Enabling Java in Latency Sensitive Applications

Gil Tene, CTO & co-Founder, Azul Systems

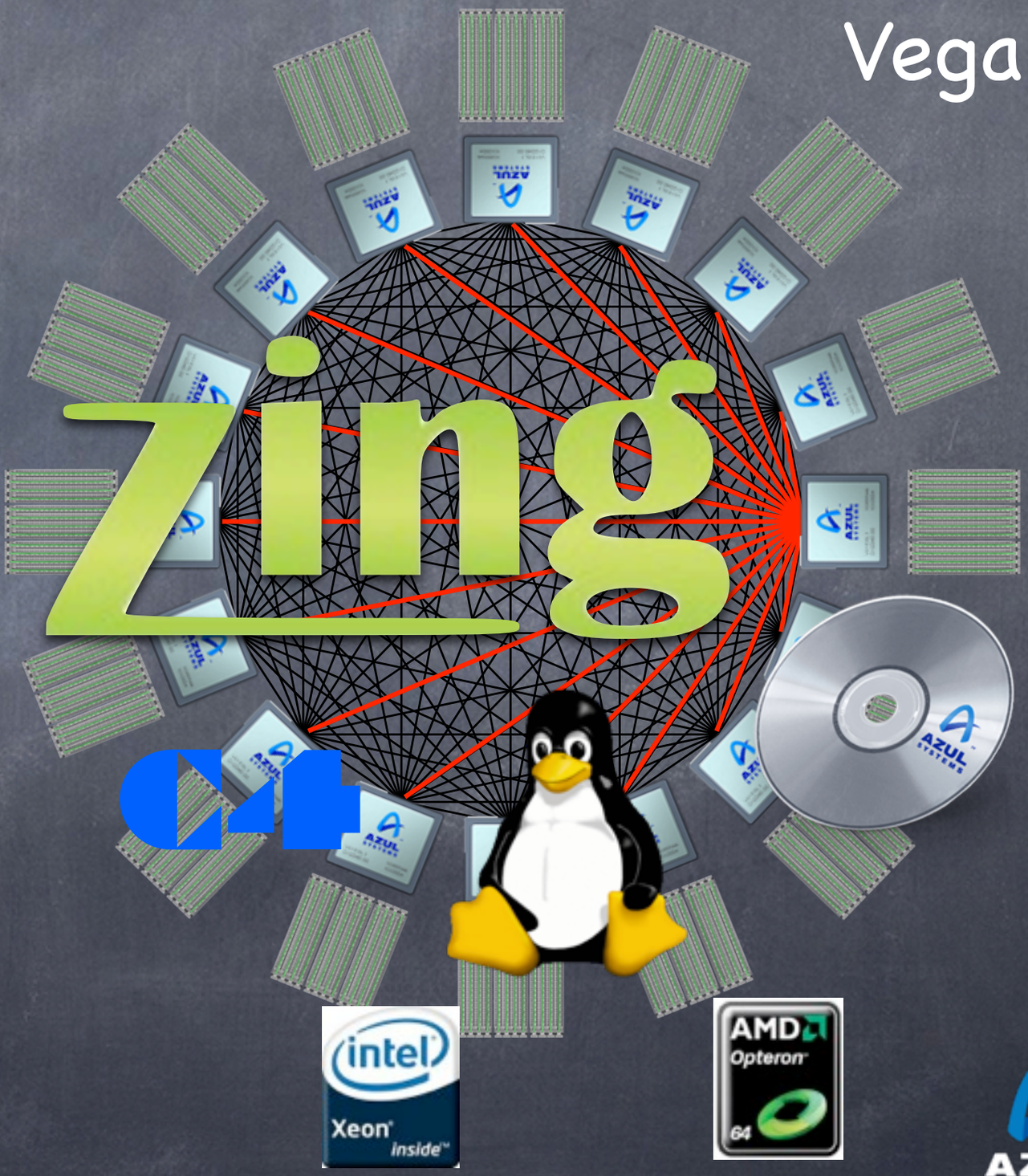
About me: Gil Tene

- co-founder, CTO @Azul Systems
- Have been working on a "think different" GC approaches since 2002
- Created Pauseless & C4 core GC algorithms (Tene, Wolf)
- A Long history building Virtual & Physical Machines, Operating Systems, Enterprise apps, etc...

* working on real-world trash compaction issues, circa 2004

About Azul

- We make scalable Virtual Machines
- Have built "whatever it takes to get job done" since 2002
- 3 generations of custom SMP Multi-core HW (Vega)
- **Zing: Pure software for commodity x86**
- Known for Low Latency, Consistent execution, and Large data set excellence



High level agenda

- Java in a low latency application world
- The (historical) fundamental problems
- What people have done to try to get around them
- What if the fundamental problems were eliminated?
- What 2013 looks like for Low latency Java developers
- What's next?

Java in the low latency world?

Java in the low latency world?

- Why do people use Java for low latency apps?
- Are they crazy?
- No. There are good, easy to articulate reasons
  - Projected lifetime cost
  - Developer productivity
  - Time-to-product, Time-to-market, …
  - Leverage, ecosystem, ability to hire

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E.g. Customer answer to: "Why do you use Java in Algo Trading?"

- Strategies have a shelf life
- We have to keep developing and deploying new ones
- Only one out of N is actually productive
- Profitability therefore depends on ability to successfully deploy new strategies, and on the cost of doing so
- Our developers seem to be able to produce 2x-3x as much when using a Java environment as they would with C/C++ ...

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So what is the problem?

Is Java Slow?

- No...
- A good programmer will get roughly the same speed from both Java and C++
- A bad programmer won't get you fast code on either
- The 50%'ile and 90%'ile are typically excellent...
- It's those pesky occasional stutters and stammers and stalls that are the problem...
- Ever hear of Garbage Collection?

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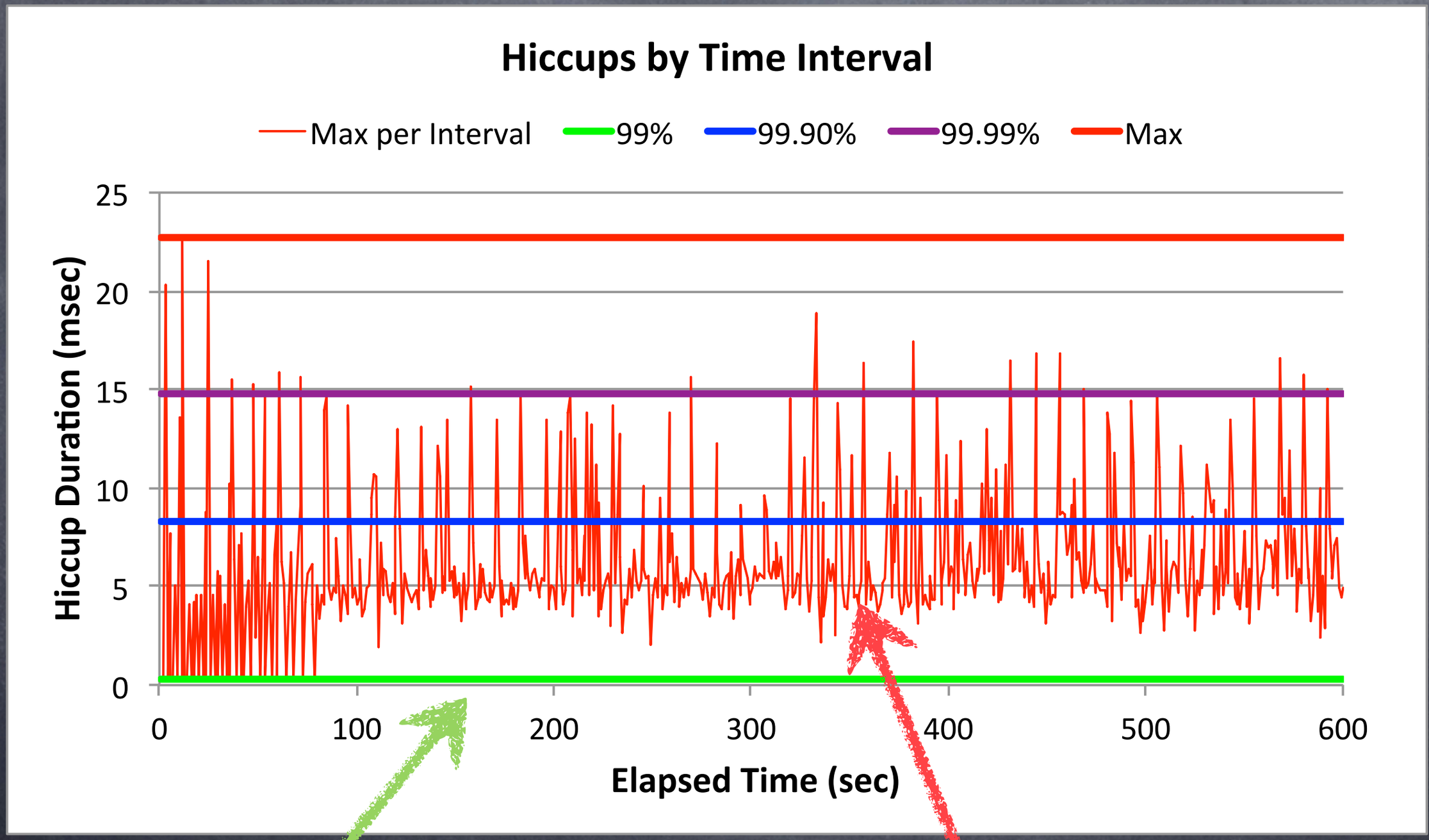
Is "jitter" even the right word for this?



99%'ile is ~60 usec

Max is ~30,000% higher than "typical"

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Stop-The-World Garbage Collection: Java's Achilles heel

- Let's ignore the bad multi-second pauses for now...
- Low latency applications regularly experience "small", "minor" GC events that range in the 10s of msec
- Frequency directly related to allocation rate
- So we have great 50%, 90%. Maybe even 99%
- But 99.9%, 99.99%, Max, all "suck"
- So bad that it affects risk, profitability, service expectations, etc.

