# Java Performance Analysis for Scientific Computing

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# Background: Where we are coming from...

- National Institute of Standards and Technology
  - US Department of Commerce
  - NIST (3,000 employees,  mainly scientists and engineers)
- middle to large-scale simulation modeling
- Fortran and C/C++ applications
- Cray C-90, IBM SP2, SGI, Alpha/PC clusters

# NIST Applied and Computational Mathematics Division

- Algorithms for simulation and modeling
- Consultants to NIST scientist and engineers
- Computational linear algebra
- Numerical solution of PDEs
- Special functions
- Multigrid and hierarchical methods
- Numerical Optimization
- Monte Carlo simulations

# Why Java?

- Portability of the Java Virtual Machine (JVM)
- Safe, minimize memory leaks and pointer errors
- Network-aware environment
- Parallel and Distributed computing
  - Threads
  - Remote Method Invocation (RMI)
- Integrated graphics
- Widely adopted
  - embedded systems, browsers, appliances
  - being adopted for teaching, development

# Why *not* Java?

- Performance
  - bytecode interpreters too slow
  - poor optimizing compilers
  - virtual machine
- lack of scientific software
  - computational libraries
  - numerical interfaces
  - major effort to port from f77/C

# Java Benchmarking: What are we really measuring?

- language vs. virtual machine (VM)
- Java -> bytecode translator
- bytecode execution (VM)
  - interpreted
  - just-in-time compilation (JIT)
  - adaptive compiler (HotSpot)
- underlying hardware

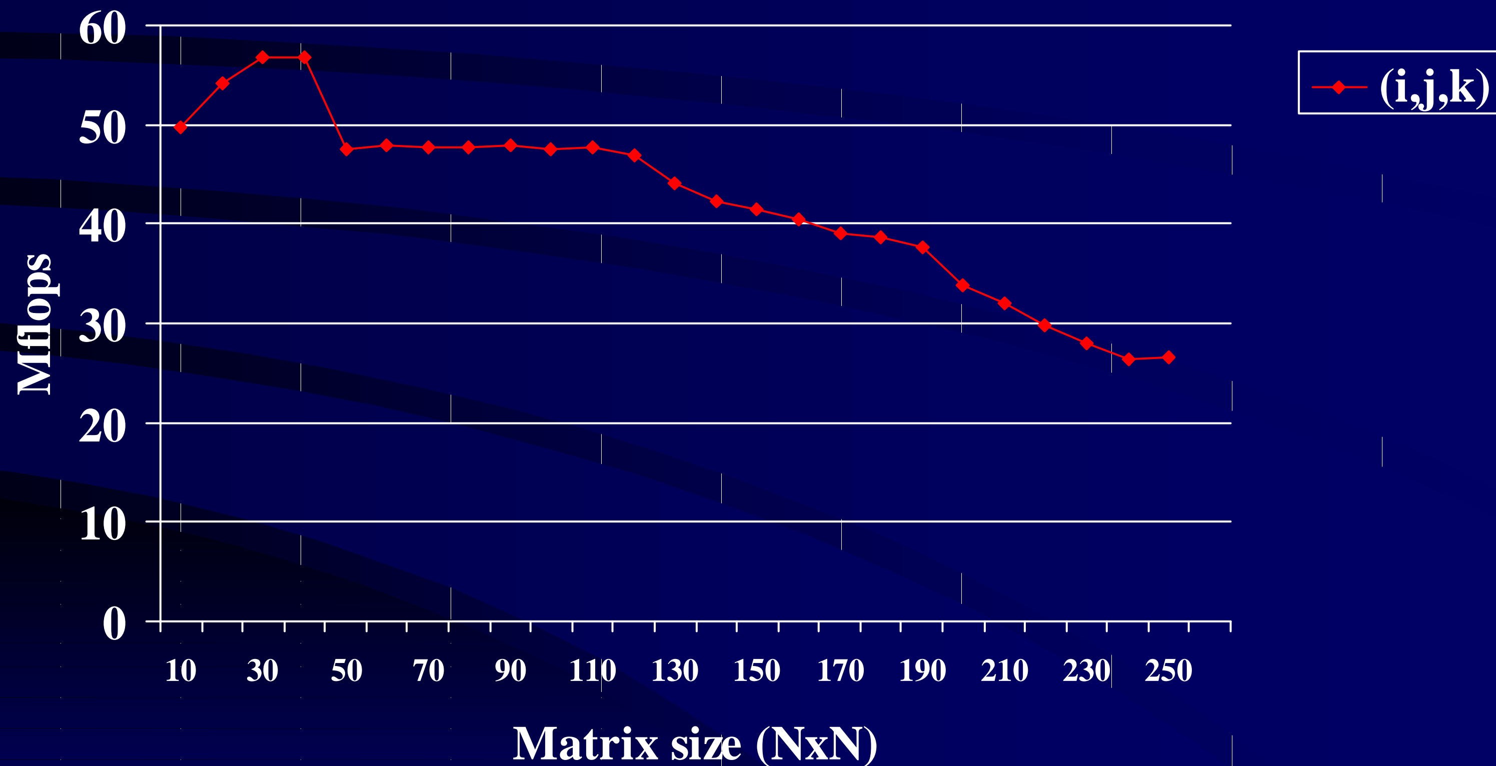
# Making Java fast(er)

- Native methods (JNI)
- stand-alone compliers (.java -> .exe)
- modified JVMs
  - (fused mult-adds, bypass array bounds checking)
- aggressive bytecode optimization
  - JITs, flash compilers, HotSpot
- bytecode transformers
- concurrency

# Computational Linear Algebra

- Time-consuming portion of PDE solvers and optimization problems
- basic matrix/vector operations (BLAS) often comprise major portion of cycles
- key: optimize BLAS

# Matrix multiply
(100% Pure Java)




*Pentium II I 500Mhz; java JDK 1.2 (Win98)

