Finding more DRAM

Mobile devices to Data centers

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Why more DRAM?

- Mobile Devices
  - Application RAM demand keep increasing
  - Limited form factor
  - No way to add more physical RAM
- Datacenter
  - DRAM cost is a major factor of the total datacenter cost
  - Over-provision and under-utilized
  - Expensive ECC RAM

Current status

- Kill background apps (Android)
  - More cold starts -> slow and power hungry
- Overcommit memory (data centers)
  - Global memory pressure -> Direct reclaim -> No performance isolation
  - High refault cost due to slow storage devices

Solution: Proactively reclaim memory

- Reclaim **unneeded** memory proactively which is **very cheap** to refault.
- Approaches
  - Userspace driven proactive reclaim (**Android**)
    - Unneeded: memory of background apps
    - Cheap refaults: in-memory compression (zram)
  - Kernel driven proactive reclaim (**Google datacenter kernel**)
    - Unneeded: maintains idle age of whole memory
    - Cheaper: in-memory compression (zswap)

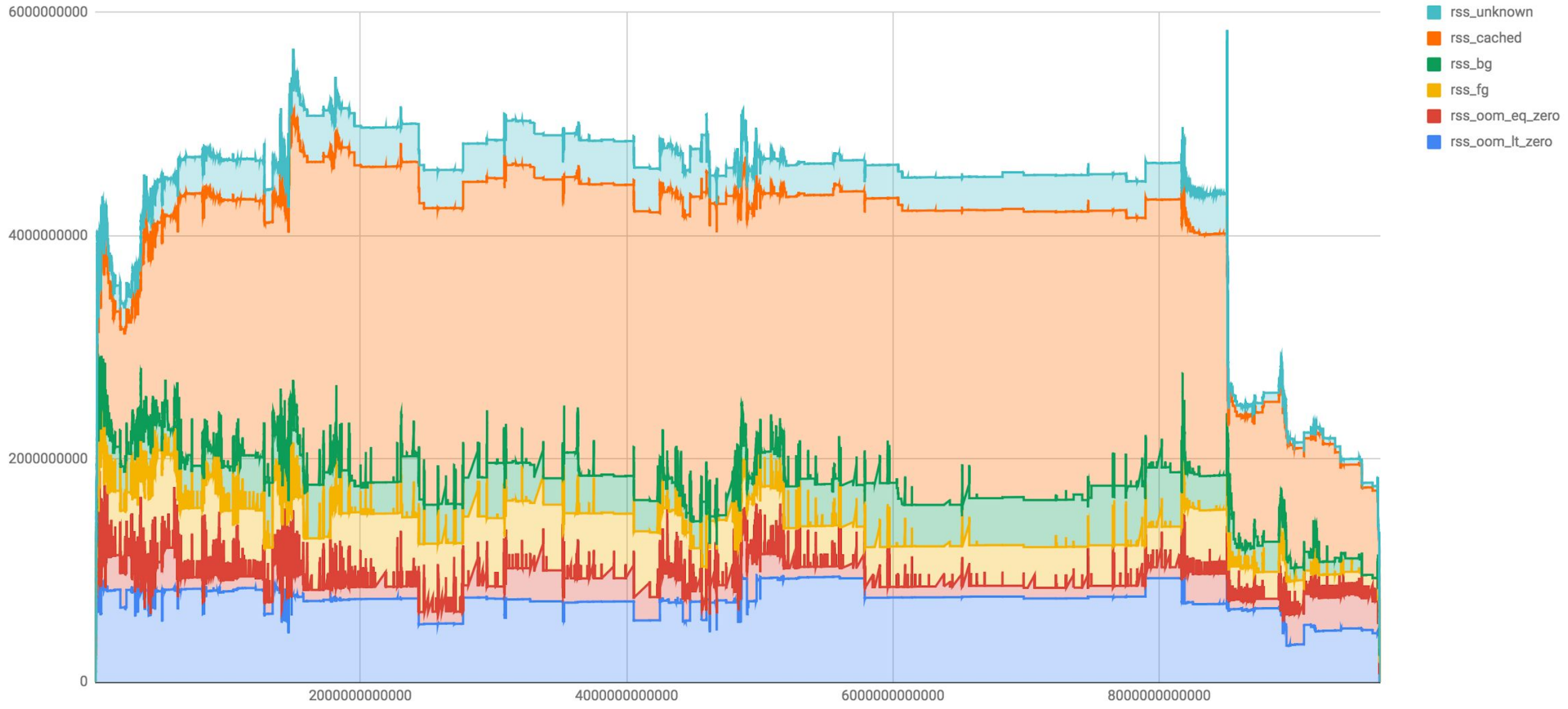
Android story

Cold starts are slow and power hungry

Can we keep more background apps alive while not affecting interactive ones?

