SMPL - Simple Parallel Language

Final Report

Ajay S S Reddy Challa, Andrei Papancea, Devashi Tandon
{ac3647, alp2200, dt2450} @columbia.edu

December 20, 2013

Contents

1. Introduction

1.1 Motivation

Up until 2006, computer scientists benefited from what is referred to as the "free lunch"[1]. Programmers did not have to focus too much on writing very efficient code, since it was known that every two years processor speeds will increase and hence help their programs run faster. According to Moore's Law[2] the number of transistors on integrated circuits doubles approximately every two years. This law still holds today, but it is not practical to increase processor speed anymore because of financial and physical constraints such as the high cost of dealing with excessive heat dissipation. Subsequently, in a multicore world, the computer scientists all over are looking at parallel programming languages as the solution.

Two issues with parallel programming are that it is not trivial given the current toolsets and that not every problem can be parallelized. Furthermore, most popular programming languages such as C, C++, Java, or Python either do not support parallel programming or they have a very complex implementation of it, since they were not built with that idea in mind. Due to the non-trivial syntax of most parallel programming -capable languages, the concept of parallel programming is rarely taught at the undergraduate level — and it is crucial to teach this concept at the undergraduate level in order to stir interest in the field and push for advancement. Hence, there is a need for programming languages with simpler syntax, that can better illustrate parallel programming concepts and that makes them more suitable for undergraduate teaching[3].

1.2 Language Description

This document describes Simple Parallel Language (SMPL) which is an approach to parallel programming that is based on a subset of the C programming language. Its major strength is that it has a clearer and simpler syntax for doing parallel programming than programs written using OpenMP or POSIX threads.

With the addition of only four keywords to the C language, SMPL gives the programmer the ability to parallelize his code with minimal effort.

---

[1] Sutter, Herb. "The free lunch is over: A fundamental turn toward concurrency in software." *Dr. Dobb's Journal* 30.3 (2005): 202-210.
[2] Schaller, Robert R. "Moore's law: past, present and future." *Spectrum, IEEE* 34.6 (1997): 52-59.
[3] Graf, Michael et al. "Selecting and using a parallel programming language." *Proceeding of the 44th ACM technical symposium on Computer science education* 6 Mar. 2013: 735-735.

2. Tutorial

2.1 A “Simple” Example

Here is a quick “Hello world!” program in SMPL:

```
1  int main(){
2    printf(“Hello world!\n”);
3  }
```

Notice anything? Yes, SMPL uses the same syntax as C. Another thing that you should notice is that there is no need to include anything. All the includes, given the features of the language are added for you for convenience.

Let’s spice things up a bit, and write a more exciting “Hello world!” program:

```
1  say(string str){
2    printf(“%s\n”,str);
3  }
4
5  int main(){
6    spawn say(“Hello”);
7    spawn say(“world”);
8    spawn say(“user!”);
9    barrier;
10   printf(“Done!\n”);
11 }
```

The program above prints the strings “Hello”, “world”, “user!” in an undetermined order, followed by the string “Done!”. What `spawn` does is creates a new thread for the given function call. Hence, the function `say` gets called three times in three different threads, but it is not possible to predict which of the three threads will finish first. The `barrier` statement prevents “Done!” from beings printed before all the other threads have finished executing.

A few last things to notice before we move on are: `void` type is optional for function definitions, which is why the `say` function does not have a type, and `string` is a type that does not exist in C, so we implemented it in SMPL for simplicity — see what we did there? Here’s the generated C code for the SMPL code above:

```
/* Code Generated from SMPL */
#include <stdio.h>
#include <stdbool.h>
#include <stdlib.h>
#include <string.h>
#include <pthread.h>

void say(char * str);
void *thread_0(void *args);
void *thread_1(void *args);
void *thread_2(void *args);

pthread_t threads[3];

void *thread_0(void *args){
    void **arg_list = (void **)args;
    char * var0 = *(char * *)arg_list[0];
    say(var0);
}

void *thread_1(void *args){
    void **arg_list = (void **)args;
    char * var0 = *(char * *)arg_list[0];
    say(var0);
}

void *thread_2(void *args){
    void **arg_list = (void **)args;
    char * var0 = *(char * *)arg_list[0];
    say(var0);
}

int main(){
    {void *args_thread_0[1];
    char * arg_lit_0_0 = "Hello";
    args_thread_0[0] = (void *)&arg_lit_0_0;
    pthread_create(&threads[0],NULL,thread_0,(void
*)args_thread_0);}
    {void *args_thread_1[1];
    char * arg_lit_1_0 = "world";
    args_thread_1[0] = (void *)&arg_lit_1_0;
    pthread_create(&threads[1],NULL,thread_1,(void
*)args_thread_1);}
    {void *args_thread_2[1];
    char * arg_lit_2_0 = "user!";
    args_thread_2[0] = (void *)&arg_lit_2_0;
```

```
47      pthread_create(&threads[2],NULL,thread_2,(void
48  *)args_thread_2);}
49      int thread_counter;
50      for(thread_counter=0;thread_counter<3;thread_counter++){
51          pthread_join(threads[thread_counter],NULL);
52      }
53      printf("Done!\n");
54  }
55
56  void say(char * str){
57      printf("%s\n",str);
58  }
```

2.2 Compiling and Running SMPL Programs

First, SMPL programs use `.smpl` as an extension, by convention. You have multiple options of interacting with the compiler (`smplc`) by using the following command line arguments:

Argument	**Description**
`-a [-t | filename]`	print the parse results (AST) of the input SMPL code
`-c [-t | filename]`	generate the C code equivalent to the input SMPL code
`-s [-t | filename]`	perform syntax check of the input SMPL code

In the table above `-t` tells the compiler to take input from the terminal and `filename` tells the compiler to compile the given file. The flags `-a`, `-c`, and `-s` *must* be followed by either `-t` or a `filename`. The SMPL compiler will output C code.

For a more concrete example, open your favorite text editor, paste any of the two "Hello world" programs above into the new file and save it as `hello.smpl`. Open the command line and run `./smplc -c hello.smpl > hello.c`. What "`> hello.c`" does is it redirects the output of the compiler to a file, rather than printing it in the terminal window.

Finally, to finish the compilation of your "Hello world" program run `gcc -pthread hello.c`. Note that trying to compile the program without the `-pthread` flag will fail, because the C output of SMPL uses the Posix Threads library to run programs in parallel.

2.3 “THE” Example

Here is a quick introduction to the four keywords that SMPL uses to perform parallelism:

1. `spawn`: tells the compiler that the function that spawn precedes should run in parallel with the caller thread.
2. `barrier`: causes all previously `spawn`-ed threads to wait for each other to complete before the program can continue
3. `lock`: synchronization mechanism that prevents multiple threads from changing a variable concurrently
4. `pfor`: a for loop whose work is divided amongst a specified number of threads

Now let’s take a look at one more example. The SMPL program below computes the sum of all the prime numbers up to one million.

```
 1  int sum = 0;
 2
 3  int isPrime(int n){
 4    int limit = n/2;
 5    int i = 0;
 6    for(i=2; i<=limit; i++)
 7      if(n%i == 0)
 8        return 0;
 9    return 1;
10  }
11
12  int main(){
13    int i;
14    int n = 1000000;
15
16    pfor(8; i; 1; n){
17      if(isPrime(i))
18        sum = sum+i;
19    }
20
21    printf("The sum of the first 1M primes is %d.\n",sum);
22  }
```

Here’s what you need to know about the code above:

1. it has the same length as the equivalent C code (in terms of functionality, not performance)

2. it uses only one SMPL keyword
3. the SMPL program completed in 27.173 seconds.
4. the equivalent C program completed in 1 minute and 11.340 seconds.

Both programs ran on the CLIC machines using the same compiler and includes. In conclusion, with very limited effort you can turn a serial C program into a parallel one. In this case, the SMPL program ran more than twice as fast than its C counterpart. Here's the C code generated for the SMPL code above is:

```
/* Code Generated from SMPL */
#include <stdio.h>
#include <stdbool.h>
#include <stdlib.h>
#include <string.h>
#include <pthread.h>

int sum = 0;

int isPrime(int n);
void *thread_0(void *args);

pthread_t threads[1];

void *thread_0(void *args){
    int temp_sum = 0;
    pthread_mutex_t pfor_global_lock=PTHREAD_MUTEX_INITIALIZER;
    void **arguments = (void **)args;
    int lower = *((int *)arguments[0]);
    int upper = *((int *)arguments[1]);    void
**thread_0_local_vars = (void **)arguments[2];
    int i = *((int *)thread_0_local_vars[0]);
    int n = *((int *)thread_0_local_vars[1]);
    for(i=lower; i<upper; i++){
        if(isPrime(i)) temp_sum=temp_sum+i;
    }
    pthread_mutex_lock(&pfor_global_lock);
    sum=sum+temp_sum;
    pthread_mutex_unlock(&pfor_global_lock);
    pthread_exit(NULL);
}

int main(){
    int i;
    int n=1000000;
```

```
36      int num_threads_0 = 8;
37      int pfor_init_0 = 1;
38      int pfor_limit_0 = n;
39
40      pthread_t pfor_threads_0[num_threads_0];
41      int pfor_uppers_0[num_threads_0];
42      int pfor_lowers_0[num_threads_0];
43      void *pfor_args_0[num_threads_0][3];
44      void *pfor_local_vars_0[2];
45      pfor_local_vars_0[0] = (void *)&i;
46      pfor_local_vars_0[1] = (void *)&n;
47      int pfor_i_0;
48
49      for(pfor_i_0=0;pfor_i_0<num_threads_0;pfor_i_0++){
50          pfor_uppers_0[pfor_i_0] =
51  pfor_init_0+((pfor_init_0+pfor_limit_0)/num_threads_0)*(pfor_i_
52  0+1)+((pfor_init_0+pfor_limit_0)%num_threads_0);
53          pfor_lowers_0[pfor_i_0] =
54  pfor_init_0+((pfor_init_0+pfor_limit_0)/num_threads_0)*pfor_i_0
55  ;
56          pfor_args_0[pfor_i_0][0] = (void
57  *)&pfor_lowers_0[pfor_i_0];
58          pfor_args_0[pfor_i_0][1] = (void
59  *)&pfor_uppers_0[pfor_i_0];
60          pfor_args_0[pfor_i_0][2] = (void *)&pfor_local_vars_0;
61      }
62
63      for(pfor_i_0=0;pfor_i_0<num_threads_0;pfor_i_0++){
64
65  pthread_create(&pfor_threads_0[pfor_i_0],NULL,thread_0,(void
66  *)&pfor_args_0[pfor_i_0]);
67      }
68
69      for(pfor_i_0=0;pfor_i_0<num_threads_0;pfor_i_0++){
70          pthread_join(pfor_threads_0[pfor_i_0],NULL);
71      }
72      printf("The sum of the first 1M primes is %d.\n",sum);
73  }
74
75  int isPrime(int n){
76      int limit=n/2;
77      int i=0;
78      for(i=2; i<=limit; i++)     if(n%i==0)     return 0;
79
80      return 1;
81  }
```

3.1 Lexical Conventions

SMPL introduces four parallel keywords. SMPL supports four types of tokens: identifiers, keywords, functions, and separators. Tabs, and newlines are ignored, while multiple spaces are contrived to only one space, which serves as a token separator.

3.1.1 Identifiers

An identifier consists of a letter followed by one or more alphanumeric and/or underscore characters. The identifiers are case-sensitive.

3.1.2 Keywords

The following set of keywords are reserved names and cannot be used as identifiers:

- ➔ `int`
- ➔ `float`
- ➔ `boolean`
- ➔ `char`
- ➔ `string`
- ➔ `void`
- ➔ `true`
- ➔ `false`
- ➔ `null`
- ➔ `if`
- ➔ `else`
- ➔ `for`
- ➔ `while`
- ➔ `return`
- ➔ `break`
- ➔ `main`
- ➔ `pfor`
- ➔ `spawn`
- ➔ `lock`
- ➔ `barrier`

3.1.3 Comments

Comments are represented in a block as follows:

```
/* single line comment */

/* multi
   line
   comment */
```

SMPL does not support comment nesting.

3.2 Types

3.2.1 Fundamental Types

In SMPL the following fundamental data types are supported:

- ➔ `int`: integer variable
- ➔ `float`: floating-point variable
- ➔ `boolean`: boolean variable (`true`, `false`)
- ➔ `char`: single ASCII character variable
- ➔ `string`: multi ASCII character variable

In addition, SMPL uses `void` to symbolize that a function has not return value.

3.2.2 Derived Types

In SMPL the following derived data types are supported:

- ➔ **functions:** sequence of code having its own execution context

Refer to section 5.3 and 5.4 on how to use these types.

3.2.3 Type Casting

Type casting is not directly supported in SMPL. So if the function takes a particular type of arguments, the variables used to call the function should be of the same type. However, a larger size variable can be assigned value from a lower size variable but not the other way. So it is legal to assign char to int variable or int to float variable but int variable cannot be assigned to char. Also, strings can be assigned to only strings. The following example illustrates how to pass variables of different types as arguments to a function:

To do something like this:

```
funca(int,int)

int a; boolean b;
call funca(a, (int) b)
```

Do:

```
int c = b;
call funca(a,c)
```

3.2.4 Storage Classes

In SMPL the scope of a fundamental type can be either of the following two storage classes:

- ➔ **local:** scope is limited to the function
- ➔ **global:** accessible in any part of the program

The scope is derived from where it is defined. If the variable is defined outside the function the scope is global, whereas if it is defined within a function the scope is local.

3.3. Expressions

3.3.1 Operators

The table below lists the operators supported by SMPL:

Operator	Description
*	multiplication
/	division
%	modulus
+	addition
-	subtraction
++	unit incrementation
--	unit decrementation
<	less than comparison
>	greater than comparison
<=	less than or equal to comparison
>=	greater than or equal to comparison
==	equality comparison
!=	inequality comparison
!	boolean NOT operator
&&	boolean AND operator
||	boolean OR operator
=	assignment
,	argument separator
;	statement separator

3.3.2 Precedence

The table below illustrates the precedence for all the operators supported by SMPL:

Precedence	Expressions/Operators
highest	`f(arg,arg,...)`
	`!b`
	`n++  n--  n * o  n / o  i % j`
	`n + o  n - o`
	`n < o  n > o  n <= o  n >= o`
	`r == r  r != r`
	`b && c`
	`b || c`
	`l = r`
lowest	`r1 , r2`

The table above illustrates how expressions are evaluated. Therefore these rules define implicit grouping, so the expression `1+2*3` is equivalent to `1+(2*3)`. If a different grouping is desired, such as `(1+2)*3`, then it needs to be explicitly specified using a pair of parentheses.

3.4. Syntax

3.4.1 Statements

A statement can have any of the following formats:

- ➔ expression;
- ➔ { statement-list }
- ➔ `if` (expression) statement `else` statement
- ➔ `while` (expression) statement
- ➔ `for` (expression ; expression ; expression) statement
- ➔ `pfor` (literal ; expression ; expression ; expression) statement
- ➔ `lock` statement
- ➔ `spawn` statement
- ➔ `barrier`;
- ➔ `break`;
- ➔ `continue`;
- ➔ `return` expression;

3.4.2 Variable Declaration

The syntax for variable declaration in SMPL has the following format:

```
type identifier; /* the identifier will be initialized to a default value */
type identifier = value; /* the identifier will be initialized to the specified value */
```

The default value for different data types is as follows:

Data Type	**Default Value**
`int`	`0`
`float`	`0.0`
`boolean`	`false`
`char`	`0` (null character)
`string`	`""` (empty string)

3.4.3 Function Declaration

The syntax for function declaration in SMPL has the following format:

```
return-type identifier(arg-type arg1, arg-type arg2, ...){
     declaration-list
     statement-list
}
```

The `return-type` of a function can be any of the fundamental types, including `void`. The `arg-type` can be any of the fundamental types, excluding `void`.

