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Microservices: Single digit microseconds latency

Dmitry Pisklov

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Outline

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- Microservice application: architecture example
- What is latency and how can we measure it
- Reducing the latency

Intro: Who we are

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- Dmitry Pisklov
  - Developer @ Chronicle Software
- Chronicle Software founder – Peter Lawrey
  - Java Champion
  - Most answers for Java and JVM on StackOverflow.com

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0. Microservices: Architecture Example

0.0. Micro-services Architecture Example

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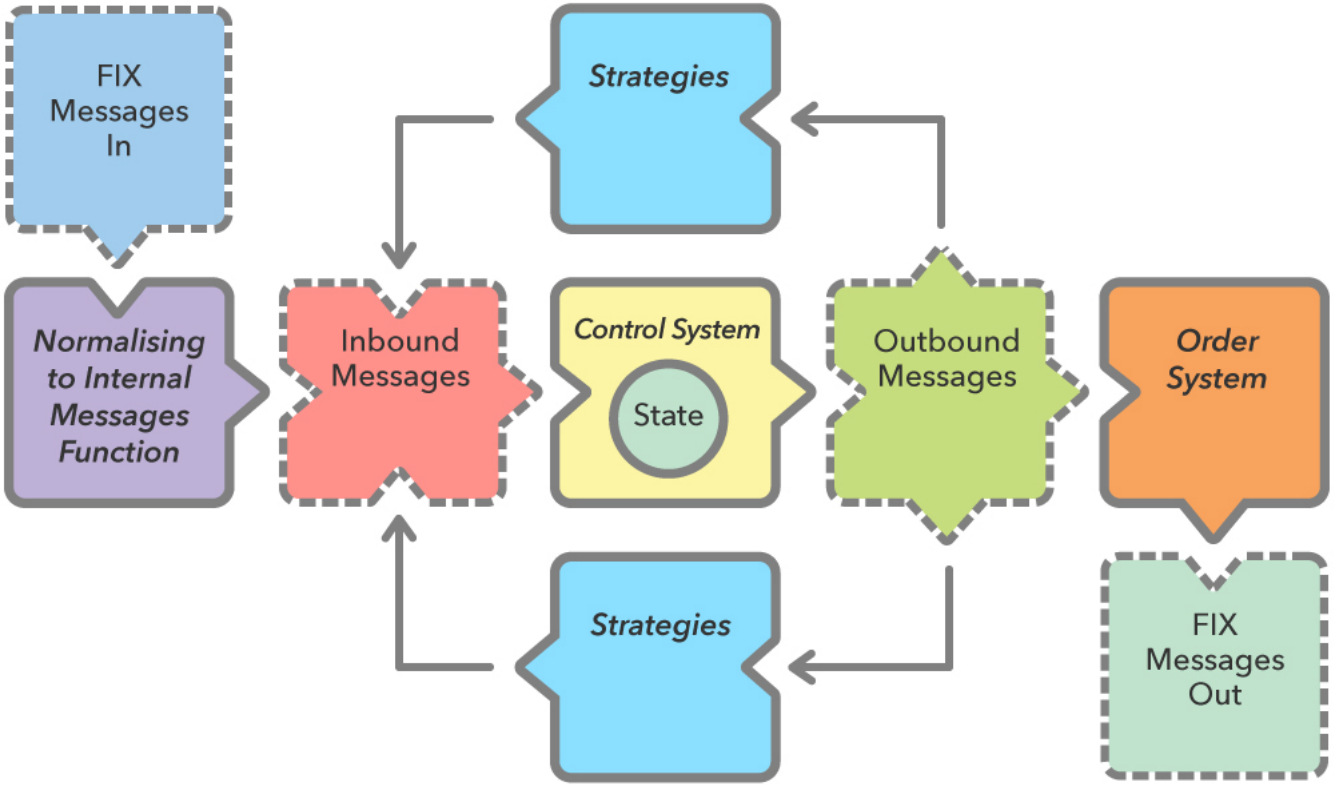

0.1. Micro-services Architecture Example

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0.2. Micro-services Architecture Example

