

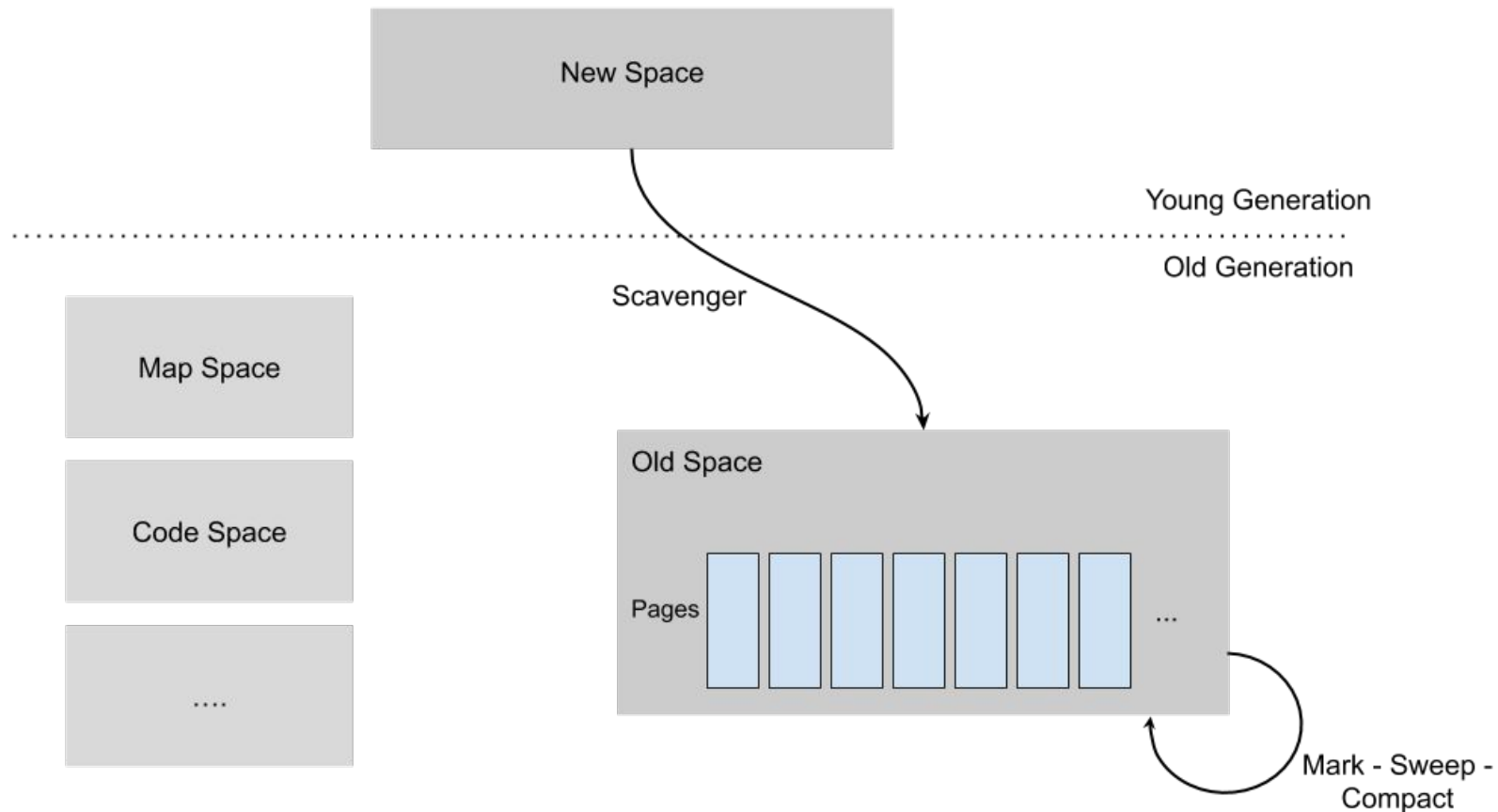
Reducing Heap Fragmentation in V8 with better FreeLists

