Chapter 1 :: Introduction

Programming Language Pragmatics

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Programming Languages

- What programming languages can you name?
- Which do you know?

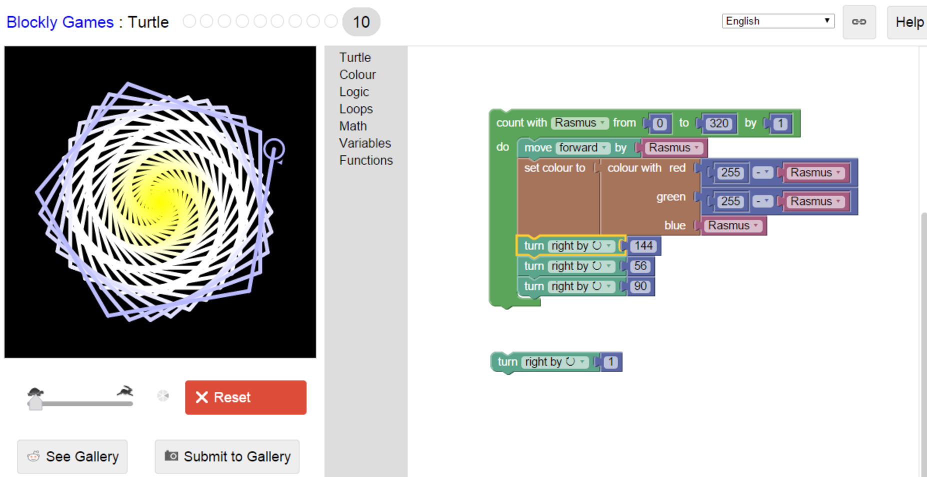
Introduction

- Why are there so many programming languages?
  - evolution -- we've learned better ways of doing things over time
  - socio-economic factors: proprietary interests, commercial advantage
  - orientation toward special purposes
  - orientation toward special hardware
  - diverse ideas about what is pleasant to use

Introduction

- What makes a language successful?
  - easy to learn (BASIC, Pascal, LOGO, Scheme, Alice)
  - easy to express things, easy use once fluent, "powerful" (C, Common Lisp, APL, Algol-68, Perl)
  - easy to implement (BASIC, Forth)
  - possible to compile to very good (fast/small) code (Fortran)
  - backing of a powerful sponsor (COBOL, PL/1, Ada, Visual Basic, C#)
  - wide dissemination at minimal cost (Pascal, Turing, Java, Alice)

Blockly Screenshot



Introduction

- Why do we have programming languages? What is a language for?
  - way of thinking -- way of expressing algorithms
  - languages from the programmer's point of view
  - abstraction of virtual machine -- way of specifying what you want the hardware to do without getting down into the bits
  - languages from the implementor's point of view

Why study programming languages?

- Help you choose a language.
  - C vs. Modula-3 vs. C++ for systems programming
  - Fortran vs. APL vs. Ada for numerical computations
  - Ada vs. Modula-2 for embedded systems
  - Common Lisp vs. Scheme vs. ML for symbolic data manipulation
  - Java vs. C/CORBA for networked PC programs

Why study programming languages?

- Make it easier to learn new languages some languages are similar; easy to walk down family tree
  - concepts have even more similarity; if you think in terms of iteration, recursion, abstraction (for example), you will find it easier to assimilate the syntax and semantic details of a new language than if you try to pick it up in a vacuum. Think of an analogy to human languages: good grasp of grammar makes it easier to pick up new languages (at least Indo-European).

Why study programming languages?

- Help you make better use of whatever language you use
  - understand obscure features:
    - In C, help you understand unions, arrays & pointers, separate compilation, varargs, catch and throw
    - In Common Lisp, help you understand first-class functions/closures, streams, catch and throw, symbol internals

Why study programming languages?

- Help you make better use of whatever language you use (2)
  - understand implementation costs: choose between alternative ways of doing things, based on knowledge of what will be done underneath:
    - use simple arithmetic e.g.(use x*x instead of x**2)
    - use C pointers or Pascal "with" statement to factor address calculations
    - avoid call by value with large data items in Pascal
    - avoid the use of call by name in Algol 60
    - choose between computation and table lookup (e.g. for cardinality operator in C or C++)

Why study programming languages?