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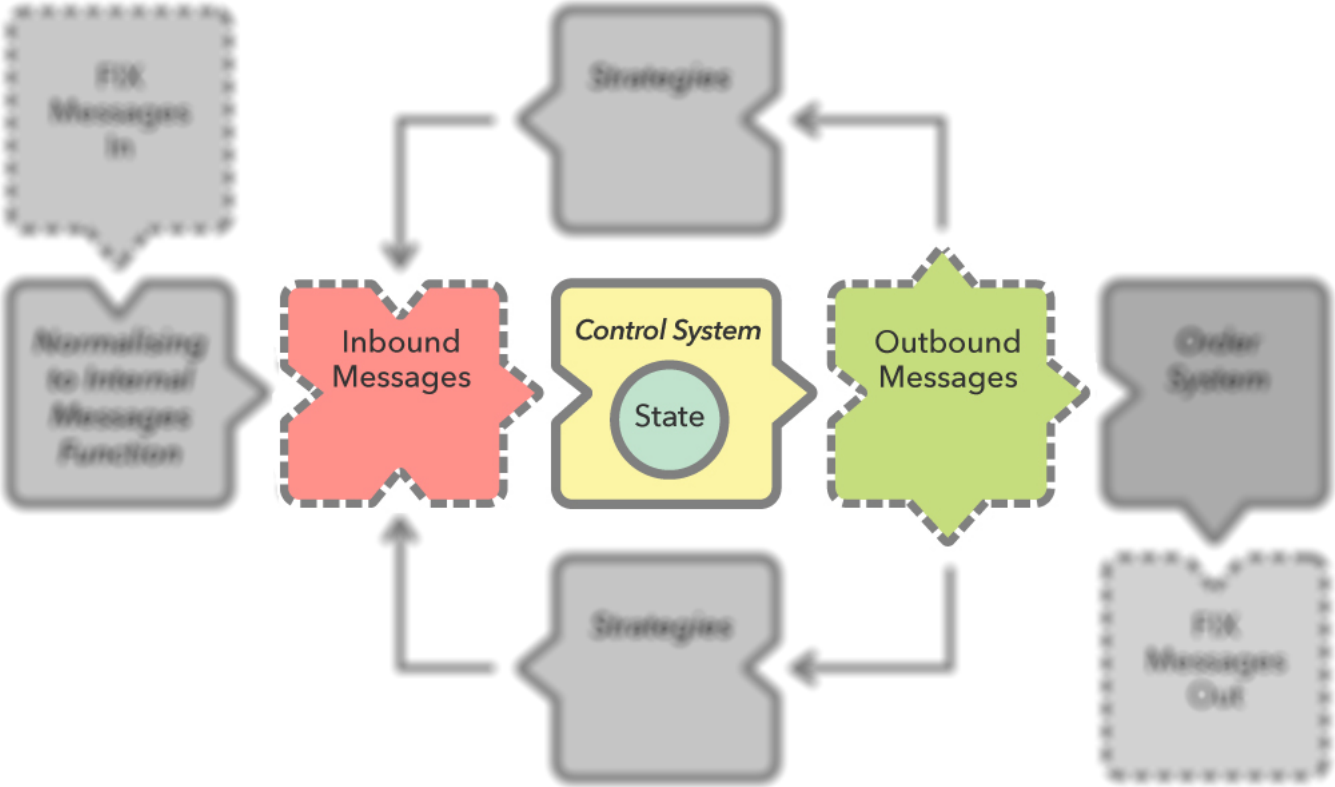

0.3. Micro-services Architecture Example

0.4. Micro-services Architecture Example

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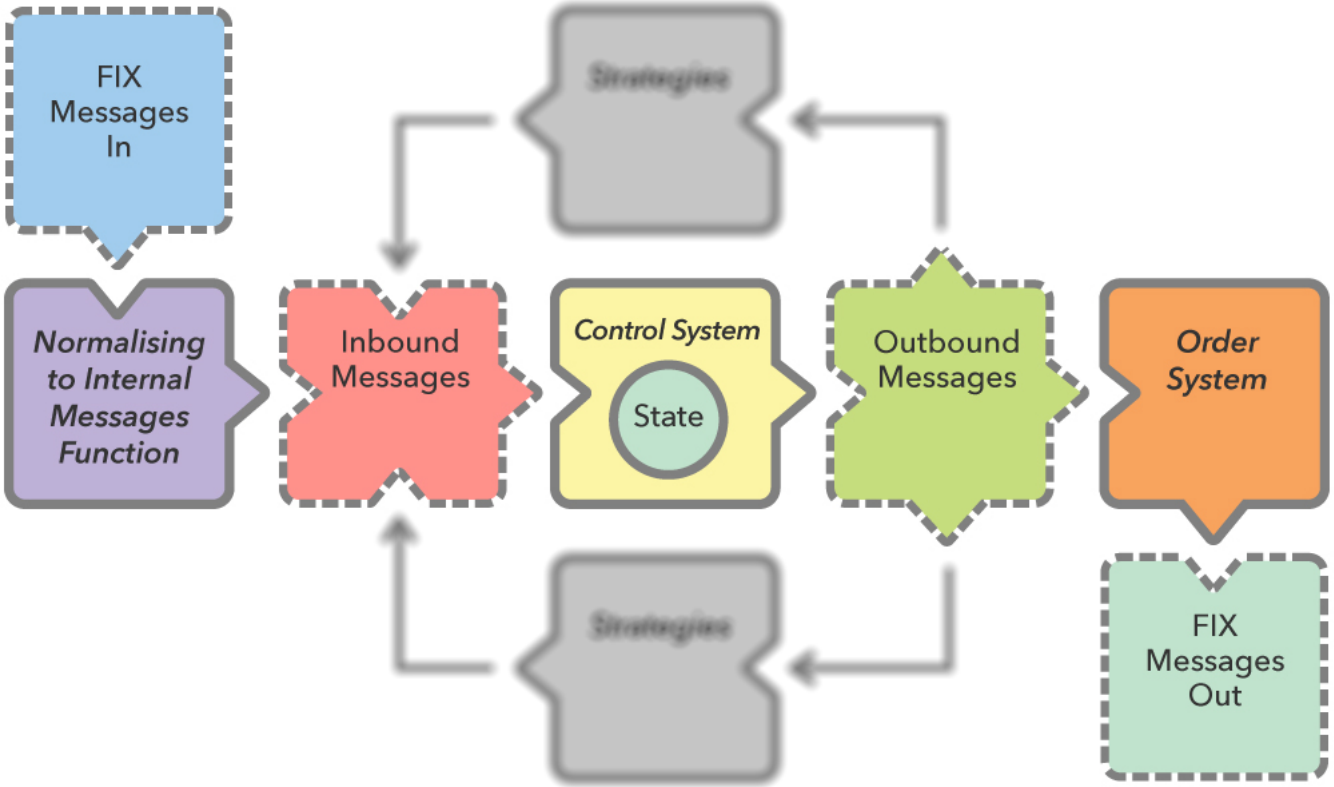