# Optimizing Java linear algebra

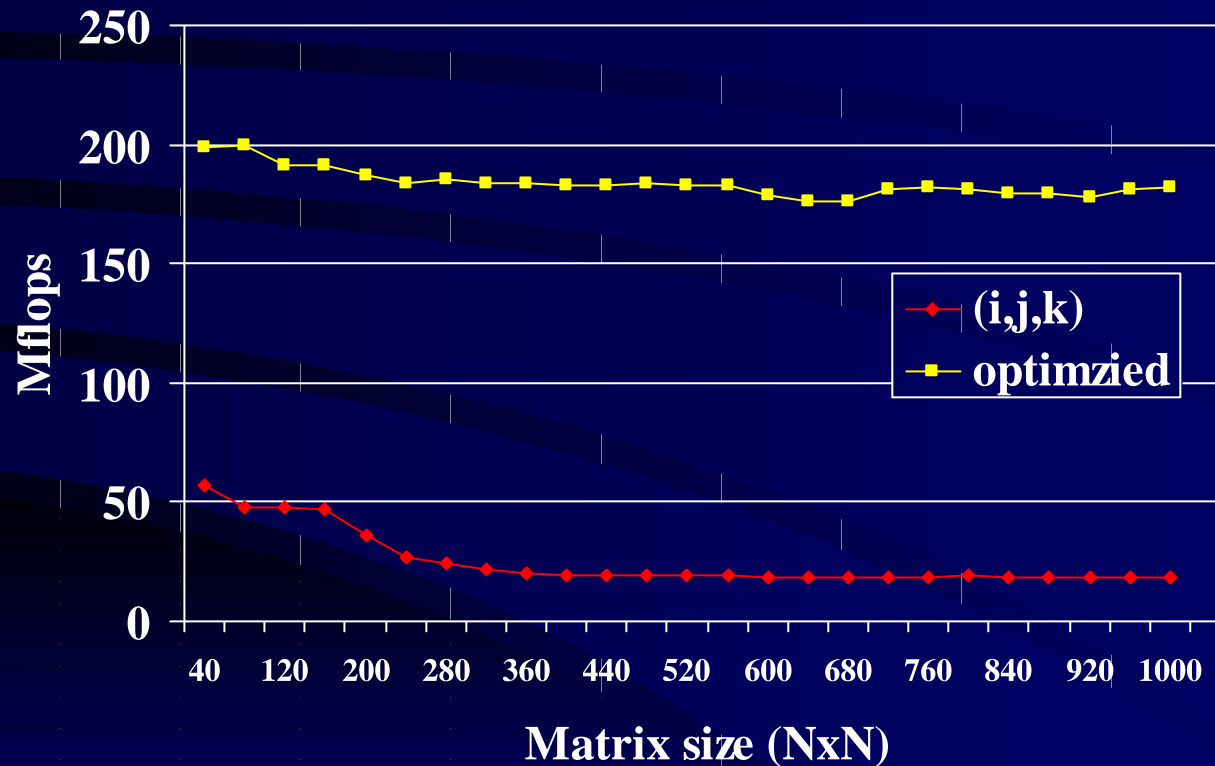
- Use native Java arrays: A[][]
- algorithms in 100% Pure Java
- exploit
  - multi-level blocking
  - loop unrolling
  - indexing optimizations
  - maximize on-chip / in-cache operations
- can be done today with *javac*, *jview*, *J++*, etc.

# Matrix Multiply: data blocking

- 1000x1000 matrices (out of cache)
- Java: 181 Mflops
- 2-level blocking:
  - 40x40 (cache)
  - 8x8 unrolled (chip)
- subtle trade-off between more temp variables and explicit indexing
- block size selection important: 64x64 yields only 143 Mflops

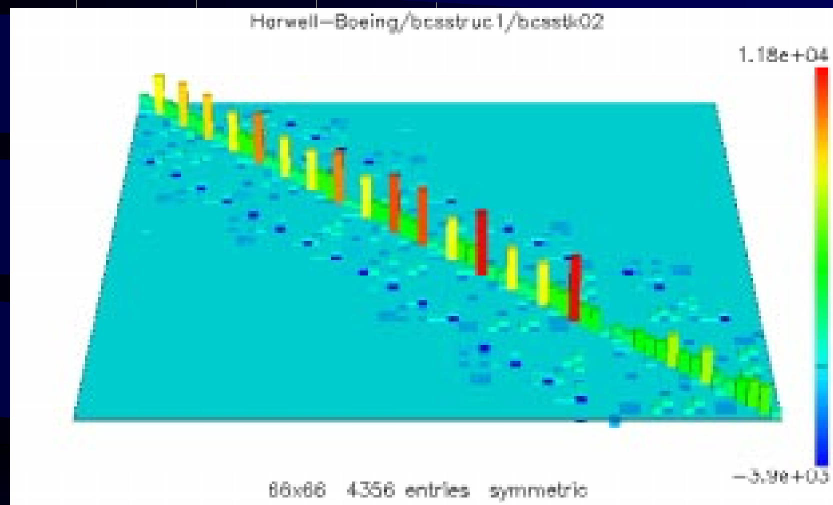
*Pentium III 500Mhz; Sun JDK 1.2 (Win98)

# Matrix multiply optimized
(100% Pure Java)




*Pentium II I 500Mhz; java JDK 1.2 (Win98)

# Sparse Matrix Computations




- unstructured pattern
- coordinate storage (CSR/CSC)
- array bounds check cannot be optimized away

# Sparse matrix/vector Multiplication

(Mflops)

| Matrix size (nnz) | C/C++ | Java |
| --- | --- | --- |
| 371 | 43.9 | 33.7 |
| 20,033 | 21.4 | 14.0 |
| 24,382 | 23.2 | 17.0 |
| 126,150 | 11.1 | 9.1 |

*266 MHz PII, Win95: Watcom C 10.6, Jview (SDK 2.0)

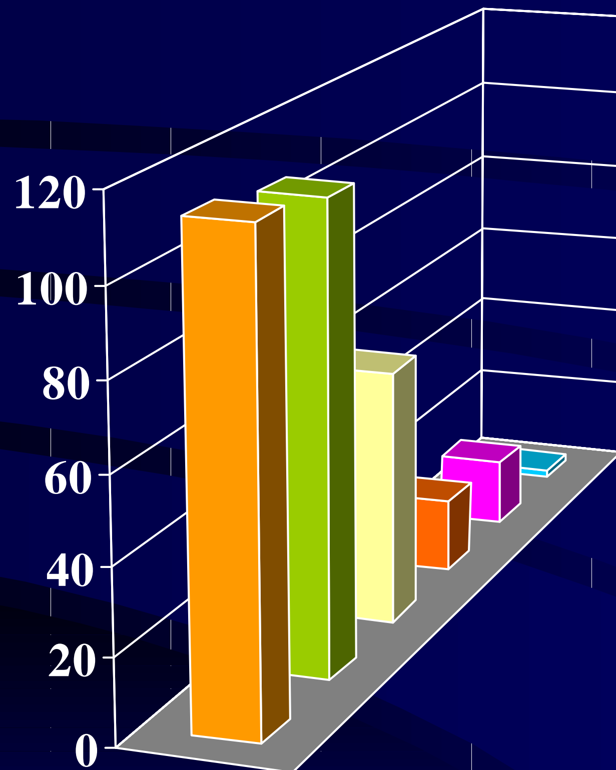
# Java Benchmarking Efforts

- Caffine Mark
- SPECjvm98
- Java Linpack
- Java Grande Forum Benchmarks
- SciMark
- Image/J benchmark
- BenchBeans
- VolanoMark
- Plasma benchmark
- RMI benchmark
- JMark
- JavaWorld benchmark
- …

# SciMark Benchmark

- Numerical benchmark for Java, C/C++
- results for over 1,000 platforms
- composite results for five kernels:
  - FFT (complex, 1D)
  - Successive Over-relaxation
  - Monte Carlo integration
  - Sparse matrix multiply
  - dense LU factorization

