F21MP

Masters Project and Dissertation

Script execution made simple with SML/NJ

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# Declaration of Authorship

I, Dayanandan Natarajan, declare that this thesis titled, 'Script execution made simple with SML/NJ’ and the work presented in it is my own. I confirm that this work submitted for assessment is my own and is expressed in my own words. Any uses made within it of the works of other authors in any form (e.g., ideas, images, text, tables, programs) are properly acknowledged at any point of their use. A list of the references employed is included.

Signed: Dayanandan Natarajan

Date: 01/05/2023

# Abstract

“Standard ML (SML) is a safe, modular, strict, functional, polymorphic programming language with compile-time type checking and type inference, garbage collection, exception handling, immutable data types and updatable references, abstract data types, and parametric modules”. Developers of compilers, programmers, and others collaborating with theorem provers have used it to create formal proofs [1]. A free and open-source compiler called SML/NJ offers an SML programming environment. While it does not evaluate, SML/NJ processes the instructions in a manner like the well-known REPL (Read-Eval-Print-Loop) approach. It reads, parses, does type checks, compiles, links, runs, and modifies global environments. It loops back through the full cycle until all the instructions have been carried out. The term "script" in this article refers to a file containing source code which are also executable files. SML/NJ doesn’t have the capability to execute a script. *smlnj-script* originally developed by project supervisor Dr Joe Wells, gave the capability to build SML scripts in a file and run like regular operating system files. Additional features include support for Unicode and regular expressions. *smlnj-script* is a slightly modified version of SML/NJ which gives the capability to execute SML programs as a script. *smlnj-script* is written as a layer on top of SML/NJ. This dissertation aims to add and merge all *smlnj-script* features into SML/NJ and eliminate the need to maintain *smlnj-script* as a separate implementation. Students, programmers, and developers will benefit from the ability to write SML programmes in a script and have them run like Python or Perl.

# Acknowledgements

I would like to thank my supervisor Dr Joe Wells for his support, guidance and knowledge sharing on this topic.

# List of Abbreviations

SML Standard ML.

SML/NJ Standard ML of New Jersey.

CM Compilation and Library Manager (a component of SML/NJ).

JSON JavaScript Object Notation.

REPL Read-Eval-Print Loop (In SML world REPL is used to denote read, parse, type check, compile, link and execute.)

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# 1. Introduction

## Basic Concepts

This paragraph will aid readers in understanding the purpose. The majority of programming languages break down the execution of a program's source code into stages like compilation, linking, and execution. In contrast to certain other programming languages like Python and Perl, where the programme can be run straight from the source code, the user must conduct or provide instructions for each phase in the former languages. Additionally, in some programming languages, running a programme on the command line requires passing the instructions through a wrapper script, which necessitates the need of two files. One of the main goals of this project is to execute an SML programme in one step using just one file.

## Aim

SML is a procedural language that supports higher-order functions and abstraction. Developers of compilers, programmers, and others collaborating with theorem provers have used SML to create formal proofs [1]. Though SML/NJ (a free and open-source compiler) offers an SML programming environment, it doesn’t evaluate and processes the instructions in a manner like the well-known REPL (Read-Eval-Print-Loop) approach. It reads, parses, does type checks, compiles, links, runs, and modifies global environments. It loops back through the full cycle until all the instructions have been carried out. SML/NJ doesn’t have the capability to execute a script (file containing source code which are also executable files). *smlnj-script* originally developed by project supervisor Dr Joe Wells, gave the capability to build SML scripts in a file and run like regular operating system files. Additional features include support for Unicode and regular expressions. *smlnj-script* is a slightly modified version of SML/NJ which gives the capability to execute SML programs as a script. *smlnj-script* is written as a layer on top of SML/NJ. This dissertation aims to add and merge all *smlnj-script* features into SML/NJ and eliminate the need to maintain *smlnj-script* as a separate implementation. Students, programmers, and developers will benefit from the ability to write SML programmes in a script and have them run like Python or Perl.

The project's goal is to make it easier for college students to complete their class assignments so they can create and execute SML programmes as a script. Additionally, the project seeks to cooperate with SML/NJ implementors to include these new capabilities and have SML/NJ published in the future.

## Objectives

The SML-NJ code will be examined for suitable places where the *smlnj-script* features can be added or merged. Before merging with SML/NJ, *smlnj-script* features will be evaluated for compatibility with the most recent version of SML/NJ and will be modified to meet new standards. SML/NJ implementors will be given information on the new features, and we'll work to have them included in a future version.

## Stakeholder

Below are the stakeholders of this work.

|  |  |
| --- | --- |
| Stakeholders | Interests |
| *Primary:* | *Have direct relationship to the project* |
| Dayanandan Natarajan (myself) | Student working on this project. |
| Joe Wells | Supervisor and original author of *smlnj-script*. |
| SML/NJ Implementors | They are the maintainers of SML/NJ and publish the SML/NJ upgrades. |
| *Secondary:* | *Have indirect relationship to the project* |
| Students | Beneficiaries of the resultant product. |
| Programmers | Beneficiaries of the resultant product. |
| Developers | Beneficiaries of the resultant product. |

# 2. Literature Review

## Standard ML (SML ’90 & ‘97)

Standard ML ‘90 is a procedural language that supports higher-order functions and abstraction very strongly because it is highly typed. SML maintains fairly similar to the λ-calculus in terms of syntax and semantics. The language has undergone a minor change and simplification to become Standard ML '97. A new SML base library was included with the language definition to allow a variety of systems and applications programming. It has a large selection of pre-defined modules that include fundamental types, input/output capabilities, and interfaces for portable operating system interaction [6].

The highlights and the principal language changes are,

1. Imperative type variables are terminated. The value restriction now performs the function of imperative type variables in limiting polymorphism when effects are present. A value expression (right-hand side) is formed from these components using products and constructions and can be either a constant, a variable, a function expression, or it can be any combination of these. [6].
2. *structure* sharing is terminated. A weaker interpretation of *structure* sharing notation is that it is a covert technique of expressing type sharing. The role of type sharing is slightly constrained to avoid clashing with type definitions [6].
3. Type definitions are added in *signatures*. Additionally, a new where type notation makes it possible to change an existing *signature* by defining the type components that make up the signature. A datatype can be defined to be the same as an existing one thanks to new kinds of datatype specifications and definitions [6].

