areas.
6	As a user, I want to be able to see textual descriptions that explain what the compiler is doing at each stage of the animation, so that I can better understand the logic of the compiler.
7	As a user, I want to be able to see any supplementary information or feedback (including address/type tables, code templates and generated object code), so that I get all the information available in order to help further my understanding.
8	As a user, I want to be able to replay an animation, so that I can review any details I missed/misunderstood.
9	As a user, I want to be able to step through the animation at my own pace, so I can more easily understand what is happening during the animation.

4.3 Functional Requirements

After creating user stories and using any previous research, a formal list of functional requirements was created. Functional requirements are intended to capture a specific function of a system:

Along with implementing the core functionality of a compiler animator (along with a few extra features), it is clear to see from functional requirements **1**, **6**, **7**, **8**, **9** and **10**, that we have more than comfortably included the elements necessary to satisfy guidelines a), b) and c).

Functional Requirement	**Description**
1	Allow users to input any arbitrary Fun program as input to the compiler animator.
2	Allow users to animate either contextual analysis or code generation separately.
3	Display the generated AST that represents the input Fun program.
4	Enable a controllable animation over this AST representing one of the two phases (contextual analysis or code generation).
5	At each step of the animation, highlight the corresponding node in the AST.
6	Allow users to play the animation continuously.
7	Allow users to pause the animation.
8	Allow users to move forwards through the animation, one step at a time.
9	Allow users to move backwards through the animation, one step at a time.
10	At each step of the animation, display messages that explain the logic of the compiler, i.e., what it is currently doing, or what it is going to do.
11	At each step of the animation, display the type table (if contextual analysis) or the address table (if code generation) in its current state during the compilation.
12	During code generation, display the code template of each node as it is visited.
13	During code generation, display the emitted object code in its current state during the compilation.
14	If a user inputs a syntactically invalid Fun program, prevent the animation and report the errors to the user.
15	If a user inputs a contextually invalid Fun program, allow animation of the contextual analysis phase but disallow animation of the code generation phase and report the errors to the user.
16	Make the full specification of the Fun language available within the web application.

4.4 Non-functional Requirements

In contrast to functional requirements that detail specific behaviours of a system, non-functional requirements often consider overall utilities of a system, such as security, usability and extensibility:

Non-Functional Requirement	**Description**
1	The application must work on all modern browsers.
2	The application must be able to interact efficiently with a Java-based application (the Fun compiler).
3	The application must be responsive, at least to a tablet level.
4	The application must ensure no malicious code can be executed

4.5 Analysis

In overview, a typical workflow for the FunCompiler might look as follows: firstly, the user arrives at the website and should be able to view the specification of Fun language before needing to use the animator. Then, the user can type a Fun program into some kind of code editor and choose to animate either contextual analysis or code generation. At this point, if there were any syntactic or contextual errors, they would be reported to the user using the semantics as defined above.

After selecting one of the two phases, the AST that represents the input program is displayed on screen along with playback buttons (play, pause, forwards, backwards). As the animation progresses, nodes within the AST are highlighted to symbolise the current progress of the compiler. As each node is highlighted, detailed information as described above is simultaneously displayed elsewhere on screen. The user is of course free to pause the animation to review the current information displayed, or rewind to review. At any point the user may modify the current input Fun program and select either the same or a different compilation phase, which will halt any current animations.

This potential workflow of the FunCompiler is enough to meet all functional requirements. The non-functional requirements cover issues that are strictly more technical, the solutions to which will be discussed during the system design and the physical implementation.

Chapter 5

Design

This chapter covers the aesthetic design process of the FunCompiler. We develop simple low-fidelity wireframe designs of the individual components of the user interface and consider how these different components might satisfy our functional requirements. We then look at a more complete design of the user interface and use "storyboards" in an attempt to illustrate an extended version of the workflow we saw in Section 4.5. Finally, in order to make the website compatible across different screen sizes, we consider a responsive design of the application.

5.1 User Interface

This section analyses the functional requirements of the FunCompiler and develops a list of potential interface components. Each component includes a wireframe design and an explanation of its purpose. We also consider how each component may realise one or many of the functional requirements (FRs).

5.1.1 Fun Specification

Since most users of the FunCompiler will be students enrolled in the Programming Languages course at Glasgow University, they will likely already have access to the full specification of the Fun language. However, embedding the Fun specification within the web application is valuable for two reasons. One, it is simply a matter of convenience, students will be able to find all the resources they need in one place. Two, inclusion of the specification helps not preclude the possibility that users could be non-students, as they would not have access to the specification otherwise.