- Help you make better use of whatever language you use (3)
  - figure out how to do things in languages that don't support them explicitly:
    - lack of suitable control structures in Fortran
    - use comments and programmer discipline for control structures
    - lack of recursion in Fortran, CSP, etc
    - write a recursive algorithm then use mechanical recursion elimination (even for things that aren't quite tail recursive)

Why study programming languages?

- Help you make better use of whatever language you use (4)
  - figure out how to do things in languages that don't support them explicitly:
    - lack of named constants and enumerations in Fortran
    - use variables that are initialized once, then never changed
    - lack of modules in C and Pascal use comments and programmer discipline
    - lack of iterators in just about everything fake them with (member?) functions

Language Categories

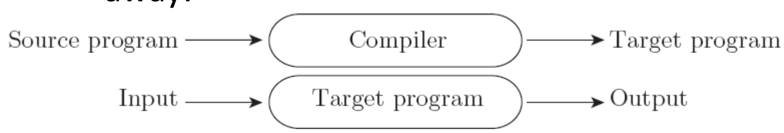
- Two common language groups
  - Imperative
    - von Neumann (Fortran, Pascal, Basic, C)
    - object-oriented (Smalltalk, Eiffel, C++, Java)
    - scripting languages (Perl, Python, JavaScript, PHP)
  - Declarative
    - functional (Scheme, ML, pure Lisp, FP)
    - logic, constraint-based (Prolog, VisiCalc, RPG)

Imperative languages

- Imperative languages, particularly the von Neumann languages, predominate
  - They will occupy the bulk of our attention
- We also plan to spend time on functional, logic languages

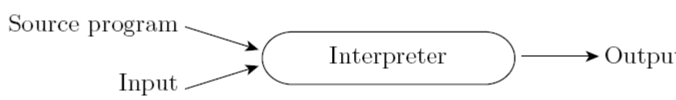
Compilation vs. Interpretation

- Compilation vs. interpretation
  - not opposites
  - not a clear-cut distinction
- Pure Compilation
  - The compiler translates the high-level source program into an equivalent target program (typically in machine language), and then goes away:



Compilation vs. Interpretation

- Pure Interpretation
  - Interpreter stays around for the execution of the program
  - Interpreter is the locus of control during execution



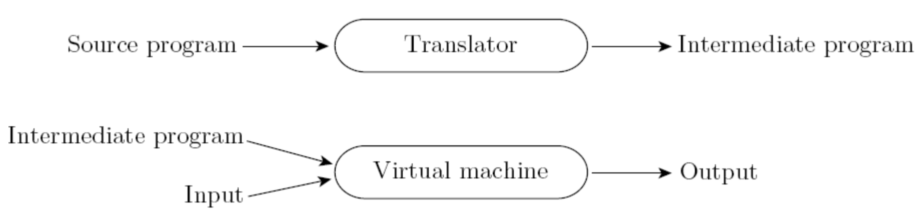
Compilation vs. Interpretation

- Interpretation:
  – Greater flexibility
  – Better diagnostics (error messages)

- Compilation
  – Better performance

Compilation vs. Interpretation

- Common case is compilation or simple pre-processing, followed by interpretation
- Most language implementations include a mixture of both compilation and interpretation



Compilation vs. Interpretation

- Note that compilation does NOT have to produce machine language for some sort of hardware
- Compilation is *translation* from one language into another, with full analysis of the meaning of the input
- Compilation entails semantic *understanding* of what is being processed; pre-processing does not
- A pre-processor will often let errors through. A compiler hides further steps; a pre-processor does not

Compilation vs. Interpretation

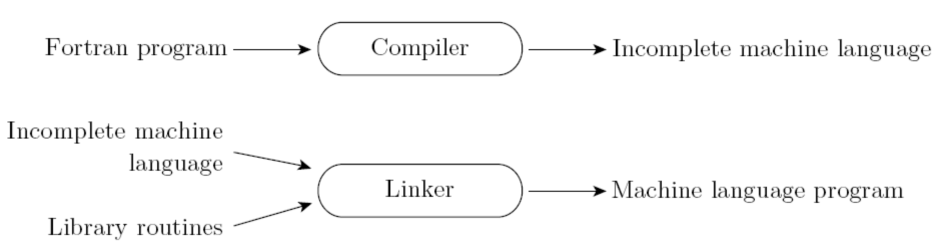
- Many compiled languages have interpreted pieces, e.g., formats in Fortran or C
- Most use “virtual instructions”
  - set operations in Pascal
  - string manipulation in Basic
- Some compilers produce nothing but virtual instructions, e.g., Pascal P-code, Java byte code, Microsoft COM+