## Implementations of SML

There are multiple variants of SML implementations available, from interpreters to byte-code compilers, to incremental compilers, to whole-program compilers. The two main capabilities which differ them are REPL and FFI. An interactive top-level read-eval-print-loop (REPL) capability enables users to enter specific top-level SML declarations, which are subsequently parsed, type verified, executed (either as machine code or as interpreted code), and the results are displayed. FFI (foreign function interface) enables calling of SML from other languages as well as functions in C libraries and other languages [7].

Some of the main implementations are

* MLton
* SML/NJ
* Poly/ML
* SML#

## SML/NJ

SML/NJ is an open-source compiler and programming environment for SML, which was developed at Bell Labs. It was initially created in collaboration between Princeton University and Bell Laboratories. Currently, researchers from Bell Laboratories, Princeton University, Yale University, and AT&T Research are working together on the project. The most recent version of SML/NJ implements the Standard ML language's SML '97 revision, including the standard basis library. The SML/NJ source code is provided without charge or warranty. In accordance with the relevant licence and copyright notice, anybody may use, copy, modify, and distribute the software [8].

Except for the runtime system, which is written in C, SML/NJ is primarily written in Standard ML. Numerous big systems have been implemented using it, particularly in the areas of applied logic and verification, programme analysis, and advanced compilers [8].

Some of the major features of the SML/NJ system are below [8],

1. An interactive top level based on incremental compilation is offered by SML/NJ.
2. SML/NJ uses Compilation Manager (from Matthias Blume), to simplify the development of large software projects.
3. A range of general-purpose data structures, algorithms, and utilities are offered by the SML/NJ library (such as finite sets and maps, regular expressions, pretty-printing). The other main SML implementations also use SML/NJ library and are periodically resynchronized. SML/NJ library not necessarily denoted as SML/NJ.
4. [Concurrent ML](http://cml.cs.uchicago.edu/) library supports the concurrent programming in SML.
5. eXene is a Concurrent ML-based graphical interface toolkit for X-windows.
6. Higher-order functors, OR-patterns (logical "or" operations), first-class continuations, and other helpful features are added to the SML '97 language by SML/NJ.
7. Higher-order *functors* are mapping between two categories. It is a module that take one or more other modules as a parameter. It allows for a generic type to apply a function inside without changing the *structure* of the generic type [18][19].
8. First-class continuations are continuations used as values. Continuations can be the value of a variable, an argument for a function call, or the return value of a function. It can be considered as a function since it takes a value and produces a value [17].
9. A simple quote/anitquote mechanism offers support for manipulating "object languages". It prevents the shell's growth of the special shell meta-characters. The command arguments contain the protected characters passed along [20].

## Programming Process – Compile, Link and Execute.

A program written in any programming language needs to be compiled and linked before execution. Programming languages vary in this process; they can be categorized as compiled or interpreted programming languages based on how they are compiled, linked, and executed. Both have their own strengths and weaknesses. The consumption is determined based on time constraints on programme development or ongoing maintenance. Because each line of an interpreted programme must be translated before execution, using an interpreted language pays off development speed for greater execution costs. Programs that are interpreted are less effective than those that are compiled. [15][16].

Compiled Programming Languages

The source code for programming languages like C/C++ must be translated into an executable file using a compiler. The final executable file is extremely effective and has an infinite number of executions. Once the source code is compiled, an executable translation takes place, and from that point forward, only loading and executing are required [15][16].

Diagram

Description automatically generated

Image1: Compiled Languages (ex: C/C++) [16].

Interpreted Programming Languages

Every time a programme is run, the source code must be parsed, interpreted, and executed in programming languages like Python and Perl. The expense of running the software goes up as a result.

Diagram

Description automatically generated

Image2: Interpreted Languages (ex: Python/Perl) [16].

Programming language like Java doesn’t fit either in compiled or interpreted language, they have their own compiler which converts the source code into byte code which can be run on any machine using their own interpreter.

## SML/NJ Compilation and Execution

When SML/NJ is started over the command line, it gets loaded and prompts to enter a top-level declaration through keyboard. When a top-level declaration is given to the prompt with a termination character semicolon (‘;’); SML/NJ understands the end of declaration and starts to process the declaration. “SML/NJ performs the following actions: elaborate (performs type checking and static analyses), compile (obtain executable machine code), execute, and finally print the result of this declaration” [22].

Rather than typing the program in top-level declarations it can be put together in a single file and loaded into SML/NJ system. SML/NJ processes the instructions using a method similar to the well-known REPL (Read-Eval-Print-Loop) methodology, though it does not evaluate. It reads, parses, does type checks, compiles, links, runs, and modifies global environments. It repeats the entire cycle in loops until all the instructions are processed. Once all the declarations in the program have been compiled and executed, dumping creates a completely pre-compiled version of the program that can start-up faster.

At any given point of time, the snapshot of application’s memory called as heap dump contains information in binary format, they contain information like objects in memory, their values, their size, and reference to other objects [23]. SML/NJ gives the capability to ship a program heap; upon loading a file in to SML/NJ compiler, it gets parsed, compiled, and executed. Dumping saves the system heap into a file. This file, which is a virtual memory image and not an executable, can be exported [22]. The exported heap can be executed by feeding the argument of the heap file to SML over a shell script.

Compilation and Library Manager (CM) is used for managing the compilation of SML programs and its required libraries. SML programs can be be organized into separate modules with its own source file with CM. It also allows each module to be compiled independently, and compiled code to be linked together to form a complete program. Each module is compiled and linked in the proper order thanks to CM's management of inter module dependencies. This helps to prevent problems with circular dependencies and guarantees that the programme is successfully compiled and linked.

A library manager is another feature of the CM system that enables the management and usage of SML libraries in SML programmes. An assortment of SML modules that can be utilised in various SML programmes make up a library.

