Performance Considerations in Concurrent Garbage-Collected Systems

Peter Holditch, Chief Architect EMEA, Azul Systems

Presented to JAOO

2008 Garbage Collection Series

About the speaker

Peter Holditch (Chief Architect, EMEA), Azul Systems

- Working with distributed TP systems for nearly 20 years
- Working with java TP systems since WLS 4.0 (9 years ago…)
- Dealing with java application performance / scale problems daily
- Concurrent GC is a must have for this…
  - Can’t scale without it

About Azul

- Azul makes scalable Java Compute Appliances
  - Power Java Virtual Machines on Solaris OS, Linux, AIX, HPUX
  - Scale individual instances to 100s of cores and 100s of GB
  - Production installations ranging from 1GB to 320GB of heap
- All our customers run business-critical java systems aided by our hardware

What's a concurrent garbage collector?

A Concurrent Collector performs garbage collection work concurrently with the application's own execution

A Parallel Collector uses multiple CPUs to perform garbage collection

Agenda

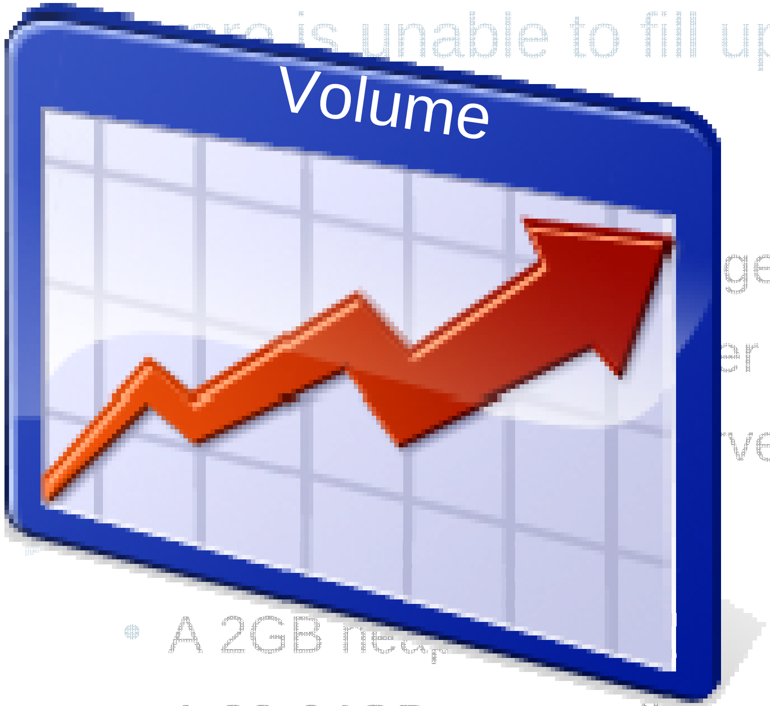
- Background – The big picture
- A load on garbage – The gory details
  - Failure & Sensitivity
  - Terminology & Metrics
  - Detail and inter-relations of key metrics
  - Collector mechanism examples
- Testing Recommendations
- Q & A

Why we really need concurrent collectors

Software is unable to fill up hardware effectively

- 2000:
  - A 512MB heap was “large”
  - A 1GB commodity server was “large”
  - A 2 core commodity server was “large”
- 2008:
  - A 2GB heap is “large”
  - A 32-64GB commodity server is “medium”
  - An 8-16 core commodity server is “medium”
- The erosion started in the late 1990s

Why we **really** need concurrent collectors



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Benefits for trading platforms