Internship presentation

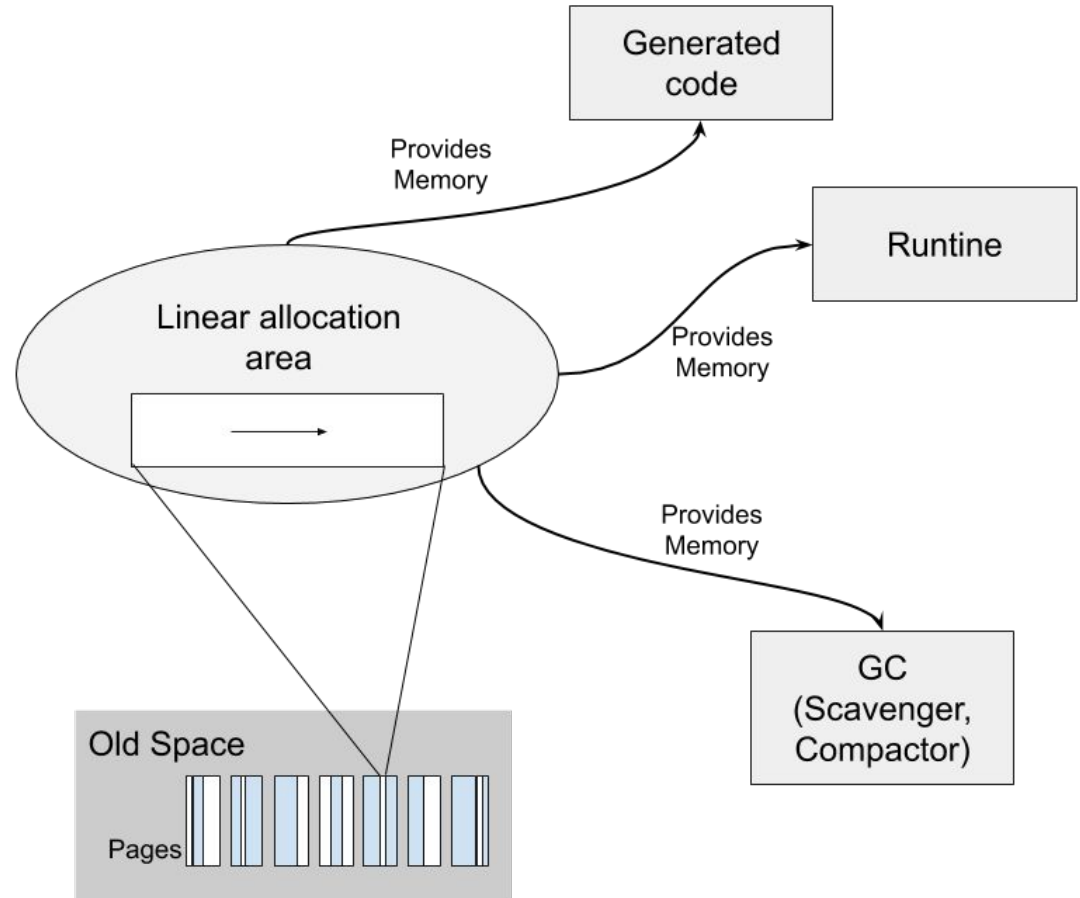
Intern: Darius Mercadier

Host: Ulan Degenbaev

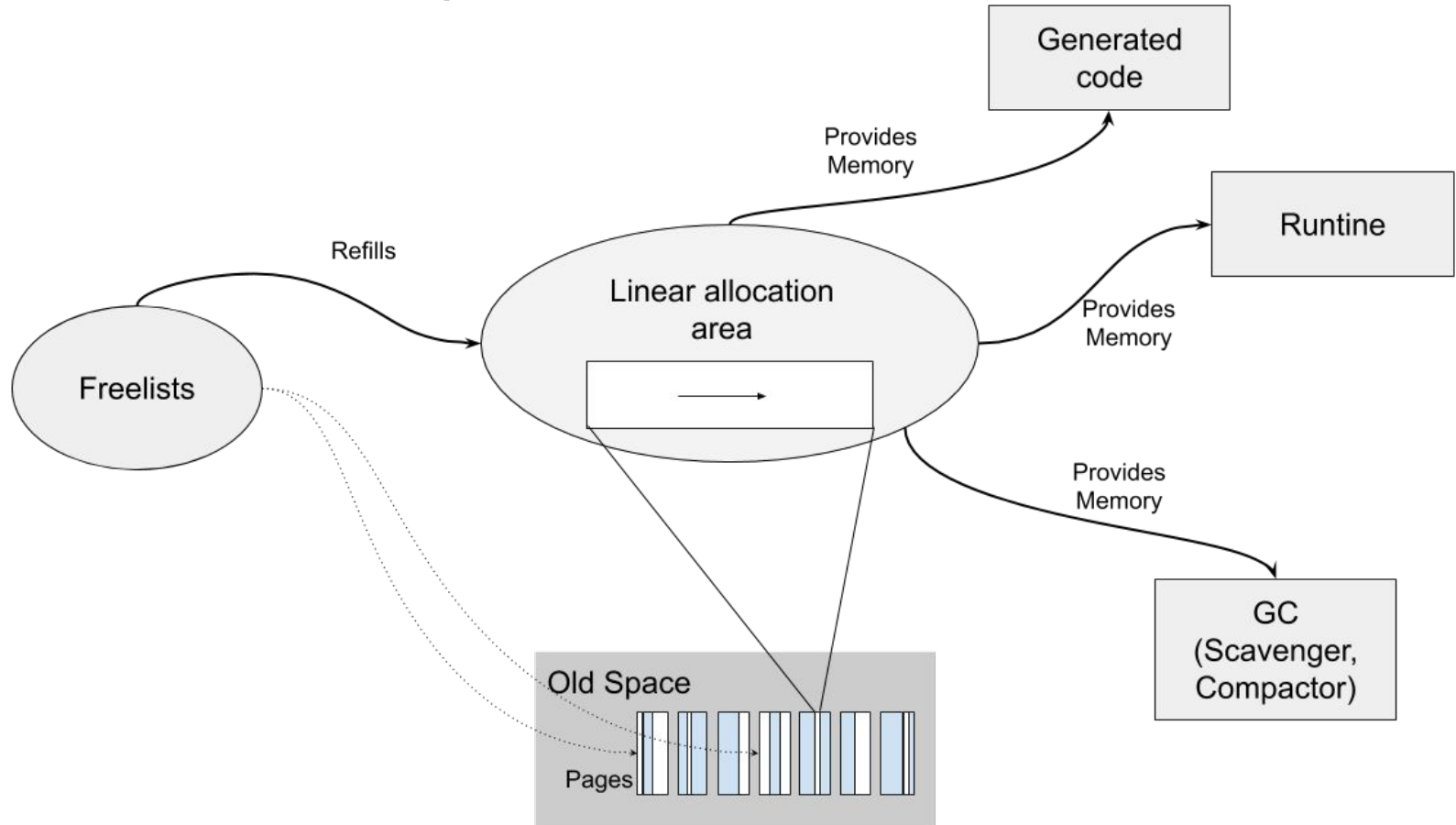
Overview of V8's Garbage Collector



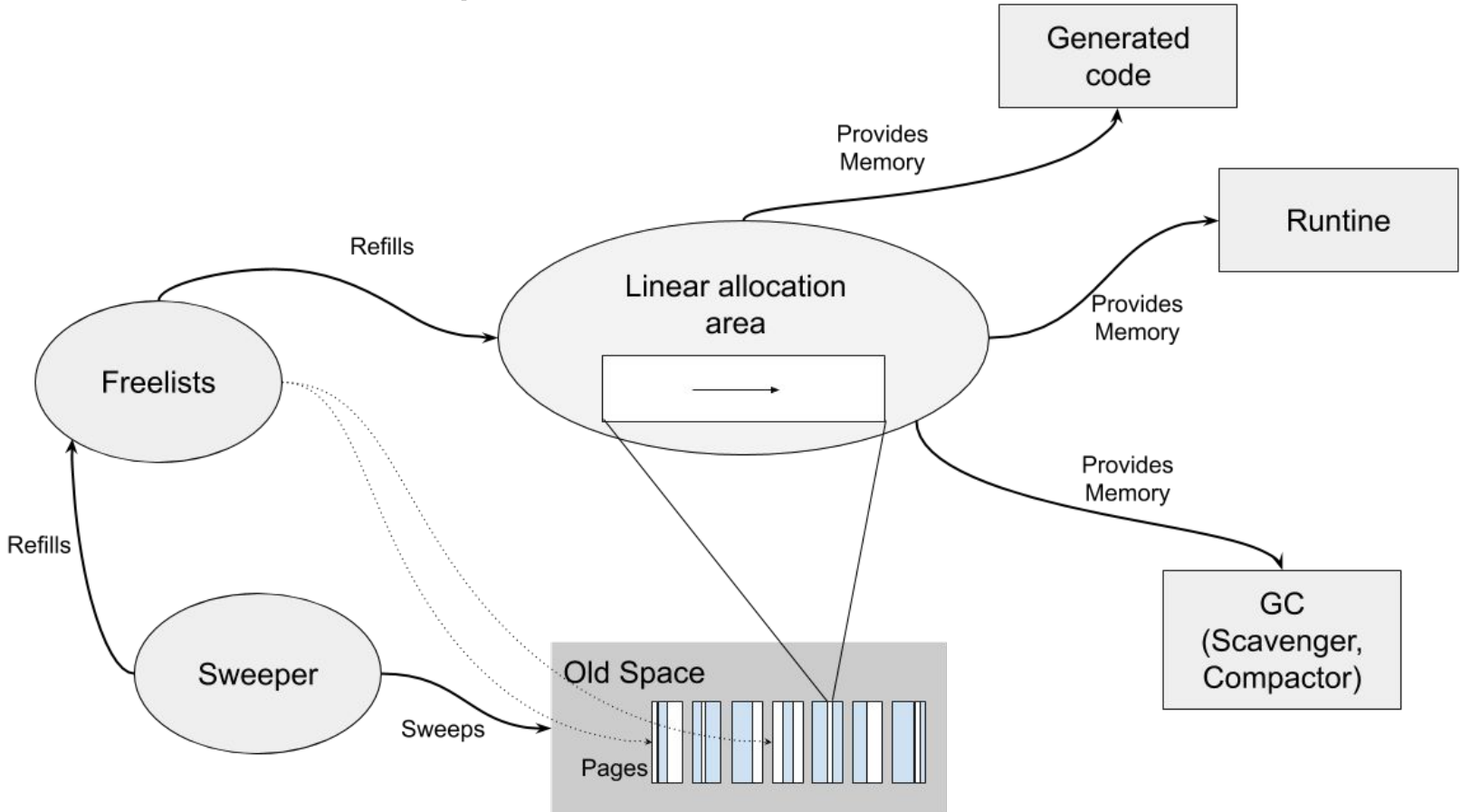
Allocations in the Old Space



