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

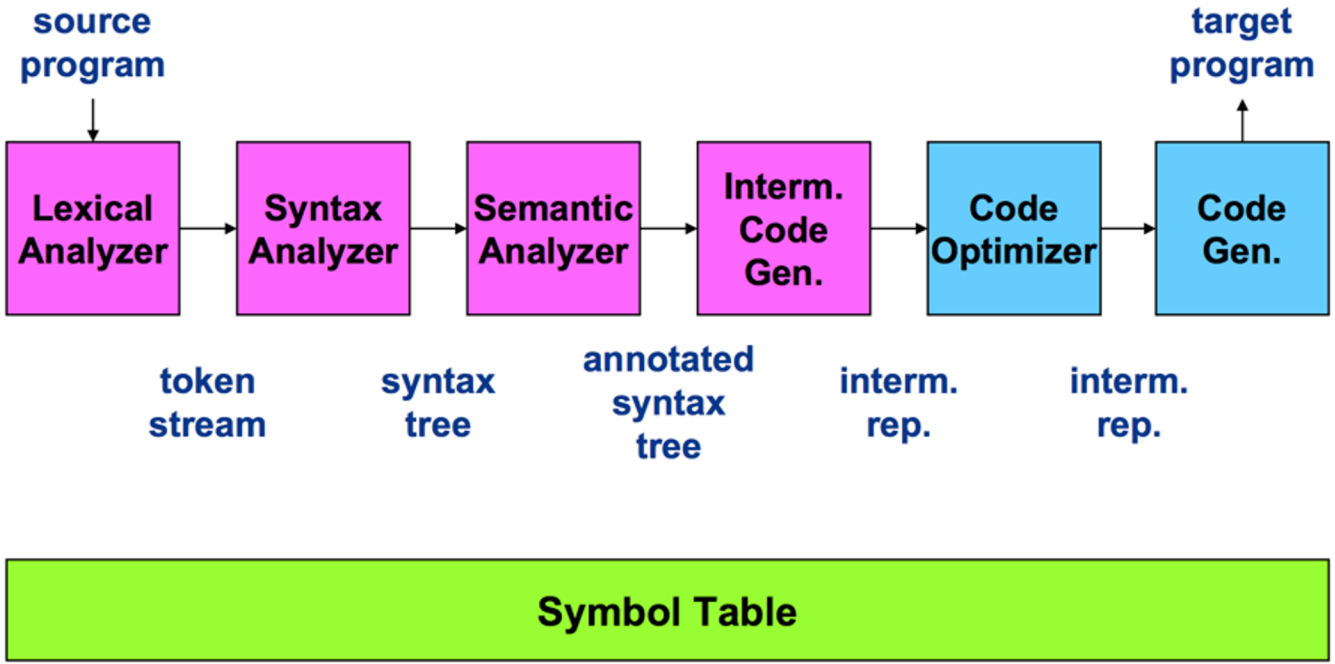
# Building a compiler

- 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



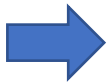
# Compiler Front-end

# Lexical Analysis

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

Example

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

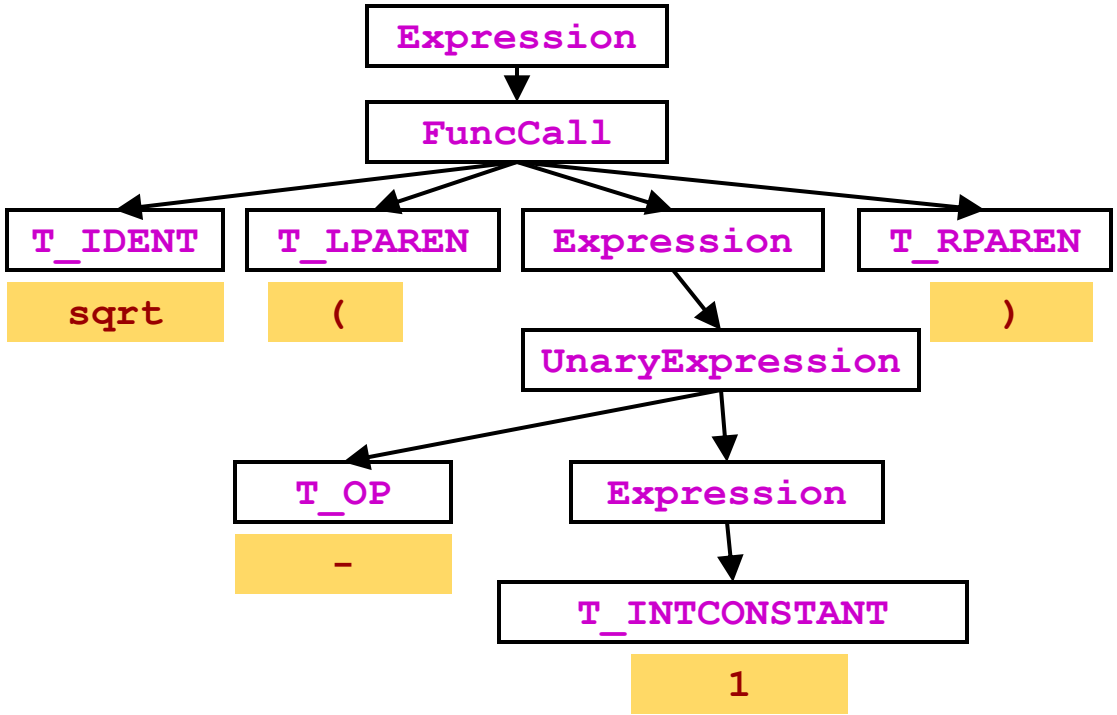


```
T_DOUBLE        ("double")
T_IDENT         ("f")
T_OP            ("=")
T_IDENT         ("sqrt")
T_LPAREN        ("(")
T_OP            ("-")
T_INTCONSTANT   ("1")
T_RPAREN        (")")
T_SEP           (";")
```

