Java or C++: Practical Advice You Can Use

Sergey Kuksenko, Aleksey Shipilev, Charlie Hunt

Java or C++: Practical Advice You Can Use

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Who are you?

- Charlie Hunt
  - Lead JVM Performance Engineer at Oracle
  - Lead author of Java Performance book (just published!)
- Sergey Kuksenko
  - JVM Performance Engineer at Oracle
- Aleksey Shipilev
  - JVM Performance Engineer at Oracle

Program Agenda

What to Expect

Making a Choice (Things to Remember)

Dynamic and Static Compilation Differences

Memory Management Differences

Concurrency Differences

Conclusion

What to Expect

- This is *neither* a session loaded with claims that Java is *always* better, faster, stronger, *nor* a session filled with C++ bashing!
  - Yes, you can go now :)
- We hope that at the end of this session, you can make an informed decision when asked to choose Java or C++ for your application.
- With this session, we would like to offer some practical advice to those who are faced with such a question.

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Making a Choice

Where to Start

- Put on your architect “hat”
- Focus on the “...ilities” for the application
  - “...ilities” are non-functional requirements
  - Security, reliability, manageability, portability, scalability, performance, etc
  - Ask all stakeholders to rank them in order of importance
  - Do not forget about other “business” pressures
    - “time to market”, “TCO”, “ROI”, etc.
- We will focus more on scalability and performance

Making a Choice

Other considerations

- The “human factor”
- Suppose a Java application
  - A team of expert Java developers will achieve better results than a team of expert C++ developers on Java almost all the time.
- Suppose a C++ application
  - A team of expert C++ developers will achieve better results than a team of expert Java developers on C++ almost all the time.

Making a Choice

Java versus C++

- Trichotomy Principle
  - For an application under consideration, a given language attribute may be
    - + more attractive
    - – less attractive
    - ≈ it does not matter
- Freedom Principle
  - C++ offers developers “anything”, but language complexity comes with it
  - Java induces more “limits” on developers, but a less complex language

Making a Choice

Tied together with “business factors”

- Java generally offers a larger set of reusable components, i.e. 3rd party libraries (free and commercial)
  - Especially true for areas such as security and logging
  - Many reusable components are implementations of a Java standard
- C++ has reusable libraries (free and commercial)
  - But, there does not appear to be agreement on how to best implement them, lack of standardization
  - Reusability and security? Java is generally better.

Making a Choice

Portability

- Java claims: “Write once, run anywhere”
  - Reality: “Write once, run where JVM is available”
  - Java portability easier to realize if platform has a JVM
- C++ claims: “Write once, compile anywhere”
  - Reality: “Write according to C++ standard(s), compile it, if it fails to compile, refactor/port/re-write it, and compile again”
  - C++, same OS, different compiler… generally portable to more platforms

Making a Choice

Scalability

- Multicore platforms are common place now
  - Developing correct, fast, and scalable applications is... well, let's face it, it's not trivial!
- Much harder to write scalable and multi-threaded applications
- More on this later

Making a Choice

Performance

- Nearly all “Java vs C++” battles waged in performance
- But, there’s many aspects of performance (next slide)
- Beware of claims made in “Java vs C++” wars
  - Don’t trust performance myths, rumors and urban legends
  - Don’t trust cross-language benchmarks
- *Do* take time to understand and reason why differences exist
- Ask questions if suspicious