0.5. Micro-services Architecture Example

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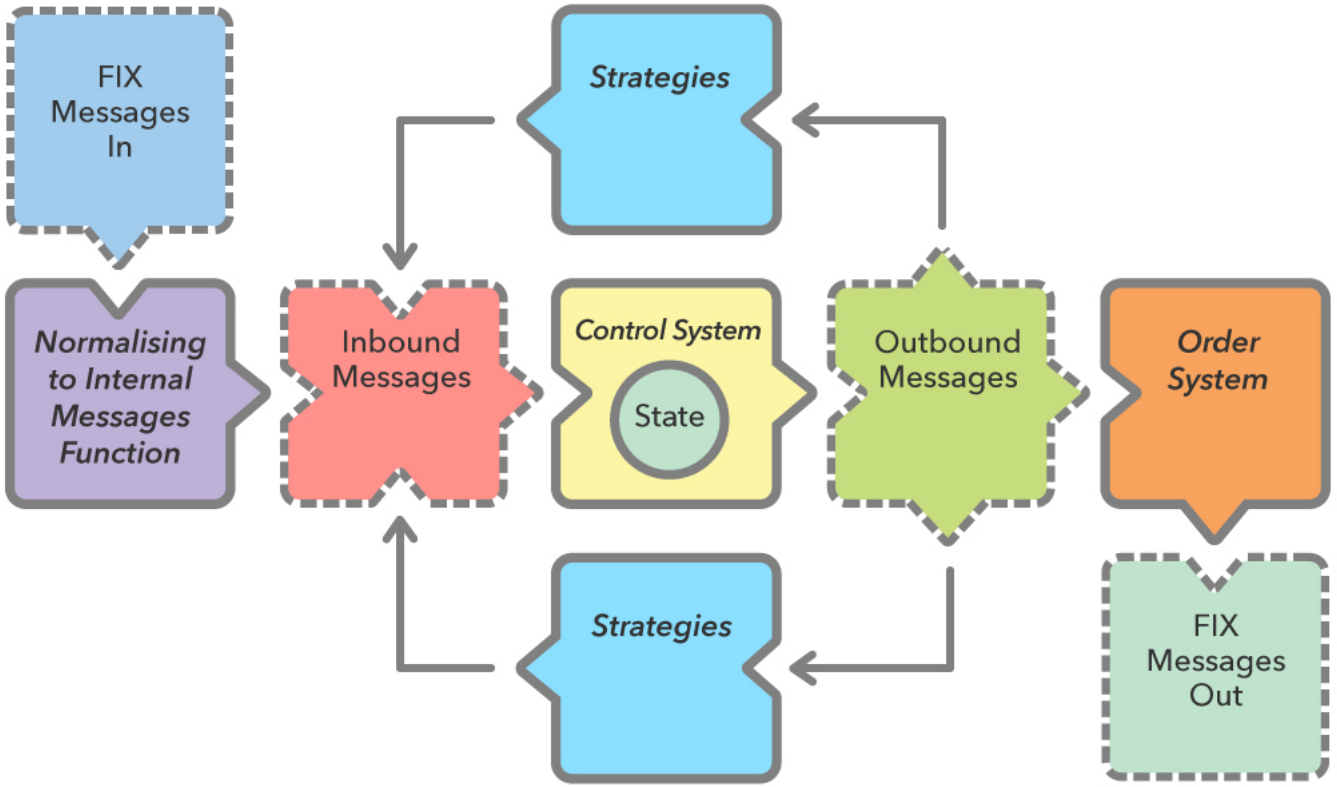
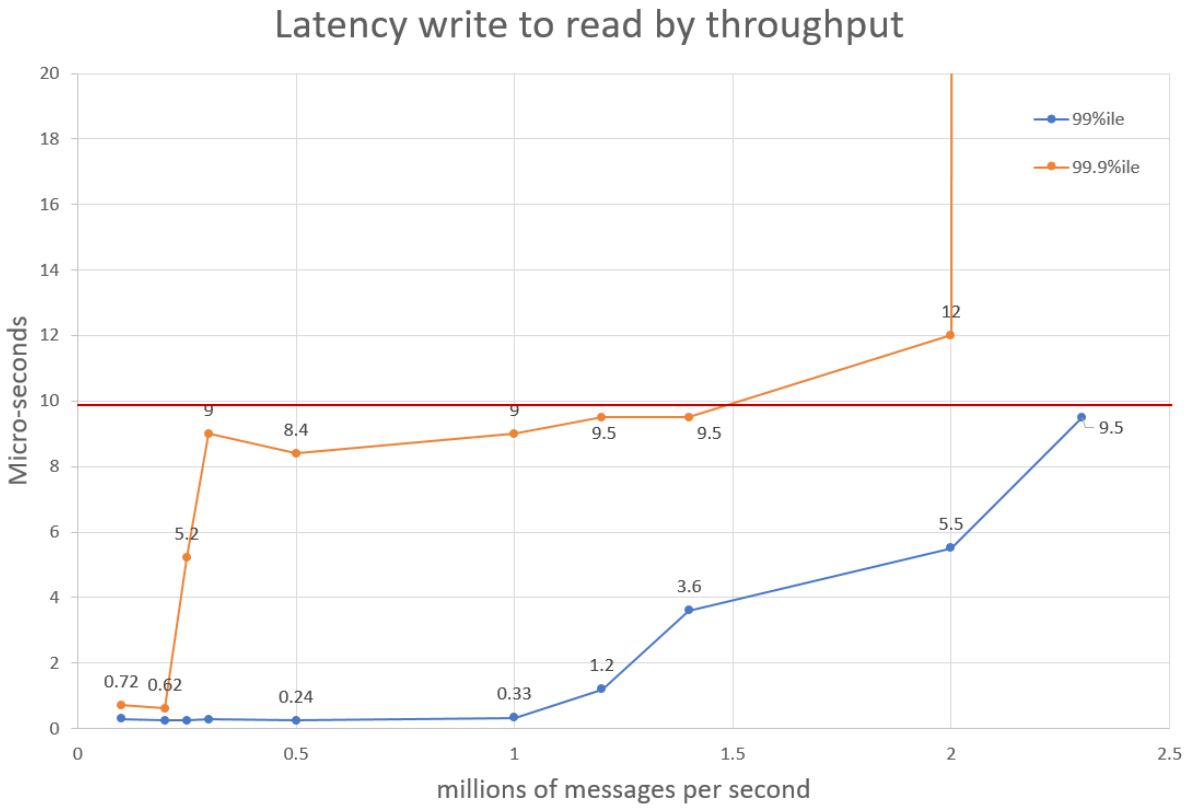


