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Kdump: towards fast and stable crash dumping on terabyte-scale memory system

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LinuxCon Japan 2013

Terabyte-scale memory system

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- Common on enterprise-class model line-up

Company	Model	Max Memory Size
SGI	SGI UV 2000	64TiB
HP	HP ProLiant DL980 G7	4TiB
IBM	System x3950 X5	3TiB
Fujitsu	PRIMEQUEST 1800E	2TiB

- Use cases
  - In-memory database
  - VM consolidation
  - HPC

Kdump issues on terabyte-scale memory system

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- Collecting crash dump takes several hours without special handling
  - Dump filtering
    - reduce size of crash dump – create “mini dump”
- Design and implementation had no longer scaled
  - Even dump filtering could take tens of minutes
  - Crash dump could fail due to too much memory consumption
- Still, full dump is necessary for Mission Critical use

What this talk explains

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- How several issues on creating “mini dump” were resolved since last year
  - ➔ For most users who think “mini dump” is enough and they don’t require rigorous failure analysis
- How can we collect “full dump” in a reasonable time and what challenges still there are
  - ➔ For users who think “full dump” is essential and require rigorous failure analysis on mission critical use

Agenda

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- Review kdump framework
- Recently fixed issues for “mini dump”
  - Memory consumption issue
  - Dump filtering performance degradation issue
- Ongoing and future work for “full dump”
  - Towards fast crash dumping for “full dump”

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Review kdump framework

Kdump: kexec-based crash dumping

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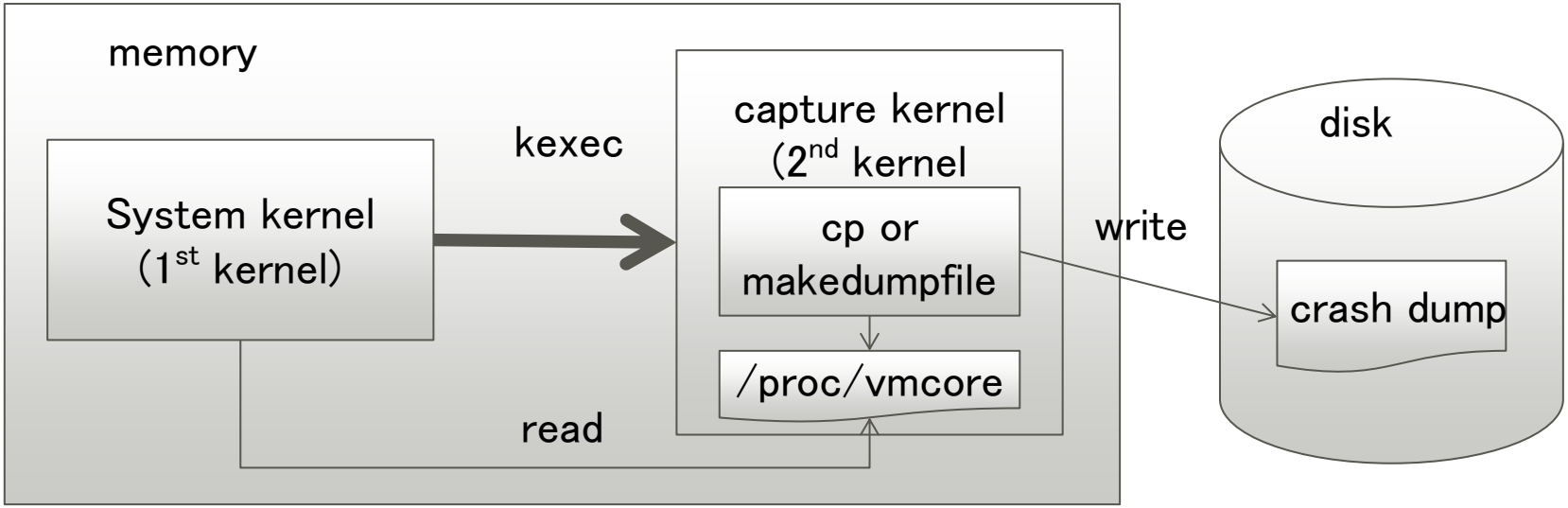
- Linux kernel standard crash dump feature
- Merged at 2.6.13
- Components related to crash dumping
  - Capture kerenel
  - makedumpfile
  - /proc/vmcore