# Syntax Analysis

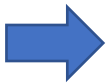
- Also called *parsing*
- Describe the set of strings that are programs using a grammar
- Structural validation
- Create a parse tree or derivation

# 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

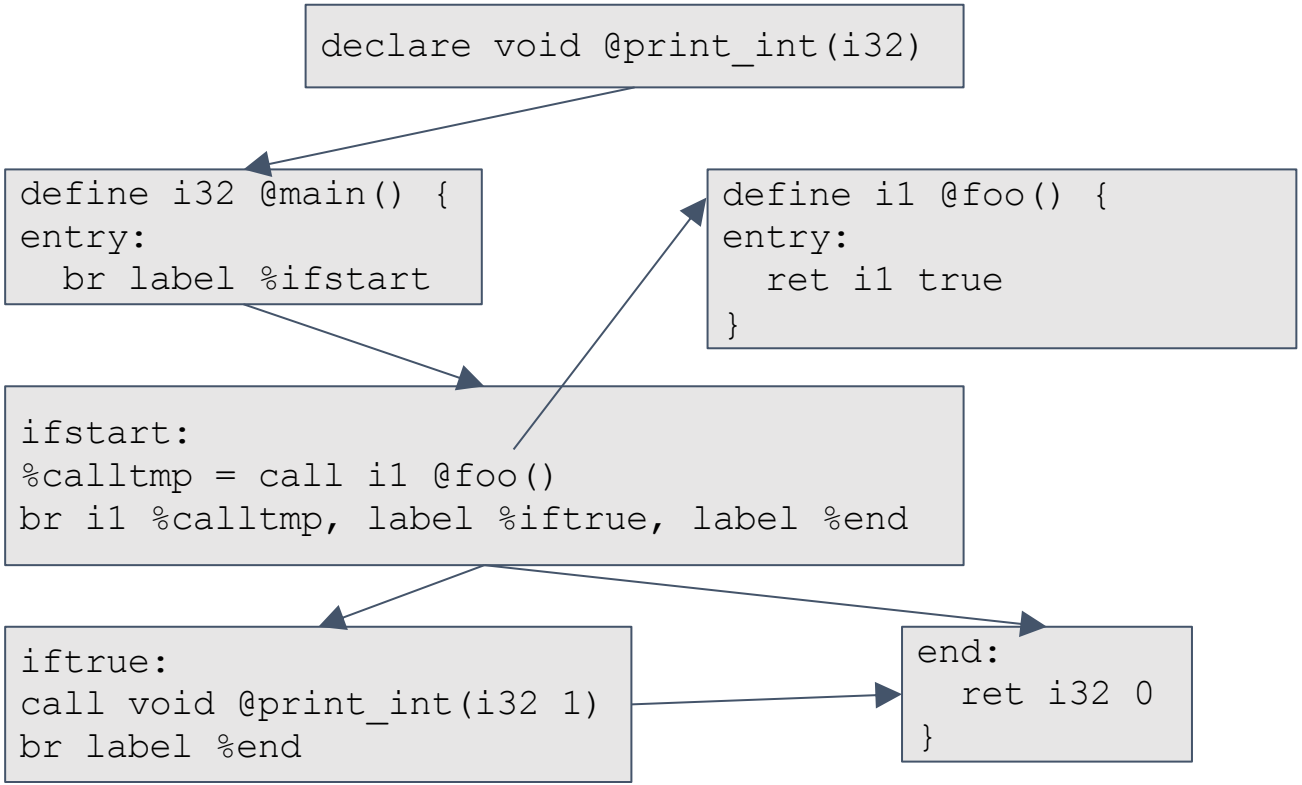
```
Program(
   ExternFunction(print_int,VoidType,VarDef(IntType)),
   Class(C,
          None,
          Method( foo,
                  BoolType,
                  None,
                  MethodBlock( None,
                               ReturnStmt(BoolExpr(True)))),
          Method( main,
                  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
}
```