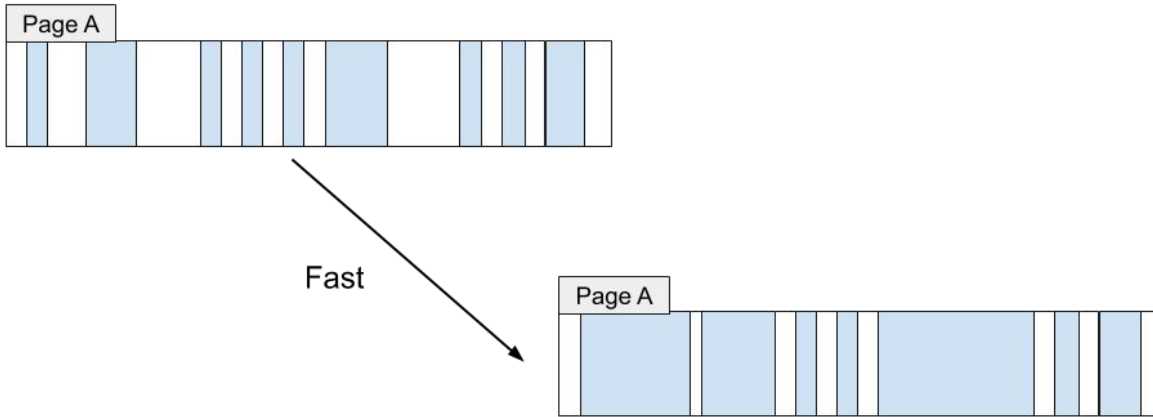
Allocations in the Old Space



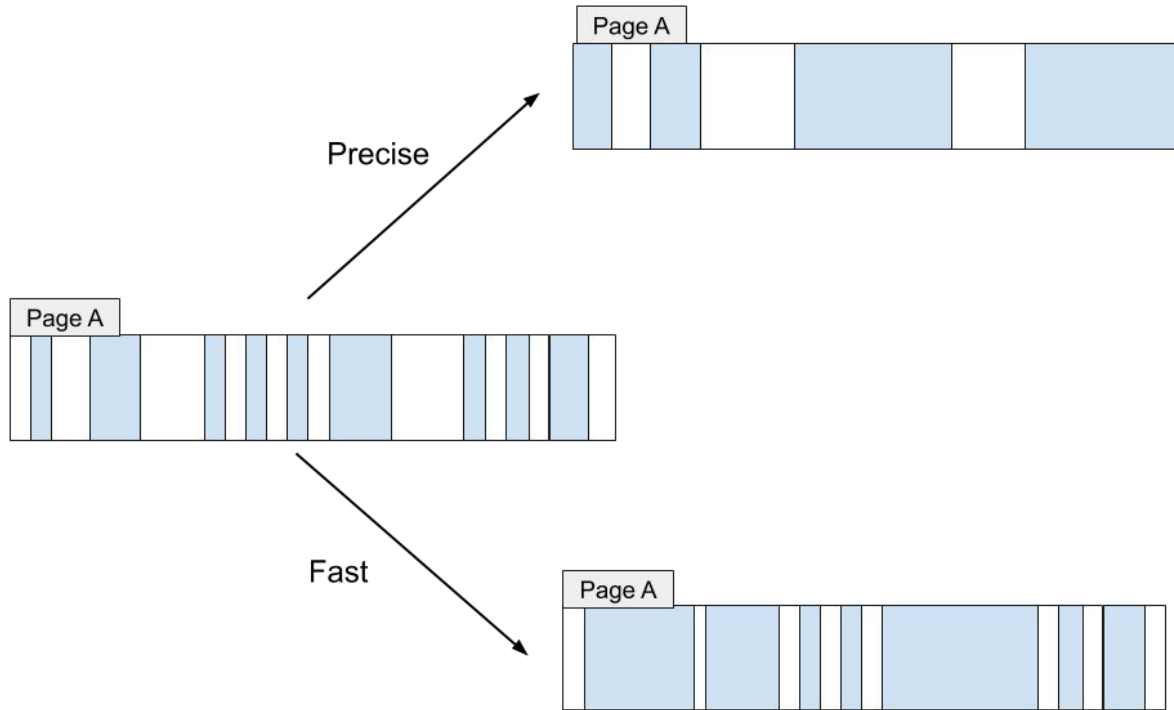
Allocations in the Old Space



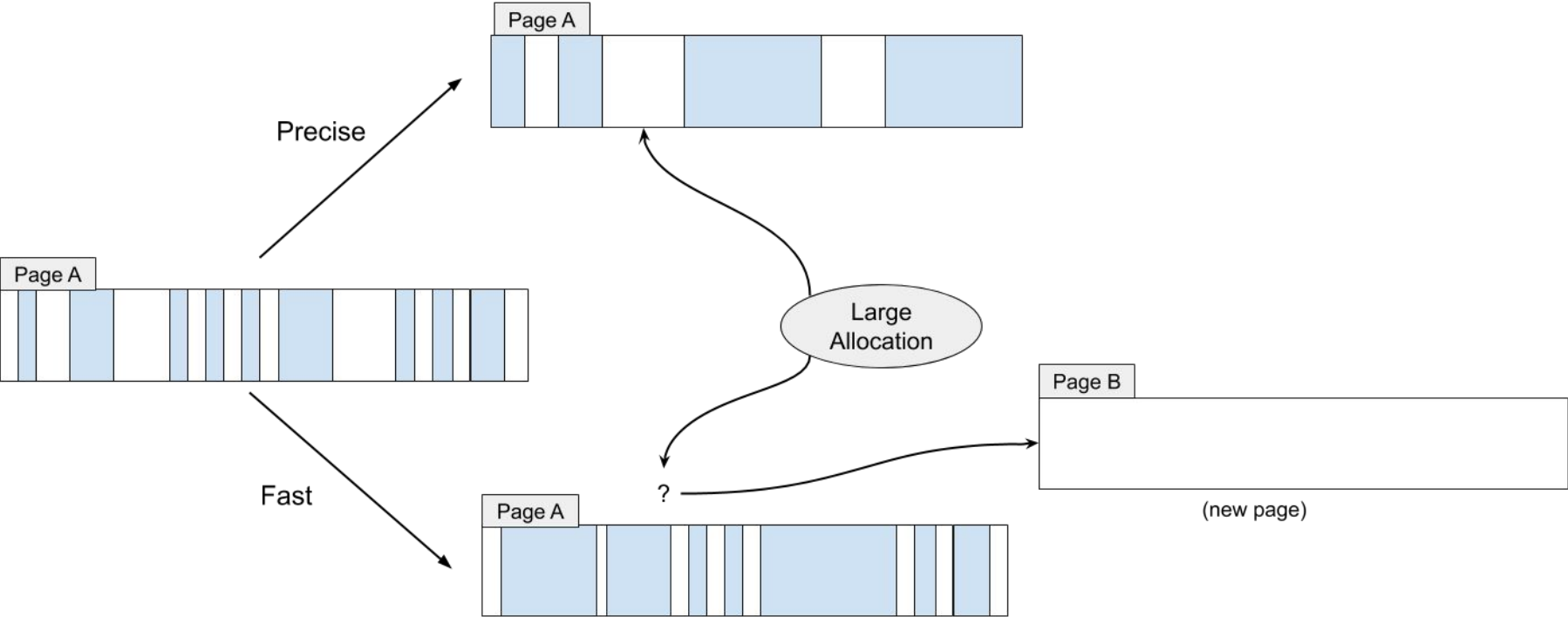
Refilling the linear allocation area: memory vs performance