Kdump: kexec-based crash dumping

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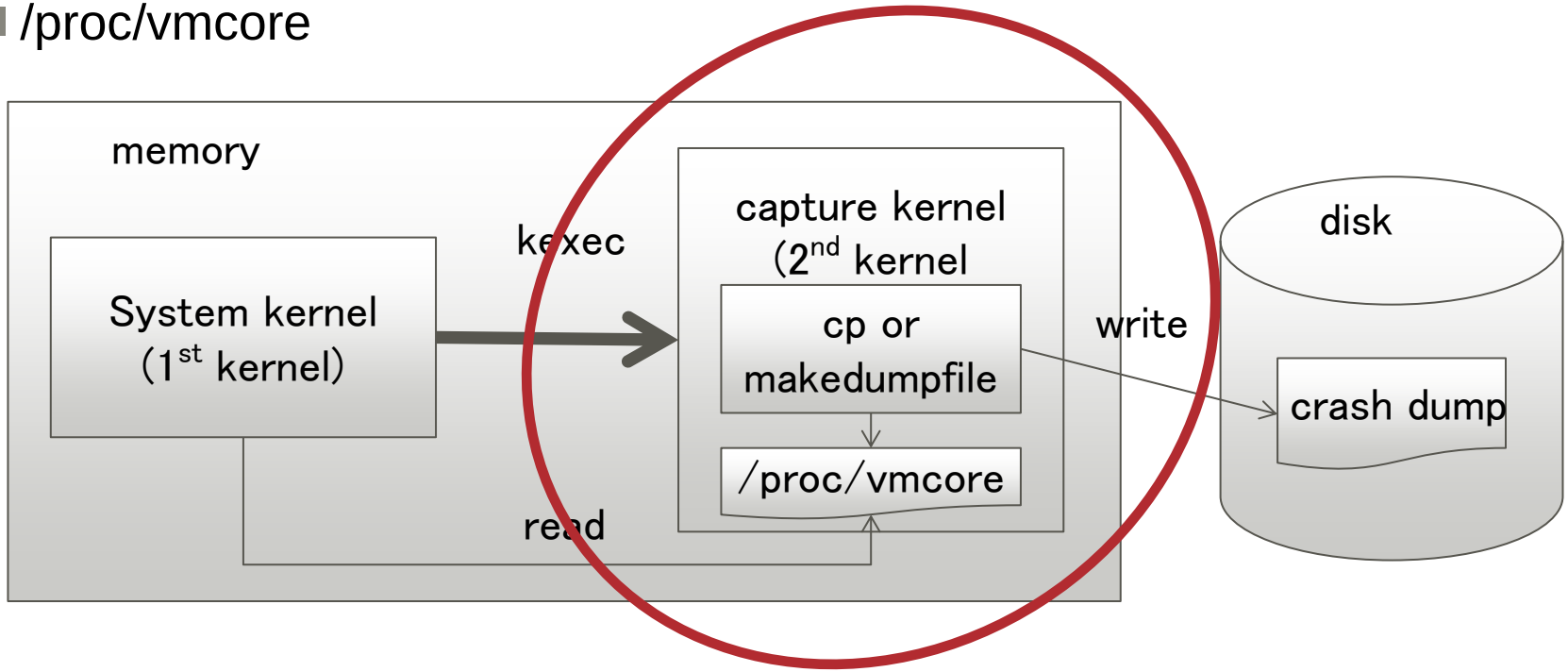
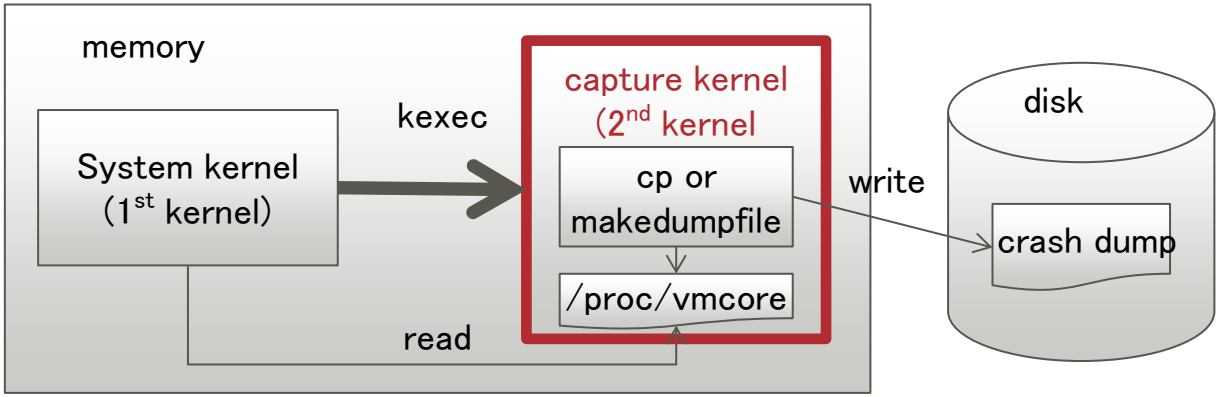