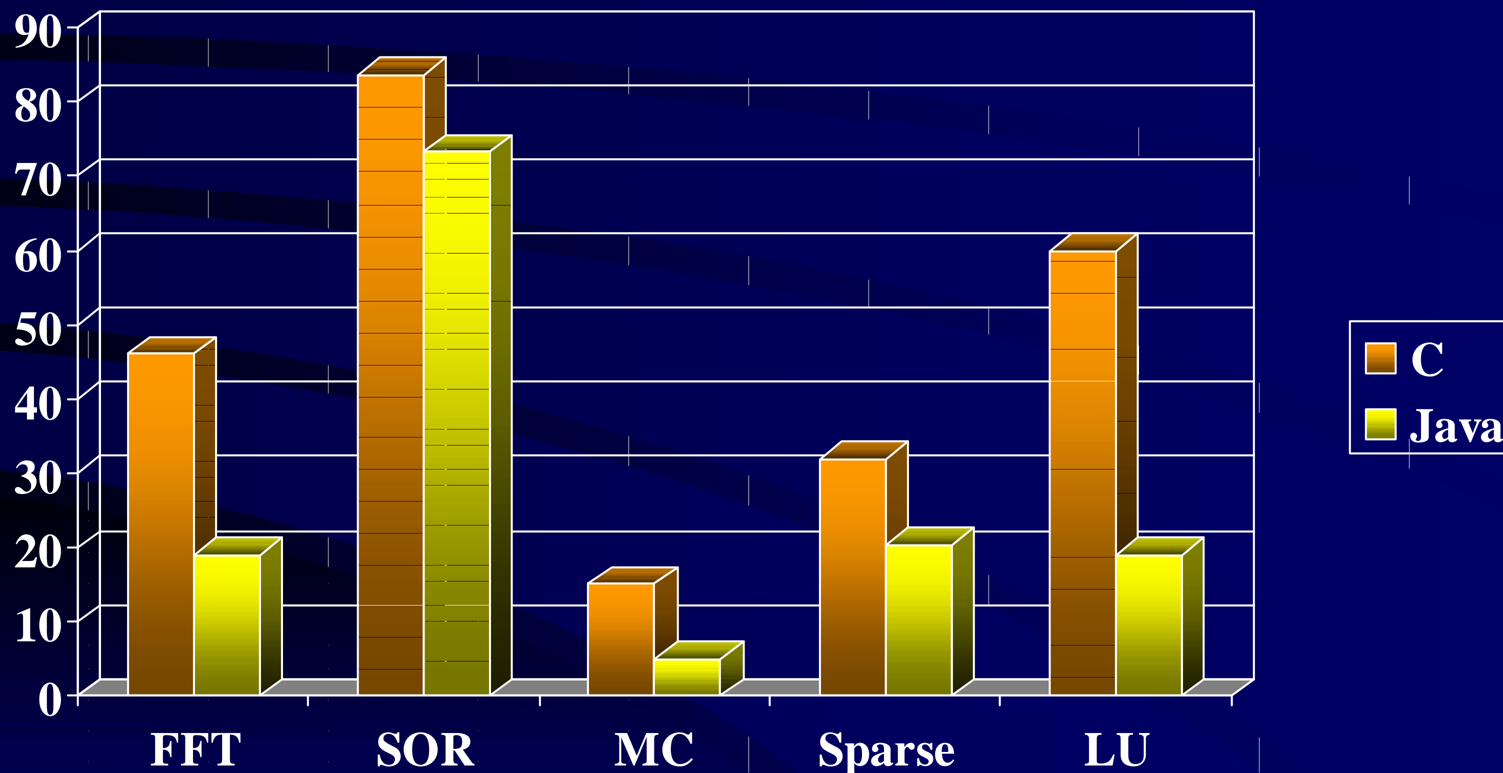
# SciMark 2.0 results




- Intel PIII (600 MHz), IBM 1.3, Linux
- AMD Athlon (750 MHz), IBM 1.1.8, OS/2
- Intel Celeron (464 MHz), MS 1.1.4, Win98
- Sun UltraSparc 60, Sun 1.1.3, Sol 2.x
- SGI MIPS (195 MHz) Sun 1.2, Unix
- Alpha EV6 (525 MHz), NE 1.1.5, Unix

# SciMark: Java vs. C

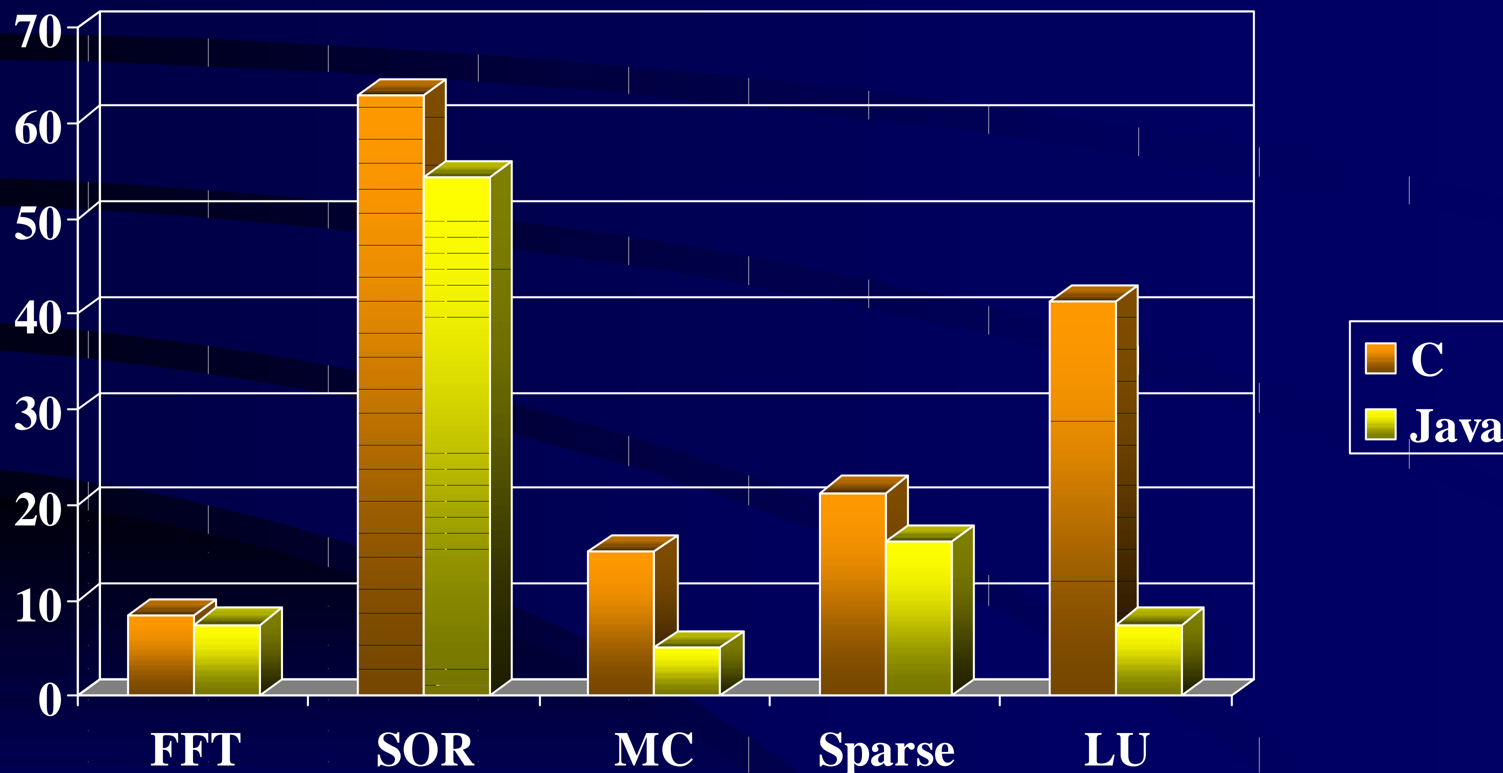
(Sun UltraSPARC 60)




