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Generational Garbage Collection

Theory and Best Practices

Overview

- Introduction to Generational Garbage Collection

- The “nursery” space
  – aka the “young” generation

- The “tenured” space
  – aka the “old” generation

- Migrating from other garbage collection modes

Introduction to Generational Garbage Collection

- **Motivation:** **Most objects die young**

- Most objects are “temporary”
  - Used as part of a calculation or transform
  - Used as part of a business transaction

- Simple example: String concatenation
  - String str = new String ("String ");
  - str += "Concatenated!";

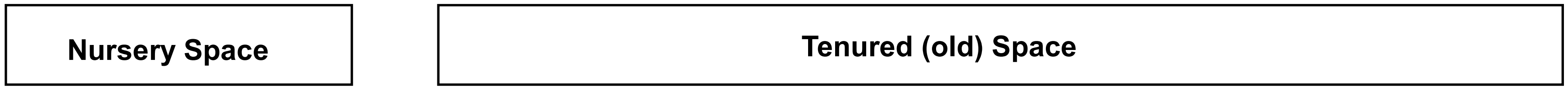
  - Results in the creation of 3 objects:
    - String object, containing “String “
    - A StringBuffer, containing “String “, and with “Concatenated!” then appended
    - String object, containing the result: “String Concatenated!”

  - 2 of those 3 objects are no longer required!

Introduction to Generational Garbage Collection

- **Solution:** **Garbage collect young objects more frequently**

- Create an additional area for young objects (nursery)
  - Create new objects into the additional area
  - Garbage collection focusses on the new area
  - Objects that survive in the new area are moved to the main area



•New object allocations
•GC'd frequently

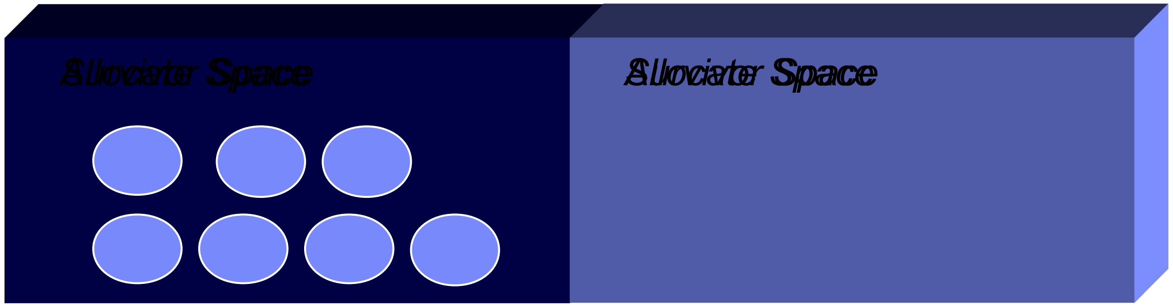
•Objects surviving from the nursery only
•GC'd infrequently

The nursery (young) space

- All objects allocated into the nursery space*
  - * unless objects are too large to fit into the nursery

- Garbage collection focusses on the nursery space
  - Garbage collected frequently
  - Garbage collections are fast (short in duration)
  - Most object do not survive a collection

Nursery space implementation



•Nursery is split into 2 spaces:

- **Allocate space**: used for new allocations and objects that survived previous collections
- **Survivor space**: used for objects surviving this collection

•Collection causes live objects to be:

- copied from allocate space to survivor space
- copied to the tenured space if they have survived sufficient collections

▪ **Note:** spaces are not equal in size – not all objects will survive so Survivor space can be smaller than Allocate space. - “Tilt Ratio”