With a separate source file for each module, libraries can be provided using the library manager in the same way that modules are. The library manager also handles the dependencies between modules in the library, ensuring that they are compiled and linked in the correct order. When a library is used in an SML program, the library manager automatically handles the loading and linking of the required library modules.

Overall, the CM system provides a powerful and flexible way to manage the compilation and linking of SML programs and libraries. By organizing programs and libraries into separate modules and managing the dependencies between them, CM helps to ensure that SML programs are correct, reliable, and maintainable [24]. CM gives the capability to load a specific file from the libraries which are precompiled. It can be loaded and added into the memory image whenever required.

To execute a SML program, the end-user needs to have two files, a program, and a wrapper script. The SML program will be run using the instructions in the wrapper script. For example, to run a program ‘helloworld.sml’ there should be wrapper script ‘helloworld.sh’ available with instructions as below,

#!/bin/sh  
sml /full/path/of/directories/to/helloworld.sml

## *smlnj-script*

*smlnj-script* program is an extension to SML/NJ implementation. In SML/NJ, reading, parsing, type checking, compiling, linking, execution, modify global environments and looping happens in separate phases and the program is executed through instructions in a wrapper script. Unix has a special support for script; with a special instruction (program name preceded by a sharp-exclamation) inside the script, the path that was initially used when attempting to start the script is passed to the interpreter programme that is given by the loader as an argument, allowing the programme to use the file as input data [14]. *smlnj-script* is an extension to SML/NJ and designed to perform all the operations in a single phase through a single file like Python or Perl. It also includes run time machinery, with additional utility functions defined and a specialized start-up routine.

The script makes use of the following capabilities,

1. All the features of the SML language (as implemented by SML/NJ).
2. The portion of the SML Basis Library that is provided by the SML/NJ implementation.
3. The SML/NJ library.
4. Additional functions provided as part of SmlnjScriptUtils *structure*.

SML/NJ scripts only type check, parse and compile each top-level form as it is encountered, which evaluates a string (using SmlnjScriptUtils.useString) or file (using “use”) at run-time to supply definitions which will allow the top-level forms to be type-checked later.

## What happens when *smlnj-script* gets loaded

When *smlnj-script* is loaded, it dumps the entire virtual memory image (of everything that’s loaded in SML/NJ at that moment) into a heap file, converts the file into assembly code, gets assembled by an assembler into a binary file which can be executed at a later stage. Upon execution it recreates a memory image and starts it up again.

## Key features of *smlnj-script*

The *smlnj-script* has the following key features,

1. Dumping and Creating executable:

SML/NJ gives the ability to dump and load back contents of virtual memory in the form of heap image into a file. When a SML is started again (later), by passing a special command line instructions through another script, the contents of the memory can be discarded and loaded with the contents of the heap image. *smlnj-script* uses SML/NJ’s built-in utility functions *exportML* to save the heap image (current state of SML/NJ) in a file [22], *exportFN* to save the current state in the form of a function (function upon restarting takes in shell command-line arguments) in a file [22], and ‘heap2exec’ to convert heap image into an executable which can be run faster. ‘heap2exec’ wraps the binary SML/NJ runtime image and converts heap image into one executable. It makes use of built-in utility ‘heap2asm’ to build a stand-alone executable from the image [25], which can be used at a later stage.

This dissertation planned to explore the use of heap2asm to generate the assembly code for the heap image. This gives the single-phased single-file capability.

1. Silencing the Compiler:

Running a script through *smlnj-script* goes thru this redevelopment loop, cycle of read, parse, type check, compile, links, execute and modify global environment. The compiler produces bunch of output messages printed for each operation which is going to confuse the user especially when there is a compilation error. silenceCompiler function gives the capability to turns off these compiler messages like print of the name, type, and value of all identifiers that get added to the top-level environment, autoloading and compilation error messages. This completely silences the compiler and hides type error messages. There is no option to turn off the messages while keeping the error messages [10]. silenceCompiler function intercept the compiler messages, accumulates these messages, and stores them in a variable to be printed to the user at a later stage when there is a compilation error or program crashes.

val silenceCompiler : unit -> unit = SmlnjScriptUtils.silenceCompiler

1. Overloading toString function:

SML/NJ has the limitation on overloading toString operator especially with complex types like constructors with arguments. To print out a list of integers or real numbers or float data types a custom-built function is needed. The toString overloading function needs further improvement and advancements to support string functions.

The toString (and %) overloaded operator:

val % : 'a -> string = ...

val toString : 'a -> string = ...

The % and toString operators are both overloaded operators to convert many types into strings. They are equivalent to Int.toString, Bool.toString, Real.toString, etc. There is a room for improvement to add support for more types, provided the type is “atomic” with SmlnjScriptUtils.extendToString [10].

1. The SmlnjScriptUtils structure:

The SmlnjScriptUtils *structure*, denoted by the short name ‘U’, is a collection of functions with its own features.

structure SmlnjScriptUtils = ...

structure U = SmlnjScriptUtils

Some of those functions,

* + 1. The raisePrintingLimitsToMax function:

val raisePrintingLimitsToMax : unit -> unit = ...

The function is very useful while debugging and the default limits cause too much of the data structures to be truncated when printed by the compiler [10].

* + 1. The interact and continue functions:

val interact : unit -> unit = ...

val continue : unit -> unit = ...

The function interact provides an interactive “read-eval-print loop” (REPL), and the function continue resumes execution by returning from a call to interact [10].

* + 1. The extendToString function

val extendToString : string -> unit = ...

The function extendToString extends the top-level overloaded operators toString and % with an additional case. Supply the name of a function of type T -> string where T is an “atomic” type. The type T is atomic when it is a type name without arguments and there is no definition available in scope that allows the compiler to deduce it is equal to a non-atomic type [10].

* + 1. The evalString and useString functions:

val evalString : string -> unit = ...

val useString : string -> unit = ...

Both evalString and useString enter into a loop of parsing the string to find a prefix that is a top-level SML form, type checking and compiling this form, and executing the resulting machine code, and then repeating with the rest of the string. The difference is that evalString throws any new top-level definitions away when it is done and returns (only their side-effects persist) while useString extends the top-level environment with the new definitions when it returns. In both cases new top-level definitions are available for remaining forms processed during the call to evalString or useString [10].

