IN4: Stages of a Compiler

Introduction to Compilers

CMPT 379: Compilers

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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
  - bison = version of yacc from the GNU project (GNU is not Unix)
- Code generation produces 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

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

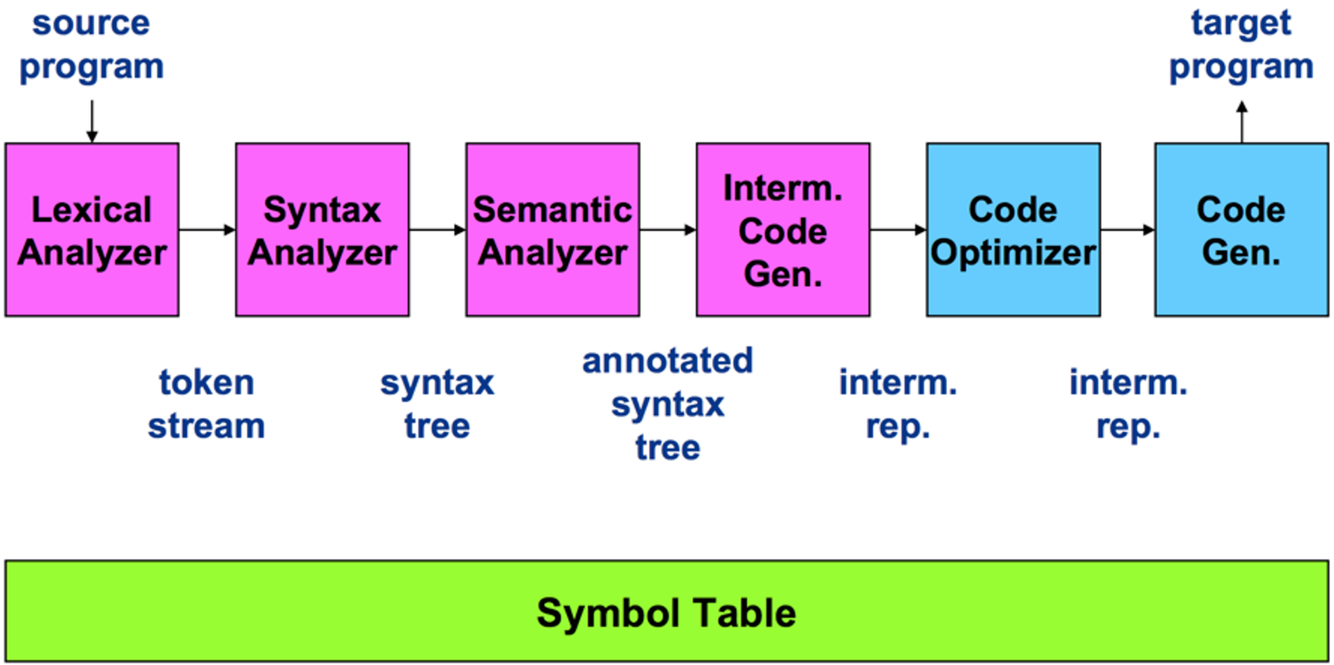
Building a compiler

- 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

Q: What should be the token for a binary subtract operator: “-”?

