IN3: Stages of a Compiler

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 all languages: implement this model
- Each language compiler is built using this general model (so-called *compiler compilers*)
  - yacc = yet another compiler compiler
- 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

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

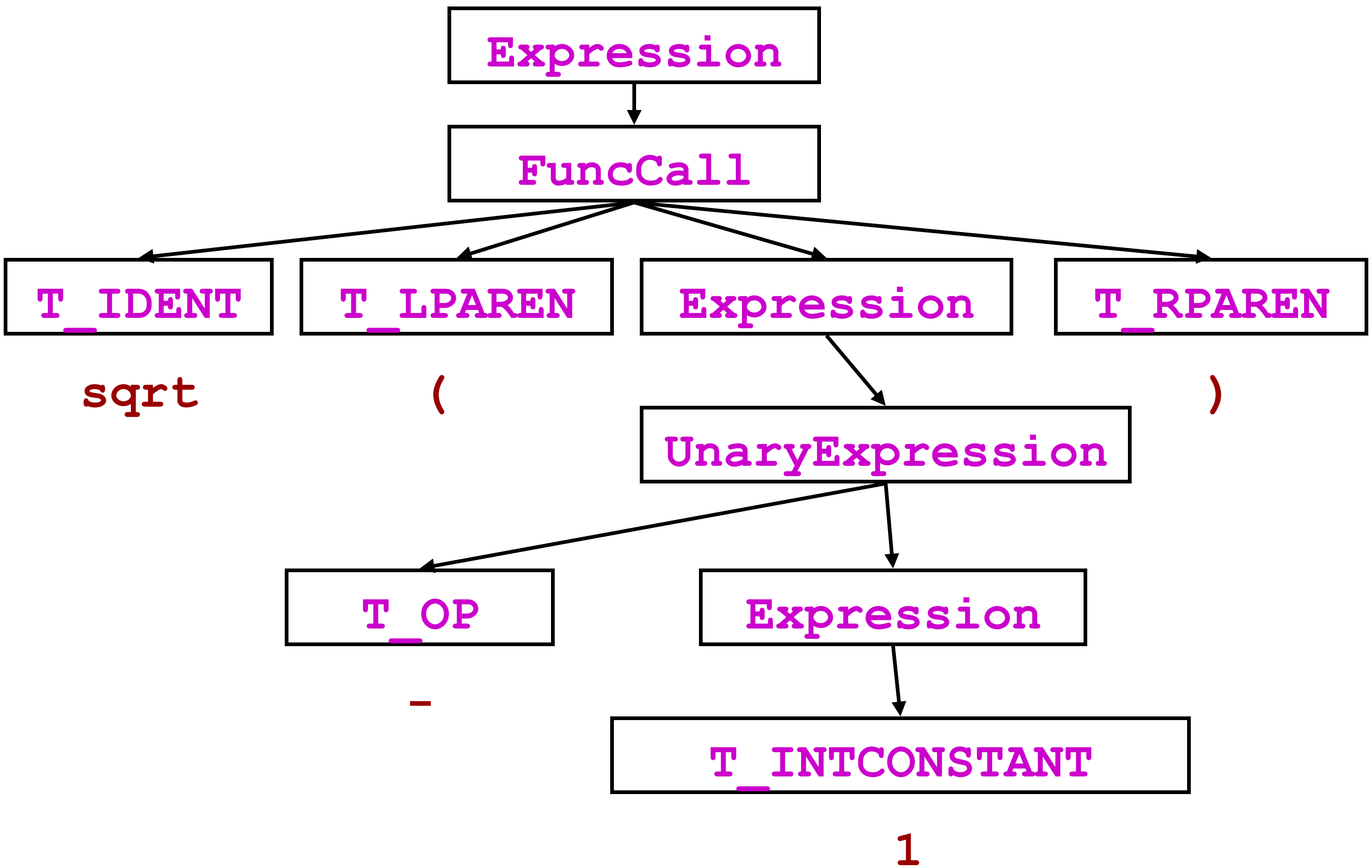
- Also called *parsing*
- Describe the set of strings that are programs using a grammar
- Pick the simplest grammar formalism possible (but not too simple)
  - Finite-state machines (Regular grammars)
  - Deterministic Context-free grammars
  - Context-free grammars
- Structural validation
- Creates parse tree or derivation

