# Taming Metaspace

Thomas Stüfe, SAP
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# Metaspace

- Metaspace contains class metadata
  – Klass, Constant Pool, Method, Annotations, Bytecode, JIT Counters etc.

- Used to live in Java Heap (Permanent Generation) pre JDK 8

- JDK 8: PermGen Removal -> Metaspace is born
  – Inspired by JRockit VM
  – JEP 122: “**JEP 122: Remove the Permanent Generation”**

- SAP involvement:
  – JDK 11: partial rework (chunk coalescation, **JDK-8198423)**
  – Analysis tools: **jcmd VM.metaspace, VM.classloaders**
  – many smaller fixes/cleanups
  – JDK 15 (?): rewrite

# Basics

# Metadata lifecycle

- Metadata are usually allocated when classes are loaded

- All metadata a loader accumulated is freed in bulk after the loader has been collected
  – Exception: Metadata may be deallocated earlier (class redefinition, load errors etc) but that’s uncommon.
  – Deallocated space still belongs to the loader.

# Why write a customized allocator?

- Bulk delete allows arena style allocation!
  – No need to track individual allocations
  – Simple pointer bump allocation possible: cheap and allows tight packing

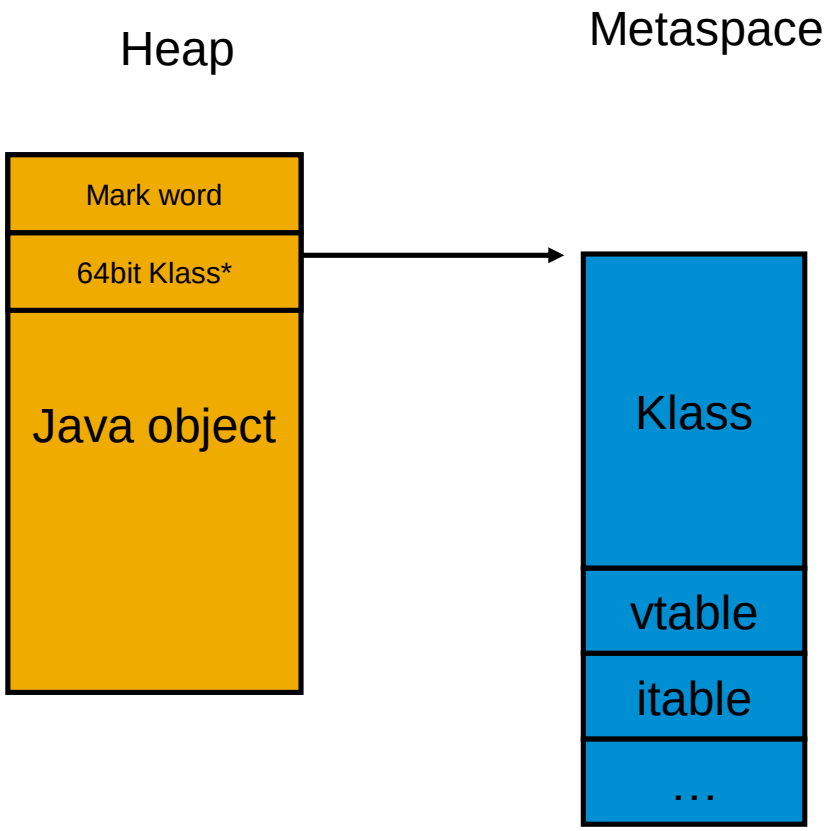
- We know the size distribution of typical allocations

- Case against malloc:
  – CompressedClassSpace
  – Platform specific limitations (e.g. sbrk hits java heap)

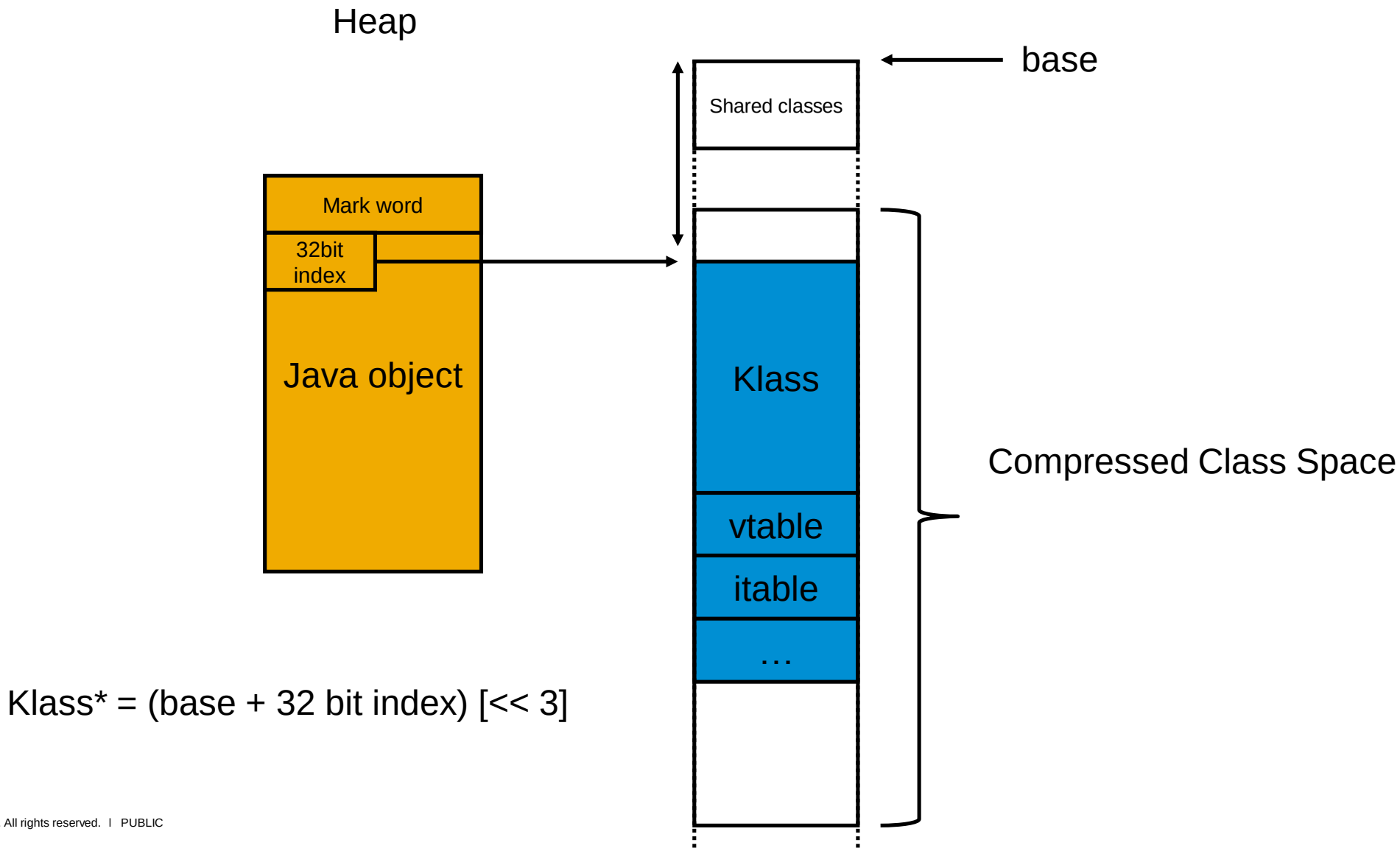
# Compressed Class Space

- Compressed Class Space is a (small) part of Metaspace
- Optimization for 64bit platforms
- Only on 64bit, if `-XX:+UseCompressedClassPointers` (on by default)

