# The NanoC Compiler

**example.mc**

// Example of a program written in NanoC, a subset of C:

// \* no func calls, etc

// \* bool and int built-in types

// \* control flows: while and if

// \* assignment, comparison, subtraction

// GCD example

int a;

int b;

a = 18;

b = 9;

while (a != b) {

if (b < a) a = a - b;

else b = b - a;

}

a = a;

**example.out**

// LLVM code for example.mc

// Run with: **lli example.out**

; ModuleID = 'NanoC'

source\_filename = "NanoC"

@fmt = private unnamed\_addr constant [4 x i8] c"%d\0A\00", align 1

@fmt.1 = private unnamed\_addr constant [4 x i8] c"%g\0A\00", align 1

@fmt.2 = private unnamed\_addr constant [4 x i8] c"%d\0A\00", align 1

@fmt.3 = private unnamed\_addr constant [4 x i8] c"%g\0A\00", align 1

@a = global i32 0 // int a;

@b = global i32 0 // int b;

declare i32 @printf(i8\*, ...)

define i32 @main() {

entry:

store i32 18, i32\* @a // a = 18;

store i32 9, i32\* @b // b = 9;

br label %while

while: ; preds = %merge, %entry

%a7 = load i32, i32\* @a

%b8 = load i32, i32\* @b

%tmp9 = icmp ne i32 %a7, %b8

br i1 %tmp9, label %while\_body, label %merge10

while\_body: ; preds = %while

%b = load i32, i32\* @b

%a = load i32, i32\* @a

%tmp = icmp slt i32 %b, %a

br i1 %tmp, label %then, label %else

merge: ; preds = %else, %then

br label %while

then: ; preds = %while\_body

%a1 = load i32, i32\* @a

%b2 = load i32, i32\* @b

%tmp3 = sub i32 %a1, %b2

store i32 %tmp3, i32\* @a

br label %merge

else: ; preds = %while\_body

%b4 = load i32, i32\* @b

%a5 = load i32, i32\* @a

%tmp6 = sub i32 %b4, %a5

store i32 %tmp6, i32\* @b

br label %merge

merge10: ; preds = %while

%a11 = load i32, i32\* @a

store i32 %a11, i32\* @a

%printf = call i32 (i8\*, ...) @printf(i8\* getelementptr inbounds ([4 x i8], [4 x i8]\* @fmt, i32 0, i32 0), i32 %a11)

ret i32 0

}

**ast.ml**

// Abstract syntax tree:

// 1. This is the scanner and parser combined to produce an AST

// 2. Then semantic analysis parses the AST and does checks and adds type information

// 3. Then IR generation converts the decorated AST into IR code

(\* Abstract Syntax Tree and functions for printing it \*)

type op = Add | Sub | Equal | Neq | Less | And | Or // binary operators

type typ = Int | Bool // types

type expr = // AST for expression

Literal of int // number literal

| BoolLit of bool // boolean literal (true or false)

| Id of string // identifier

| Binop of expr \* op \* expr // binary oper over 2 smaller exp’s

| Assign of string \* expr // assignment, in C it has ret val

type stmt = // AST for statement

Block of stmt list // list of statements

| Expr of expr // simple expression (ex. Assignment)

| If of expr \* stmt \* stmt // if statement

| While of expr \* stmt // while statement

type program = { // AST for program (NOTE: a record)

locals: (typ \* string) list; // declarations

body: stmt list; // statements

}

// ALTERNATIVELY:

type bind = typ \* string

type program = {

locals: bind list;

body: stmt list;

}

// AST is done above, below is just functions to print the original program for debugging