* Sun JDK 1.2, javac -0; Sun cc -0; Solaris 2.x

# SciMark (large): Java vs. C

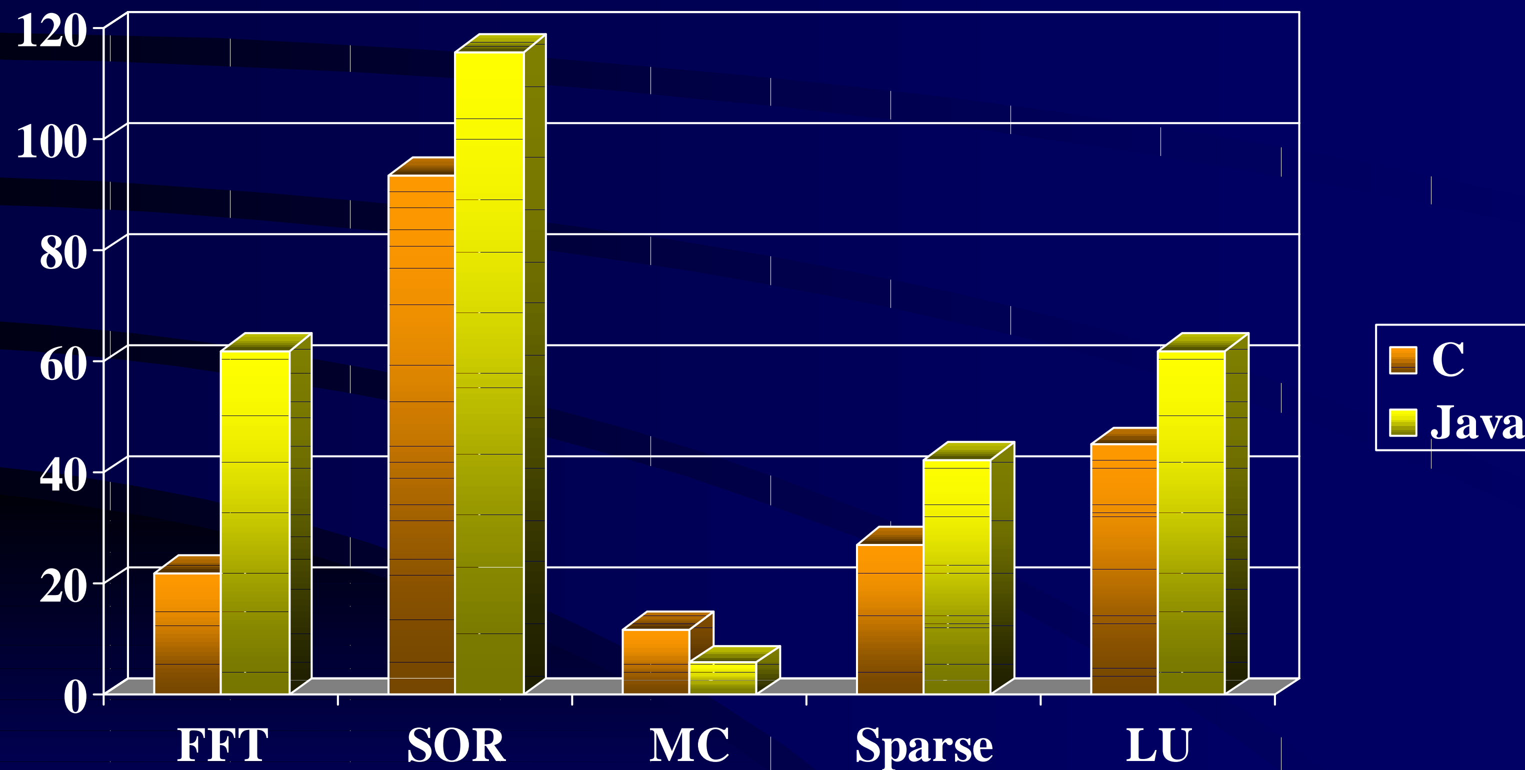
(Sun UltraSPARC 60)




* Sun JDK 1.2, javac -0; Sun cc -0; Solaris 2.x

# SciMark: Java vs. C

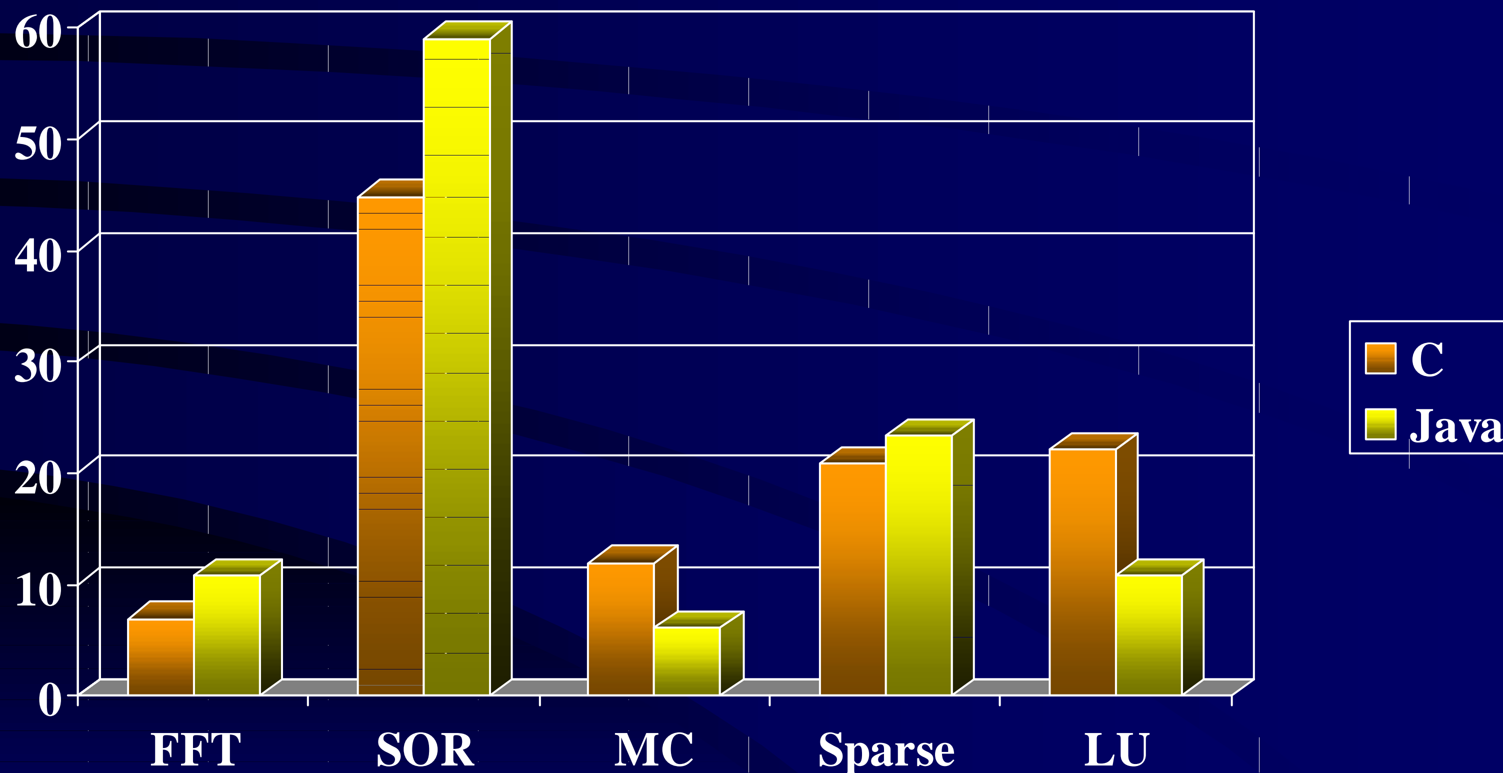
(Intel PIII 500MHz, Win98)