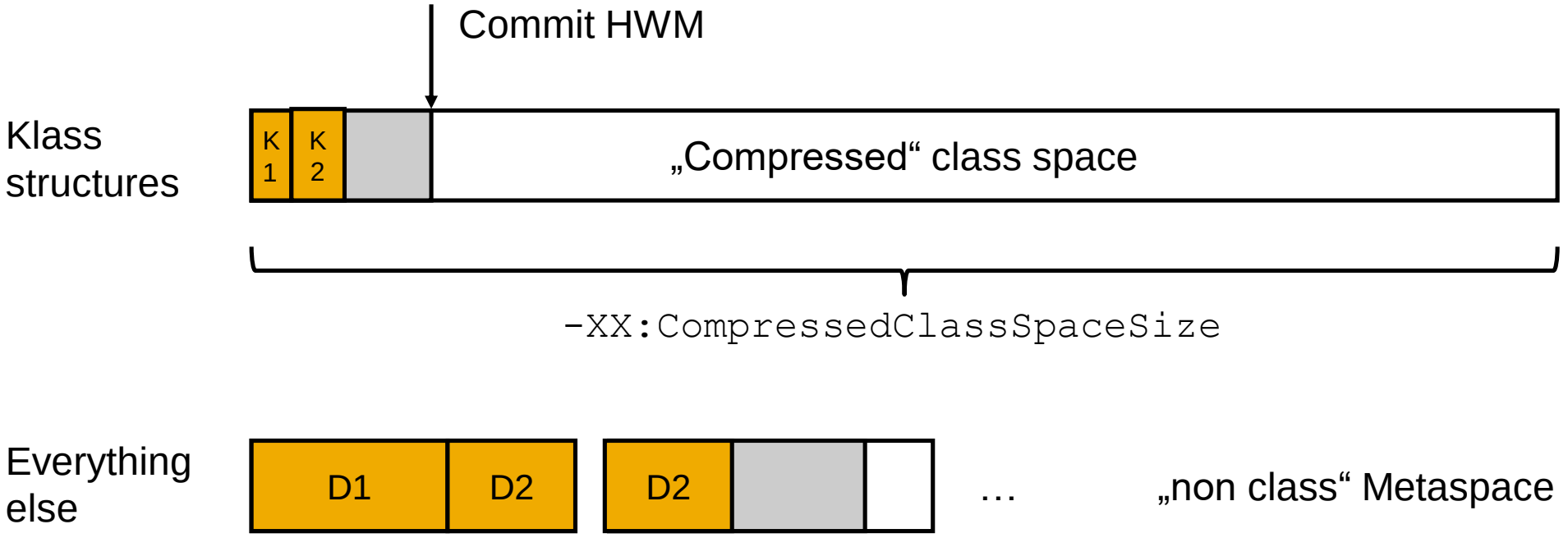
# Compressed Class Space



# Compressed Class Space



# Metaspace has two parts




Sizes per class:

- ~1K Klass (500+ … 500K)
- ~6K non-class (~2K … xxK)

# Limits

- **CompressedClassSpaceSize**:
  - Reserved size of compressed class space. Max 3G.
  - Has to be specified. If omitted, defaults to 1G (~ 1 million classes)
- **MaxMetaspaceSize**
  - Limits sum of all committed space (class + nonclass)
  - Default infinite.

- Sizing:
  - Undersizing can hurt (OOMs, GCs)
  - Oversizing is usually not a problem. When in doubt, keep the defaults.

# Metaspace induced GCs

- GC is blind to Metaspace consumption, so we check periodically if classes can be collected

- GC threshold:
  - When sum of committed space reaches threshold, a GC is done to check if loaders are collectable and Metaspace can be released.
  - Threshold may go up or down depending on how the GC went

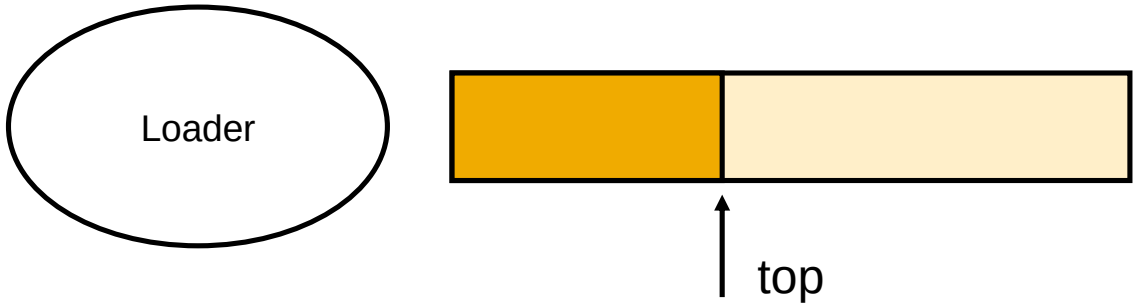
- We also attempt a GC before throwing a Metaspace OOM

- *MetaspaceSize* sets the initial threshold value
  - Set to a large value (e.g. max) to disable threshold

# Current implementation

# Current implementation (1)

(much simplified)




- Loader owns a chunk of memory.
- Allocates from it via pointer bump.
  - Remember: we do not need to track individual allocations for freeing.

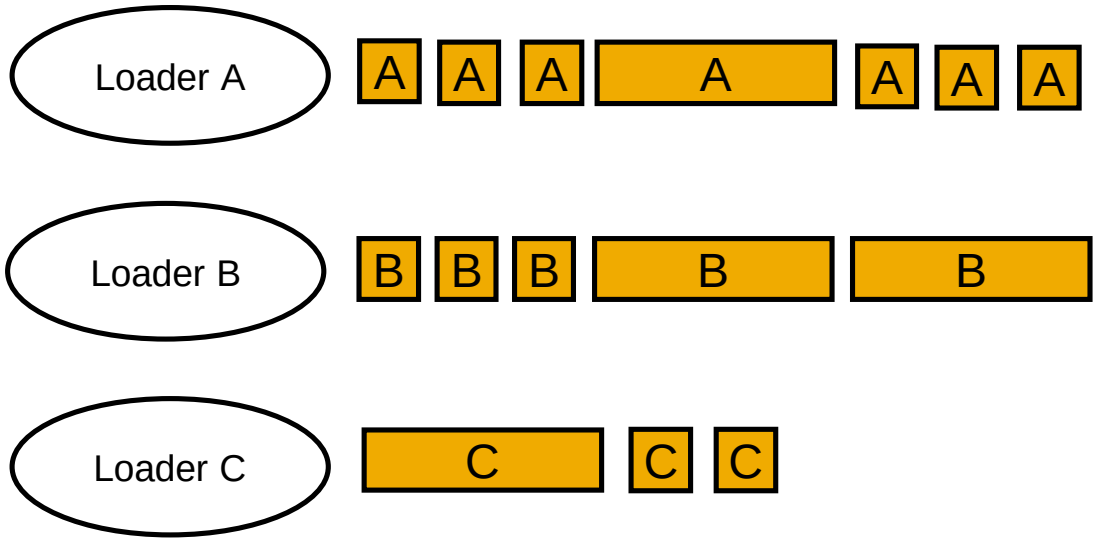
# Current implementation (2)

(much simplified)

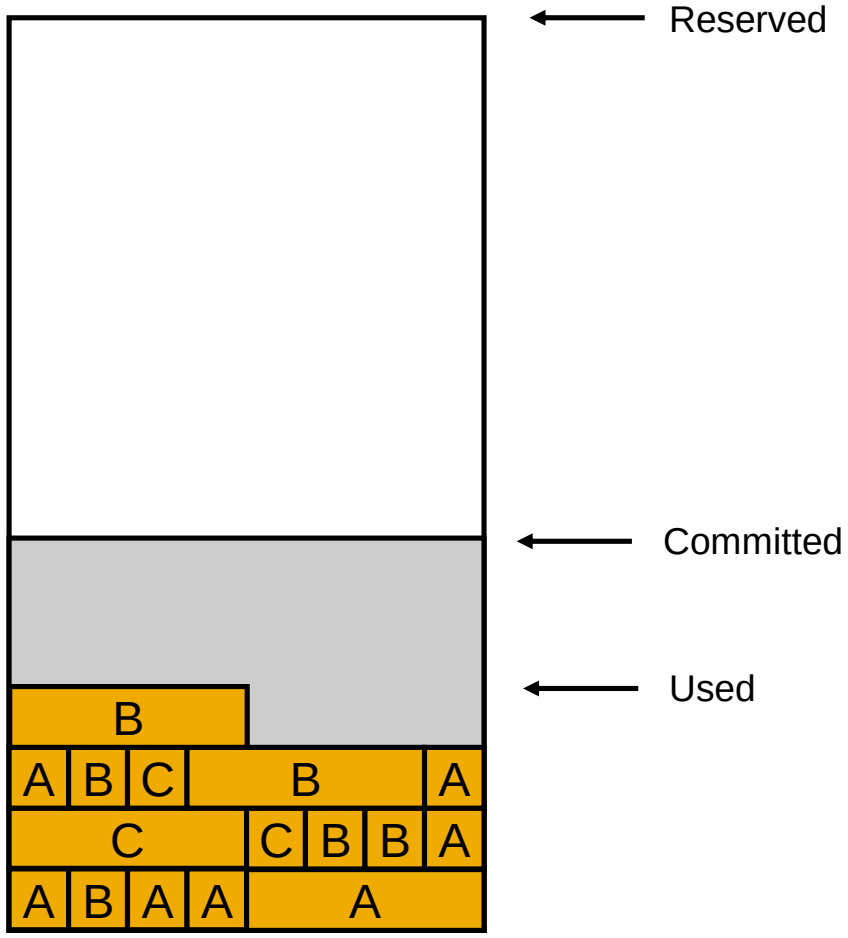

- If chunk is used up, Loader aquires a new one from the metaspace allocator.
- Retired chunks are kept in list
- Leftover space is kept for later reuse