(\* Pretty-printing functions \*)

let string\_of\_op = function

Add -> "+"

| Sub -> "-"

| Equal -> "=="

| Neq -> "!="

| Less -> "<"

| And -> "&&"

| Or -> "||"

let rec string\_of\_expr = function

Literal(l) -> string\_of\_int l

| BoolLit(true) -> "true"

| BoolLit(false) -> "false"

| Id(s) -> s

| Binop(e1, o, e2) ->

string\_of\_expr e1 ^ " " ^ string\_of\_op o ^ " " ^ string\_of\_expr e2

| Assign(v, e) -> v ^ " = " ^ string\_of\_expr e

let rec string\_of\_stmt = function

Block(stmts) ->

"{\n" ^ String.concat "" (List.map string\_of\_stmt stmts) ^ "}\n"

| Expr(expr) -> string\_of\_expr expr ^ ";\n";

| If(e, s1, s2) -> "if (" ^ string\_of\_expr e ^ ")\n" ^

string\_of\_stmt s1 ^ "else\n" ^ string\_of\_stmt s2

| While(e, s) -> "while (" ^ string\_of\_expr e ^ ") " ^ string\_of\_stmt s

let string\_of\_typ = function

Int -> "int"

| Bool -> "bool"

let string\_of\_vdecl (t, id) = string\_of\_typ t ^ " " ^ id ^ ";\n"

let string\_of\_program fdecl =

"\nParsed program: \n" ^

String.concat "" (List.map string\_of\_vdecl fdecl.locals) ^

String.concat "" (List.map string\_of\_stmt fdecl.body) ^

"\n"

**nanocparse.mly**

// Ocaml yacc file

// Tokens for AST and parser to construct the AST

/\* Ocamlyacc parser for NanoC \*/

%{

open Ast // definition of the AST

%}

// All acceptable tokens for language

%token SEMI LPAREN RPAREN LBRACE RBRACE PLUS MINUS ASSIGN

%token EQ NEQ LT AND OR

%token IF ELSE WHILE INT BOOL

%token <int> LITERAL // this token exports an int

%token <bool> BLIT // this token exports a bool

%token <string> ID // this token exports a string (var)

%token EOF // special token for EOF

%start program // entry rule for the parser

%type <Ast.program> program // this rule exports an object of type Ast.program

// NOTE: from ast.ml:

// type program = {

// locals: (typ \* string) list;

// body: stmt list;

// }

// Associativity and precedence (in order of increasing precedence!)

%right ASSIGN

%left OR

%left AND

%left EQ NEQ

%left LT

%left PLUS MINUS

// See the scanner in scanner.mll before proceeding

%%

// Rules to parse the input (program)

program: // progam is:

vdecl\_list stmt\_list EOF { {locals=$1; body=$2} } // declarations followed by statements and EOF

// assigns vdecl\_list to local and stmt\_list to body

vdecl\_list:

/\*nothing\*/ { [] } // empty list!

| vdecl vdecl\_list { $1 :: $2 } // list of head (declaration) + tail (may be empty)

vdecl:

typ ID SEMI { ($1, $2) } // variable declaration: type, identifier, semicolon

// produces a tuple of (type, identifier)

typ: // NOTE: from ast.ml: type bind = typ \* string

INT { Int }

| BOOL { Bool }

stmt\_list: // similar to list of declarations

/\*nothing\*/ { [] }

| stmt stmt\_list { $1 :: $2 }

stmt:

expr SEMI { Expr $1 } // from ast.ml: Expr of expr

// NOTE: if stml\_list was defined as: stmt\_list stmt { $2 :: $1 } above

// then the below should have { Block (List.rev $2) } for the correct order

| LBRACE stmt\_list RBRACE { Block $2 } // from ast.ml: Block of stmt list

| IF LPAREN expr RPAREN stmt ELSE stmt { If ($3, $5, $7) } // If of expr \* stmt \* stmt

| WHILE LPAREN expr RPAREN stmt { While ($3, $5) } // While of expr \* stmt

expr:

