Embedded Linux Conference
North America

Introduction to NAND Flash Aware Hibernation-based Boot

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Overview

- Boot time reduction
  - Traditional boot time reduction techniques
- Hibernation boot
  - Hibernation (suspend to disk)
  - Cold vs. hibernation boot time
- Proposal for a new hibernation boot
  - Improving hibernation boot speed.
  - Extending the lifetime of the flash memory.

Boot time reduction

Boot time reduction

- Why is it important?
  - To improve user experience

    Convenience and customer satisfaction
  - Regulatory requirements

    There are critical safety reasons that drive boot time requirements for the automotive industry.
  - Marketing

    Have you seen one second Android boot?

Traditional techniques

- Measuring
  - Bootchart: a tool for performance analysis and visualization of the Linux boot process.
- Optimizing
  - bootloader, kernel and user space
  - Do it in parallel(independent tasks).
  - Maximizing I/O and minimizing the amount of data.
- Maintainability
  - How maintainable is it?

Hibernation Boot

What is hibernation?

- Hibernation (suspend to disk)
  - Hibernation in computing is powering down a computer while retaining its state.
  - Upon hibernation, the computer saves the contents of its random access memory (snapshot image) to a hard disk or other non-volatile storage.
  - Upon resumption, the computer is exactly as it was before entering hibernation.

Case Study

- Using i.MX 8MQ as a case study for hibernation boot
  - CPU (4 cores) with 3GB memory and eMMC
  - Bootloader: U-boot
  - Kernel: 4.9(base kernel for hibernation)
  - Android(Oreo)

Cold vs. Hibernation boot time

- Cold boot
  - Android is not optimized for fast boot.
- Hibernation boot
  - The way the upstream kernel uses for hibernation.
  - Snapshot Image: around 900 MiB
- Measurement
  - from power-on to starting Android launch
  - Cold boot: 14.8 sec.
  - Hibernation boot: 11.2 sec.

Proposal for a new hibernation boot

Optimizing hibernation boot time

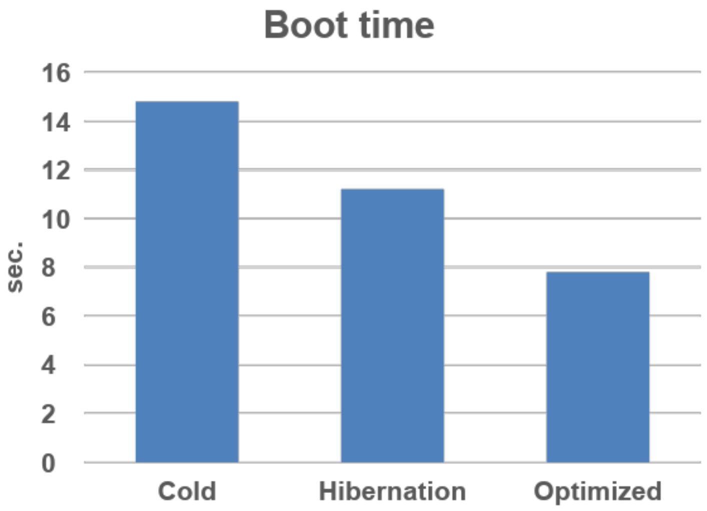
- Upstream kernel hibernation
  - Not optimized for fast boot
- Image load time >> (suspend + resume) time
  - Reducing image size leads to faster image load time.
- Reducing snapshot image size
  - Swap out pages as much as possible.
  - Clear page cache.(sync;echo 3 > /proc/sys/vm/drop_caches)
  - Deduplicate pages and compress.

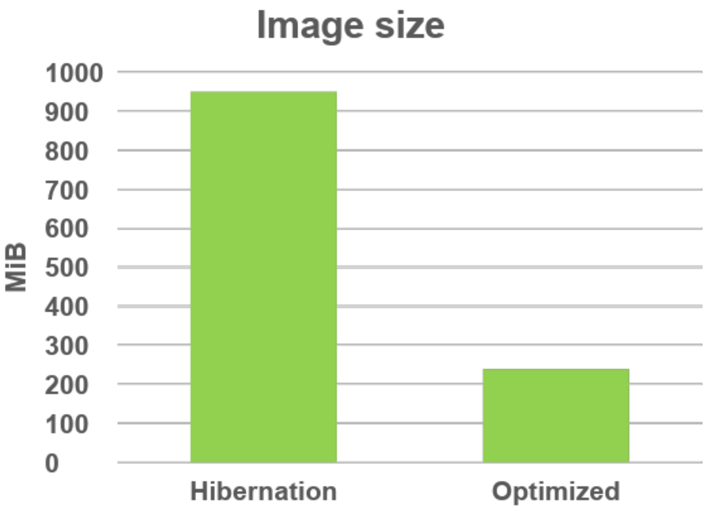
Deduplicate pages in memory

0	1	2	3	4	5	6	7	8	9
aaa	bbb	ccc	aaa	ddd	aaa	eee	fff	aaa	bbb
aaa	bbb	ccc		ddd		eee	fff		
aaa	bbb	ccc	ddd	eee	fff				