# Current implementation (3)

(much simplified)

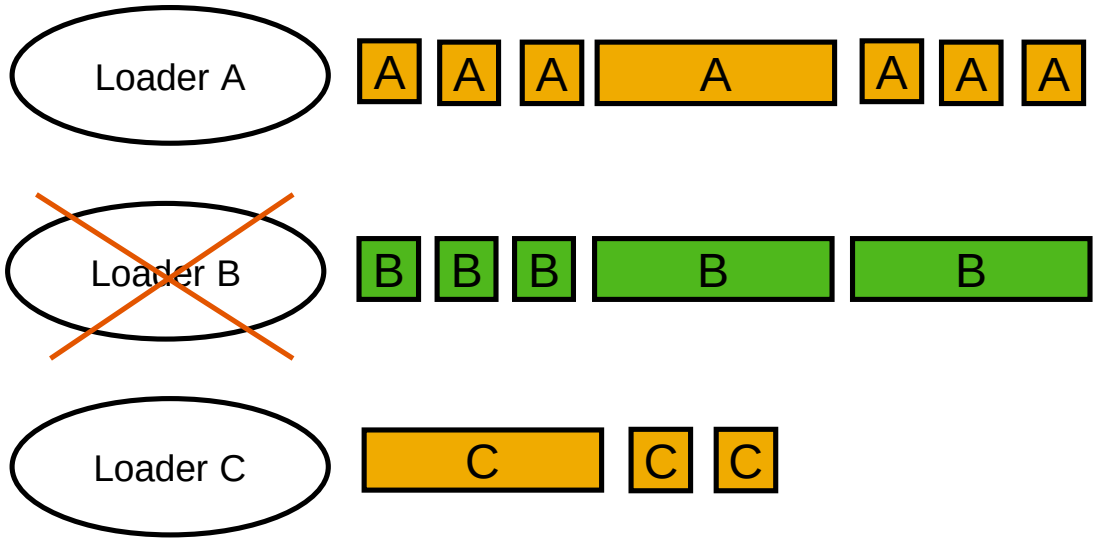



Chunks are carved from metaspace memory as they are allocated.

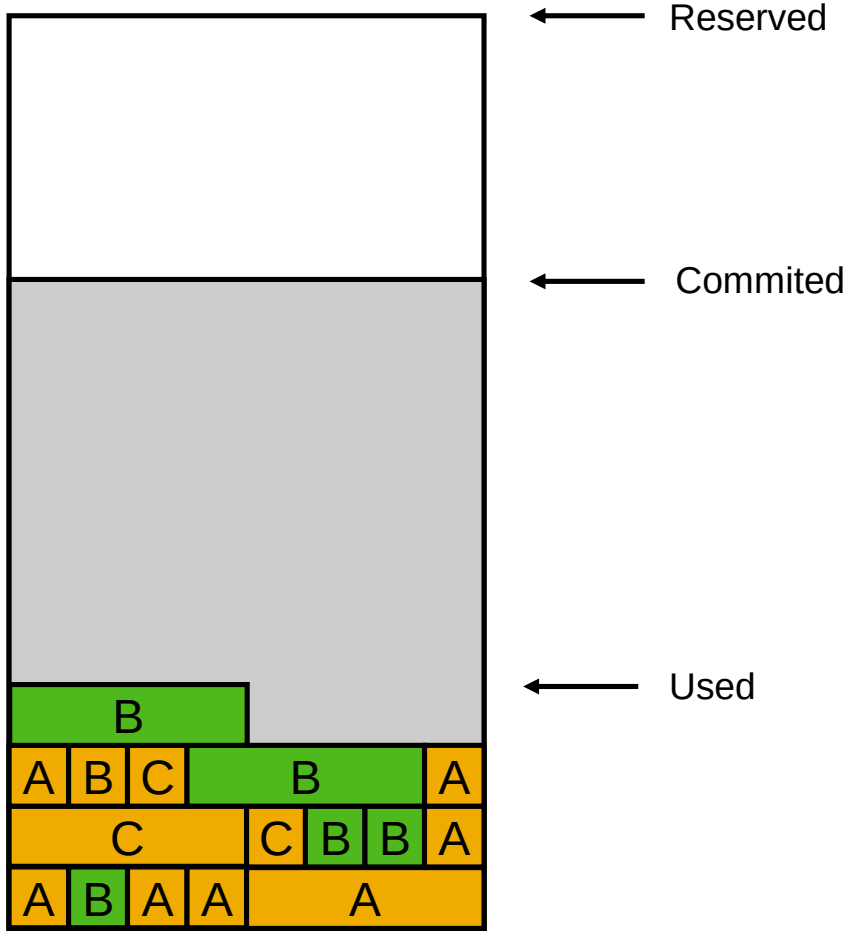


# Current implementation (4)

(much simplified)

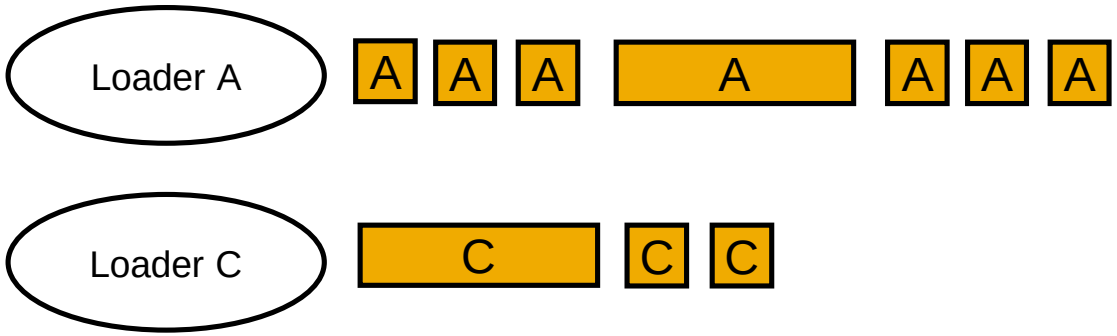


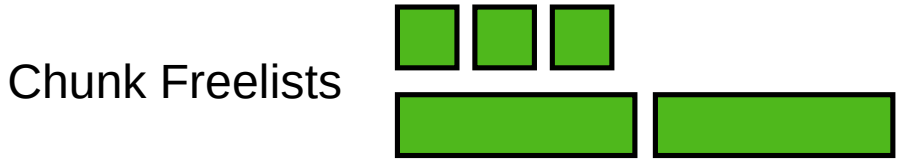

When a loader dies, its chunks are marked as free…

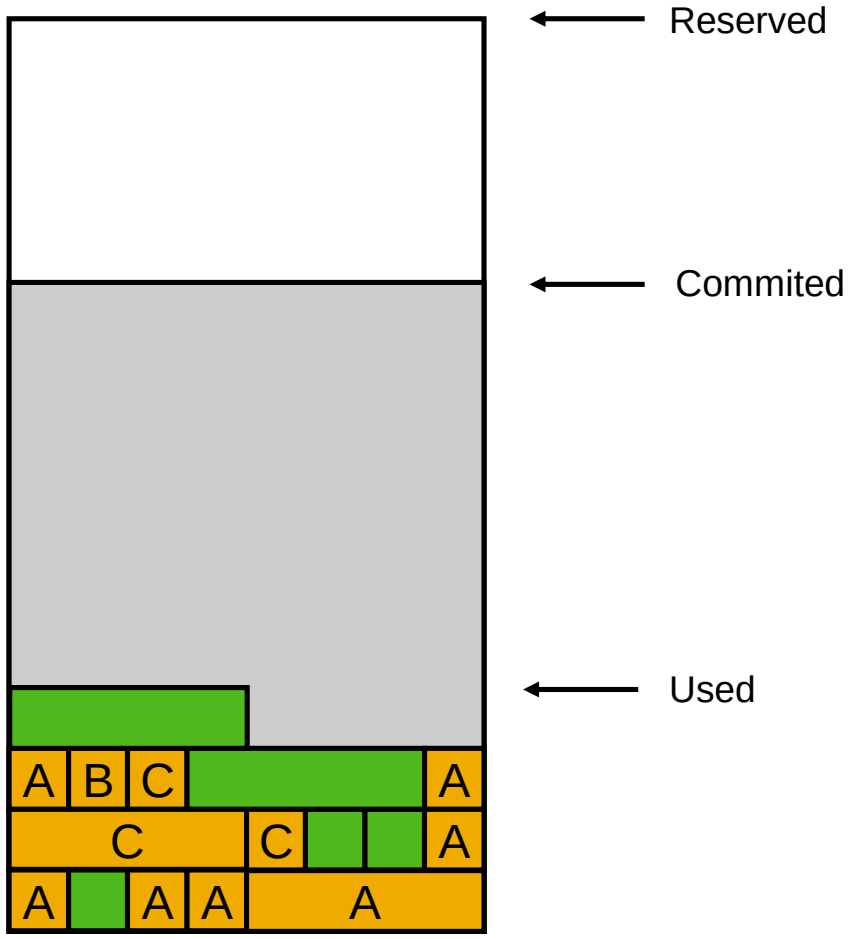


# Current implementation (5)

(very much simplified)




…and added to global freelists, sorted by size.