CALYPSO

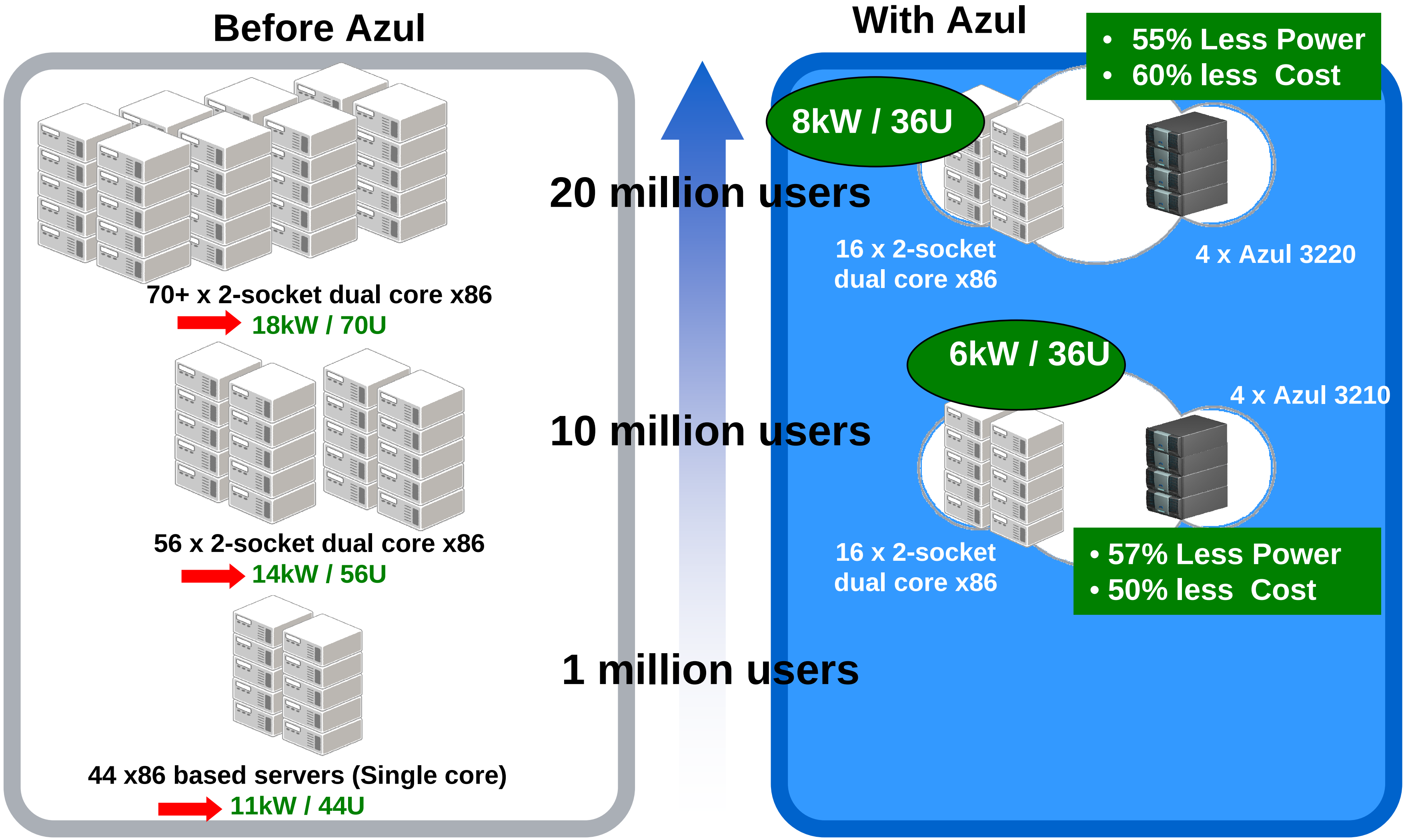
User	Issue	Azul benefit to Data Server	Benefit
NY Investment Bank #1	Trading volumes peak at 156k conc > 10 se tim	Heap size increased	Trading volume increased .6M concurrent response times
NY Investment Bank #2	Ba tra ho Sta GC live		ion reduced s eporting data ng throughput bility and consistency
UK Investment Bank #1	4-h job Lin co		ed by 4X to eporting data ng throughput
UK Investment bank #2	End-of to 150k tr Trading vo trades / second 3 minute peak GC pauses with 10 GB heap	GC pauses reduced from 3 mins to < 1 second	clearing volume d 2X to 300k trades volume increased 2X to 12 trades / second Fast, consistent response times

10x increase in trading volume
3-4x shorter batch duration
2x greater clearing volume