3.4.4 Parallel Constructs

3.4.4.1 spawn

The `spawn` statement creates a thread for the given statement. Its syntax looks as follows:

```
spawn function_call;
```

`spawn` is transformed into C code by creating a new thread using `pthread_create`. The code generator creates an array of void pointers to store all the variables passed as arguments to spawn, if any. Furthermore, if the variables passed as arguments are literals, the code generator will place the literals in variables so their pointer can be placed in the array of arguments. A new wrapper function is created in which the actual function call is called. We did this because `pthread_create` requires a function whose return type is void. Last, the reference to this new thread is stored in an array, that will later be used to join threads.

3.4.4.2 barrier

The `barrier` statement prevents execution of code following it until all the threads `spawn`ed prior to it finish executing. Its syntax looks as follows:

```
barrier;
```

Here is a code example of when you would need `barrier`:

```
spawn thread1();
```

```
spawn thread2();

print("Done!");
```

Note that in the example above, `thread1` and/or `thread2` could finish after the printing is done, which is probably an undesired result. Subsequently, using a `barrier` above the `print` statement, would prevent the program execution to reach the latter before all the `spawn`ed threads have completed. The fix would look like this:

```
spawn thread1();
spawn thread2();

barrier;

print("Done!");
```

`barrier` is transformed into C code using a `for` loop that iterates through all the array of threads. Inside that loop, each thread is joined using `pthread_join`.

3.4.4.3 lock

The `lock` statement prevents other threads from accessing or modifying the contents of the statement that it precedes until the latter's computation finishes. Its syntax looks as follows:

```
lock statement
```

Once the computation finishes, the lock will be automatically removed.

Here is a code example of when you would need a `lock`:

```
int sum=0;

int add_to_sum(int val){
   sum = sum+val;
}

int main(){
   int i;
```

```
   pfor(4;i;0;10000){
      add_to_sum(i);
   }
   printf("The sum is %d.\n",sum);
}
```

Note that in the example above, each of the four threads that pfor creates will attempt to modify sum at the same time, creating concurrency problems and therefore outputting a different result every time the program runs. Subsequently, using a `lock` around the `sum = sum+val` statement, would prevent a thread from modifying the variable while another is already trying to change it. The fix would look like this:

```
int sum=0;
int add_to_sum(int val){
   lock sum = sum+val;
}

int main(){
   int i;
   pfor(4;i;0;10000){
      add_to_sum(i);
   }
   printf("The sum is %d.\n",sum);
}
```

`lock` is transformed into C code by creating a new `pthread_mutex` and putting `pthread_mutex_lock / unlock` statements around the statement that is being locked.

3.4.4.4 pfor

The `pfor` statement defines a `for` loop that splits up the work in its body into multiple threads. Its syntax has the following format:

```
pfor(k; counter; init; limit)
     statement
```

In the example above, `k` represents the number of threads that `pfor` will break its body into. For instance, if `k=4` then the work of the statements in the body of `pfor` will be broken into 4 separate

threads. `counter` represents the counter variable name that will be used within the `pfor` body (i.e. `i`). `init` represents the initialization of the loop counter, and `limit` represents the upper limit/stop condition.

The `pfor` construct uses an implicit `barrier` in order to ensure that all the threads have finished before proceeding to the next statement. The `pfor` construct also places an implicit `lock` on all the assignment operations. Nonetheless, the `pfor` construct assumes a unit-incrementing loop. Basically, the `pfor` loop defined above would be equivalent to the following pseudo-code:

```
pfor(k; counter=init; counter < limit; counter++)
     statement
```

Note that you should be cautious about `spawn`ing threads inside `pfor` since that would entail `spawn`ing threads inside other threads and create unexpected concurrency problems.

`pfor` is transformed into C code by using a fusion of how the other parallel constructs are generated. First, the `for` loop boundaries for each thread are created and saved in an array of void pointers. In this array of pointers we also save the pointers to all the local variables in the function in which `pfor` is defined. We do this in order to replicate the environment in the thread function that is generated and that will be spawned `k` times. Next, we generate a for loop that iterates k number of times and spawns the thread function with the specific upper and lower bound values for that thread. The thread function is generated similar to how the `spawn` thread function is generated, with the addition that global variable assignments inside the `pfor` body will have an implicit lock placed on them. Lastly, we generate the equivalent of a barrier, so that all the spawned threads are joined before the execution of the program continues.

For the cases that `pfor` cannot parallelize (i.e. computations that are reliant on previous steps), you can implement the `pfor` functionality using spawns, barriers, and locks.

4. Project Plan

4.1 Team Responsibilities

The team responsibilities were divided as follows:

Team Member	Responsibilities
Ajay	syntax definition, test script setup, test case creation
Andrei	code generation, code generation optimization, documentation, presentation
Devashi	semantic analysis, optimization, compiler front end, building the “lego” blocks aka “Hello World” Program

This is a rough outline, since there were improvements made by each of the members in multiple areas.

4.2 Project Timeline

The project timeline for SMPL is shown below:

Date	Milestone
September 18	Language Proposal complete
October 26	Language Reference Manual complete
November 11	scanner, parser, AST complete
November 13	“Hello World” program runs
November 15	automated testing script complete
November 23	spawn, lock, barrier complete
December 12	semantic analysis complete
December 14	optimization complete
December 16	pfor, code generation, debugging complete
December 17	final report complete

4.3 Software Development Environment

The programming and development environments for SMPL are:

1. Development environment: vim and emacs on the CLIC machines
2. Programming environment: OCaml, version 3.12.1

4.4 Processes followed

The following processes were followed for the development of the compiler:

1. Version Control: GITHUB repository https://github.com/ndrppnc/smpl/tree/master/compiler
2. Coding style for Ocaml Code: General Vim editor indentation and formatting
3. Coding style for output C code: Four space indentation for each code block
4. Development Process: We broke down the code into two components: Section 1 was scanner/parser/AST and section 2 was the semantic verification and code generation. For section 2 we prepared the basic code blocks by building the "Hello World" program and then filling in the pieces
5. Testing process: As the code was developed test cases were written to test the code. Some test cases were borrowed from microC and migrated to SMPL syntax, to test the basic C constructs.

4.5 Project Log

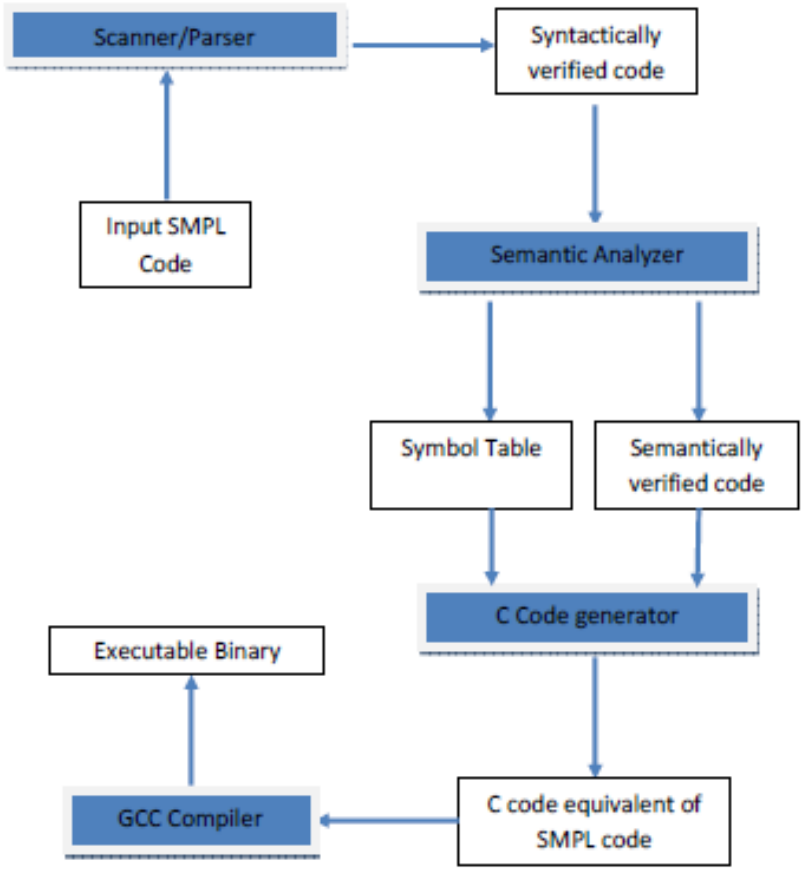
Date	**Milestone**
September 10	language idea defined
September 18	Language Proposal complete
September 22	changed syntax to look like C
October 20	first version of scanner and parser complete
October 26	Language Reference Manual complete
November 11	scanner, parser, AST complete
November 13	"Hello World" program runs
November 15	automated testing script complete

November 23	spawn, lock, barrier complete
December 7	added an env variable that gets computed during semantic analysis
December 8	added reference count in the env, for functions, local, and global variables
December 11	added ++ and -- operators
December 12	semantic analysis complete
December 13	started optimization for code generation by removing unused variables and func
December 14	optimization complete
December 16	pfor, code generation, debugging complete
December 17	final report complete

5. Architectural Design

5.1 Architecture

The architecture of our compiler is a standard one. The input code in SMPL syntax is submitted to the compiler which then generates an output C code. The C code can then be compiled using a C compiler and executed. The advantage of writing the program in SMPL instead of directly writing in C is that SMPL provides simple constructs to write the code. The complexity of creating thread functions and parallelizing the code by creating multiple threads is handled by our compiler and is transparent to the programmer. The flow diagram is as follows:



5.2 Error Recovery

Error reporting and recovery is an important part of the compiler. For parsing errors, the compiler simply reports that there is an error in parsing the SMPL code. In order to figure out the issue, code comments can be used to narrow down the line which led to the parsing issue. This is a limitation in the compiler since Ocaml doesn't provide a convenient way to report line numbers and specific reasons for parsing errors.

The second type of errors is the semantic check failures. These include passing wrong argument types to functions, use of undefined variables/functions, using break/continue outside loop and so on. These errors are caught by the semantic checker. The semantic checker accurately reports the error with a sufficiently detailed reason and the function in which the error was seen. However, it doesn't report the line number of the code in which the error occurred, since the compiler doesn't maintain the line number information of the file. While parsing the code, the code is not necessarily parsed in the order in which it appears in the file.

Runtime errors are not caught by the compiler. This is generally true for any compiler as by definition runtime errors are ones that escaped the compiler and occur only when the code is executed. The SMPL compiler generates a C code but doesn't validate it in any way. The code is stable enough to give a working C code in most cases, but could possibly spit out a code that doesn't compile in GCC as a result of some bug in the SMPL compiler. These errors are not caught by the compiler and would be seen only when the C code is compiled/executed.

5.3 Optimizations

This is one of the cool features of our compiler. The original design of SMPL or the compiler functionality did not include this, but after understanding how a compiler works, we decided to implement perform one optimization.

The compiler eliminates dead code from the SMPL code and does not include it in the output C code. Dead code optimized by our compiler may include unused global variables, unused local variables, or unused functions. All of these are removed by the compiler while generating the output code.

Dead code is identified by the semantic checker while generating the symbol table. It parses the code and increases the reference count of variables and functions once a usage of any of them is seen. However, it also keeps track of usage of functions from main. So if a global variable is used only in an unused function, the reference count for the global will not be updated. Similarly, if function *a* calls function *b*, but function *a* is not called from any path from main function, then both function *a* and

function *b* are treated as dead code.

The implementation of reference count is done using a two stack method. Two lists (stacks) one of visited functions and another one of unvisited functions is maintained. The parsing is done starting from main function which is first put in the unvisited function stack. As function calls are seen in main, the functions are added to the unvisited stack. The functions are popped from the top of unvisited stack and then pushed to the visited stack and after that their body is processed. If the function is found in the visited stack and a call for it is seen, the reference count is not updated. This takes care of both direct and indirect recursive calls. Hence if function a calls itself but no other function calls function *a*, it is still a dead function and will not get executed. This is handled by our algorithm and the function is removed from the output C code.

Once all the reference counts are generated, the C code generation logic checks for the reference count and if it is 0, does not output the function/variable in the resultant C code.

However, there is one downside of this optimization. The semantic checker ignores semantic analysis of the dead code in most cases. However, since the code is anyways going to be removed from the output C code, this should be an acceptable limitation of the compiler.

Example SMPL code (with dead code):

```
1  int unused1 = 0;
2  char unused2 = 'c';
3  float used1 = 2.0;
4  void main()
5  {
6     int test = 0;
7     used1 = 4.0;
8     printf("%f \n", used1);
9     func1_used();
10 }
11
12 func1_unused()
13 {
14    unused2 = 'd';
15    func2_unused(unused2);
16 }
```

```
17
18 func2_unused(char var)
19 {
20     printf("%c", var);
21     /* Indirect recursion */
22     func1_unused();
23 }
24
25 func1_used()
26 {
27     int unused_local = 100;
28     printf("This function had an unused variable\n");
29 }
```

Output C code (dead code eliminated):

```
/* Code Generated from SMPL */
#include <stdio.h>
#include <stdbool.h>
#include <stdlib.h>
#include <string.h>
#include <pthread.h>

float used1 = 2.;
void func1_used();

void main();

void func1_used(){
    printf("This function had an unused variable\n");
}

void main(){
    used1=4.;
    printf("%f \n",used1);
    func1_used();
}
```

6. Test Plan

6.1 Testing Phases

6.1.1 Unit Testing

Unit testing was done at very frequent intervals, where each unit developed was tested rigorously using multiple cases. The scanner,parse and the ast were tested in phase 1 and in the later phase the semantic checker and the code generator were tested.

6.1.2 Integration Testing

In this phase,the various modules were put together and tested as a whole. Initially the syntax of the the code was tested using multiple test cases and it was also ensured that only the correct syntax is accepted by running multiple fail test cases. Later on, the semantic checker was integrated and the semantics of the code were checked to be accurate without violating any of the rules of the language. In the final phase the code generator was added to the system and was tested to generate the corresponding C code.

6.1.3 System Testing

In order to ensure the proper working of the system, we began with a simple ‘Hello-World’ program and went on to test various constructs, function and also the parallel aspects of the language using a variety of test cases and also cross-checking against the expected output.

6.2 Automation

A shell script was written in order to automate the test cases at each level, syntax, semantic, code generation and accurate execution

6.3 Test Suites

Tests were classified as Syntax, Semantic and Execution tests and were run at different phases during the construction of the compiler. The following aspects of the program were tested in order:-
As a method of syntax verification, accurate parsing was ensured by running various pass and fail test cases, in semantic checking the semantic checker was verified to accept syntax that complies with various rules such of the language. In the case of code generation, the generated code was run on the c compiler and the output verified against the expected results.

7. Lessons Learned

7.1 Ajay

Regular team meetings helped us plan and develop the language with a clear outlook. Defining the syntax is a crucial part and should be done realistically without being too fancy.
Keeping the syntax simple helped us focus on the core functionality of the compiler and we were able to deliver the promised model on time.
Integrating and testing the code from time to time is important and is much effective as compared to bulk testing.