Let’s shrink them!

Where all the memory is being used?



Userspace driven proactive reclaim

Idea: keep more RAM available for interactive applications by hinting kernel about processes unlikely to be used in the near future

Solution: proactively reclaim application memory after its transition into non-interactive state

Implementation: new process_madvise() APIs:

- MADV_COLD and MADV_PAGEOUT merged into mm tree
- process_madvice() syscall under development

Results: decreased number of kills under memory pressure

- 15% less kills from the dogfood population
- up to 30% less kills while running stress tests

android

Experiment #1: proactively reclaim all pages

App cycle order:	ABCABC	ABCBA
Launch time	No change	8% regression
# of kills	50% less kills	19% more kills
notes	major faults for file-mapped pages increased by 6%	

Observation:
file LRU is very small
memory spikes result in more kills

Conclusion: proactively reclaiming file-backed pages is not a good idea.

How about deactivating file-backed pages them instead?

android

Experiment #2: reclaim anonymous and deactivate file-backed pages

App cycle order:	ABCABC	ABCBA
Launch time	29% decrease	15% decrease
# of kills	21% less kills	40% more kills

Observation: app-compaction is trying to allocate more memory while system is under heavy memory pressure, making the situation worse and increasing lmk kills

Conclusion: userspace should avoid doing app-compaction while the system is under heavy memory pressure

Results

When app-compaction is timed correctly we get 15% less kills from the dogfood population and up to 30% less kills while running stress tests

A popular game: ~1.8GB in game, 1.7GB in background, ~700MB compacted

No noticeable penalty on warm start observed for high-end devices

Reduced number of cold starts

Implementation: process_madvise()

Use process_madvise() with MADV_COLD and MADV_PAGEOUT to hint the kernel that process won't be used in the near future.

MADV_COLD deactivates active pages speeding up their reclaim in case of memory pressure

MADV_PAGEOUT reclaims private pages immediately

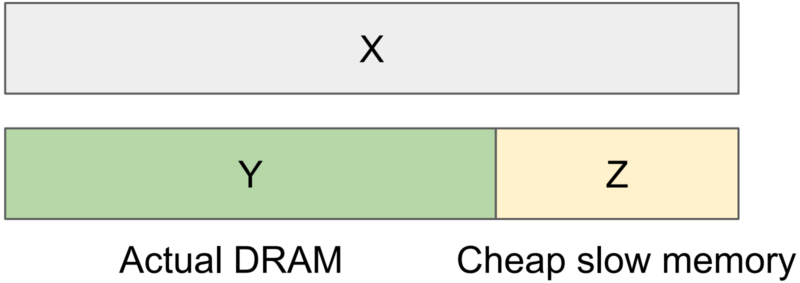
Status: MADV_COLD and MADV_PAGEOUT options for madvise() are in MM tree, process_madvise() syscall is under development

Proactive reclaim for Data Centers

- Finding memory to reclaim proactively
- Reclaim memory

Google data center Memory Overcommit Model

- Replace part of DRAM with cheap slow memory (or far memory)
- Memory Provisioning
  - Quota request
  - Translates to

