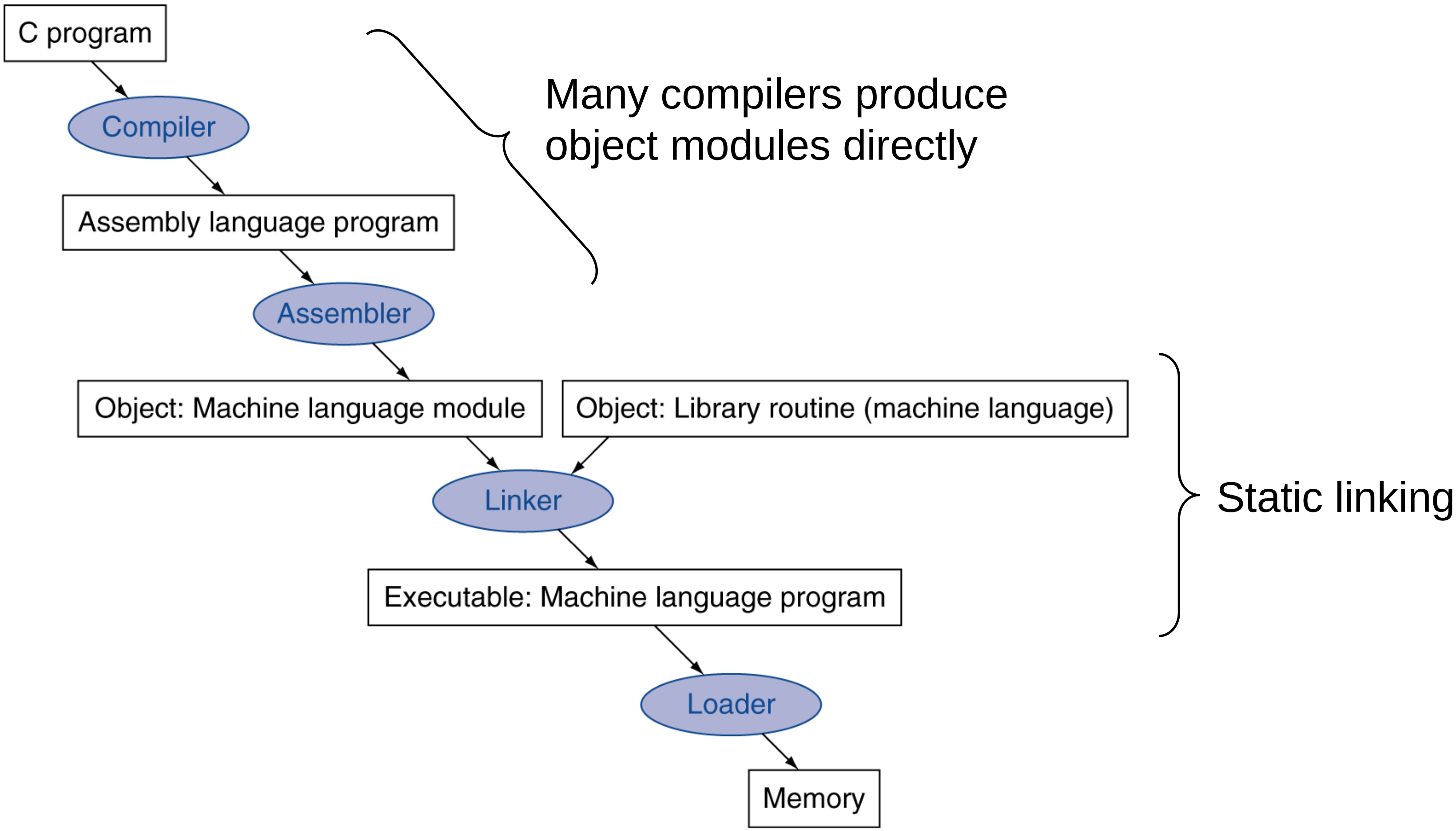
Chapter 2

Instructions: Language of the Computer

Translation and Startup



Assembler Pseudoinstructions

- Most assembler instructions represent machine instructions one-to-one
- Pseudoinstructions: figments of the assembler's imagination

```
move $t0, $t1     →  add $t0, $zero, $t1
blt $t0, $t1, L   →  slt $at, $t0, $t1
                     bne $at, $zero, L
```