* Sun JDK 1.2, javac -0; Microsoft VC++ 5.0, cl -0; Win98

# SciMark (large): Java vs. C

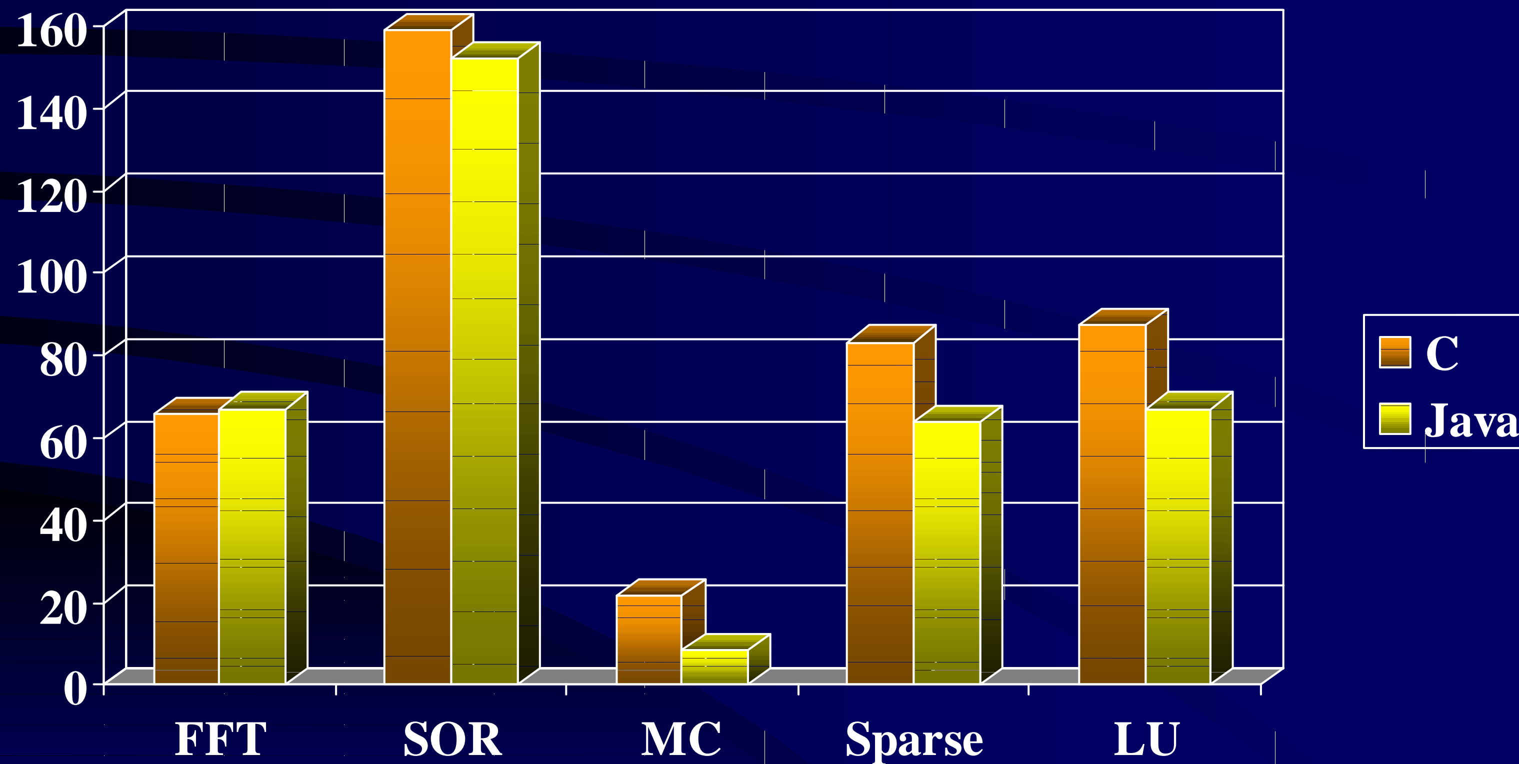
(Intel PIII 500MHz, Win98)




* Sun JDK 1.2, javac -0; Microsoft VC++ 5.0, cl -0; Win98

# SciMark: Java vs. C

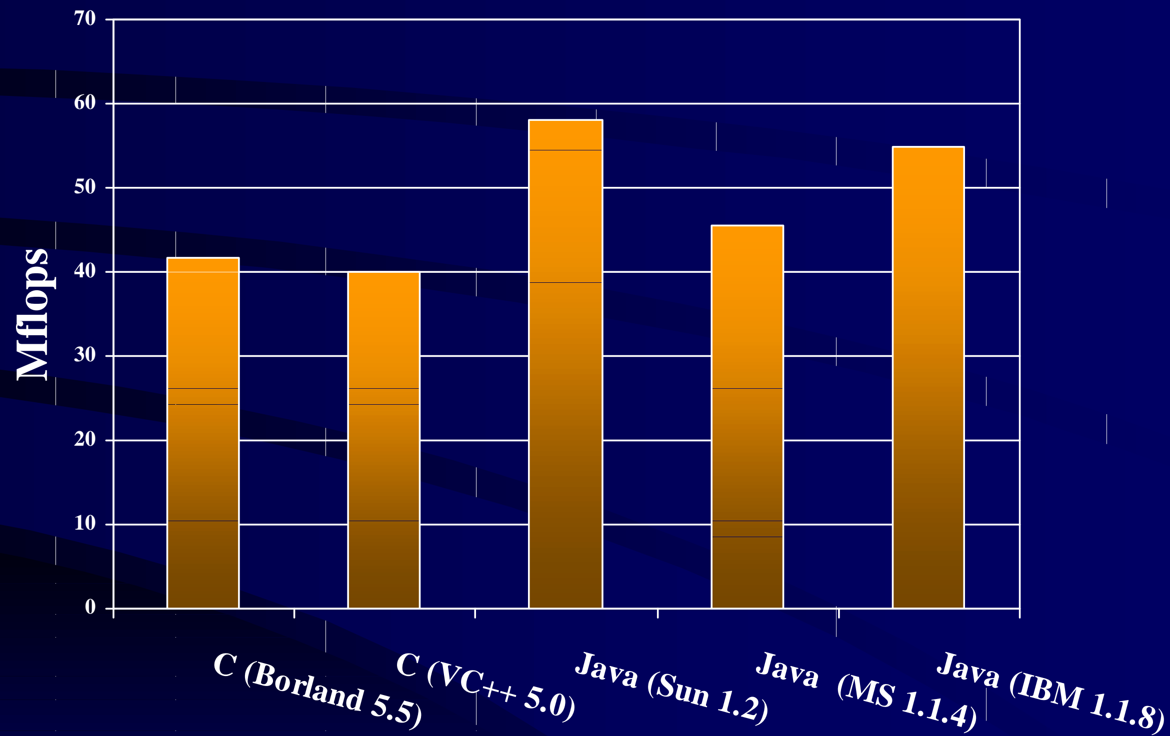
(Intel PIII 500MHz, Linux)