7.2 Andrei

OCaml is an extremely powerful language. Extremely annoying at first, yet powerful. That quote from the first class about the student “complaining” that “never have I written so little that does so much” is entirely valid. I can imagine how implementing a language in Java, Python, or C can be a tremendous pain.

Furthermore, it was interesting to see how we progressed as a team from “let’s use this syntax so that it is easier to parse” to understanding that what we might perceive difficult is completely trivial for the computer to do, as far as the language has a grammar that can be parsed.

Lessons learned? Start early. Start early. Start early. That includes programming in OCaml and writing your language. Also, do not attempt to implement 10,000 features because it is a) infeasible and b) out of the scope of this class.

7.3 Devashi

The project was the most interesting part of this course. I learnt more about how a compiler works and what goes on behind it by implementing one myself. Ocaml can be tedious and yet very convenient to code in. It is tedious because it takes time to catch up with the programming style of a functional language after coming from a C programmer background. Documents are sparse but the course slides helped. In my opinion we took a lot of time in identifying how to start writing the compiler. The assignments helped build the understanding but the project framework and how to write a Hello World program should be understood early into the course. This will help in delivering more functionality in the project. Working in a team and delivering the project in the given timeframe was a good learning experience.

8. References

We have modeled our Language Reference Manual and final report after the following four documents:

1. http://www.cs.columbia.edu/~sedwards/classes/2013/w4115-fall/clrm.pdf
2. http://www.cs.columbia.edu/~sedwards/classes/2013/w4115-summer2/lrms/CLIP.pdf
3. http://www.cs.columbia.edu/~sedwards/classes/2012/w4115-fall/reports/Funk.pdf
4. http://www.cs.columbia.edu/~sedwards/classes/2003/w4115/conway-report.pdf

Appendix

Makefile

```
# Author: Devashi Tandon
TARFILES = Makefile scanner.mll parser.mly ast.mli printast.ml semantic_checker.ml compile.ml smpl.ml

OBJS = ast.cmo parser.cmo scanner.cmo printast.cmo semantic_checker.cmo compile.cmo smplc.cmo

smplc : $(OBJS)
	ocamlc str.cma -o smplc $(OBJS)

scanner.ml : scanner.mll
	ocamllex scanner.mll

parser.ml parser.mli : parser.mly
	ocamlyacc parser.mly

%.cmi : %.mli
	ocamlc -c $<

%.cmo : %.ml
	ocamlc -c $<

smplcompiler.tar.gz : $(TARFILES)
	cd .. && tar zcf smplcompiler/smplcompiler.tar.gz $(TARFILES:%=smplcompiler/%)

.PHONY : clean
clean :
	rm -f smplc parser.ml parser.mli scanner.ml *.cmo *.cmi
```

```
# Generated by ocamldep *.ml *.mli
ast.cmo:
ast.cmx:
compile.cmo: semantic_checker.cmo ast.cmo
compile.cmx: semantic_checker.cmx ast.cmx
parser.cmo: ast.cmo parser.cmi
parser.cmx: ast.cmx parser.cmi
printast.cmo: ast.cmo
printast.cmx: ast.cmx
scanner.cmo: parser.cmi
scanner.cmx: parser.cmx
semantic_checker.cmo: ast.cmo
semantic_checker.cmx: ast.cmx
smplc.cmo: semantic_checker.cmo scanner.cmo printast.cmo parser.cmi \
  compile.cmo
smplc.cmx: semantic_checker.cmx scanner.cmx printast.cmx parser.cmx \
  compile.cmx
parser.cmi: ast.cmo
```

ast.ml

```
# Primary author: Andrei Papancea
# Secondary author: Devashi Tandon
type op = Add | Sub | Mult | Div | Mod | Equal | Neq | Less | Leq | Greater | Geq | And | Or

type data_type =
    IntType of string
  | FloatType of string
  | BoolType of string
  | CharType of string
  | StrType of string
  | VoidType of string

type literal =
    Integer of int
  | Float of float
```

```
  | Boolean of bool
  | Char of char
  | String of string

type expr =
    Id of string
  | Literal of literal
  | Binop of expr * op * expr
  | Not of expr
  | Pp of string
  | Mm of string
  | Assign of expr * expr
  | Call of string * expr list
  | Paren of expr
  | Noexpr

type stmt =
    Block of stmt list
  | Expr of expr
  | Return of expr
  | Break of expr
  | Continue of expr
  | Declare of data_type
  | DeclareAssign of data_type * expr
  | If of expr * stmt * stmt
  | For of expr * expr * expr * stmt
  | While of expr * stmt
  | Pfor of expr * expr * expr * expr * stmt
  | Spawn of expr
  | Lock of stmt
  | Barrier of expr

type func_decl = {
    fname : data_type;
    formals : data_type list;
    body : stmt list;
  }
```

```
type program = (data_type * literal) list * func_decl list
```

printast.ml

```
#Author: Devashi Tandon
open Ast

let string_of_data_type = function
  IntType(s) -> "Integer-" ^ s
  | FloatType(s) -> "Float-" ^ s
  | BoolType(s) -> "Boolean-" ^ s
  | CharType(s) -> "Char-" ^ s
  | StrType(s) -> "Str-" ^ s
  | VoidType(s) -> "Void-" ^ s

let string_of_literal = function
  Integer(i) -> "Integer Lit: " ^ string_of_int i
  | Float(f) -> "Float Lit: " ^ string_of_float f
  | Boolean(b) -> "Boolean Lit: " ^ string_of_bool b
  | Char(c) -> "Char Lit: " ^ Char.escaped c
  | String(s) -> "String Lit: \"" ^ s ^ "\""

let rec string_of_expr = function
  Literal(l) -> string_of_literal l
  | Id(s) -> "ID:" ^ s
  | Paren(s) -> "(" ^ string_of_expr s ^ ")"
  | Binop(e1, o, e2) -> "BINOP:" ^ string_of_expr e1 ^ " " ^
     (match o with
       Add -> "PLUS"
     | Sub -> "MINUS"
     | Mult -> "TIMES"
     | Div -> "DIV"
     | Mod -> "MOD"
     | Equal -> "EQUAL"
     | Neq -> "NOTEQUAL"
     | Greater -> "GT"
     | Geq -> "GTE"
```

```
    | Less -> "LT"
    | Leq -> "LTE"
    | And -> "AND"
    | Or -> "OR") ^ " " ^ string_of_expr e2
  | Not(e1) -> "BINOP:" ^ "NOT" ^ string_of_expr e1
  | Pp(id) -> "INCREMENT " ^ id
  | Mm(id) -> "DECREMENT " ^ id
  | Assign(id, idx) -> "ASSIGN- " ^
    (match id with
      Id(id) -> id
      | _ -> "ERROR") ^ "to: [" ^ string_of_expr idx ^ "]"
  | Call(s1, al) -> "Call: " ^ s1 ^ ": (" ^ String.concat ","
      (List.map (fun e -> string_of_expr e ) al) ^ ")"
  | Noexpr -> "NoExpr\n"

let rec string_of_stmt = function
   Block(stmts) ->
     "{\n" ^ String.concat "" (List.map string_of_stmt stmts) ^ "}\n"
  | Expr(e) -> "EXPR: [" ^ string_of_expr e ^ "]\n"
  | Return(e) -> "RETURN " ^ string_of_expr e ^ ";\n"
  | Break(e) -> "BREAK " ^ string_of_expr e ^ ";\n"
  | Continue(e) -> "CONTINUE " ^ string_of_expr e ^ ";\n"
  | Declare(d) -> "Declare " ^ string_of_data_type d ^ ";\n"
  | DeclareAssign(d, e) -> "DeclareAssign " ^ string_of_data_type d ^
                    ": AND Assign: " ^ string_of_expr e ^ ";\n"
  | If (p, t, f) ->
      "IF " ^ string_of_expr p
                    ^ " THEN DO "
         ^ string_of_stmt t
         ^ " ELSE DO " ^ string_of_stmt f ^ ";\n"
  | For (s, e, se, b) ->
           "DECLARE: " ^ string_of_expr s
                ^ " AND DO " ^ string_of_stmt b
                                ^ " WHILE " ^ string_of_expr e
                                ^ " PERFORMING " ^ string_of_expr se ^ ";\n"
  | While (e, b) -> " WHILE " ^ string_of_expr e ^ " DO " ^ string_of_stmt b ^ ";\n"
  | Pfor(t, c, s, e, b) -> "PFOR: Threads: " ^ string_of_expr t ^ "; Variable: "
  ^ string_of_expr c ^ " " ^ string_of_expr s
```

```
                ^ " AND DO " ^ string_of_stmt b
                                ^ " WHILE " ^ string_of_expr e ^ ";\n"
  | Spawn(e) -> "Spawn: " ^ string_of_expr e ^ "\n"
  | Lock(s) -> "Lock: " ^ string_of_stmt s ^ "\n"
  | Barrier(e) -> "Barrier: " ^ string_of_expr e ^ "\n"


  let string_of_vdecl id = "long " ^ id ^ ";\n"

let string_of_fdecl fdecl =
  "FUNCTION " ^ string_of_data_type fdecl.fname ^ "(" ^
    String.concat "," (List.map string_of_data_type fdecl.formals) ^
    ")\n{\n" ^
  String.concat "" (List.map string_of_stmt fdecl.body) ^
  "}\n"


let string_of_globals globals =
  "GLOBALS " ^ string_of_data_type (fst globals) ^ " = " ^ string_of_literal (snd globals)

let parse_program (vars, funcs) =
  "Vars: \n" ^ String.concat ";\n" (List.map string_of_globals vars) ^ "\n"
  ^ "Funcs: \n" ^ String.concat "\n" (List.map string_of_fdecl funcs)
```

scanner.mll

```
# Primary author: Devashi Tandon
# Secondary author: Andrei Papancea
{ open Parser
  open Str
}

rule token = parse
  [' ' '\t' '\r' '\n'] { token lexbuf }
| "/*"     { comment lexbuf }          (* Comments *)
| '('      { LPAREN }
| ')'      { RPAREN }
```

```
| '{'      { LBRACE }
| '}'      { RBRACE }
| ';'      { SEMI }
| ','      { COMMA }
| '+'      { PLUS }
| '-'      { MINUS }
| '*'      { TIMES }
| '/'      { DIVIDE }
| '%'      { MODULUS }
| '='      { ASSIGN }
| "!"        { NOT }
| "&&"               { AND }
| "||"        { OR }
| "=="     { EQ }
| "!="     { NEQ }
| '<'      { LT }
| "<="     { LEQ }
| ">"      { GT }
| ">="     { GEQ }
| "++"       { PP }
| "--"       { MM }
| "if"     { IF }
| "else"   { ELSE }
| "for"    { FOR }
| "while"  { WHILE }
| "return" { RETURN }
| "break"  { BREAK }
| "continue"{ CONTINUE }
| "spawn"  { SPAWN }
| "lock"   { LOCK }
| "barrier" { BARRIER }
| "pfor"   { PFOR }
| "int"    { INT }
| "float"  { FLOAT }
| "boolean" { BOOLEAN }
| "char"   { CHAR }
| "string" { STRING }
| "void"   { VOID }
```

```
| "null"    { NULL }
| "true"  as lxm { BOOL_LIT(bool_of_string lxm) }
| "false" as lxm { BOOL_LIT(bool_of_string lxm) }
| ['0'-'9']+ as lit { INTEGER_LIT(int_of_string lit) }
| ['0'-'9']+'.'['0'-'9']*('e'['-''+']?['0'-'9']+)? as lit { FLOAT_LIT(float_of_string lit) }
| '.'['0'-'9']+('e'['-''+']?['0'-'9']+)? as lit { FLOAT_LIT(float_of_string lit) }
| ['0'-'9']+'e'['-''+']?['0'-'9']+ as lit { FLOAT_LIT(float_of_string lit) }
| '''(_)''' as lxm { CHAR_LIT(lxm.[1]) }
| '"'([^'"''\\']*('\\'_[^'"''\\']*)* as lxm)'"' { STRING_LIT(lxm) }
| ['a'-'z' 'A'-'Z']['a'-'z' 'A'-'Z' '0'-'9' '_']* as lxm { ID(lxm) }
| eof { EOF }
| _ as char { raise (Failure("illegal character " ^ Char.escaped char)) }

and comment = parse
  "*/" { token lexbuf }
| _    { comment lexbuf }
```

parser.mly

```
# Authors: Devashi Tandon, Andrei Papancea
%{ open Ast %}

%token SEMI LPAREN RPAREN LBRACE RBRACE COMMA
%token PLUS MINUS PP MM TIMES DIVIDE MODULUS ASSIGN
%token AND OR NOT
%token EQ NEQ LT LEQ GT GEQ
%token RETURN IF ELSE FOR WHILE INT
%token INT FLOAT BOOLEAN CHAR STRING
%token SPAWN PFOR LOCK BARRIER
%token BREAK CONTINUE
%token VOID NULL
%token <int> INTEGER_LIT
%token <float> FLOAT_LIT
%token <bool> BOOL_LIT
%token <char> CHAR_LIT
%token <string> STRING_LIT
%token <string> ID
```

```
%token GLOBAL
%token EOF

%nonassoc NOELSE
%nonassoc ELSE
%right ASSIGN
%left OR
%left AND
%left EQ NEQ
%left LT GT LEQ GEQ
%left PLUS MINUS
%left TIMES DIVIDE MODULUS
%left NOT

%start program
%type < Ast.program> program

%%

program:
  /* nothing */ { [], [] }
 | program fdecl { fst $1, ($2 :: snd $1)} /* devashi: What the heck is this? */
 | program vdecl ASSIGN type_literal SEMI { ( ($2,$4) :: fst $1), snd $1 }  /* devashi: What the heck is this? */

fdecl:
      ID LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
      {{ fname = VoidType($1); formals = $3; body = List.rev $6 }}
 | VOID ID LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
   {{ fname = VoidType($2); formals = $4; body = List.rev $7 }}
 | vdecl LPAREN formals_opt RPAREN LBRACE stmt_list RBRACE
   {{ fname = $1; formals = $3; body = List.rev $6 }}

formals_opt:
   /* nothing */ { [] }
 | formal_list   { List.rev $1 }

formal_list:
 vdecl { [$1] }
```

```
  | formal_list COMMA vdecl { $3 :: $1 }

vdecl:
   INT ID { IntType($2) }
 | FLOAT ID { FloatType($2) }
 | BOOLEAN ID { BoolType($2) }
 | CHAR ID { CharType($2) }
 | STRING ID { StrType($2) }

stmt_list:
    /* nothing */  { [] }
  | stmt_list stmt { $2 :: $1 }

stmt:
    expr SEMI { Expr($1) }
  | vdecl SEMI { Declare($1) }
  | vdecl ASSIGN expr SEMI { DeclareAssign($1, $3) }
  | RETURN expr_opt SEMI { Return($2) }
  | BREAK empty_opt SEMI { Break($2) }
  | CONTINUE empty_opt SEMI { Continue($2) }
  | LBRACE stmt_list RBRACE { Block(List.rev $2) }
  | IF LPAREN expr RPAREN stmt %prec NOELSE { If($3, $5, Block([])) }
  | IF LPAREN expr RPAREN stmt ELSE stmt    { If($3, $5, $7) }
  | FOR LPAREN expr_opt SEMI expr_opt SEMI expr_opt RPAREN stmt
     { For($3, $5, $7, $9) }
  | WHILE LPAREN expr RPAREN stmt { While($3, $5) }
  | PFOR LPAREN expr_opt SEMI expr_opt SEMI expr_opt SEMI expr_opt RPAREN stmt
     { Pfor($3, $5, $7, $9, $11) }
  | SPAWN call_opt SEMI { Spawn($2) }
  | LOCK stmt { Lock($2) }
  | BARRIER empty_opt SEMI { Barrier($2) }

call_opt:
  ID LPAREN actuals_opt RPAREN { Call($1, $3) }

empty_opt:
    /* nothing */ { Noexpr }
```

```
expr_opt:
    /* nothing */ { Noexpr }
  | expr         { $1 }

type_literal:
  INTEGER_LIT          { Integer($1) }
  | FLOAT_LIT          { Float($1) }
  | BOOL_LIT           { Boolean($1) }
  | CHAR_LIT           { Char($1) }
  | STRING_LIT         { String($1) }

expr:
    ID           { Id($1) }
  | ID PP              { Pp($1) }
  | ID MM              { Mm($1) }
  | type_literal   { Literal($1) }
  | expr PLUS   expr { Binop($1, Add,   $3) }
  | expr MINUS  expr { Binop($1, Sub,   $3) }
  | expr TIMES  expr { Binop($1, Mult,  $3) }
  | expr DIVIDE expr { Binop($1, Div,   $3) }
  | expr MODULUS expr { Binop($1, Mod,   $3) }
  | expr AND    expr { Binop($1, And, $3) }
  | expr OR     expr { Binop($1, Or, $3) }
  | NOT expr         { Not($2) }
  | expr EQ     expr { Binop($1, Equal, $3) }
  | expr NEQ    expr { Binop($1, Neq,   $3) }
  | expr LT     expr { Binop($1, Less,  $3) }
  | expr LEQ    expr { Binop($1, Leq,   $3) }
  | expr GT     expr { Binop($1, Greater,  $3) }
  | expr GEQ    expr { Binop($1, Geq,   $3) }
  | ID ASSIGN   expr { Assign(Id($1), $3) }
  | LPAREN expr RPAREN { Paren($2) }
  | ID LPAREN actuals_opt RPAREN { Call($1, $3) }

actuals_opt:
    /* nothing */ { [] }
  | actuals_list  { List.rev $1 }
```

```
actuals_list:
   expr                { [$1] }
 | actuals_list COMMA expr { $3 :: $1 }
```