LITERAL { Literal($1) } // $1 here is the object exported by the LITERAL token

// from %token <int> LITERAL we know it exports an int

| BLIT { BoolLit($1) }

| ID { Id($1) }

| expr PLUS expr { Binop($1, Add, $3) }

| expr MINUS expr { Binop($1, Sub, $3) }

| expr EQ expr { Binop($1, Equal, $3) }

| expr NEQ expr { Binop($1, Neq, $3) }

| expr LT expr { Binop($1, Less, $3) }

| expr AND expr { Binop($1, And, $3) }

| expr OR expr { Binop($1, Or, $3) }

| ID ASSIGN expr { Assign($1, $3) } // ASSIGN is the “=”, we turn it into Assign object

| LPAREN expr RPAREN { $2 }

**scanner.mll**

// Scanner for language – Ocaml lex file

// Maps patterns to tokens (with attributes) that are generated from them

(\* Ocamllex scanner for NanoC \*)

{ open Nanocparse } // Header to add OCaml native code

// opens nanocparse module w/ token definitions

let digit = ['0'-'9'] in // pattern for digit

let letter = ['a'-'z' 'A'-'Z'] in // pattern for letter

rule token = parse

[' ' '\t' '\r' '\n'] { token lexbuf } (\* Whitespace \*)// “token lexbuf” means apply token rule to rest of buf

| "/\*" { comment lexbuf } (\* Comments \*)// apply the comment rule (below) to rest of input buffer

| '(' { LPAREN } // chars below are simply parsed in the respective token

| ')' { RPAREN }

| '{' { LBRACE }

| '}' { RBRACE }

| ';' { SEMI }

| '+' { PLUS }

| '-' { MINUS }

| '=' { ASSIGN }

| "==" { EQ }

| "!=" { NEQ }

| '<' { LT }

| "&&" { AND }

| "||" { OR }

| "if" { IF }

| "else" { ELSE }

| "while" { WHILE }

| "int" { INT }

| "bool" { BOOL }

// NOTE: from nanocparse.mly:

// <bool> BLIT

// …

// | BLIT { BoolLit($1) }

// and from ast.ml:

// | BoolLit of bool

| "true" { BLIT(true) }

| "false" { BLIT(false) }

// NOTE: from nanocparse.mly:

// %token <int> LITERAL

// …

// LITERAL { Literal($1) }

// and from ast.ml:

// Literal of int

| digit+ as lxm { LITERAL(int\_of\_string lxm)} // construct LITERAL of int value of lxm (digit+)

// NOTE: from nanocparse.mly:

// %token <string> ID

// …

// | ID { Id($1) }

// and from ast.ml:

// | Id of string

| letter (letter | digit | '\_')\* as lxm { ID(lxm) }

| eof { EOF } // token for EOF

| \_ as char { raise (Failure("illegal character " ^ Char.escaped char)) } // error for any other case

and comment = parse

"\*/" { token lexbuf }

| \_ { comment lexbuf }

**We can compile and try the above phases before we move on.**

With something like this (say, in test1.ml):

open Ast

let \_ =

let lexbuf = Lexing.from\_channel stdin in // Lexing module turns input into lexical buffer

let program = Nanocparse.program Scanner.token lexbuf in // this assigns the AST in program

print\_endline (string\_of\_program program) // converts the AST back into program instructions

ocamlbuild test1.native // test1.native is the target we are building

./test1.native

<input program text, say from example.mc>

^D

**sast.ml**

// Semantic analysis

// Adds type info to AST and checks types and scopes to produce a decorated AST

// The types here describe the decorated AST that results from semantic analysis

(\* Semantically-checked Abstract Syntax Tree and functions for printing it \*)

open Ast

// NOTE: here we know (or can infer) the type, so we want to decorate the AST with that information