* RH Linux 6.2, gcc -06, IBM JDK 1.3, javac -O

# SciMark results

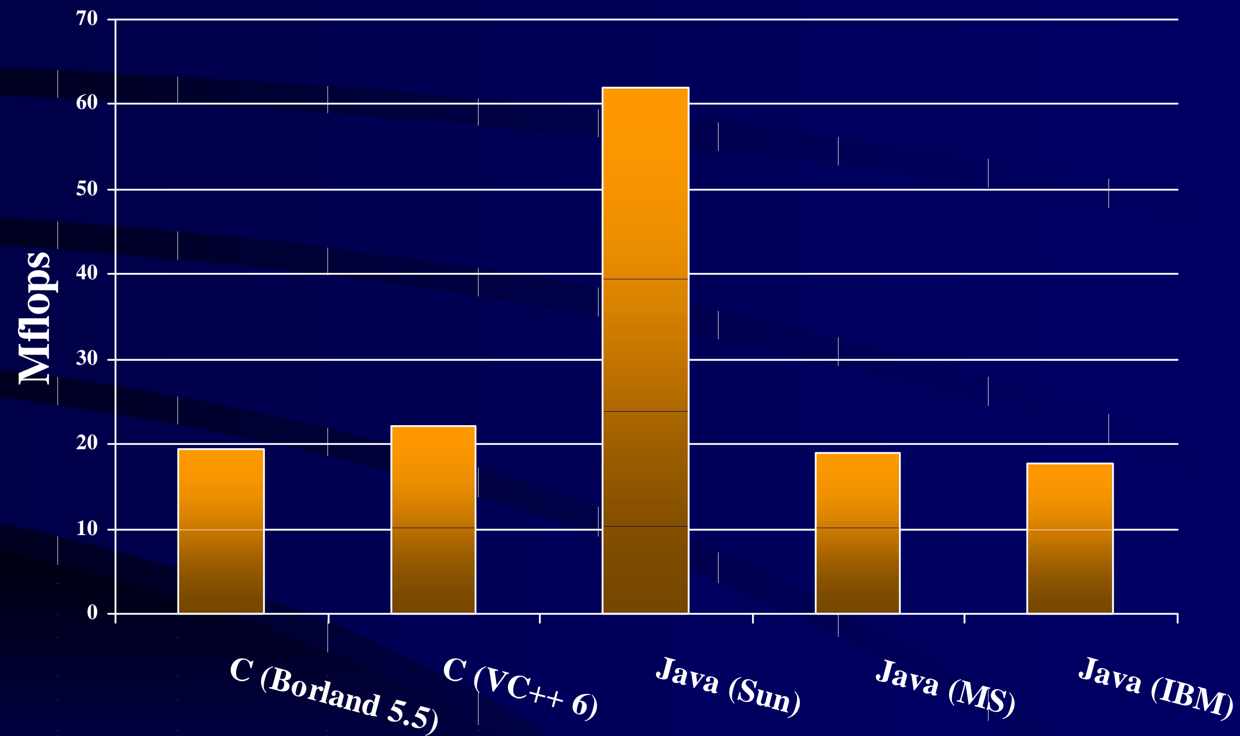
## 500 MHz PIII (Mflops)




*500MHz PIII, Microsoft C/C++ 5.0 (cl -O2x -G6), Sun JDK 1.2, Microsoft JDK 1.1.4, IBM JRE 1.1.8