Making a Choice

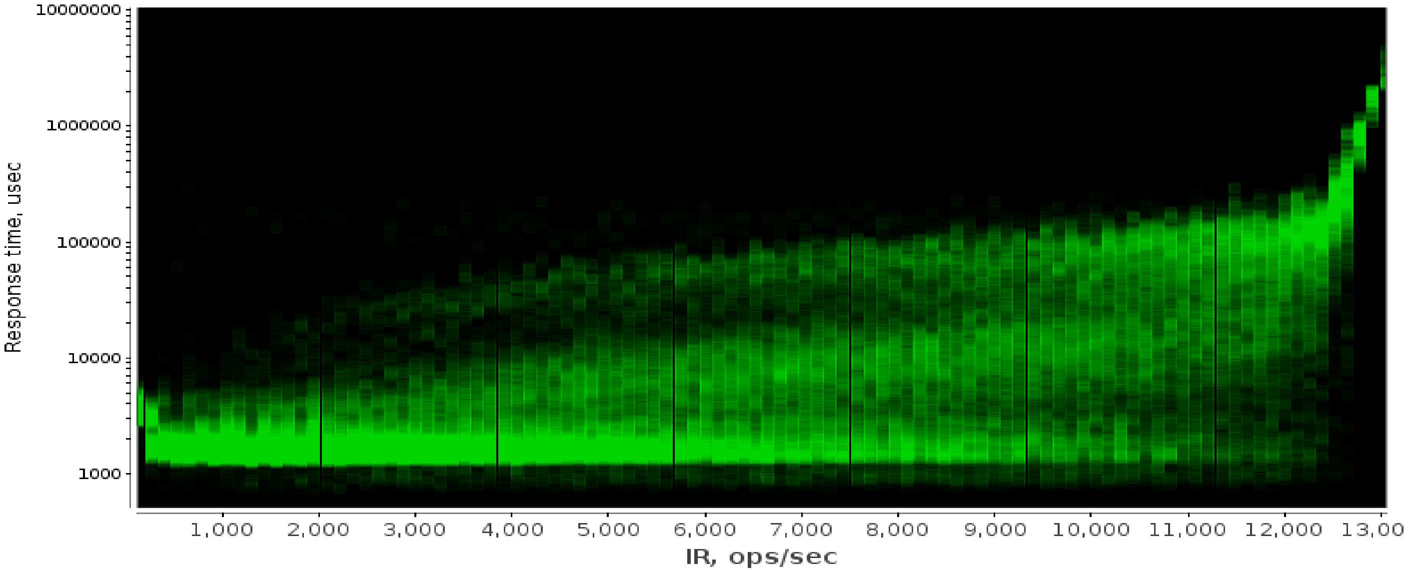
Performance Aspects

- **Throughput**, “How much work done per some period of time?”
- **Latency**, “How long it takes to respond to some stimulus?”
- **Footprint**, “How much memory does it consume?”
- **Startup time**, “How long does it take the application to initialize?”
- **Time to performance**, “How long does it take until the application hits peak performance?”
- **Predictability**, “How much jitter in all of the above?”

Making a Choice

Performance Aspects

- Throughput versus latency



Making a Choice

Common Java vs C++ mistakes

- Claim

  "Java has a big runtime (JIT, GC, classloaders) that is why Java will lose at all performance aspects"

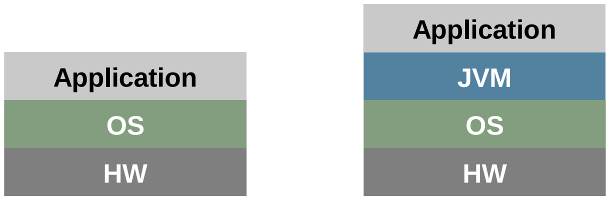
- Reality

  "Java has a big runtime (JIT, GC, classloaders) that is why Java may lose (or may win) at some performance aspects"

Making a Choice

Common Java vs C++ mistakes

C++ stack Java stack

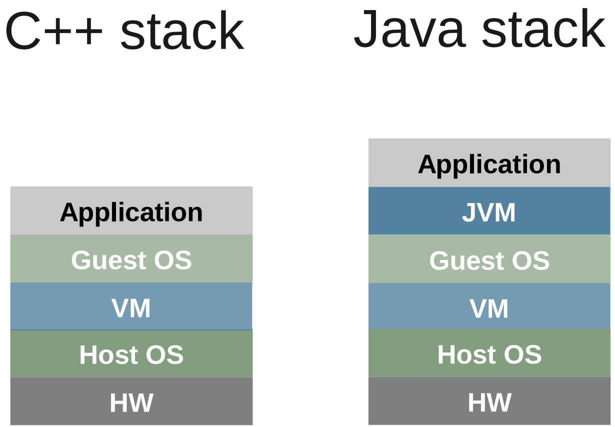


Does one extra layer affect performance?

- Nearly all performance degradation claims about JVM miss the fact hardware and operating system can also impact performance (and predictability)
- Real Story: C++ application migrated to more recent Linux kernel
  - Observed huge performance regression
  - Root cause: thread starvation due to change in default CPU scheduler

Making a Choice

Common Java vs C++ mistakes



In reality,
there are more layers!