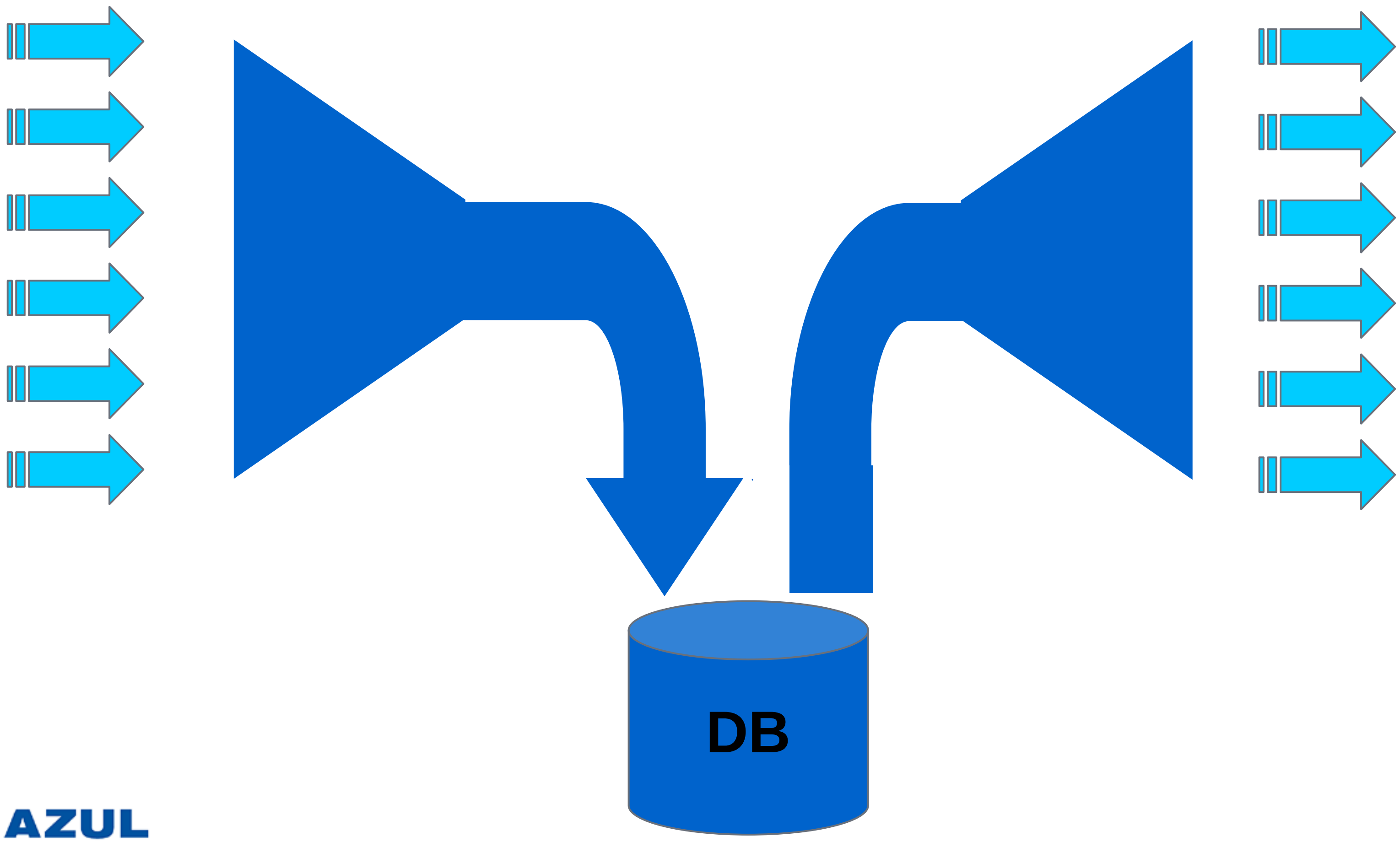
Ability to run on-line processing and end of day concurrently

Azul uniquely delivers these benefits
with no application changes
(and in a reduced datacentre footprint)