Refilling the linear allocation area: memory vs performance

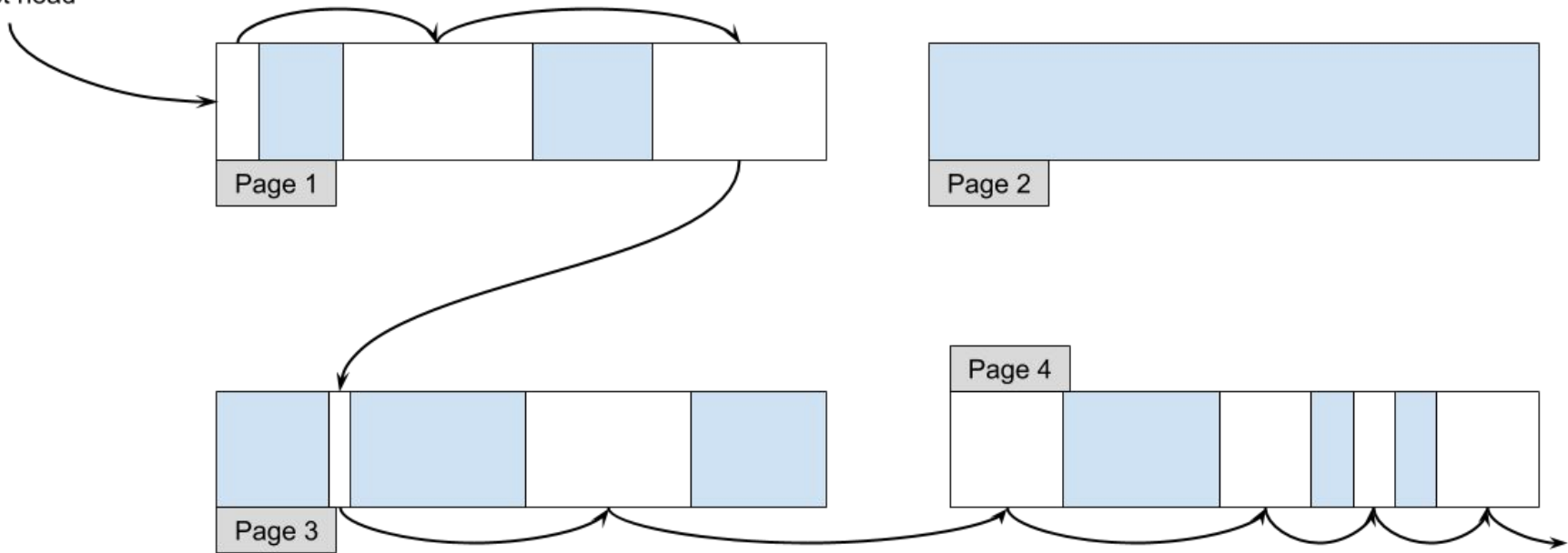


Refilling the linear allocation area: memory vs performance

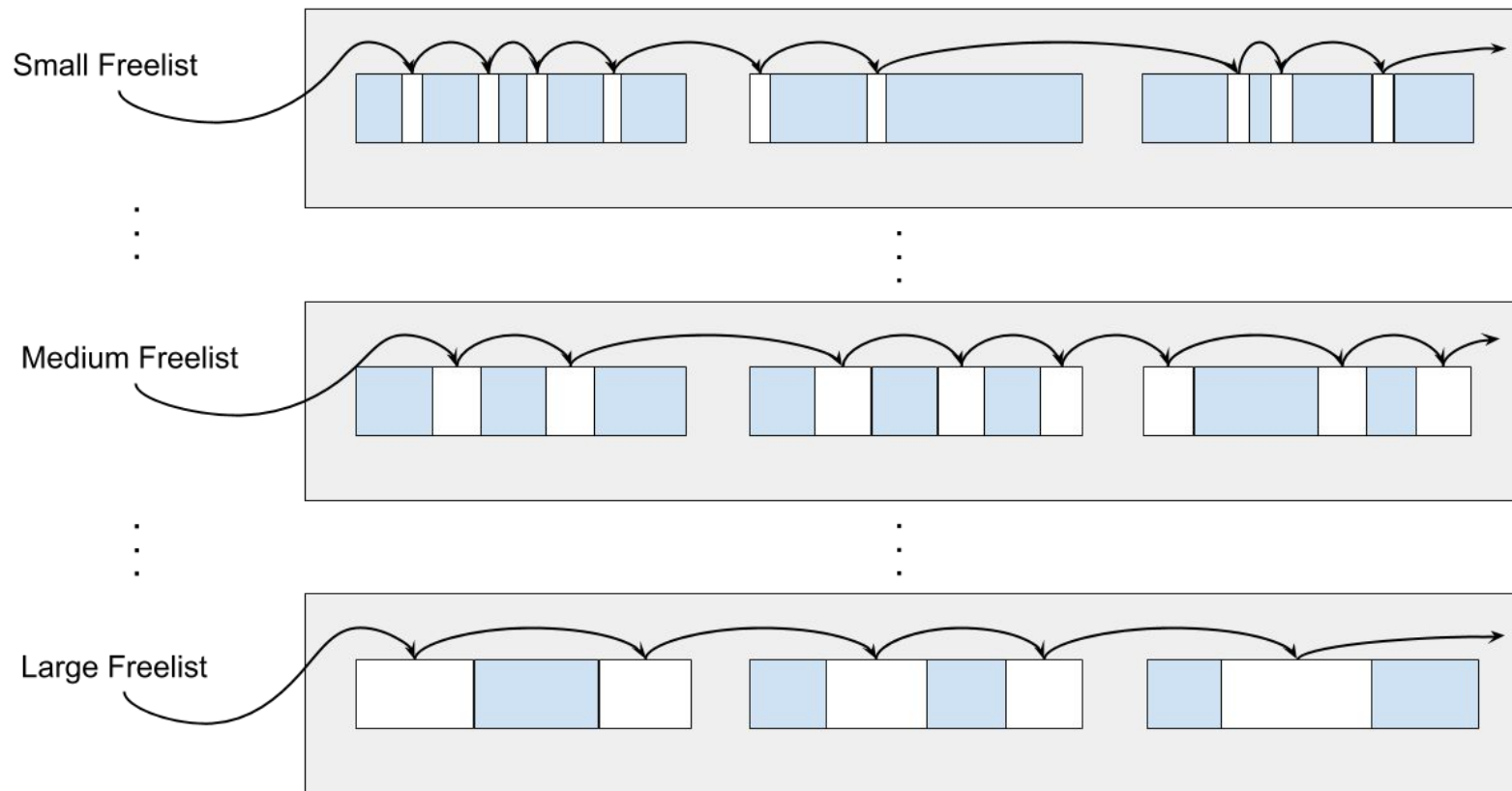


Single Freelist (OCaml, ...)

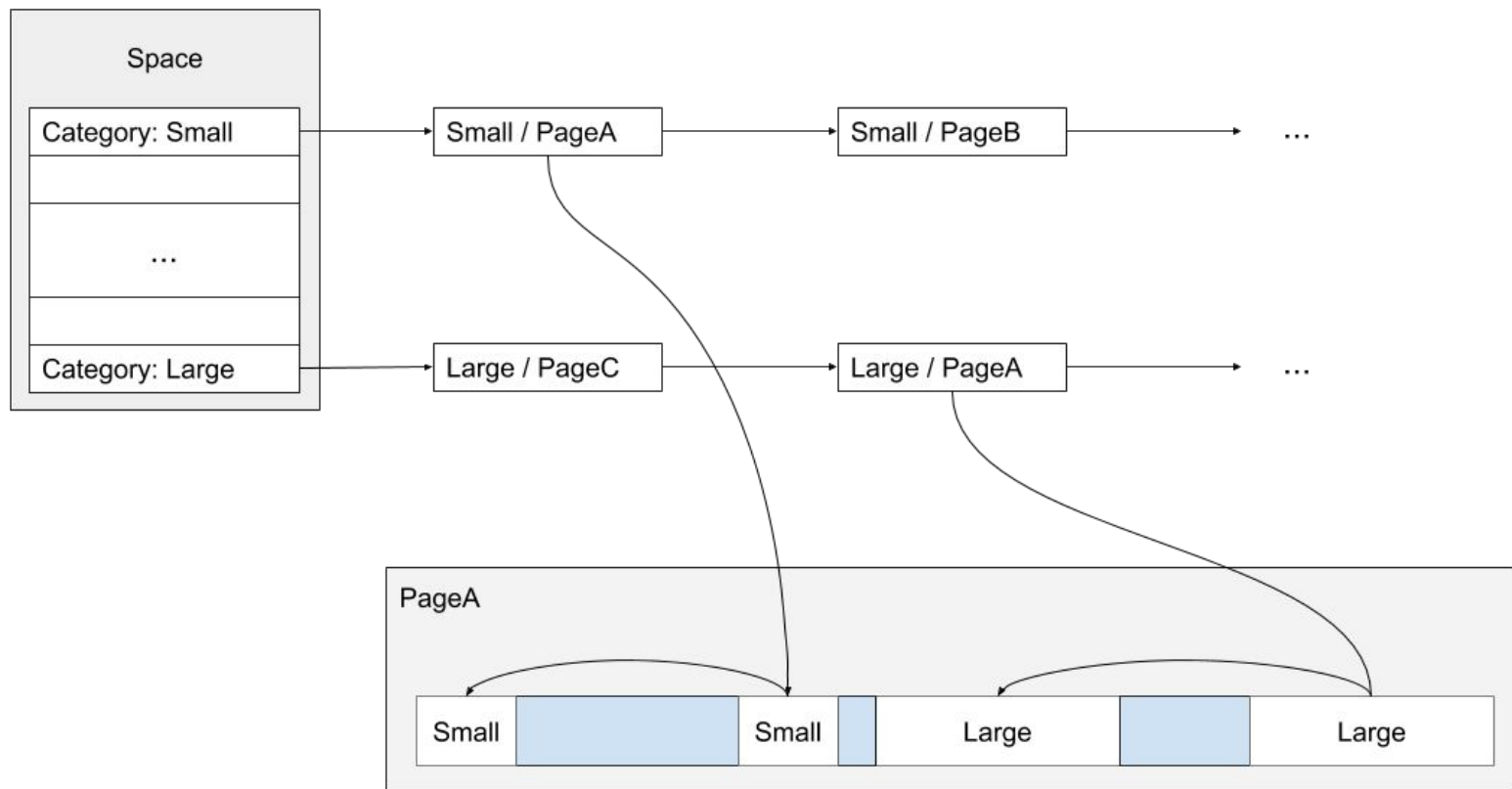
Freelist head



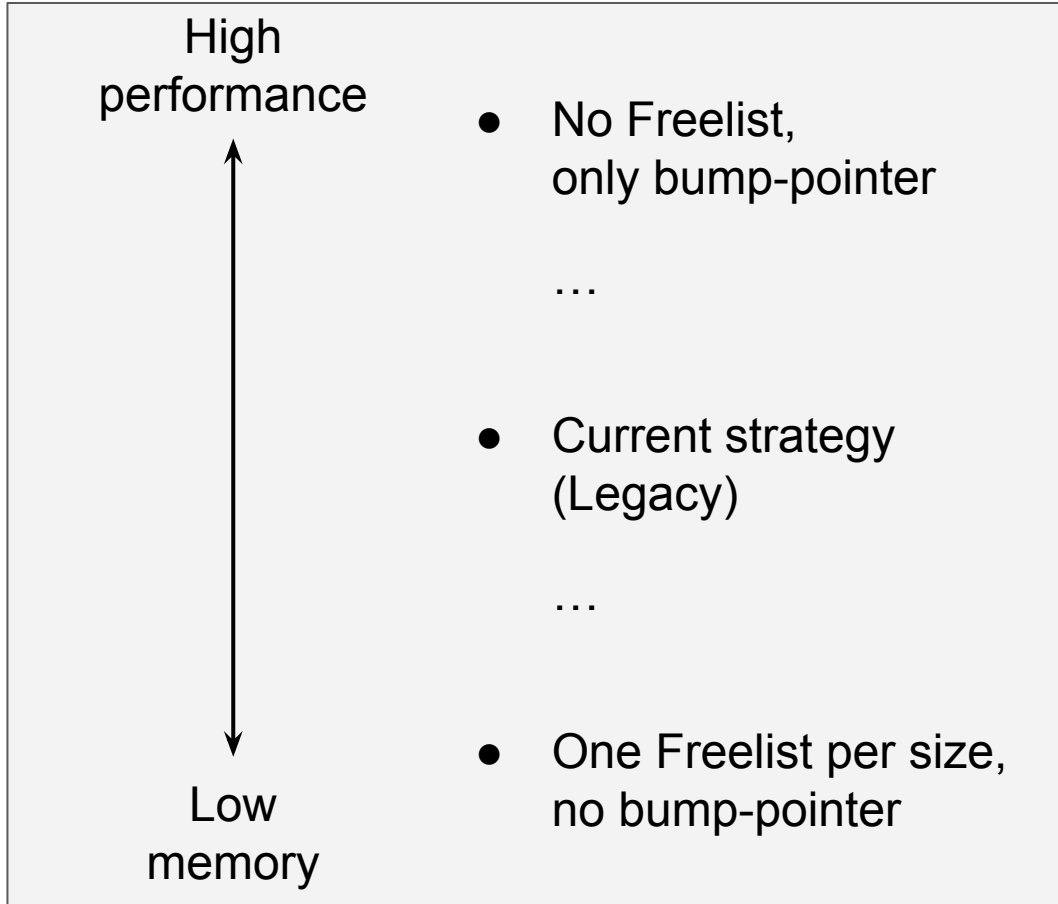
Segregating pages per size-class (Go, SpiderMonkey, ...)