- Could changes in host OS, VM, guest OS impact application performance?
- Note, update to a more recent JVM is subject to performance changes too
- Also realize a change to more recent hardware could also impact performance

Program Agenda

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Dynamic and Static Compilation Differences

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Dynamic and Static Compilation Differences

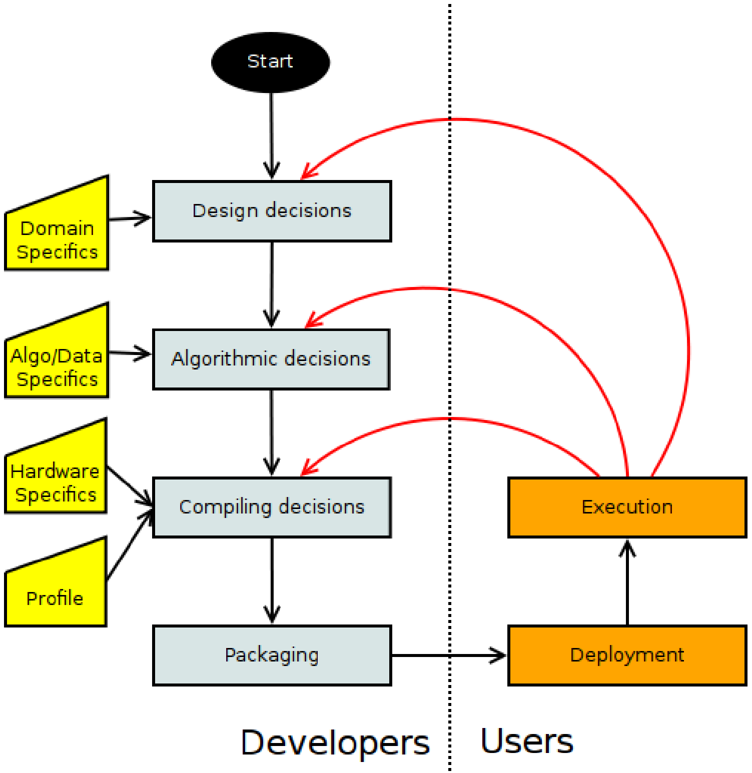
Bird-Eye Difference

- Modern C++ compilers are *static*
  - Source code → Native object code → Native executable
  - Most of compilation work happens before executing
  - “ahead-of-time” compilation
- Modern Java VMs use *dynamic* compilers
  - Source code → Bytecode → JITted code → Interpreter + JITted executable
  - Most of compilation work happens during executing
  - “just-in-time” (JIT) compilation

Dynamic and Static Compilation Differences

Static Compilation

- Static Compilation (C++ alike)
  - Has knowledge about all constructs in the program during compilation
  - Once compiled, there's no re-optimization unless the program is shut down, recompiled, and restarted
  - Execution of a code path usually takes the same execution time
  - Does not require code paths to be executed before compiling them



Dynamic and Static Compilation Differences

Static Compilation

- Most people argue that...

Static compilation has theoretically unlimited compilation time.

↓

Static compiler can do more sophisticated optimizations.

↓

Statically compiled code is always faster.

- Which consequence is really true?