semantic_checker.ml

```
# Primary author: Devashi Tandon
open Ast
open Str

module VarMap = Map.Make(struct
            type t = string * string
            let compare x y = Pervasives.compare x y
      end)
module StringMap = Map.Make(String)

(* Symbol table: Information about all the symbols *)
type env = {
   globals_map     : (string * int) StringMap.t; (* global variable name-> type, ref_count *)
   functions_map   : (string * int) StringMap.t; (* function name -> return type, ref_count *)
   formals_map     : (string) VarMap.t; (* function name:argument name -> types *)
   locals_map      : (string * int) VarMap.t; (*function name:local variable name -> type, ref_count *)
   unvisited_funcs : string list; (* maintains function call stack for getting ref_count *)
   visited_funcs   : string list; (* maintains list of visited functions *)
   formals_list    : (string * data_type) list; (* needed as map stores in alphabetical order, not in order of
insertion*)
   visited_all     : bool;
   valid_syntax    : bool
 }


let print_map = false
let print_process_funcs = false

let validate_program (globalvars, funcs) =
   let print_string str_to_print =
      print_string ("/* " ^ str_to_print ^ " */\n")
```

```
in let id_of_data_type = function
    IntType(s) -> s
    | FloatType(s) -> s
    | BoolType(s) -> s
    | CharType(s) -> s
    | StrType(s) -> s
    | VoidType(s) -> s

in let get_data_type = function
    IntType(s) -> "integer"
    | FloatType(s) -> "float"
    | BoolType(s) -> "boolean"
    | CharType(s) -> "char"
    | StrType(s) -> "string"
    | VoidType(s) -> "void"

in let string_of_data_type = function
    IntType(s) -> "integer " ^ s
    | FloatType(s) -> "float " ^ s
    | BoolType(s) -> "boolean " ^ s
    | CharType(s) -> "char " ^ s
    | StrType(s) -> "string " ^ s
    | VoidType(s) -> "void " ^ s

in let string_of_literal = function
    Integer(i) -> "integer value: " ^ string_of_int i
    | Float(f) -> "float value: " ^ string_of_float f
    | Boolean(b) -> "boolean value: " ^ string_of_bool b
    | Char(c) -> "char value: " ^ Char.escaped c
    | String(s) -> "string value: \"" ^ s ^ "\""

in let get_literal_type = function
    Integer(s) -> "integer"
    | Float(s) -> "float"
    | Boolean(s) -> "boolean"
    | Char(s) -> "char"
    | String(s) -> "string"
```

```
in let global_map =
   List.fold_left (fun m global ->
      let dt_global = id_of_data_type(fst global) in
      let found = StringMap.mem dt_global m in
      if(found = false) then
         (StringMap.add dt_global (get_data_type(fst global), 0) m)
      else
         raise (Failure ("global variable " ^ dt_global ^
         " is redefined"))
   ) StringMap.empty globalvars
in let function_map =
   List.fold_left (fun m func ->
      let id_func = id_of_data_type(func.fname) in
      let found = StringMap.mem id_func m in
      if(found = true) then
         raise (Failure ("Function " ^ id_func ^ " is redefined"))
      else (
         let found = StringMap.mem id_func global_map in
         if(found = false) then
            (StringMap.add id_func (get_data_type(func.fname), 0) m)
         else
            raise (Failure ("Function " ^ id_func ^
            " conflicts with a global variable"))
      )
   ) StringMap.empty funcs
in let func_decl_map =
   List.fold_left (fun m func -> StringMap.add
   (id_of_data_type(func.fname)) func m)
   StringMap.empty funcs
in let global_env = {
   globals_map = global_map;
   functions_map = function_map;
   formals_map = VarMap.empty;
   locals_map = VarMap.empty;
   unvisited_funcs = ["main"];
   visited_funcs = [];
   formals_list = [];
   visited_all = false;
```

```
    valid_syntax = false;
  }
  in let reserved_keyword keyword =
    if((keyword = "printf")||(keyword = "threads")||
    (keyword = "pthread_create")||(keyword = "pthread_join")
    ||(keyword = "pthread_mutex_t")||(keyword = "pthread_mutex_lock")
    ||(keyword = "pthread_mutex_unlock")||(keyword = "NULL")) then
      true
    else (
      let regex = Str.regexp ("\\(thread_.*\\)\\|\\(pfor_uppers_.*\\)"^
      "\\|\\(pfor_lowers_*\\)\\|\\(pfor_args_*\\)\\|\\(pfor_limit_*\\)"^
      "\\|\\(pfor_i_*\\)\\|\\(pfor_threads_*\\)\\|\\(pfor_init_*\\)"^
      "\\|\\(num_threads_*\\)\\|\\(lock_*\\)")
      in if(Str.string_match regex keyword 0) then
        true
      else
        false
    )
  in let supported_typecasting type_left type_right =
    if(type_left = "float" && (type_right =
      "integer"||type_right = "boolean"||type_right = "char")) then
      true
    else if(type_left = "integer" && (type_right =
        "boolean"||type_right = "char")) then
      true
    else if(type_left = "char" && type_right = "integer") then
      true
    else
      false

  (* For debugging purposes *)
  in let print_global_map env =
    StringMap.iter (fun dt_key (vartype, ref) -> print_string ("Global var: id: " ^
    dt_key ^ " type=" ^ vartype ^ " ref=" ^ (string_of_int ref)))
    env.globals_map
  in let print_function_map env =
    StringMap.iter (fun dt_key (vartype, ref) -> print_string ("Function: id: " ^
    dt_key ^ " type=" ^ vartype ^ " ref=" ^ (string_of_int ref)))
```

```
    env.functions_map
in let print_locals_map env =
    VarMap.iter (fun (dt_func, dt_var) (var_type, var_ref) ->
        print_string ("Local Variable Func: " ^ dt_func ^ " var: " ^ dt_var ^
        " type: " ^ var_type ^ " ref= " ^ string_of_int var_ref)
    ) env.locals_map
in let print_formals_map env =
    VarMap.iter (fun (dt_func, dt_arg) (arg_type) ->
        print_string ("Map Arguments Func: " ^ dt_func ^ " arg: " ^ dt_arg ^ " type: " ^
        arg_type)
    ) env.formals_map
in let print_formals_list env =
    List.iter (fun (fname_id, arg) ->
        print_string ("List Arguments Func: " ^ fname_id ^ " arg: " ^
        (id_of_data_type arg) ^ " type: " ^ (get_data_type arg))
    ) env.formals_list
in let print_unvisited_funcs env =
    List.iter (fun f -> print_string ("unvisited: "^f)) env.unvisited_funcs
in let print_visited_funcs env =
    List.iter (fun f -> print_string ("visited: "^f)) env.visited_funcs


in let validate_global variable =
    if (get_data_type (fst variable) <> get_literal_type (snd variable)) then
        raise (Failure ("Global variable " ^ string_of_data_type (fst variable)
            ^ " is assigned a " ^ string_of_literal (snd variable)))

in let add_local_var_to_map fname_id var env =
    let id_var = id_of_data_type var in
    let found = VarMap.mem (fname_id, id_var) env.locals_map in
    if(found = false) then
        { env with locals_map =
            VarMap.add (fname_id, id_var) ((get_data_type var), 0)
            env.locals_map }
    else
        raise (Failure ("Function " ^ fname_id ^
        " contains more than one local variable with the name " ^ id_var))
```

```
in let process_formals fname_id arg env =
   let id_arg = id_of_data_type arg in
   if(reserved_keyword id_arg) then
      raise (Failure ("Function:"^fname_id^": '"
            ^ id_arg ^ "' is a reserved keyword. It cannot be "
            ^ "used as an argument name"))
   else(
      let found = VarMap.mem (fname_id, id_arg) env.formals_map in
      if(found = false) then (
         let new_env = { env with formals_list =
            (fname_id, arg) :: env.formals_list }
         in
         { new_env with formals_map =
            VarMap.add (fname_id, id_arg) (get_data_type arg)
            new_env.formals_map }
      )
      else
         raise (Failure ("Function " ^ fname_id ^
         " contains more than one argument with the name " ^ id_arg))
   )

in let get_func_formals_list fname_id env =
   List.fold_left (fun arg_list (dt_func, arg) ->
      if(dt_func = fname_id) then
         arg :: arg_list
      else
         arg_list
   ) [] env.formals_list



in let rec process_expr fname_id env = function
     Literal(l) -> env
   | Paren(s) -> process_expr fname_id env s
   | Binop(e1, _, e2) ->
         let new_env = process_expr fname_id env e1 in
         process_expr fname_id new_env e2
   | Not(e1) ->
```

```
        process_expr fname_id env e1
    | Assign(id, idx) ->
        let new_env = process_expr fname_id env id in
        process_expr fname_id new_env idx
    | Id(s)| Pp(s)| Mm(s) ->
      let (var_type, ref_count) = try VarMap.find (fname_id, s) env.locals_map
                with Not_found -> ("", 0) in
      if(var_type = "") then (
        let var_type  = try VarMap.find (fname_id, s) env.formals_map
                    with Not_found -> "" in
        if(var_type = "") then (
          let (var_type, ref_count) = try StringMap.find s env.globals_map
                    with Not_found -> ("", 0) in
          if(var_type = "") then (
            raise (Failure ("Variable '" ^ s ^ "' " ^ "in function '" ^
              fname_id ^ "' is not defined"))
          ) else (
            { env with globals_map =
              StringMap.add s (var_type, ref_count+1) env.globals_map
            }
          ))
        else (
          env
        )
      ) else (
      { env with locals_map =
        VarMap.add (fname_id, s) (var_type, ref_count+1)
        env.locals_map }
      )
    | Call(s1, al) ->
        let (var_type, ref_count) = try StringMap.find s1 env.functions_map
                              with Not_found -> ("", 0) in
        if(var_type = "" && (s1 <> "printf")) then
          raise (Failure ("Function '" ^ s1 ^ "' is not defined"))
        else (
          if(List.mem s1 env.visited_funcs = false) then (
            let env = { env with  unvisited_funcs =
              if((List.mem s1 env.unvisited_funcs = false)
```

```
                && s1 <> "printf") then
                  s1::env.unvisited_funcs
                else
                  env.unvisited_funcs
                } in
              let mod_env = { env with functions_map =
                StringMap.add s1 (var_type, ref_count+1) env.functions_map
              }
              in List.fold_left (fun old_env arg ->
              process_expr fname_id old_env arg) mod_env al
            ) else (
              List.fold_left (fun old_env arg ->
                process_expr fname_id old_env arg) env al
            )
          )
  | Noexpr -> env

in let update_env_map curr_env functions =
  List.fold_left (fun env argument ->
      process_formals (id_of_data_type functions.fname) argument env)
    curr_env functions.formals

in let rec process_func_body fname env = function
  Block(stmts) ->
    List.fold_left (fun env_temp line ->
      process_func_body fname env_temp line) env stmts
  | Expr(exp) -> process_expr (id_of_data_type fname) env exp
  | Return(exp) -> process_expr (id_of_data_type fname) env exp
  | Break(_) -> env
  | Continue(_) -> env
  | Declare(decl) ->
    add_local_var_to_map (id_of_data_type fname) decl env
  | DeclareAssign(decl, exp) ->
    let new_env = add_local_var_to_map (id_of_data_type fname) decl env
    in process_expr (id_of_data_type fname) new_env exp
  | If (cond, then_clause, else_clause) ->
      let first_env = process_expr (id_of_data_type fname) env cond
      in let second_env = process_func_body fname first_env then_clause
```

```
            in process_func_body fname second_env else_clause
    | For (init, cond, inc, body) ->
            let first_env = process_expr (id_of_data_type fname) env init
            in let second_env = process_expr (id_of_data_type fname) first_env cond
            in let third_env = process_expr (id_of_data_type fname) second_env inc
            in process_func_body fname third_env body
    | While (exp, body) ->
            let first_env = process_expr (id_of_data_type fname) env exp
            in process_func_body fname first_env body
    | Pfor(threads, counter, init, cond, body) ->
            let first_env = process_expr (id_of_data_type fname) env threads
            in let second_env = process_expr (id_of_data_type fname) first_env counter
            in let third_env = process_expr (id_of_data_type fname) second_env init
            in let fourth_env = process_expr (id_of_data_type fname) third_env cond
            in process_func_body fname fourth_env body
    | Spawn(exp) -> process_expr (id_of_data_type fname) env exp
    | Lock(stmt) -> process_func_body fname env stmt
    | Barrier(exp) -> env

in let process_func env =
    let fname_id =
        match env.unvisited_funcs with
        [] -> ""
        | hd::tl -> hd
    in if(fname_id = "") then
        { env with visited_all = true }
    else if(fname_id <> "printf") then (
        let env = if(fname_id = "main") then
            let (var_type, ref_count) = try StringMap.find fname_id
            env.functions_map with Not_found -> raise (Failure ("function '" ^
            fname_id ^ "' not defined")) in
            { env with functions_map =
                StringMap.add fname_id (var_type, ref_count+1) env.functions_map}
        else
            env
        in let fdecl = try StringMap.find fname_id func_decl_map
                with Not_found ->
                    raise (Failure ("function '" ^ fname_id ^ "' not defined"))
```

```
        in let p_env = { env with  unvisited_funcs = List.tl env.unvisited_funcs }
        in let p_env = { p_env with visited_funcs = fname_id :: p_env.visited_funcs } in
        List.fold_left (fun env_temp line ->
            process_func_body fdecl.fname env_temp line) p_env fdecl.body
    ) else (
        env
    )

in let rec process_code env =
    let new_env = process_func env in
    if(new_env.visited_all = false) then
        let _ = if(print_process_funcs) then (
            print_string ("process_code");
            print_unvisited_funcs new_env;
            print_visited_funcs new_env
        )
        in process_code new_env
    else
        new_env

in let rec verify_expr fname_id env is_in_loop = function
    Literal(l) -> get_literal_type(l)
    | Paren(s) -> verify_expr fname_id env is_in_loop s
    | Binop(e1, o, e2) ->
            let type_e1 = verify_expr fname_id env is_in_loop e1
            in let type_e2 = verify_expr fname_id env is_in_loop e2
            in (match o with
              Add|Sub|Mult|Div|Mod ->
                  if((type_e1 = "string") || (type_e2 = "string")) then
                    raise (Failure ("Invalid operand to string in function " ^
                    fname_id))
                  else if((type_e1 = "void") || (type_e2 = "void")) then
                    raise (Failure ("Invalid operand to void in function " ^
                    fname_id))
                  else if((type_e1 = "float") || (type_e2 = "float")) then
                    "float"
                  else if((type_e1 = "integer") || (type_e2 = "integer")) then
                    "integer"
```

```
            else if((type_e1 = "char") || (type_e2 = "char")) then
              "char"
            else if((type_e1 = "boolean") || (type_e2 = "boolean")) then
              "boolean"
            else
              raise (Failure ("Invalid data type in function " ^
              fname_id))
        | Equal|Neq|Greater|Geq|Less|Leq ->
            if((type_e1 = "string") && (type_e2 <> "string")) then
              raise (Failure ("Invalid operand to string in function " ^
              fname_id))
            else if((type_e2 = "string") && (type_e1 <> "string")) then
               raise (Failure ("Invalid operand to string in function "
               ^ fname_id))
            else if((type_e1 = "void") || (type_e2 = "void")) then
              raise (Failure ("Invalid operand to void in function " ^
            fname_id))
            else
               "boolean"
        | And|Or -> "boolean"
        )
    | Not(e) -> "boolean"
    | Assign(id, idx) ->
        let type_id = verify_expr fname_id env is_in_loop id
        in let type_right = verify_expr fname_id env is_in_loop idx
        in let id_name = (match id with
           Id(s) -> s
           | _ -> raise (Failure ("Unexpected error during Assign in function " ^
                 fname_id))
        )
        in if(type_id <> type_right) then (
           if((supported_typecasting type_id type_right) = true) then
              type_id
           else
              raise (Failure ("Type mismatch:" ^ type_id ^ " variable "
                 ^ id_name ^ " is assigned " ^ type_right ^
                 " in function " ^ fname_id)))
        else
```

```
            type_id
    | Id(s) ->
          let (var_type, _) = try VarMap.find (fname_id, s) env.locals_map
                        with Not_found -> ("", 0) in
          if(var_type = "") then (
             let var_type  = try VarMap.find (fname_id, s) env.formals_map
                        with Not_found -> "" in
             if(var_type = "") then (
                let (var_type, ref_count) = try StringMap.find s env.globals_map
                                  with Not_found -> ("", 0) in
                if(var_type = "") then (
                   raise (Failure ("Variable '" ^ s ^ "' " ^ "in function '" ^
                              fname_id ^ "' is not defined"))
                 ) else
                   var_type
             ) else
                var_type
          ) else
             var_type
    | Pp(s)|Mm(s) ->
          let (var_type, _) = try VarMap.find (fname_id, s) env.locals_map
                        with Not_found -> ("", 0) in
          if(var_type = "") then (
             let var_type  = try VarMap.find (fname_id, s) env.formals_map
                        with Not_found -> "" in
             if(var_type = "") then (
                let (var_type, ref_count) = try StringMap.find s env.globals_map
                                  with Not_found -> ("", 0) in
                if(var_type = "") then (
                   raise (Failure ("Variable '" ^ s ^ "' " ^ "in function '" ^
                              fname_id ^ "' is not defined"))
                 ) else (
                    if(var_type <> "integer") then
                       raise (Failure ("Function: '" ^ fname_id ^ "': Variable '"
                       ^ s ^ "' " ^ "is of type " ^ var_type ^
                       ". However ++ and -- are supported only for integers"))
                    else
                       var_type
```

```
            )
        ) else (
            if(var_type <> "integer") then
                raise (Failure ("Function: '" ^ fname_id ^ "': Variable '"
                    ^ s ^ "' " ^ "is of type " ^ var_type ^
                    ". However ++ and -- are supported only for integers"))
            else
                var_type
        )
    ) else (
        if(var_type <> "integer") then
            raise (Failure ("Function: '" ^ fname_id ^ "': Variable '"
                    ^ s ^ "' " ^ "is of type " ^ var_type ^
                    ". However ++ and -- are supported only for integers"))
        else
            var_type
    )
| Call(s1, al) ->
    let (var_type, _) = try StringMap.find s1 env.functions_map
                        with Not_found -> ("", 0) in
    if(var_type = "" && (s1 <> "printf")) then
        raise (Failure ("Function '" ^ s1 ^ "' is not defined"))
    else (
        if(s1 = "printf") then
            var_type
        else (
            let arg_list = get_func_formals_list s1 env
            in let _ = try (List.iter2 (fun arg value ->
                let a_type = verify_expr fname_id env is_in_loop value in
                    if(get_data_type(arg) <> a_type) then (
                        raise(Failure ("Function "^fname_id^": call to:"^s1^
                        " arg "^(id_of_data_type arg)^" is of type "^(get_data_type arg)^
                        " but it is called with type "^a_type)))
                )arg_list al)
                with Invalid_argument(s) ->
                    (raise(Failure (fname_id^": call to:"^s1^
                    " number of arguments don't match")))
            in var_type
```

```
            )
        )

  | Noexpr -> ""

in let rec verify_func_body fname env data_type is_in_loop = function
   Block(stmts) ->
     List.fold_left (fun new_data_type line ->
       verify_func_body fname env new_data_type is_in_loop line) data_type stmts
  | Expr(exp) -> verify_expr (id_of_data_type fname) env is_in_loop exp
  | Return(exp) ->
       let return_type = verify_expr (id_of_data_type fname) env
       is_in_loop exp
       in let func_return_type = get_data_type (fname)
       in if((func_return_type = return_type) || (func_return_type =
          "void" && return_type = "" )) then
          ""
       else(
          if(return_type = "") then
             raise (Failure (" The return type of function " ^
             id_of_data_type (fname) ^ " is " ^ func_return_type ^
             " but it returns " ^ "void" ^ " type"))
          else
             raise (Failure (" The return type of function " ^
             id_of_data_type (fname) ^ " is " ^ func_return_type ^
             " but it returns " ^ return_type ^ " type"))
       )
  | Break(_) ->
       if(is_in_loop) then
            ""
       else
          raise (Failure ("Function:"^ id_of_data_type (fname) ^
          " break statement not within a loop"))
  | Continue(_) ->
       if(is_in_loop) then
            ""
       else
          raise (Failure ("Function:"^ id_of_data_type (fname) ^
```

```
            "' continue statement not within a loop"))
    | Declare(decl) ->
        (*TODO: Throw a warning if global or arg is
    defined with same name *)
        let func_name = id_of_data_type decl in
        if(reserved_keyword func_name) then
          raise (Failure ("Function:"^id_of_data_type(fname)^": '"
          ^ func_name ^ "' is a reserved keyword. It cannot be "
          ^ "used as a variable name"))
        else
          ""
    | DeclareAssign(decl, exp) ->
        (*TODO: Throw a warning if global or arg is
    defined with same name *)
        let func_name = id_of_data_type decl in
        if(reserved_keyword func_name) then
          raise (Failure ("Function:"^id_of_data_type(fname)^": '"
          ^ func_name ^ "' is a reserved keyword. It cannot be "
          ^ "used as a variable name"))
        else(
        let assign_type = verify_expr (id_of_data_type fname) env
        is_in_loop exp
        in if(get_data_type (decl) = assign_type) then
          ""
        else
          if((supported_typecasting (get_data_type (decl)) assign_type)) then
            ""
          else
            raise (Failure ("Local variable " ^ string_of_data_type (decl)
              ^ " is assigned a " ^ assign_type ^ " in function " ^
              id_of_data_type (fname)))
        )
    | If (cond, then_clause, else_clause) ->
        let _ = verify_expr (id_of_data_type fname) env is_in_loop cond
        in let _ = verify_func_body fname env "" is_in_loop then_clause
        in let _ = verify_func_body fname env "" is_in_loop else_clause
        in ""
    | For (init, cond, inc, body) ->
```

```
        let _ = verify_expr (id_of_data_type fname) env is_in_loop init
        in let _ = verify_expr (id_of_data_type fname) env is_in_loop cond
        in let _ = verify_expr (id_of_data_type fname) env is_in_loop inc
        in let _ = verify_func_body fname env "" true body
        in ""
    | While (exp, body) ->
        let _ = verify_expr (id_of_data_type fname) env is_in_loop exp
        in let _ = verify_func_body fname env "" true body
        in ""
    | Pfor(threads, counter, init, cond, body) ->
        let _ = match counter with
        Id(s) ->
          let counter_type = verify_expr (id_of_data_type fname) env
          is_in_loop counter in
          if(counter_type <> "integer") then
          raise (Failure ("Function: "^(id_of_data_type fname)^
          "counter in pfor should be an integer variable ONLY."^
          " Here it is "^ (counter_type)))
        | _ -> raise(Failure ("Function: "^(id_of_data_type fname)^
            " counter in pfor should be an integer variable name ONLY"))
        in let data_type =
          verify_expr (id_of_data_type fname) env is_in_loop threads
        in if(data_type <> "integer") then
          raise (Failure ("Function:"^(id_of_data_type fname)^
            " First argument to pfor should be of type integer"))
        else (
          let data_type = verify_expr (id_of_data_type fname) env
          is_in_loop init
          in if(data_type <> "integer") then
            raise (Failure ("Function:"^(id_of_data_type fname)^
            " Second argument to pfor should be of type integer"))
          else (
            let data_type = verify_expr (id_of_data_type fname) env
            is_in_loop cond
            in if(data_type <> "integer") then
              raise (Failure ("Function:"^(id_of_data_type fname)^
              " Third argument to pfor should be of type integer"))
            else (
```

```
                let _ = verify_func_body fname env "" true body
                in ""
            )
        )
    )
  | Spawn(exp) ->
      let _ = match exp with
      Call(s1, al) -> if(s1 = "printf") then
                raise (Failure ("Function:"^(id_of_data_type
                fname)^ " printf is not allowed in spawn"))
      | _ -> raise (Failure ("Function:"^(id_of_data_type fname)^
          " Invalid spawn syntax. spawn accepts" ^
          " only function calls"))
      in let _ = verify_expr (id_of_data_type fname) env is_in_loop exp
      in ""
  | Lock(stmt) ->
      let _ = verify_func_body fname env "" is_in_loop stmt
      in ""
  | Barrier(exp) -> ""

in let verify_function env str_dt fdecl =
  List.fold_left (fun str_data_type line ->
    verify_func_body fdecl.fname env str_data_type false line
    ) str_dt fdecl.body

in let final_env curr_env valid =
  { curr_env with valid_syntax = valid }

in let _ = List.iter validate_global globalvars
in let first_env = List.fold_left (fun env func_list ->
      update_env_map env func_list) global_env funcs
in let second_env = process_code first_env
in let _ = List.fold_left (fun str_dt func ->
  let func_name = id_of_data_type func.fname
  in if(reserved_keyword func_name) then
    raise (Failure ("Function:"^func_name^": "^func_name^
        " is a reserved keyword. It cannot be used as a"^
        " function name"))
```

```
      else
        verify_function second_env str_dt func
      ) "" funcs
  in if (print_map) then (
      let _ = print_global_map second_env in
      let _ = print_function_map second_env in
      let _ = print_locals_map second_env in
      let _ = print_formals_map second_env in
      let _ = print_formals_list second_env
      in final_env second_env true)
  else (
      final_env second_env true)
```