Original	Duplicate
0	3
0	5
0	8
1	9

Boot time and Image size





Extending the lifetime of flash memory

- Flash memory has a limited lifetime.
- How to maximize lifetime of flash memory in hibernation?
  - Decreasing the write amplification and the amount of data to be written.
- Log-structured block management
  - Dividing up the chosen partition into segments.
  - Writing to segments sequentially and decreasing the write amplification.
- Storage-based data deduplication
  - Reducing the amount of data to be written.
  - Data deduplication and Compression

Storage-based data deduplication

- Deduplication process
  - All pages are hashed first.
  - Unique pages are identified and stored with the hash values in the flash memory.
  - Pages are compared to the stored copy using hash values and whenever a match occurs, the redundant page is replaced with the entry in the map table that points to the stored page.

Storage allocations

- Clusters and blocks
  - A chosen partition is made up of clusters (apart form swap partition).
  - A cluster is composed of blocks. A block is 4KB, the allocation unit size.
  - Basically blocks of idle clusters are allocated when data is written to the clusters.
  - Used clusters are reclaimed when they are no longer used and discarded by garbage collector to become idle clusters.
  - Clusters are not overwritten until discarded (except header).

Cluster types

- Map: Locate meta and data clusters.
- Meta: A PFN(Physical Frame Number) table
- Data(Un/compressed): where snapshot image data is written.
- Dedupe: A table which has start block addresses of each hot clusters
- Usage count: Store usage count on each blocks
- Garbage collection: A table which has a list of clusters to be discarded
- Idle: To be allocated for use in the future

Disk layout

- Clusters(segmentation)

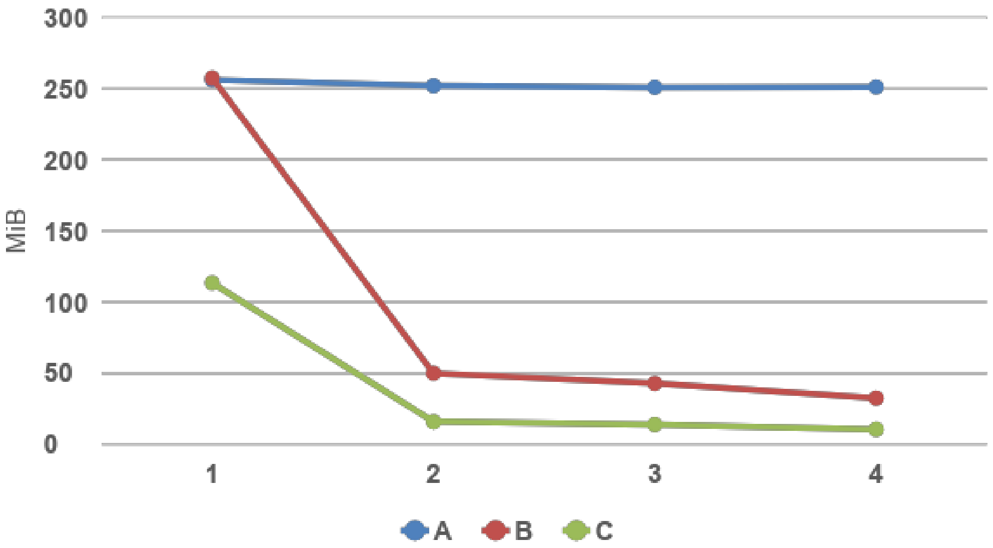
Header	**Map**	**Meta**	**Dedupe**	**Usage**	**GC**	**Data**	**Idle**