Dynamic and Static Compilation Differences

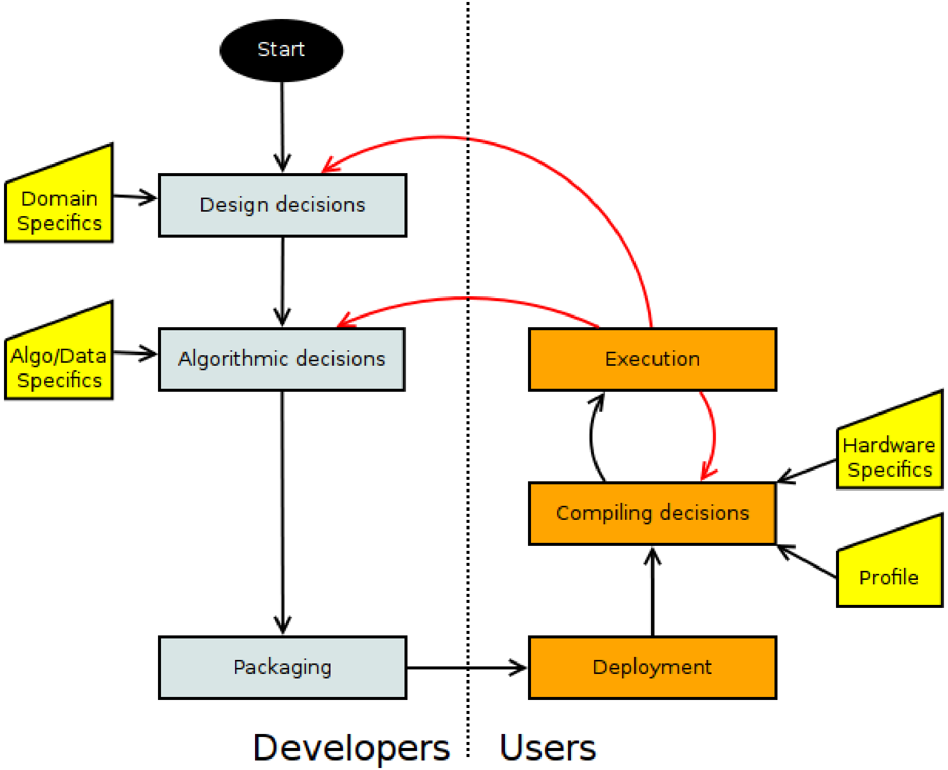
Dynamic Compilation

- Dynamic Compilation (JIT)
  - Has knowledge of the classes loaded and methods the program has executed
  - Makes optimization decisions based on code paths executed
    - Code generation depends on what is observed: classes that have been loaded, code paths executed, branches taken
  - May re-optimize if assumption was wrong, or alternative code paths taken
    - Instruction path length may change between invocations of methods as a result of de-optimization / re-compilation

Dynamic and Static Compilation Differences

Dynamic Compilation

- Can do non-conservative optimizations in dynamic
- Separates optimization from *product delivery* cycle
  - Update JVM, run the same application, realize improved performance!
  - Can be "tuned" to the target platform



Dynamic and Static Compilation Differences

Profile-guided optimization

- PGO = using profile for more efficient optimization
- Frequently advertised as unique Java feature
- ...but all modern C++ compilers also have it
  - Microsoft claims MSVC PGO gives +10% - +30% better performance
  - GCC claims +20% on average
  - Oracle Solaris Studio: +15% on more “integer” code, little gain on “floating”
- What kind of performance? (throughput? latency?)

Dynamic and Static Compilation Differences

Profile-guided optimization

- PGO in static compilers
  - Developers should care about it
  - Profiles should be collected before the final compilation and should cover ALL typical usage scenarios
  - Inconsistent profiled usage scenario may lead to performance degradation in the most common use case

Dynamic and Static Compilation Differences

Profile-guided optimization

- PGO in JVMs
  - Always have it, turned on by default
  - Developers (usually) not interested or concerned about it
  - Profile is always consistent to execution scenario

Dynamic and Static Compilation Differences

Inlining and devirtualization

- Inlining is the most profitable compiler optimization
  - Rather straightforward to implement
  - Huge benefits: expands the scope for other optimizations
- OOP needs polymorphism, that implies virtual calls
  - Prevents naïve inlining
  - Devirtualization is required
  - (This does not mean you should not write OOP code)

Dynamic and Static Compilation Differences

Inlining and devirtualization

- C++ inlining
  - “inline” keyword is just a hint, compiler itself decides what can be inlined
- C++ devirtualization
  - Manually controlled by developer
    - Developers should care at design stage, trading off extensibility for performance: should library method be *virtual,* or not? *final*, or not?
    - Often premature optimization
  - Can be done by compiler
    - Requires whole program analysis
    - May be broken by low-level code

Dynamic and Static Compilation Differences

Inlining and devirtualization

- JVM devirtualization
  - Developers shouldn't care
  - Analyze hierarchy of currently loaded classes
  - Efficiently devirtualize **all** monomorphic calls
  - Able to devirtualize polymorphic calls

Dynamic and Static Compilation Differences

Inlining and devirtualization

- JVM may inline dynamic methods!
  - Reflection calls
  - Runtime-synthesized methods
    - JSR 292
- Can you do the same in C++?