compile.ml

```
# Primary author: Andrei Papancea

open Ast
open String

module VarMap = Map.Make(struct
            type t = string * string
            let compare x y = Pervasives.compare x y
      end)

let includes =
   "#include <stdio.h>\n" ^
   "#include <stdbool.h>\n" ^
   "#include <stdlib.h>\n" ^
   "#include <string.h>\n" ^
   "#include <pthread.h>\n\n"

let rec string_of_data_type = function
   IntType(s) -> "int " ^ s
 | FloatType(s) -> "float " ^ s
 | BoolType(s) -> "bool " ^ s
```

```
  | CharType(s) -> "char " ^ s
  | StrType(s) -> "char * " ^ s
  | VoidType(s) -> "void " ^ s

let convert_data_type = function
    "integer" -> "int"
  | "float" -> "float"
  | "boolean" -> "bool"
  | "char" -> "char"
  | "string" -> "char *"
  | _ -> ""

let get_data_type = function
    IntType(s) -> "int"
  | FloatType(s) -> "float"
  | BoolType(s) -> "bool"
  | CharType(s) -> "char"
  | StrType(s) -> "char *"
  | VoidType(s) -> "void"

let id_of_data_type = function
    IntType(s) -> s
  | FloatType(s) -> s
  | BoolType(s) -> s
  | CharType(s) -> s
  | StrType(s) -> s
  | VoidType(s) -> s

let rec string_of_literal = function
    Integer(i) -> string_of_int i
  | Float(f) -> string_of_float f
  | Boolean(b) -> string_of_bool b
  | Char(c) -> "'" ^ Char.escaped c ^ "'"
  | String(s) -> "\"" ^ s ^ "\""

let type_of_literal = function
    Integer(i) -> "int"
  | Float(f) -> "float"
```

```
  | Boolean(b) -> "bool"
  | Char(c) -> "char"
  | String(s) -> "char *"

let is_literal = function
    Literal(l) -> true
  | _ -> false

let get_literal_type = function
    Literal(l) -> type_of_literal(l)
  | _ -> ""

let is_assignment = function
    Assign(a, b) -> true
  | _ -> false

(* keep track of assignments
  in pfor. REMOVE THE REFERENCE VARIABLES *)
let assignments_in_pfor = ref ""
let defs_in_pfor = ref ""
let globals_in_pfor_assignments = ref []
let globals_init_values = ref []

let generate_code (vars, funcs) env =
    let rec append_env env = function
    [] -> []
    | hd::tl -> (env, hd)::append_env env tl
    in let env_vars = append_env env vars in
    let global_inits =
       ignore (List.map (fun (env,globals) ->
            let data_type = fst globals in
            let var_id = id_of_data_type data_type in
            let (global_type, ref_count) = try Semantic_checker.StringMap.find
            var_id env.Semantic_checker.globals_map with Not_found -> (var_id, 0)  in
            if(ref_count <> 0) then (
         match data_type with
         IntType(s) -> globals_init_values := (s,string_of_literal (snd globals))::!globals_init_values; ""
       | FloatType(s) -> globals_init_values := (s,string_of_literal (snd globals))::!globals_init_values; ""
```

```
        | BoolType(s) -> globals_init_values := (s,string_of_literal (snd globals))::!globals_init_values; ""
        | CharType(s) -> globals_init_values := (s,"'" ^ string_of_literal (snd globals) ^ "'")::!globals_init_values;
""
        | StrType(s) -> globals_init_values := (s,string_of_literal (snd globals))::!globals_init_values; ""
        | VoidType(s) -> ("")
        ) else ("")
       ) env_vars); ""
   in let rec convert_expr env is_pfor is_replace myA myB = function
   Id(x)  -> if is_replace && x = myA then
                myB
             else
                  if is_pfor then (
                    let (var_type, ref_count) = try Semantic_checker.StringMap.find x
env.Semantic_checker.globals_map
                                        with Not_found -> ("", 0) in
                 if(var_type = "") then x else (
                      (if not (List.mem_assoc x !globals_in_pfor_assignments) then (
                            globals_in_pfor_assignments := (x,var_type) :: !globals_in_pfor_assignments
                         ) else ());
                      "temp_" ^ x
                )
                   ) else x
  | Literal(l) -> string_of_literal l
  | Paren(a) -> "(" ^ convert_expr env is_pfor is_replace myA myB a ^ ")"
  | Binop(a, Add, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "+" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Sub, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "-" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Mult, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "*" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Div, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "/" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Mod, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "%" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, And, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "&&" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Or, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "||" ^ convert_expr env is_pfor
is_replace myA myB b)
```

```
  | Binop(a, Equal, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "==" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Neq, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "!=" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Less, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "<" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Leq, b) -> (convert_expr env is_pfor is_replace myA myB a ^ "<=" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Greater, b) -> (convert_expr env is_pfor is_replace myA myB a ^ ">" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Binop(a, Geq, b) -> (convert_expr env is_pfor is_replace myA myB a ^ ">=" ^ convert_expr env is_pfor
is_replace myA myB b)
  | Not(e) -> "!" ^ convert_expr env is_pfor is_replace myA myB e
  | Pp(id) -> (id ^ "++")
  | Mm(id) -> (id ^ "--")
  | Assign(a, b) -> if is_pfor then (
                  assignments_in_pfor :=       !assignments_in_pfor ^
                                          "    pthread_mutex_lock(&pfor_global_lock);\n" ^
                                          "    " ^ (convert_expr env false is_replace myA myB a ^ "=" ^
                                              (convert_expr env false true "i" (convert_expr env is_pfor false myA myB
a) b) ^ ";\n") ^
                                          "    " ^ "pthread_mutex_unlock(&pfor_global_lock);\n";
                  (convert_expr env is_pfor is_replace myA myB a ^ "=" ^ convert_expr env is_pfor false myA
myB b)
               ) else
                  (convert_expr env is_pfor is_replace myA myB a ^ "=" ^ convert_expr env is_pfor is_replace
myA myB b)
  | Call(s1, al) -> if (s1 = "printf") then
                 ("printf" ^ "(" ^
                   ((convert_expr env is_pfor is_replace myA myB (List.hd al)) ^
                     (List.fold_left (fun acc x -> acc ^ "," ^ (convert_expr env is_pfor is_replace myA myB x)) ""
(List.tl al)))
                   ^ ")")
                else (s1 ^ "(" ^ String.concat ","
                   (List.map (fun e -> convert_expr env is_pfor is_replace myA myB e ) al) ^ ")")
  | Noexpr -> ""

  in let rec indent n =
```

```
    if n = 1 then
        "    "
    else
        "    "^indent(n-1)

in let build_args (a,n,num_indent,env,is_pfor) =
    let list_size = List.length a in
    let lit_counter = Array.make 1 0 in
    if list_size > 0 then
        indent num_indent ^ "void *args_thread_" ^ n ^ "[" ^ string_of_int list_size ^ "];\n" ^
        (fst (List.fold_left (fun (acc,k) x -> (acc ^
                        (if is_literal(x) then
                            indent num_indent ^ get_literal_type x ^ " arg_lit_" ^ n ^ "_"
                            ^ (string_of_int k) ^ " = " ^ convert_expr env is_pfor false "x" "y" x ^ ";\n"
                        else
                            ""),k+1)) ("",0) a)) ^
        (fst (List.fold_left (fun (acc,k) x -> (acc ^
                            indent num_indent ^ "args_thread_" ^ n ^ "[" ^ (string_of_int k) ^ "] =
(void *)&" ^
                        (if is_literal(x) then
                            (lit_counter.(0) <- lit_counter.(0)+1;
                            "arg_lit_" ^ n ^ "_" ^ (string_of_int (lit_counter.(0)-1)))
                        else
                            convert_expr env is_pfor false "x" "y" x)
                        ^ ";\n",k+1)) ("",0) a))
    else
        ""

  in let get_func_formals_list fname_id env =
    List.fold_left (fun arg_list (dt_func, arg) ->
      if(dt_func = fname_id) then
        arg :: arg_list
      else
        arg_list
    ) [] env.Semantic_checker.formals_list

  in let get_func_locals_list fname_id env =
    Semantic_checker.VarMap.fold (fun (my_fun, var_id) (var_type, ref) var_list ->
```

```
        if(my_fun = fname_id) then (
          let (var_type, ref_count) = try Semantic_checker.VarMap.find
          (fname_id,var_id) env.Semantic_checker.locals_map with Not_found -> (var_id, 0) in
          if(ref_count <> 0) then (
            (var_id,var_type) :: var_list
          ) else var_list
        ) else
          var_list
      ) env.Semantic_checker.locals_map []

  in let rec build_vars (f,n,counter,s,k,env) =
      let test = Array.make 1 0 in
      let data_type = Array.make 1 "" in
      let var_type = List.iter (fun arg ->
            if counter-n = test.(0) then (
          data_type.(0) <- (get_data_type arg);
          test.(0) <- test.(0)+1
        ) else
          test.(0) <- test.(0)+1
      ) (List.rev (get_func_formals_list f env)); data_type.(0) in
      let my_var = (indent 1) ^ var_type ^ " var" ^ (string_of_int (n-1)) ^ " = *(" ^ var_type ^ " *)arg_list[" ^
(string_of_int (n-1)) ^ "];\n" in
      if n = 1 then
       (1,my_var ^ s)
      else
       build_vars (f,n-1,counter,my_var ^ s,k+1,env)

  in let build_thread_func (f,a,n,env) =
      let list_size = List.length a in
      "void *thread_" ^ n ^ "(void *args){\n" ^
      (if list_size > 0 then
          (indent 1) ^"void **arg_list = (void **)args;\n" ^
       (snd (build_vars (f,list_size,list_size,"",0,env)))
      else
       "") ^
      (indent 1) ^ f ^ "(" ^
      (if list_size > 0 then
          ("var0" ^ (fst (List.fold_left (fun (acc, k) x -> (acc ^ ",var" ^ (string_of_int k), k+1)) ("",1) (List.tl a)))
```

```
^ ");\n")
      else
           "") ^
      "}\n\n"

   in let build_pfor (f,n,i,l,c,remove,num_indent,env) =
      let num_threads = n in
      let init = i in
      let limit = l in
      let k = string_of_int c in
      let locals_list = List.rev (get_func_locals_list f env) in
      indent num_indent ^ "int num_threads_" ^ k ^ " = " ^ num_threads ^ ";\n" ^
      indent num_indent ^ "int pfor_init_" ^ k ^ " = " ^ init ^ ";\n" ^
       indent num_indent ^ "int pfor_limit_" ^ k ^ " = " ^ limit ^ ";\n\n" ^
       indent num_indent ^ "pthread_t pfor_threads_" ^ k ^ "[num_threads_" ^ k ^ "];\n" ^
      indent num_indent ^ "int pfor_uppers_" ^ k ^ "[num_threads_" ^ k ^ "];\n" ^
      indent num_indent ^ "int pfor_lowers_" ^ k ^ "[num_threads_" ^ k ^ "];\n" ^
      indent num_indent ^ "void *pfor_args_" ^ k ^ "[num_threads_" ^ k ^ "][3];\n" ^
      indent num_indent ^ "void *pfor_local_vars_" ^ k ^ "[" ^ string_of_int (List.length locals_list) ^ "];\n" ^
      (fst (List.fold_left (fun (acc, count) (var_id, var_type) ->
            if not (List.mem var_id remove) then (
             (acc ^ indent num_indent ^ "pfor_local_vars_" ^ k ^ "[" ^ string_of_int count ^ "] = (void *)&" ^
var_id ^ ";\n", count+1)
          ) else
               (acc, count)
      ) ("",0) locals_list)) ^
      indent num_indent ^ "int pfor_i_" ^ k ^ ";\n\n" ^
      indent num_indent ^ "for(pfor_i_" ^ k ^ "=0;pfor_i_" ^ k ^ "<num_threads_" ^ k ^ ";pfor_i_" ^ k ^
"++){\n" ^
      indent (num_indent+1) ^ "pfor_uppers_" ^ k ^ "[pfor_i_" ^ k ^ "] = pfor_init_" ^ k ^ "+((pfor_init_" ^ k ^
"+pfor_limit_" ^ k ^ ")/num_threads_" ^ k ^ ")*(pfor_i_" ^ k ^ "+1)+((pfor_init_" ^ k ^ "+pfor_limit_" ^ k ^
")%num_threads_" ^ k ^ ");\n" ^
      indent (num_indent+1) ^ "pfor_lowers_" ^ k ^ "[pfor_i_" ^ k ^ "] = pfor_init_" ^ k ^ "+((pfor_init_" ^ k ^
"+pfor_limit_" ^ k ^ ")/num_threads_" ^ k ^ ")*pfor_i_" ^ k ^ ";\n" ^
      indent (num_indent+1) ^ "pfor_args_" ^ k ^ "[pfor_i_" ^ k ^ "][0] = (void *)&pfor_lowers_" ^ k ^
"[pfor_i_" ^ k ^ "];\n" ^
      indent (num_indent+1) ^ "pfor_args_" ^ k ^ "[pfor_i_" ^ k ^ "][1] = (void *)&pfor_uppers_" ^ k ^
"[pfor_i_" ^ k ^ "];\n" ^
```

```
      indent (num_indent+1) ^ "pfor_args_" ^ k ^ "[pfor_i_" ^ k ^ "][2] = (void *)&pfor_local_vars_" ^ k ^ ";\n"
^
      indent num_indent ^ "}\n\n" ^
      indent num_indent ^ "for(pfor_i_" ^ k ^ "=0;pfor_i_" ^ k ^ "<num_threads_" ^ k ^ ";pfor_i_" ^ k ^
"++){\n" ^
      indent (num_indent+1) ^ "pthread_create(&pfor_threads_" ^ k ^ "[pfor_i_" ^ k ^ "],NULL,thread_" ^ k ^
",(void *)&pfor_args_" ^ k ^ "[pfor_i_" ^ k ^ "]);\n" ^
      indent num_indent ^ "}\n\n" ^
      indent num_indent ^ "for(pfor_i_" ^ k ^ "=0;pfor_i_" ^ k ^ "<num_threads_" ^ k ^ ";pfor_i_" ^ k ^
"++){\n" ^
      indent (num_indent+1) ^ "pthread_join(pfor_threads_" ^ k ^ "[pfor_i_" ^ k ^ "],NULL);\n" ^
       indent num_indent ^ "}\n"

(* myenv stores counters for the
  number of locks, threads, and
  pfors -- in that order *)
  in let myenv = Array.make 3 0
  in let thread_funcs = Array.make 2 []
  in let remove = Array.make 1 []

  in let rec convert_stmt num_indent env currf is_pfor is_replace myA myB = function
  Expr(e) -> indent num_indent ^ convert_expr env is_pfor is_replace myA myB e ^ ";\n"
 | Declare(e) -> let data_type = e in
          let var_id = id_of_data_type data_type in
          let (var_type, ref_count) = try Semantic_checker.VarMap.find
          (currf,var_id) env.Semantic_checker.locals_map with Not_found -> (var_id, 0) in
          if(ref_count <> 0) then (
            if is_pfor then (
                remove.(0) <- var_id::remove.(0); ()
            ) else ();
                  indent num_indent ^ string_of_data_type e ^ ";\n"
          ) else ("")
 | DeclareAssign(a, b) -> let data_type = a in
                  let var_id = id_of_data_type data_type in
                  let (var_type, ref_count) = try Semantic_checker.VarMap.find
                  (currf,var_id) env.Semantic_checker.locals_map with Not_found -> (var_id, 0) in
                  if(ref_count <> 0) then (
                      if is_pfor then (
```

```
                                remove.(0) <- var_id::remove.(0); ()
                            ) else ();
                        indent num_indent ^ string_of_data_type a ^ "=" ^ convert_expr env is_pfor is_replace
myA myB b ^ ";\n"
                    ) else ("")
  | Return(e) -> indent num_indent ^ "return " ^ convert_expr env is_pfor is_replace myA myB e ^ ";\n"
  | Break(e) -> indent num_indent ^ "break;\n"
  | Continue(e) -> indent num_indent ^ "continue;\n"
  | Block(s) -> if (List.length s = 0) then "" else "{\n" ^ (List.fold_left (fun acc x ->
        acc ^ convert_stmt (num_indent + 1) env currf is_pfor is_replace myA myB x) "" s) ^ (indent
(num_indent)) ^ "}\n"
  | If(e, s, n) -> let else_block = convert_stmt num_indent env currf is_pfor is_replace myA myB n in
            if (else_block = "") then (indent num_indent) ^ "if(" ^ convert_expr env is_pfor is_replace myA
myB e ^ ")" ^
              convert_stmt num_indent env currf is_pfor is_replace myA myB s
            else (indent num_indent) ^ "if(" ^ convert_expr env is_pfor is_replace myA myB e ^ ")" ^
              convert_stmt num_indent env currf is_pfor is_replace myA myB s ^(indent num_indent) ^ "else" ^
else_block
  | For(i, c, u, s) -> (indent num_indent) ^ "for(" ^ convert_expr env is_pfor is_replace myA myB i ^ "; " ^
convert_expr env is_pfor is_replace myA myB c ^ "; " ^
                                        convert_expr env is_pfor is_replace myA myB u ^ ")" ^
                                    convert_stmt (num_indent) env currf is_pfor is_replace myA myB s ^ "\n"
  | While(e, s) -> (indent num_indent) ^ "while(" ^ convert_expr env is_pfor is_replace myA myB e ^ ")"
             ^ convert_stmt (num_indent) env currf is_pfor is_replace myA myB s
  | Lock(s) -> myenv.(0) <- myenv.(0)+1; let lock = string_of_int myenv.(0) in
            (indent num_indent) ^ "pthread_mutex_lock(&m" ^ lock ^ ");\n" ^ convert_stmt num_indent env
currf is_pfor is_replace myA myB s ^
            "pthread_mutex_unlock(&m" ^ lock ^ ");\n"
  | Barrier(e) ->(indent num_indent) ^ "int thread_counter;\n"^(indent num_indent) ^
"for(thread_counter=0;thread_counter<" ^
            string_of_int myenv.(1) ^ ";thread_counter++){\n" ^(indent (num_indent+1)) ^
              "pthread_join(threads[thread_counter],NULL);\n" ^(indent num_indent) ^ "}\n"
  | Spawn(Call(id,args)) -> myenv.(1) <- myenv.(1)+1;
                  (thread_funcs.(0) <- (build_thread_func (id,args,string_of_int
(myenv.(1)-1),env))::thread_funcs.(0));
                  let thread = string_of_int (myenv.(1)-1) in
                  (build_args (args,thread,num_indent,env,is_pfor)) ^
                  indent num_indent ^ "pthread_create(&threads[" ^ thread ^ "],NULL,thread_" ^ string_of_int
```

```
(myenv.(1)-1) ^ ",(void *)"
                                ^ (if List.length args > 0 then
                                        "args_thread_" ^ thread
                                  else
                                        "NULL")
                                ^ ");\n"
  | Pfor(t, k, i, b, s) -> let build_pfor_func (stmt,n,env) =
                        assignments_in_pfor := "";
                        globals_in_pfor_assignments := [];
                        let counter = convert_expr env is_pfor is_replace myA myB k in
                        (indent 1) ^ "pthread_mutex_t pfor_global_lock=PTHREAD_MUTEX_INITIALIZER;\n" ^
                        (indent 1) ^ "void **arguments = (void **)args;\n" ^
                         (indent 1) ^ "int lower = *((int *)arguments[0]);\n" ^
                        (indent 1) ^ "int upper = *((int *)arguments[1]);" ^
                        (let locals = (List.fold_left (fun (acc, count) (var_id, var_type) ->
                                if not (List.mem var_id remove.(0)) then (
                              (acc ^ indent num_indent ^ (convert_data_type var_type) ^
                                " " ^ var_id ^ " = " ^ "*((" ^ convert_data_type var_type ^ "
*)thread_0_local_vars[" ^ string_of_int count ^ "]);\n", count+1)
                                ) else (acc, count)
                        ) ("",0) (List.rev (get_func_locals_list currf env))) in
                        if snd locals > 0 then (
                                (indent 1) ^ "void **thread_0_local_vars = (void **)arguments[2];\n" ^
                                (fst locals)
                        ) else "") ^
                        (indent 1) ^"for(" ^ counter ^ "=lower; " ^ counter ^ "<upper; " ^ counter ^ "++)" ^
                        convert_stmt 1 env currf true is_replace myA myB stmt in
                let get_global_init var_id =
                        List.fold_left (fun acc (id,value) -> if var_id = id then value else acc) "" !globals_init_values
in
                myenv.(1) <- myenv.(1)+1;
                let pfor_func = (build_pfor_func (s,string_of_int (myenv.(1)-1),env)) in
                let globals_in_assignments = List.fold_left (fun acc (var_id,var_type) ->
                                                acc ^ "    " ^ convert_data_type var_type ^ " temp_" ^ var_id ^ " =
                                                get_global_init var_id ^ ";\n"
                                        ) "" !globals_in_pfor_assignments in
                (thread_funcs.(0) <- ("void *thread_" ^ string_of_int (myenv.(1)-1) ^ "(void *args){\n" ^
                                globals_in_assignments ^
```

```
                                pfor_func ^ !assignments_in_pfor ^
                                (indent 1) ^"pthread_exit(NULL);\n" ^
                                "}\n\n")::thread_funcs.(0));
                build_pfor (currf,(convert_expr env is_pfor is_replace myA myB t),
                                (convert_expr env is_pfor is_replace myA myB i),
                                (convert_expr env is_pfor is_replace myA myB b),
                        myenv.(1)-1,remove.(0),num_indent,env)
| Spawn(_) -> "" (* trying to spawn anything but a function call will be ignored *)

in let rec locks (n,l) =
    if n = 0 then
        (0, l)
    else
        locks (n-1, ("pthread_mutex_t m" ^ string_of_int (n) ^ "=PTHREAD_MUTEX_INITIALIZER;\n") :: l)

in let rec threads (n,l) =
    if n = 0 then
     (0, l)
    else
     threads (n-1, ("void *thread_" ^ string_of_int (n-1) ^ "(void *args);\n") :: l)

in let convert_globals (env, globals) =
  let data_type = fst globals in
  let var_id = id_of_data_type data_type in
  let (global_type, ref_count) = try Semantic_checker.StringMap.find
  var_id env.Semantic_checker.globals_map with Not_found -> (var_id, 0)  in
  if(ref_count <> 0) then (
    match data_type with
      IntType(s) -> "int " ^ s ^ " = " ^ string_of_literal (snd globals) ^ ";"
    | FloatType(s) -> "float " ^ s ^ " = " ^ string_of_literal (snd globals) ^ ";"
    | BoolType(s) -> "bool " ^ s ^ " = " ^ string_of_literal (snd globals) ^ ";"
    | CharType(s) -> "char " ^ s ^ " = " ^ "'" ^ string_of_literal (snd globals) ^ "';"
    | StrType(s) -> "char " ^ s ^ "[" ^
                string_of_int (String.length (string_of_literal(snd globals)) - 1)
                ^ "]" ^ " = " ^ string_of_literal (snd globals) ^ ";"
    | VoidType(s) -> ""
  ) else ("")
```

```
  in let string_of_fdecl (env,fdecl) =
    let data_type = fdecl.fname in
    let var_id = id_of_data_type data_type in
    let (func_type, ref_count) = try Semantic_checker.StringMap.find
    var_id env.Semantic_checker.functions_map with Not_found -> (var_id, 0)  in
    if(ref_count <> 0) then (
       string_of_data_type fdecl.fname ^ "(" ^
       String.concat "," (List.map string_of_data_type fdecl.formals) ^
       "){\n" ^
       String.concat "" (List.map (convert_stmt 1 env (id_of_data_type fdecl.fname) false false "x" "y")
fdecl.body) ^
       "}\n"
    ) else ("")

  in let rec append_env env = function
    [] -> []
    | hd::tl -> (env, hd)::append_env env tl

    in let env_vars = append_env env vars in
    let env_funcs = append_env env funcs in
    "/* Code Generated from SMPL */\n" ^ includes ^
    String.concat "\n" (List.map convert_globals env_vars) ^ global_inits ^ "\n\n" ^
    String.concat "\n" (List.map (fun (tenv,fdecl) ->
       let name = string_of_data_type fdecl.fname in
       if name <> "int main" then (
          let data_type = fdecl.fname in
          let var_id = id_of_data_type data_type in
          let (func_type, ref_count) = try Semantic_checker.StringMap.find
          var_id env.Semantic_checker.functions_map with Not_found -> (var_id, 0)  in
          if(ref_count <> 0) then (
             string_of_data_type fdecl.fname ^ "(" ^ String.concat "," (List.map string_of_data_type
fdecl.formals) ^ ");"
          ) else ("")
       ) else
          ""
    ) env_funcs) ^
    (List.fold_left (fun acc x -> acc ^ x) "" (snd (locks (myenv.(0), [])))) ^ "\n" ^
    (List.fold_left (fun acc x -> acc ^ x) "" (snd (threads (myenv.(1), [])))) ^ "\n" ^
```

```
  (if myenv.(1) > 0 then "pthread_t threads[" ^ string_of_int myenv.(1) ^ "];\n\n" else "") ^
  (List.fold_left (fun acc x -> x ^ acc) "" thread_funcs.(0) ^
   String.concat "\n" (List.map string_of_fdecl env_funcs))
```

