

Notes for CSC 254, 13 Dec. 2023

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Run-time Systems

A **library** is preexisting code you can call.

A **run-time system** is a library that makes assumptions about how the compiler works

- may use tables generated by the compiler
- may examine or manipulate heap or stack layout
- e.g., GC requires help finding root pointers and type descriptors; needs compiler to generate write barriers

A **virtual machine** is a run-time system that provides/specifies everything the program needs, including the instruction set

The Java Virtual Machine (JVM)

Recall how Java works

compiler translates Java source to Java byte code (JBC)
byte code runs on virtual machine
virtual machine may execute code via interpretation,
JIT compilation, or some combination of the two

The JVM's machine architecture provides

all & only Java's built-in types

(invokedynamic was added to the JVM for Java 7, to support
Java lambdas & dynamic languages)

type safety

definite assignment

garbage collection

threads

global **constant pool**, per-thread stacks, heap, method (code) area

[each stack frame contains

array of locals & formals

each slot 32 bits wide (longs and doubles take 2)

can be reused for temporally disjoint data of different types

expression evaluation stack

(sized to accommodate largest expression in the method)]

implicit references (“registers”) for the current program counter, frame, top of operand stack within frame, symbol table info in constant pool

The JVM also defines the format of `.class` files

At start-up, the JVM

- loads the given class file (which must have a `main()`)

- verifies that it satisfies various invariants

 - type safety

 - no operand stack overflow or underflow

 - all references to the constant pool and the locals array are within bounds

 - all constant pool entries are well formed

 - no inheritance from a final class

 - definite assignment

 - (several of these require ***data flow analysis***)

- allocates and initializes static data

- links to library classes

- calls `main()` in a single thread

The Java Byte Code instruction set includes

- load-store

 - back and forth between local variable array and operand stack

- arithmetic

 - all done implicitly on the operand stack

- type conversion

- object management

 - new, field and array element access, reflection

- push, pop, dup, swap

- branches, switch

 - specify targets as indices in the instruction array of the current method

- static and virtual method calls

 - specify target symbolically by name (index in constant pool)

- throw exception

- monitor enter, exit (`wait`, `notify`, and `notifyAll` are method calls)

<pre> public void insert(int v) { node n = head; while (n.next != null && n.next.val < v) { n = n.next; } if (n.next == null n.next.val > v) { node t = new node(); t.val = v; t.next = n.next; n.next = t; } // else v already in set } </pre>	<pre> Code: Stack=3, Locals=4, Args_size=2 0: aload_0 // this 1: getfield #4; //Field head:LLLset\$node; 4: astore_2 5: aload_2 // n 6: getfield #5; //Field LLset\$node.next:LLLset\$node; 9: ifnull 31 // conditional branch 12: aload_2 13: getfield #5; //Field LLset\$node.next:LLLset\$node; 16: getfield #6; //Field LLset\$node.val:I 19: iload_1 // v 20: if_icmpge 31 23: aload_2 24: getfield #5; //Field LLset\$node.next:LLLset\$node; 27: astore_2 28: goto 5 31: aload_2 32: getfield #5; //Field LLset\$node.next:LLLset\$node; 35: ifnull 49 38: aload_2 39: getfield #5; //Field LLset\$node.next:LLLset\$node; 42: getfield #6; //Field LLset\$node.val:I 45: iload_1 46: if_icmple 76 49: new #2; //class LLset\$node 52: dup 53: aload_0 54: invokespecial #3; //Method LLset\$node."<init>":(LLLset;)V 57: astore_3 58: aload_3 // t 59: iload_1 60: putfield #6; //Field LLset\$node.val:I 63: aload_3 64: aload_2 65: getfield #5; //Field LLset\$node.next:LLLset\$node; 68: putfield #5; //Field LLset\$node.next:LLLset\$node; 71: aload_2 72: aload_3 73: putfield #5; //Field LLset\$node.next:LLLset\$node; 76: return </pre>
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Figure 16.2 Java source and bytecode for a list insertion method. Output on the right was produced by Oracle's javac (compiler) and javap (disassembler) tools, with additional comments inserted by hand.

The Common Language Infrastructure (CLI) is similar to the JVM but more general
(The Common Language Runtime [CLR] is Microsoft's implementation)

- explicit support for multiple programming languages

- (Microsoft supports C#, F#, Visual Basic, Managed C++, and JScript)

- richer common type system (CTS)

- richer calling mechanisms (including tail recursion)

- multiple pointer and reference types

- support for unsafe code

- etc.