// this is because nanoc is statically typed

// This is a new type for expressions that adds that type information

type sexpr = typ \* sx // sexpr consists of type information + a typed expression (sx)

and sx = // a typed expr. (sx) is either a literal or operation on typed expr.’s

SLiteral of int // NOTE: Can’t reuse Literal here, has to be different in OCaml

| SBoolLit of bool

| SId of string

| SBinop of sexpr \* op \* sexpr // we must use sexpr here to have type information

| SAssign of string \* sexpr

// similar for statement

// This is a new type for statements that adds type information

type sstmt =

SBlock of sstmt list

| SExpr of sexpr

| SIf of sexpr \* sstmt \* sstmt

| SWhile of sexpr \* sstmt

// similar for program

type sprogram = {

slocals : (typ \* string) list;

sbody : sstmt list;

}

// this concludes the semantically-decorated AST, below are printing functions

(\* Pretty-printing functions \*)

let rec string\_of\_sexpr (t, e) =

"(" ^ string\_of\_typ t ^ " : " ^ (match e with

SLiteral(l) -> string\_of\_int l

| SBoolLit(true) -> "true"

| SBoolLit(false) -> "false"

| SId(s) -> s

| SBinop(e1, o, e2) ->

string\_of\_sexpr e1 ^ " " ^ string\_of\_op o ^ " " ^ string\_of\_sexpr e2

| SAssign(v, e) -> v ^ " = " ^ string\_of\_sexpr e

) ^ ")"

let rec string\_of\_sstmt = function

SBlock(stmts) ->

"{\n" ^ String.concat "" (List.map string\_of\_sstmt stmts) ^ "}\n"

| SExpr(expr) -> string\_of\_sexpr expr ^ ";\n";

| SIf(e, s1, s2) -> "if (" ^ string\_of\_sexpr e ^ ")\n" ^

string\_of\_sstmt s1 ^ "else\n" ^ string\_of\_sstmt s2

| SWhile(e, s) -> "while (" ^ string\_of\_sexpr e ^ ") " ^ string\_of\_sstmt s

let string\_of\_sprogram fdecl =

"\nSementically checked program: \n" ^

String.concat "" (List.map string\_of\_vdecl fdecl.slocals) ^

String.concat "" (List.map string\_of\_sstmt fdecl.sbody) ^

"\n"

**semant.ml**

// Semantic analysis module

(\* Semantic checking for the NanoC compiler \*)

open Ast

open Sast

module StringMap = Map.Make(String)

(\* Semantic checking of the AST. Returns an sAST if successful,

throws an exception if something is wrong.

Check each global variable, then check each function \*)

// This is the semantic check function that maps AST to sAST

let check program = // function that takes a program of type Ast.program as input

// and produces output of type Sast.sprogram

// Given a list of variable declarations, check if there are any duplicates

(\* Verify a list of bindings has no duplicate names \*)

let check\_binds (kind : string) (binds : (typ \* string) list) =

let rec dups = function

[] -> ()

| ((\_,n1) :: (\_,n2) :: \_) when n1 = n2 -> // then, check if the front two in list have same name

raise (Failure ("duplicate " ^ kind ^ " " ^ n1))

| \_ :: t -> dups t // finally, check list tail

in dups (List.sort (fun (\_,a) (\_,b) -> compare a b) binds) // first, sort the declaration list

in

(\* Make sure no locals duplicate \*)

check\_binds "local" program.locals;

// Builds the symbol table from variable declarations (no nesting)

// MicroC will use multiple level

(\* Build local symbol table of variables for this function \*)

let symbols = List.fold\_left (fun m (ty, name) -> StringMap.add name ty m)