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One way to deal with Stop-The-World GC

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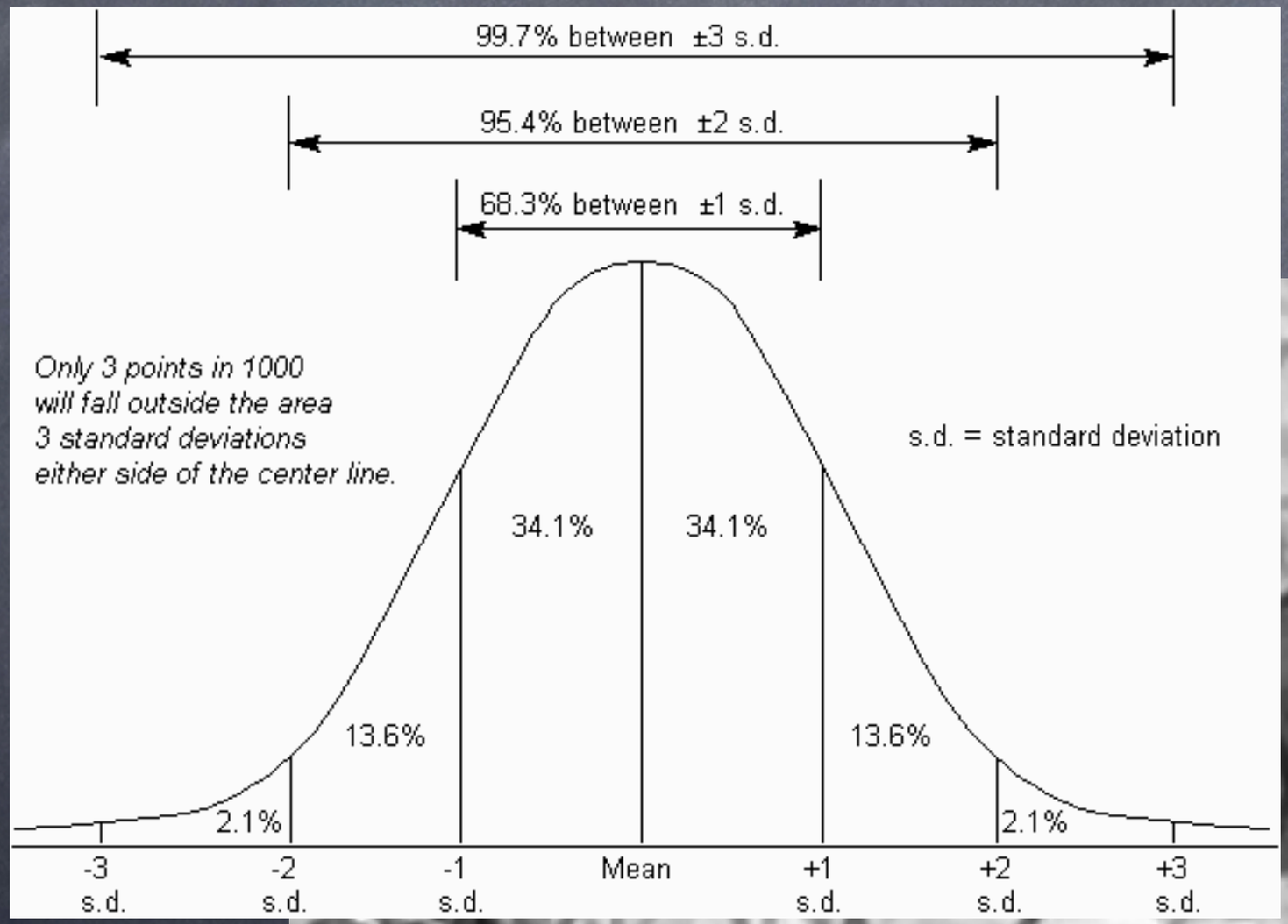
A common way to "deal" with STW-GC

Averages and Standard Deviation



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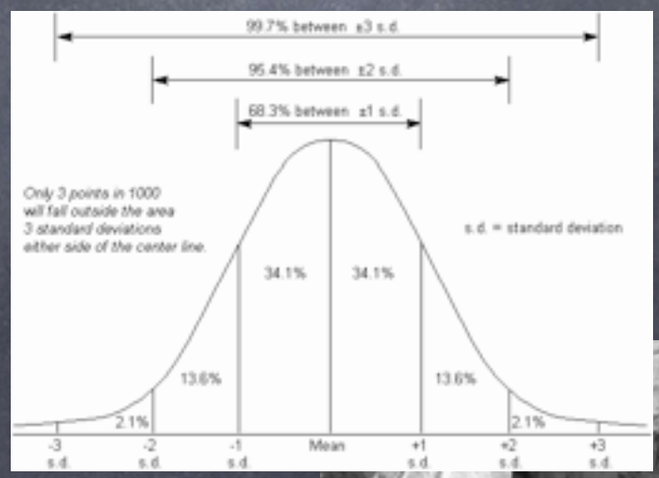
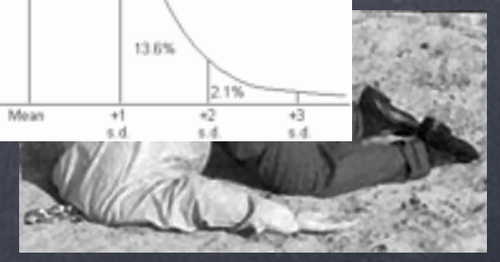
Reality: Latency is usually strongly "multi-modal"

- Usually does't look anything like a normal distribution
- In software systems, usually sees periodic freezes
- Complete shifts from one mode/behavior to another
- Mode A: "good".
- Mode B: "Somewhat bad"
- Mode C: "terrible", ...
- ....





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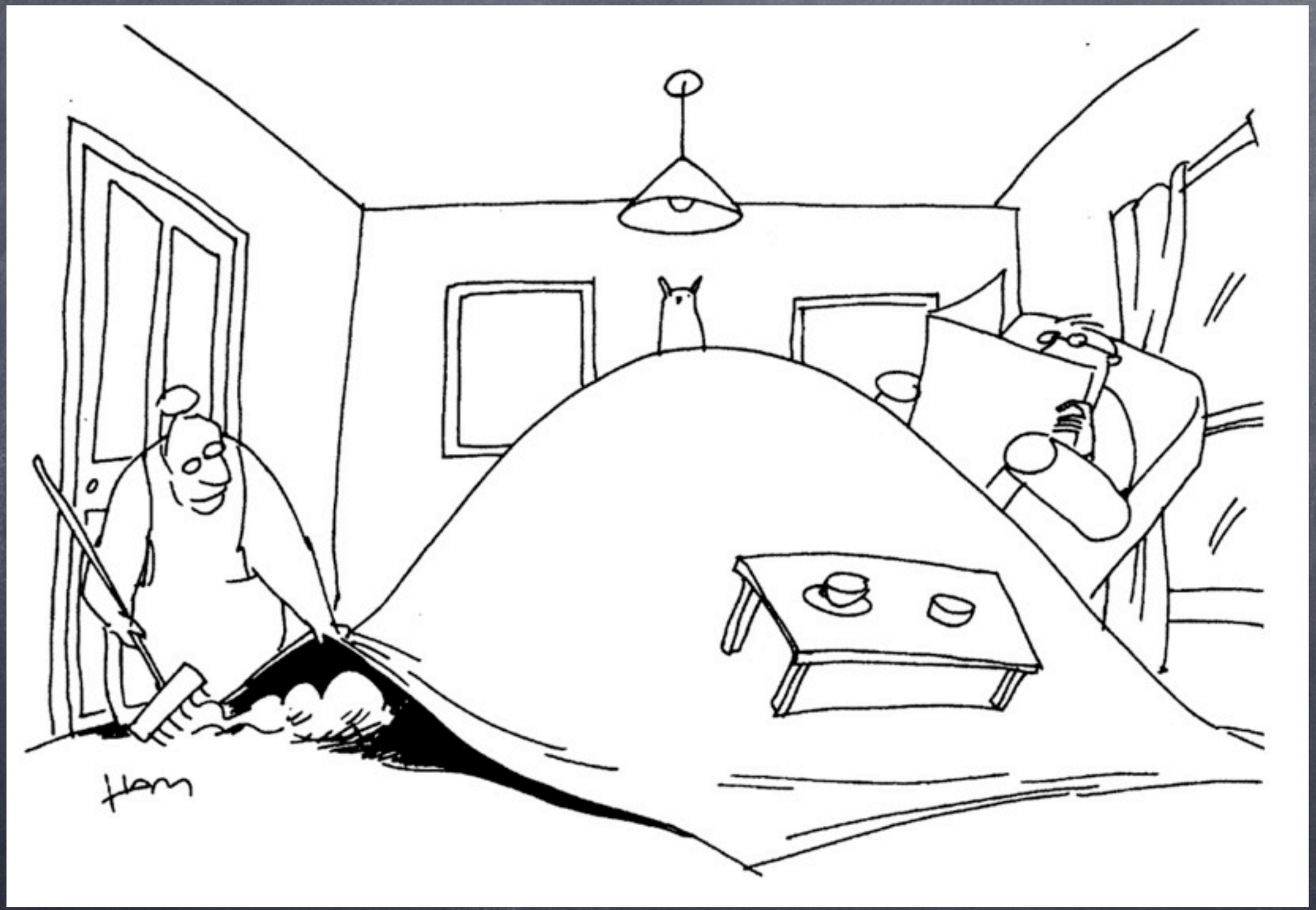
Another way to deal with STW-GC



Another way to cope: "Creative Language"

- "Guarantee a worst case of 5 msec, 99% of the time"

- "Mostly" Concurrent, "Mostly" Incremental

Translation: "Will at times exhibit long monolithic stop-the-world pauses"

- "Fairly Consistent"

Translation: "Will sometimes show results well outside this range"

- "Typical pauses in the tens of milliseconds"

Translation: "Some pauses are much longer than tens of milliseconds"

What do actual low latency developers do about it?