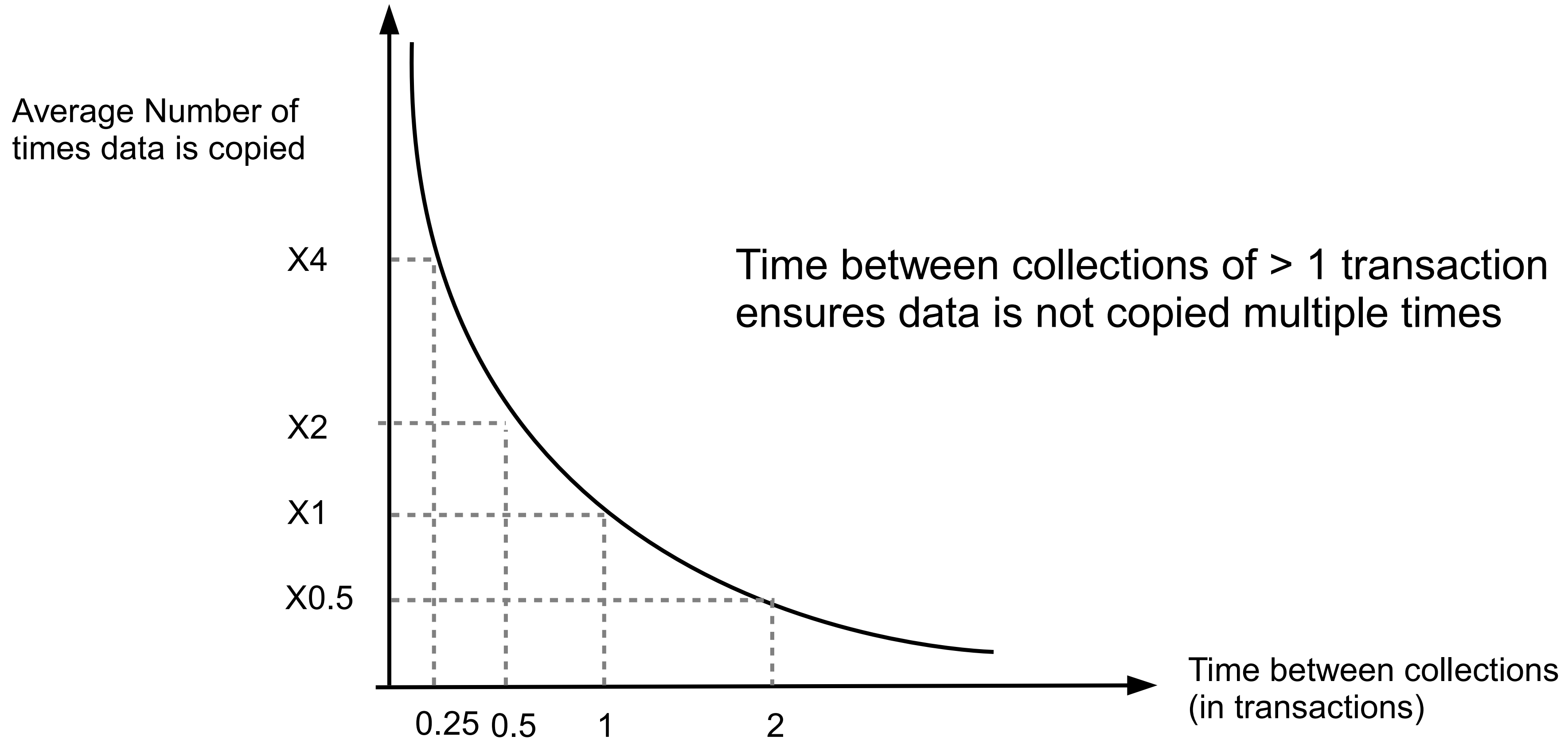
Nursery space considerations

- Nursery collections **work by copying data** from allocate to survivor
  - Copying of data is a relative expensive (time consuming) task
- Nursery collection **duration is proportional to amount of data copied**
  - Number of objects and size of nursery heap are only secondary factors*
- Only a finite / **fixed amount of data needs to copied**
  - The amount of data being used for any in-flight work (transactions)
  - ie. For a WebContainer with 50 threads, there can only be 50 in-flight transactions at any time
- **The duration of a nursery collection is fixed, and dependent on the size of a set of transactions**
  - Not dependent on the size of the nursery*

*size of the heap does have a small effect, but this is related to traversal of memory only

Optimal size for the nursery space

- Theory shows that the longer the time between nursery collections, the less times on average an object is copied:



How large should the nursery be?

- Ideally as large as possible!
  - The larger the nursery, the longer the time between GC cycles
  - The same amount of data is copied regardless
  - Therefore the larger the nursery, the lower the GC overhead

  - Large nurseries also mean very large objects are unlikely to be allocated directly into the tenured space