  - $at (register 1): assembler temporary

Producing an Object Module

- Assembler (or compiler) translates program into machine instructions
- Provides information for building a complete program from the pieces
  - Header: described contents of object module
  - Text segment: translated instructions
  - Static data segment: data allocated for the life of the program
  - Relocation info: for contents that depend on absolute location of loaded program
  - Symbol table: global definitions and external refs
  - Debug info: for associating with source code

Linking Object Modules

- Produces an executable image
  1. Merges segments
  2. Resolve labels (determine their addresses)
  3. Patch location-dependent and external refs
- Could leave location dependencies for fixing by a relocating loader
  - But with virtual memory, no need to do this
  - Program can be loaded into absolute location in virtual memory space

Loading a Program

- Load from image file on disk into memory
  1. Read header to determine segment sizes
  2. Create virtual address space
  3. Copy text and initialized data into memory
     - Or set page table entries so they can be faulted in
  4. Set up arguments on stack
  5. Initialize registers (including $sp, $fp, $gp)
  6. Jump to startup routine
     - Copies arguments to $a0, … and calls main
     - When main returns, do exit syscall

Dynamic Linking

- Only link/load library procedure when it is called
  - Requires procedure code to be relocatable
  - Avoids image bloat caused by static linking of all (transitively) referenced libraries
  - Automatically picks up new library versions