StringMap.empty program.locals

in

(\* Return a variable from our local symbol table \*)

let type\_of\_identifier s = // looks up the type of an identifier in symbol table

try StringMap.find s symbols

with Not\_found -> raise (Failure ("undeclared identifier " ^ s))

in

(\* Return a semantically-checked expression, i.e., with a type \*)

let rec check\_expr = function // takes expr and generates sexpr

Literal l -> (Int, SLiteral l)

| BoolLit l -> (Bool, SBoolLit l)

| Id var -> (type\_of\_identifier var, SId var)

| Assign(var, e) as ex ->

let lt = type\_of\_identifier var // LHS type

and (rt, e') = check\_expr e in // RHS type

if lt = rt then (lt, SAssign(var, (rt, e'))) // NOTE: SAssign of string \* sexpr

else raise (Failure ("illegal assignment " ^ string\_of\_typ lt ^ " = " ^

string\_of\_typ rt ^ " in " ^ string\_of\_expr ex))

| Binop(e1, op, e2) as e ->

let (t1, e1') = check\_expr e1

and (t2, e2') = check\_expr e2 in

let err = "illegal binary operator " ^

string\_of\_typ t1 ^ " " ^ string\_of\_op op ^ " " ^

string\_of\_typ t2 ^ " in " ^ string\_of\_expr e

in

if t1 = t2 then

let ty = match op with

Add | Sub when t1 = Int -> Int

| Equal | Neq -> Bool

| Less when t1 = Int -> Bool

| And | Or when t1 = Bool -> Bool

| \_ -> raise (Failure err)

in (ty, SBinop((t1, e1'), op, (t2, e2')))

else raise (Failure err)

in

let check\_bool\_expr e = // first, parse e (expr) into an sexpr, then check its type

let (t, e') = check\_expr e in

if t = Bool then (t, e') else raise (Failure ("expected Boolean expression in " ^ string\_of\_expr e))

// Above can be done as:

// match t with

// | Bool -> (t, e’)

// | \_ -> raise …

in

// NOTE: use and keyword below because the definitions of check\_stmt\_list and check\_stmt depend on one another

let rec check\_stmt\_list = function // takes stmt list and generates sstmt list

[] -> []

// Optimization to flatten blocks by concatenating to a single statement list

| Block sl :: sl' -> check\_stmt\_list (sl @ sl') // sl’ is just another variable name, diff than sl

| s :: sl -> check\_stmt s :: check\_stmt\_list sl // check\_stmt s to sstmt then check\_stmt\_list the rest

and check\_stmt = function // takes stmt and converts it to sstmt

| Expr e -> SExpr(check\_expr e)

| If(e, st1, st2) -> SIf(check\_bool\_expr e, check\_stmt st1, check\_stmt st2) // check\_bool\_expr forces bool

| While(e, st) -> SWhile(check\_bool\_expr e, check\_stmt st) // check\_bool\_expr forces bool

| Block sl -> SBlock(check\_stmt\_list sl)

in

{

slocals = program.locals; // since declarations in AST and decorated AST same: (typ \* string) list

sbody = check\_stmt\_list program.body // check\_stmt\_list is func to parse/decorate program.body to sstmt list

}

**We can compile and try the above phases before we move on.**

With something like this (say, in test2.ml):

open Sast

let \_ =

let lexbuf = Lexing.from\_channel stdin in // Lexing module turns input into lexical buffer

let program = Nanocparse.program Scanner.token lexbuf in // this assigns the AST in program

let sprogram = Semant.check program in // this checks the AST and converts it to sAST

print\_endline (string\_of\_program sprogram) // converts the sAST back into program instructions

ocamlbuild test2.native // test2.native is the target we are building

./test2.native

<input program text, say from example.mc>

^D

**irgen.ml**

// Intermediate code generator

(\* IR generation: translate takes a semantically checked AST and

produces LLVM IR

LLVM tutorial: Make sure to read the OCaml version of the tutorial

http://llvm.org/docs/tutorial/index.html

Detailed documentation on the OCaml LLVM library:

http://llvm.moe/

http://llvm.moe/ocaml/

\*)

module L = Llvm // open Llvm module and rename it to L

module A = Ast // open Ast module and rename it to Ast

open Sast

module StringMap = Map.Make(String)

// translate function that takes Sast.program and returns Llvm.module

// this does all of the translation work

(\* translate : Sast.program -> Llvm.module \*)

let translate program =

let context = L.global\_context () in // define global context to remember types, functions, etc.

