Is
Code Optimization
Research Relevant?

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Motivation

- A Polemic by Rob Pike
- Proebsting's Law
- Some of my own musings

Systems Software Research is Irrelevant

- A Polemic by Rob Pike
- An interesting read
- I'm not going to try to repeat it
  - get it yourself and read

Proebsting's Law

- Moore's law
  - chip density doubles every 18 months
  - often reflected in CPU power doubling every 18 months
- Proebsting's Law
  - compiler technology doubles CPU power every 18 years

Todd's justification

- Difference between optimizing and non-optimizing compiler about 4x.
- Assume compiler technology represents 36 years of progress
  - compiler technology doubles CPU power every 18 years
  - less than 4% a year

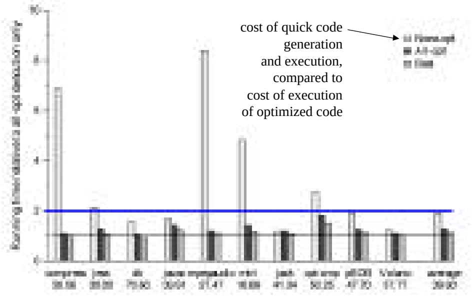
Let's check Todd's numbers

- Benefits from compiler optimization
- Very few cases with more than a factor of 2 difference
- 1.2 to 1.5 not uncommon
  - gcc ratio tends to be low
    - because unoptimized version is still pretty good
- Some exceptions
  - Matrix matrix multiplication

Jalepeño comparison

- Jalepeño has two compilers
  - quick compiler
    - designed to generate code as quickly as possible
  - optimizing compiler
    - aggressive optimizing compiler
- Use result from another paper
  - compare cost to compile and execute using quick compiler
  - vs. execution time only using opt. compiler

Results (from Arnold et al., 2000)



Benefits from optimization

- 4x is a reasonable estimate, perhaps generous
- 36 years is arbitrary, designed to get the magic 18 years
- where will we be 18 years from now?

18 years from now

- If we pull a Pentium III out of the deep freeze, apply our future compiler technology to SPECINT2000, and get an additional 2x speed improvement
  - I will be impressed/amazed

Irrelevant is OK

- Some of my best friends work on structural complexity theory

- But if we want to be more relevant,
  - what, if anything, should we be doing differently?

Code optimization is relevant

- Nobody is going to turn off their optimization and discard a factor of 2x
  - unless they don’t trust their optimizer
- But we already have code optimization
  - How much better can we make it?
  - A lot of us teach compilers from a 15 year old textbook
  - What can further research contribute?

Importance of Performance

- In many situations,
  - time to market
  - reliability
  - safety
- are much more important than 5-15% performance gains

Code optimization can help

- Human reality is, people tweak their code for performance
  - get that extra 5-15%
  - result is often hard to understand and maintain
  - “manual optimization” may even introduce errors
- Or use C or C++ rather than Java

Optimization of high level code

- Remove performance penalty for
  - using higher level constructs
  - safety checks (e.g., array bounds checks)
  - writing clean, simple code
    - no benefit to applying loop unrolling by hand
  - Encourage ADT’s that are as efficient as primitive types
- Benefit: cleaner, higher level code gets written

How would we know?

- Many benchmark programs
  - have been hand-tuned to near death
  - use such bad programming I wouldn’t allow undergraduates to see them
  - have been converted from Fortran
    - or written by people with a Fortran mindset

An example

- In work with a student, generated C++ code to perform sparse matrix computations
  - assumed the C++ compiler would optimize it well
  - Dec C++ compiler passed
  - GCC and Sun compiler failed horribly
    - factor of 3x slowdown
  - nothing fancy; gcc was just brain dead

We need high level benchmarks

- Benchmarks should be code that is
  - easy to understand
  - easy to reuse, composed from libraries
  - as close as possible to how you would describe the algorithm
- Languages should have performance requirements
  - e.g., tail recursion is efficient

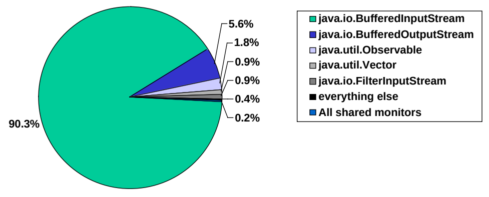
An Example

- In Java, synchronization on thread local objects is “useless”
- Allows classes to be designed to be thread safe
  - without regard to their use
- Lots of recent papers on removing “useless” synchronization
  - how much can it help

Cost of Synchronization

- Few good public multithreaded benchmarks
- Volano Benchmark
  - Most widely used server benchmark
  - Multithreaded chat room server
  - Client performs 4.8M synchronizations
    - 8K useful (0.2%)
  - Server 43M synchronizations
    - 1.7M useful (4%)

Synchronization in VolanoMark Client



7,684 synchronizations on shared monitors
4,828,130 thread local synchronizations

Cost of Synchronization in VolanoMark

- Removed synchronization of
  - java.io.BufferedInputStream
  - java.io.BufferedOutputStream
- Performance (2 processor Ultra 60)
  - HotSpot (1.3 beta)
    - Original: 4788
    - Altered: 4923 (+3%)
  - Exact VM (1.2.2)
    - Original: 6649
    - Altered: 6874 (+3%)