* + 1. The StringSet and StringMap *structures*:

structure StringSet : ORD\_SET = ...

structure StringMap : ORD\_MAP = ...

The *structures* StringSet and StringMap provide implementations of sets and finite maps (finite maps are sometimes called “dictionaries” or “associative arrays”) for the type “string”. The operations available are defined in the ORD\\_SET and ORD\\_MAP *signatures*, which are part of the SML/NJ library [10].

* + 1. The q and qq quoting functions:

val q = SmlnjScriptUtils.q

val qq = SmlnjScriptUtils.qq

The functions q and qq are abbreviations for things in SmlnjScriptUtils, giving you a compact syntax for writing strings with stuff spliced into a string template. These operators are intended to be used with SML/NJ’s quasiquote syntax to make quoting operators [10]. The quasiquote syntax is also supported by Moscow ML and the ML Kit, but is not supported by some other major SML implementations like MLton and Poly/ML.

To illustrate, here are some expressions that evaluate to true:

let val x = 7 in q`The value of x is ^(% x)!` = "The value of x is 7!" end

let val y = "Jack" in qq`My name is ^y.\n` = "My name is Jack.\n" end

In the above code, the use of ‘% x’ is a use of toString feature. Both ‘q’ and ‘%’ are two independent features, combined together they give the capability to print a string in middle of a string or include value of a variable. The difference between q and qq is that qq interprets SML-style escape syntax in the literal text while q does not. For example, this evaluates to true:

q`This is not a newline: \n` = "This is not a newline: \\n"

The names q and qq are loosely inspired by Perl’s q and qq operators [10].

This dissertation planned to add these functions into SML/NJ.

1. CM Autoloading:

Some of the libraries which come with SML/NJ as part of Compilation and Library Manager are not loaded initially. It needs some expertise to load these libraries which is unusual for an end user. *smlnj-script* loads such libraries and make them available to the user, one of the common is regular expression library. This eliminates the need for end user’s knowledge on CM.autoload.

1. Parse, Eval & Format:

Parse, Eval & Format gives the capability to make use of compilers ability to pretty print data which it has for implementing the redevelopment loop. In the last phase of the loop the results are printed out, SML/NJ has built-in ability to print out results of many types though they are not ordinarily available to the end users and programmers. At the end of each iteration loop this stores the value of the expressions which need to be printed out in a variable. It ignores the irrelevant part and keeps only the relevant part. This helps to convert the data of many types to strings.

1. Parser Combinators:

Parser Combinators gives the capability to operate on streams of arbitrary types rather than just streams of chars. This allows to implement Unicode support using the utf8 encoding.

1. UTF8 processing:

This module provides a structure with types and utility functions to work with Unicode characters written in utf8. It also provides structure with definitions which are needed during bootstrap and normal use. This gives the ability to create stream of Unicode characters from a stream of bytes (old style ASCII characters).

1. Process function:

*smlnj-script* gives a value-added interface on top of the subprocess handling available in SML/NJ.

1. XML Wrapping:

This module is derived from a SML XML library and works of Tom Murphy VII. It’s used to parse XML files.

1. Utility functions:

*smlnj-script* have utility functions to handle basic data operations and load required libraries. Structures String and CharVector have good overlap, some members in CharVector don’t have no equivalents in String and the same goes for Substring and CharVectorSlice. The function is customized to give the capability of string repetitions, concatenations, comparison, and conversion operations. One of the capabilities is to auto load JSON library, so that end user need not to load the JSON library.

This dissertation planned to add these functions into SML/NJ.

## How to run a *smlnj-script*

In UNIX, to execute a file or script, it needs to have ‘execute’ permissions and it should start with a hashbang character followed by the path to the interpreter and any optional argument as follows,

#!PATH-TO-INTERPRETER OPTIONAL-ARGUMENT

*smlnj-script* file also follows the same. The script should start with,

#!/usr/bin/env smlnj-script

where /usr/bin/env is the path to the directory where *smlnj-script* is located.

The Interpreter can be invoked directly passing it the name of the script as its first argument. For example, to run a script ‘HelloWorld’ with three arguments arg1, arg2 and arg3, the interpreter can be invoked as below,

smlnj-script HelloWorld arg1 arg2 arg3

The script ‘HelloWorld’ should have ‘execute’ permission.

## How to work with SML/NJ

Users can invoke SML by typing the key word ‘SML’ over command prompt in Windows or terminal in Linux, which will load SML in interaction mode,

$ sml

Standard ML of New Jersey (32-bit) v110.99.3 [built: Sun Apr 16 18:42:54 2023]

-

Users can break the interactive mode and come out of SML by issuing the keyboar shortcut ‘Ctrl+D’ or by issuing the SML command (OS.Process.exit OS.Process.success).

$ sml

Standard ML of New Jersey (32-bit) v110.99.3 [built: Sun Apr 16 18:42:54 2023]

- ^D

$

Users can type in the instructions line by line with the delimiter semicolon (‘;’) at the end of line. The semicolon denotes the end of line and instructs the compiler to process the line thru REPL.

$ sml

Standard ML of New Jersey (32-bit) v110.99.3 [built: Sun Apr 16 18:42:54 2023]

- val x = "Hello World\n";

val x = "Hello World\n" : string

- print x;

Hello World

val it = () : unit

-

If an instruction is not delimited by a semicolon, the compiler will assume the instructions are continuing in next line and wait for a semicolon to mark the end of the instruction and submit it for REPL.

- val x = "Hello World\n"

= ;

val x = "Hello World\n" : string

- print

= x

= ;

Hello World

val it = () : unit

-

## What happens when SML/NJ is loaded

Now we know when a user invokes SML, an interactive system gets loaded and available to the user so that the instructions are keyed-in line by line to get processed. Let’s go little deep into what happens after the SML is invoked and before the interactive terminal is presented to the user.

SML/NJ is built on both C and SML language. The key functions to interact with the operating system are written in C and the additional functions on top of it are written in SML. If we look closely into the installation log of SML, we can understand this, all the C programs will be compiled and loaded to create a run file and followed by all SML code, parsed, compiled and loaded (which generates a heap image). The run file made of C binaries is an executable which takes the heap image as argument to load the SML.