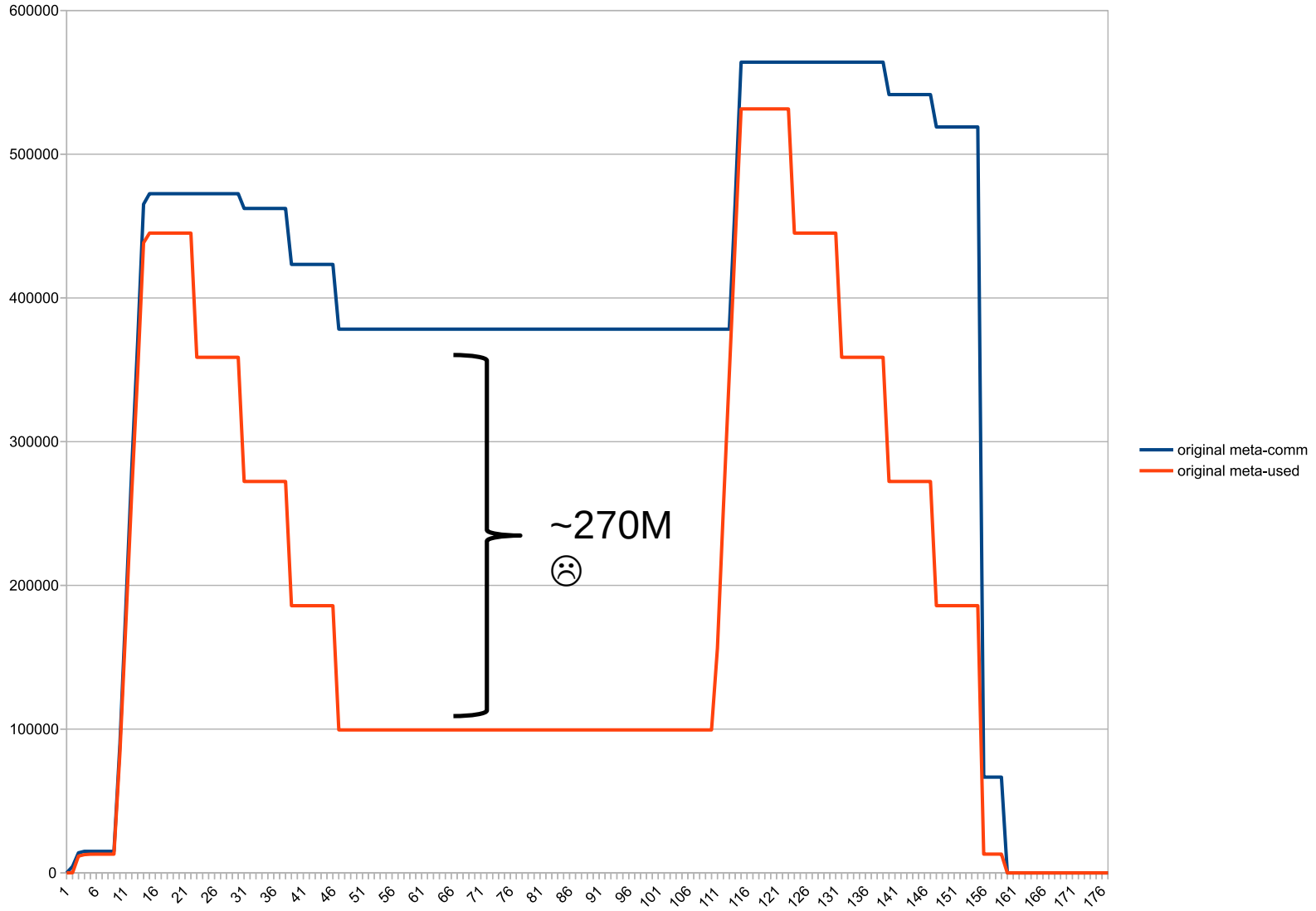
# Problems with the current implementation

- Freelists can get huge.
  – We have seen used:free ratios of 1:3 and worse
  – =>Metaspace is not really elastic.

- Intra-chunk waste
  – At some point loader typically stops loading classes; remaining chunk space is wasted
  – Worse with many tiny loaders (reflection delegator classes, lambda anonymous classes)

- Code bloat
  – Expensive to maintain.
  – Code base grew over time and has gotten overly complicated.

# Huge freelists: Committed vs used space, after class unloading



# Huge Freelists (`jcmd VM.metaspace` output)

```
jcmd 27265 VM.metaspace

27265:
…

Waste (percentages refer to total committed size 373,48 MB):
              Committed unused:    280,00 KB ( <1%)
        Waste in chunks in use:      2,45 KB ( <1%)
         Free in chunks in use:      6,34 MB (  2%)
     Overhead in chunks in use:    186,75 KB ( <1%)
                 In free chunks:    269,56 MB ( 72%)
Deallocated from chunks in use:    998,98 KB ( <1%) (1763 blocks)
                       -total-:    277,33 MB ( 74%)
```

# Monitoring with `jcmd VM.metaspace` (since JDK11)

- Detailed analysis of Metaspace occupancy
- Usage stats, chunk statistics and -geometry, freelists, …
- Show all loaders and/or all loaded classes and their space consumption
- Detailed summary waste section
- Help is your friend (`jcmd help VM.Metaspace`)

# Reimplementation

# Basic idea

- Uncommit chunks in freelists

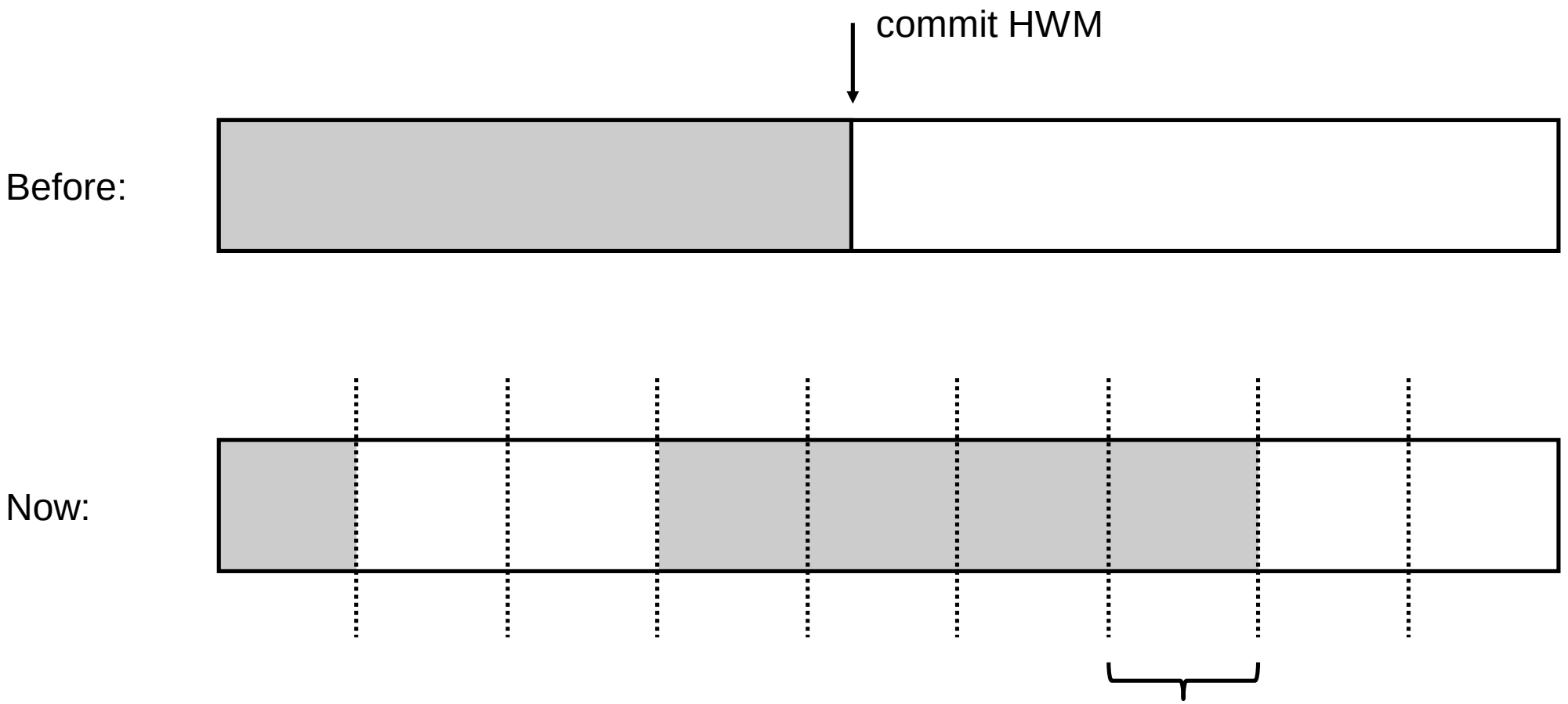
- Delay committing chunks until they are actually used
  – Partly commit them piece wise (like a thread stack)
  – Removes the penalty of handing out large chunks to class loaders

