G1 – Not Never Done!

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Program Agenda

1. Parallel Full GC
2. Faster Card Scanning
3. Rebuild Remembered Sets Concurrently
4. Abortable Mixed Collections
5. Automatic Thread Sizing
6. Participate!
Program Agenda

1. Parallel Full GC
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G1 Parallel Full GC

• G1 Full GC very slow
  – High worst-case latencies and bad throughput
  – Goal: be on par with Parallel GC Full GC

• Solution
  – Parallelize Mark-Sweep-Compact
G1 Parallel Full GC

Relative Full GC time (G1 Parallel Full GC = 1)

- system.gc() test
  - performs many System.gc(), very small live set, 5G heap

- BigRAMTester
  - LRU-cache-stress test application, many references, large (90%) live set, 10G heap (JDK-8152438)

- TreeFragger
  - Fragmentation-inducing benchmark from RedHat, medium live set, 20G heap
G1 Parallel Full GC

• Available since build jdk-10-ea+34
Program Agenda

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Faster Card Scanning

What is a card?

Java Heap

Region

Object

Reference
Faster Card Scanning

What is a card?

Java Heap

Region
Object
Reference
Faster Card Scanning

What is a card?

Java Heap

Region

Object

Reference

Move
Faster Card Scanning

What is a card?

Java Heap

Region
Object
Reference
Remembered set
Remembered set entry

What is a card?
Faster Card Scanning

What is a card?

Java Heap

Region
Object
Reference
Remembered set
Remembered set entry

Move
Faster Card Scanning

What is a card? A small subdivision of memory
Faster Card Scanning

Problem

• GC needs to find references in cards in remembered sets to moved objects quickly
Faster Card Scanning

Solution

• Refactor and improve scanning and updating remembered sets
  – Remove overly generic code
  – Replace by specialized code for different situations
  – Subsume and remove obsolete checks
Faster Card Scanning

Normalized Pause Time on BigRAMTester

Pause time normalized to worst [%]

GC # [1]

job-10-max 20
Faster Card Scanning

![Normalized Pause Time on BigRAMTester](image-url)
Faster Card Scanning

• Available since build jdk-10-ea+21
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Rebuild Remembered Sets Concurrently

Problem

• Remembered sets may occupy a lot of memory
  – Known to take ~20% of total heap in some situations
    • E.g. 20GB with a 100GB heap
  – Upper Bounds are even higher
    • $O(#\text{regions}^2)$

• Old regions use most remembered set memory
Rebuild Remembered Sets Concurrently

Collection Cycle - Some Young-Only GCs

YO  IM  YO  YO  YO  Mixed

YO ... Young-Only
IM ... Initial-Mark
Rebuild Remembered Sets Concurrently

Collection Cycle - Start marking with Initial Mark

YO … Young-Only
IM … Initial-Mark
Rebuild Remembered Sets Concurrently
Collection Cycle - Some more Young-Only while marking

YO ... Young-Only
IM ... Initial-Mark

YO ... Young-Only

Remembered set

Region
Object
Rebuild Remembered Sets Concurrently

Collection Cycle - Marking finished

YO IM YO

Remark

Cleanup

YO YO Mixed

YO ... Young-Only
IM ... Initial-Mark

Remembered set

Region

Object
Rebuild Remembered Sets Concurrently

Collection Cycle - Create “live data map”

YO  IM  YO  YO
Remark

YO  Mixed
Cleanup

YO ... Young-Only
IM  ... Initial-Mark

Remembered set

Region
Object

Region
Object
Rebuild Remembered Sets Concurrently
Collection Cycle - Clean out obsolete remembered set entries

YO IM YO YO
Remark Cleanup YO Mixed
YO ... Young-Only
IM ... Initial-Mark

Remembered set

Region
Object
Rebuild Remembered Sets Concurrently
Collection Cycle - Wait for old gen reclamation start

YO IM YO YO YO Mixed
YO ... Young-Only
IM ... Initial-Mark

Remembered set
Region
Object
Rebuild Remembered Sets Concurrently

Collection Cycle - Region gets evacuated
Rebuild Remembered Sets Concurrently

Collection Cycle - Region does not get reclaimed

YO  IM  YO  YO  YO  Mixed

YO ... Young-Only
IM ... Initial-Mark

Remembered set

Region
Object
Rebuild Remembered Sets Concurrently

**Key observations**

- G1 maintains remembered sets all the time for all regions
  - Not required
    - Young regions: always
    - Old regions: only needed during Mixed GC

- Removing obsolete remembered set entries is costly
  - Create live data map
  - Remove remembered set entries during Cleanup
Rebuild Remembered Sets Concurrently

Solution

• Only keep required remembered sets when needed
  – For collection set regions only (<< all regions!)
  – Minimizes fragmentation

• Construct remembered sets concurrently between Remark and Cleanup
  – Instead of live data map calculation
  – No removal of obsolete remembered set entries during Cleanup pause
Rebuild Remembered Sets Concurrently

**Side effects**

- Lengthens time from Remark to Cleanup
  - Up to 30% longer marking cycles
  - Dynamic IHOP automatically adapts