Dynamic and Static Compilation Differences

Inlining and devirtualization

- JVM may inline dynamic methods!
  - Reflection calls
  - Runtime-synthesized methods
    - JSR 292
- Can you do the same in C++?
  - You can, if you have a compiler, and not afraid to patch object code.
  - (Assuming you will not resort to Lua, etc.)

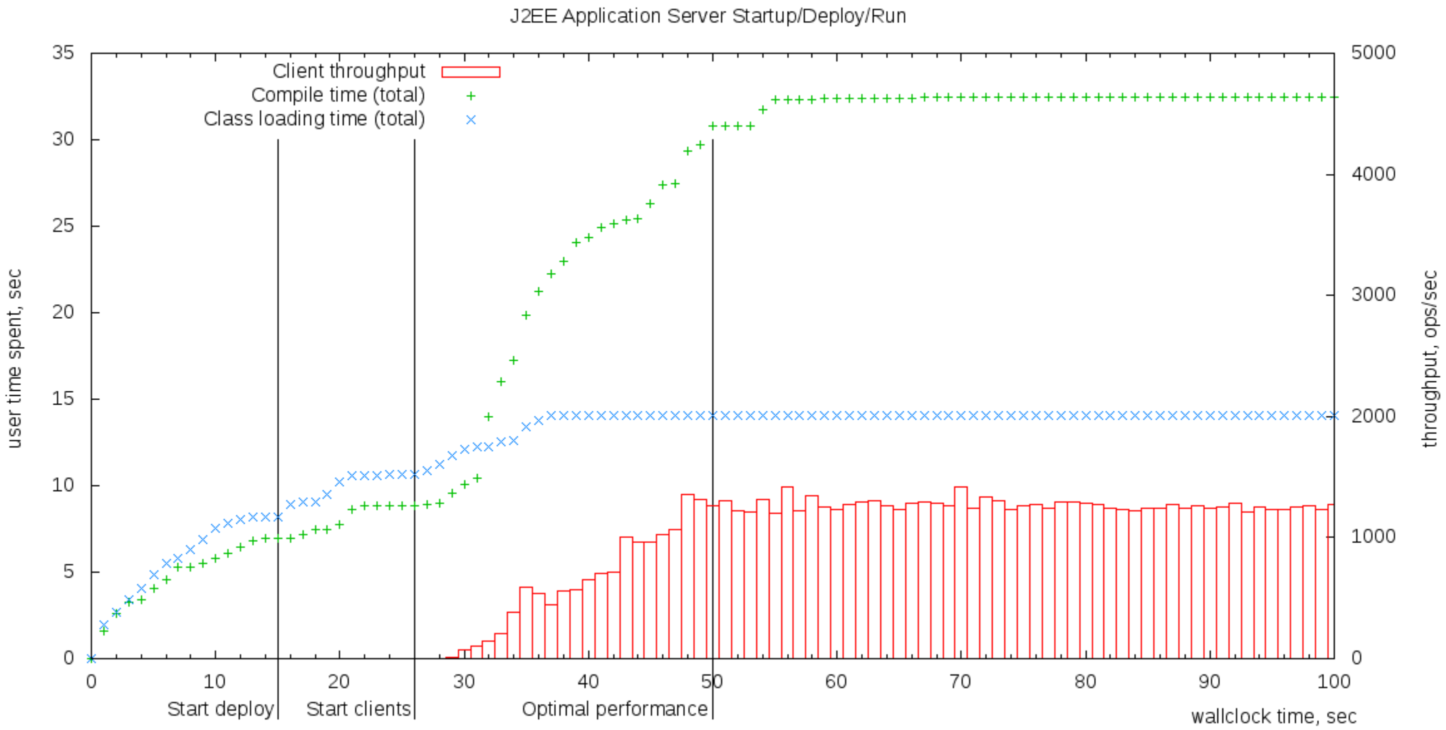
Dynamic and Static Compilation Differences

Dynamic compilation overhead

- Is dynamic compilation overhead essential?
  - The longer your application runs, the less the overhead
- Trading off compilation time, not application time
  - Steal some cycles very early in execution
  - Done automagically and transparently to application
- Most of “perceived” overhead is compiler waiting for more data
  - ...thus running semi-optimal code for time being