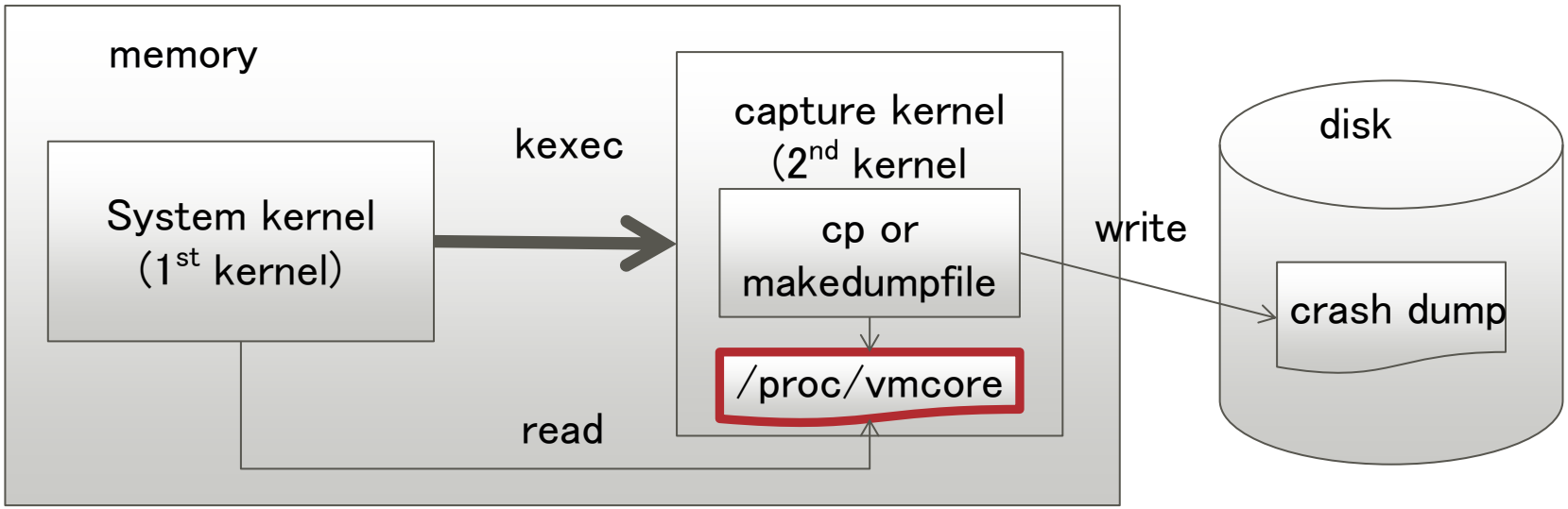
Capture kernel

- Kernel booted from system kernel
- Running on the memory reserved at system kernel
  - crashkernel=<memory size>
    - 128MiB ~ 512MiB
- Has /proc/vmcore