# Concern: keep number of virtual memory areas low

- (Linux): we decommit with mmap(MAP_NORESERVE) && mprotect(PROT_NONE)
  - Higher commit/uncommit fragmentation results in higher number of VMAs
  - Kernel keeps vma structures in list and rb tree
  - Too many of them may affect vma lookup
  - And we may hit process limits

- So: keep an eye on commit granularity

# Commit granules



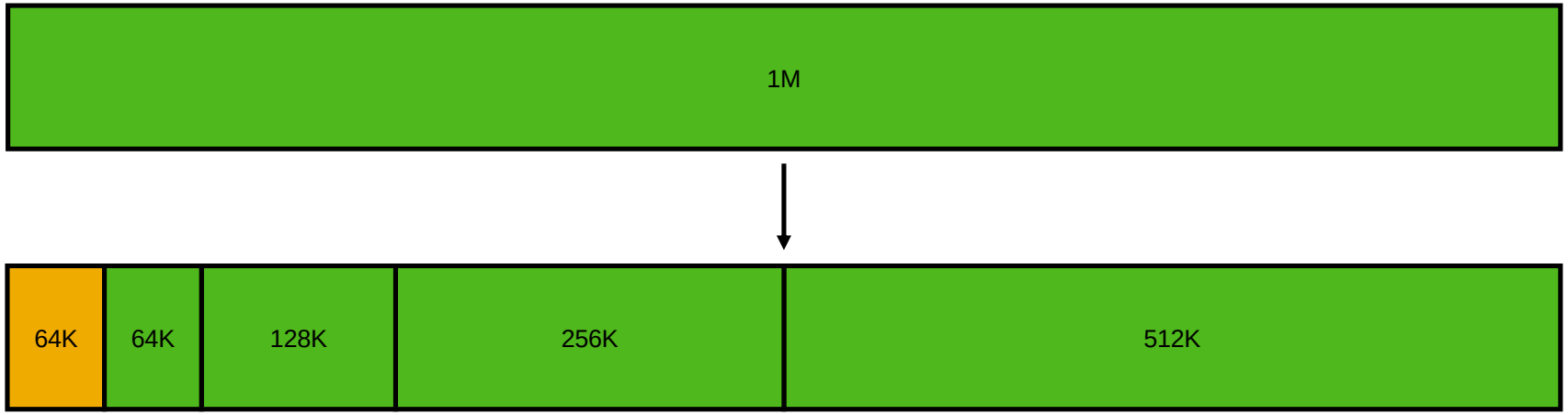
# Current chunk allocation scheme unsuited for uncommitting chunks

- Odd chunk geometry
  - Difficult to merge and split
  - High fragmentation
  - Complex code
- Chunk headers are a problem

# Pow 2 based buddy allocator for chunks

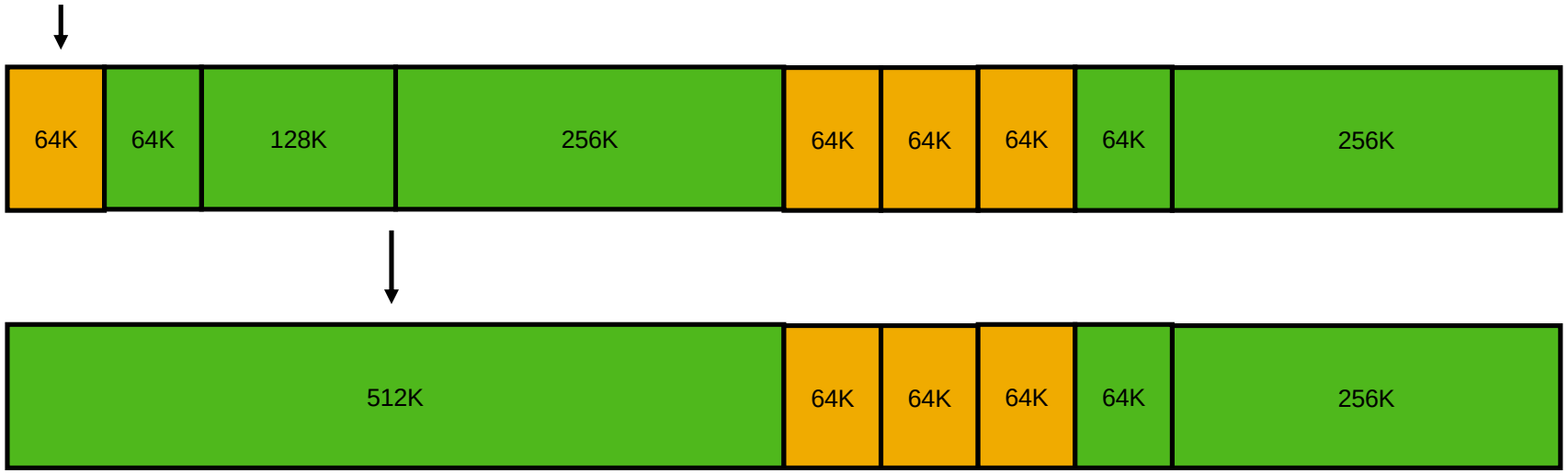
- Power 2 based buddy allocation scheme
- Chunks sized from 1K … 4M in pow2 steps
- Dead simple to split and merge.
- Low external defragmentation -> Leads to larger free contiguous areas.
- Standard algorithm widely known

# Buddy allocator: Allocation




- Remove chunk from freelist
- Optionally split until desired size is reached
- Return result chunk; put splinter chunks back to freelist