Dynamic and Static Compilation Differences

Dynamic compilation overhead



Dynamic and Static Compilation Differences

General Advice

- Look at what's needed for the application
  - Rapid startup? Must it run at peak performance immediately?
  - Is predictable throughput required, (varies little run-to-run)?
  - What about pause time requirements?
  - Are there branches in the hot code path that are considered “exceptional” branches?
  - Are there implementations of interfaces or virtual methods which are expected to never, or rarely, be taken?
  - Time to market? (programmer productivity and memory management, maintenance)

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Memory Management Differences

- The largest battlefield in Java vs C++ wars
- Java:
  - Automatic dynamic memory management (garbage collection)
- C++:
  - Stack-based memory management (RAII)
  - Explicit dynamic memory management (new/delete, malloc/free)

Memory Management Differences

C++ RAII

- RAII – Resource Acquisition Is Initialization
  - Scope-based resource allocation/deallocation
  - Very good for heavy resources (file handles, etc)
    - Java analogue: try/finally, AutoCloseable (Java7)

- Is RAII good for memory?

Memory Management Differences

C++ RAII

- Stack-based memory allocation advantages:
  - Allocation/deallocation has marginal cost
  - Very good data locality
  - Very good thread locality
  - Allocation is cache-friendly

Memory Management Differences

C++ RAII

- Stack-based memory allocation caveats:
  - Buffer overrun is a top security bug for many years:
    - “CWE/SANS TOP 25 Most Dangerous Software Errors”, 2011
    - http://www.sans.org/top25-software-errors/
  - Without qualitative development, leads to more data copying than heap-based allocation (negates performance)
  - May require larger stack sizes
    - Running with lots of threads is hard

Memory Management Differences

Explicit memory management (C++)

- Common myths:
  - New/delete (malloc/free) have zero performance cost
  - Memory footprint is minimal (the same as required to the application)
  - No pauses
  - Manual memory management is always scalable
- Did you forget about memory allocator?
- What memory allocator is used in your application?
  - default (which one?), ptmalloc, dlmalloc, hoard, jemalloc, tcmalloc, custom, etc...

Memory Management Differences

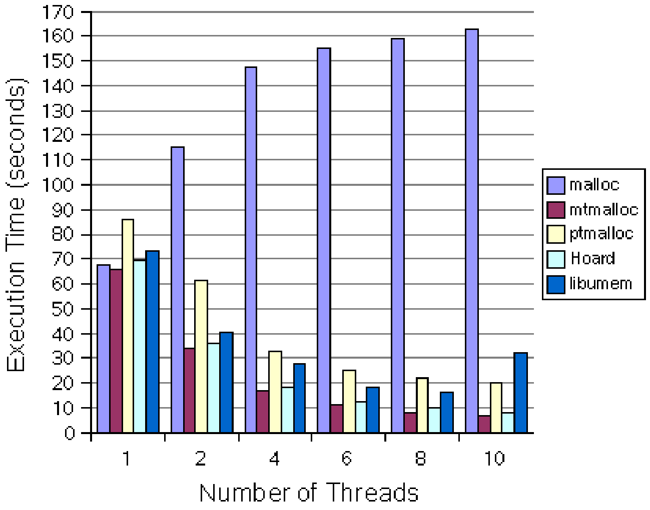
Explicit memory management (C++)

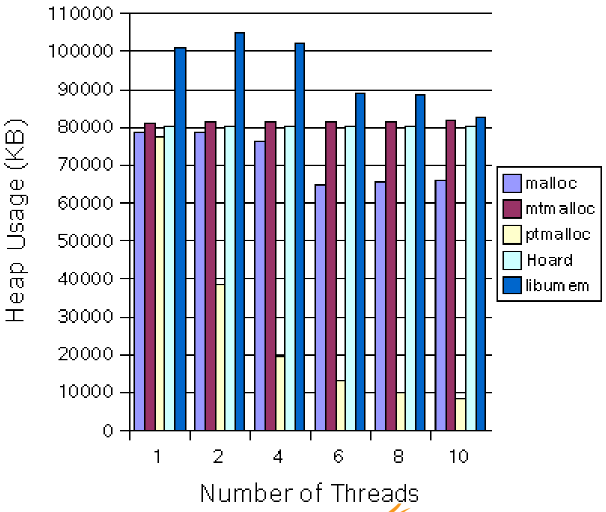
- Many articles challenge these mythes
  - David Detlefs , Al Dosser , Benjamin Zorn, "Memory allocation costs in large C and C++ programs", Software—Practice & Experience, v.24 n.6, p.527-542, June 1994.
  - Analyzed 11 applications and 4 allocators:
    - Program execution time varies by **20%**
    - Max memory footprint varies by **25%**

