IN4: Stages of a Compiler

Introduction to Compilers

CMPT 379: Compilers

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anoopsarkar.github.io/compilers-class

Building a compiler

- Programming languages have a lot in common
- Do not write a compiler for each language
- Create a general mathematical model for the **structure** of all languages
- Implement a compiler using this model
- Write a compiler for writing compilers!

Building a compiler

- Each language compiler is built using a compiler-compiler:
  - yacc = yet another compiler compiler
- Code generation is done to an intermediate assembly language
- This intermediate language is shared across different computer architectures (x86, MIPS, ARM, etc.)
- Code optimization ideas can also be shared across languages

Demo: compiler for the expr language

Building a compiler

- The cost of compiling and executing should be managed
- No program that violates the definition of the language should escape
- No program that is valid should be rejected

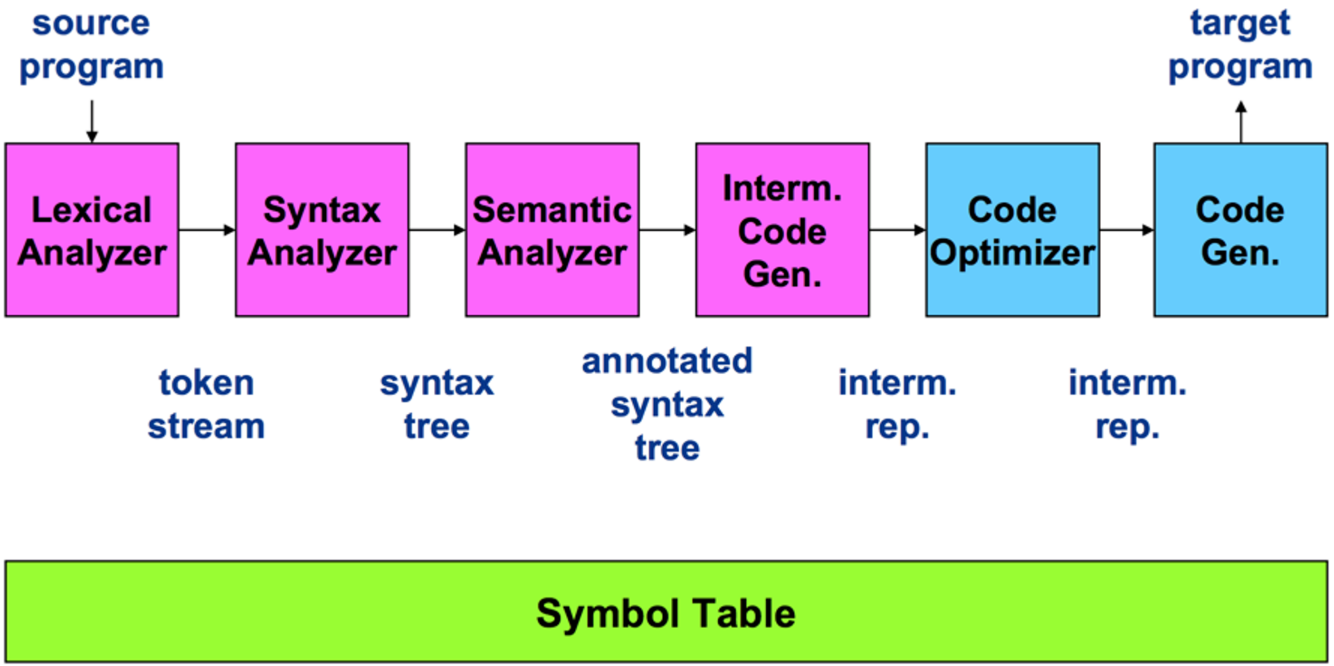
Building a compiler

- Requirements for building a compiler:
  - Symbol-table management
  - Error detection and reporting
- Stages of a compiler:
  - Analysis (front-end)
  - Synthesis (back-end)

Stages of a Compiler

- Analysis (Front-end)
  - Lexical analysis
  - Syntax analysis (parsing)
  - Semantic analysis (type-checking)
- Synthesis (Back-end)
  - Intermediate code generation
  - Code optimization
  - Code generation