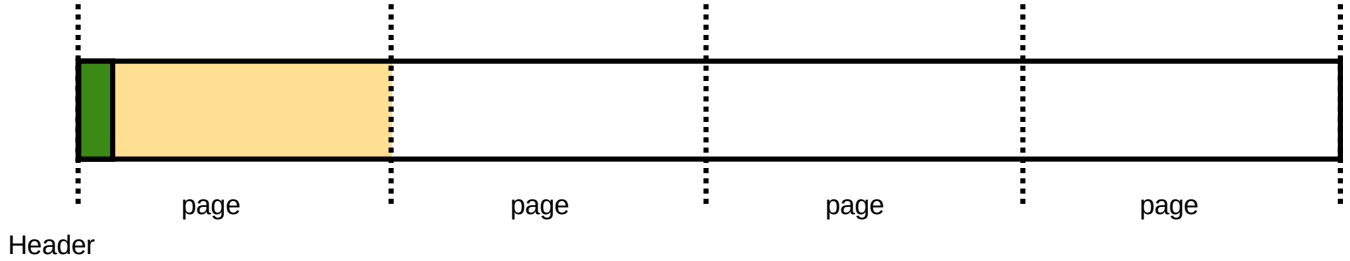
# Buddy allocator: Deallocation



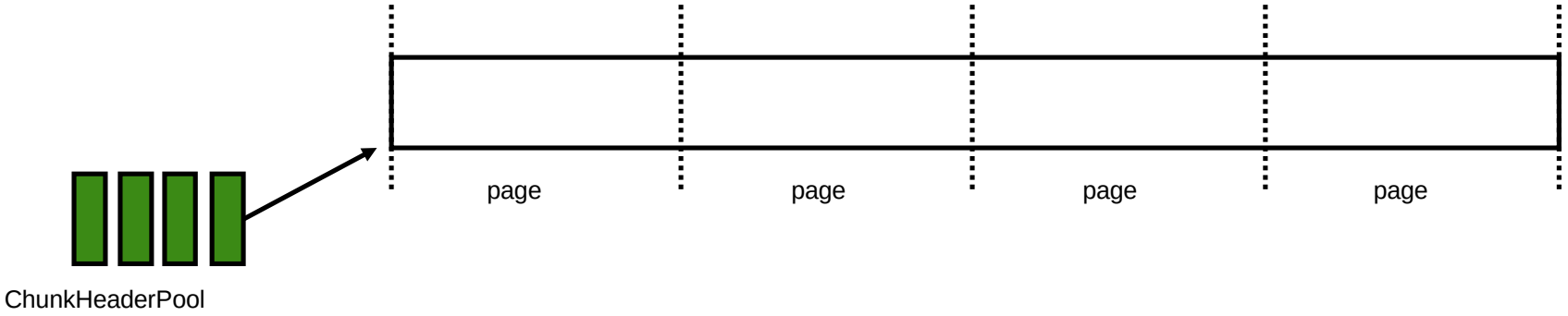

- Mark chunk as free
- If buddy chunk is free and unsplit: remove from freelist and merge with chunk
  – Repeat until root chunk sized reached or until buddy is not free
- Return result chunk to free list

# Chunk headers needed to go

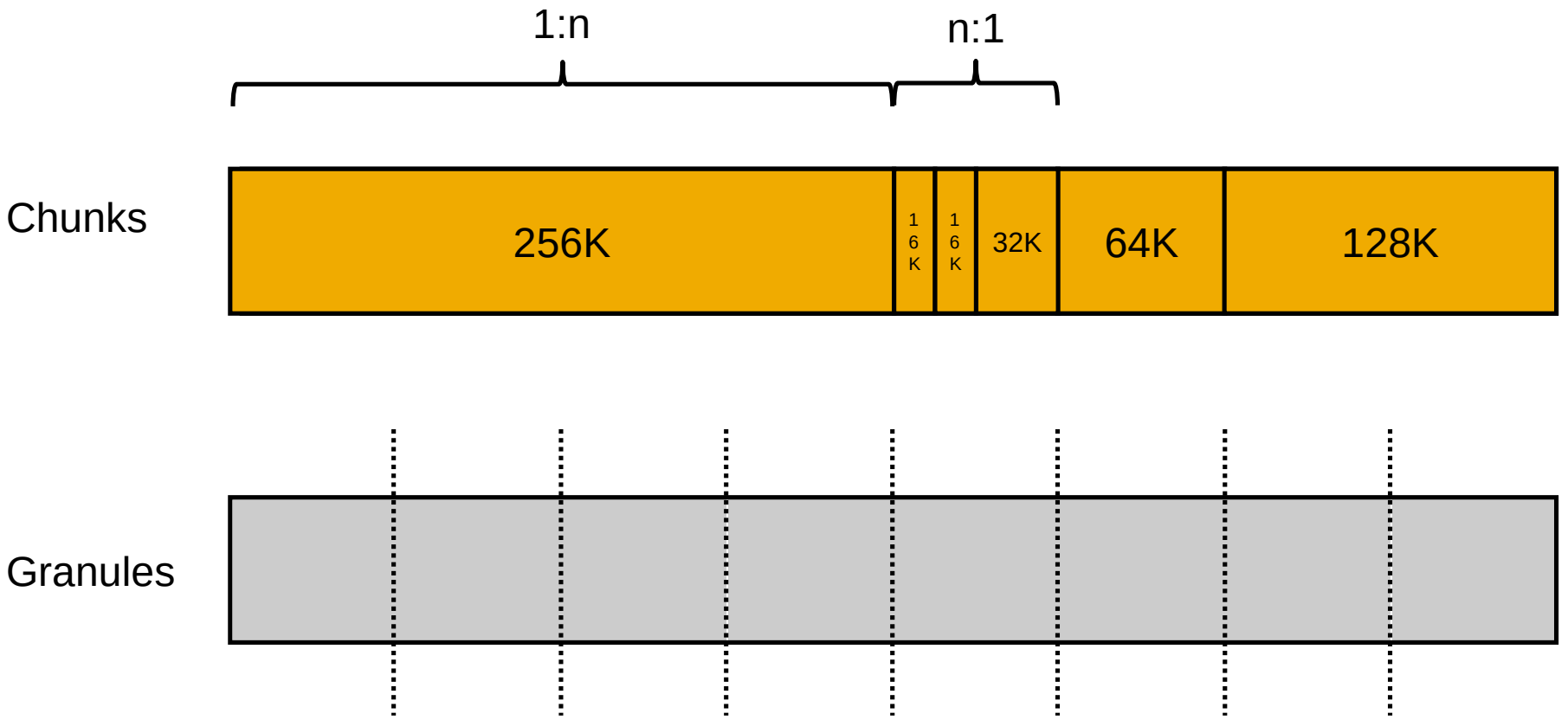
Before




Now

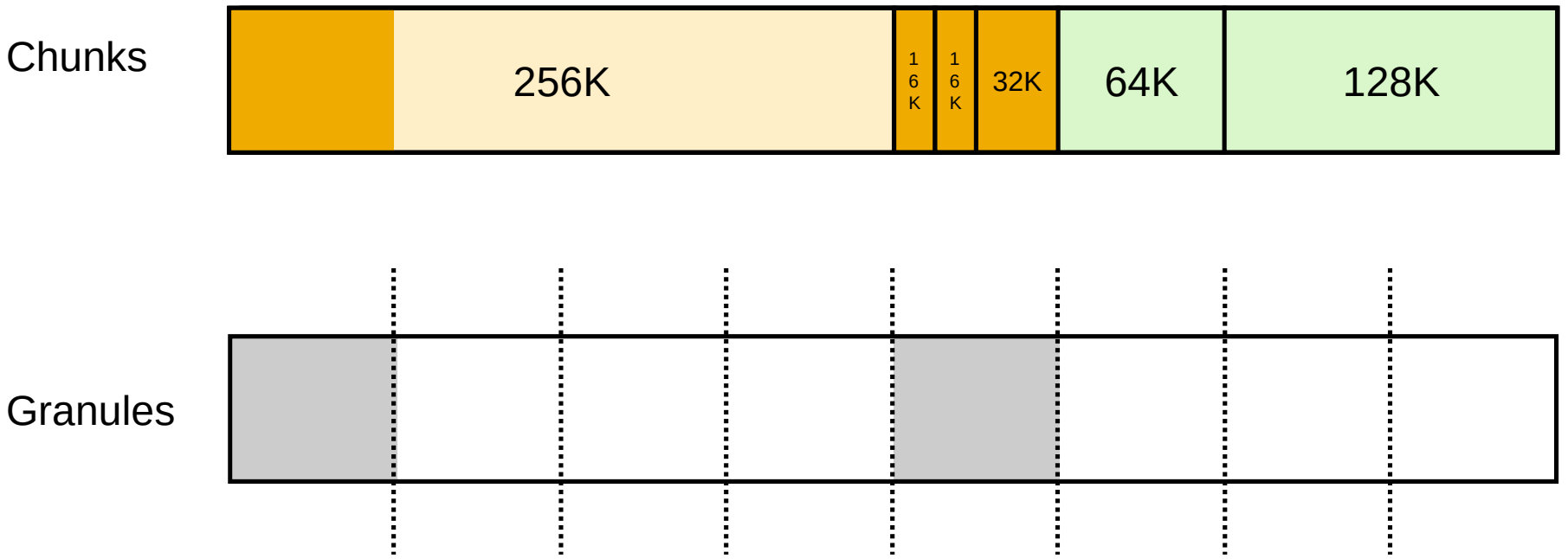


# Granules and chunks




- A larger chunk can span multiple granules (1:n)
- Multiple small chunks can cover a single granule (n:1)