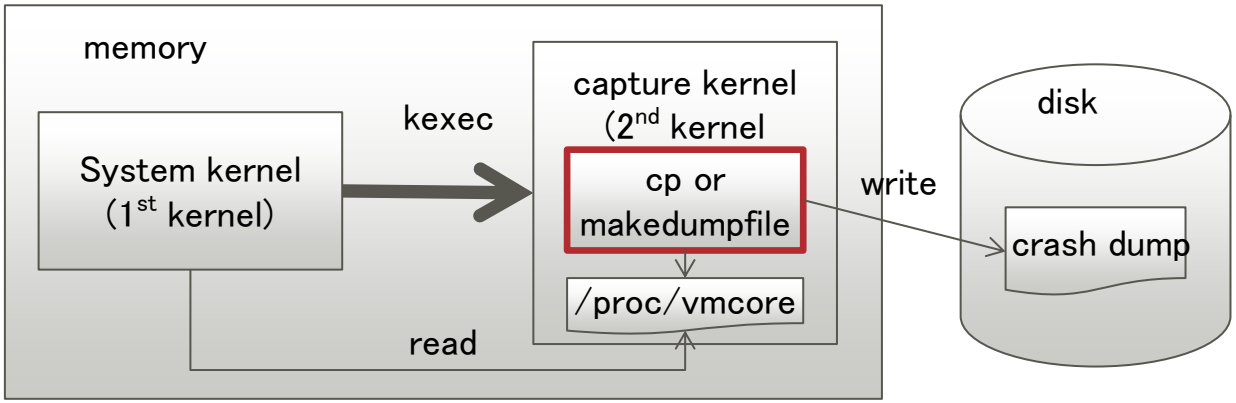
/proc/vmcore

- File interface for capture kernel to access system kernel as ELF binary format
  - Use user-space tools for copying crash dump
    - Make some additional processing if necessary
  - cp /proc/vmcore /mnt/dump



makedumpfile

- Copy vmcore with some additioanl processing
  - Compression
  - Dump filtering --- create mini dump
    - Free pages
    - Page cache
    - Page cache (meta data)
    - User data
    - Zero page



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Recently fixed issues for “mini dump”

- Memory consumption issue
- Dump filtering performance degradation issue

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Recently fixed issues for “mini dump”

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Capture kernel has severe memory limitation

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- Reserved memory: 512 MiB
- Cannot assume other disks
  - Continue working in ramdisk
    - System kernel's rootfs can be broken
  - On network configuration dump device is not connected
    - scp /proc/vmcore user@192.168.122.22:/mnt/dump
- ➔ important to use memory efficiently