0.6. How fast is fast? Example measured



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1. Latency: what is it and how to measure latency?

1.0. Measuring latency

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- What is Latency?
- Latency in Microservices

1.0. Measuring latency

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- What is Latency?
- Latency in Microservices
  - Service response time
    - Marshaling time
    - Computation time

1.0. Measuring latency

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- What is Latency?
- Latency in Microservices
  - Service response time
    - Marshaling time
    - Computation time
  - IPC latency

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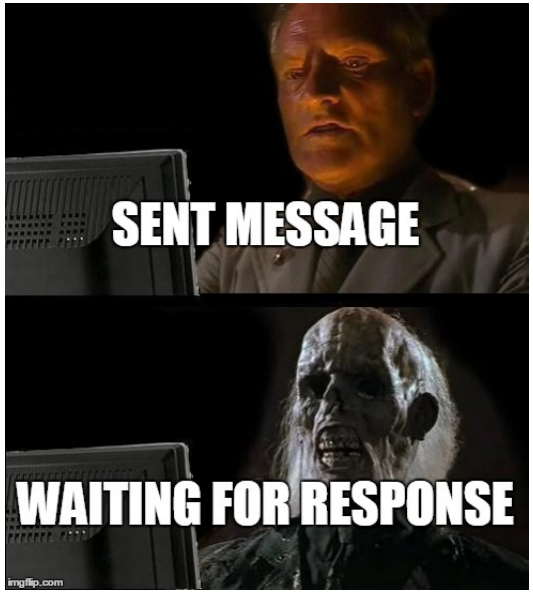
- Measuring latency – how?



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- JMH is for Micro-benchmarks
- JLBH – Java Latency Benchmark Harness
- Documentation and examples
  - GitHub - https://github.com/OpenHFT/Chronicle-Core#jlbh

1.2. JMH vs JLBH: why we use JLBH

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- Code running in context – full stack
- Variable throughput
  - For each throughput we can estimate max tail latency and provide SLAs
- Accounts for coordinated omission
- Various sampling points in the code

1.3. Measuring latency – JLBH example

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```
End to End: (1,000,000)                          50/90 99/99.9 99.99/99.999 - worst was 7.8 /
--------------------------------------------------------------------------------------------
-------------------------------- BENCHMARK RESULTS (RUN 5) ----------------------------------
Run time: 10.825s
Correcting for co-ordinated:false
Target throughput:100000/s = 1 message every 10us
End to End: (1,000,000)                          50/90 99/99.9 99.99/99.999 - worst was 7.5 /
--------------------------------------------------------------------------------------------
--------------------------------- SUMMARY (end to end)-----------------------------------------
Percentile   run1         run2         run3         run4         run5      % Variation
50:             7.99         7.53         7.22         7.83         7.49         5.32
90:          6047.74         8.62        10.05        10.20        93.15        86.73
99:         22994.94       747.78      2485.25      7362.56      8646.66        87.57
99.7:       31825.92      1956.35     44613.63     36126.72     14348.29        93.56
99.9:       41402.37      3245.06     64307.20     56115.20     18063.36        92.62
worst:      51265.54      8884.22    194576.38     77299.71     24698.88        93.30
--------------------------------------------------------------------------------------------
```

1.3. Measuring latency – JLBH example

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worst:      51265.54      8884.22    194576.38     77299.71     24698.88        93.30
--------------------------------------------------------------------------------------------
```

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- Community asks – we do!

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2. Fighting latency in Your Software

2.0. Use less code to achieve perfection

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“Perfection is achieved, not when there is nothing more to add, but when there is nothing left to take away.”

– Antoine de Saint-Exupéry

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- JVM only inlines smaller methods
  - `-XX:InlineSmallCode=`*`size`*
  - `-XX:MaxInlineSize=`*`size`*
- Large methods are not JIT-compiled
  - `-XX:-DontCompileHugeMethods`
  - `-XX:HugeMethodLimit=`*`size`*