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

Example

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

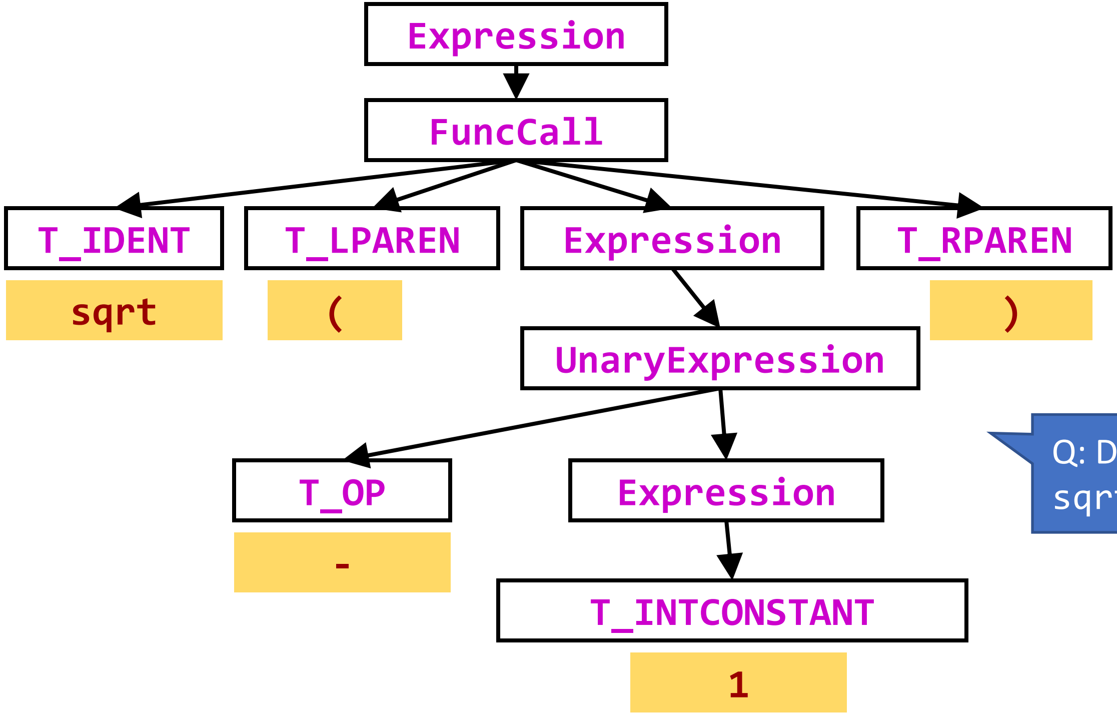
→

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)`



Q: Draw a parse tree for `sqrt(sqrt(256))`

Abstract Syntax Tree

Notation is similar to function calls. e.g. `Foo(a,b)`

```
sqrt(-1)
```

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

Q: How many nodes in the abstract syntax tree compared to the (concrete) syntax tree in the previous slide?

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

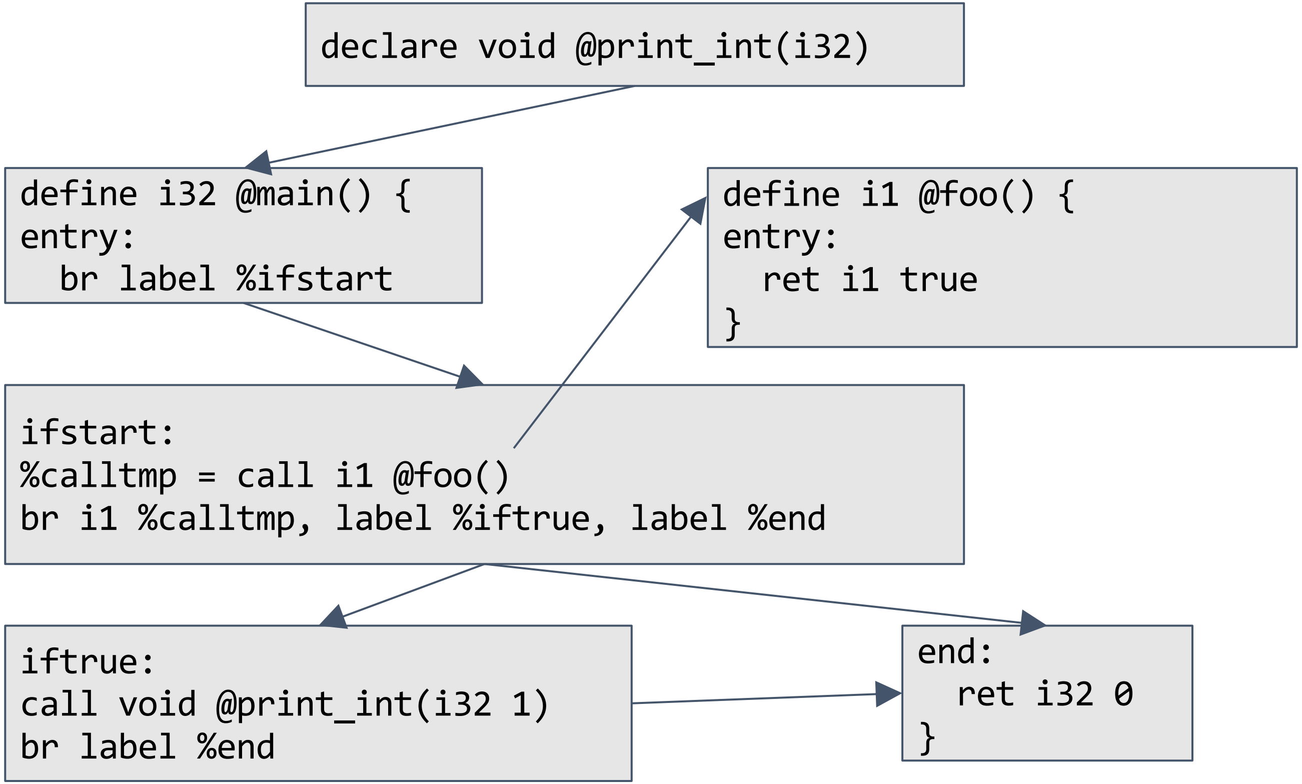
```
Program(
   ExternFunction(print_int,VoidType,VarDef(IntType)),
   Class(  C,
          None,
          Method(  foo,
                   BoolType,
                   None,
                   MethodBlock(       None,
                                      ReturnStmt(BoolExpr(True))),
          Method(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