- They use "Java" instead of Java
- They write "in the Java syntax"
- They avoid allocation as much as possible
- E.g. They build their own object pools for everything
- They write all the code they use (no 3rd party libs)
- They train developers for their local discipline
- In short: They revert to many of the practices that hurt productivity. They loose out on much of Java.

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What do low latency (Java) developers with all this effort?

- They still see pauses (usually ranging to tens of msec)
- They do get fewer (as in less frequent) pauses
- And they see fewer people able to do the job
- And they have to write EVERYTHING themselves
- And they get to debug malloc/free patterns again
- And they can only use memory in certain ways
- ...
- Some call it "fun"... Others "duct tape engineering"...

was
It ~~is~~ an industry-wide problem

Stop-The-World GC mechanisms contradict the fundamental requirements of low latency & low jitter apps

It's 2013... We now have Zing.

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The common GC behavior across ALL currently shipping (non-Zing) JVMs

- ALL use a Monolithic Stop-the-world NewGen
  - "small" periodic pauses (small as in 10s of msec)
  - pauses more frequent with higher throughput or allocation rates
- Development focus for ALL is on Oldgen collectors
  - Focus is on trying to address the many-second pause problem
  - Usually by sweeping it farther and farther the rug
  - "Mostly X" (e.g. "mostly concurrent") hides the fact that they refer only to the OldGen part of the collector
  - E.g. CMS, G1, Balanced.... all are OldGen-only efforts
- ALL use a Fallback to Full Stop-the-world Collection
  - Used to recover when other mechanisms (inevitably) fail
  - Also hidden under the term "Mostly"...

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A Recipe: address STW-GC head-on

- At Azul, we decided to focus on the core problems
- Scale & productivity limited by responsiveness/latency
- And it's not the "typical" latency, it's the outliers...
- Even "short" GC pauses must be considered a problem

- Responsiveness must be unlinked from key metrics:
  - Transaction Rate, Concurrent users, Data set size, etc.
  - Heap size, Live Set size, Allocation rate, Mutation rate
  - Responsiveness must be continually sustainable
  - Can't ignore "rare but periodic" events

- Eliminate ALL Stop-The-World Fallbacks

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The Zing "C4" Collector
Continuously Concurrent Compacting Collector

- Concurrent, compacting old generation
- Concurrent, compacting new generation
- No stop-the-world fallback
  - Always compacts, and always does so concurrently

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Benefits

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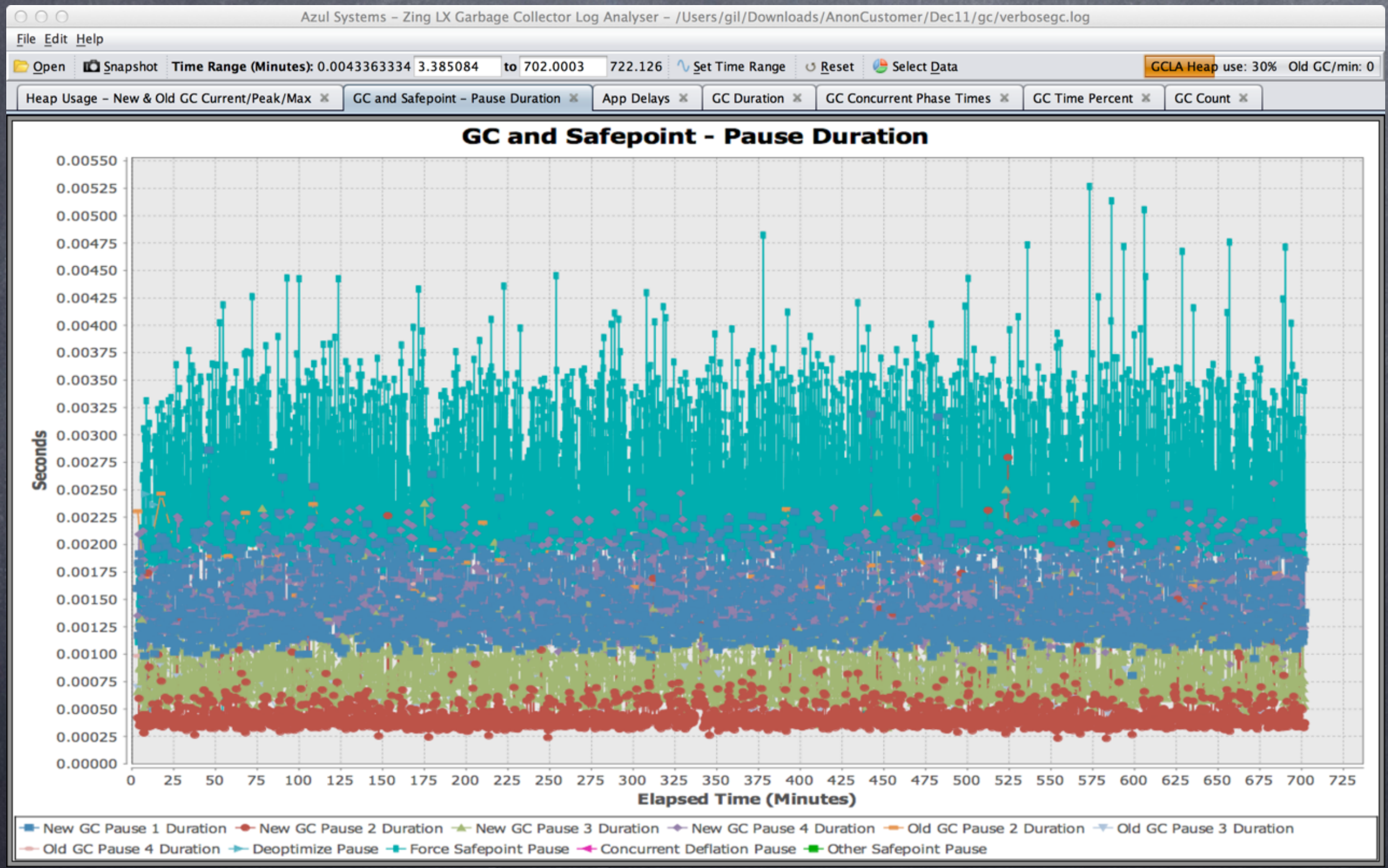
An example of "First day's run" behavior
E-Commerce application



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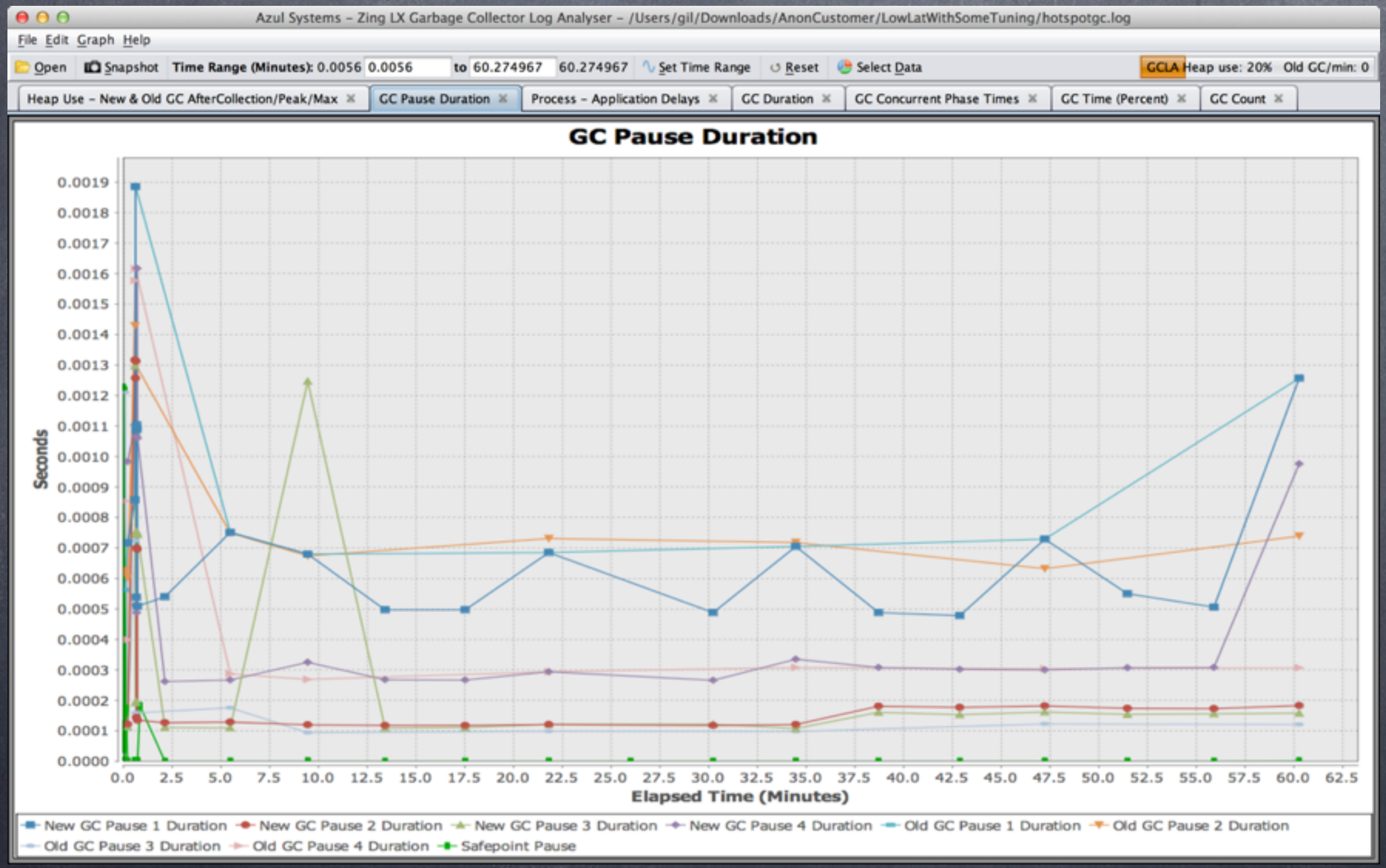
An example of behavior after 4 days of system tuning
Low latency application