Multiple freelists with non-segregated pages (V8, Dart, ...)

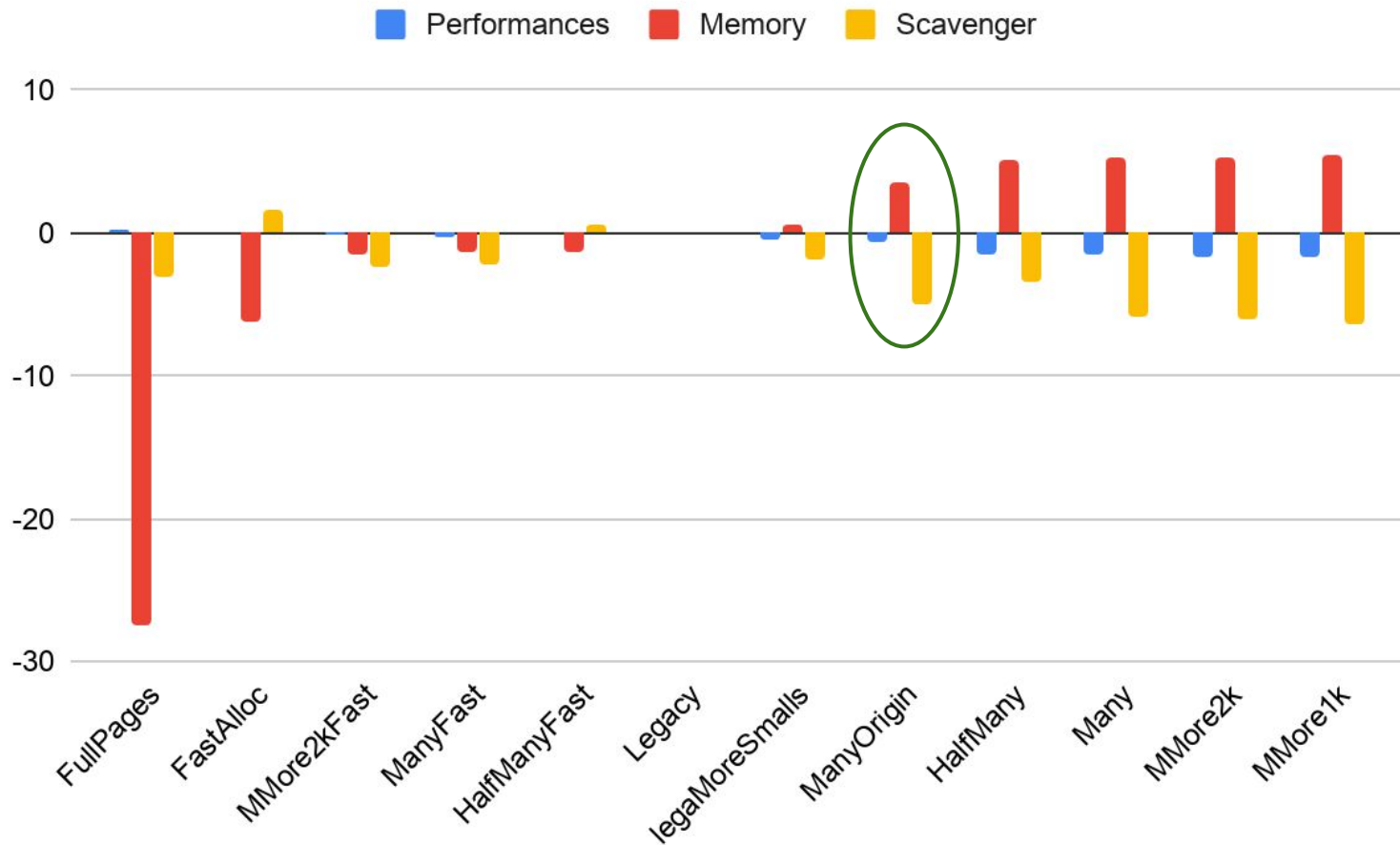


Exploring Freelists trade-offs

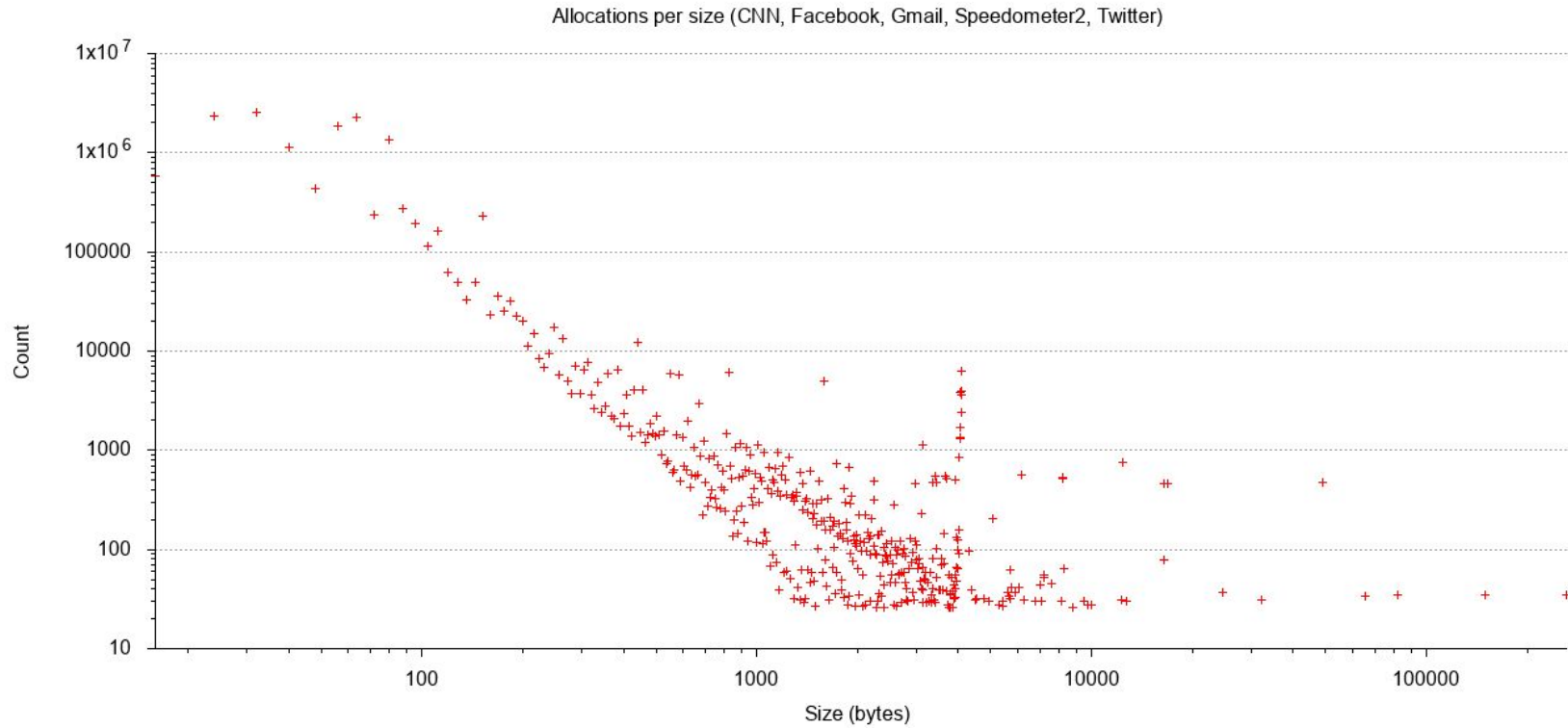


- How to speed up allocations?
- How to reduce memory?
- How many Freelists to use?
- What boundaries to chose for the Freelists?