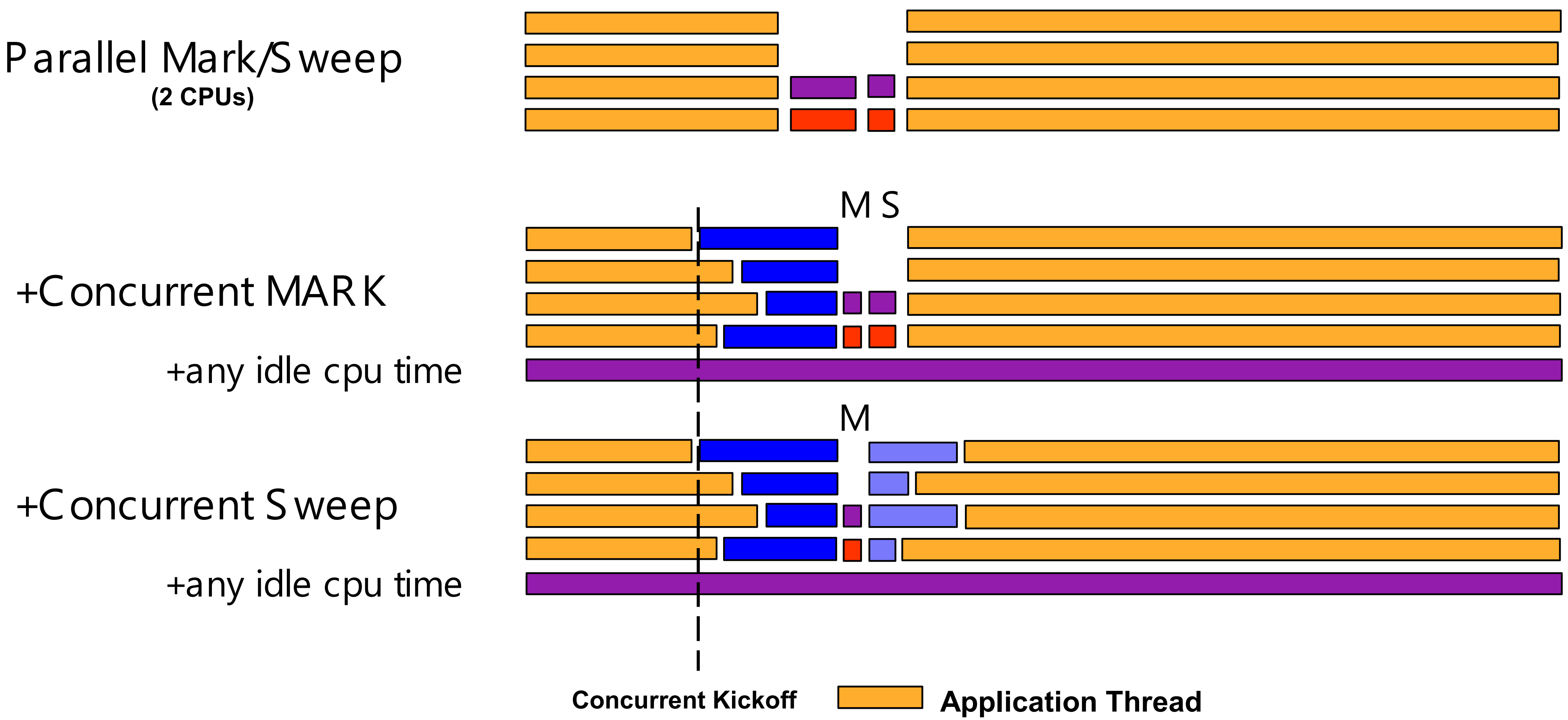
- Disadvantages of very large nursery spaces:
  - Lots a physical memory and process address space is required
    - Not necessarily possible on 32bit hardware

The tenured (old) space

- Exactly the same as the Java heap in the non-Generational case
  - "New" objects just happen to be copied (tenured) from the nursery space
  - Meaning less garbage to collect, and much fewer GC cycles occurring

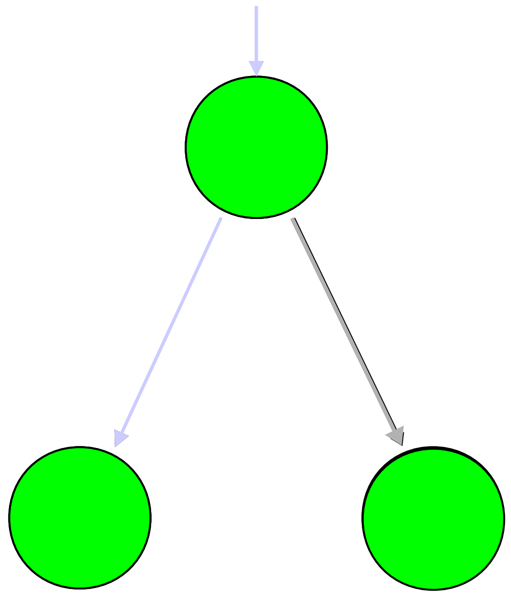
- Garbage collected using parallel concurrent mark/sweep with compaction avoidance
  - The same as running "optavgpause" in the non-Generational case
  - Designed to use available CPUs and processing power using GC helper threads:
    - Additional parked thread per available processing unit
    - Wakes up during GC to share workload
    - Configured using -Xgcthreads
  - Reduces GC pause times by marking and sweeping concurrently
    - Reduction in pause times of 90 to 95% vs. non-concurrent GC