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Measuring Theory in Practice

jHiccup:
A tool that measures and reports
(as your application is running)
if your JVM is actually running
all the time

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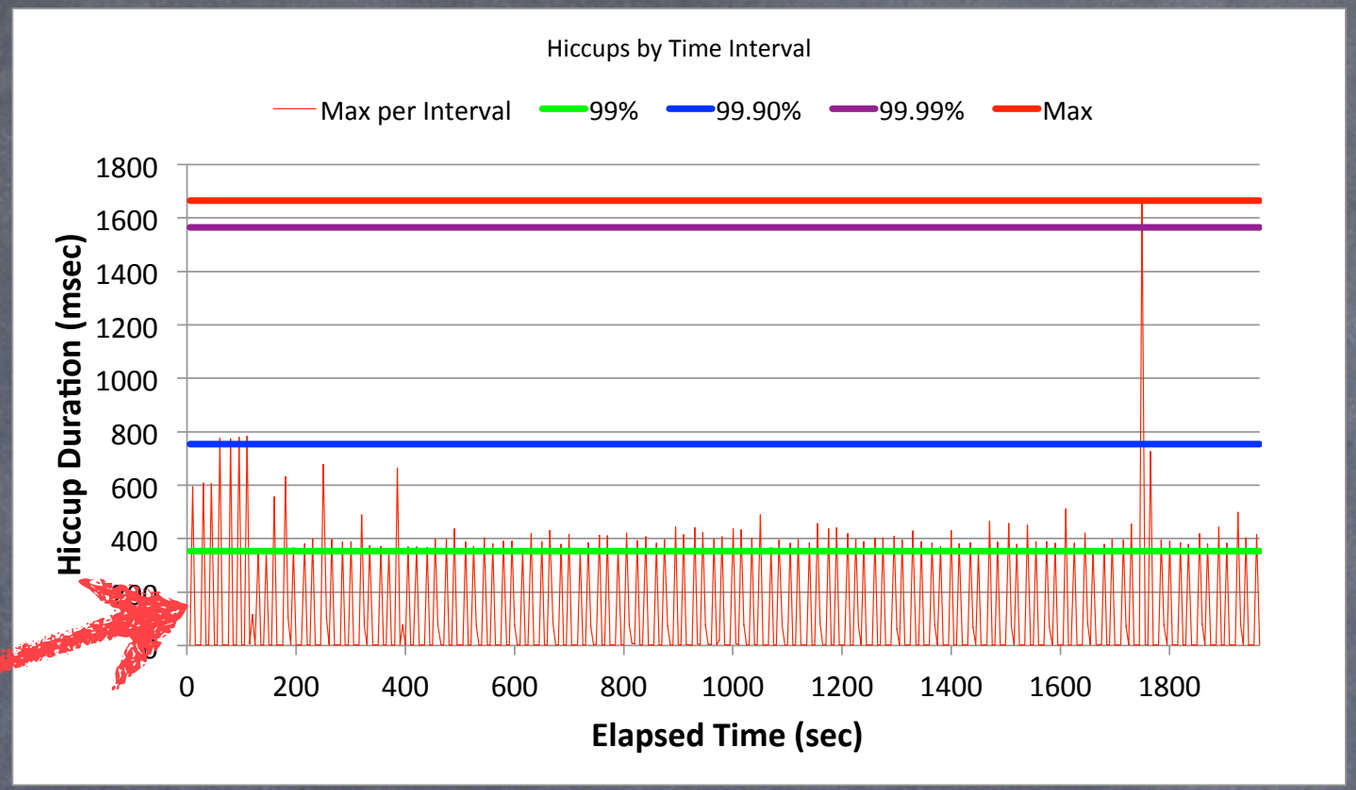
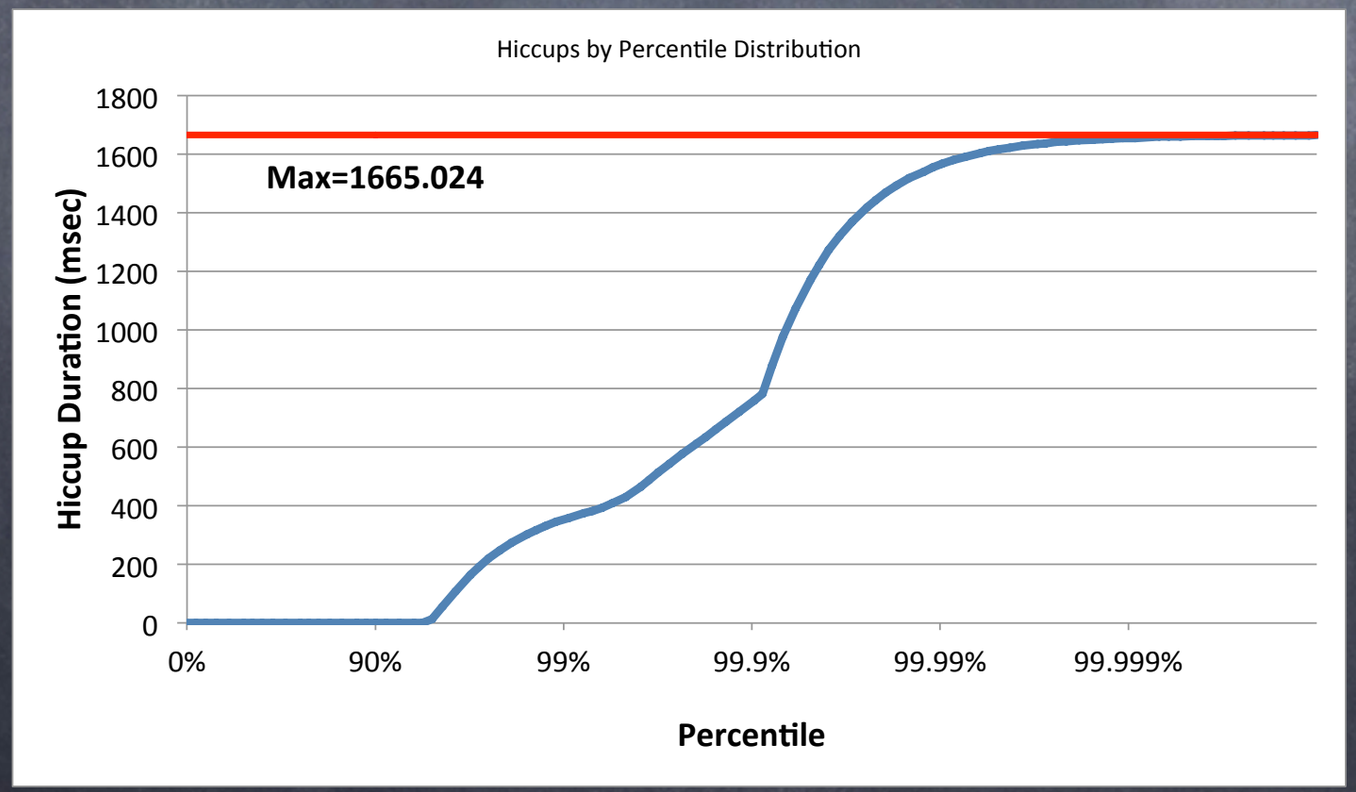
Discontinuities in Java platform execution - Easy To Measure

I call these "hiccups"





A telco App with a bit of a "problem"

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Fun with jHiccup

Charles Nutter @headius 20 Jan

jHiccup, @AzulSystems' free tool to show you why your JVM sucks compared to Zing: bit.ly/wsH5A8 (thx @bascule)