2.2. Use specializations – with care

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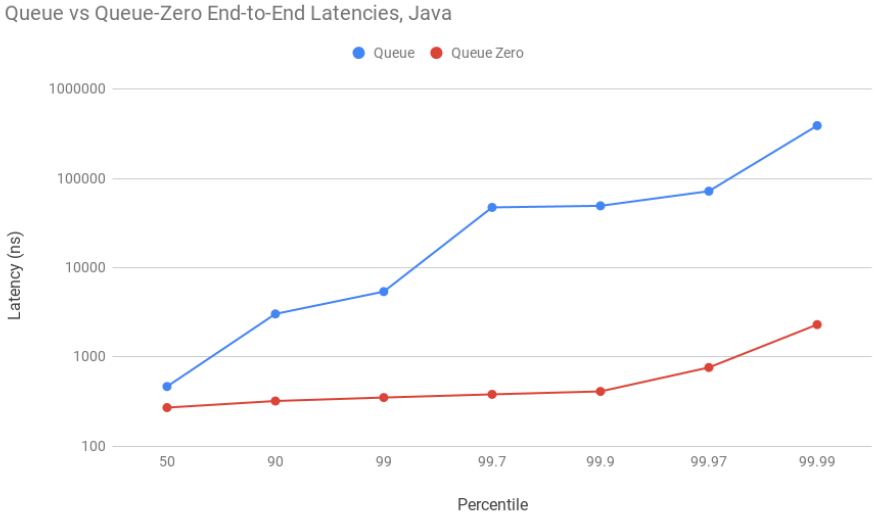
- Specialized code is faster
  - Less checks, less conditions, less data written
  - More limitations



2.3. Generate optimized code

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- Primitive specializations
- Generated efficient marshaling/unmarshaling code
- Koloboke collections by Roman Leventov – only generates actually used methods

2.4.0. Specialization example – Koloboke

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```
@KolobokeMap
public abstract class LongLongMap {

    public abstract void justPut(long key, long value);

    public abstract long get(long key);

    public abstract int size();

    public abstract boolean containsKey(long key);

    public abstract void clear();

    public abstract void forEach(LongLongConsume var1);

}
```

2.4.1. Specialization example – Koloboke

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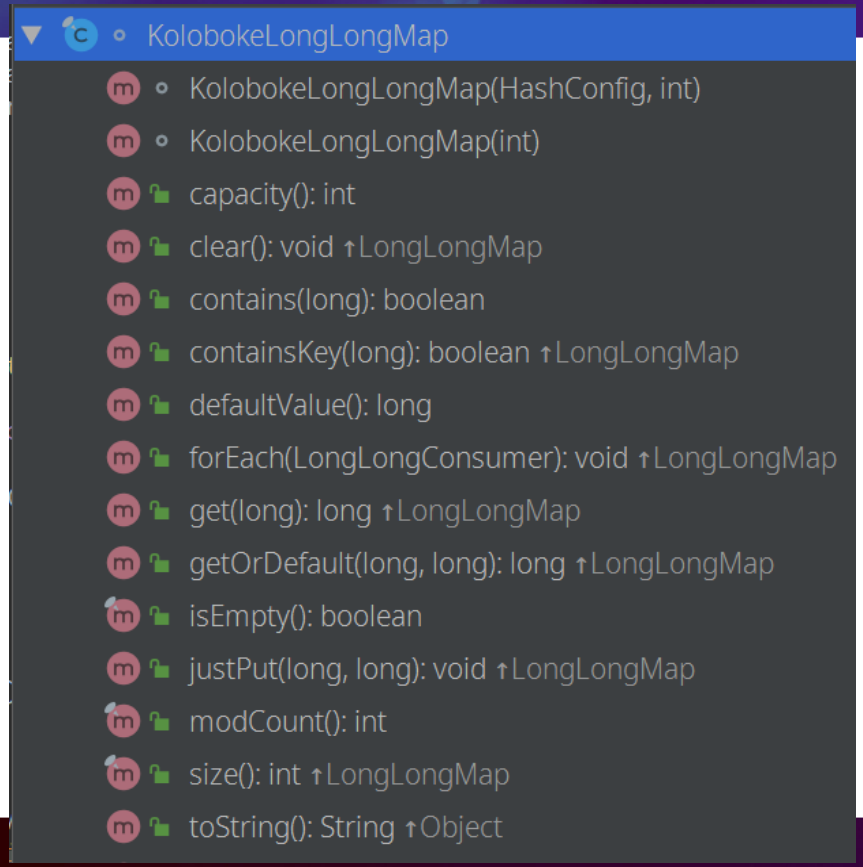

2.5. Multithreading? Forget it!

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- Threads are evil (for microservices)
  - Single-threaded application with event loop
    - Even faster on dedicated CPU

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  - Shared memory & CAS for synchronization – only when needed, avoid sharing data

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- Threads are evil (for microservices)
  - Single-threaded application with event loop
    - Even faster on dedicated CPU
  - Shared memory & CAS for synchronization – only when needed, avoid sharing data
  - Memory barriers – use minimally required!
    - StoreLoad (volatile)
    - StoreStore (ordered a.k.a. lazySet)

2.8. Memory barriers benchmarked

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- How fast are different barriers?

```
public final void lazySet(long newValue) {
    unsafe.putOrderedLong( o: this, valueOffset, newValue);
}
```

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- How fast are different barriers?

```
public final void lazySet(long newValue) {
    unsafe.putOrderedLong( o: this, valueOffset, newValue);
}
```

Benchmark	Mode	Samples	Score	Score error	Units
lazySetLong	avgt	5	17.630	0.650	ns/op
volatileSetLong	avgt	5	23.009	0.794	ns/op

2.9. Memory barriers usage example

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```
public WireOut marshallable(@NotNull WriteMarshallable object) {
    long position = bytes.writePosition();
    bytes.writeInt(0);

    object.writeMarshallable( wire: RawWire.this);

    int length = Maths.toInt32( x: bytes.writePosition() - position - 4);
    bytes.writeOrderedInt(position, length);
    return RawWire.this;
}
```

2.10. Java – what means my name to you?

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- Know your language
  - How efficient JDK data structures are?