Log from terminal when SML is invoked,

$ sml

CMD=`basename "$0"`

basename "$0"

++ basename /usr/local/smlnj/bin/sml

+ CMD=sml

…

…

…

exec "$RUN" @SMLcmdname="$0" "$HEAP" $ALLOC "$@"

+ exec /usr/local/smlnj/bin/.run/run.x86-darwin @SMLcmdname=/usr/local/smlnj/bin/sml @SMLload=/usr/local/smlnj/bin/.heap/sml

Standard ML of New Jersey (32-bit) v110.99.3 [built: Sun Apr 16 18:42:54 2023]

-

C executables starts the boot process which creates a boot environment and loads default basic functions creating a pervasive environment for the interactive system. When the boot environment is loaded, it looks for any command line arguments supplied by user and if there is any, appropriate action is performed. The pervasive environment is binded with basic functions like arithmetic operations, string operations, infix binding of symbols and overloaded bindings that use overloaded declarations. When the interactive system is made available to the user, not all the structures are pre-loaded, only the structures which contains the basic functions are loaded. Not all the structures are loaded to minimize the usage of memory and to optimize the performance. Auto-loading process helps to load the necessary libraries in the pervasive environment. A select few important libraries are set up to automatically load and are made available in the top-level environment as needed.

# 3. Requirements Analysis

## Functional Requirements

The following are the functional requirements originally planned to be analyzed, built, tested, and delivered.

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Requirement Description** | **MoSCoW** | **Priority** |
| 1 | Identify the right module and merge *smlnj-script*’s single-phased single-file capability into SML/NJ. | M | High |
| 2 | Identify the right module and merge *smlnj-script*’s SilenceCompiler function into SML/NJ. | M | High |
| 3 | Identify the right module and merge *smlnj-script*’s toString overloading capability into SML/NJ. | M | High |
| 4 | Identify the right module and merge *smlnj-script*’s CM Autoloading capability into SML/NJ. | M | High |
| 5 | Identify the right module and merge *smlnj-script*’s Parse, Eval & Format functions into SML/NJ. | M | High |
| 6 | Identify the right module and merge *smlnj-script*’s Parser Combinators capability into SML/NJ. | M | Medium |
| 7 | Identify the right module and merge *smlnj-script*’s Utf8 processing capability into SML/NJ. | M | Medium |
| 8 | Identify the right module and merge *smlnj-script*’s Process functions into SML/NJ. | S/C | Low |
| 9 | Identify the right module and merge *smlnj-script*’s XML Wrapping capability into SML/NJ. | S/C | Low |
| 10 | Identify the right module and merge *smlnj-script*’s Utility functions into SML/NJ. | S/C | Low |

## Non-Functional Requirements

The following non-functional requirements planned to be analyzed, built, tested, and delivered.

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Requirement Description** | **MoSCoW** | **Priority** |
| 1 | Usability – End users, programmers, developers, and students should be able to use this final product to run the scripts with minimal effort. | M | High |
| 2 | Stability – The final product should be stable enough to run the scripts without getting crashed. | M | High |
| 3 | Reliability – The final product should be capable to producing accurate results. | M | High |

## Evaluation

The single-phased single-file processing of the finished product will be assessed. Without the need for a wrapper script, a user should be able to create an SML program in a single flat file by beginning the first line with "#! path-to-interpreter" and continuing with SML code in successive lines. The finished product will also be assessed for portability; users should be able to turn an SML program into an executable and use it afterwards. We'll assess the end product's reliability, stability, and usage. Show the SML/NJ maintainers the changed version for consideration of inclusion in the upcoming release.

# 4. Methodology

This dissertation's major objective is to incorporate *smlnj-script* capabilities into SML/NJ in order to do away with the necessity to maintain *smlnj-script* as a separate addition to SML/NJ. To determine where to incorporate *smlnj-script* capabilities, the SML/NJ core code will be examined. It is necessary to evaluate and investigate SML/NJ’s Compilation and Library Manager to discover the proper incantations and make advantage of its capacity to carry out efficient autoloading without requiring the script writer to possess in-depth knowledge of SML/NJ. We will investigate the built-in utilities of SML/NJ, such as "exportML," "exportFn," "heap2exec," and "heap2asm," to implement a better interface for portability and single-phased single-file executions. Before merging with SML/NJ, *smlnj-script* features will be evaluated for compatibility with the most recent version of SML/NJ and will be modified to meet new standards.

The project's goal is to introduce new features to SML/NJ implementors so they can be included in a later release. In the event of a redistribution, the initiative will assist licencing agreements between HWU and SML/NJ implementors. We anticipate that HWU will either unilaterally licence the project code under the same conditions as SML/NJ or will assign its copyright interest in *smlnj-script* to "The Fellowship of SML/NJ," with either course of action being discussed with SML/NJ maintainers before moving forward.

# 5. Professional, Legal, Ethical, and Social issues

## Professional Issues

* This project conforms to the terms and conditions of the SML/NJ licence and use of all software and technologies provided by HWU in line with their terms of licence and terms and conditions.
* If SML/NJ implementors agree to the change, this project will be included back into SML/NJ with the appropriate licencing approval from Dr. Joe Wells and HWU for utilising *smlnj-script* features.
* Any open-source software from a third party that is utilised will receive due acknowledgement.

## Legal Issues

* This project adheres to HWU's licencing policies and any source code protected by intellectual property rights is reused.
* If an agreement between HWU and SML/NJ implementors is necessary to add project features to SML/NJ, it will be arranged. If the agreement is unsuccessful or if either party is unwilling, the project shall remain the property of the author and HWU.
* For any exploitation and dissemination of third-party content, formal approval from the contributors will be obtained.

## Ethical Issues

* No human survey has been done or will be done; this project is a technical implementation on top of an existing open-source tool; it does not involve any sensitive personal data of an individual. Only source code and author information are gathered for this project.

## Social Issues

* This project stores source code and compiler information, as well as personally identifiable information like author names, which are both preserved and cited in the project papers.