Retweeted by Gil Tene

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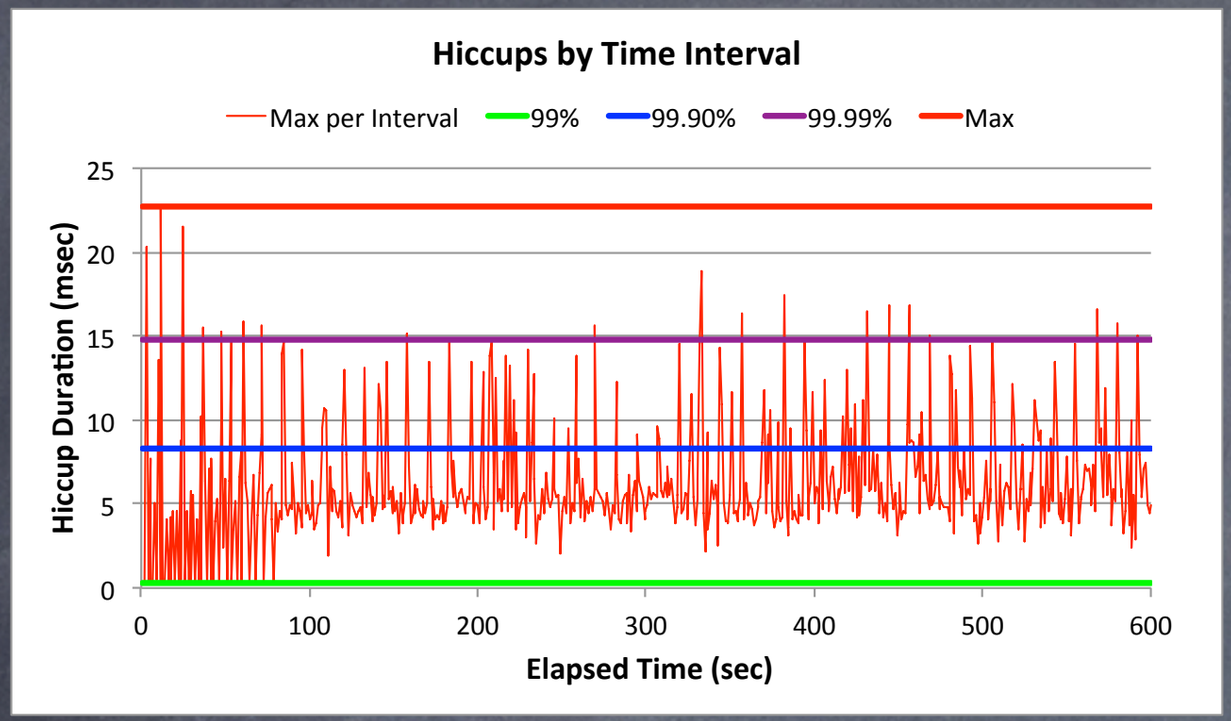
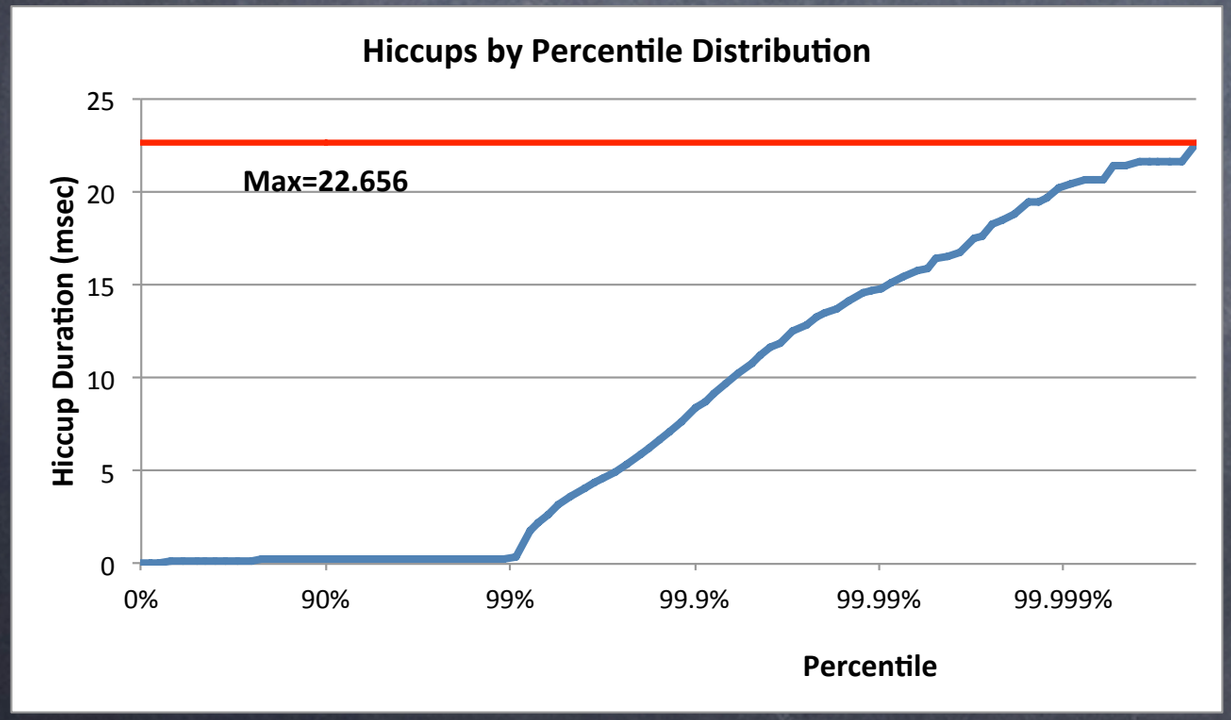
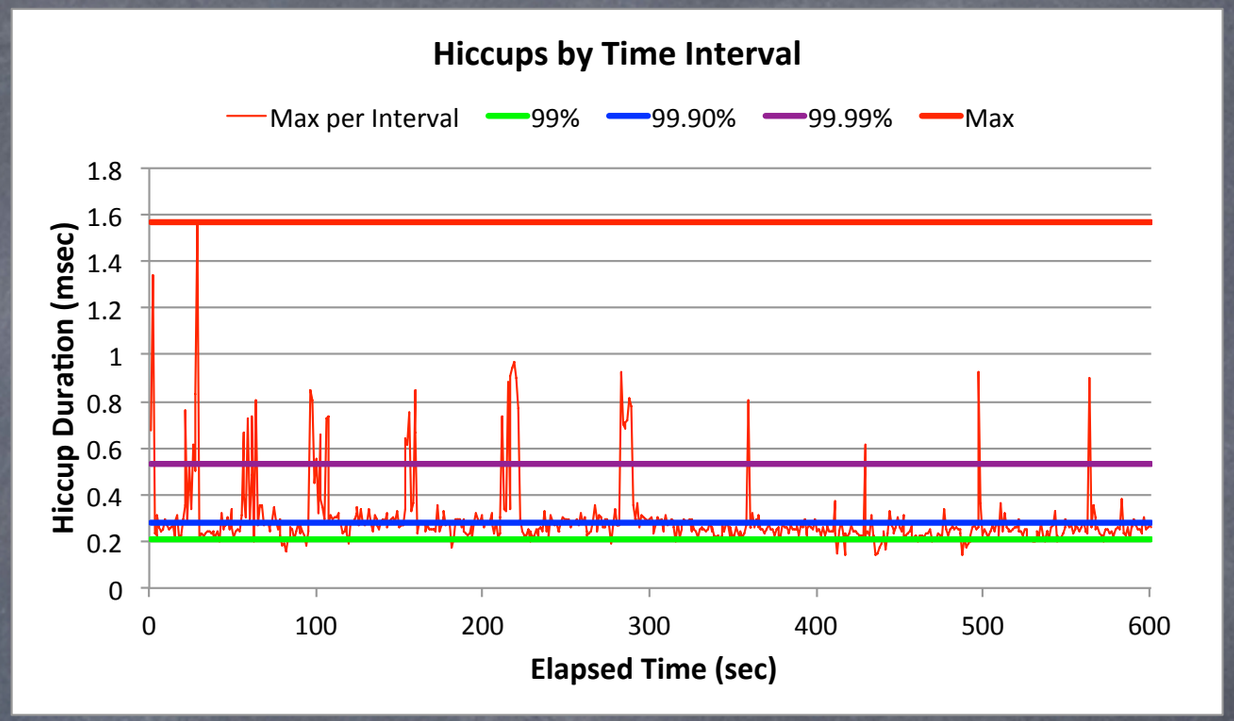
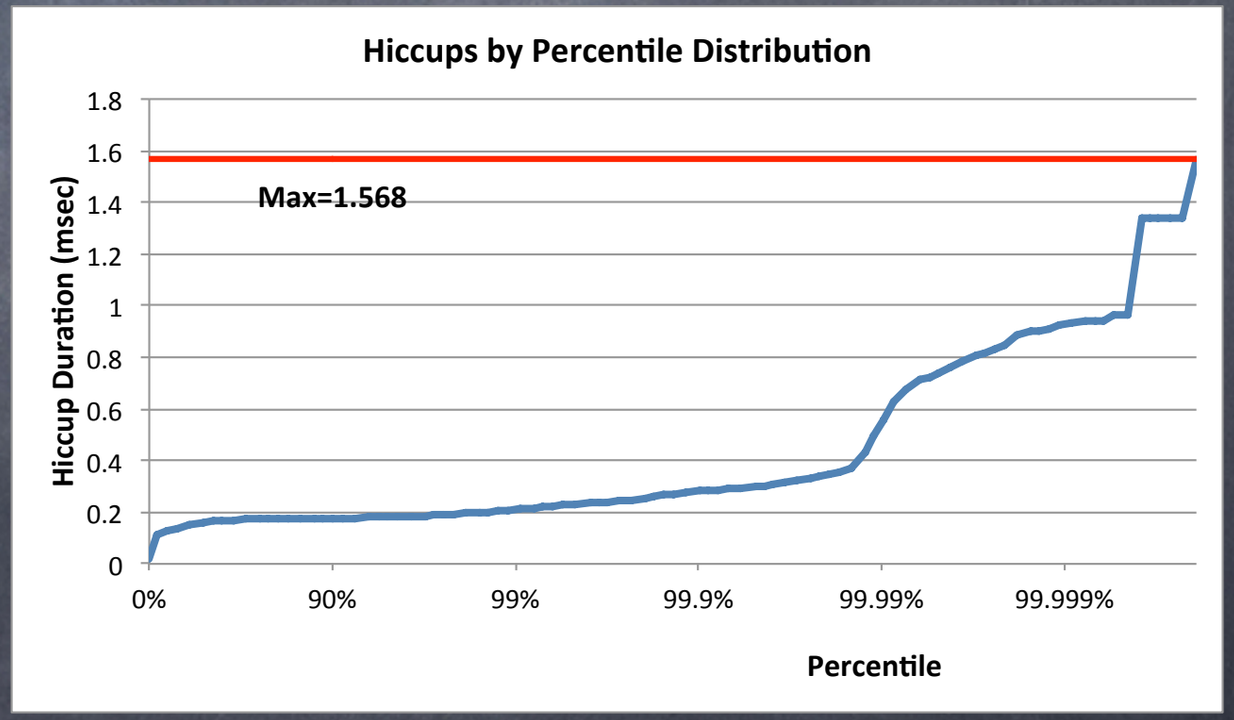
Oracle HotSpot (pure newgen)