- Data cluster

Chunk Table size	**Chunk Table(hash, byte offset, size)**	**Chunks**

The amount of data written

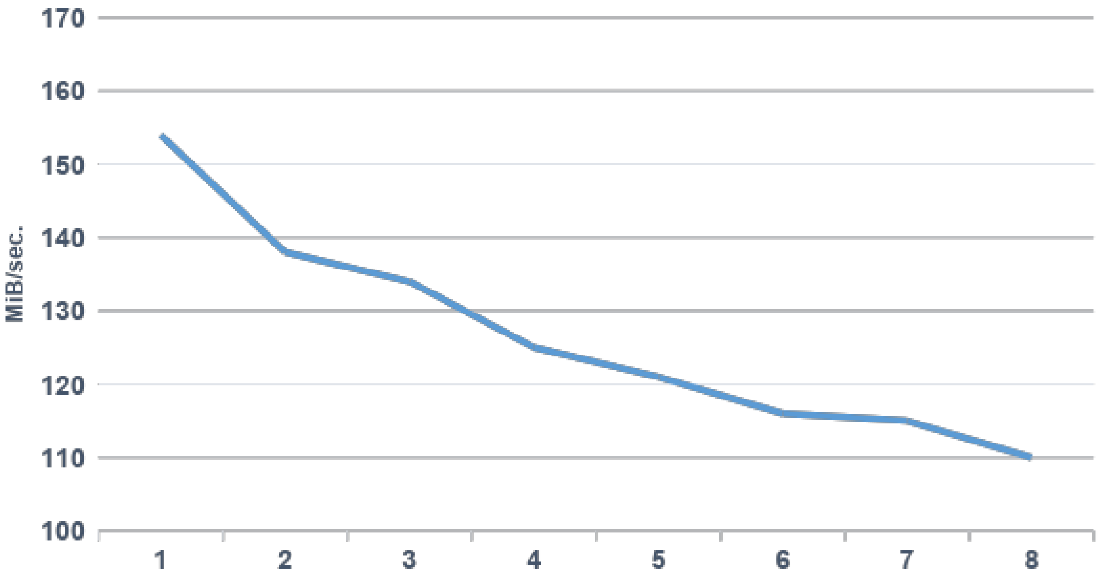
- A: Deduplicate(memory)
- B: A + Deduplicate(storage)
- C: Compress(B)



Performance regression

- Image loading speed is getting slower
  - Upon hibernation, snapshot image is fragmented by the storage-based deduplication process.
  - Accessing fragmented image requires more block I/O frequency.(a more random I/O pattern)

Image Loading Performance



Defragmentation

- Selective deduplication
  - Choose hot data clusters based on the number of hot blocks(usage count > a specified threshold).
  - Deduplicate snapshot image with hot data clusters.
  - Cold data clusters will be reclaimed.
  - A slight increase in image size
- Hot and Cold clusters
  - Hot clusters: to be used to deduplicate the new snapshot image
  - Cold clusters: not to be used for deduplication and reclaimed