# 6. Project Risk Assessment

The following risks have been identified, impact analysed, and mitigated.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Likelihood** | **Impact** | **Mitigation** |
| Author’s medical emergency. | Medium | High | Work with supervisor and University for extension. |
| Supervisor’s medical emergency. | Medium | High | Work with University and personal tutor for additional support. |
| Loss of project artifacts. | Low | Medium | Periodic backup will be taken in Github and University locations. |
| SML/NJ releases a new update. | Low | Low | Features that are planned to merge with SML/NJ will be modified to adapt to latest update from SML/NJ. |
| Unavailability of technical information | High | High | Reach out to SML/NJ implementor for details. |
| Project gets delayed and overrun planned timeframe. | Medium | Medium | Hight priority requirements will take precedence. |
| Software not compatible with Author’s hardware. | Low | Low | University resources will be utilized. |

# 7. Implementation

## Software and Hardware used

SML/NJ version 110.99.3 (32 bit) was used on an Intel based MacBook pro with macOS 10.13.16. Though SML has latest versions 2021.1 and 2022.2 with 64-bit support, we encountered issues with few structures like Backend which are recognised by SML but unable to load its associated structures and functions in interaction mode. We finally decided to use 110.99.3 32-bit version of SML since 32-bit support stopped with 110.99.3.

Default SML implementation doesn’t come with source code. SML has to be manually installed with the support for source code update and recompilation. Once the installation files are downloaded from SML/NJ download site, the targets file in *config* folder need to be updated to request for source code before installation. This will enable the capability to update the source code, rebuild and reinstall SML.

## Files modified

The following files ins the SML/NJ library were amended to include the *smlnj-script* capabilities in to SML/NJ,

* smlnj/base/cm/main/[cm-boot.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/cm-boot.sml)
* smlnj/base/system/smlnj/internal/[boot-env-fn.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/boot-env-fn.sml)
* smlnj/base/compiler/TopLevel/interact/[interact.sig](https://github.com/dn2007hw/SMLNJScripts/blob/main/interact.sig" \o "interact.sig)
* smlnj/base/compiler/TopLevel/interact/[interact.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/interact.sml" \o "interact.sml)
* smlnj/base/compiler/TopLevel/backend/[backend-fn.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/backend-fn.sml)
* smlnj/base/compiler/TopLevel/backend/[backend.sig](https://github.com/dn2007hw/SMLNJScripts/blob/main/backend.sig" \o "backend.sig)
* smlnj/base/compiler/TopLevel/interact/[mutecompiler.sig](https://github.com/dn2007hw/SMLNJScripts/blob/main/mutecompiler.sig" \o "mutecompiler.sig) (New component)
* smlnj/base/compiler/TopLevel/interact/[mutecompiler.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/mutecompiler.sml" \o "mutecompiler.sml) (New component)
* smlnj/base/compiler/[INDEX](https://github.com/dn2007hw/SMLNJScripts/blob/main/INDEX)
* smlnj/base/compiler/[MAP](https://github.com/dn2007hw/SMLNJScripts/blob/main/MAP)
* smlnj/base/compiler/[core.cm](https://github.com/dn2007hw/SMLNJScripts/blob/main/core.cm)

## Change details

The following section will detail the changes that are made in SML/NJ to add the features of *smlnj-script*,

### [cm-boot.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/cm-boot.sml)

cm-boot.sml is the very first file that is loaded when the CM system is invoked. It contains the basic definitions and functions that are needed to initialize the system. Some of the key structures and functions are defined in this file. Structure CM is defined with main functions like CM.make, CM.recompile, and CM.sources to manage the compilation process. Functor LinkCM (which is linked with Structure Backend) is defined with key functions and one such is to process the command-line arguments passed by user through functions ‘args’ and ‘carg’.

Based on the command-line arguments passed, appropriate functions are invoked, if a file is passed as an argument, its passed thru function ‘processFile’ for further processing. In ‘processFile’, the file extension is evaluated for and put through another function ‘useFile’ for extensions ‘sml’, ‘sig’ and ‘fun’, and function make for extension ‘cm’.

In addition to that it also defines the basic error handling and exception handling functions that are used throughout the CM system. These functions are used to handle errors and exceptions that occur during the compilation process in a more efficient way.

cm-boot.sml plays a vital role in initializing the CM system and providing the basic functionality that is needed for managing the compilation of SML programs.

The following changes were made in cm-boot.sml to recognise the new command line parameter passed from script.

1. ‘init’ function is the point of entry for all the functionalities defined in cm-bool.sml. It’s been called with other key functions imported from other structures as arguments. A new function ‘useScriptFile’ added in Structure Interact is been added as an additional argument to ‘init’ function. Purpose and usage of ‘useScriptFile’ will be detailed in the upcoming sections.

fun init (bootdir, de, er, useStream, useScriptFile, useFile, errorwrap, icm) = let

1. Function ‘procCmdLine’ is one of the key functions in cm-boot.sml which process the command-line instructions and arguments. A new function ‘processFileScript’ is added as a sub function to ‘procCMdLine’. ‘processFileScript’ takes the script file name passed as argument, performs a validation through function ‘checkSharpbang’, consumes the contents of first line through function ‘eatuntilnewline’ and calls the function ‘useScriptFile’ to process the script. The ‘useScriptFile’ function is called with file name and its content in the form of stream as arguments.

fun processFileScript (fname) = let

val stream = TextIO.openIn fname

val isscript = checkSharpbang stream

in

if (isscript) = false

then ( Say.say [ "!\* Script file doesn't start with #!. \n" ] )

else ( useScriptFile (fname, stream) )

end

1. Function ‘checkSharpbang’ takes file stream as an argument, which is called with the script file contents as a stream from the calling function. The function is used to verify whether the first line of the stream starts with ‘#!’. In that case the function returns a Boolean response ‘true’ and if the stream doesn’t start with ‘#!’ then the function returns the Boolean response ‘false’.