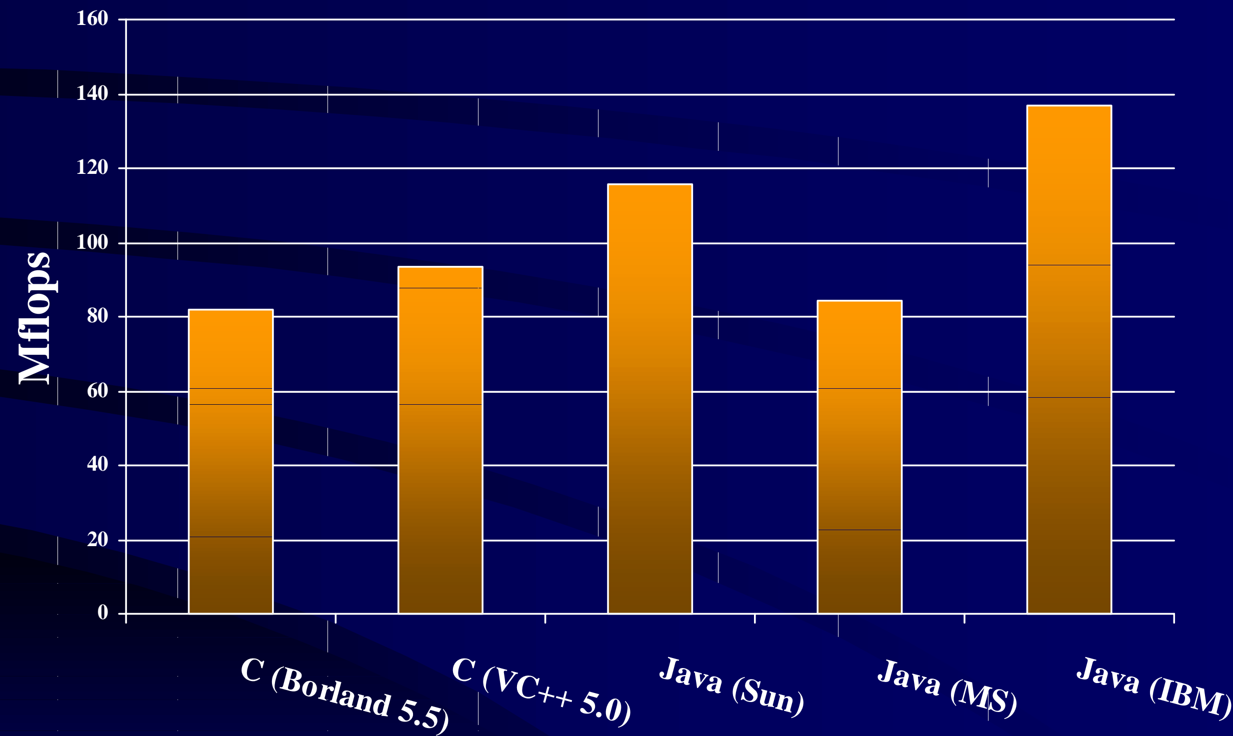
# SciMark FFT results

## Intel 500MHz PIII (Mflops)



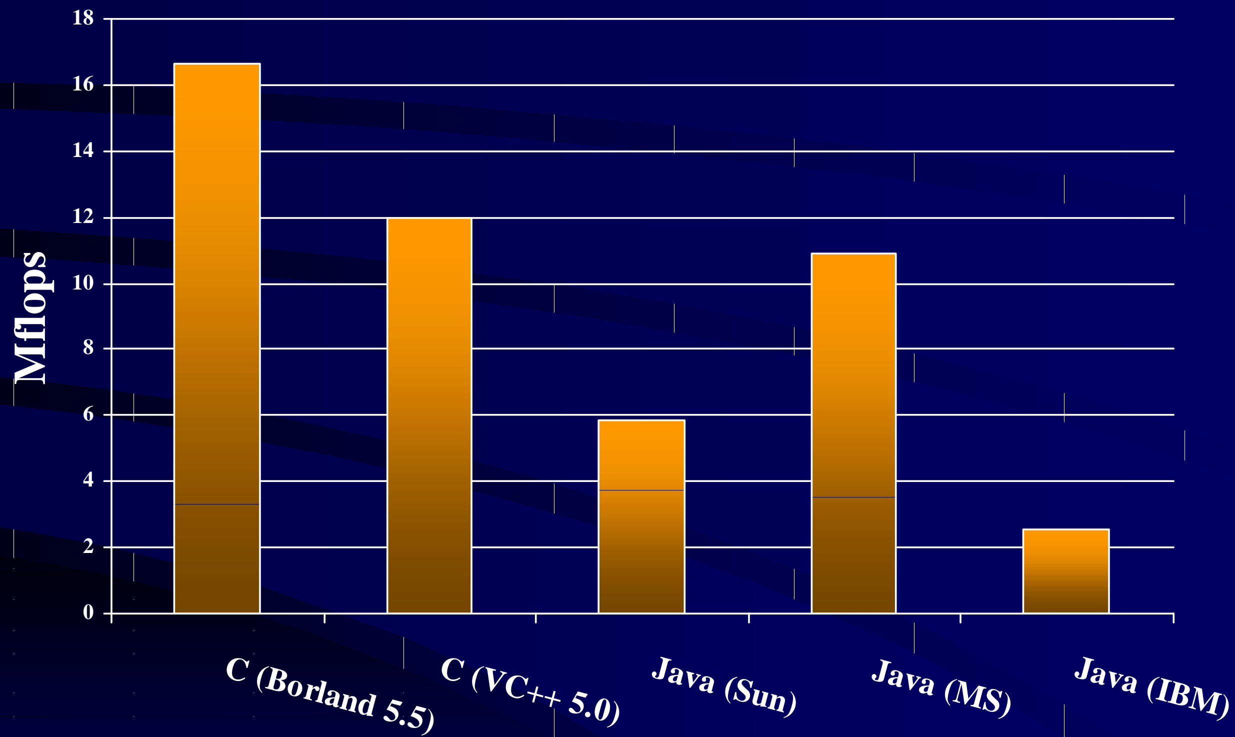

*500MHz PIII, Microsoft C/C++ 5.0 (cl -O2x -G6), Sun JDK 1.2, Microsoft JDK 1.1.4, IBM JRE 1.1.8

# SciMark SOR results
(Mflops)



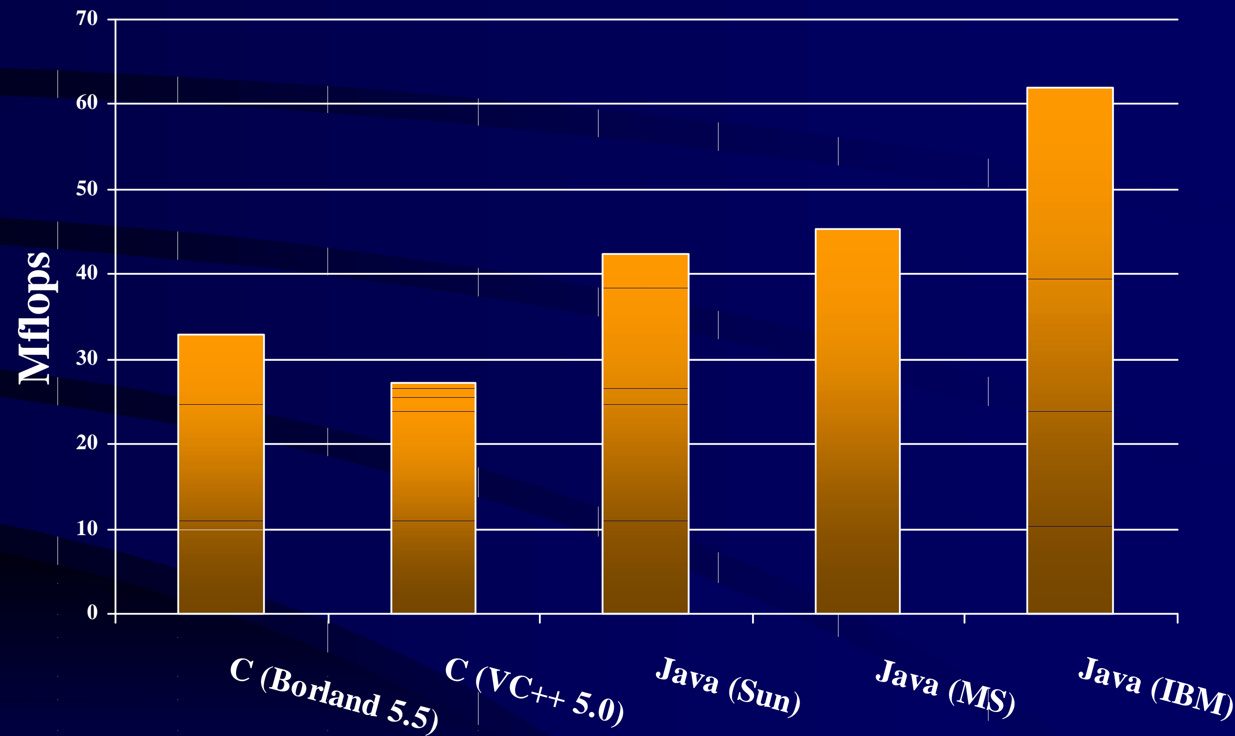

*500MHz PIII, Microsoft C/C++ 5.0 (cl -O2x -G6), Sun JDK 1.2, Microsoft JDK 1.1.4, IBM JRE 1.1.8