(\* Create the LLVM compilation module into which

we will generate code \*)

let the\_module = L.create\_module context "NanoC" in // create module for compiled code w/ context & name

(\* Get types from the context \*)

let i32\_t = L.i32\_type context // get 32-bit int type from context (for integers)

and i1\_t = L.i1\_type context in // get 1-bit int type from content (for Booleans)

(\* Return the LLVM type for a NanoC type \*) // maps AST type to llvm type

let ltype\_of\_typ = function

A.Int -> i32\_t

| A.Bool -> i1\_t

in

// map of global variables

(\* Create a map of global variables after creating each \*)

let global\_vars : L.llvalue StringMap.t =

// given a variable declaration w/ type t and name n, and a map m

let global\_var m (t, n) =

// initial value

let init = L.const\_int (ltype\_of\_typ t) 0

// define global var w/ name n, initial value init, and in the\_module

// i.e. given a map, global\_var will add the name n and the global definition into the map

in StringMap.add n (L.define\_global n init the\_module) m in

// fold left all variable declarations in program.slocals

List.fold\_left global\_var StringMap.empty program.slocals in

// lookup a name to get the llvm global var definition for it

(\* Return the value for a variable or formal argument.

Check global names \*)

let lookup n = StringMap.find n global\_vars in

// turns an expression into a list of llvm instructions

// builder argument is the position for the next generated instruction, pointer to position in module

//

(\* Construct code for an expression; return its value \*)

// returns the temporal that is equal to value of entire expression (in llvm each expr is new temporal)

let rec build\_expr builder ((\_, e) : sexpr) = match e with

SLiteral i -> L.const\_int i32\_t i // for number, return its const value (no code, just addr)

| SBoolLit b -> L.const\_int i1\_t (if b then 1 else 0) // return 1 or 0 for bool (no code, just addr)

// lookup var and load it (from static mem region for globals)

// this generates code at the current position in builder and mutates builder to move to next position

| SId s -> L.build\_load (lookup s) s builder

// generate instruction to calculate e, return it in e’ (a temporal) and then store it in memory store

// and return the value of the expression e’

| SAssign (s, e) -> let e' = build\_expr builder e in

ignore(L.build\_store e' (lookup s) builder); e'

// for binary ops, evalueate e1 and e2, then generate the instruction to perform the operation

| SBinop (e1, op, e2) ->

let e1' = build\_expr builder e1

and e2' = build\_expr builder e2 in

(match op with

A.Add -> L.build\_add

| A.Sub -> L.build\_sub

| A.And -> L.build\_and

| A.Or -> L.build\_or

| A.Equal -> L.build\_icmp L.Icmp.Eq

| A.Neq -> L.build\_icmp L.Icmp.Ne

| A.Less -> L.build\_icmp L.Icmp.Slt

) e1' e2' "tmp" builder // generates new temporal name & inserts it into builder (to be used for result)

// NOTE: the above is a 3-address code: the operator followed by 3 addresses (two source and one dest)

in

// we reviewed the concept of basic blocks, either:

// 1. beginning of program, or

// 2. starting after a label, or

// 3. starting after some conditional jump

// and is a sequence of instructions w/o any jump, until we hit a label or conditional jump

// i.e. the only entry point in block is the first instruction and guarantees that, once entered, it completes

// execution of all instructions in the block and the only exit is the end of the block

// LLVM insists every basic block ends w/ jump or conditional jump, but in our language we do not enforce that

// (ex. the “else” block from “Basic Blocks and Control-Flow Graphs” of ir.pdf slide does not end w/ any jump)

// the benefit of always having jump at the end (as LLVM insists) is that you don’t care about the sequence of

// the resulting blocks, because every block jumps to next block explicitly.