smplc.ml

```
# Primary Author: Devashi Tandon
type action = DumpAst | CodeGen | SyntaxCheck | InvalidArg

let help_msg = "NAME: \n\tsmpl - Compiler for generating C code for SMPL" ^
      " - SMall Paraller Language\nARGUMENTS:\n\t -a code-input Print the parse" ^
      " results of the input SMPL code \n\t -c code-input Generate the C" ^
      " code equivalent to the input SMPL code\n\t -s code-input Just check" ^
      " the syntax of the SMPL code\n code-input can be one of the" ^
      " following:\n\t -t Take input from terminal\n\t <file-name> Take input" ^
      " from file\nEXAMPLES:\n\t./smplc -a -t : Take code input from" ^
      " terminal and print the parse results.\n\t./smplc -c hello.smpl >" ^
      " hello.c: Compile the SMPL code in hello.smpl and write the generated C" ^
      " code to hello.c\n\nAUTHORS:\n\tWritten" ^
      " by Ajay Siva Santosh, Andrei Papancea, Devashi Tandon\n\n"

let process_program lexbuf action =
   let expr = Parser.program Scanner.token lexbuf in
   let verified_env = Semantic_checker.validate_program expr in
   if (verified_env.Semantic_checker.valid_syntax) then
      match action with
      DumpAst ->
         let result = Printast.parse_program expr in
         print_string result
      | CodeGen ->
         let result = Compile.generate_code (expr) verified_env in
         print_string result
      | SyntaxCheck -> print_string "Validation is complete\n"
      | InvalidArg  -> print_string help_msg

let _ =
```

```
if Array.length Sys.argv <> 3 then (
   print_string help_msg
) else (
   let action = try List.assoc Sys.argv.(1)
      [ ("-a", DumpAst); ("-c", CodeGen); ("-s", SyntaxCheck)  ]
   with Not_found -> InvalidArg in
   match action with
   InvalidArg -> print_string help_msg
   | _ ->
      let src_file = Sys.argv.(2) in
      if(src_file = "-t") then
         let lexbuf = Lexing.from_channel stdin in
         process_program lexbuf action
      else
         let lexbuf = Lexing.from_channel (open_in src_file) in
         process_program lexbuf action
)
```