Parallel and Concurrent Mark Sweep Collection



Concurrent Mark – hidden object issue

- Higher heap usage…

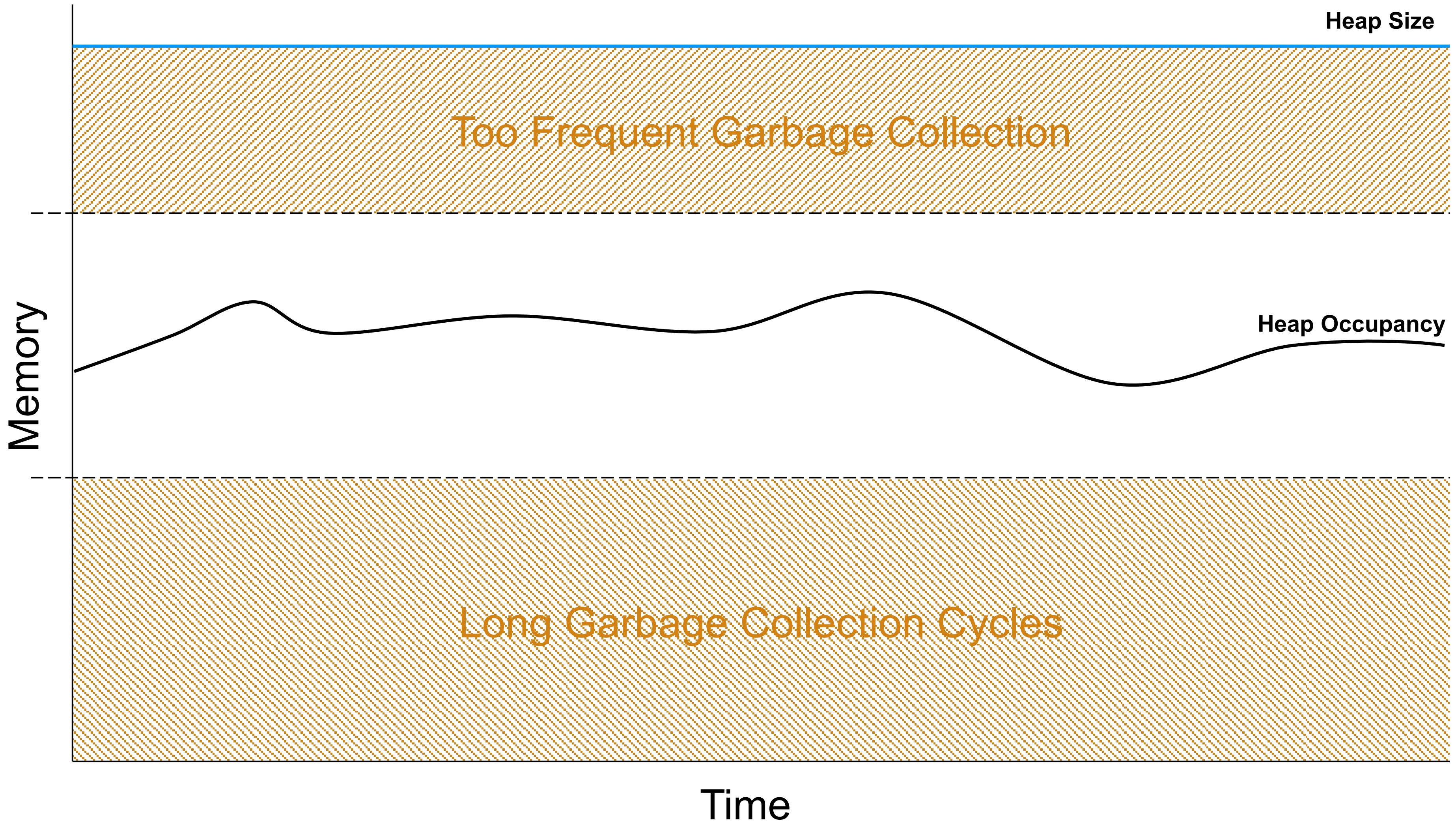


The “correct” tenured heap size

- GC will adapt heap size to keep occupancy between 40% and 70%
  - Heap occupancy over 70% causes frequent GC cycles
    - Which generally means reduced performance
  - Heap occupancy below 40% means infrequent GC cycles, but cycles longer than they needs to be
    - Which means longer pause times that necessary
    - Which generally means reduced performance

- The maximum heap size setting should therefore be 43% larger than the maximum occupancy of the application
  - Maximum occupancy + 43% means occupancy at 70% of total heap
  - eg. For 70MB occupancy, 100MB Max heap required, which is 70MB + 43% of 70MB

The "correct" tenured heap size


Heap Size
Too Frequent Garbage Collection
Memory
Heap Occupancy
Long Garbage Collection Cycles
Time

Fixed heap sizes vs. Variable heap sizes

- Should the heap size be “fixed”?
  - ie. Minimum heap size (-Xms) = Maximum heap size (-Xmx)?

- Each option has advantages and disadvantages
  - As for most performance tuning, you must select which is right for the particular application

- Variable Heap Sizes
  - GC will adapt heap size to keep occupancy between 40% and 70%
  - Expands and Shrinks the Java heap
  - Allows for scenario where usage varies over time
  - Where variations would take usage outside of the 40-70% window

- Fixed Heap Sizes
  - Does not expand or shrink the Java heap

Heap expansion and shrinkage

- Act of heap expansion and shrinkage is relatively “cheap”
- However, a compaction of the Java heap is sometimes required
  - **Expansion:** for some expansions, GC may have already compacted to try to allocate the object before expansion
  - **Shrinkage:** GC may need to compact to move objects from the area of the heap being “shrunk”
- Whilst expansion and shrinkage optimizes heap occupancy, it (usually) does so at the cost of compaction cycles