As seen in Figure 5.1, the specification consists of seven sections. Tabs along the top allow the user to navigate between each section. Each section contains varying amounts of information to explain each concept (FR **16**).

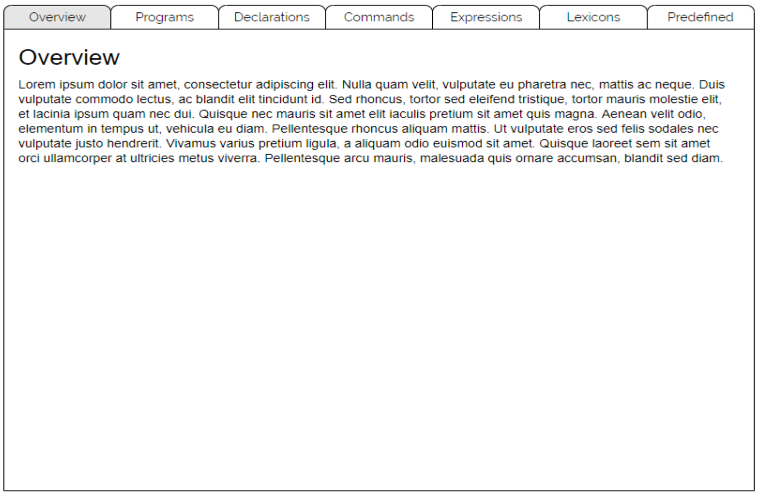


Figure 5.1: Fun Specification Wireframe

5.1.2 Code Editor

The code editor will be the area where the user inputs a Fun program. Ideally, the code editor should follow some semantics of standard programmatic text editors, including syntax highlighting and auto-indentation.

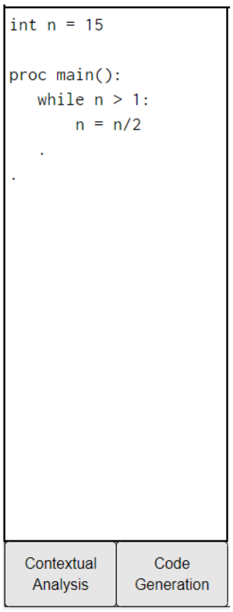


Figure 5.2: Code Editor Wireframe

Figure 5.2 shows the code editor with some example code inserted (FR **1**). Also notice that we have attached “Contextual Analysis” and “Code Generation” buttons to the bottom of the code editor. These buttons will allow the user to submit the input text and animate the respective phase (FR **2**).

5.1.3 AST

As previously stated, the animation will be performed over an AST. The AST will be displayed in a conventional tree format, where the animator will highlight each node in the AST, corresponding to the progress of the compiler.

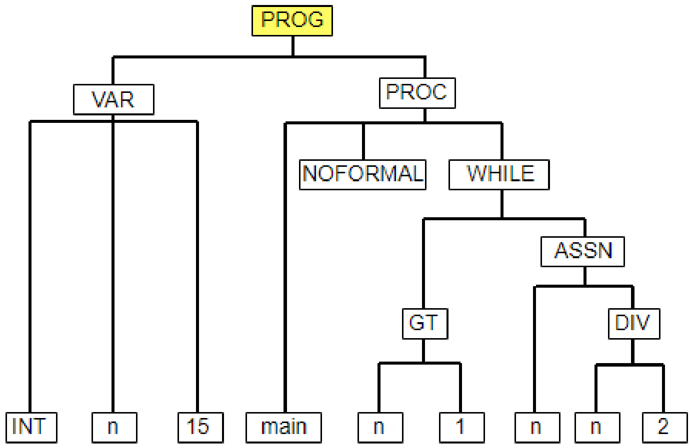


Figure 5.3: AST Wireframe

Figure 5.3 shows the structure of an AST for the Fun program used in the previous code editor wireframe. The highlighted "PROG" node symbolises the traversal of the compiler (FR **3, 5**).

5.1.4 Playback Controls

Users require access to controls that play, pause and move through the animation step-wise, backwards or forwards.