Test Cases

Test Scripts

run-semantics.sh

```
# Primary Author: Ajay Challa
#!/bin/sh

SMPL="../smplc -s "

files="tests/semantic_pass_cases/*.smpl"

CleanUp() {
	rm test.out test.null
}

GetError() {
	eval "$SMPL $1" 2> test.out 1> test.null
	wc -l test.out | awk '{print $1}'
}

for file in $files
do
	errors=$(GetError $file)
	GetError $file
	if [ $errors -eq 0 ]
	then
		echo "Test: " $file " passed."
	else
		echo $file " failed to pass."
		exit 1
	fi
done
CleanUp
echo "All tests passed.\n"
```

run-execution.sh

```
# Primary Author: Ajay Challa
#!/bin/sh
```

```
SMPL="../smplc -c "

files="tests/execution_cases/*.smpl"

CleanUp() {
        rm test.out test.null test.c result.out a.out
}

GetError() {
        eval "$SMPL $1" 2> test.out 1> test.null
        wc -l test.out | awk '{print $1}'
}

GenerateCode() {
    $SMPL $1 > test.c
    gcc -pthread test.c
    ./a.out > result.out
    BASEFILE=`echo $1 | sed -e "s/smpl/out/g"`
    diff -b "$BASEFILE" result.out 2>&1 || {
        echo "FAILED $BASEFILE differs for $1" 1>&2
        echo $1 " failed to pass."
        exit 1
    }
}

for file in $files
do
        errors=$(GetError $file)
        GetError $file
        if [ $errors -eq 0 ]
        then
          GenerateCode $file
                echo "Test: " $file " passed."
        else
                echo $file " failed to pass."
                exit 1
        fi
done
```

```
CleanUp
echo "All tests passed.\n"
```

Demo Test Cases

pfor-test1.smpl

```
# Primary Author: Ajay Challa
main()
{
   int i;

   pfor (10;i;0;100)
   {
      printf("%d\n",i);
   }
   printf("%d\n",42);
}
```

pfor-test2.smpl

```
# Primary Author: Ajay Challa
int sum = 0;

int isPrime(int n){
  int limit = n/2;
  int i = 0;
  for(i=2; i<=limit; i++)
    if(n%i == 0)
      return 0;
  return 1;
}

int main(){
```

```
  int i;
  int n = 1000000;

  pfor(8; i; 1; n){
    if(isPrime(i))
      sum = sum+i;
  }

  printf("The sum of the first 1M primes is %d.\n",sum);
}
```

lock-test1.smpl

```
# Primary Author: Ajay Challa
main()
{
    int i;
    int j=0;

    pfor (5;i;10;100)
    {
        printf("%d\n",i);
        lock
        {
            j=j+1;
        }
    }
    printf("%d\n",42);
}
```

dead-code.smpl

```
# Primary Author: Ajay Challa
int unused1 = 0;
char unused2 = 'c';
```

```
float used1 = 2.0;
void main()
{
   used1 = 4.0;
   printf("%f \n", used1);
}

func1_unused()
{
   unused2 = 'd';
   func2_unused(unused2);
}

func2_unused(char var)
{
   printf("%c", var);
   func1_unused();
}
```

dead-code2.smpl

```
# Primary Author: Ajay Challa
int unused1 = 0;
char unused2 = 'c';
float used1 = 2.0;
void main()
{
   used1 = 4.0;
   printf("%f \n", used1);
}

func1_unused()
{
   unused2 = 'd';
   func1_unused();
}
```

```
func2_unused(char var)
{
   unused1 = 5;
   printf("%c", var);
}
```

used-code.smpl

```
# Primary Author: Ajay Challa
int unused1 = 0;
char unused2 = 'c';
float used1 = 2.0;
void main()
{
   used1 = 4.0;
   printf("%f \n", used1);
   func1_unused();
}

func1_unused()
{
   unused2 = 'd';
   func2_unused(unused2);
}

func2_unused(char var)
{
   printf("%c", var);
   func1_unused();
}
```

Execution Test Cases

barrier-test1.smpl

```
# Primary Author: Ajay Challa
int a=10;
main()
{
   int i=0;
   spawn fun();
   barrier;
   printf("The value of i is %d \n", i);
}
fun()
{ int i=0;
 while(i<100)
       {
          i=i+1;
       }
       printf("Done");
}
```

test-for1.smpl

```
# Primary Author: Ajay Challa
main()
{
  int i;
  for (i = 0 ; i < 5 ; i = i + 1) {
    printf("%d \n",i);
  }
  printf("%d \n",42);
}
```

test-func1.smpl

```
# Primary Author: Ajay Challa
main()
{
```

```
  int a=0;
  a = add(39,3);
  printf("%d \n",a);
}

int add(int a,int b)
{
 return(a+b);
}
```

test-func2.smpl

```
# Primary Author: Ajay Challa
int fun(int x, int y)
{
  return 0;
}

main()
{
  int i;
  i = 1;

  fun(i = 2, i = i+1);

  printf("%d \n",i);

}
```

test-func3.smpl

```
# Primary Author: Ajay Challa
```

```
printem(int a,int b,int c,int d)
{
  printf("%d \n",a);
  printf("%d \n",b);
  printf("%d \n",c);
  printf("%d \n",d);
}

main()
{
  printem(42,17,192,8);
}
```

test-func4.smpl

```
# Primary Author: Ajay Challa
int a=0; /* Global variable */

int inca() { a = a + 1; return a; }  /* Increment a; return its new value */

int add2(int x,int y) { return x + y; }

main() {
  a = 0;
  printf("%d \n",add2(inca(), a));
}
int a=0;
int b=0;

printa()
{
  printf("%d \n",a);
}

printb()
{
```

```
  printf("%d \n",b);
}

incab()
{
  a = a + 1;
  b = b + 1;
}

main()
{
  a = 42;
  b = 21;
  printa();
  printb();
  incab();
  printa();
  printb();
}
```

test-gcd.smpl

```
# Primary Author: Ajay Challa
int gcd(int a, int b) {
  while (a != b) {
    if (a > b) a = a - b;
    else b = b - a;
  }
  return a;
}

main()
{
  printf("%d \n",gcd(2, 14));
  printf("%d \n",gcd(3, 15));
```

```
  printf("%d \n",gcd(99, 121));
}
```