Conditions for expansion

- Not enough free space available for object allocation after GC has complete
  - Occurs after a compaction cycle
  - Typically occurs where there is fragmentation or during rapid occupancy growth (ie, application startup)

- Heap occupancy is over 70%
  - Compaction unlikely

- More than 13% of time is spent in GC
  - Compaction unlikely

Conditions for shrinkage

- Heap occupancy is under 40%

- And the following is not true:
  - Heap has been recently expanded (last 3 cycles)
  - GC is a result of a System.GC() call

- Compaction occurs if:
  - An object exists in the area being shrunk
  - GC did not shrink on the previous cycle

- Compaction is therefore likely to occur

Introduction to -Xminf and -Xmaxf

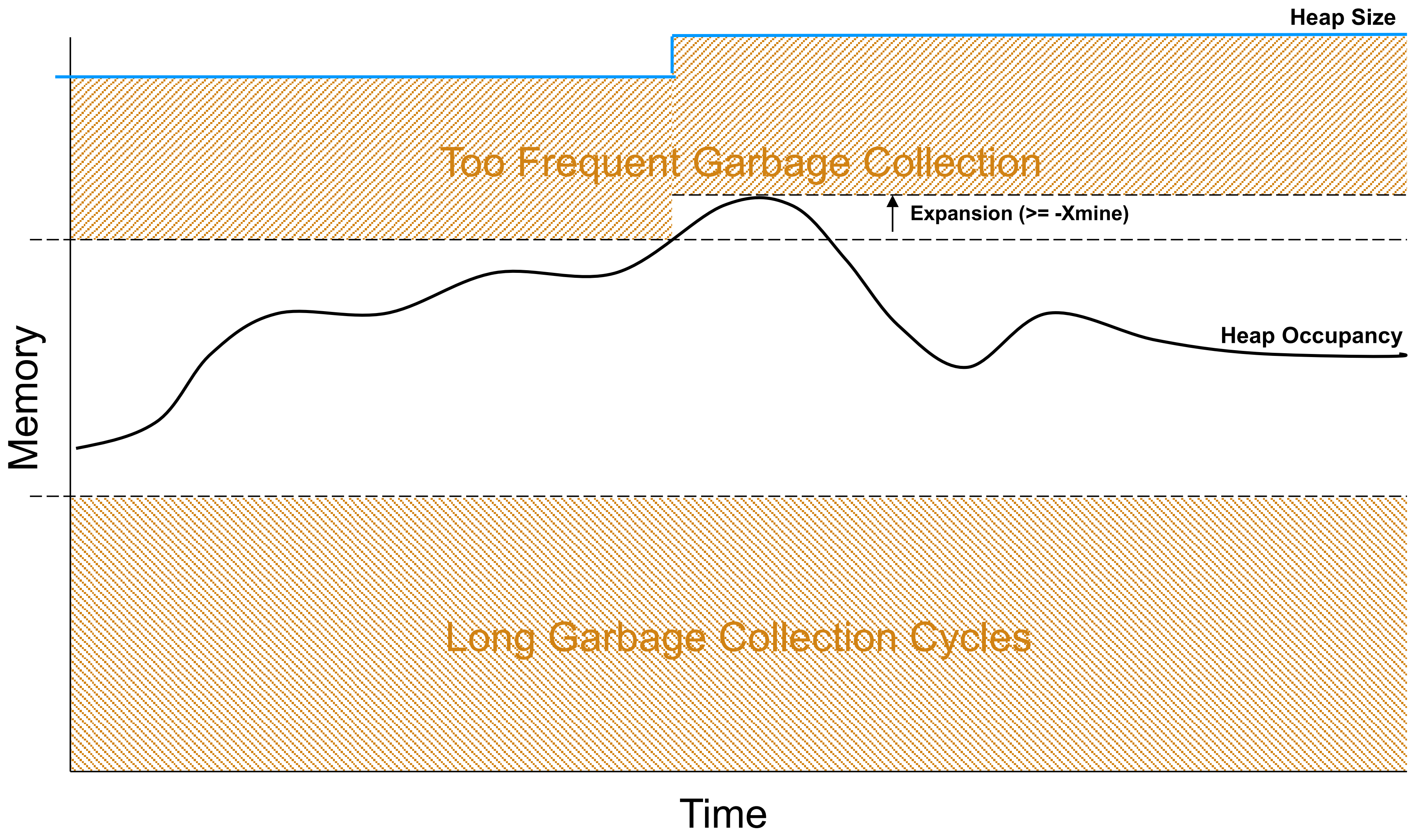
- The –Xmaxf and –Xminf settings control the 40% and 70% occupancy bounds
  - **-Xmaxf:** the maximum heap space free before shrinkage (default is 0.6 for 60%)
  - **-Xminf:** the minimum heap space before expansion (default is 0.3 for 70%)
- Can be used to “move” optimum occupancy window if required by the application
  - eg. Lower heap utilization required for more infrequenct GC cycles
- Can be used to prevent shrinkage
  - -Xmaxf1.0 would mean shrinkage only when heap is 100% free
  - Would completely remove shrinkage capability