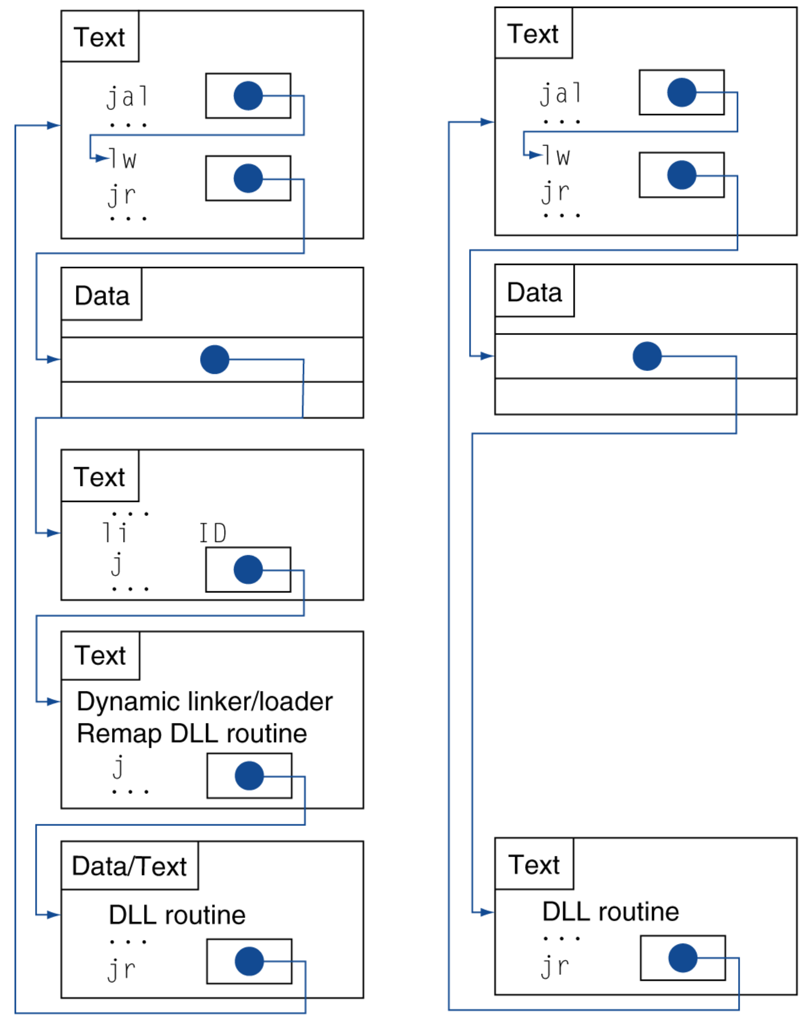
Lazy Linkage

Indirection table

Stub: Loads routine ID,
Jump to linker/loader

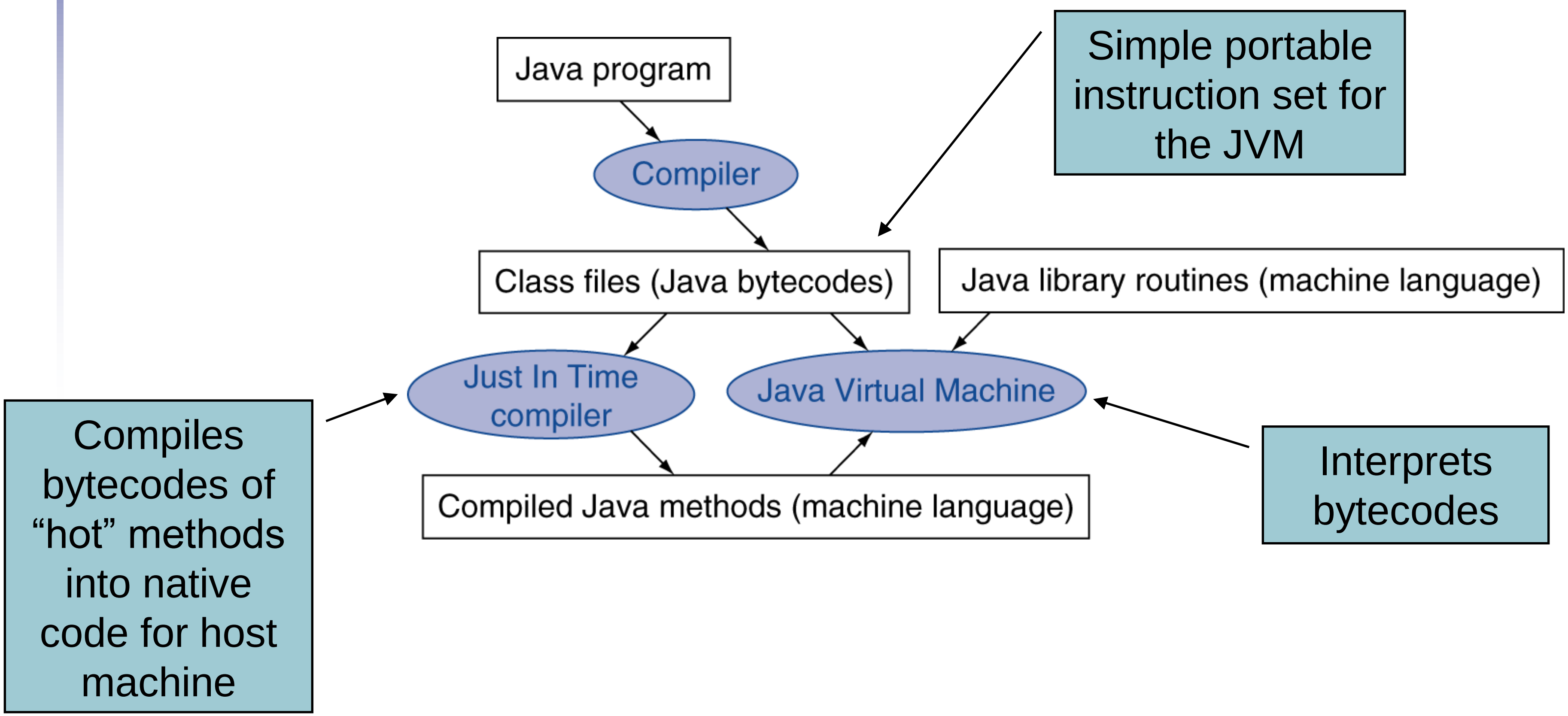
Linker/loader code

Dynamically
mapped code



a. First call to DLL routine
b. Subsequent calls to DLL routine

Starting Java Applications



C Sort Example

- Illustrates use of assembly instructions for a C bubble sort function
- Swap procedure (leaf)

```
void swap(int v[], int k)
{
  int temp;
  temp = v[k];
  v[k] = v[k+1];
  v[k+1] = temp;
}
```