test-global1.smpl

```
# Primary Author: Ajay Challa
int a=0;
int b=0;

printa()
{
  printf("%d \n",a);
}

printb()
{
  printf("%d \n",b);
}

incab()
{
  a = a + 1;
  b = b + 1;
}

main()
{
  a = 42;
  b = 21;
  printa();
  printb();
  incab();
  printa();
  printb();
}
```

test-hello.smpl

```
# Primary Author: Ajay Challa
main()
{
  printf("%d \n",42);
  printf("%d \n",71);
  printf("%d \n",1);
}
```

test-if1.smpl

```
# Primary Author: Ajay Challa
main()
{
  if (1) printf("%d \n",42);
  printf("%d \n",17);
}
```

test-if2.smpl

```
# Primary Author: Ajay Challa
main()
{
  if (1) printf("%d \n",42); else printf("%d \n",8);
  printf("%d \n",17);
}
```

test-if3.smpl

```
# Primary Author: Ajay Challa
```

```
main()
{
  if (0) printf("%d \n",42);
  printf("%d \n",17);
}
```

test-ops1.smpl

```
# Primary Author: Ajay Challa
main()
{
  printf("%d \n",1 + 2);
  printf("%d \n",1 - 2);
  printf("%d \n",1 * 2);
  printf("%d \n",100 / 2);
  printf("%d \n",99);
  printf("%d \n",1 == 2);
  printf("%d \n",1 == 1);
  printf("%d \n",99);
  printf("%d \n",1 != 2);
  printf("%d \n",1 != 1);
  printf("%d \n",99);
  printf("%d \n",1 < 2);
  printf("%d \n",2 < 1);
  printf("%d \n",99);
  printf("%d \n",1 <= 2);
  printf("%d \n",1 <= 1);
  printf("%d \n",2 <= 1);
  printf("%d \n",99);
  printf("%d \n",1 > 2);
  printf("%d \n",2 > 1);
  printf("%d \n",99);
  printf("%d \n",1 >= 2);
  printf("%d \n",1 >= 1);
  printf("%d \n",2 >= 1);
}
```

test-stmts1.smpl

```
# Primary Author: Ajay Challa
int foo(int a, int b) {
  int i;
  if (a)
    return b + 3;
  else
    for (i = 0 ; i < 5 ; i = i + 1)
      b = b + 5;
  return b;
}

main() {
  printf("%d \n",foo(1,42));
  printf("%d \n",foo(0,37));
}
```

test-var1.smpl

```
# Primary Author: Ajay Challa
main()
{
  int a;
  a = 42;
  printf("%d \n",a);
}
```

test-var2.smpl

```
# Primary Author: Ajay Challa
main()
```

```
{
  int a;
  int b;
  a = 42;
  b = 57;
  printf("%d \n",a + b * 3);
}
```

test-var3.smpl

```
# Primary Author: Ajay Challa
int a=0;

print2(int x,int y) {
  printf("%d \n",x);
  printf("%d \n",y);
}

main()
{
  int b;
  a = 42;
  b = 57;
  print2(
   a + b * 3,
   77);
}
```

test-while1.smpl

```
# Primary Author: Ajay Challa
main()
{
  int i;
  i = 5;
```

```
  while (i > 0) {
    printf("%d \n",i);
    i = i - 1;
  }
  printf("%d \n",42);
}
```

hello-world.smpl

```
# Primary Author: Ajay Challa
int itest = 13;
float ftest = 1.0;
char ctest = 'c';
boolean btest = true;
string stest = "I am working fine now\n";

int main(int a, int b)
{
    /* test program */
    printf("%s", stest);
}
```

lock-test2.smpl

```
# Primary Author: Ajay Challa
int sum=0;
int add_to_sum(int val){
   lock sum = sum+val;
}

int main(){
   int i;
   pfor(4;i;0;10000){
      add_to_sum(i);
   }
```

```
   printf("The sum is %d.\n",sum);
}
```

pfor-test2.smpl

```
# Primary Author: Ajay Challa
int sum = 0;

int isPrime(int n){
  int limit = n/2;
  int i = 0;
  for(i=2; i<=limit; i++)
    if(n%i == 0)
      return 0;
  return 1;
}

int main(){
  int i;
  int n = 10000;

  pfor(8; i; 1; n){
    if(isPrime(i))
      sum = sum+i;
  }

  printf("The sum of the first 1M primes is %d.\n",sum);
}
```

spawn-test1.smpl

```
# Primary Author: Ajay Challa
func()
{
   int i;
```

```
    for(i=0;i<100;i=i+1)
    {

        printf("%d \n",i+100);
    }
}
main()
{ spawn func();
}
```

test-arith1.smpl

```
# Primary Author: Ajay Challa
main()
{
  printf("%d\n",39 + 3);
}
```

test-arith2.smpl

```
# Primary Author: Ajay Challa
main()
{
  printf("%d \n",1 + 2 * 3 + 4);
}
```

test-arith3.smpl

```
# Primary Author: Ajay Challa
int a=0; /* Global variable */

int inca() { a = a + 1; return a; }  /* Increment a; return its new value */
```

```
main() {
  a = 42;    /* Initialize a */
  printf("%d \n",inca() + a);
}
```

test-arith4.smpl

```
# Primary Author: Ajay Challa
int g=0;

main() {
  int l;
  l = 1;
  printf("%d \n",l);
  g = 3;
  printf("%d \n",g);
  l = 5;
  printf("%d \n",l+100);
  g = 7;
  printf("%d \n",g+100);
}
```

test-fib.smpl

```
# Primary Author: Ajay Challa
int fib(int x)
{
  if (x < 2) return 1;
  return fib(x-1) + fib(x-2);
}

main()
{
  printf("%d \n",fib(0));
  printf("%d \n",fib(1));
```

```
  printf("%d \n",fib(2));
  printf("%d \n",fib(3));
  printf("%d \n",fib(4));
  printf("%d \n",fib(5));
}
```

Semantic Pass Cases

Declaration.smpl

```
# Primary Author: Ajay Challa
int a=10;
char c='a';
boolean b=true;
float f=10.0;

void main()
{}
```

Function.smpl

```
# Primary Author: Ajay Challa
int a=10;
char ch='a';
int b=5;

fun()
{ int c=b+c;
}
main()
{ fun();
}
```

Test1.smpl

```
# Primary Author: Ajay Challa
int a=1;
int k=2;
int c=3;
int b=12;
char d='a';

fun()
{
   int m;
   if(a-b){
      c=4;
   } else {
      m=c;
   }
}



main()
{
   if(a-b){
      c=4;
   }
   else {
      d=c;
   }
   fun();
}
```

arithmetic.smpl

```
# Primary Author: Ajay Challa
int a=10;
int b=5;
```

```
void  main()
{

printf(a+b);
printf(a-b);
printf(a/b);
printf(a*b);
printf(a%b);

}
```

barrier-test1.smpl

```
# Primary Author: Ajay Challa
int a=10;
main()
{
   int i=0;
   spawn fun();
   barrier;
   printf("The value of i is %d", i);
}
fun()
{ int i=0;
 while(i<100)
      {
         i=i+1;
      }
      printf("Done");
}
```

binop.smpl

```
# Primary Author: Ajay Challa
int a=5;
```

```
float f=3.0;
boolean b=false;
char c='k';
string s="hello";

main()
{
/* binop arithmetic*/
printf(a+b);
printf(a+f);
printf(a+c);
printf(a/b);
printf(a/f);
printf(a/c);
printf(a-b);
printf(a-f);
printf(a-c);
printf(a*b);
printf(a-f);
printf(a-c);

/*binop logical*/

boolean l=a>f;
boolean l1=a<f;
boolean l2=a>=f;
boolean l3=a<b;
boolean l4=a<=b;
boolean l5=c!=b;
}
```

break_test.smpl

```
# Primary Author: Ajay Challa
int count = 0;
int i=0;
```

```
void main()
{ for(i=0;i<10;i+1)

  {count=count+1;
  if(count==5)
  { printf("breaking");
    break;
  }
  else
 { printf("continuing");
  /* continue; */
 }
}  }
```

calling_fun.smpl

```
# Primary Author: Ajay Challa
int a=1;
int b=0;
char c='a';
int k=0;

fun()
{ if(a-b)
{c=4;}
else
{k=c;
 a=a/0;
}
}

int fail=10;

main()
{ if(a-b)
{c=4;
```

```
fun();}

else
{k=c;}

fun();
}
```

casting.smpl

```
# Primary Author: Ajay Challa
int a=10;
char c='c';
float f=10.0;
boolean b=true;

main()
{

a=c;

a=b;

c=a;




f=a;
f=b;
f=c;

int r=a+b;



}
```

data_types.smpl

```
# Primary Author: Ajay Challa
int a=10;
float b=10.0;
boolean flag=true;
string s="hello";

main()
{}
```

for-test.smpl

```
# Primary Author: Ajay Challa
int i=0;

main()
{



for( i=0;i<10;i+1)
{printf("%d",i);}

}
```

hello-world.smpl

```
# Primary Author: Ajay Challa
int itest = 13;
float ftest = 1.0;
char ctest = 'c';
boolean btest = true;
string stest = "I am working fine now\n";
```

```
int main(int a, int b)
{
   /* test program */
   printf("Hello World.. I have arrived\n");
}
```

lock-test1.smpl

```
# Primary Author: Ajay Challa
main()
{
   int i;
   int j=0;

   pfor (5;i;10;100)
   {
      printf("%d",i);
      lock
      {
         j=j+1;
      }
   }
   printf("%d",42);
}
```

logical.smpl

```
# Primary Author: Ajay Challa
int a = 10;
int b = 5;
boolean b1=true;
boolean b2=false;

void main()
{
```

```
if(a>b)
{ printf("a is greater than b");
}

if(a<b)
{ printf("a is less than b");
}

if(a<=b)
{ printf("a is less than or equal to b");
}

if(a==b)
{ printf("a is equal to b");
}

if(a!=b)
{ printf("a is not equal to b");
}

if((a!=b))
{ printf("a is equal to b");
}

if(a>=b)
{ printf("a is greater than or equal to b");
}

if(b1 && b2)
{ printf("both are true");
}

if(b1 || b2)
{ printf(" one or both are true");
}

}
```

main.smpl

```
# Primary Author: Ajay Challa
int a=10;
boolean b=true;
int k=0;

void main()
{
  k=a+10;

}
```

multiplespawntest.smpl

```
# Primary Author: Ajay Challa
int j=5;
int i=4;
fun1()
{while(i<10) printf("%d",i);}
fun2()
{while(j<20) printf("%d",j);}

main(){

    int i=0;
    int j=10;
    int k=20;
    int l=30;
spawn fun1();
spawn fun2();
    barrier;
printf("done \n");
}
```

parantheses.smpl

```
# Primary Author: Ajay Challa
main()
{
int Rpar_test=(2*4)+(5*6);
}
```

pfortest1.smpl

```
# Primary Author: Ajay Challa
main()
{
   int i;

   pfor (10;i;0;100)
   {
      printf("%d",i);
   }
   printf("%d",42);
}
```

return_stmt.smpl

```
# Primary Author: Ajay Challa
int a=1;
int b=2;
int k=3;
int d=12;
char c='a';

int fun()
{ if(a-b)
```

```
{c=4;}
else
{k=c;}
return(1);
}

int fail=10;

main()
{ if(a-b)
{c=4;
 fun();}

else
{k=c;}
}
```

test-prog.smpl

```
# Primary Author: Ajay Challa
int itest = 13;
float ftest = 1.0;
char ctest = 'c';
boolean btest = true;

funca(int a1, int a2)
{
   printf(a1, a2);
}

int main(int a, float b)
{
   /* test program */
   int i = 0;
   string stest = "I am working fine now\n";
   for(i=10;i<20;i++)
```

```
    {
        printf(itest, ftest, ctest, btest, a, b);
        break;
    }
    i = 100;
    pfor(5;i;30;320)
    {
        printf(itest, ftest, ctest, btest, a, b);
    }
 /*   spawn(funca(5,3));*/
    printf("This is a string\" \t\n");
    barrier;
}
```

threadtest1.smpl

```
# Primary Author: Ajay Challa
int limit=0;
void main()
{
    int i = 0;
    int sum = 0;
    int n;
    int t;
    printf("Enter the number of threads t: ");
        lock {
            sum = sum + i;
        }

    printf("The sum of the first %d numbers is %d.\n",
            limit,sum);
}
```

while_test.smpl

```
# Primary Author: Ajay Challa
int i=10;

main()
{

while(i!=0)
{ printf("%d",i);
  i-1;
}

}
```

Semantic Fail Cases

Declaration.smpl

```
# Primary Author: Ajay Challa

int a=10;
char c='a';
main()
{
a=7.0;
c=8.0;
}
```

keywords.smpl

```
# Primary Author: Ajay Challa

int printf=1;
char f='a';
main()
```

```
{}
```

binop.smpl

```
# Primary Author: Ajay Challa

string s="hello";
string s1="world";
main()
{ s1=s+s1;
}
```

casting.smpl

```
# Primary Author: Ajay Challa

int a=5;
boolean b=false;
char c='c';
float f=7.0;

main()
{

a=b;
a=c;
a=f;

b=a;
b=c;
b=f;

c=a;
c=b;
c=f;
```

```
f=a;
f=b;
f=c;

}
```

fnkeyword.smpl

```
# Primary Author: Ajay Challa

printf()
{}
main()
{printf();
}
```

key.smpl

```
# Primary Author: Ajay Challa

int printf=5;



main()
{}
```

pfor.smpl

```
# Primary Author:Ajay Challa
{ pfor(3;i=0;i<10;i+1)
  printf("hello");
}
```

redeclaration.smpl

```
# Primary Author: Ajay Challa

int a=10;
char a='a';
main()
{}
```

ref-count.smpl

```
# Primary Author: Ajay Challa

int itest = 13;
float ftest = 1.0;
char ctest = 'c';
boolean btest = true;

funca(int a, int a2)
{
   int int_funca;
   printf(a, a2);
   /*funcb("abc");*/
}

int main(int a, float b)
{
   /* test program */
   {
   int i = 3;
   int j;
   int k;
   funca(itest, ftest);
   int n = ((j+k)*funcb());
```

```
    n = (9+5)*(k+i);
    funca(btest, itest);
    string stest;
    int main_int;
    break;
    if(i<10 || i>5)
    {
        i = 9;
        return ((5+3)*funcd());
    } else {
        return funca(1,3);
    }
    for(i=10;i<20;i=i+1)
    {
        printf(itest, ftest, ctest, btest, a, b);
        printf("%s %d\n", stest, 9);
        break;
    }
    while(j < 100) {
        funce();
    }
    lock {
    funca(i,j);
    funca(j,k);
    funca((((j+k)*i) < n),(3));
    spawn funca(5,3);
    }
    barrier;
    printf("This is a string\" \t\n");
    }
}

int funcd(){
return 5;
}

int funce(){
return 6;
```

```
}

funcb (string abc)
{
printf("got it");
funcc();
funcc();
/*funca();*/
}
funcc()
{
return;
}
```

samename.smpl

```
# Primary Author: Ajay Challa

int fun1=10;

fun1()
{ int a=10;
  a=a+1;
}

main()
{ fun1();
}
```

samenameargs.smpl

```
# Primary Author: Ajay Challa

fn(int a,int a)
{}
```

```
main()
{int a=10;
int b=10;
fn(a,b);
}
```

undef.smpl

```
# Primary Author: Ajay Challa

main()
{ fn();
}
```

undefined.smpl

```
# Primary Author: Ajay Challa

fn()
{ int a;
  int b=c+a;
}
main()
{ fn();
}
```