CSE 5239: Compile-Time Program Analysis and Transformations

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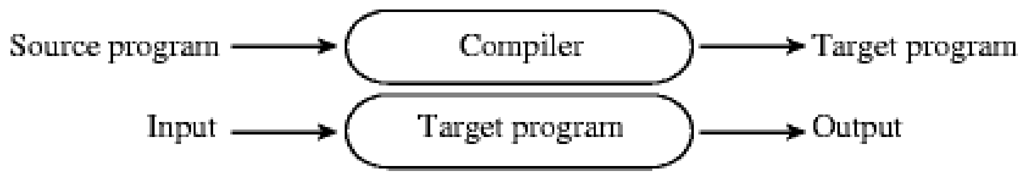
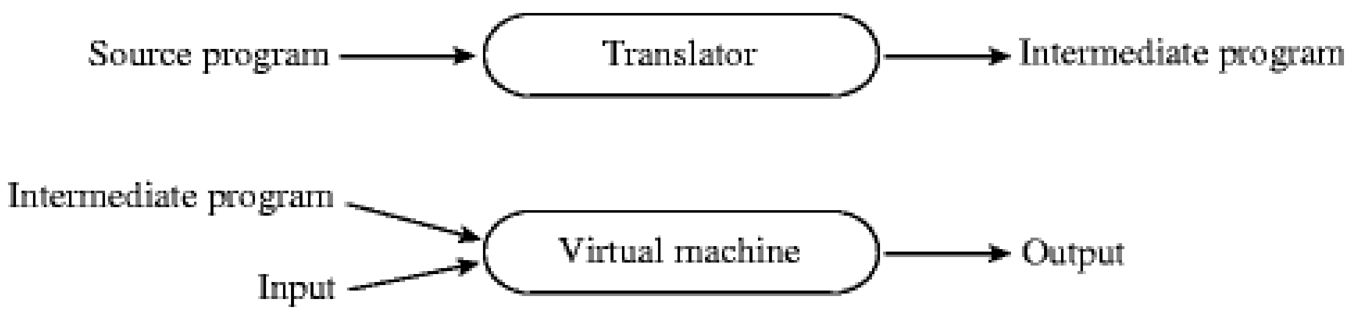
Use Cases for Compile-Time Analysis (1/2)

- Traditional compilation (C,C++,Fortran)



  – Analysis in the compiler for correctness & performance

- Modern compilation (Java w/ bytecode, C# w/ CIL)



  – Analysis in the translator (e.g., javac)
  – Lightweight analysis in the just-in-time (JIT) compiler inside the virtual machine

Use Cases for Compile-Time Analysis (2/2)

- Software development environments
  - E.g., in Eclipse: finds code smells and potential defects; performs code refactoring
- Software verification/checking tools
  - Prove the absence of certain categories of defects
- Testing tools
  - E.g., for regression testing – which tests do **not** need to be rerun after some changes to the program?
- Also: comprehension tools, debugging tools (after failure), performance analysis tools, etc.
- More generally, static analysis (vs. dynamic analysis)

Inside a Traditional Compiler: Front End

- Lexical analyzer (aka scanner)
  - Converts ASCII or Unicode to a stream of tokens
- Syntax analyzer (aka parser)
  - Creates a parse tree from the token stream
- Semantic analyzer
  - Type checking and conversions; other semantic checks
  - Some compile-time analyses done here, on the AST
- Generator of intermediate code
  - A parse tree is too high-level for code generation & optimization
  - Create lower-level **intermediate representation** (IR): e.g., three-address code

Inside the Compiler: Middle Part

- Compile-time analysis of intermediate code
  - Additional IRs: control-flow graph (CFG), static single-assignment form (SSA), def-use graph, etc.
  - Control-flow analysis, data-flow analysis, pointer analysis, side-effect analysis, polyhedral analysis, …
- Machine-independent optimization of intermediate code: better three-address code
  - Copy propagation, dead code elimination, code motion, constant propagation, redundancy elimination, parallelization, data locality optimizations, …
- Currently, this is where most of compiler research is focused

Three-Address Code

- ASTs are high-level IRs
  - Close to the source language
  - Suitable for tasks such as type checking
- Three-address code is a lower-level IR
  - Closer to the target language (i.e., assembly code)
  - Suitable for tasks such as code generation/optimization
- Basic ideas
  - A small number of simple instructions: e.g. **x = y op z**
  - A number of compiler-generated temporary variables

    a = b + c + d; in source code → **t = b + c; a = t + d;**
  - Simple flow of control – conditional and unconditional jumps to labeled statements

Important Note

- The choice of the program representation on which to perform analysis is critical
  - E.g. if you are writing an Eclipse plug-in, you have access to the AST, but not to a lower-level IR
    - Plus, the results of the analysis are useful for ASTs (e.g., code smells reported to the programmer)
- In a compiler, we usually prefer to have access to a lower-level IR, since the analyses and transformations are easier
  - In this course, we will focus on this scenario

Addresses and Instructions

- "Address": a program variable, a constant, or a compiler-generated temporary variable
- Instructions
  - **x = y op z**: binary operator *op*; y and z are variables, temporaries, or constants; x is a variable or a temporary
  - **x = op y**: unary operator *op*; y is a variable, a temporary, or a constant; x is a variable or a temporary
  - **x = y**: copy instruction; y is a variable, a temporary, or a constant; x is a variable or a temporary
  - Arrays, flow-of-control
  - Each instruction contains at most three "addresses"
    - Thus, three-address code

Simple Examples

x = y produces one three-address instruction

Left: a pointer to the symbol table entry for x

Right: a pointer to the symbol table entry for y

For convenience, we will write this as **x = y**

x = - y produces **t1 = - y**; **x = t1**;

x = y + z produces **t1 = y + z**; **x = t1**;

x = y + z + w produces **t1 = y + z**; **t2 = t1 + w**; **x = t2**;

x = y + - z produces **t1 = - z**; **t2 = y + t1**; **x = t2**;

Flow of Control

- Three-address instructions
  - **goto L**: unconditional jump to the three-address instruction with label L
  - **if (x relop y) goto L**: x and y are variables, temporaries, or constants; relop $\in$ { <, <=, ==, !=, >, >= }
- The labels are symbolic names

More Examples

- Possible three-address code: two versions
  - Example: **if (x < 100 || x > 200 && x != y) x = 0;**

```
if (x < 100) goto L2;
goto L3;
L3: if (x > 200) goto L4;
goto L1;
L4: if (x != y) goto L2;
goto L1;
L2: x = 0;
L1: ...;
```

```
if (x < 100) goto L2;
if (x <= 200) goto L1;
if (x == y) goto L1;
L2: x = 0;
L1: ...;
```

Main Topics

- **Control-flow analysis**: what sequences of instructions could be executed at run time?
  - Infinite number of sequences → need finite static representation (control-flow graph)
- **Data-flow analysis**: what are the effects of these instruction sequences on the state of the program?
  - Infinite (or very large) sets of possible states → need finite/small abstractions, often with loss of precision
  - Key technical challenges: abstractions must be
    - correct (depending on the client)
    - precise and efficient-to-compute
- **Code transformations**: enabled by analysis