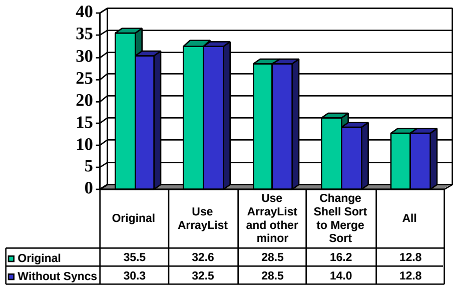
Some observations

- Not a big win (3%)
- Which JVM used more of an issue
  - Exact JVM does a better job of interfacing with Solaris networking libraries
- Library design is important
  - BufferedInputStream should never have been designed as a synchronized class

Cost of Synchronization in SpecJVM DB Benchmark

- Program in the Spec JVM benchmark
- Does lots of synchronization
  - > 53,000,000 syncs
    - 99.9% comes from use of Vector
  - Benchmark is single threaded, all of it is useless
- Tried
  - Remove synchronizations
  - Switching to ArrayList
  - Improving the algorithm

Execution Time of Spec JVM _209_db, Hotspot Server



	Original	Use ArrayList	Use ArrayList and other minor	Change Shell Sort to Merge Sort	All
🟩 Original	35.5	32.6	28.5	16.2	12.8
🟦 Without Syncs	30.3	32.5	28.5	14.0	12.8

Lessons

- Synchronization cost can be substantial
  - 10-20% for DB benchmark
  - recoding or better compiler opts would help
- But the real problem was the algorithm
  - Cost of stupidity higher than cost of synchronization
  - Used built-in merge sort rather than hand-coded shell sort

Small Research Idea

- Develop a tools that analyzes a program
  - Searches for quadratic sorting algorithms
- Don't try to automatically update algorithm, or guarantee 100% accuracy
- Lots of stories about programs that contained a quadratic sort
  - not noticed until it was run on large inputs

Need Performance Tools

- gprof is pretty bad
- quantify and similar tools are better
  - still hard to isolate performance problems
  - particularly in libraries

Java Performance

- Non-graphical Java applications are pretty fast
- Swing performance is poor to fair
  - compiler optimizations aren't going to help
  - What needs to be changed?
    - Do we need to junk Swing and use a different API, or redesign the implementation
  - How can tools help?

The cost of errors

- The cost incurred by buffer overruns
  - crashes and attacks
- is far greater than the cost of even naïve bounds checks
- Others
  - general crashes, freezes, blue screen of death
  - viruses

OK, what should we do?

- A lot of steps have already been taken:
  - Java is type-safe, has GC, does bounds checks, never forgets to release a lock
- But the lesson hasn't taken hold
  - C# allows unsafe code that does raw pointer smashing
    - so does Java through JNI
      - a transition mechanism only (I hope)

More to do

- Add whatever static checking we can
  - use generic polymorphism, rather than Java's generic containers

Data structure invariants

- Most useful kinds of invariants
- For example
  - this is a doubly linked list
  - n is the length of the list reachable from p
- Naïve checking is expensive
  - can we do efficiently?
  - good research problem

Data race detection

- Finding errors and performance bottlenecks in multithreaded programs is going to be a big issue
- Tools exist for dynamic data race detection
  - papers say 10-30x slowdown
  - commercial tools have a 100-9000x slowdown
  - lots of room for improvement

As if People Programmed

- A lot of this comes back to:
- Doing compiler research, as though programs were written by people
  - who are still around and care about getting their program written correctly and quickly
  - and who also care about the performance
    - are willing to fix/improve algorithms
  - would happily interact with compiler/tools
    - if it was useful

If you want to get it published

- Compile dusty benchmarks
  - run them on their one data set
- All programs are "correct"
  - any deviations from official output is unacceptable
  - DB benchmark uses unstable shell sort
    - can't replace it with stable merge sort
- No human involvement is allowed

Understandable

- Easy to measure the improvement a paper provides
  - what is the improvement in the SPECINT numbers?
- Much harder to objectively measure the things that matter

Consider

- A paper allows higher level constructs to be compiled efficiently
  - since they couldn’t be compiled efficiently before, no benchmarks use them
  - author provides his own benchmarks, show substantial improvement on benchmarks he wrote
  - one man’s high level construct is another’s contrived example

Human experiments ☹

- To determine if some tool can help people find performance bottlenecks more effectively
  - need to do human experiments
  - probably with students
    - what do these results say about professional programmers?
  - Very, very hard
    - Done in Software Eng.

Some things to think about

- Most of the SPECINT benchmarks are done
  - no new research is going to get enough additional performance out of SPECINT
  - to warrant folding it into an industrial strength compiler
  - unless you come up with something very simple to implement

Encourage use of high-level constructs

- Reduce performance penalty for good coding style
- Eliminate motivation and reward for low level programming
- Example problems:
  - remove implicit down casts performed by GJ
  - compile a MATLAB-like language

New ways to evaluate papers

- We need well-written benchmarks
- We need new ways to evaluate papers
  - that take programmers into account

The big question

- What are we doing that is going to change
  - the way people use/experience computers,
  - or the way people write software
- five, ten or twenty years down the road?

- Software is hard…
  - improving the way software is written is harder