Stages of a Compiler



Compiler Front-end

Lexical Analysis

Also called *scanning*, take input program *string* and convert into tokens

Example

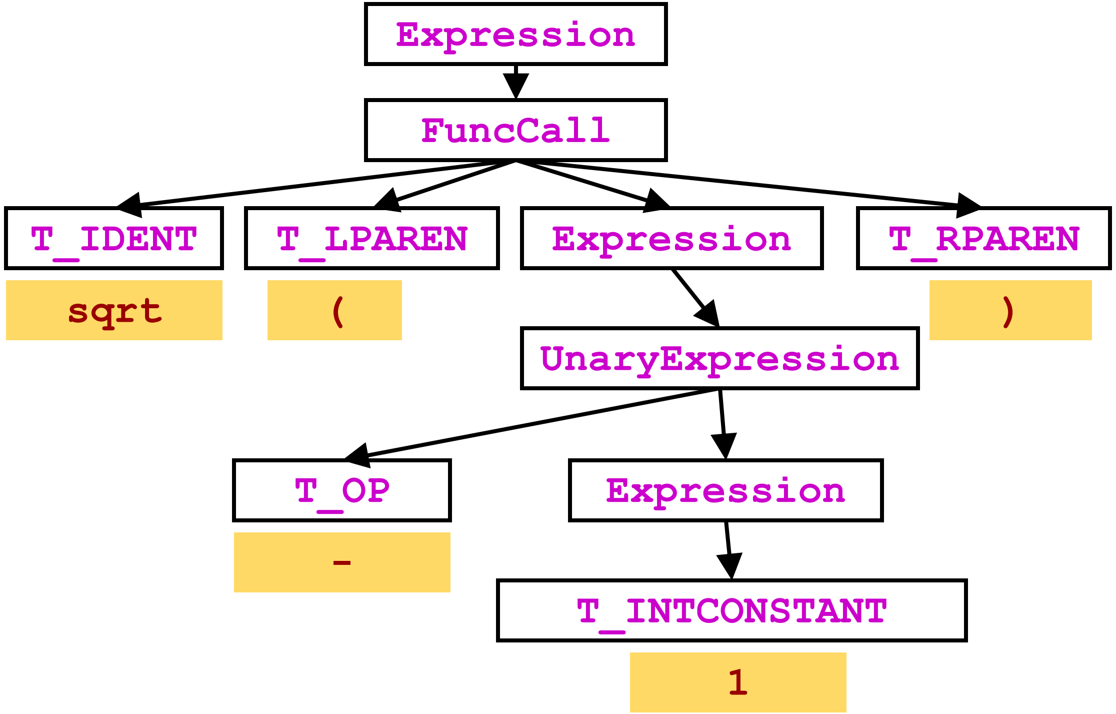
```
double f = sqrt(-1);
```

```
T_DOUBLE
("double")
T_IDENT                 ("f")
T_OP                    ("=")
T_IDENT    ("sqrt")
T_LPAREN                ("(")
T_OP                    ("-")
T_INTCONSTANT ("1")
T_RPAREN                (")")
T_SEP      (";")
```

Syntax Analysis

- Also called *parsing*
- Describe the set of strings that are programs using a grammar
- Structural validation
- Create a parse tree or derivation

Parse tree for `sqrt(-1)`



Abstract Syntax Tree

```
sqrt(-1)
```

➡

```
MethodCall (
    sqrt,
    UnaryExpr( UnaryMinus,
               Number(1)
    )
)
```

Semantic analysis

- “does it make sense”? Checking semantic rules,
  - Is there a `main` function?
  - Is variable declared?
  - Are operand types compatible? (coercion)
  - Do function arguments match function declarations?
- Type checking
- Static vs. run-time semantic checks
  - Array bounds, return values do not match definition

Compiler Back-end

Source -> abstract syntax tree

```
extern void print_int(int);

class C {
  bool foo() { return(true); }
  int main() {
    if (foo()) {
      print_int(1); }
    }
}
```

Source -> abstract syntax tree

```
Program(
   ExternFunction(print_int,VoidType,VarDef(IntType)),
   Class(C,
          None,
          Method(foo,
                 BoolType,
                 None,
                 MethodBlock( None,
                              ReturnStmt(BoolExpr(True)))),
   Method( main,
              IntType,
              None,
              MethodBlock(  None,
                           IfStmt(MethodCall(foo,None),
                                  Block(None,
                                        MethodCall(print_int,Number(1)))
                                     ,
                            None)))))
```