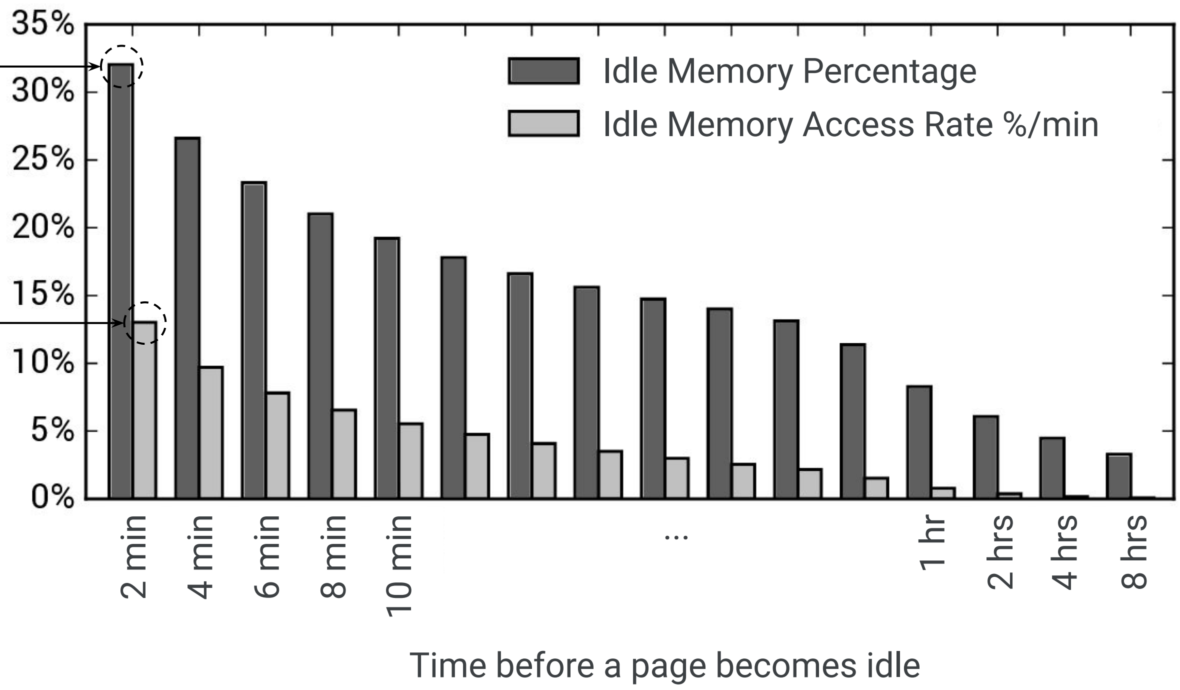


- Cheap slow memory is completely **transparent** to the users
  - Examples: **ZSWAP**, PMEM(slower+cheaper), swap (remote/local).
- Size of cheap slow memory == Idle Memory Estimation

Idle Memory in across **Google**'s Datacenters

Opportunity:
32% of memory usage is idle

Challenge:
Frequent accesses to idle memory



Existing mechanisms

- Why not kswapd
  - Reclaim based on watermarks
  - Aims to balance nodes
  - Too many complicated heuristics
- Page Idle Tracking
  - High CPU overhead
  - High memory overhead

```
for pfn in Machine:
  flag   = read("/proc/kpageflags")
  cgroup = read("/proc/kpagecgroup")
  idle   = read("/sys/kernel/mm/page_idle/bitmap")
  // Track idle pages for each page and their cgroups.
```

Our Approach

- kstaled (in-kernel page idle tracking)
  - No memory overhead (by storing age in page flags)
  - CPU overhead is similar to Page Idle Tracking
- kreclaimd
  - a kernel thread scanning all PFNs and reclaiming idle pages
- Per-memcg knobs
  - Idle age threshold for reclaiming anon and file pages
  - Page idle age histograms

kstaled CPU overhead

- CPU usage increases linearly with the RAM size
  - Spends 100% of a CPU for 512 GiB
- CPU usage increases linearly with the scan frequency
  - Spends 80% of a CPU for 60 sec cycle
- 50% time spent in rmap_walk

kstaled optimizations

- Remove rmap_walk from kstaled
  - Link all PMD pages into per-node linked list
  - Traverse PMD linked list to extract access bit
  - Traverse PFNs to age all the pages
- 3.5x CPU usage reduction by kstaled
  - Allows to scan larger systems or with higher frequency
- Remove PFN scanning from kreclaimd
  - kstaled passes idle pages to kreclaimd through a queue
- 1.5x CPU usage reduction by kreclaimd

Upstream concerns (during LSFMM'19)

- Bypassing existing LRUs
- High CPU cost
- Potential way forward
  - Decouple ageing from memory pressure
  - Use ages to sort LRUs
  - User controlled trigger for ageing and LRU sorting

Discussion points

1. Avoid direct reclaim at all cost.
2. process_madvise() parameters - vector (efficiency) vs a single VMA (simple error handling).
3. VMAs might change between reading /proc/maps and process_madvise() and hint might be applied to a wrong VMA. Possible solutions:
    a. Limit process_madvise() to non-destructive hints only to minimize the price of an unlikely mistake
    b. Introduce a new syscall to get MM snapshot ID and pass it to process_madvise() to detect possible VMA changes