Compilation vs. Interpretation

- Implementation strategies:
  - Preprocessor
    - Removes comments and white space
    - Groups characters into *tokens* (keywords, identifiers, numbers, symbols)
    - Expands abbreviations in the style of a macro assembler
    - Identifies higher-level syntactic structures (loops, subroutines)

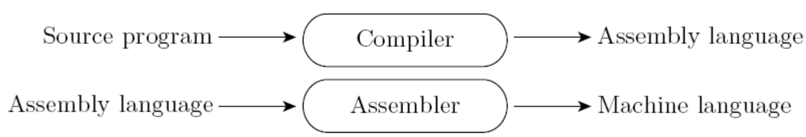
Compilation vs. Interpretation

- Implementation strategies:
  - Library of Routines and Linking
    - Compiler uses a *linker* program to merge the appropriate *library* of subroutines (e.g., math functions such as sin, cos, log, etc.) into the final program:



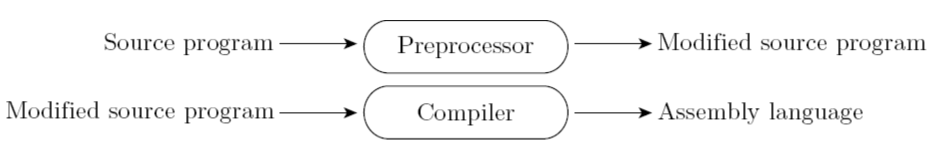
Compilation vs. Interpretation

- Implementation strategies:
  - Post-compilation Assembly
    - Facilitates debugging (assembly language easier for people to read)
    - Isolates the compiler from changes in the format of machine language files (only assembler must be changed, is shared by many compilers)



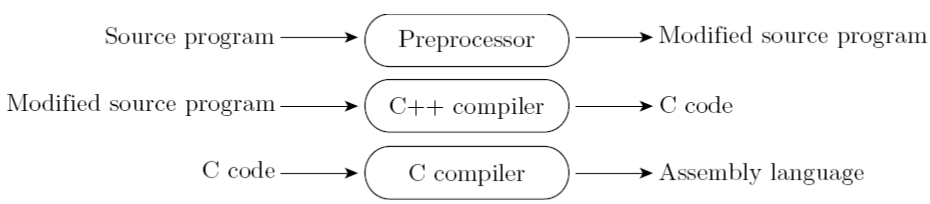
Compilation vs. Interpretation

- Implementation strategies:
  - The C Preprocessor (conditional compilation)
    - Preprocessor deletes portions of code, which allows several versions of a program to be built from the same source



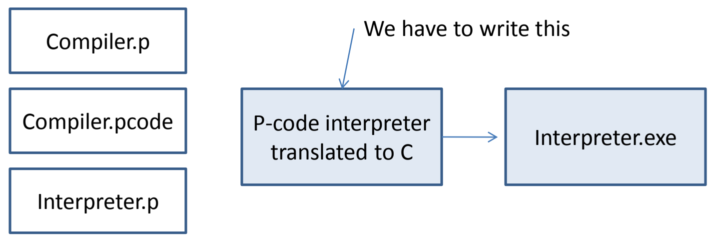
Compilation vs. Interpretation

- Implementation strategies:
  - Source-to-Source Translation (C++)
    - C++ implementations based on the early AT&T compiler generated an intermediate program in C, instead of an assembly language:

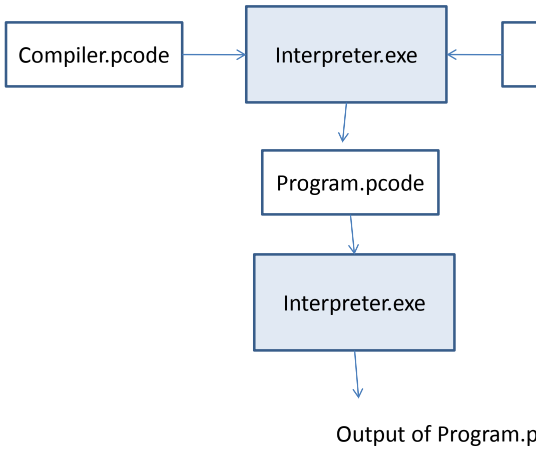


Compilation vs. Interpretation

- Implementation strategies:
  - *Bootstrapping*
- Early Pascal compilers built around a set of tools that included:
  - A Pascal compiler, written in Pascal, that would generate output in P-code, a simple stack-based language
  - A Pascal compiler already translated into P-code
  - A P-code interpreter, written in Pascal

