Compilers and Programming Languages

IE 496 Lecture 4

Readings for This Lecture

- “Basics of Compiler Design”, Torben Ægidius Mogensen
- “Source Code Optimization“ Felix von Leitner

What is a Compiler?

- A compiler is a computer program that translates a *programming language* into a *machine language*.
- Programming languages are meant to be human-readable.
- Machine languages are the native instructions understood by the CPU.
- To write effective code, it helps to understand how compilers work.

Compiler Optimization

- Most machine languages are actually fairly simple.
- However, this makes them tedious to work with directly.
- The purpose of a programming language is to hide details so programs can be expressed more naturally.
- The instructions are at a higher level of abstraction.
- Unfortunately, this makes it easy to write inefficient code.
- Besides performing the translation to machine code, a compiler also tries to optimize the resulting code.
- The programmer can sometimes help this along.

Machine Language

- Data handling and Memory operations
  - set a register to a fixed constant value
  - move data from a memory location to a register, or vice versa.
  - read and write data from hardware devices
- Arithmetic and Logic
  - add, subtract, multiply, or divide the values of two registers, placing the result in a register
  - perform bitwise operations
  - compare two values in registers

Source: Wikipedia (http://en.wikipedia.org/wiki/Instruction_set)

Machine Language (cont.)

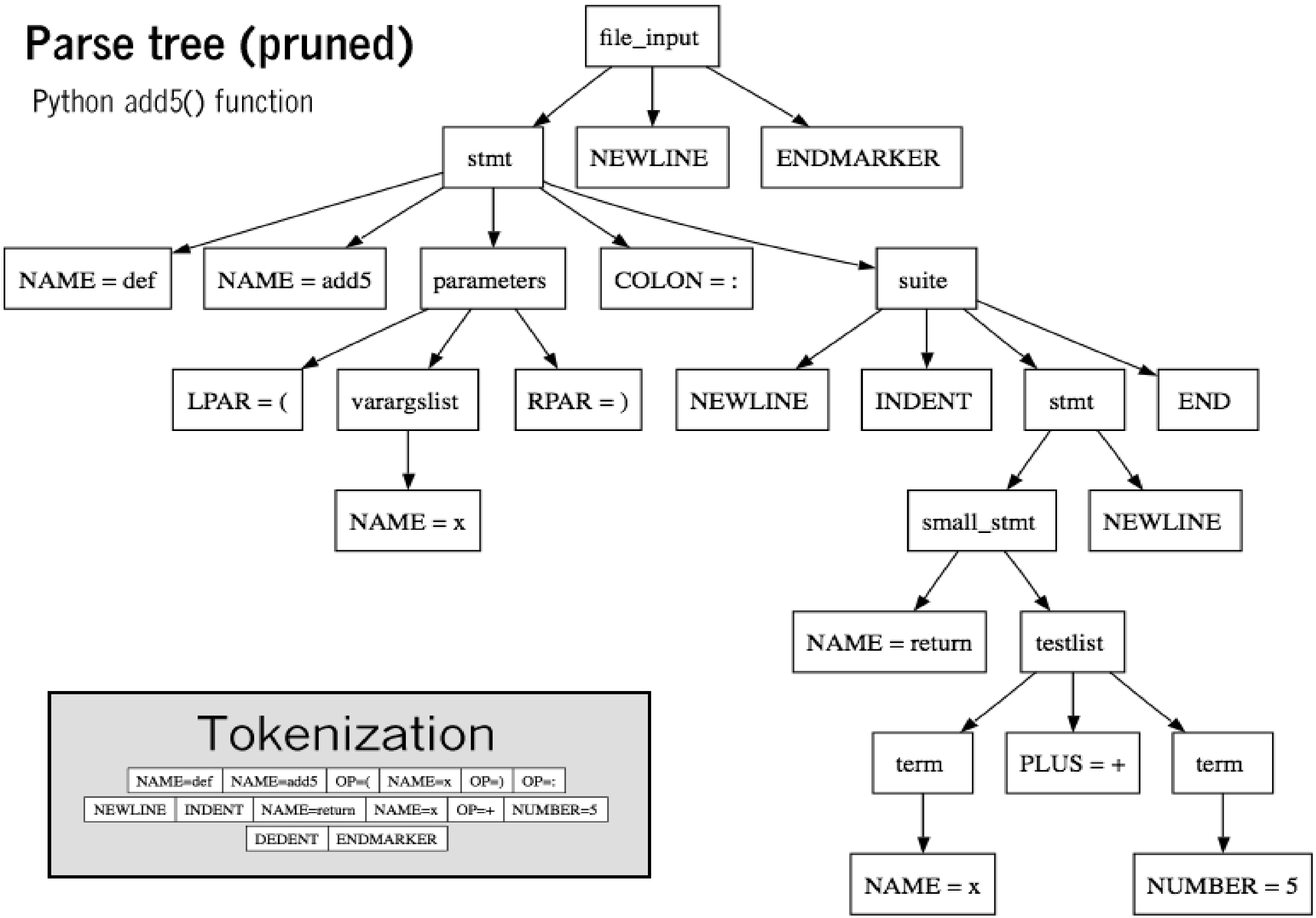
- Control flow
  - branch to another location in the program and execute instructions there
  - conditionally branch to another location if a certain condition holds
  - indirectly branch to another location, but save the location of the next instruction as a point to return to (a call)