(\* LLVM insists each basic block end with exactly one "terminator"

instruction that transfers control. This function runs "instr builder"

if the current block does not already have a terminator. Used,

e.g., to handle the "fall off the end of the function" case. \*)

// so, this function terminates the basic block in builder with instr, if necessary

let add\_terminal builder instr =

match L.block\_terminator (L.insertion\_block builder) with

Some \_ -> () // if block has a terminator, do nothing

| None -> ignore (instr builder) in // otherwise, add instr to the builder (as terminator)

(\* Build the code for the given statement; return the builder for

the statement's successor (i.e., the next instruction will be built

after the one generated by this call) \*)

// this is how we generate llvm instructions for a statement:

// the\_function is the statement you want to insert the instruction(s) for

// builder is the builder to use when inserting the instruction(s)

// and returns a builder (i.e. what is the next position to insert instructions)

let rec build\_stmt the\_function builder = function

// starting w/ provided builder, apply build\_stmt function to the list of statements

// each time returning a new builder that is forwarded to next statement in list

// the result is an aggregated builder

SBlock sl -> List.fold\_left (build\_stmt the\_function) builder sl

| SExpr e -> ignore(build\_expr builder e); builder // for expr, simply generate list of instructions for it

// ignore returned temporal value for expression above, since we want to return builder (already mutated)

| SIf (predicate, then\_stmt, else\_stmt) ->

let bool\_val = build\_expr builder predicate in // generate code for expression and remember its address

let then\_bb = L.append\_block context "then" the\_function in // generate label for then

ignore (build\_stmt the\_function (L.builder\_at\_end context then\_bb) then\_stmt); // gen code for then branch

// right after the then label that was just generated

let else\_bb = L.append\_block context "else" the\_function in // generate label for else

ignore (build\_stmt the\_function (L.builder\_at\_end context else\_bb) else\_stmt); // gen code for else branch

// right after the else label that was just generated

let end\_bb = L.append\_block context "if\_end" the\_function in // generate label for end of if

// because both then and else will jump to end of if

let build\_br\_end = L.build\_br end\_bb in (\* partial function \*)

add\_terminal (L.builder\_at\_end context then\_bb) build\_br\_end; // add jump to end of if to end of then

add\_terminal (L.builder\_at\_end context else\_bb) build\_br\_end; // add jump to end of if to end of else

ignore(L.build\_cond\_br bool\_val then\_bb else\_bb builder); // build conditional jump to then\_bb or else\_bb

L.builder\_at\_end context end\_bb

| SWhile (predicate, body) ->

let while\_bb = L.append\_block context "while" the\_function in

let build\_br\_while = L.build\_br while\_bb in (\* partial function \*)

ignore (build\_br\_while builder);

let while\_builder = L.builder\_at\_end context while\_bb in

let bool\_val = build\_expr while\_builder predicate in

let body\_bb = L.append\_block context "while\_body" the\_function in

add\_terminal (build\_stmt the\_function (L.builder\_at\_end context body\_bb) body) build\_br\_while;

let end\_bb = L.append\_block context "while\_end" the\_function in

ignore(L.build\_cond\_br bool\_val body\_bb end\_bb while\_builder);

L.builder\_at\_end context end\_bb

in

(\* Fill in the body of the given function \*)

let build\_program fdecl =

(\* Define each function (arguments and return type) so we can

call it even before we've created its body \*)

let main\_decl : L.llvalue =

let ftype = L.function\_type i32\_t [||]

in L.define\_function "main" ftype the\_module in

let the\_function = main\_decl in

let builder = L.builder\_at\_end context (L.entry\_block the\_function) in

(\* Build the code for each statement in the function \*)

let builder\_end = List.fold\_left (build\_stmt the\_function) builder fdecl.sbody in

(\* Add a return if the last block falls off the end \*)

add\_terminal builder\_end (L.build\_ret (L.const\_int i32\_t 0))

in

build\_program program;

the\_module