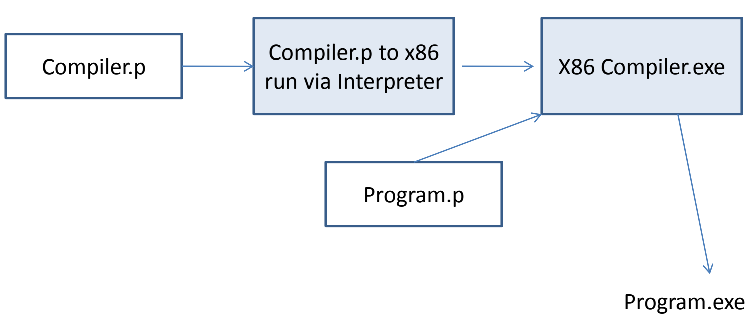


Pascal Interpeter



Bootstrap compiler

Modify Compiler.p to compile to native code instead of P-code, then use the compiler to compile itself



Compilation vs. Interpretation

- Implementation strategies:
  - Compilation of Interpreted Languages
    - The compiler generates code that makes assumptions about decisions that won't be finalized until runtime. If these assumptions are valid, the code runs very fast. If not, a dynamic check will revert to the interpreter.

Compilation vs. Interpretation

- Implementation strategies:
  - Dynamic and Just-in-Time Compilation
    - In some cases a programming system may deliberately delay compilation until the last possible moment.
      - Lisp or Prolog invoke the compiler on the fly, to translate newly created source into machine language, or to optimize the code for a particular input set.
      - The Java language definition defines a machine-independent intermediate form known as *byte code*. Byte code is the standard format for distribution of Java programs.
      - The main C# compiler produces .NET Common Language Runtime (CLR), which is then translated into machine code immediately prior to execution.

Compilation vs. Interpretation

- Compilers exist for some interpreted languages, but they aren't pure:
  - selective compilation of compilable pieces and extra-sophisticated pre-processing of remaining source.
  - Interpretation of parts of code, at least, is still necessary for reasons above.
- Unconventional compilers
  - text formatters
  - silicon compilers
  - query language processors

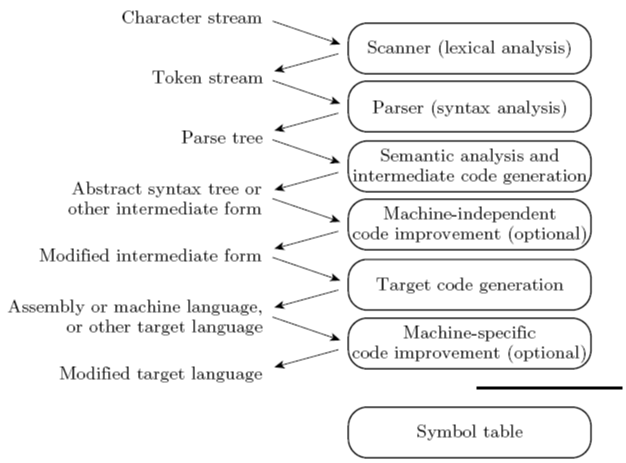
Programming Environment Tools

- Tools; Integrated in an Integrated Development Environment (IDE)

Type	Unix examples
Editors	vi, emacs
Pretty printers	cb, indent
Pre-processors (esp. macros)	cpp, m4, watfor
Debuggers	adb, sdb, dbx, gdb
Style checkers	lint, purify
Module management	make
Version management	sccs, rcs
Assemblers	as
Link editors, loaders	Id, Id-so
Perusal tools	More, less, od, nm
Program cross-reference	ctags