# Granules and chunks

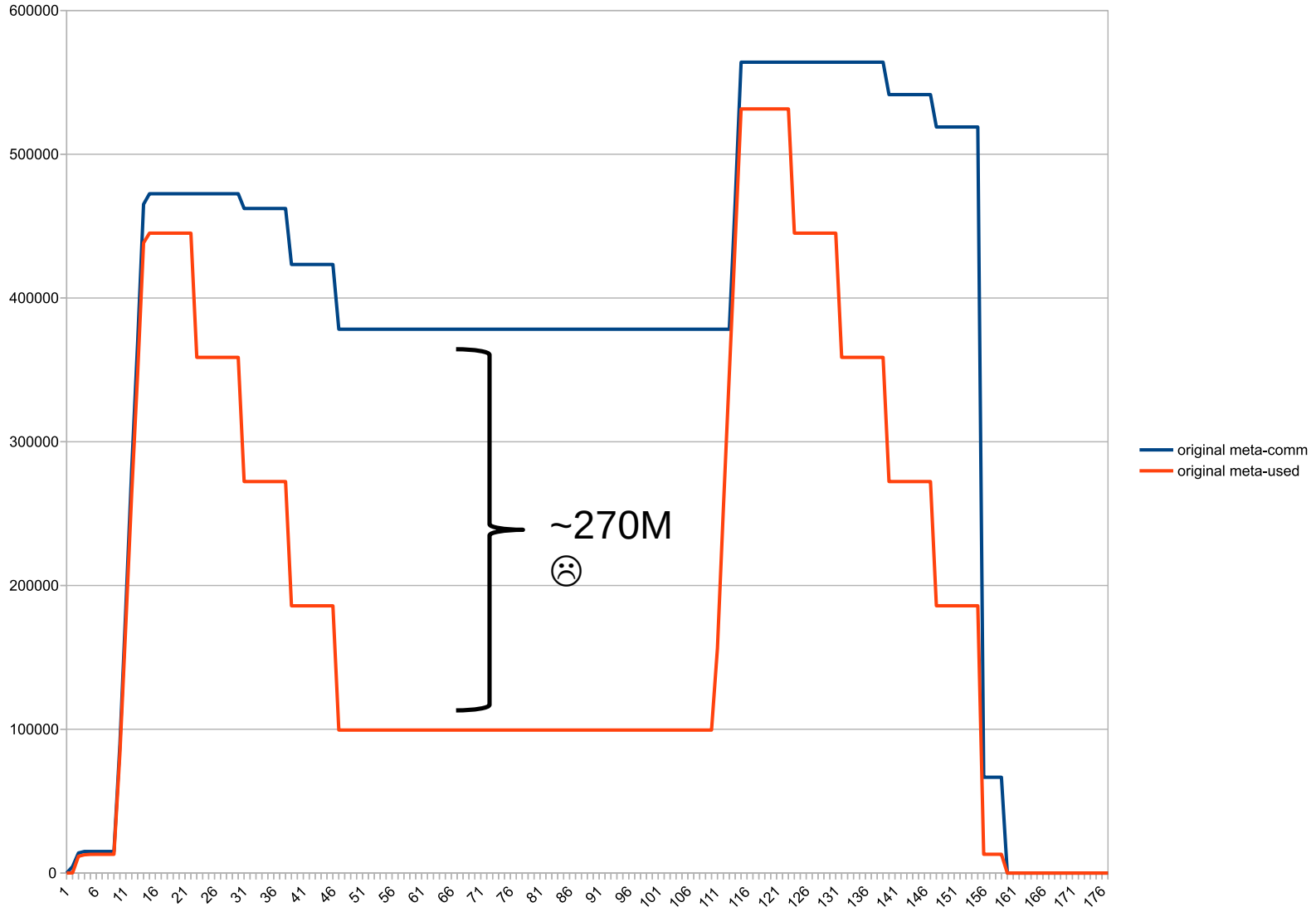



- Free chunks spanning 1+ granules can be uncommitted
- A chunk spanning >1 granules can be committed on demand

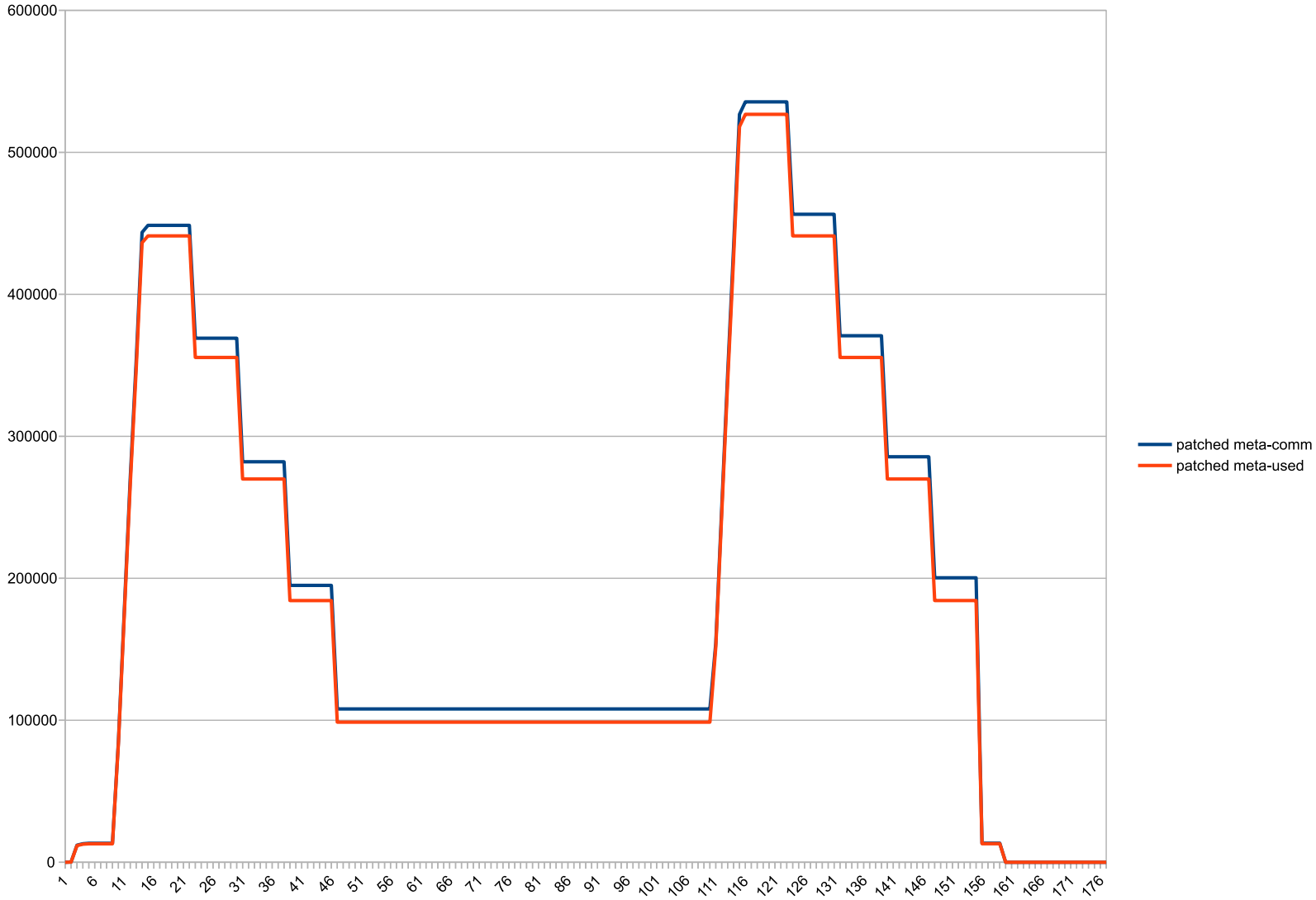
# What else changed

- Got rid of humongous chunks :)
- Got rid of occupancy map
- Better deallocation management
- Chunks can now often grow in-place
  - Saves overhead and reduces intrachunk waste
- Code is cleaner and more maintainable; better separation of concerns and testability.