  - v in $a0, k in $a1, temp in $t0

The Procedure Swap

```
swap: sll $t1, $a1, 2   # $t1 = k * 4
      add $t1, $a0, $t1 # $t1 = v+(k*4)
                        #   (address of v[k])
      lw $t0, 0($t1)    # $t0 (temp) = v[k]
      lw $t2, 4($t1)    # $t2 = v[k+1]
      sw $t2, 0($t1)    # v[k] = $t2 (v[k+1])
      sw $t0, 4($t1)    # v[k+1] = $t0 (temp)
      jr $ra            # return to calling routine
```

The Sort Procedure in C

- Non-leaf (calls swap)

```
void sort (int v[], int n)
{
  int i, j;
  for (i = 0; i < n; i += 1) {
    for (j = i – 1;
         j >= 0 && v[j] > v[j + 1];
         j -= 1) {
      swap(v,j);
    }
  }
}
```

  - v in $a0, k in $a1, i in $s0, j in $s1

The Procedure Body

```
         move $s2, $a0            # save $a0 into $s2
         move $s3, $a1            # save $a1 into $s3
         move $s0, $zero          # i = 0
for1tst: slt  $t0, $s0, $s3       # $t0 = 0 if $s0 ≥ $s3 (i ≥ n)
         beq  $t0, $zero, exit1   # go to exit1 if $s0 ≥ $s3 (i ≥ n)
         addi $s1, $s0, –1        # j = i – 1
for2tst: slti $t0, $s1, 0         # $t0 = 1 if $s1 < 0 (j < 0)
         bne  $t0, $zero, exit2   # go to exit2 if $s1 < 0 (j < 0)
         sll  $t1, $s1, 2         # $t1 = j * 4
         add  $t2, $s2, $t1       # $t2 = v + (j * 4)
         lw   $t3, 0($t2)         # $t3 = v[j]
         lw   $t4, 4($t2)         # $t4 = v[j + 1]
         slt  $t0, $t4, $t3       # $t0 = 0 if $t4 ≥ $t3
         beq  $t0, $zero, exit2   # go to exit2 if $t4 ≥ $t3
         move $a0, $s2            # 1st param of swap is v (old $a0)
         move $a1, $s1            # 2nd param of swap is j
         jal  swap                # call swap procedure
         addi $s1, $s1, –1        # j –= 1
         j    for2tst             # jump to test of inner loop
exit2:   addi $s0, $s0, 1         # i += 1
         j    for1tst             # jump to test of outer loop
```