An Overview of Compilation

- Phases of Compilation



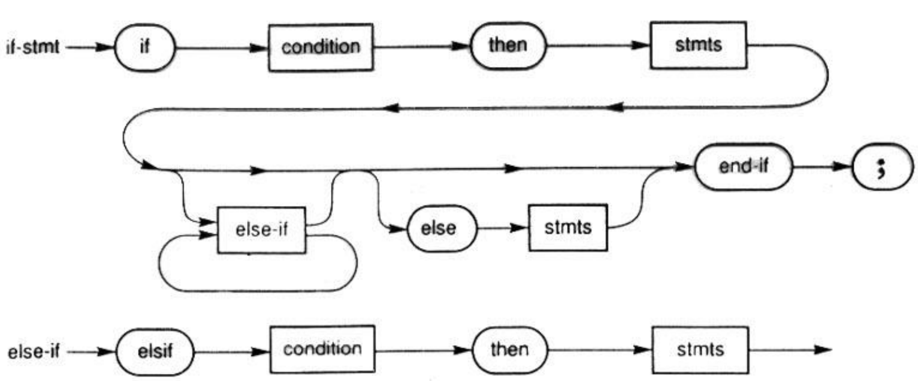
An Overview of Compilation

- ***Scanning***:
  - divides the program into "tokens", which are the smallest meaningful units; this saves time, since character-by-character processing is slow
  - we can tune the scanner better if its job is simple; it also saves complexity (lots of it) for later stages
  - you can design a parser to take characters instead of tokens as input, but it isn't pretty
  - scanning is recognition of a *regular language*, e.g., via DFA (deterministic finite automaton)

An Overview of Compilation

- ***Parsing*** is recognition of a *context-free language*, e.g., via Pushdown Automaton (PDA)
  - Parsing discovers the "context free" structure of the program
  - Informally, it finds the structure you can describe with syntax diagrams (the "circles and arrows" in a Pascal manual)

Pascal “Railroad” diagram



An Overview of Compilation

- ***Semantic analysis*** is the discovery of *meaning* in the program
  - The compiler actually does what is called STATIC semantic analysis. That's the meaning that can be figured out at compile time
  - Some things (e.g., array subscript out of bounds) can't be figured out until run time. Things like that are part of the program's DYNAMIC semantics

An Overview of Compilation

- ***Intermediate form*** (IF) done after semantic analysis (*if* the program passes all checks)
  - IFs are often chosen for machine independence, ease of optimization, or compactness (these are somewhat contradictory)
  - They often resemble machine code for some imaginary idealized machine; e.g. a stack machine, or a machine with arbitrarily many registers
  - Many compilers actually move the code through more than one IF

An Overview of Compilation

- ***Optimization*** takes an intermediate-code program and produces another one that does the same thing faster, or in less space
  - The term is a misnomer; we just *improve* code
  - The optimization phase is optional
- ***Code generation phase*** produces assembly language or (sometime) relocatable machine language

An Overview of Compilation

- Certain ***machine-specific optimizations*** (use of special instructions or addressing modes, etc.) may be performed during or after ***target code generation***
- ***Symbol table***: all phases rely on a symbol table that keeps track of all the identifiers in the program and what the compiler knows about them
  - This symbol table may be retained (in some form) for use by a debugger, even after compilation has completed

An Overview of Compilation

- Lexical and Syntax Analysis
  - GCD Program (Pascal)

```
program gcd(input, output);
var i, j : integer;
begin
    read(i, j);
    while i <> j do
        if i > j then i := i - j
        else j := j - i;
    writeln(i)
end.
```

An Overview of Compilation

- Lexical and Syntax Analysis
  - GCD Program Tokens
    - Scanning (*lexical analysis*) and parsing recognize the structure of the program, groups characters into *tokens*, the smallest meaningful units of the program

program	gcd	(	input	,	output	)	;
var	i	,	j	:	integer	;	begin
read	(	i	,	j	)	;	while
i	<>	j	do	if	i	>	j
then	i	:=	i	-	j	else	j
:=	j	-	i	;	writeln	(	i
)	end	.					