(a) Play

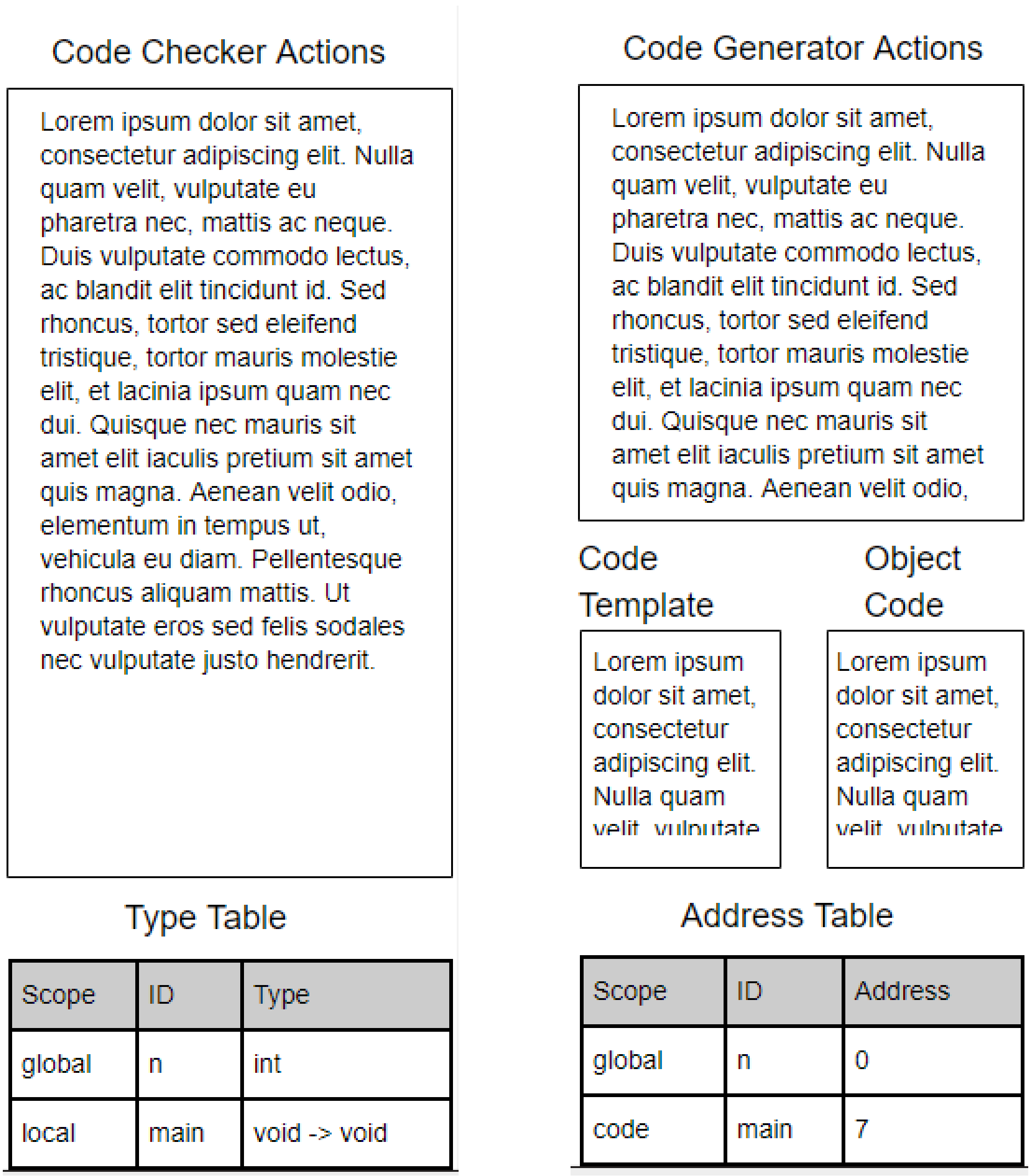
(b) Pause

Figure 5.4: Playback Controls Wireframe

Figure 5.4 shows two sets of playback controls (FR **4**). Intuitively, when the play button is pressed, it should be replaced with the pause button and vice versa. If the user pressed the play button, the animator will highlight the next node in the sequence at a regular time intervals (for example, every second) (FR **6**). If the user presses the pause button, the currently highlighted node should remain highlighted (FR **7**). If the user presses the forwards/backwards buttons, this will highlight the next/previous node in the sequence, one node per button press (FR **8, 9**). If the animation is currently playing when a forwards or backwards button is pressed, it should be implicitly paused.

5.1.5 Analytics

As the animation progresses, analytical information relevant to the current stage of the traversal should be displayed. The information displayed differs slightly depending on whether the user is animating contextual analysis or code generation.



(a) Contextual Analysis (b) Code Generation

Figure 5.5: Analytics Wireframe

Appendices

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