Zing





Low latency trading application

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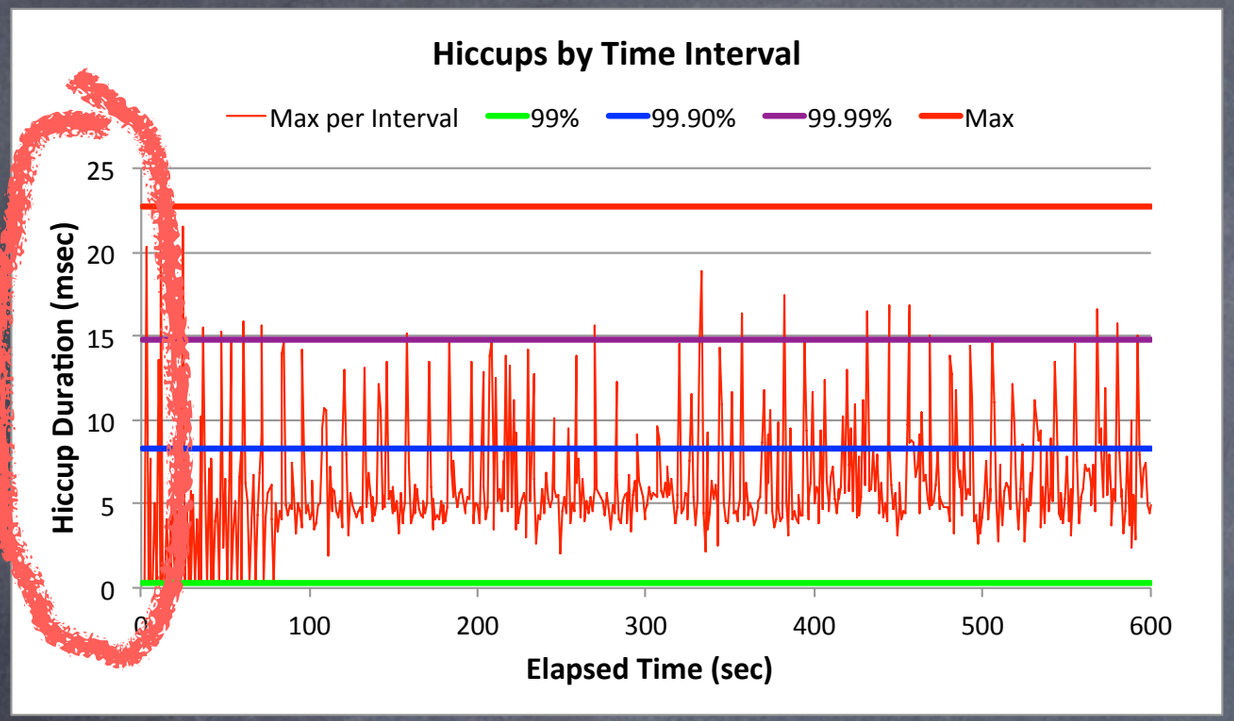
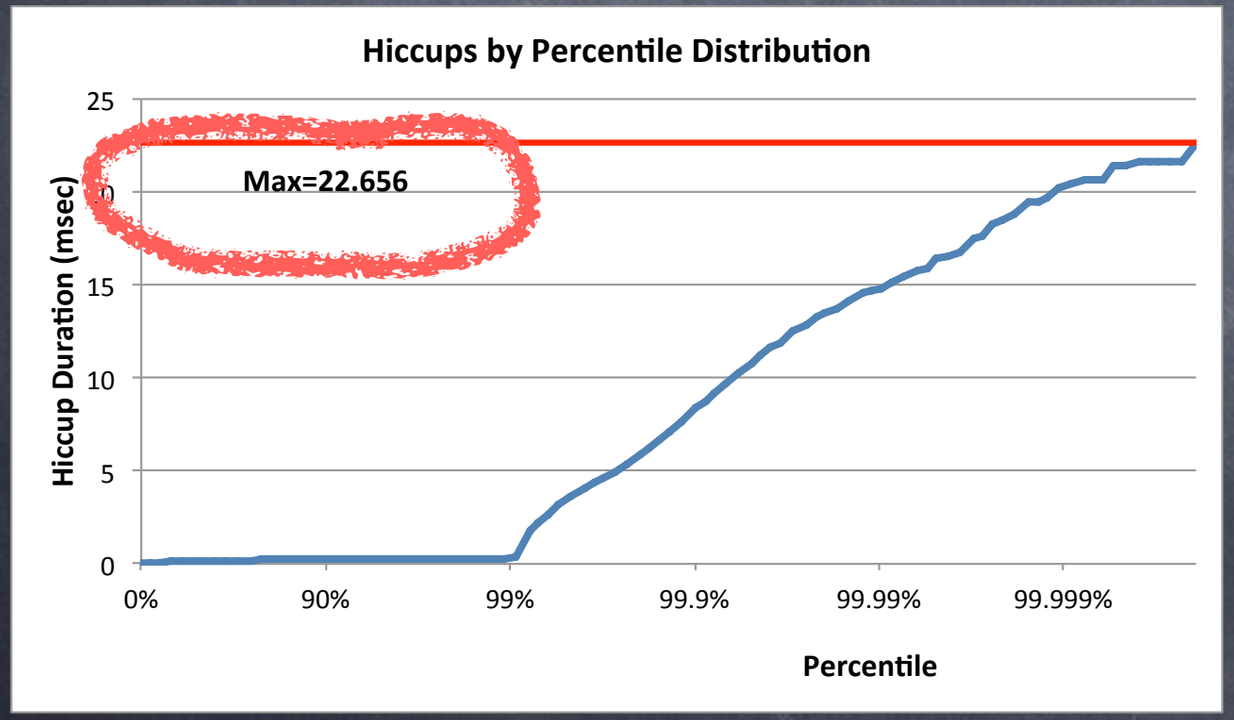
Oracle HotSpot (pure newgen)





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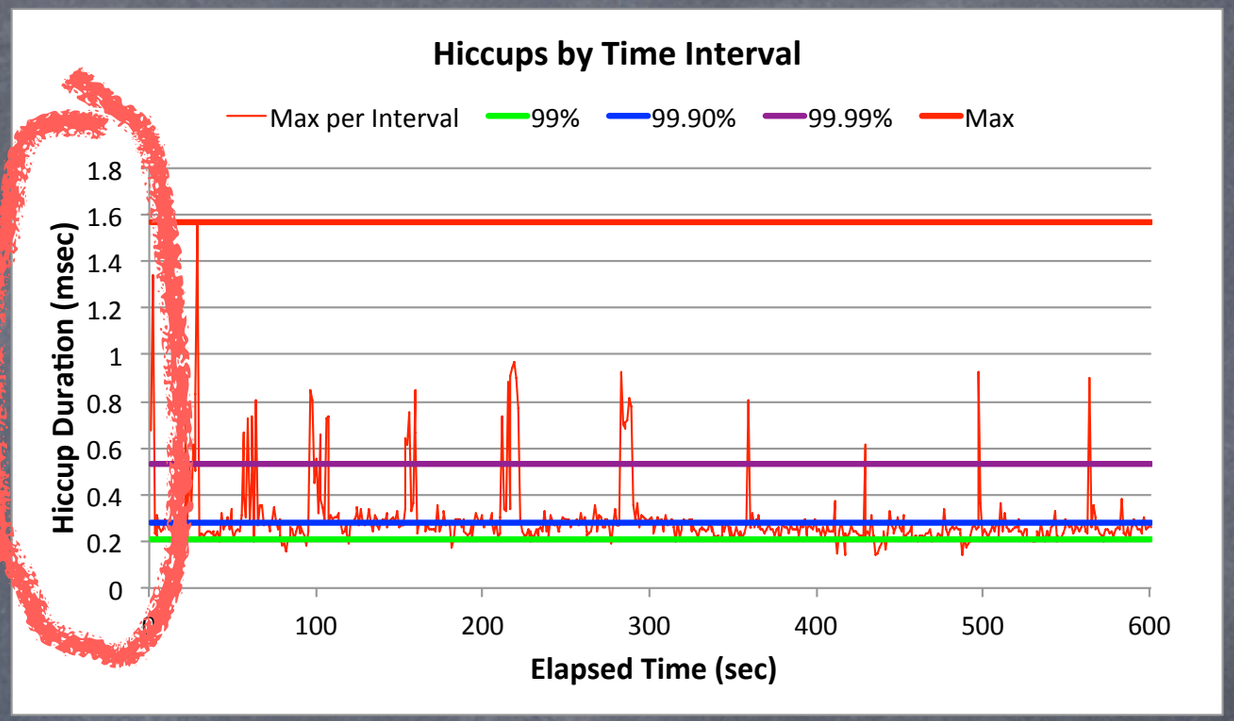