Move params

Outer loop

Inner loop

Pass params & call

Inner loop

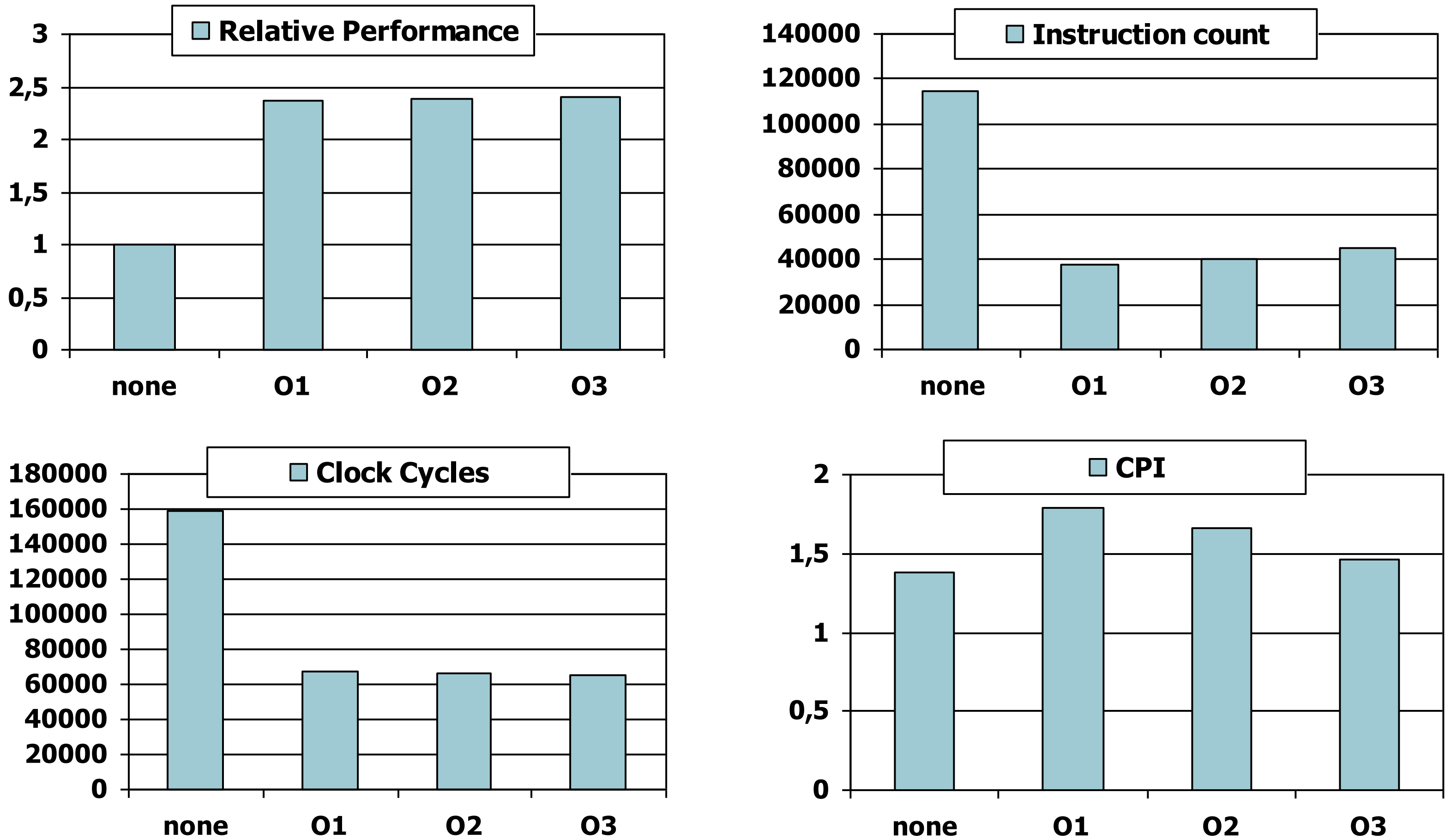
Outer loop

The Full Procedure

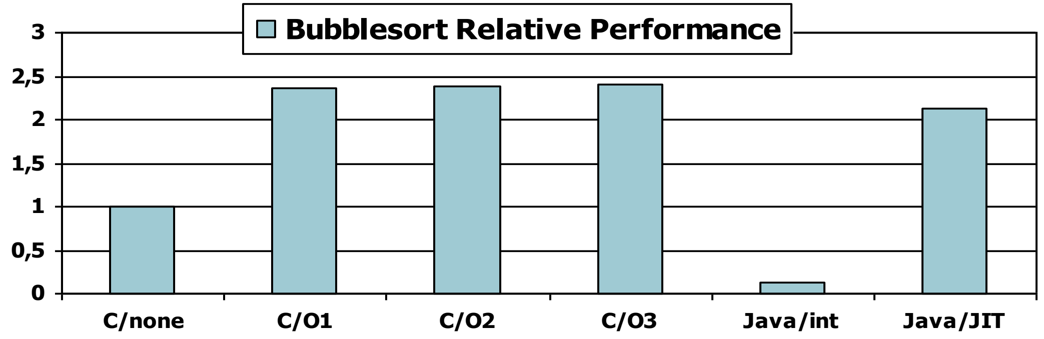
```
sort:    addi $sp,$sp, –20       # make room on stack for 5 registers
         sw $ra, 16($sp)         # save $ra on stack
         sw $s3,12($sp)          # save $s3 on stack
         sw $s2, 8($sp)          # save $s2 on stack
         sw $s1, 4($sp)          # save $s1 on stack
         sw $s0, 0($sp)          # save $s0 on stack
         …                       # procedure body
         …
         exit1: lw $s0, 0($sp)   # restore $s0 from stack
         lw $s1, 4($sp)          # restore $s1 from stack
         lw $s2, 8($sp)          # restore $s2 from stack