Scale Without Sprawl



High throughput, large dataset problems



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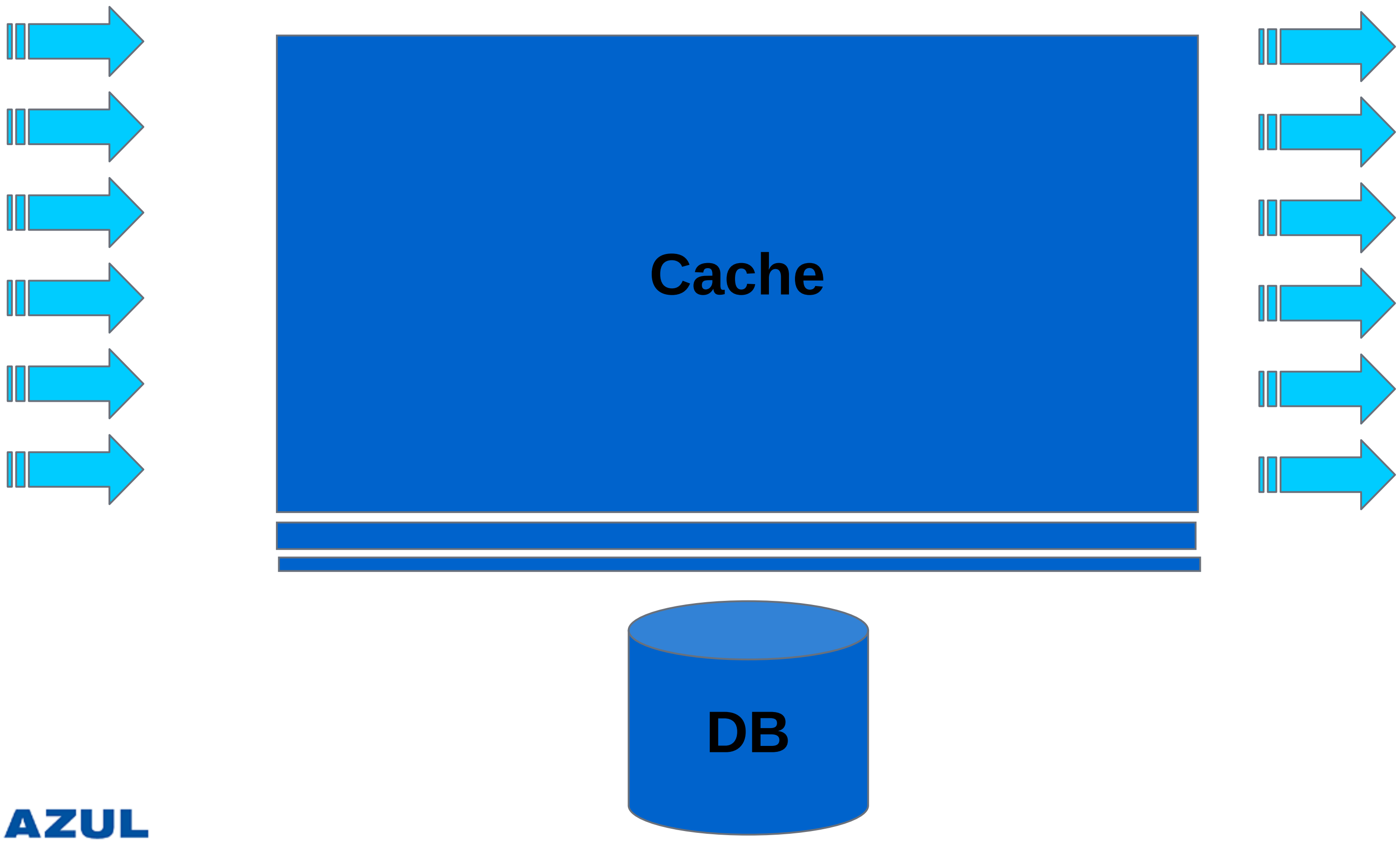
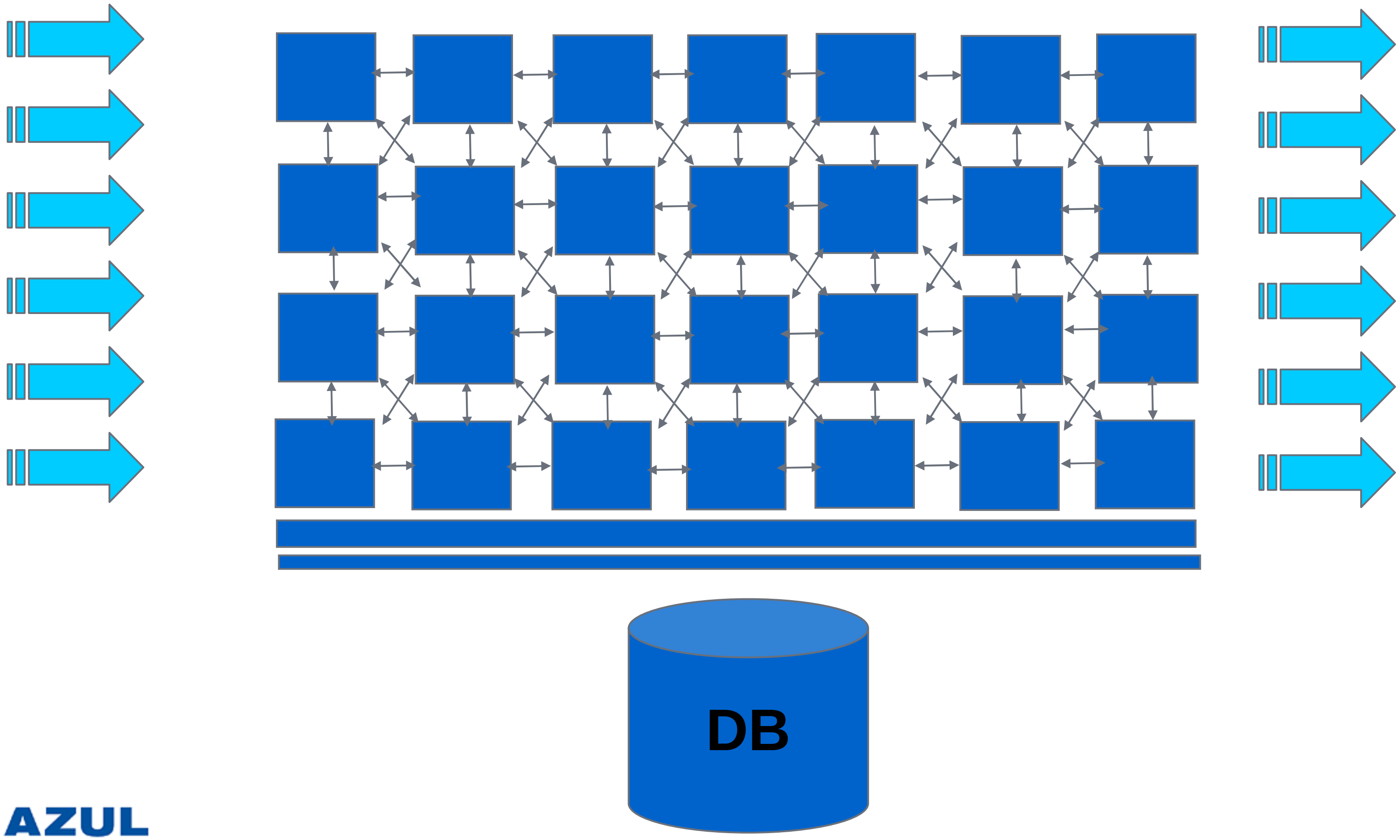