fun checkSharpbang (instream : TextIO.instream): bool = let

val c = TextIO.input1 instream

in

case c of

SOME #"#" => (

case TextIO.lookahead instream of

SOME #"!" => eatuntilnewline instream

| SOME c => false

| NONE => false

)

| SOME c => false

| NONE => false

end

1. If the file that come in as an argument to function ‘processFileScript’ is confirmed as script by function ‘checkSharpbang’, then the contents of first line of the script until the new line character ‘\n’ is consumed since the REPL won’t be able to process the first line. The first line of the script starting with ‘#!’ is more for the operating system to understand and SML won’t be able to understand the instructions. To consume the first line of the script function ‘eatuntilneline’ is called with the script file stream passed as an argument.
2. Function ‘eatuntilneline’ will consume all the characters in the script first line until a new line ‘\n’ character is encountered. Once the new line character is reached the function returns Boolean value ‘true’ to the calling function, which at that point will have the file stream stripped with first line, passes the file stream for further processing.

fun eatuntilnewline (instream : TextIO.instream): bool = let

val c = TextIO.input1 instream

in

case TextIO.lookahead instream of

SOME #"\n" => true

| SOME c => eatuntilnewline instream

| NONE => false

end

1. Function args is updated to recognise the new parameter which is passed from command-line for scripts. The new function ‘nextargscript’ is called upon encountering the script parameter.

fun args ([], \_) = ()

| args ("-a" :: \_, \_) = nextarg autoload'

| args ("-m" :: \_, \_) = nextarg make'

| args (["-H"], \_) = (help NONE; quit ())

| args ("-H" :: \_ :: \_, mk) = (help NONE; nextarg mk)

| args (["-S"], \_) = (showcur NONE; quit ())

| args ("-S" :: \_ :: \_, mk) = (showcur NONE; nextarg mk)

| args (["-E"], \_) = (show\_envvars NONE; quit ())

| args ("-E" :: \_ :: \_, mk) = (show\_envvars NONE; nextarg mk)

| args ("--script" :: \_, \_) = (nextargscript ()) (\* line added by DAYA \*)

| args ("@CMbuild" :: rest, \_) = mlbuild rest

| args (["@CMredump", heapfile], \_) = redump\_heap heapfile

| args (f :: rest, mk) =

(carg (String.substring (f, 0, 2)

handle General.Subscript => "",

f, mk, List.null rest);

nextarg mk)

and nextarg mk =

let val l = SMLofNJ.getArgs ()

in SMLofNJ.shiftArgs (); args (l, mk)

end

1. Function ‘nextargscript’ will look for the remaining arguments in the arguments list. The head of the remaining argument’s list which is expected to be the file name of the script is retrieved. Function ‘processFileScript’ is called with file name as the argument.

and nextargscript () =

let val l = SMLofNJ.getArgs ()

in SMLofNJ.shiftArgs (); processFileScript (hd l); quit ()

end

### boot-env-fn[.sml](https://github.com/dn2007hw/SMLNJScripts/blob/main/cm-boot.sml)

In functor BootEnvF, cminit function declaration is amended to include the newly added function useScriptFile.

functor BootEnvF (datatype envrequest = AUTOLOAD | BARE

val architecture: string

val cminit : string \* DynamicEnv.env \* envrequest

\* (TextIO.instream -> unit)(\* useStream \*)

\* (string \* TextIO.instream -> unit) (\* useScriptFile \*)

\* (string -> unit) (\* useFile \*)

\* ((string -> unit) -> (string -> unit))

(\* errorwrap \*)

\* ({ manageImport:

Ast.dec \* EnvRef.envref -> unit,

managePrint:

Symbol.symbol \* EnvRef.envref -> unit,

getPending : unit -> Symbol.symbol list }

-> unit)

-> (unit -> unit) option

val cmbmake: string \* bool -> unit) :> BOOTENV = struct

### interact.sig & interact.sml

A new function (useScriptFile) is added to Backend.Interact structure, which takes the file name and its content as a stream and process the stream by passing it to EvalLoop.evalStream. The compiler messages are muted and unmuted before the processing of the file. (Functions silenceCompiler, dummyfn and unsilenceCompiler will be explained later in this document)

1. New function declaration is added to interact.sig,

val useStream : TextIO.instream -> unit

val useScriptFile : string \* TextIO.instream -> unit (\* Addded by DAYA \*)

val evalStream : TextIO.instream \* Environment.environment -> Environment.environment

1. New function definition is added to interact.sml,

fun useScriptFile (fname, stream) = (

Mutecompiler.silenceCompiler () ;

EvalLoop.evalStream ("<instream>", (TextIO.openString "Backend.Mutecompiler.mcdummyfn ();") ) ;

Mutecompiler.unsilenceCompiler () ;

(EvalLoop.evalStream (fname, stream))

handle exn => (

Mutecompiler.printStashedCompilerOutput ();

Mutecompiler.unsilenceCompiler ();

EvalLoop.uncaughtExnMessage exn

)

)

### backend.sig

A new structure Mutecompiler is declared within signature BACKEND,

signature BACKEND = sig

structure Profile : PROFILE

structure Compile : COMPILE

structure Interact : INTERACT

structure Mutecompiler : MUTECOMPILER

structure Machine : MACHINE

val architecture: string

val abi\_variant: string option

end

### backend-fn.sml

New structure Mutecompiler is defined within functor BackendFn,

structure Mutecompiler = Mutecompiler

### mutecompiler.sig

New signature MUTECOMPILER is defined with all the global variables and functions that are part of Structure Mutecompiler,

### mutecompiler.sml

New structure Mutecompiler has two core functions silencecompiler and unsilencecompier.

1. silencecompiler function mutes the compiler messages by saving the current printing limits in a ref cell and then set them all to zero.
2. unsilencecompiler function unmutes the compiler messages by restoring the printing limits.
3. dummyfn function which does nothing is created and invoked to preload the Mutecompiler structure before the script is passed to evalloop, this is to supress the structure auto-loading logs in the script results.

### INDEX, MAP and core.cm

INDEX, MAP and core.cm are updated with definitions for signature MUTECOMPILER and structure Mutecompiler.