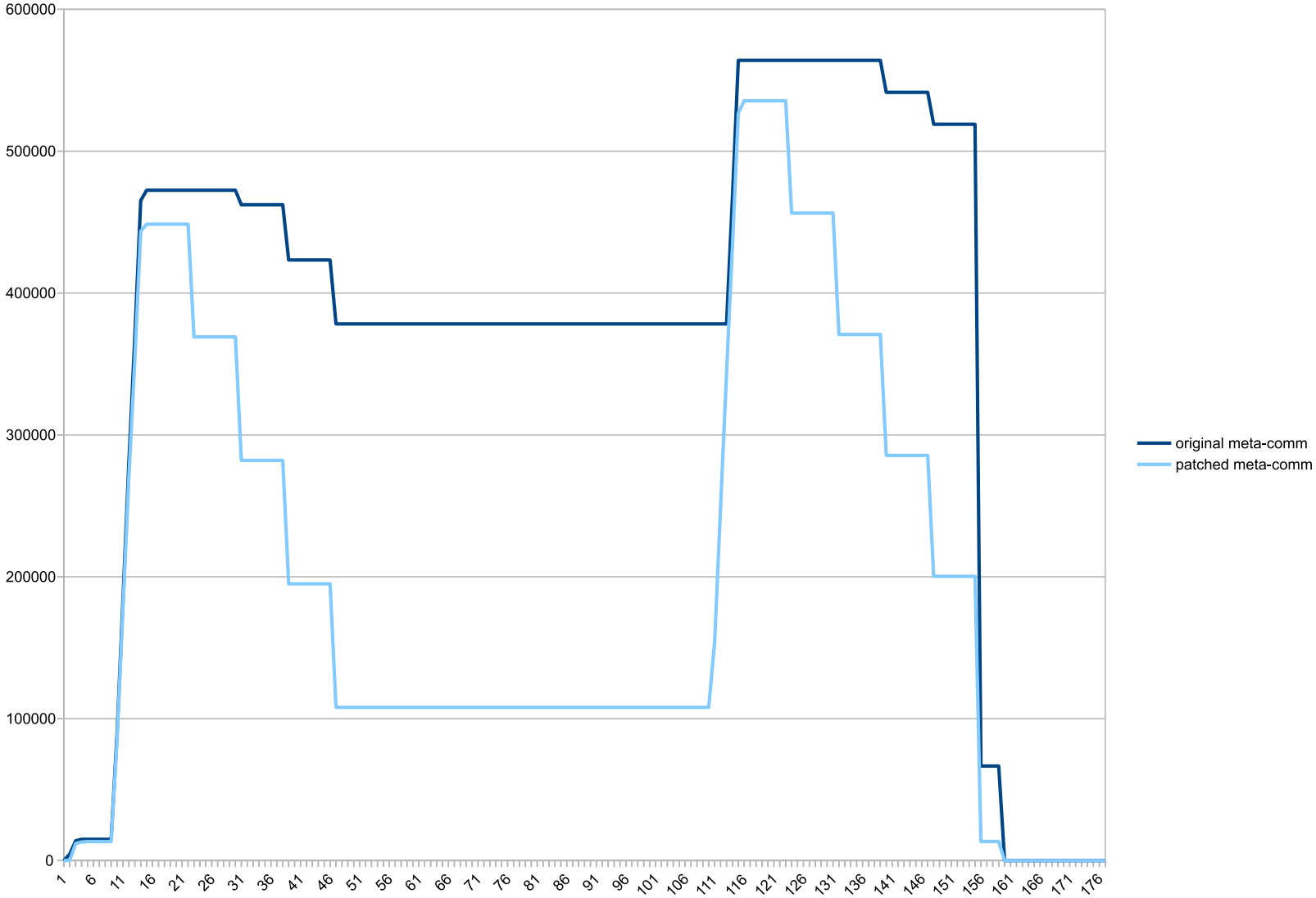
# Result: Committed vs used, Stock JDK14



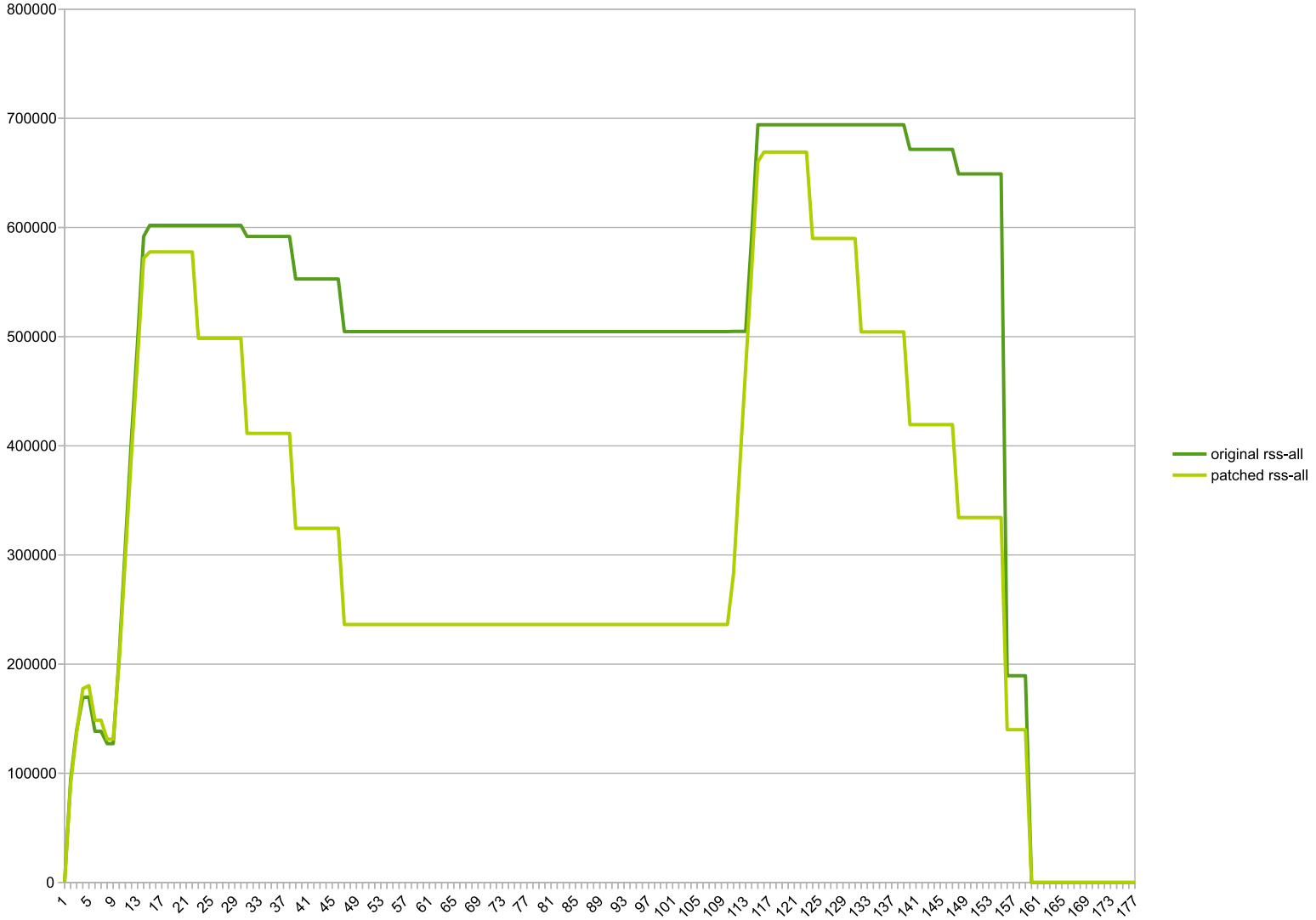
# Result: Committed vs used, Patched JDK14



# Result: committed Metaspace, Stock vs Patched VM



# Result: RSS, Stock vs Patched VM



# Modest decrease in consumption beyond class unloading

- Wildfly standalone after startup: 61m->54m, -7m, (11%)
- Eclipse CDT, hotspot project after C++ indexing: 138m->129m, -9m (12%)
- jruby helloworld.rb (invokedynamic, compile=FORCE): 41m->38m, -3m, (1.2%)

# How do we go from here?

- Patch is stable. Needs more tests and may need smaller fixes but it works.

- Patch lives in jdk/sandbox repository, branch "stuefe-new-metaspace-branch“
  – http://hg.openjdk.java.net/jdk/sandbox/

- JEP exists in Draft state (“Elastic Metaspace”: https://openjdk.java.net/jeps/8221173 )

- JDK15?
  – Very difficult to bring such a large patch upstream

- A good candidate for backporting!
  – Would make a lot of sense in 11/8
  – Large patch but Metaspace is quite isolated. Should not be too much of a hassle.

# Thank you.

Contact information:

**Thomas Stüfe**
@tstuefe
thomas.stuefe@sap.com
stuefe.de

# Q/A