# SciMark Monte Carlo results
(Mflops)



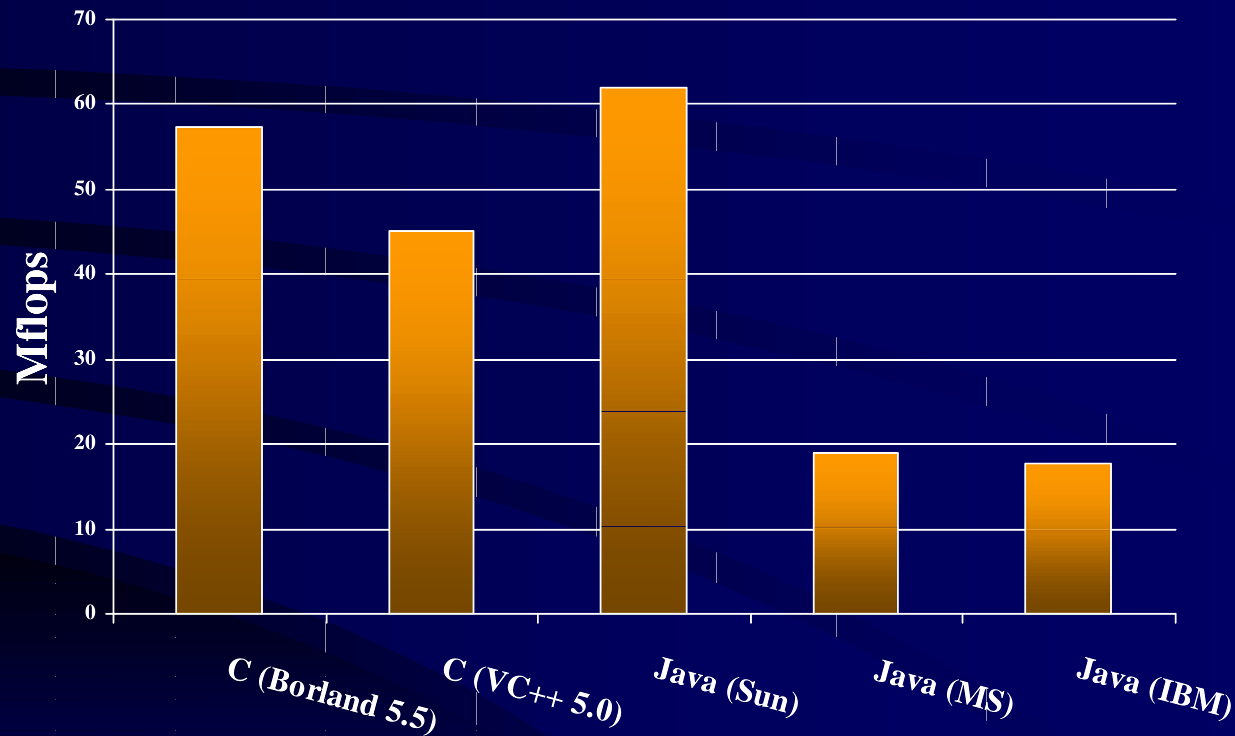

*500MHz PIII, Microsoft C/C++ 5.0 (cl -O2x -G6), Sun JDK 1.2, Microsoft JDK 1.1.4, IBM JRE 1.1.8

# SciMark Sparse-Matmult results
(Mflops)




*500MHz PIII, Microsoft C/C++ 5.0 (cl -O2x -G6), Sun JDK 1.2, Microsoft JDK 1.1.4, IBM JRE 1.1.8

# SciMark LU results
(Mflops)




*500MHz PIII, Microsoft C/C++ 5.0 (cl -O2x -G6), Sun JDK 1.2, Microsoft JDK 1.1.4, IBM JRE 1.1.8

# C vs. Java

- Why C is faster than Java
  - direct mapping to hardware
  - more opportunities for aggressive optimization
  - no garbage collection
- Why Java is faster than C (?)
  - different compilers/optimizations
  - performance more a factor of economics than technology
  - C compilers could be further improved

# Current JVMs are quite good...

- 1000x1000 matrix multiply over 180Mflops
  - 500 MHz Intel PIII, Win98, JDK 1.2
- Scimark high score: 163.0 Mflops
  - 933 MHz Intel PIII, Linux, IBM JDK 1.3

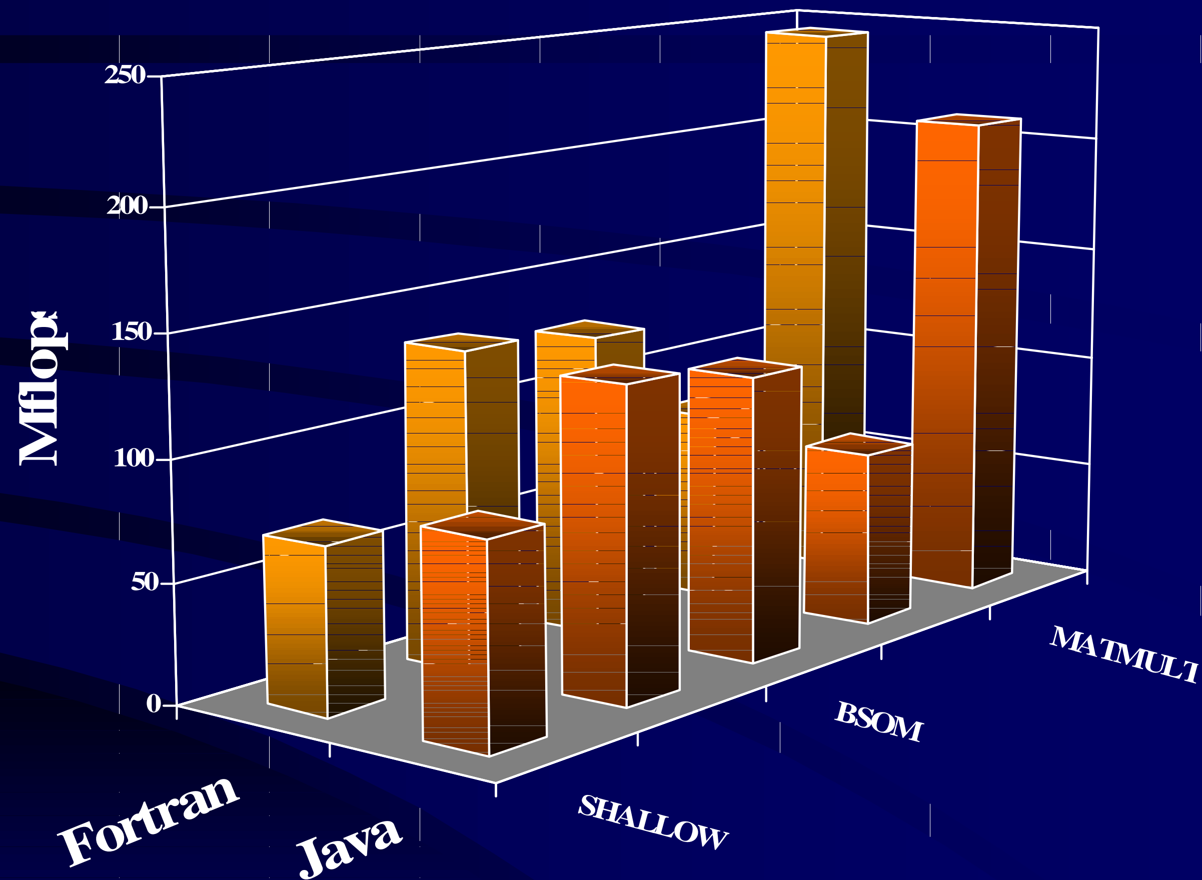
# Another approach...

- Use an aggressive optimizing compiler
- code using Array classes which mimic Fortran storage
  - e.g. A[i][j] becomes A.get(i,j)
  - ugly, but can be fixed with operator overloading extensions
- “cheat” a little to exploit hardware (FMAs)
- result: 80+% of Fortran on RS/6000

# IBM High Performance Compiler

- Snir, Moreria, et. al
- native compiler (.java -> .exe)
- requires source code
- can’t embed in browser, but…
- produces very fast codes

# Java vs. Fortran Performance




*IBM RS/6000 67MHz POWER2 (266 Mflops peak) AIX Fortran, HPJC

# Conclusions

- Java numerics can be competitive with C
  - 50% “rule of thumb” for many instances
  - can achieve efficiency of optimized C/Fortran
- best Java performance on commodity platforms
- new compiling and execution environments are further improving these numbers.

# Java Resources for Scientific Computing

- Java Numerics Group
  - http://math.nist.gov/javanumerics
    - Java Grande Forum
      - http://www.javagrade.org
    - SciMark Benchmark
      - http://math.nist.gov/scimark