Comparing all our FreeLists



Allocation sizes



-> Optimizing small allocations is more important

Details of our new Freelist

Fast path

1. Size +2KB
2. (fallback) 256B - 2KB
(for size ≤ 128 only)
3. (fallback) precise

Details of our new Freelist

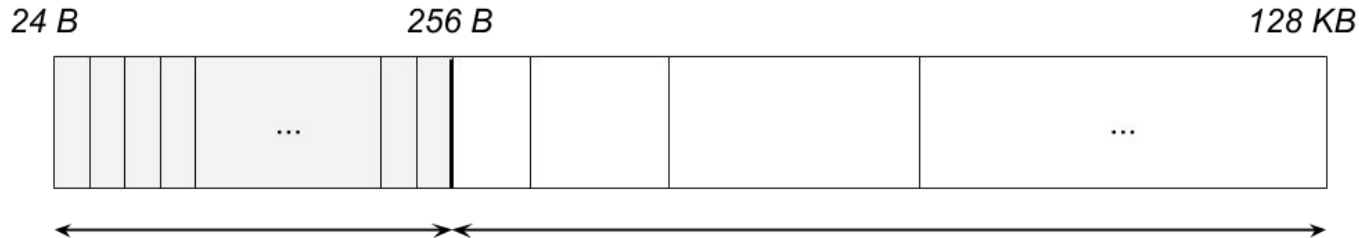


Linear categories
| $C(0) = 24$
| $C(i+1) = C(i)+8$
(30 categories)

Fast path

1. Size +2KB
2. (fallback) 256B - 2KB
(for size ≤ 128 only)
3. (fallback) precise

Details of our new Freelist



Linear categories

| $C(0) = 24$

| $C(i+1) = C(i)+8$

(30 categories)

Exponential categories

| $C(31) = 256$

| $C(32) = 384$

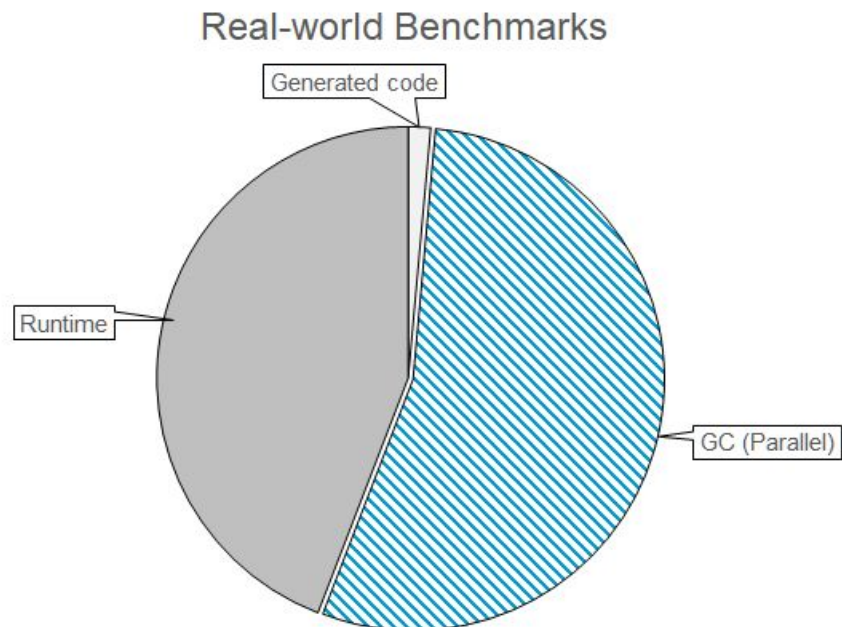
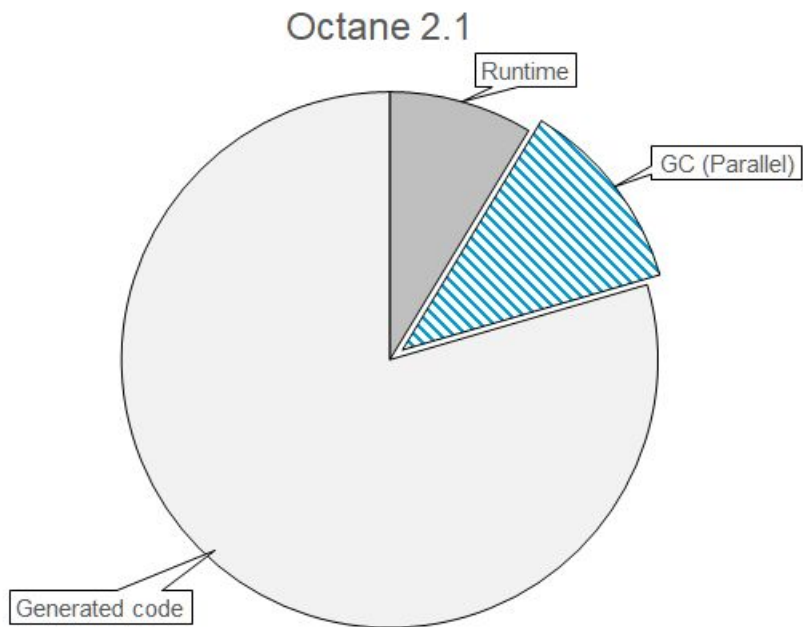
| $C(i+1) = C(i-1)*2$

(16 categories)

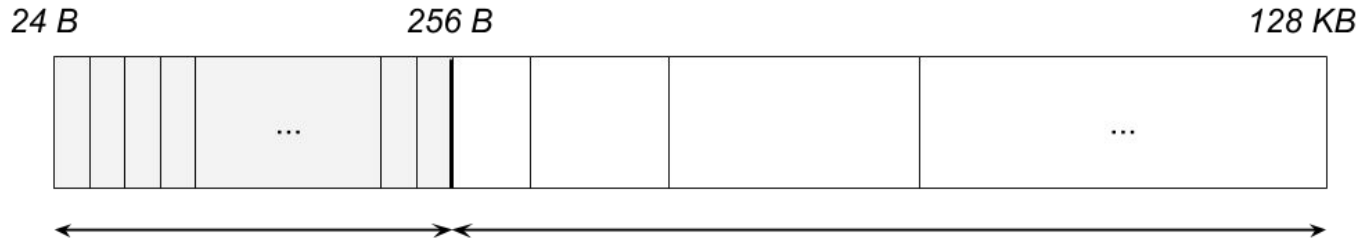
Fast path

1. Size +2KB
2. (fallback) 256B - 2KB
(for size ≤ 128 only)
3. (fallback) precise

Origins of allocations in the old generation



Details of our new Freelist



Linear categories

| $C(0) = 24$

| $C(i+1) = C(i)+8$

(30 categories)

Exponential categories

| $C(31) = 256$

| $C(32) = 384$

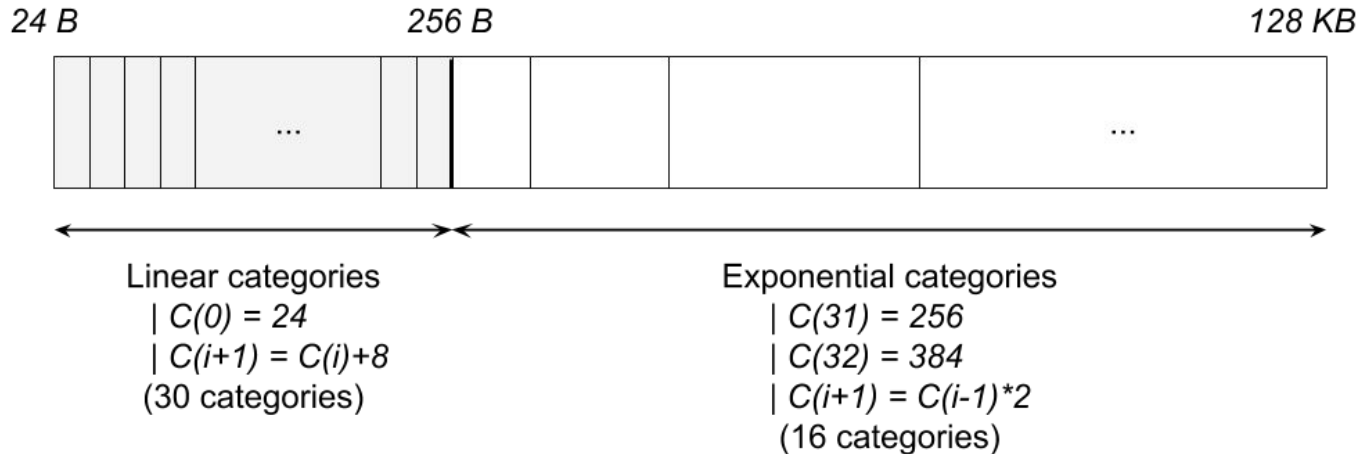
| $C(i+1) = C(i-1)*2$

(16 categories)

Fast path

1. Size +2KB
2. (fallback) 256B - 2KB
(for size ≤ 128 only)
3. (fallback) precise

Details of our new Freelist



Allocation Strategy

- Runtime / Generated Code: Fast
- GC (Scavenger): Precise

Fast path

1. Size +2KB
2. (fallback) 256B - 2KB
(for size ≤ 128 only)
3. (fallback) precise

So much green!