Introduction to -Xmine and -Xmaxe

- The –Xmaxe and –Xmine settings control the bounds of the size of each expansion step
  - **-Xmaxe**: the maximum amount of memory to add to the heap size in the case of expansion (default is unlimited)
  - **-Xmine**: the minimum amount of memory to add to the heap size in the case of expansion (default is 1MB)

- Can be used to reduce/prevent compaction due to expansion
  - Reduce expansions by setting a large -Xmine

Garbage Collection managed heap sizing


Heap Size
Too Frequent Garbage Collection
Expansion (>= -Xmine)
Heap Occupancy
Memory
Long Garbage Collection Cycles
Time

Fixed or variable?

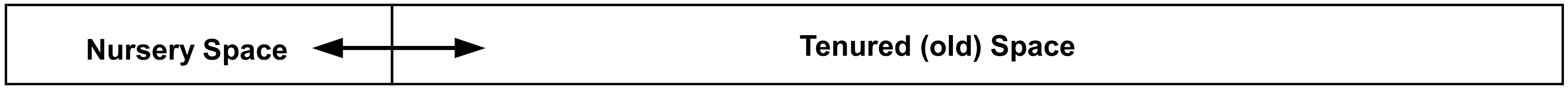
- Again, dependent on application

- For "flat" memory usage, use fixed
- For widely varying memory usage, consider variable

- Variable provides more flexibility and ability to avoid OutOfMemoryErrors
  - Some of the disadvantages can be avoided:
  - -Xms set to lowest steady state memory usage prevents expansion at startup
  - -Xmaxf1 will remove shrinkage
  - -Xminf can be used to prevent compaction before expansion
  - -Xmine can be used to reduce expansions

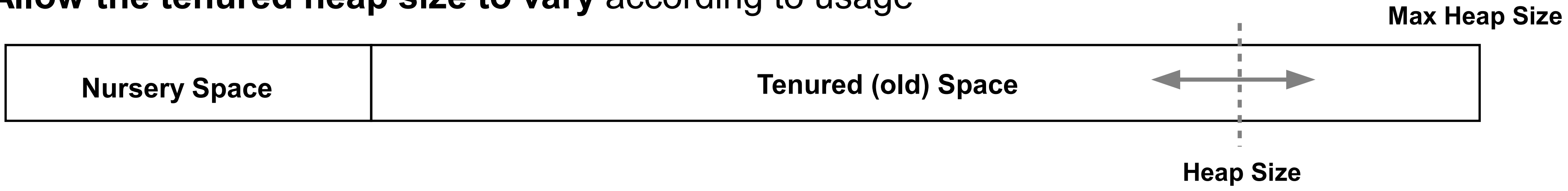
Putting the two together...

- Nursery space and Tenured space are actually allocated as a single chunk of memory
  – Actually possible for the boundary between the nursery and tenured spaces to move:



  – However this is **not recommended**

- **Recommended mode** is to:
  – **Fix the nursery size** at as large a value as possible
  – **Allow the tenured heap size to vary** according to usage



Choosing between Generational and Non-Generational modes

- Rate of Garbage Collection
  - High rates of object “burn” point to large numbers of transitional objects, and therefore the application may well benefit from the use of **gencon**

- Large Object Allocations?
  - The allocation of very large objects adversely affects gencon unless the nursery is sufficiently large enough. The application may well benefit from **optavgpause**

- Large heap usage variations
  - The optavgpause algorithms are best suited to consistent allocation profiles
  - To a certain extent this applies to gencon as well
  - However, **gencon** may be better suited

- Rule of thumb: if GC overhead is > 10%, you’ve most likely chosen the wrong one

Migrating from other GC modes

- Other garbage collection modes do not have a nursery heap
  – Maximum heap size (-Xmx) is tenured heap only

- When migrating to generational it can be required to increase the maximum heap size

– Non-generational:	-Xmx1024M	gives 1G tenured heap
– Generational:	-Xmx1024M	gives 64M nursery and 960M tenured

- As some of the nursery is survivor space, there is a net reduction in available Java heap
  – “Tilt Ratio” determines how much is “lost”

- Recommended **starting point is to set the tenured heap to the previous maximum heap size**:
  – ie. -Xmos = -Xms and -Xmox = -Xmx

- And **allocate the nursery and an additional heap space**

- This means there is a **net increase in memory usage when moving to generational**

Example of Generational vs Non-Generational

Monitoring GC activity

- Use of Verbose GC logging
  - only data that is required for GC performance tuning
  - Graph Verbose GC output using GC and Memory Visualizer (GCMV) from ISA

- Activated using command line options

```
-verbose:gc
-Xverbosegclog:[DIR_PATH][FILE_NAME]
-Xverbosegclog:[DIR_PATH][FILE_NAME],X,Y
```