```
declare void @print_int(i32)
```

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

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

```
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
}
```

Assembly language output from IR

```

          .section
          __TEXT,__text,regular,pure_i
nstructions
          .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

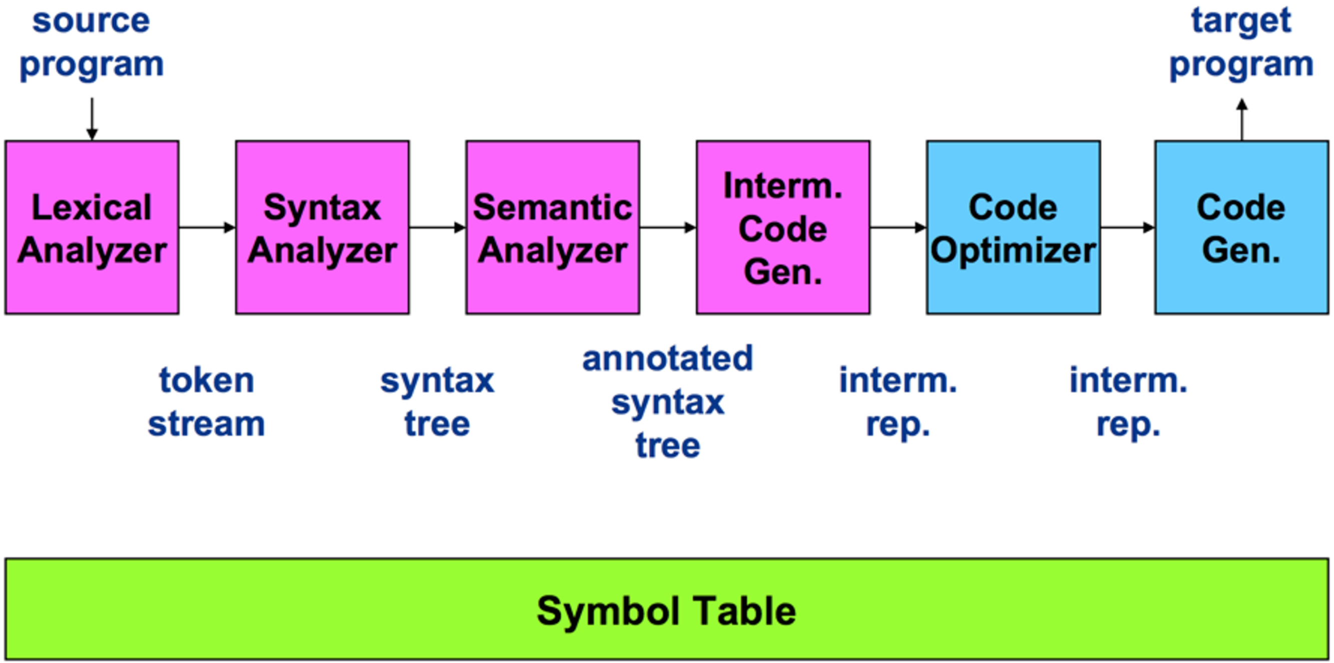
```
; ModuleID = 'C'

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



Demo: compiler for the expr language

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