- Improves Throughput and Pause Times
  - Less work outside of rebuild phase, creates dense remembered sets
Rebuild Remembered Sets Concurrently

Side effects

• Lengthens time from Remark to Cleanup
  – Up to 30% longer marking cycles
  – Dynamic IHOP automatically adapts

• Improves Throughput and Pause Times
  – Less work outside of rebuild phase, creates dense remembered sets

• Allows bounded remembered set memory usage
  – Just stop collecting remembered sets for some regions
Rebuild Remembered Sets Concurrently

Remembered set memory usage on BigRAMTester

• Baseline:
  – ~10% of maximum heap size

• Current:
  – ~0.5% outside of rebuilding and mixed gc phase
  – ~7.5% after rebuilding 60% of the heap
Rebuild Remembered Sets Concurrently

Normalized Pause Time on BigRAMTester

Pause time normalized to worst [%]

GC # [1]

0% 20% 40% 60% 80% 100%

jdk-10-es+20  jdk-10-es+21
Rebuild Remembered Sets Concurrently

Normalized Pause Time on BigRAMTester

Pause time normalized to worst [%]

GC # [1]

jhm-10-mu+20  jhm-10-mu+31  jhm-latest-dev
Rebuild Remembered Sets Concurrently

• More information: JDK-8180415
• Work in progress
Program Agenda

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Abortable Mixed Collections

Problem

• G1 strives to keep pause time goal
  – Determines “Collection set” using predictions at the start of GC
• Particularly during Mixed collections predictions are hard
  – G1 mispredicts often
  – Significant effort to tune Mixed collection pauses
Abortable Mixed Collections

Java Heap

Free
Old
Young
Abortable Mixed Collections

Collection set

Java Heap

Free
Old
Young
Abortable Mixed Collections

Current evacuation policy

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free

Old

Young
Abortable Mixed Collections

Current evacuation policy

Java Heap Before

Java Heap After

Free
Old
Young

Time taken

Max Pause Time

Current evacuation policy
Abortable Mixed Collections

Current evacuation policy exceeds pause time

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free
Old
Young
Abortable Mixed Collections

Solution

• Incrementally evacuate collection set
  – “Abort” evacuation if next increment would take too long
Abortable Mixed Collections

Try again, incrementally

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free

Old

Young
Abortable Mixed Collections

First Young regions as a whole

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free  Old  Young
Abortable Mixed Collections

“Large” set of Old regions

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free
Old
Young

Large set of Old regions
Abortable Mixed Collections

“Small” set of Old regions

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free

Old

Young
Abortable Mixed Collections

“Abort”

Java Heap Before

Java Heap After

Max Pause Time

Time taken

Free
Old
Young
Abortable Mixed Collections

• Enter “abortable mode” only if needed
  – To decrease overhead
• More information
  – JEP draft: Abortable mixed collections for G1 [JDK-8190269]
• Work in progress
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Automatic Thread Sizing

Problem

• Manually setting the right number of threads impossible
  – Or even not even desired
  – Lots of work as hardware, application, even application phase specific
  – Can only set number of threads statically for everything
    • e.g. -XX:ParallelGCThreads, -XX:ConcGCThreads, -XX:ParallelRefProcEnabled

• Benefits of using the right number of threads
  – Saves resources, faster startup
  – (Small pause time improvements)
Automatic Thread Sizing

Solution

• Let G1 automatically decide the optimal number of threads
  – G1 already tracks lots of statistics about a GC
    • Actual bytes copied
    • References processed
    • Cards scanned
    • ...
  – Actually G1 already does that for a lot of phases since JDK9....
Automatic Thread Sizing - Example

**Overall Pause time**

**#Threads in Evacuation phase**
Automatic Thread Sizing

• More information: JEP 308: G1 ergonomics [JDK-8172792]
• Work in progress
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Participate!

• Hang out on hotspot-gc-use@openjdk.java.net
  – Provide answers to community

• Fix small bugs
  – Bugs labeled “starter”/“cleanup” on Hotspot GC component at https://bugs.openjdk.java.net
  – Discuss at hotspot-gc-dev@openjdk.java.net

• Interesting larger projects
Participate! - Larger projects

- NMethod barriers
- Throughput barriers
- NUMA support
Participate! – NMethod barriers

- NMethod barriers
  - Small piece of code that is run before NMethod is entered
    - Could be used to disable pre-barrier when not in use
    - Most of the time!

```java
... cmpb ofs(%tls), 0 ... nop
jz NoPreBarrier ... nop
call slow_path ... nop
NoPreBarrier:
... ...
```
Participate! – Throughput barriers

• Throughput barriers
  – G1 has throughput deficiencies
  – Mostly write barrier related

• Use Parallel GC barrier instead of large G1 barrier
  – Increases throughput
  – May or may not have some impact on latency/pause time

• More information: FOSDEM 2017 talk
  Three ideas for the G1 GC (and how to get involved)
Participate! - NUMA support

• NUMA support
  – Improve throughput on large multi-socket machines
  – Exploit memory locality
  – JEP 137 open for 6 years now (JDK-8046147)
Questions?

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