2.11. Java SDK efficiency

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- Know your language
  - How efficient JDK data structures are? HashMap#put:

```
if ((p = tab[i = (n - 1) & hash]) == null)
    tab[i] = newNode(hash, key, value, next: null);
```

```
Node<K,V> newNode(int hash, K key, V value, Node<K,V> next) {
    return new Node<>(hash, key, value, next);
}
```

2.12. YAGNI

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- Know your language (Doug bless Java!)
- YAGNI – don’t write code for what you don’t use

2.13. To framework or not to framework

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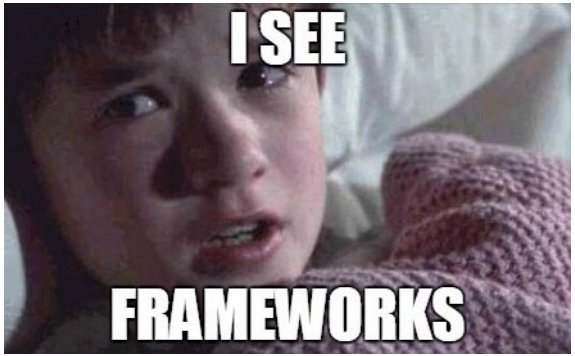
- Know your language (Doug bless Java!)
- YAGNI – don’t write code for what you don’t use
- If it can be done without a 3rd party library/framework – do it!



2.14. Safety first?

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- Know your language (Doug bless Java!)
- YAGNI – don’t write code for what you don’t use
- If it can be done without a 3rd party library/framework – do it!
- Don’t be afraid to be Unsafe – it’s not scary! (provided you know what you are doing…)

2.15.0. Cutting off safety nets – example

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```
public int read(ByteBuffer buf) throws IOException {

    if (buf == null)
        throw new NullPointerException();

    synchronized (readLock) {
        if (!ensureReadOpen())
            return -1;
        int n = 0;
        try {
            begin();

            synchronized (stateLock) {
                if (!isOpen()) {
                    return 0;
                }
                readerThread = NativeThread.current();
            }

            for (;;) {
                n = IOUtil.read(fd, buf, -1, nd);
                if ((n == IOStatus.INTERRUPTED) && isOpen()) {
                    continue;
                }
                return IOStatus.normalize(n);
            }

        } finally {
            readerCleanup();
            end(n > 0 || (n == IOStatus.UNAVAILABLE));
            synchronized (stateLock) {
                if ((n <= 0) && (!isInputOpen))
                    return IOStatus.EOF;
            }
            assert IOStatus.check(n);

        }
    }
}
```

2.15.1. Cutting off safety nets – example

Chronicle SOFTWARE

```
synchronized (readLock) {
    if (!ensureReadOpen())
        return -1;
    int n = 0;
    try {
        begin();

        synchronized (stateLock) {
            if (!isOpen()) {
                return 0;
            }
            readerThread = NativeThread.current();
        }
```

2.15.2. Cutting off safety nets – example

Chronicle SOFTWARE

```
} finally {
    readerCleanup();
    end(n > 0 || (n == IOStatus.UNAVAILABLE));
    synchronized (stateLock) {
        if ((n <= 0) && (!isInputOpen))
            return IOStatus.EOF;
    }
```

2.15.3. Cutting off safety nets – example

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```
for (;;) {
    n = IOUtil.read(fd, buf, -1, nd);
    if ((n == IOStatus.INTERRUPTED) && isOpen()) {
        continue;
    }
    return IOStatus.normalize(n);
}
```

```
static int read(FileDescriptor fd, ByteBuffer dst, long position,
                NativeDispatcher nd)
        throws IOException
{
    if (dst.isReadOnly())
        throw new IllegalArgumentException("Read-only buffer");
    if (dst instanceof DirectBuffer)
        return readIntoNativeBuffer(fd, dst, position, nd);
```

2.15.4. Cutting off safety nets – example

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```
Class<?> fdi = Class.forName("sun.nio.ch.FileDispatcherImpl");
Method read0 = Jvm.getMethod(fdi, name: "read0", FileDescriptor.class, long.class, int.class);
READ0_MH = MethodHandles.lookup().unreflect(read0);
```

2.15.4. Cutting off safety nets – example

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```
Class<?> fdi = Class.forName("sun.nio.ch.FileDispatcherImpl");
Method read0 = Jvm.getMethod(fdi, name: "read0", FileDescriptor.class, long.class, int.class);
READ0_MH = MethodHandles.lookup().unreflect(read0);
```

```
public int read(ByteBuffer buf) throws IOException {
    if (buf == null)
        throw new NullPointerException();

    if (isBlocking() || !isOpen() || !(buf instanceof DirectBuffer))
        return super.read(buf);
    return read0(buf);
}
```

2.15.5. Cutting off safety nets – example

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```
int read0(ByteBuffer buf) throws IOException {
    final long address = ((DirectBuffer) buf).address() + buf.position();
    int n = OS.read0(fd, address, buf.remaining());
    if ((n == IOStatus.INTERRUPTED) && socketChannel.isOpen()) {
        return 0;
    }
    int ret = IOStatus.normalize(n);
    if (ret > 0)
        buf.position(buf.position() + ret);
    else if (ret < 0)
        open = false;
    return ret;
}
```

2.15.6. Cutting off safety nets – example

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- Numbers? I haz sum 4 u!
  - 50%-tile: 6.8 → 5.7 µs
  - 90%-tile: 8.2 → 7.1 µs
  - Consistently 1.1µs less
    - YMMV

2.16. Waiting for something – eagerly!

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- Use busy loops when waiting on condition and non-blocking operations
  - wait/notify or sleep are slower, and also stalling CPU
  - `while (condition) Thread.yield();`
  - `while (condition);`
    - The lowest latency
    - Avoids CPU slowdown

2.17. Busy wait vs sleep example

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- BUSY100

  50/90 97/99 99.7/99.9 99.97/99.99 - worst
  0.095/0.11 0.11/0.16 0.36/0.65 0.65/0.65-0.65