<input type="checkbox"/>		689661 - 689715	ChromiumPerf	Android Nexus5 Perf	system_health.memory_mobile	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/load_media/load_media_dailymotion	1.7% 108.6 KiB
<input type="checkbox"/>		689661 - 689715	ChromiumPerf	Android Nexus5 Perf	system_health.memory_mobile	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_social/browse_social_tumblr_infinite_scroll_2018	2.2% 1.3 MiB
<input type="checkbox"/>		689661 - 689715	ChromiumPerf	Android Nexus5 Perf	system_health.memory_mobile	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/load_search/load_search_baidu_2018	2.1% 174.3 KiB
<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_ghi_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_accessibility_media/browse_accessibility_media_youtube	1.4% 580.5 KiB
<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_ghi_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_media/browse_media_flickr_infinite_scroll	1.5% 380.4 KiB
<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_ghi_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_accessibility_tech/browse_accessibility_tech_codesearch_2018	1.5% 297.6 KiB
<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_ghi_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_media/browse_media_pinterest_2018	3.5% 1.7 MiB
<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_ghi_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/load_games/load_games_alphabet_y_2018	1.4% 189.5 KiB
<input type="checkbox"/>		689711 - 689746	ChromiumPerf	mac-10_12_laptop_low_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_media/browse_media_flickr_infinite_scroll	1.8% 441.2 KiB
<input type="checkbox"/>		689711 - 689746	ChromiumPerf	mac-10_12_laptop_low_end-perf	system_health.memory_desktop	memory:chrome:all_processes:reported_by_chrome:v8:effective_size_avg/browse_media/browse_media_pinterest_2018	3.0% 1.5 MiB
<input type="checkbox"/>		689697 - 689754	ChromiumPerf	Android Nexus6 WebView Perf	system_health.memory_mobile	memory:webview:all_processes:reported_by_chrome:v8:effective_size_avg/browse_social/browse_social_tumblr_infinite_scroll_2018	2.2% 1.3 MiB

... but also a bit of red

<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_high_end-perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/load_news/load_news_qq	1.9% 1.5 MiB
<input type="checkbox"/>		689699 - 689724	ChromiumPerf	mac-10_13_laptop_high_end-perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/load_tools/load_tools_gmail	1.0% 607.2 KiB
<input type="checkbox"/>		689492 - 689730	ChromiumPerf	Win 7 Nvidia GPU Perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/browse_tech/browse_tech_discourse_infinite_scroll_2018	2.1% 484.9 KiB
<input type="checkbox"/>		689492 - 689730	ChromiumPerf	Win 7 Nvidia GPU Perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/load_tools/load_tools_gmail	2.2% 729.5 KiB
<input type="checkbox"/>		689492 - 689730	ChromiumPerf	Win 7 Nvidia GPU Perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/browse_tools/browse_tools_earth	2.7% 804.5 KiB
<input type="checkbox"/>		689711 - 689746	ChromiumPerf	mac-10_12_laptop_low_end-perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/load_news/load_news_qq	1.9% 1.6 MiB
<input type="checkbox"/>		689637 - 689791	ChromiumPerf	win-10-perf	system_health.memory_de sktop	memory:chrome:all_processes:reported_by_chrome:mallocc:effective_size_avg/browse_tech/browse_tech_discourse_infinite_scroll_2018	2.1% 479.6 KiB

Conclusion

- Better understanding of memory/performance trade-offs
- Flexible new FreeList:
 - -3.5% (avg) old space size at (almost) no cost
 - Can be made more space-efficient for low memory devices
 - Can be tuned for more performances
 - Compactor can be (partly) turned off
- A lot of results about Freelists [[doc](#)]

Future Work

- (Make FreeListCategory more lightweight)
- Tune FreeList strategy at runtime
- Evaluate and optimize “end of cycle” latency
- Generalize to segregated pages