         lw $s3,12($sp)          # restore $s3 from stack
         lw $ra,16($sp)          # restore $ra from stack
         addi $sp,$sp, 20        # restore stack pointer
         jr $ra                  # return to calling routine
```

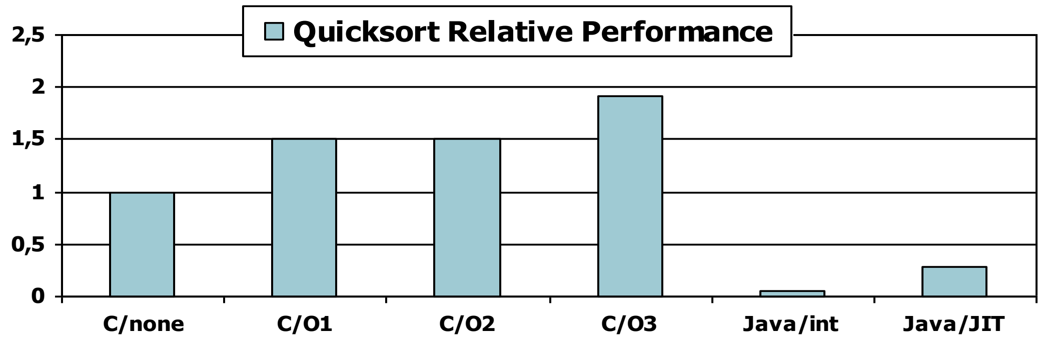
Effect of Compiler Optimization

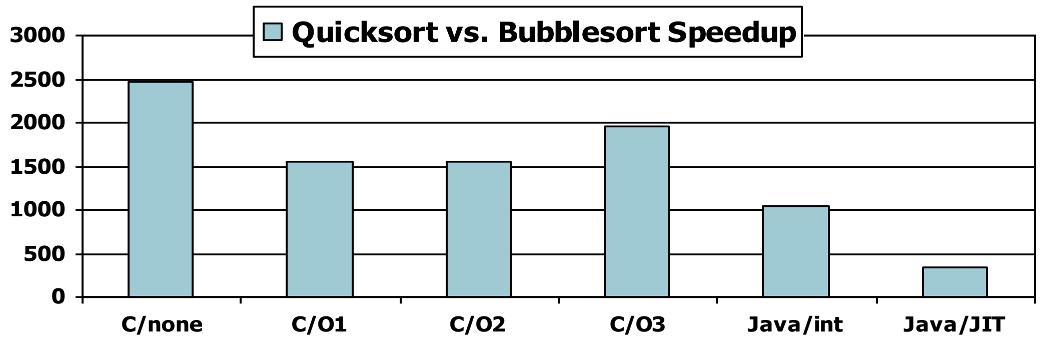
Compiled with gcc for Pentium 4 under Linux



Effect of Language and Algorithm







Lessons Learnt

- Instruction count and CPI are not good performance indicators in isolation
- Compiler optimizations are sensitive to the algorithm
- Java/JIT compiled code is significantly faster than JVM interpreted
  - Comparable to optimized C in some cases
- Nothing can fix a dumb algorithm!