# 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

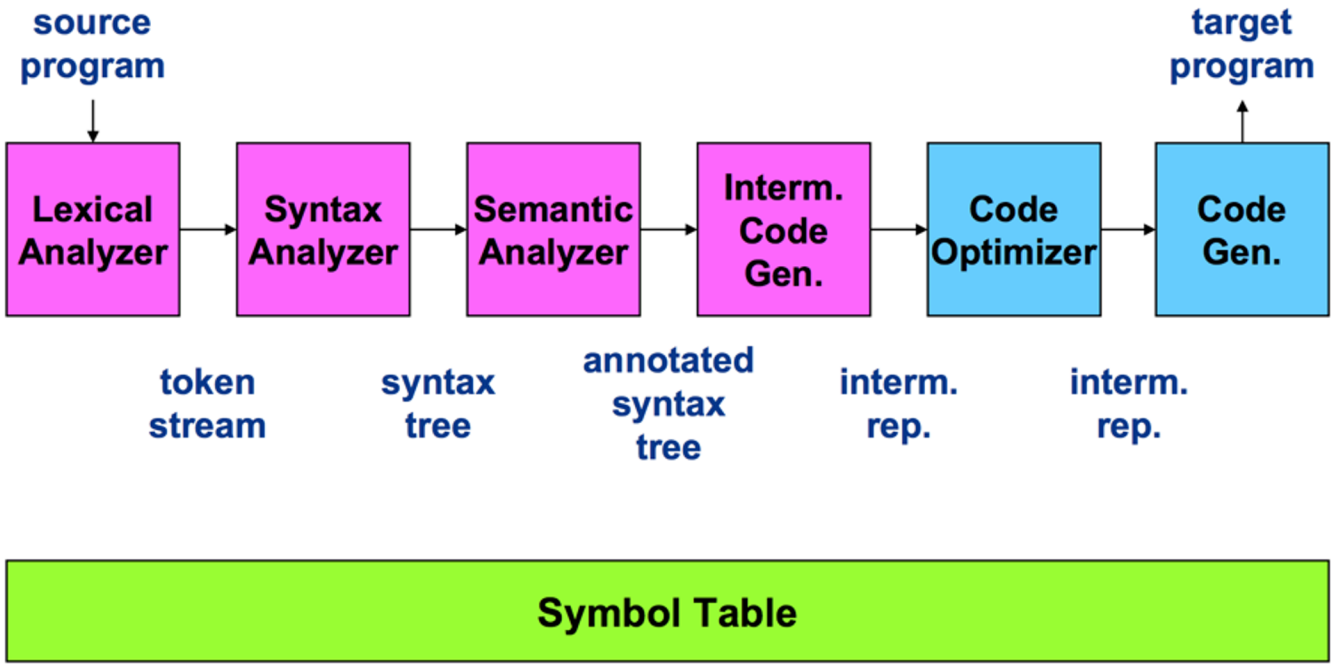
```
; ModuleID = 'C'

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