Memory Management Differences

Explicit memory management (C++)

- Joseph Attardi, Neelakanth Nadgir, "A Comparison of Memory Allocators in Multiprocessors", June 2003
  - http://developers.sun.com/solaris/articles/multiproc/multiproc.html





Memory Management Differences

Explicit memory management (C++)

- “How to avoid pauses in their entirety?”
- If you google it, most of the answers are in form:

Allocate all required memory
at application initialization

Memory Management Differences

Explicit memory management (C++)

- Issues:
  - Heap fragmentation
  - Scalability:
    - Heap contention
    - False sharing
  - Some concurrent lock-free algorithms may be implemented only with GC
  - NUMA
- All these issues are solvable (at what cost?)

Memory Management Differences

Garbage Collection

- Easy to use
- May give better performance due to:
  - Really cheap and thread local allocation (by default in HotSpot and other JVMs)
  - When the application satisfies the generational hypothesis
  - Improve data locality
  - -XX:+UseNUMA
  - -XX:+CompressedOops
  - -XX:+LargePages (just turn on)

Memory Management Differences

Garbage Collection

- Matthew Hertz , Emery D. Berger,
  "Quantifying the performance of garbage collection vs. explicit memory management"
  - "GC is almost always faster as explicit memory management, but requires larger amount of RAM"
  - GC may require as much as 3x more RAM to operate efficiently

Memory Management Differences

Garbage Collection

- Works well for throughput
  - just set up enough heap size and turn on ParallelOld collector.
- Can be challenging for predictable low latency
  - Tune CMS or use G1 (don't forget – may sacrifice some throughput)
- Can be difficult for guaranteed / soft real time latency
  - JRockit Deterministic Garbage Collection
- Poor choice when minimal / very small memory footprint is required
  - Paging is killer for GC

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Concurrency Differences

Java

- Threads
  - Supported ever since
- Locks
  - Supported ever since
  - java.util.concurrent.locks.* since Java 5, circa 2004
- Memory Model
  - In place ever since
  - Correct since Java 5, circa 2004

Concurrency Differences

C++

- Threads
  - Before 2011, only libraries: Pthreads, Threads, Boost, Intel TBB
  - C++11: built-in support
- Locks
  - Before 2011, only libraries: Mutex, Boost locks, futex, etc
  - C++11: built-in mutexes
- Memory Model
  - Only in C++11: built-in memory model

Concurrency Differences

C++

- C++ is so flexible and powerful, that...
  - It's hard to write concurrent applications
  - It's hard to write *portable* concurrent applications
  - It's hard to write *efficient and* portable concurrent applications
- “Threads Cannot Be Implemented as a Library”, Hans-J. Boehm
  - No rules for memory ordering, i.e. no memory model
  - Compilers bail out on concurrency optimizations
  - (Primary motivation for built-in thread support in C++11)

Concurrency Differences

Java “unique features”

- Versatile concurrent lock-free primitives (j.u.c.*)
- Many j.u.c.* primitives support fairness
  - Otherwise impossible to fight starvation
- Thread pools
- Fork/Join framework
- Biased Locking
  - Impossible to do in unmanaged environments, e.g. C++

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Conclusion

Java or C++?

- It depends :-) … on what is most important to the application and its stakeholders
- Which is best for your application can be determined by prioritizing the "ilities" and other "business factors"
  - Ask all application stakeholders to prioritize
    - May likely have different priorities
    - Get agreement on which are most important

Conclusion

Java or C++?

- Evaluate and document the advantages and challenges of using each technology
  - Start with the highest priority first
  - Take into consideration various aspects, especially performance
  - Don't forget to include and evaluate "business factors”
  - Also consider that technologies evolve and what existing challenges may be addressed for a technology during the application's lifetime
  - Evaluation may require some quantification of the magnitude of the difference between the two technologies, i.e. peak throughput, predictability, memory footprint, time to market

Conclusion

Java or C++?

- The Decision?
  - Prioritization and evaluation of advantages & challenges will guide you to an informed decision as to the best choice for the application under consideration.

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