High throughput, large dataset problems



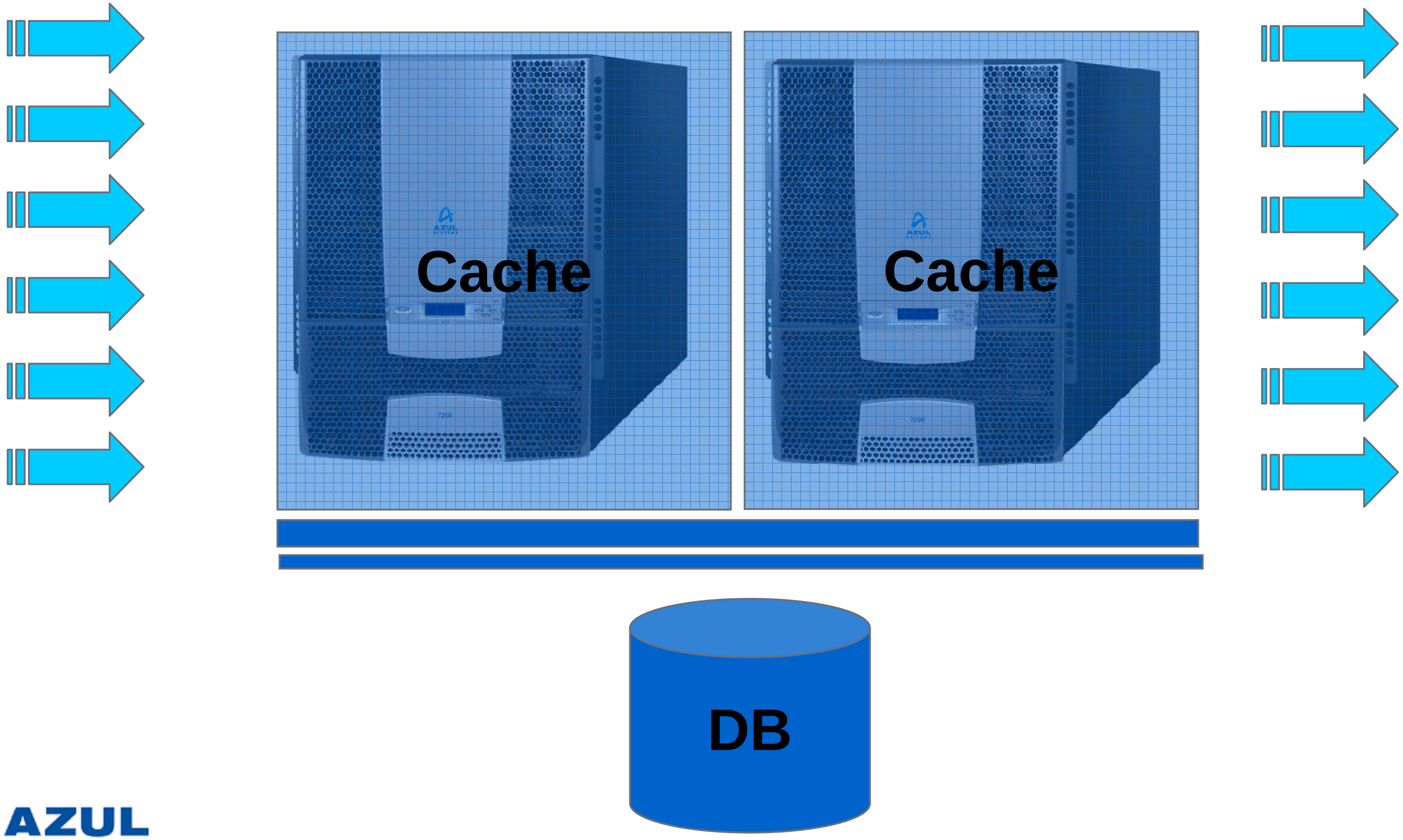
High throughput, large dataset problems

GigaSpaces

GEMFIRE THE ENTERPRISE DATA FABRIC

TERRACOTTA

ORACLE Coherence



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What constitutes "failure" for a collector?

It's not just about correctness any more

- A Stop-The-World collector fails if it gets it wrong…
- A concurrent collector [also] fails if it stops the application for longer than requirements permit
  - "Occasional pauses" longer than SLA allows are real failures
    - Even if the Application Instance or JVM didn't crash
  - Otherwise, you would have used a STW collector to begin with
- Simple example: Clustering
    - Node failover must occur in X seconds or less
    - A GC pause longer than X will trigger failover. It's a fault.
      (If you don't think so, ask the guy whose pager just went off…)

Concurrent collectors can be sensitive

Go out of the smooth operating range, and you'll pause

- Correctness now includes response time
- Just because it didn't pause under load X, doesn't mean it won't pause under load Y
- Outside of the smooth operating range:
  - More state (with no additional load) can cause a pause
  - More load (with no additional state) can cause a pause
  - Different use patterns can cause a pause
- Understand/Characterize your smooth operating range

Terminology

Useful terms for discussing concurrent collection

- Mutator
  - Your program…
- Parallel
  - Can use multiple CPUs
- Concurrent
  - Runs concurrently with program
- Pause time
  - Time during which mutator is not running any code
- Generational
  - Collects young objects and long lived objects separately.
- Promotion
  - Allocation into old generation
- Marking
  - Finding all live objects
- Sweeping
  - Locating the dead objects
- Compaction
  - Defragments heap
  - Moves objects in memory
  - Remaps all affected references
  - Frees contiguous memory regions

Metrics

Useful metrics for discussing concurrent collection

- Heap population (aka Live set)
  - How much of your heap is alive
- Allocation rate
  - How fast you allocate
- Mutation rate
  - How fast your program updates references in memory
- Heap Shape
  - The shape of the live object graph
  - * Hard to quantify as a metric...
- Object Lifetime
  - How long objects live
- Cycle time
  - How long it takes the collector to free up memory
- Marking time
  - How long it takes the collector to find all live objects
- Sweep time
  - How long it takes to locate dead objects
  - * Relevant for Mark-Sweep
- Compaction time
  - How long it takes to free up memory by relocating objects
  - * Relevant for Mark-Compact

Cycle Time

How long until we can have some more free memory?

- Heap Population (Live Set) matters
  - The more objects there are to paint, the longer it takes
- Heap Shape matters
  - Affects how well a parallel marker will do
  - One long linked list is the worst case of most markers
- How many passes matters
  - A multi-pass marker revisits references modified in each pass
  - Marking time can therefore vary significantly with load

Heap Population (Live Set)

It’s not as simple as you might think…

- In a Stop-The-World situation, this is simple
  - Start with the “roots” and paint the world
  - Only things you have actual references to are alive
- When mutator runs concurrently with GC:
  - Not a “snapshot” of a single program state
  - Objects allocated during GC cycle are considered “live”
  - Objects that die after GC starts may be considered “live”
  - Weak references “strengthened” during GC…
- So assume:
  - Live_Set >= STW_live_set + (Allocation_Rate * Cycle_time)

Mutation rate

Does your program do any real work?