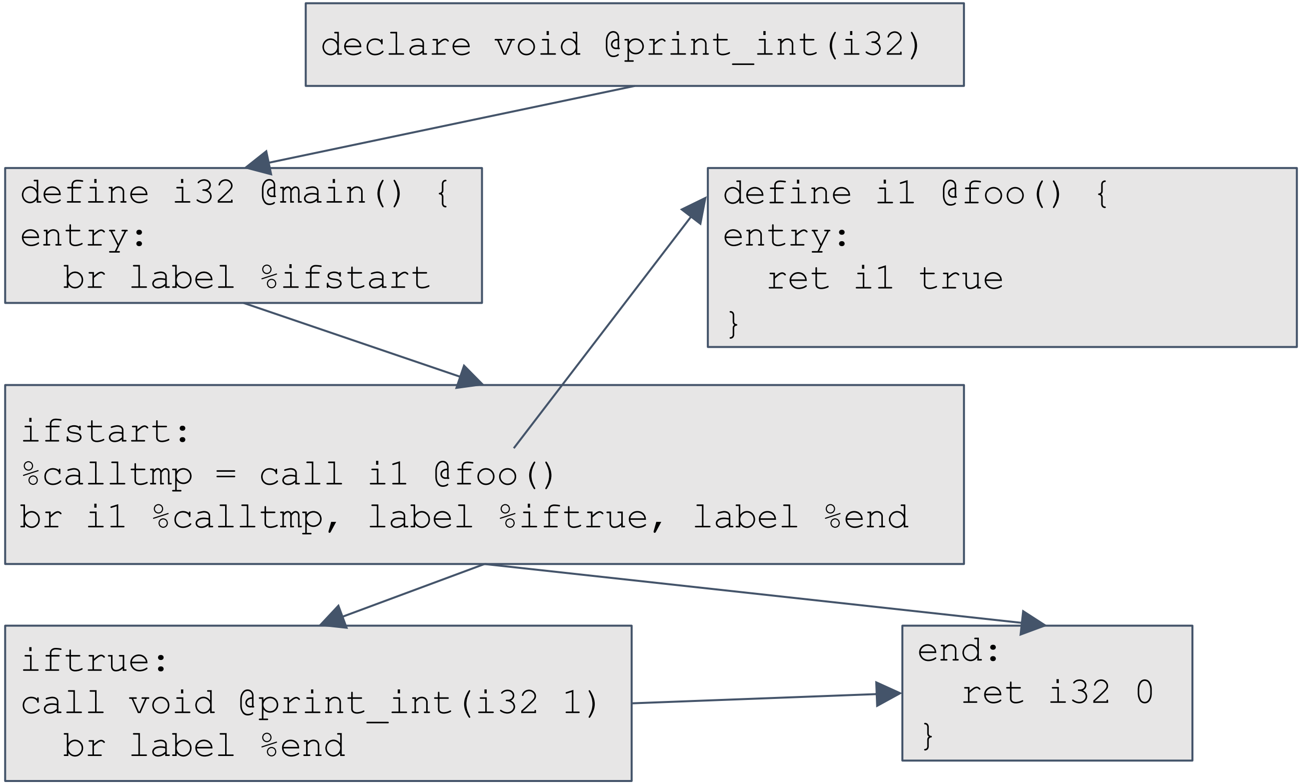
Intermediate representation

```
; ModuleID = 'C'

declare void
@print_int(i32)

define i1 @foo() {
entry:
  ret i1 true
}
```

```
define i32 @main() {
entry:
  br label %ifstart
ifstart:
%calltmp = call i1 @foo()
  br i1 %calltmp, label %iftrue, label %end
iftrue:
call void @print_int(i32 1)
  br label %end
end:
  ret i32 0
}
```

