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

### Table:

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<thead>
<tr>
<th>Original</th>
<th>Duplicate</th>
</tr>
</thead>
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<tr>
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</tr>
<tr>
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<td>5</td>
</tr>
<tr>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
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</tbody>
</table>

### Diagram:

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<td>ddd</td>
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Boot time and Image size

**Boot time**
- Cold: 16 sec.
- Hibernation: 14 sec.
- Optimized: 6 sec.

**Image size**
- Hibernation: 1000 MIB
- Optimized: 100 MIB
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)

<table>
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<tr>
<th>Header</th>
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<th>Meta</th>
<th>Dedupe</th>
<th>Usage</th>
<th>GC</th>
<th>Data</th>
<th>Idle</th>
</tr>
</thead>
</table>

- 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)
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?