```
BUSY100 {
    public void disturb() { busyWait( nanos: 1.0E8D); }
},
```

- PAUSE1

  50/90 97/99 99.7/99.9 99.97/99.99 - worst
  0.26/0.34 0.59/0.66 0.71/0.75 12/13 - 16

```
PAUSE1 {
    public void disturb() { Jvm.pause( millis: 1L); }
},
```

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- Strings
  - Strings are immutable (and expensive)
  - Use StringBuilder Luke (and you can share it!)
  - Chronicle Bytes – can do much more, heap or off heap

2.19. Bytes code examples

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```
Bytes b = Bytes.from("Hello World");
try {
    b.readSkip(6);
    assertTrue(StringUtils.isEqual( S: "World", b));
} finally {
    b.release();
}
```

2.20. Bytes code examples

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```
Bytes b = Bytes.from("Hello World");
try {
    b.readSkip(6);
    assertTrue(StringUtils.isEqual( S: "World", b));
} finally {
    b.release();
}
```

```
b.append("Hello World");
b.move( from: 3,  to: 1,  length: 3);
assertEquals( expected: "Hlo o World", b.toString());
b.move( from: 3,  to: 5,  length: 3);
assertEquals( expected: "Hlo o o rld", b.toString());
```

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- Garbage Collection
  - Even minor collections are slow for us (several ms)
  - Avoid garbage at all cost

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- Garbage Collection
  - Even minor collections are slow for us (several ms)
  - Avoid garbage at all cost
    - Reuse objects (especially when marshalling)

```
private final TransactionsRequest tr = new TransactionRequest();

public receive(WireIn wire) {
    tr.reset();
    wire.read().marshallable(tr);
    process(tr);
}
```

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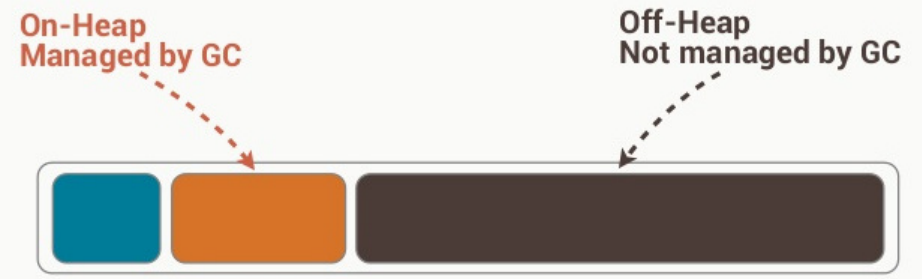
- Garbage Collection
  - Even minor collections are slow for us (several ms)
  - Avoid garbage at all cost
    - Reuse objects (especially when marshalling)
    - Pool objects if you can’t reuse single object
    - Most of all – use off-heap memory



2.23. Object pooling example

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```
public class StringBuilderPool {
    private final ThreadLocal<StringBuilder> sbtl = withInitial(
            () -> new StringBuilder( capacity: 128));

    @ForceInline
    public StringBuilder acquireStringBuilder() {
        StringBuilder sb = sbtl.get();
        sb.setLength(0);
        return sb;
    }
}
```

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3. Fighting latency: Inter-process communication

3.0. Memory vs Network IO vs Disk IO

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- Writing/reading to/from memory is the fastest option
  - Right after CPU caches...
  - Remember about “mechanical sympathy”

3.0. Memory vs Network IO vs Disk IO

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- Writing/reading to/from memory is the fastest option
  - Right after CPU caches...
  - Remember about “mechanical sympathy”
- Disk IO is slower than DC-local network IO
  - UDP is faster than TCP

3.1. Writing to memory + writing to disk

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- What if we can write to main memory while OS writes to (local) disk for us?

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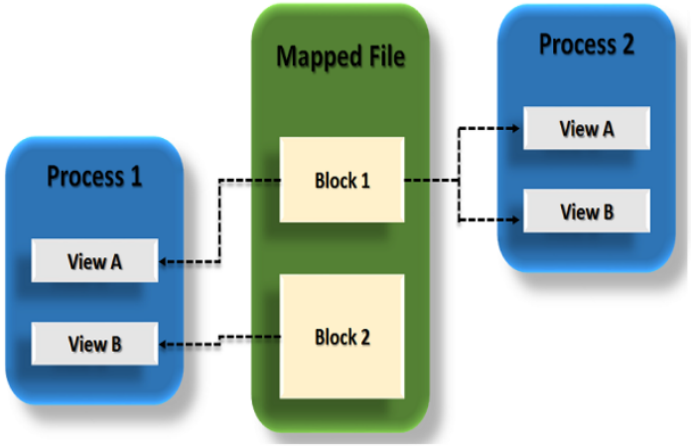
- What if we can write to main memory while OS writes to (local) disk for us?
- Welcome to memory-mapped files



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- What if we can write to main memory while OS writes to (local) disk for us?
- Welcome to memory-mapped files
  - Memory-mapping is shared between processes – effectively providing shared memory IPC

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- Chronicle Queue – uses off-heap memory to map files
  - **4µs roundtrip** on consumer-grade (a.k.a. desktop) box for 1024 bytes-long message

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- [Un]Marshaling can be the biggest contribution to latency
  - Choose (and benchmark) your tools
    - SBE (Agrona)
    - Chronicle Wire
    - Protobuf
    - FlatBuffers etc...