Translation from IR to machine specific assembly

Intermediate representation



Assembly language output from IR

```
            .section
            __TEXT,__text,regula
r,pure_instructions
            .globl      _foo
            .align      4, 0x90
@foo
            .cfi_startproc
%entry
            mov         al, 1
            ret
            .cfi_endproc

            .globl      _main
            .align      4, 0x90
```

```
@main
            .cfi_startproc
%entry
            push        rax
Ltmp0:
            .cfi_def_cfa_offset 16
            call        _foo
            test        al, 1
            je          LBB1_2
%iftrue
            mov         edi, 1
            call        _print_int
%end
            xor         eax, eax
            pop         rdx
            ret
            .cfi_endproc
```

x86
assembly

Code optimization

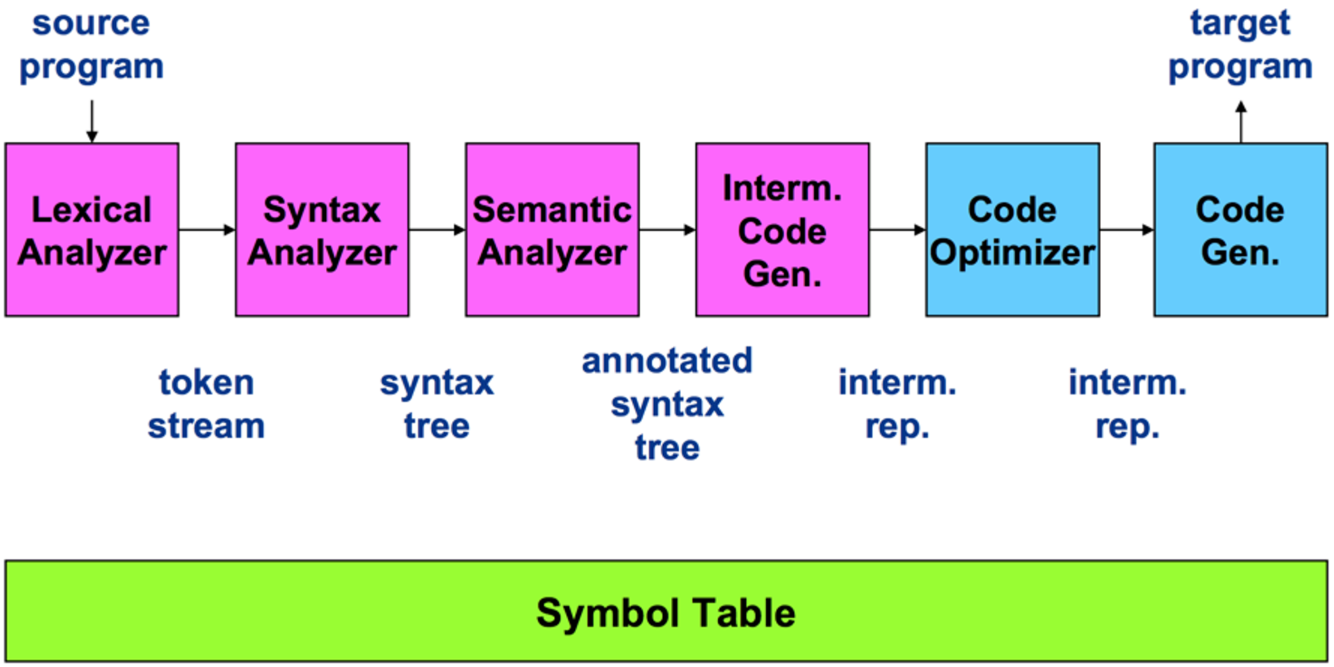
```
; ModuleID = 'C'

declare void @print_int(i32)

define i32 @main() {
entry:
  br label %ifstart

ifstart:
  call void @print_int(i32 1)
  br label %end

end:
  ret i32 0
}
```

Code Optimization

x86 assembly

```
        .section
        __TEXT,__text,regular,pure_instructions
        .macosx_version_min 10, 11
        .globl      _main
        .p2align    4, 0x90
_main:
        .cfi_startproc
## BB#0:
        pushq       %rax
Ltmp0:
        .cfi_def_cfa_offset 16
        movl        $1, %edi
        callq       _print_int
        xorl        %eax, %eax
        popq        %rcx
        retq
        .cfi_endproc
```

Stages of a Compiler



Wrap Up

- Analysis/Synthesis
  - Translation from string to executable
- Divide and conquer
  - Build one component at a time
  - Theoretical analysis will ensure we keep things **simple** and **correct**
  - Create a complex piece of software