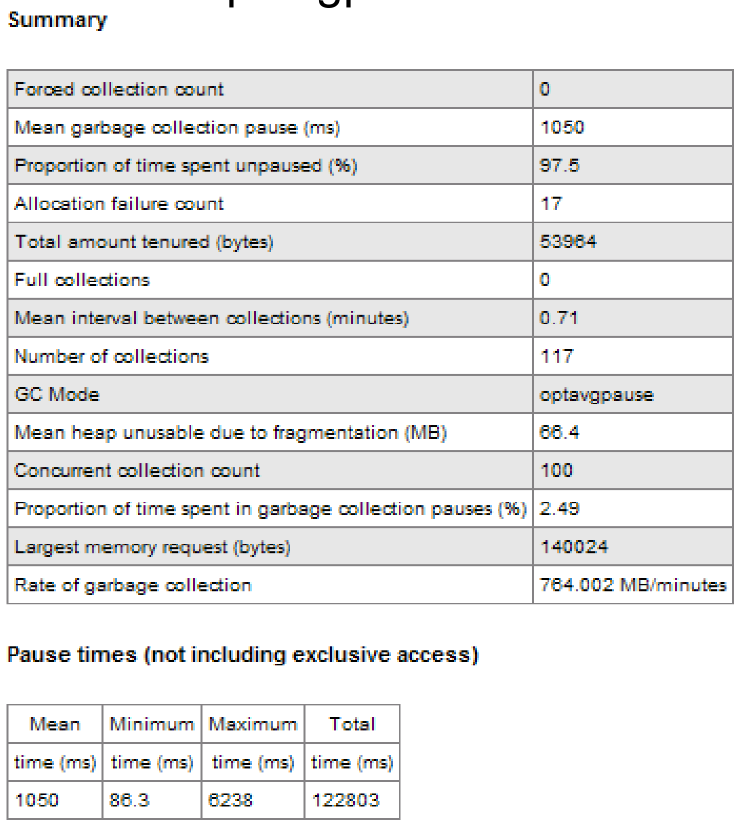
  – where:

`[DIR_PATH]`	is the directory where the file should be written
`[FILE_NAME]`	is the name of the file to write the logging to
`X`	is the number of files to
`Y`	is the number of GC cycles a file should contain

- Performance Cost:
  - (very) basic testing shows a 1% overhead for GC duration of 200ms
  - eg. if application GC overhead is 5%, it would become 5.05%

Rate of garbage collection

optavgpause



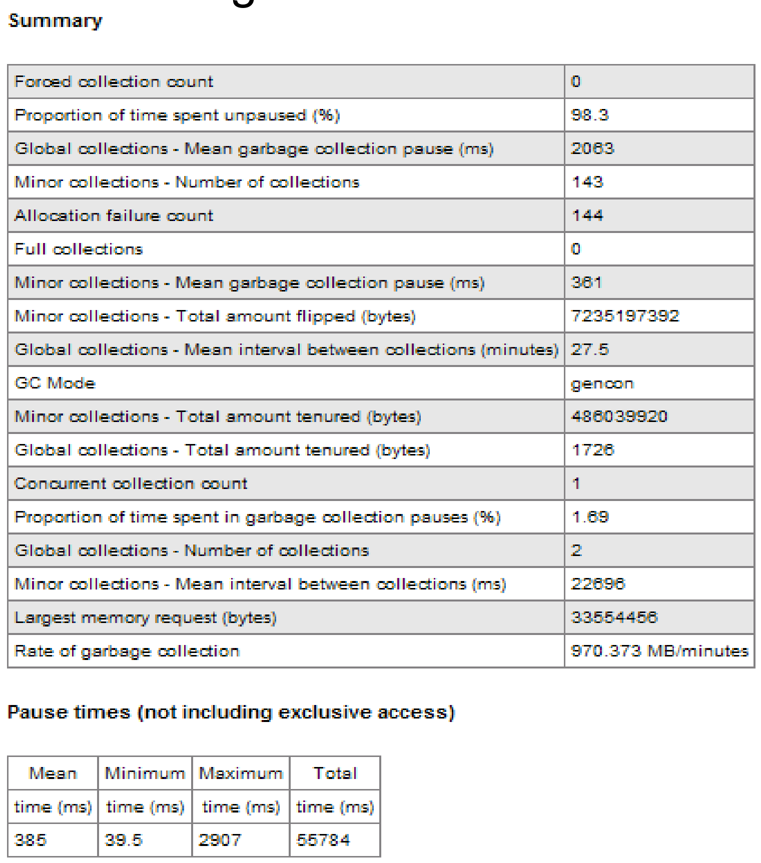
Summary

Forced collection count	0
Mean garbage collection pause (ms)	1050
Proportion of time spent unpaused (%)	97.5
Allocation failure count	17
Total amount tenured (bytes)	53964
Full collections	0
Mean interval between collections (minutes)	0.71
Number of collections	117
GC Mode	optavgpause
Mean heap unusable due to fragmentation (MB)	66.4
Concurrent collection count	100
Proportion of time spent in garbage collection pauses (%)	2.49
Largest memory request (bytes)	140024
Rate of garbage collection	764.002 MB/minutes