Derivation of `sqrt(-1)`

```
Expression -> UnaryExpression
Expression -> FuncCall
Expression -> T_INTCONSTANT
UnaryExpression -> T_OP Expression
FuncCall  -> T_IDENT T_LPAREN Expression T_RPAREN
```

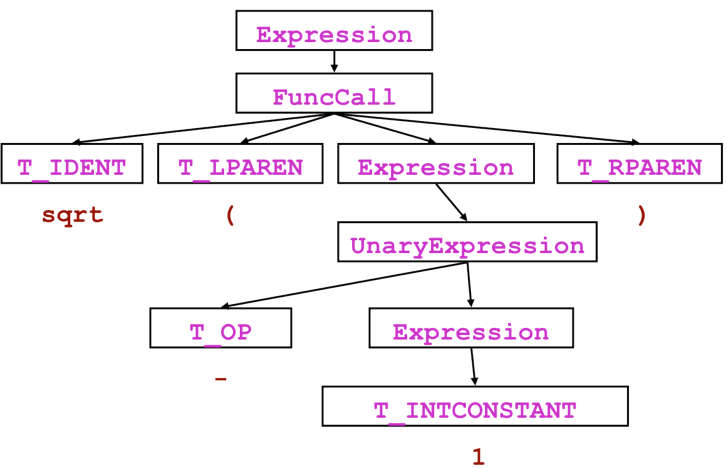
```
Expression
   -> FuncCall
   -> T_IDENT T_LPAREN Expression T_RPAREN
   -> T_IDENT T_LPAREN UnaryExpression T_RPAREN
   -> T_IDENT T_LPAREN T_OP Expression T_RPAREN
   -> T_IDENT T_LPAREN T_OP T_INTCONSTANT T_RPAREN
```

Parse Trees



Expression
FuncCall
T_IDENT
T_LPAREN
Expression
T_RPAREN
sqrt
(
UnaryExpression
)
T_OP
Expression
-
T_INTCONSTANT
1

Abstract Syntax Tree




```
[Expr(
      value=Call(
                 func=Attribute(
                                value=Name(
                                           id='math',
                                           ctx=Load()
                                          ),
                                attr='sqrt',
                                ctx=Load()
                               ),
                 args=[Num(n=-1)],
                 keywords=[],
                 starargs=None,
                 kwargs=None
                )
     )
]
```

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: *operational* or *denotational* semantics
- Static vs. run-time semantic checks
  - Array bounds, return values do not match definition

Intermediate Code Generation

- Three-address code (TAC)

```
j = 2 * i + 1;
if (j >= n)
   j = 2 * i + 3;
return a[j];
```

```
      _t1 = 2 * i
      _t2 = _t1 + 1
      j = _t2
      _t3 = j < n
      if _t3 goto L0
      _t4 = 2 * i
      _t5 = _t4 + 3
      j = _t5
L0:   _t6 = a[j]
      return _t6
```

Code Optimization

- Example

```
        _t1 = 2 * i
        _t2 = _t1 + 1
        j = _t2
        _t3 = j < n
        if _t3 goto L0
        _t4 = 2 * i
        _t5 = _t4 + 3
        j = _t5
L0:     _t6 = a[j]
        return _t6
```

```
        _t1 = 2 * i

        j = _t1 + 1
        _t3 = j < n
        if _t3 goto L0

        j = _t1 + 3

L0:     _t6 = a[j]
        return _t6
```

Object code generation

- Example: *a* in `$a0`, *i* in `$a1`, *n* in `$a2`

```
_t1 = 2 * i

j = _t1 + 1
_t3 = j < n
if _t3 goto L0

j = _t1 + 3
```

```
mulo $t1, $a0, 2

add $s0, $t1, 1
seq $t2, $s0, $a2
beq $t2, 1, L0

add $s0, $t1, 3
```

Bootstrapping a Compiler

- Machine code at the beginning
- Make a simple subset of the language, write a compiler for it, and then use that subset for the rest of the language definition
- Bootstrap from a simpler language
  - C++ ("C with classes")
- Interpreters
- Cross compilation

Modern challenges

- Instruction Parallelism
  - Out of order execution; branch prediction
- Parallel algorithms:
  - Grid computing,
  - multi-core computers
- Memory hierarchy: register, cache, memory
- Binary translation, e.g. x86 to VLIW
- New computer architectures, e.g. streaming algorithms
- Hardware synthesis / Compiled simulations

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