- Mutation rate is generally linear to work performed
  - The higher the load, the higher the mutation rate
- A multi-pass marker can be sensitive to mutation:
  - Revisits references modified in each pass
  - Higher mutation rate → longer cycle times
  - Can reach a point where marker cannot keep up with mutator
  - e.g. one marking thread vs.15 mutator threads
- Some common use patterns have high mutation rates
  - e.g. LRU cache

Object lifetime

Objects are active in the Old Generation

- Most **allocated** objects do die young
  - So generational collection is an effective filter
- However, most **live** objects are old
  - You’re not just making all those objects up every cycle…
- Large heaps tend to see real churn & real mutation
  - e.g. caching is a very common use pattern for large memory
- OldGen is under constant pressure in the real world
  - Unlike some/most benchmarks (e.g. SPECjbb)

Major things that happen in a pause

The non-concurrent parts of “mostly concurrent”

- If collector does Reference processing in a pause
  - Weak, Soft, Final ref traversal
  - Pause length depends on # of refs.
  - Sensitive to common use cases of weak refs
    - e.g. LRU & multi-index cache patterns
- If the collector marks mutated refs in a pause
  - Pause length depends on mutation rate
  - Sensitive to load
- If the collector performs compaction in a pause…

More things that may happen in a pause

More “mostly concurrent” secrets

- When collector does Code & Class things in a pause
  - Class unloading, Code cache cleaning, System Dictionary, etc.
  - Can depend on class and code churn rates
  - Becomes a real problem if full collection is required (PermGen)
- GC/Mutator Synchronization, Safe Points
  - Can depend on time-to-safepoint affecting runtime artifacts:
    - Long running no-safepoint loops (some optimizers do this).
    - Huge object cloning, allocation (some runtimes won’t break it up).
- Stack scanning (look for refs in mutator stacks)
  - Can depend on # of threads and stack depths

Fragmentation & Compaction

You can't delay it forever

- Fragmentation *will* happen
  - Compaction can be delayed, but not avoided
  - "*Compaction is done with the application paused. However, it is a necessary evil, because without it, the heap will be useless…*" (JRockit RT tuning guide).
- If Compaction is done as a stop-the-world pause
  - It will generally be your worst case pause
  - It is a likely failure of concurrent collection
- Measurements without compaction are meaningless
  - Unless you can prove that compaction won't happen (Good luck with that)

Example: HotSpot CMS

Collector mechanism examples

- Stop-the-world compacting new gen (ParNew)
- Mostly Concurrent, non-compacting old gen (CMS)
  - Mostly Concurrent marking
    - Mark concurrently while mutator is running
    - Track mutations in card marks
    - Revisit mutated cards (repeat as needed)
    - Stop-the-world to catch up on mutations, ref processing, etc.
  - Concurrent Sweeping
  - Does not Compact (maintains free list, does not move objects)
- Fallback to Full Collection (Stop the world, serial).
    - Used for Compaction, etc.

Example: Azul GPGC

Collector mechanism examples

- Concurrent, compacting new generation
- Concurrent, compacting old generation
- Concurrent guaranteed-single-pass marker
  - Oblivious to mutation rate
  - Concurrent ref (weak, soft, final) processing
- Concurrent Compactor
  - Objects moved without stopping mutator
  - Can relocate entire generation (New, Old) in every GC cycle
- No Stop-the-world fallback
  - Always compacts, and does so concurrently

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Measurement Recommendations

When you are actually interested in the results…

- Measure application – not synthetic tests
  - Garbage in, Garbage out
- Avoid the urge to tune GC out of the testing window
  - You're only fooling yourself
  - Your application needs to run for more than 20 minutes, right?
  - Most industry benchmarks are tuned to avoid GC during test ☹
- Rule of Thumb:
  - You should see 5+ of the "bad" GCs during test period
  - Otherwise, you simply did not test real behavior
  - Test until you can show it's stable (e.g. What if it trends up?)
  - Believe your application, not -verbosegc

Measurement Techniques

Make reality happen

- Aim for 20-30 minute “stable load” tests
  - If test is longer, you won’t do it enough times to get good data
  - Don’t “ramp” load during test period – it will defeat the purpose
  - We want to see several days worth of GC in 20-30 minutes
- Add low-load noise to trigger “real” GC behavior
  - Don’t go overboard
  - A moderately churning large LRU cache can often do the trick
  - A gentle heap fragmentation inducer is a sure bet
  - Can easily be added orthogonally to application activity
  - See Azul’s “Fragger” example (http://e2e.azulsystems.com)