Source: Wikipedia (http://en.wikipedia.org/wiki/Instruction_set)

Steps in Compilation

1. Lexical analysis: Divides the text into *tokens*
2. Syntax analysis: Generates the *syntax tree*
3. Type checking: Checks for type consistency
4. Intermediate code generation: Translates code to machine independent intermediate language
5. Register allocation: Assigns variables to registers
6. Machine code generation: Generates machines code (textual)
7. Assembly and linking: Creates final binaries

Lexical and Syntax Analysis



Source: Wikipedia (http://en.wikipedia.org/wiki/File:Python_add5_parse.png)

Type Checking

- One of the major differences between programming languages is whether and how they do type checking.
- Type checking ensures that the program doesn't perform operations that are undefined for a given type.
- Machine language is an untyped language, as it regards all data as just strings of bits.
- Most other languages have some kind of typing
  - Strong/weak
  - Static/dynamic
  - Explicit/implicit
  - Safe/unsafe

Interpreted Languages

- In an interpreted language, the program is executed directly using the syntax tree.
- This results in a number of inefficiencies, so interpreted languages tend to be slower than compiled ones.
- Python is an example of an interpreted language.
- You can call C/C++ from Python, so a good strategy is to use C++ for functions for which speed matters.

Intermediate Code Generation

- Intermediate code is similar to machine code except that it is machine independent.
- For example, such code assumes an infinite number of registers.
- To make translation easier, most instructions are *atomic*.
- Translation of intermediate code to machine code is then independent of programming language.
- This makes it easier to port existing compilers to new architectures and to create compilers for new languages.

Machine Code Generation

- The final step is translating the intermediate code to machine code.
- This encompasses a number of different issues.
- Some instruction sets include nonatomic instructions of which we should take advantage.
- There are also a large number of variants on conditional jumps.
- Perhaps the most interesting step, however, is *register allocation.*

Register Allocation

- The *register allocation problem* is to map a large number of variables to a small number of registers.
- This is done by assigning multiple variables to the same register using *liveness analysis.*
- By anayzing when different variables are alive and dead, i.e., are never used again, we create a conflict graph.
- The nodes are variables and the edges indicate a conflict.
- The problem of finding the minimum number of registers is equivalent to *graph coloring.*
- If there aren't enough registers, then we have *spilling.*

Optimizations

- Common subexpression elimination: Evaluate common subexpressions once

  Example: a[i] := a[i]+2

- Code hoisting: Remove code from loops that doesn't need to be executed every time. Example:

  ```
  while (j < k) {
      sum = sum + a[i][j];
      j++;
  }
  ```

  A large part of the calculation of a[i][j] is repeated each time

- Constant propagation: Replace constants with the actual value

Loop Unrolling

- Although loops make code easier to read, they can be very inefficient.
- This is due to the overhead in incrementing the loop counter, loss of efficiency from combined writes, etc.

Normal loop

```
int x;
for (x = 0; x < 100; x++)
{
    delete(x);
}
//.
//.
//.
//.
```

After loop unrolling

```
int x;
for (x = 0; x < 100; x += 5)
{
    delete(x);
    delete(x+1);
    delete(x+2);
    delete(x+3);
    delete(x+4);
}
```

Picture: Wikipedia (http://en.wikipedia.org/wiki/Loop_unwinding)

Tail Recursion

- Recursion is a very effective tool for expressing algorithms succinctly.
- However it can generate inefficient code due to the overhead of function calls.
- If the last call in a function is recursive, it is easy to replace the recursion with iteration.

```
long fact(long x) {
     if (x<=0) return 1;
     return x*fact(x-1);
}
```

Vectorization

- Because it's more efficient to write entire words to memory at once, compilers may “vectorize.”

```
int zero(char* array) {
    unsigned long i;
    for (i=0; i<1024; ++i)
        array[i]=23;
}
```

- On a 32-bit machine, it's more efficient here to write `0x23232323` 256 times.

Dirty Tricks

- Casting to unsigned makes negative values wrap to be very large.

```
int regular(int i) {
     if (i>5 && i<100)
     return 1;
     exit(0);
}
int clever(int i) {
     return (((unsigned)i) - 6 > 93);
}
```

- Comparison against zero is also more efficient than comparison against nonzero (count down instead of up!).

Bit Operations

- Because computers store numbers in binary, operations that involve flipping or shifting bits are very efficient.
- For example, multiplying by 2 is just shifting all bits to the left and adding a zero.
- This can be taken advantage of in many situations.
- Modern compilers will do this automatically.