Benchmarking tools

```

dmercadier@mercadier ~/chromium/src % ./compare.pl --opts=-gc-freelist-strategy={0,1} --name=cmp-exps-5
dmercadier@mercadier ~/chromium/src % ./summarize_results.pl --dir=tools/perf/results/cmp-exps-5 --labels --ref=Legacy
Reading files..... done.
Computing statistics..... done

***** JS:duration (avg) *****
| FastAlloc | FullPages | HalfMany | HalfManyFast | Legacy | MMore1k | MMore2k | MMore2kFast | Many | ManyFast | ManyOrigin | legaMoreSmalls
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
cnn | 2.18K (x1.00) | 2.19K (x1.00) | 2.29K (x0.99) | 2.22K (x0.99) | 2.19K (x1.00) | 2.29K (x0.99) | 2.37K (x0.99) | 2.20K (x0.99) | 2.22K (x0.99) | 2.19K (x1.00) | 2.29K (x0.99) | 2.29K (x0.99)
discourse | 4.76K (x1.01) | 4.77K (x1.00) | 4.81K (x0.99) | 4.77K (x1.00) | 4.79K (x1.00) | 4.81K (x1.00) | 4.82K (x0.99) | 4.78K (x1.00) | 4.78K (x1.00) | 4.77K (x1.00) | 4.79K (x1.00) | 4.81K (x1.00)
facebook | 4.48K (x1.00) | 4.49K (x1.00) | 4.59K (x0.99) | 4.49K (x0.99) | 4.47K (x1.00) | 4.49K (x1.00) | 4.57K (x0.99) | 4.46K (x1.00) | 4.49K (x0.99) | 4.48K (x1.00) | 4.59K (x0.99) | 4.48K (x1.00)
flipboard | 1.56K (x1.00) | 1.56K (x1.01) | 1.59K (x0.99) | 1.56K (x1.01) | 1.57K (x1.00) | 1.59K (x0.99) | 1.58K (x0.99) | 1.56K (x1.00) | 1.59K (x0.99) | 1.57K (x1.00) | 1.57K (x1.00) | 1.57K (x1.00)
google_india | 243.55 (x1.00) | 243.36 (x1.00) | 247.40 (x0.99) | 241.59 (x1.01) | 243.73 (x1.00) | 245.43 (x0.99) | 246.17 (x0.99) | 244.93 (x1.00) | 247.42 (x0.99) | 246.26 (x0.99) | 244.00 (x1.00) | 243.24 (x1.00)
maps | 4.16K (x1.00) | 4.15K (x1.00) | 4.19K (x1.00) | 4.15K (x1.00) | 4.17K (x1.00) | 4.15K (x1.00) | 4.15K (x1.00) | 4.15K (x1.00) | 4.14K (x1.01) | 4.15K (x1.00) | 4.16K (x1.00) | 4.16K (x1.00)
nytimes | 9.02K (x1.00) | 8.97K (x1.01) | 9.11K (x0.99) | 9.00K (x1.00) | 9.02K (x1.00) | 9.24K (x0.99) | 9.29K (x0.97) | 9.03K (x1.00) | 9.24K (x0.99) | 9.04K (x1.00) | 9.09K (x0.99) | 9.09K (x0.99)
reddit | 5.55K (x0.98) | 5.53K (x0.99) | 5.58K (x0.98) | 5.49K (x0.99) | 5.46K (x1.00) | 5.63K (x0.97) | 5.59K (x0.98) | 5.56K (x0.98) | 5.54K (x0.99) | 5.53K (x0.99) | 5.53K (x0.99) | 5.63K (x0.97)
speedometer2 | 39.58K (x1.00) | 39.53K (x1.01) | 31.20K (x0.99) | 30.68K (x1.00) | 30.72K (x1.00) | 31.27K (x0.98) | 31.25K (x0.98) | 30.69K (x1.00) | 31.20K (x0.99) | 30.76K (x1.00) | 30.97K (x0.99) | 30.75K (x1.00)
twitter_infinite_scroll | 716.03 (x1.01) | 715.92 (x1.01) | 725.11 (x1.00) | 714.02 (x1.01) | 722.59 (x1.00) | 738.53 (x0.98) | 728.57 (x0.99) | 717.13 (x1.01) | 736.21 (x0.98) | 718.22 (x1.01) | 717.26 (x1.01) | 716.94 (x1.01)
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
overall | x1.001 | x1.002 | x0.998 | x1.001 | x1.000 | x0.998 | x0.997 | x0.999 | x0.997 | x0.998 | x0.995 | x0.995

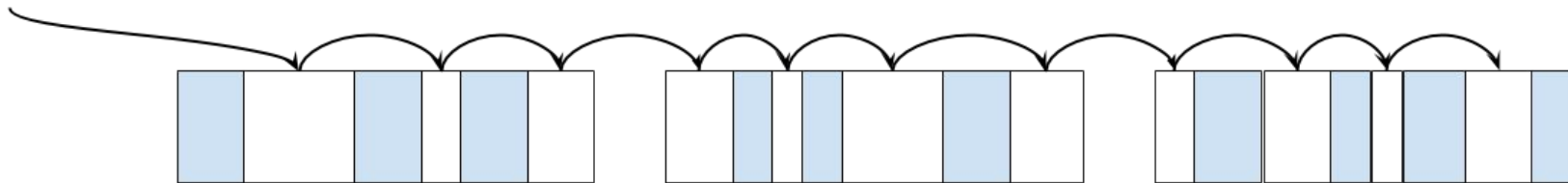
***** old_space:effective_size (max) *****
| FastAlloc | FullPages | HalfMany | HalfManyFast | Legacy | MMore1k | MMore2k | MMore2kFast | Many | ManyFast | ManyOrigin | legaMoreSmalls
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
cnn | 81.26M (x0.93) | 87.90M (x0.86) | 70.45M (x1.07) | 78.05M (x0.97) | 75.43M (x1.00) | 72.00M (x1.05) | 70.89M (x1.06) | 79.30M (x0.95) | 71.86M (x1.05) | 77.76M (x0.97) | 73.94M (x1.02) | 74.56M (x1.01)
discourse | 32.69M (x0.94) | 47.49M (x0.85) | 27.62M (x1.11) | 31.12M (x0.98) | 30.62M (x1.00) | 27.64M (x1.11) | 27.61M (x1.11) | 31.10M (x0.98) | 27.59M (x1.11) | 31.02M (x0.99) | 29.06M (x1.05) | 30.52M (x1.00)
facebook | 94.79M (x0.97) | 108.11M (x0.85) | 86.95M (x1.06) | 89.79M (x1.03) | 92.06M (x1.00) | 86.74M (x1.06) | 86.83M (x1.06) | 89.61M (x1.03) | 86.98M (x1.06) | 89.23M (x1.03) | 87.81M (x1.05) | 91.75M (x1.00)
flipboard | 47.52M (x0.97) | 52.75M (x0.87) | 42.27M (x1.09) | 44.61M (x1.03) | 46.08M (x1.00) | 42.29M (x1.09) | 41.86M (x1.10) | 44.70M (x1.03) | 41.84M (x1.10) | 45.06M (x1.02) | 43.76M (x1.05) | 45.87M (x1.00)
google_india | 38.73M (x0.97) | 20.74M (x0.88) | 17.92M (x1.01) | 17.91M (x1.01) | 18.15M (x1.00) | 17.80M (x1.02) | 17.59M (x1.03) | 17.88M (x1.02) | 17.61M (x1.03) | 17.95M (x1.01) | 17.96M (x1.01) | 17.99M (x1.01)
maps | 98.52M (x0.94) | 120.86M (x0.77) | 92.06M (x1.01) | 96.11M (x0.97) | 92.78M (x1.00) | 90.65M (x1.02) | 91.22M (x1.02) | 95.79M (x0.97) | 91.70M (x1.01) | 95.85M (x0.97) | 91.85M (x1.01) | 93.08M (x1.00)
nytimes | 132.97M (x0.95) | 181.07M (x0.76) | 117.91M (x1.07) | 126.47M (x1.00) | 125.89M (x1.00) | 115.53M (x1.09) | 117.82M (x1.07) | 126.75M (x0.99) | 116.57M (x1.08) | 128.01M (x0.98) | 118.59M (x1.06) | 125.16M (x1.01)
reddit | 168.46M (x0.92) | 191.16M (x0.86) | 145.58M (x1.05) | 158.16M (x0.97) | 153.23M (x1.00) | 145.43M (x1.05) | 145.16M (x1.06) | 157.30M (x0.97) | 145.23M (x1.06) | 157.43M (x0.97) | 147.06M (x1.04) | 151.38M (x1.01)
speedometer2 | 32.13M (x0.93) | 37.80M (x0.79) | 28.85M (x1.04) | 30.17M (x0.99) | 29.92M (x1.00) | 29.41M (x1.02) | 29.25M (x1.02) | 31.70M (x0.94) | 29.06M (x1.03) | 31.15M (x0.96) | 29.66M (x1.02) | 29.99M (x1.00)
twitter_infinite_scroll | 25.64M (x0.92) | 28.90M (x0.92) | 23.02M (x1.03) | 24.06M (x0.98) | 23.63M (x1.00) | 23.04M (x1.03) | 23.03M (x1.03) | 23.91M (x0.99) | 23.18M (x1.02) | 23.97M (x0.99) | 23.42M (x1.01) | 23.54M (x1.00)
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
overall | x0.944 | x0.707 | x1.053 | x0.993 | x1.000 | x1.054 | x1.056 | x0.988 | x1.055 | x0.988 | x1.033 | x1.005

***** v8-gc-scavenger (avg) *****
| FastAlloc | FullPages | HalfMany | HalfManyFast | Legacy | MMore1k | MMore2k | MMore2kFast | Many | ManyFast | ManyOrigin | legaMoreSmalls
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
cnn | 1.85 (x1.02) | 1.93 (x0.98) | 1.89 (x0.95) | 1.90 (x0.99) | 1.89 (x1.00) | 2.09 (x0.91) | 2.09 (x0.93) | 2.04 (x0.97) | 2.05 (x0.92) | 1.96 (x0.97) | 2.02 (x0.99) | 1.92 (x0.99)
discourse | 1.03 (x1.02) | 1.19 (x0.96) | 1.13 (x0.93) | 1.09 (x1.00) | 1.06 (x1.00) | 1.10 (x0.99) | 1.10 (x0.99) | 1.09 (x0.97) | 1.10 (x0.99) | 1.09 (x0.97) | 1.14 (x0.93) | 1.09 (x0.97)
facebook | 1.52 (x1.00) | 1.61 (x0.94) | 1.60 (x0.95) | 1.55 (x0.98) | 1.52 (x1.00) | 1.61 (x0.94) | 1.61 (x0.94) | 1.54 (x0.99) | 1.59 (x0.96) | 1.57 (x0.97) | 1.61 (x0.95) | 1.59 (x0.96)
flipboard | 1.24 (x1.02) | 1.27 (x0.99) | 1.30 (x0.97) | 1.26 (x1.00) | 1.26 (x1.00) | 1.33 (x0.99) | 1.33 (x0.99) | 1.29 (x0.98) | 1.34 (x0.94) | 1.30 (x0.97) | 1.33 (x0.96) | 1.30 (x0.97)
google_india | 2.04 (x0.93) | 2.07 (x1.01) | 2.10 (x0.99) | 1.98 (x1.06) | 2.09 (x1.00) | 2.12 (x0.99) | 2.17 (x0.96) | 2.15 (x0.99) | 2.14 (x0.98) | 2.16 (x0.97) | 2.12 (x0.99) | 2.11 (x0.99)
maps | 1.42 (x1.02) | 1.49 (x0.95) | 1.52 (x0.95) | 1.44 (x1.00) | 1.44 (x1.00) | 1.57 (x0.91) | 1.59 (x0.91) | 1.50 (x0.95) | 1.55 (x0.93) | 1.47 (x0.98) | 1.55 (x0.93) | 1.50 (x0.95)
nytimes | 1.30 (x0.99) | 1.47 (x0.89) | 1.35 (x0.99) | 1.31 (x0.99) | 1.29 (x1.00) | 1.39 (x0.93) | 1.40 (x0.92) | 1.34 (x0.97) | 1.30 (x0.95) | 1.33 (x0.97) | 1.30 (x0.95) | 1.30 (x0.95)
reddit | 1.65 (x1.03) | 1.69 (x1.01) | 1.73 (x0.98) | 1.69 (x1.01) | 1.70 (x1.00) | 1.77 (x0.96) | 1.77 (x0.96) | 1.70 (x1.00) | 1.78 (x0.95) | 1.69 (x1.01) | 1.77 (x0.96) | 1.69 (x1.00)
speedometer2 | 0.74 (x1.01) | 0.78 (x0.95) | 0.79 (x0.95) | 0.75 (x0.99) | 0.74 (x1.00) | 0.80 (x0.92) | 0.79 (x0.94) | 0.79 (x0.94) | 0.79 (x0.94) | 0.76 (x0.97) | 0.80 (x0.93) | 0.76 (x0.98)
twitter_infinite_scroll | 1.33 (x1.03) | 1.37 (x1.00) | 1.34 (x1.02) | 1.32 (x1.03) | 1.36 (x1.00) | 1.41 (x0.97) | 1.35 (x1.01) | 1.38 (x0.99) | 1.40 (x0.97) | 1.33 (x1.03) | 1.37 (x0.99) | 1.34 (x1.02)
-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
overall | x1.016 | x0.908 | x0.966 | x1.004 | x1.000 | x0.938 | x0.942 | x0.975 | x0.943 | x0.979 | x0.952 | x0.980

```


Map Space Freelist

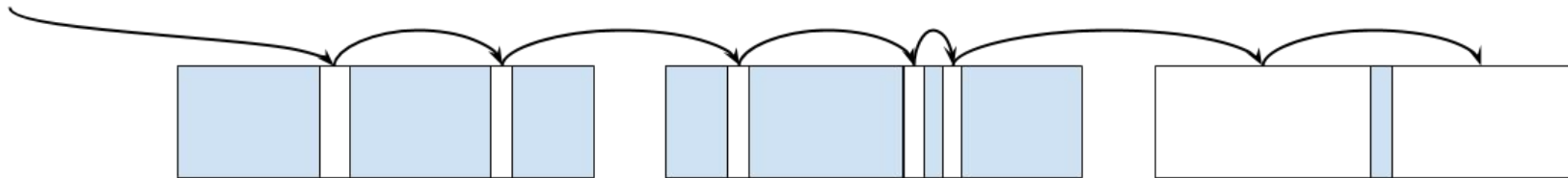
Map Freelist



Unsorted pages

Sorted by free bytes pages

Map Freelist



Optimization: Caching empty categories