Establish smooth operating range

Know where it works, and know where it doesn't…

- Test main metrics for sensitivity
- Stress Heap population, allocation, mutation, etc.
- Add artificial load-linear stress if needed
  - E.g. Increase allocation and mutation per transaction
  - E.g. Increase state per session, increase static state
  - E.g. Increase session length in time
  - Drive load with artificially enhanced GC stress
  - Keep increasing until you find out where GC breaks SLA in test
  - Then back off and test for stability

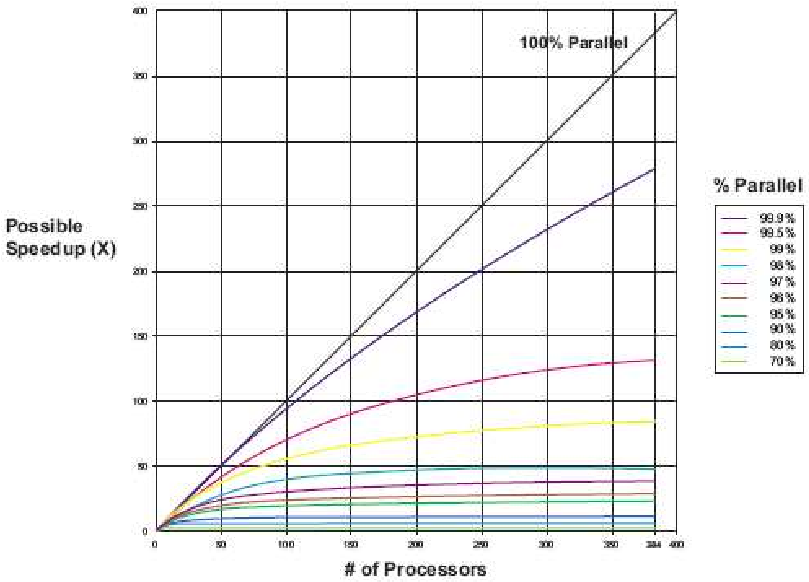
Summary

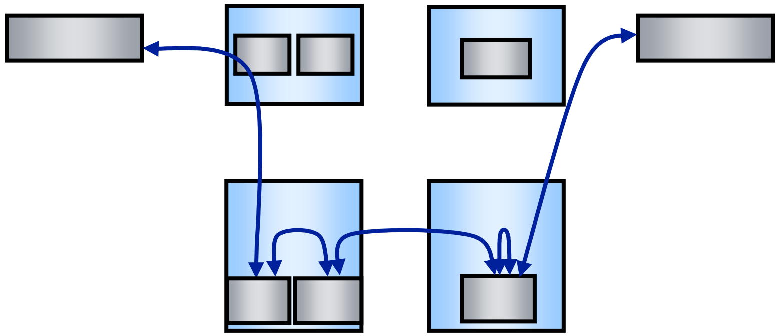
Know where the cliff is, then stay away from the edge…

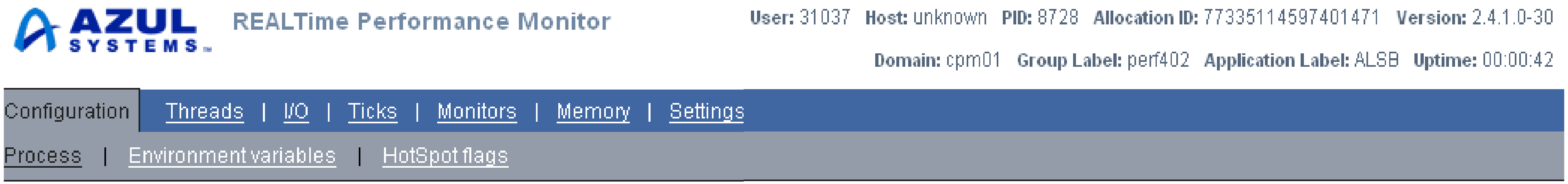
- Sensitivity is key
  - If it fails, it will be without warning
- Know where you stand on key measurable metrics
  - Application driven: Live Set, Allocation rate, Heap size
  - GC driven: Cycle times, Compaction Time, Pause times
- Deal with robustness first, and only then with efficiency
  - But efficient and 2% away from failure is not a good thing
- Establish your envelope
  - Only then will you know how safe (or unsafe) you are

http://e2e.azulsystems.com

Other Azul application scale enablers …







Q&A

Performance Considerations in Concurrent Garbage–Collected Environments

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Tak!

If you have further questions… Please visit our booth (en route to kammermusik sal, rytmisk sal)

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