Usage count on blocks

- Heat map

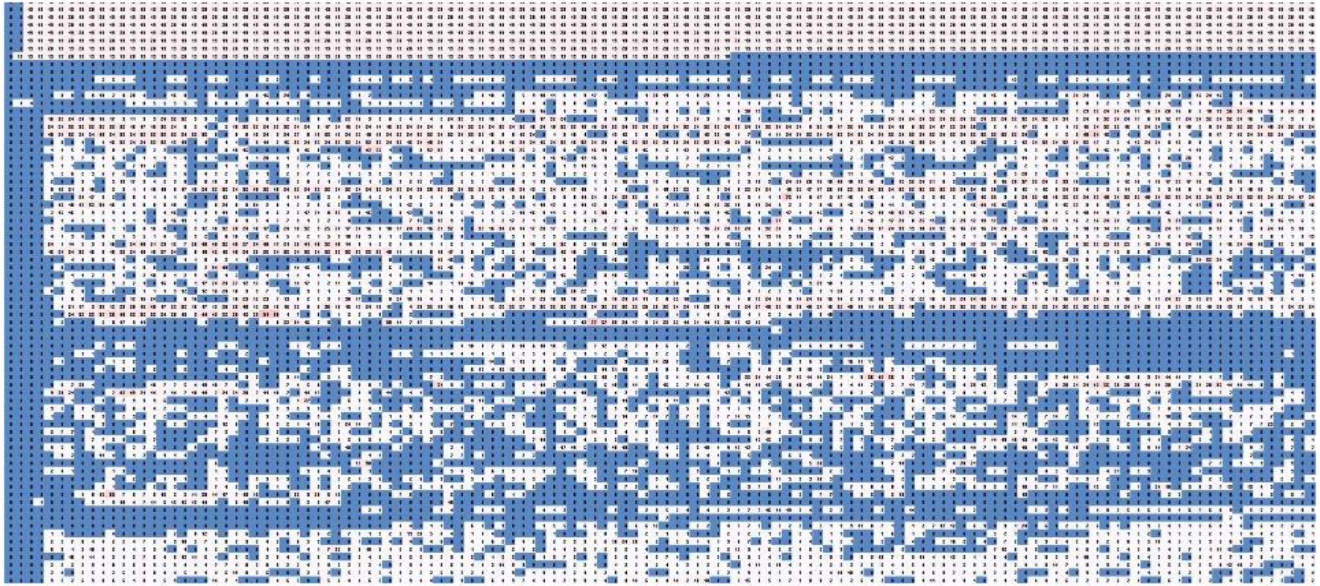
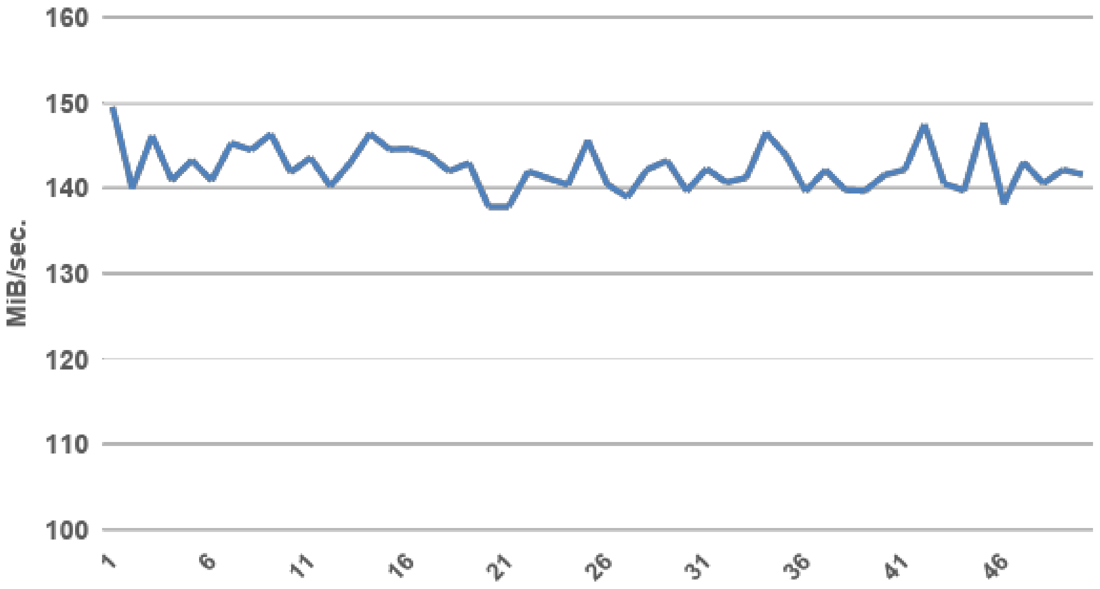
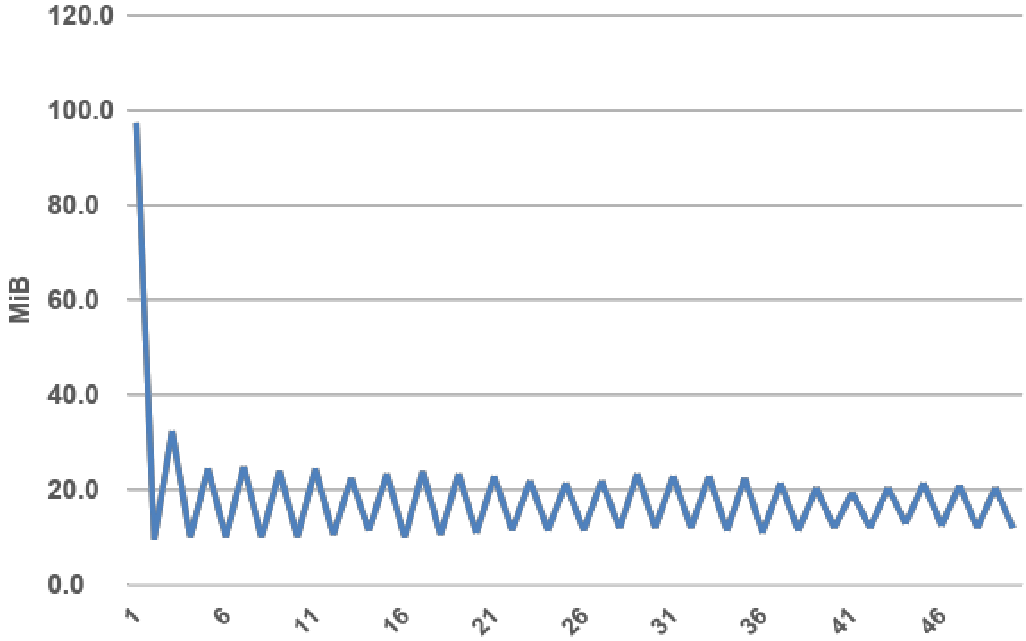


Image Loading Performance (after)



The amount of data written (after)



Reclaim clusters

- In case of running out of idle clusters
  - Reclaim occurs when the number of idle clusters is below a threshold.
  - Cold and less hot data clusters are reclaimed to get more idle clusters for the next snapshot image.
- Other used clusters
  - Other used clusters are reclaimed after resumed.

Garbage Collection

- Garbage collector
  - A background thread which performs automatic storage management for hibernation.
  - Discarding the reclaimed clusters.
  - Garbage collection will occur at run time when the number of reclaimed clusters is above a threshold.

Questions?

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