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- [Un]Marshaling can be the biggest contribution to latency
  - Choose (and benchmark) your tools
    - SBE (Agrona)
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    - Protobuf
    - FlatBuffers etc...

4. Fighting latency: Environment (OS & hardware)

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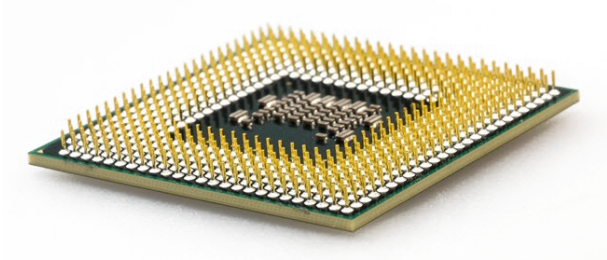
- Intel C-states
  - They will kill your latency!
  - `intel_idle.max_cstate=0 processor.max_cstate=0 idle=poll`



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- Intel C-states
  - They will kill your latency!
- Turbo boost
  - Check your BIOS
  - Depends on thermal envelope
    - Careful – AVX throttling!

4.2. CPU: governors

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- Intel C-states
  - They will kill your latency!
- Turbo boost
- CPU caches
- Linux CPU governors

```
# cpupower frequency-set -g performance
```

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- Intel C-states
  - They will kill your latency!
- Turbo boost
- CPU caches
- Linux CPU governors
- Cool CPU is – surprisingly – slow

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- Isolate OS threads
  - `isolcpus`
- Isolate IRQs
- Threads CPU affinity

For more – come to the discussion zone!

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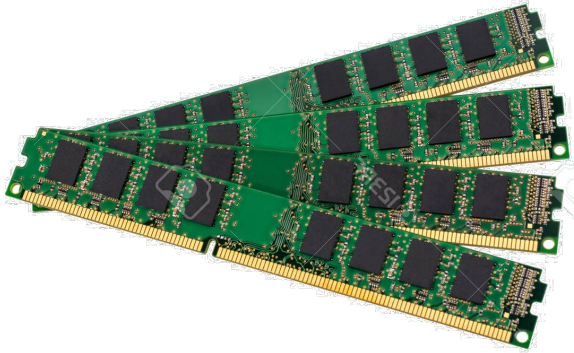
- Swap kills your performance
  - `sysctl -w vm.swappiness=0`



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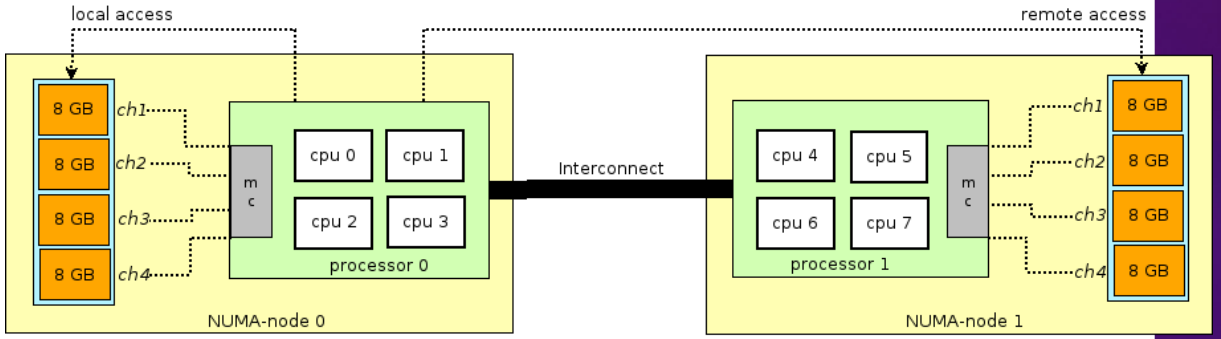
- Swap kills your performance
  - `sysctl -w vm.swappiness=0`
- NUMA
  - `numactl`
  - Disable node interleaving



4.7. Memory management: THP

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- Swap kills your performance
  - `sysctl -w vm.swappiness=0`
- NUMA
  - `numactl`
  - Disable node interleaving
- Transparent Huge Pages are bad
  - `transparent_hugepage=never`

4.8. Disk: IO scheduler

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- SSD disks only
  - Disable IO scheduler
    - `elevator=noop`

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- SSD disks only
  - Disable IO scheduler
- File system matters
  - ext4 is faster than xfs
    - `barrier=0`
    - `noatime`

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- Kernel operations are expensive
  - Kernel bypass is faster
    - Solarflare networks

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- Kernel operations are expensive
  - Kernel bypass is faster
    - Solarflare networks
  - Memory-mapped writes are user-space
    - OS later flushes data to disk asynchronously

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- System-specific tools
  - RedHat/CentOS: tuned
    - `tuned-adm profile latency-performance`

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- System-specific tools
  - RedHat/CentOS: tuned
    - `tuned-adm profile latency-performance`
- Optimizing network IO
  - Kernel TCP buffers
    - `sysctl -w net.core.rmem_max=2097152`
    - `sysctl -w net.core.wmem_max=2097152`

Summary

Summary & take away

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- Microservices – not necessarily slow thing in the cloud
- JLBH rulez – use it!
- Your environment can be friend – or foe, your choice
  - If you do the homework

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Thank you for your attention!

Q & A

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Linkedin: “Chronicle Performance Engineers”

Blog: http://vanilla-java.github.io/

Blog: http://blog.pisklov.me

http://chronicle.software

https://github.com/OpenHFT/