1. [INDEX](https://github.com/dn2007hw/SMLNJScripts/blob/main/INDEX)

MUTECOMPILER

TopLevel/interact/mutecompiler.sig

Mutecompiler

TopLevel/interact/mutecompiler.sml

1. MAP

interact/

envref.sml

supports top-level environment management

defs: ENVREF, EnvRef : ENVREF

evalloop.sig,sml

top-level read-eval-print loop

defs: EVALLOOP, EvalLoopF: TOP\_COMPILE => EVALLOOP

interact.sig,sml

creating top-level loops

defs: INTERACT, Interact: EVALLOOP => INTERACT

mutecompiler.sig,sml

allow compiler silencing

defs: MUTECOMPILER, Mutecompiler

1. [core.cm](https://github.com/dn2007hw/SMLNJScripts/blob/main/core.cm)

TopLevel/interact/mutecompiler.sig

TopLevel/interact/mutecompiler.sml

## Writing a script

The script should start with ‘#!’ in the first line followed by the environment location, command-line parameters ‘-Ssml’ and ‘—script’, a new line and then followed by the SML code or program.

Example script named ‘sample’,

--------------beginning of the script-------------

#!/usr/bin/env -Ssml –script

;(\*-\*-SML-\*-\*)

val () = print "Hello World\n";

--------------end of the script---------------------

## Running a script

The script ‘sample’ can be executed from Linux terminal or command prompt as a regular OS script as below provided it is given execution permission,

$ ./sample

## Additional functions

1. The compiler messages can be muted/suppressed by invoking the silencecompiler function as below in the script,

val \_ = Backend.Mutecompiler.silenceCompiler ();

1. The compiler messages can be unmuted by invoking the unsilencecompiler function as below in the script,

val \_ = Backend.Mutecompiler.unsilenceCompiler ();

1. Whenever an error is encountered in compiling, by default only last 5 lines of the suppressed compiler messages are printed to the user and this limit can be pre-set in script as below,

Backend.Mutecompiler.printlineLimit := 10;

1. Whenever compiler messages are muted by calling silenceCompiler function, variable declarations are stashed with ‘#’ in suppressed compiler messages to save memory. To see the original content in case of debugging, this can be retrieved by amending the Control print parameters and restoring the print limits by increasing the string depth and calling the restorePrintingLimits function as below in the script,

Control.Print.stringDepth := 999;

val \_ = Backend.Mutecompiler.restorePrintingLimits ();

## SML/NJ Version used

Our development and testing is based on Standard ML of New Jersey (32-bit) v110.99.3 on an Intel based macOS 10.13.16.

# 8. Evaluation and Results

## Test Details

### Test Script #1

#!/usr/bin/env -Ssml --script

;(\* SML code starts here \*)

val x = "Hello World x\n";

val () = print x;

val y = "Hello World y\n";

val () = print y;

val z = "Hello World z\n";

val () = print z;

### Test Result #1

$ ./exml07

Standard ML of New Jersey (32-bit) v110.99.3 [built: Mon Apr 10 18:03:19 2023]

val x = "Hello World x\n" : string

Hello World x

val y = "Hello World y\n" : string

Hello World y

val z = "Hello World z\n" : string

Hello World z

$

### Test Script #2

#!/usr/bin/env -Ssml --script

;(\* SML code starts here \*)

val \_ = Backend.Mutecompiler.silenceCompiler ();

val x = "Hello World x\n";

val () = print x;

val y = "Hello World y\n";

val () = print y;

val z = "Hello World z\n";

val () = print z;

### Test Result #2

$ ./exml07

Standard ML of New Jersey (32-bit) v110.99.3 [built: Mon Apr 10 18:03:19 2023]

Hello World x

Hello World y

Hello World z

$

### Test Script #3

#!/usr/bin/env -Ssml --script

;(\*-\*-SML-\*-\*)

val x = "Hello World x\n";

val () = print x;

val \_ = Backend.Mutecompiler.silenceCompiler ();

val y = "Hello World y\n";

val () = print y;

val \_ = Backend.Mutecompiler.unsilenceCompiler ();

val z = "Hello World z\n";

val () = print z;

### Test Result #3

$ ./sample

Standard ML of New Jersey (32-bit) v110.99.3 [built: Mon Apr 10 18:03:19 2023]

val x = "Hello World x\n" : string

Hello World x

Hello World y

val z = "Hello World z\n" : string

Hello World z

$

### Test Script #4

#!/usr/bin/env -Ssml --script

;(\*-\*-SML-\*-\*)

val x = "Hello World x\n";

val () = print x;

val \_ = Backend.Mutecompiler.silenceCompiler ();

Control.Print.stringDepth := 999;

val \_ = Backend.Mutecompiler.restorePrintingLimits ();

val y = "Hello World y\n";

val () == print y;

val \_ = Backend.Mutecompiler.unsilenceCompiler ();

val z = "Hello World z\n";

val () = print z;

### Test Result #4

$ ./sample

Standard ML of New Jersey (32-bit) v110.99.3 [built: Mon Apr 10 18:03:19 2023]

val x = "Hello World x\n" : string

Hello World x

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

The last 5 lines 31 through 35 of suppressed compiler messages are:

[library $SMLNJ-MLRISC/IA32.cm is stable]

[autoloading done]

val it = # : unit

val y = "Hello World y\n" : string

./exml07:8.18-9.4 Error: syntax error: deleting SEMICOLON VAL

\_\_\_\_\_\_\_\_\_\_\_\_\_End of suppressed compiler messages.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

uncaught exception Compile [Compile: "syntax error"]

raised at: ../compiler/Parse/main/smlfile.sml:19.24-19.46

../compiler/TopLevel/interact/evalloop.sml:45.54

../compiler/TopLevel/interact/evalloop.sml:306.20-306.23$

# 9. Conclusion and Future Work

The project intended to make SML programming simpler for developers, programmers, and students such that the code may be written and executed in a single source file like Python and Perl. And to integrate *smlnj-script* capabilities into SML/NJ and do away with the requirement to maintain a separate *smlnj-script* implementation.

The dissertation was successful in identifying the modules of SML/NJ to append the key *smlnj-script* capabilities. We were able to amend SML/NJ to recognise the SML script and evaluate the instructions in the source file. Also gives the user the capability to silence and unsilenced the compiler messages. Further work is needed to encapsulate the string overloading and other utility functions into SML/NJ.

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