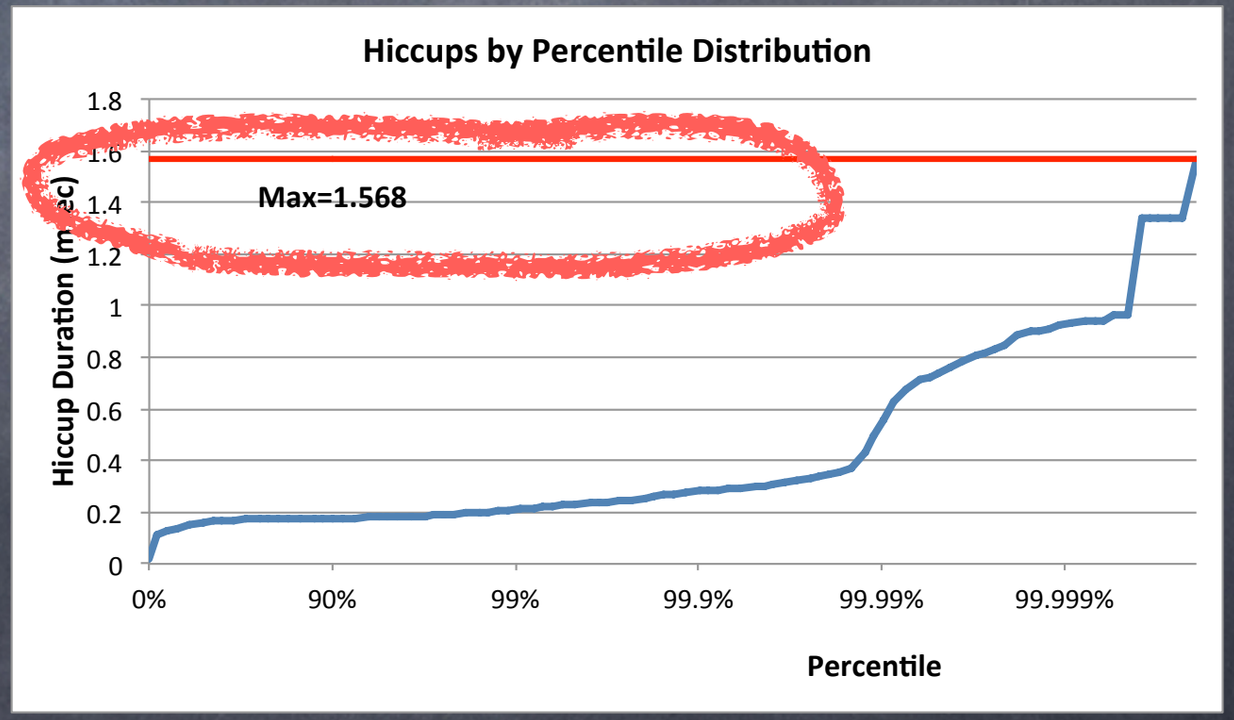

Low latency trading application

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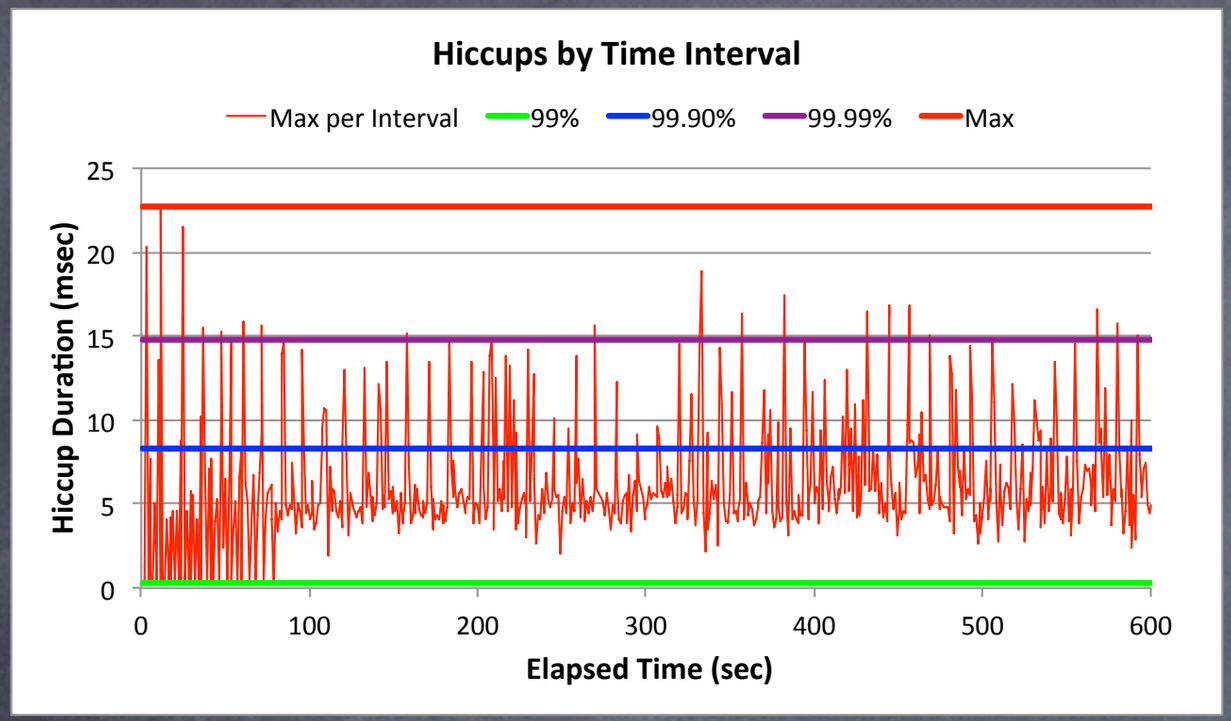
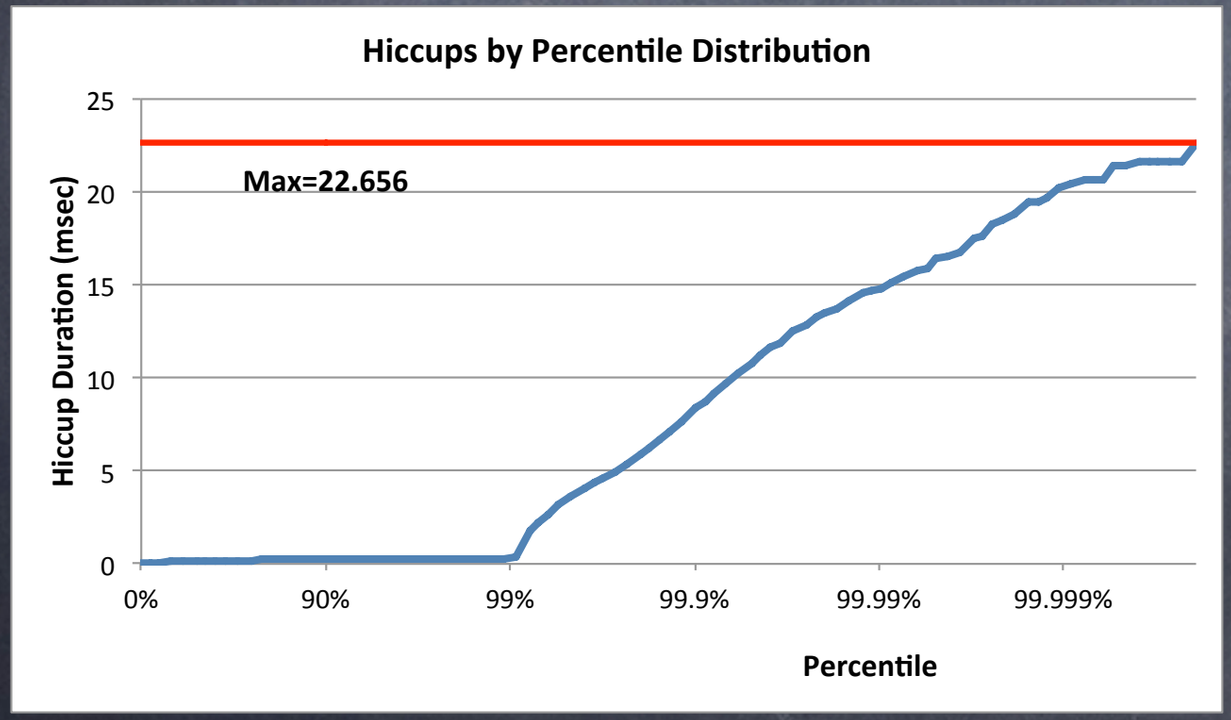
Oracle HotSpot (pure newgen)





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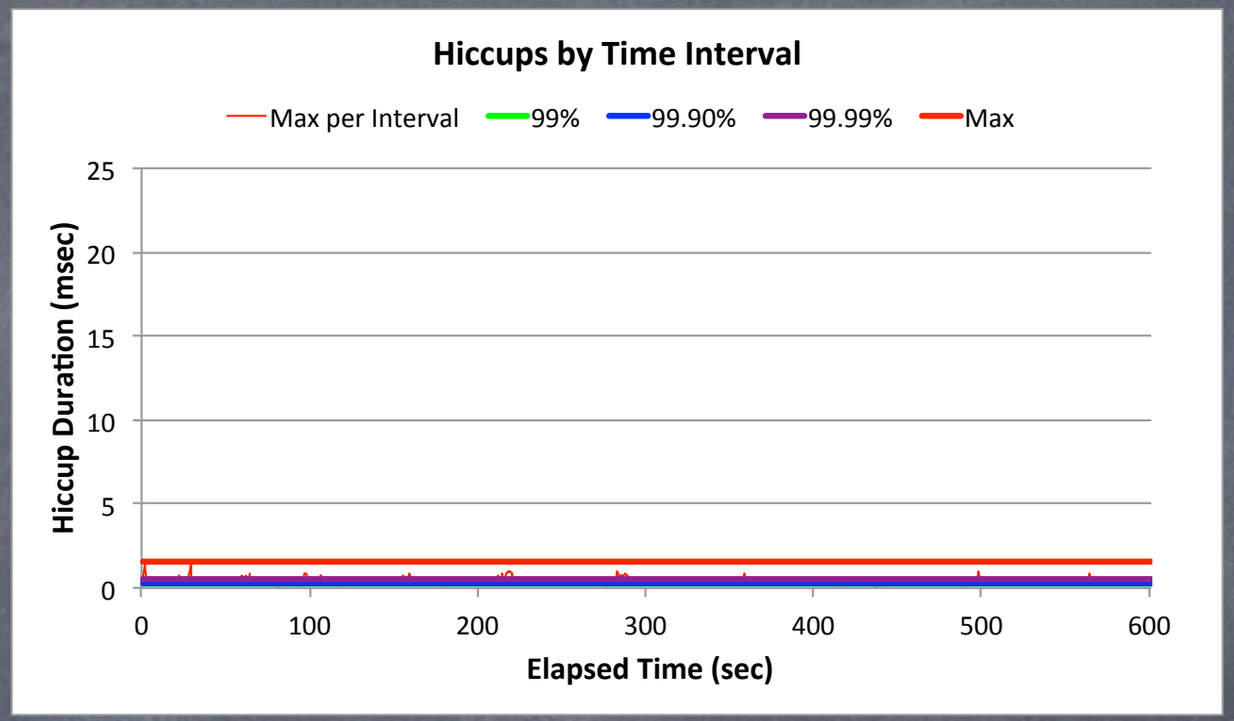