Common Intermediate Language (CIL) is the JBC analogue

JIT-centric: several tradeoffs made against interpretation

- type information in objects, not opcodes

- separate spaces for arguments and locals

- built-in support for generics

Lazy binding of machine code

JIT

- tradeoff between load time and optimization quality

- HotSpot has "client" and "server" modes

- faster than you might think (heavy lifting done by javac)

- incremental compilation

- compilation of hot methods in parallel with interpretation

- caching of machine code across runs

- dynamic inlining

Binary translation

- FX!32 (x86 → Alpha)

- Apple Rosetta (PowerPC → x86), Rosetta2 (x86 → ARM)

- challenges:

- where are the function boundaries?

- what are types of data in memory?

- what locations are targets of branches?

- self-modifying code

- dynamically generated code

- introspection

Binary rewriting

trace scheduling

HP Dynamo (PA-RISC) & DynamoRIO (x86), late 1990s

instrumentation

statistics gathering

simulate new architectures

insert dynamic semantic checks

sandboxing (a.k.a. **software fault isolation** -- SFI)

Pin, Valgrind tools

trace-based

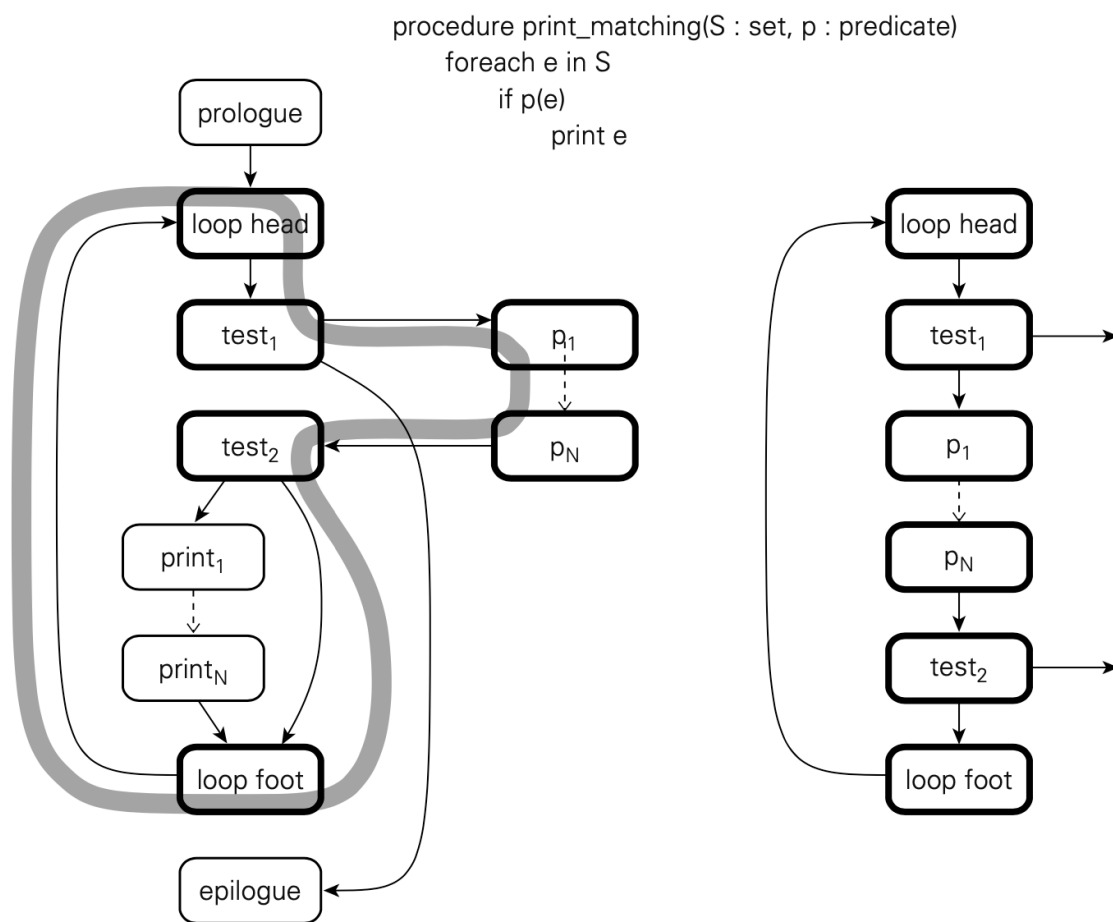


Figure 16.3 Creation of a partial execution trace. Procedure `print_matching` (shown at top) is often called with a particular predicate, `p`, which is usually false. The control flow graph (left, with hot blocks in bold and the hot path in grey) can be reorganized at run time to improve instruction-cache locality and to optimize across abstraction boundaries (right).

(Interestingly, some processors cache traces like these in hardware.)

To learn more about language tools, take 2/455!