Pause times (not including exclusive access)

Mean time (ms)	Minimum time (ms)	Maximum time (ms)	Total time (ms)
1050	86.3	6238	122803

gencon



Summary

Forced collection count	0
Proportion of time spent unpaused (%)	98.3
Global collections - Mean garbage collection pause (ms)	2063
Minor collections - Number of collections	143
Allocation failure count	144
Full collections	0
Minor collections - Mean garbage collection pause (ms)	361
Minor collections - Total amount flipped (bytes)	7235197392
Global collections - Mean interval between collections (minutes)	27.5
GC Mode	gencon
Minor collections - Total amount tenured (bytes)	486039920
Global collections - Total amount tenured (bytes)	1726
Concurrent collection count	1
Proportion of time spent in garbage collection pauses (%)	1.69
Global collections - Number of collections	2
Minor collections - Mean interval between collections (ms)	22696
Largest memory request (bytes)	33554456
Rate of garbage collection	970.373 MB/minutes

Pause times (not including exclusive access)

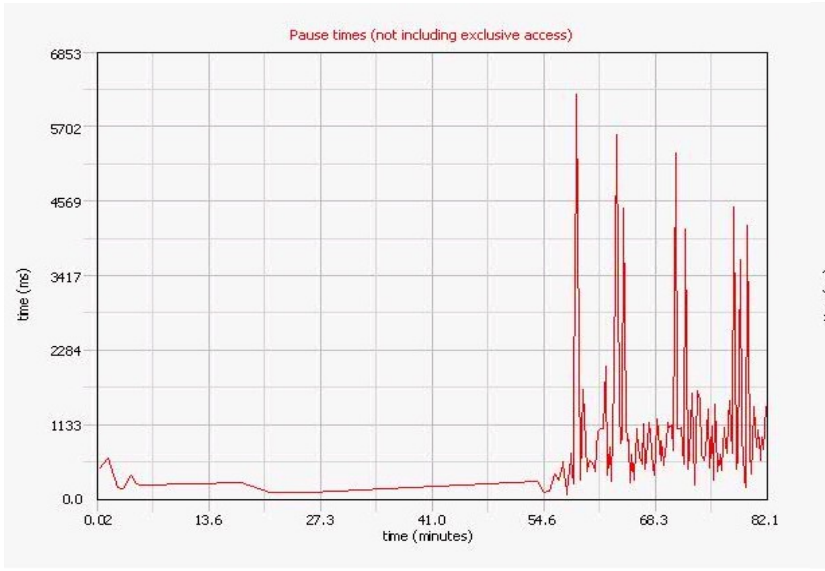
Mean time (ms)	Minimum time (ms)	Maximum time (ms)	Total time (ms)
385	39.5	2907	55784

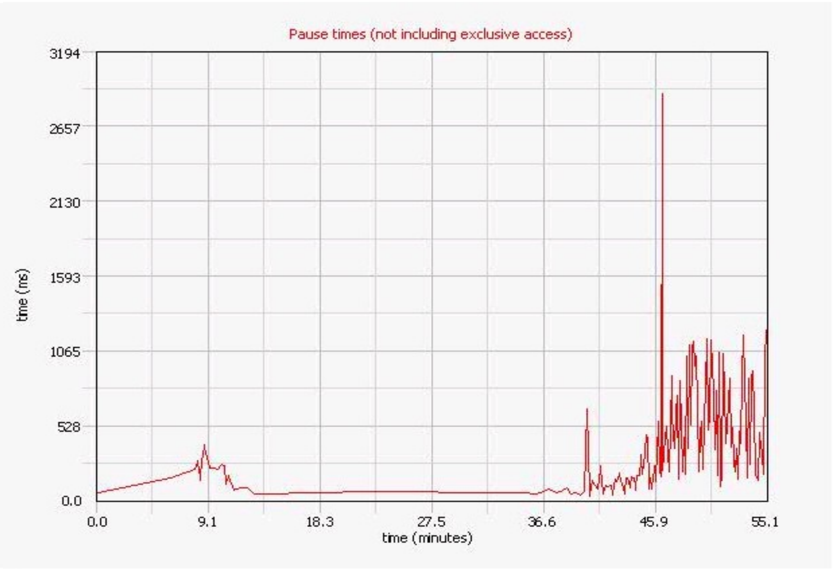
- Gencon could handle a higher “rate of garbage collection”
- Gencon had a smaller percentage of time in garbage collection
- Gencon had a shorter maximum pause time

Rate of garbage collection

optavgpause

gencon





- Gencon provides less frequent long Garbage Collection cycles
- Gencon provides a shorter longest Garbage Collection cycle

Questions?