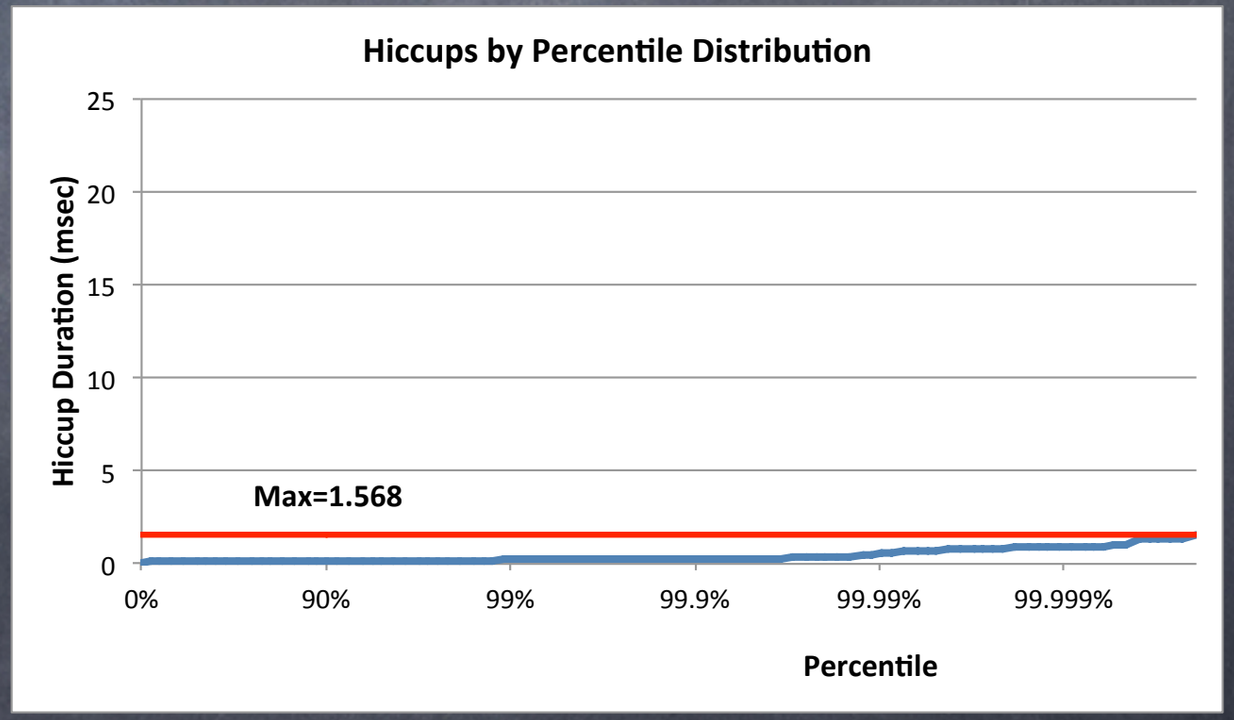

Low latency - Drawn to scale

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Lets not forget about GC tuning

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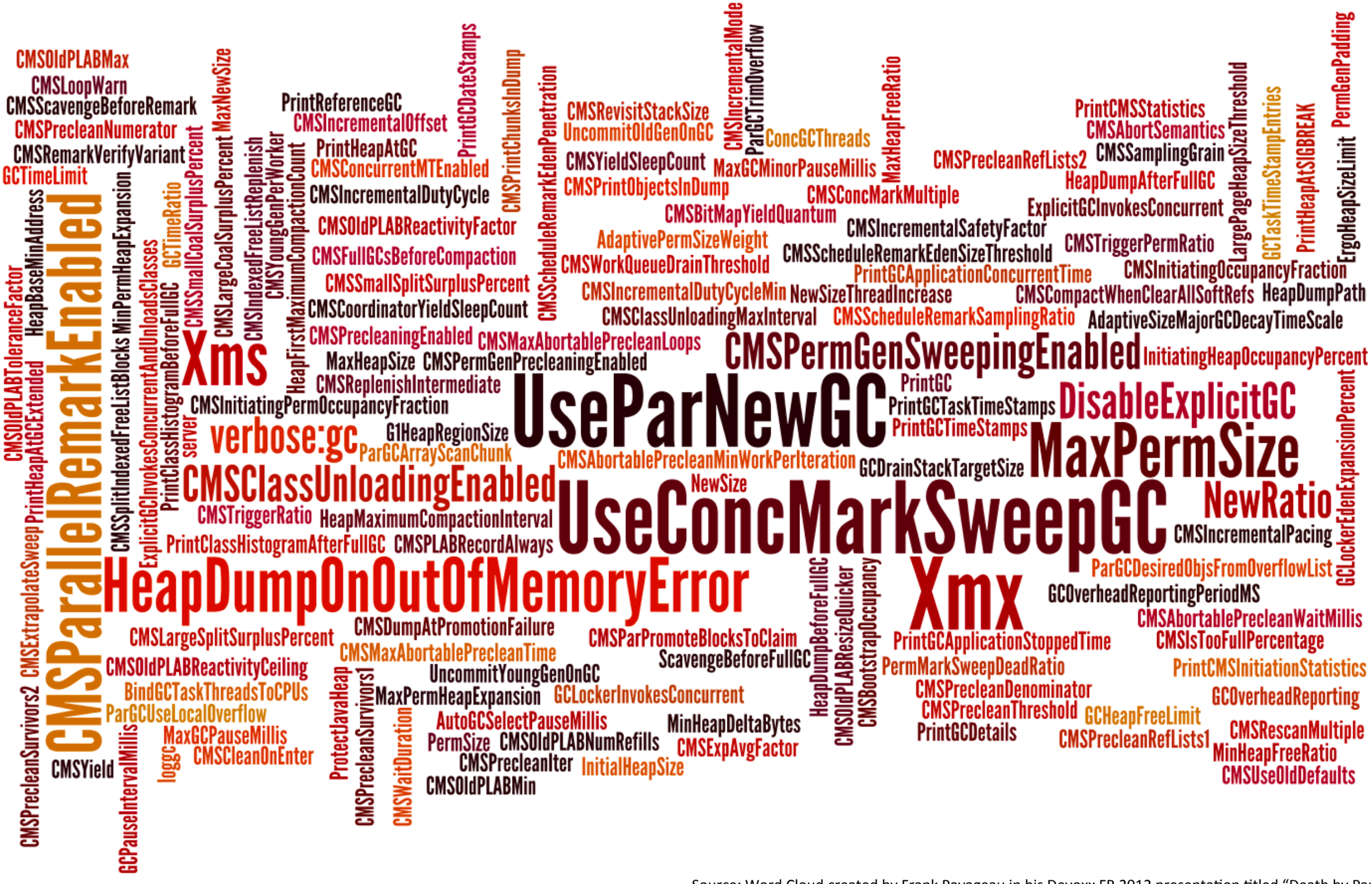
Java GC tuning is "hard"...

Examples of actual command line GC tuning parameters:

```
Java -Xmx12g -XX:MaxPermSize=64M -XX:PermSize=32M -XX:MaxNewSize=2g
        -XX:NewSize=1g -XX:SurvivorRatio=128 -XX:+UseParNewGC
        -XX:+UseConcMarkSweepGC -XX:MaxTenuringThreshold=0
        -XX:CMSInitiatingOccupancyFraction=60 -XX:+CMSParallelRemarkEnabled
        -XX:+UseCMSInitiatingOccupancyOnly -XX:ParallelGCThreads=12
        -XX:LargePageSizeInBytes=256m ...

Java -Xms8g -Xmx8g -Xmn2g -XX:PermSize=64M -XX:MaxPermSize=256M
        -XX:-OmitStackTraceInFastThrow -XX:SurvivorRatio=2 -XX:-UseAdaptiveSizePolicy
        -XX:+UseConcMarkSweepGC -XX:+CMSConcurrentMTEnabled
        -XX:+CMSParallelRemarkEnabled -XX:+CMSParallelSurvivorRemarkEnabled
        -XX:CMSMaxAbortablePrecleanTime=10000 -XX:+UseCMSInitiatingOccupancyOnly
        -XX:CMSInitiatingOccupancyFraction=63 -XX:+UseParNewGC -Xnoclassgc ...
```

A few GC tuning flags



Source: Word Cloud created by Frank Pavageau in his Devoxx FR 2012 presentation titled “Death by Pauses”

The complete guide to Zing GC tuning

java -Xmx40g

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So what's next?

GC is only the biggest problem...

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JVMs make many tradeoffs often trading speed vs. outliers

- Some speed techniques come at extreme outlier costs
  - E.g. ("regular") biased locking
  - E.g. counted loops optimizations
- Deoptimization
- Lock deflation
- Weak References, Soft References, Finalizers
- Time To Safe Point (TTSP)

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Time To Safepoint (TTSP)
Your new #1 enemy

- (Once GC itself was taken care of)
- Many things in a JVM (still) use a global safepoint
  - All threads brought to a halt, at a "safe to analuze" point in code, and then released after work is done.
  - E.g. GC phase shifts, Deoptimization, Class unloading, Thread Dumps, Lock Deflation, etc. etc.
- A single thread with a long time-to-safepoint path can cause an effective pause for all other threads
- Many code paths in the JVM are long...

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Time To Safepoint (TTSP)
the most common examples

- Array copies and object clone()
- Counted loops
- Many other other variants in the runtime...
- Measure, Measure, Measure...
- Zing has a built-in TTSP profiler
- At Azul, I walk around with a 0.5msec stick...

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OS related stuff (once GC and TTSP are taken care of)

- OS related hiccups tend to dominate once GC and TTSP are removed as issues.
- Take scheduling pressure seriously (Duh?)
- Hyper-threading (good? bad?)
- Swapping (Duh!)
- Power management
- Transparent Huge Pages (THP).
- ...

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Takeaway: In 2013, "Real" Java is finally viable for low latency applications

- GC is no longer a dominant issue, even for outliers
- 2-3msec **worst observed case** with "easy" tuning
- < 1 msec **worst observed case** is very doable
- No need to code in special ways any more
  - You can finally use "real" Java for everything
  - You can finally 3rd party libraries without worries
  - You can finally use as much memory as you want
  - You can finally use regular (good) programmers

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One-liner Takeaway:

Zing: A cure for the Java hiccups

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Q & A

One-liner Takeaway:

Zing: A cure for the Java hiccups

jHiccup:

http://www.azulsystems.com/dev_resources/jhiccup

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