An Overview of Compilation

- Lexical and Syntax Analysis
  - Context-Free Grammar and Parsing
    - Parsing organizes tokens into a *parse tree* that represents higher-level constructs in terms of their constituents
    - Potentially recursive rules known as *context-free grammar* define the ways in which these constituents combine

An Overview of Compilation

- Context-Free Grammar and Parsing
  - Example (Pascal program)

program ⟶ `PROGRAM id ( id` *more_ids* `) ;` *block* `.`

where

block ⟶ *labels constants types variables subroutines* `BEGIN` *stmt* *more_stmts* `END`

and

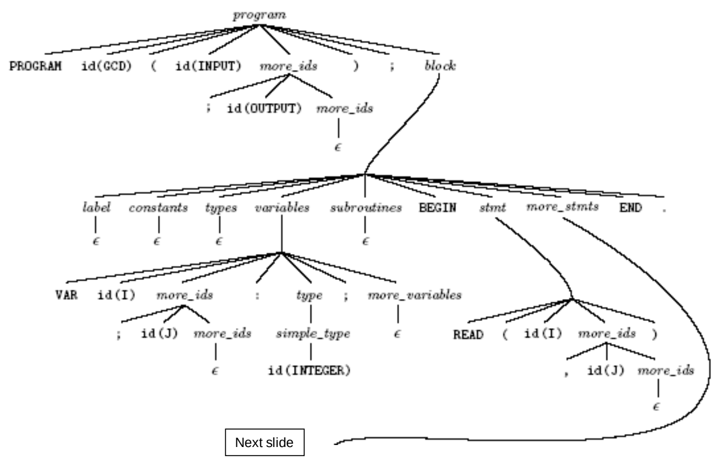
more_ids ⟶ `, id` *more_ids*

or

more_ids ⟶ ϵ

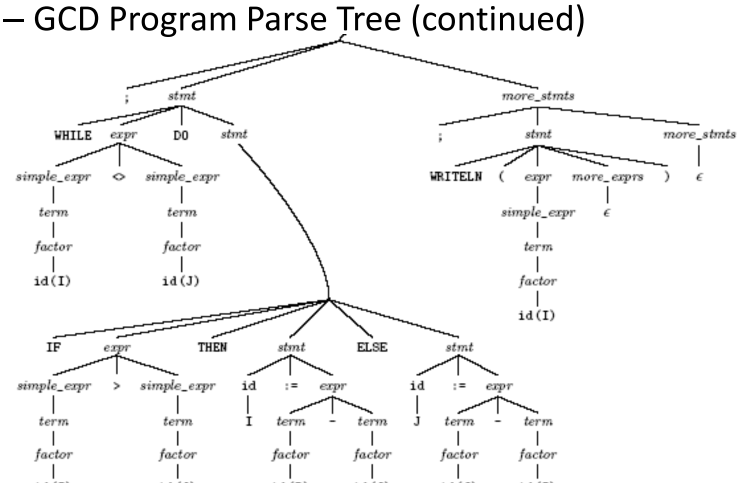
An Overview of Compilation

- Context-Free Grammar and Parsing
  - GCD Program Concrete Parse Tree



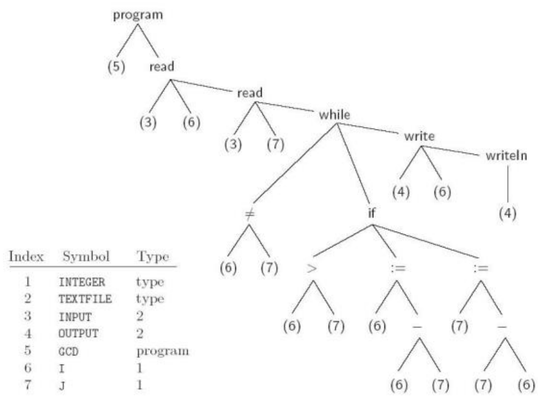
An Overview of Compilation

- Context-Free Grammar and Parsing
  - GCD Program Parse Tree (continued)



An Overview of Compilation

- Syntax Tree
  - GCD Program Abstract Parse Tree



Index	Symbol	Type
1	INTEGER	type
2	TEXTFILE	type
3	INPUT	2
4	OUTPUT	2
5	GCD	program
6	I	1
7	J	1

Figure 1.4: **Syntax tree and symbol table for the GCD program.**

Code Generation

- Naïve MIPS assembly code fragment

```
addiu    sp, sp, -32        # Reserve room for local vars
sw       ra, 20(sp)         # save return address
jal      getint             # read
nop
sw       v0, 28(sp)         # store i
jal      getint             # read
nop
sw       v0, 24(sp)         # store j
lw       t6, 28(sp)         # load i to t6
lw       t7, 24(sp)         # load j to t7
nop
beq      t6, t7, D          # branch if I = J
nop
A: lw    t8, 28(sp)         # load I
...
```