Memory consumption issue

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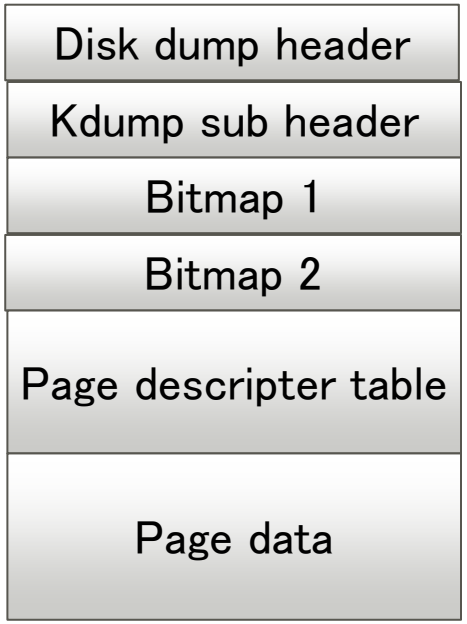
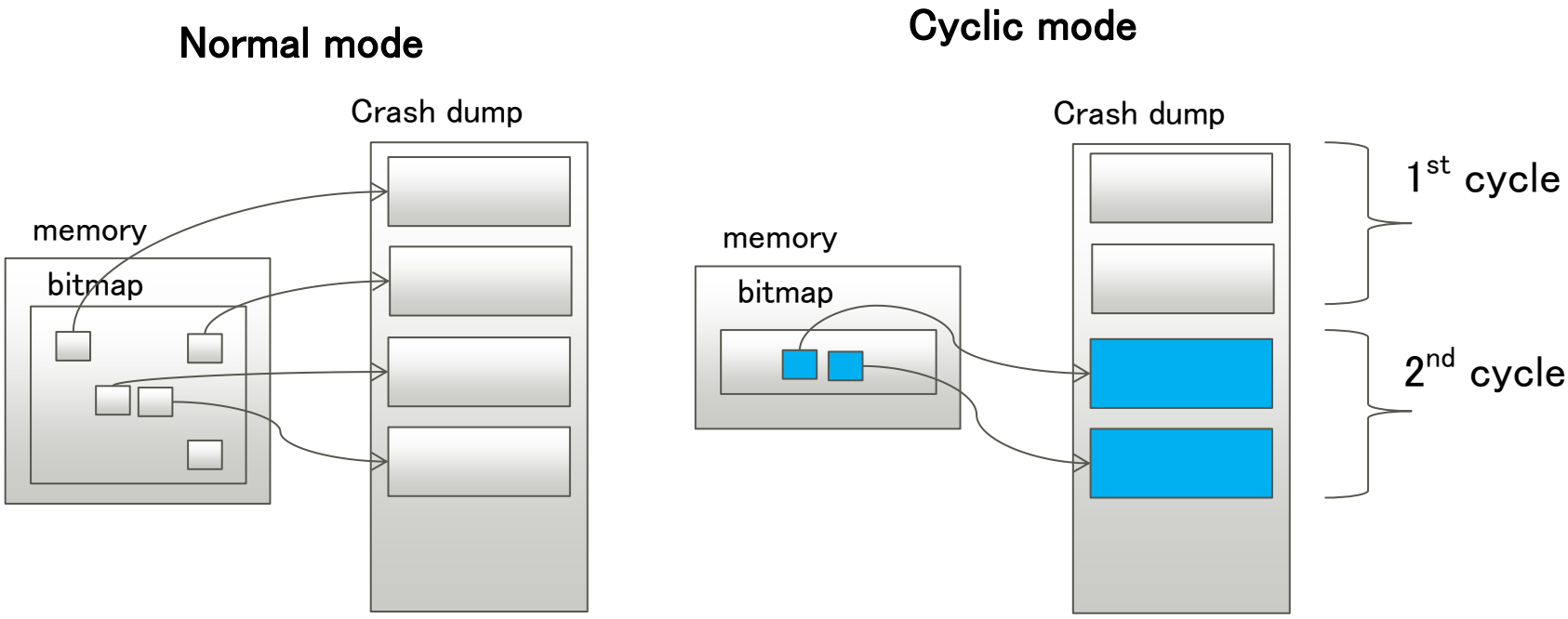
- Problem
  - Makdumpfile had consumed much memory on terabyte-scale memory system
  - Killed by OOM killer, failing to collect crash dump
- Cause
  - Makedumpfile's dump format has two bitmaps that grow in proportion to system memory size
    - 1TiB memory⇔32 MiB bitmap
  - Two bitmaps are allocated at a time on memory
    - On 8TiB, bitmap size exceeds size of reserved memory
    - 2 * 32 * 8 = 512MiB



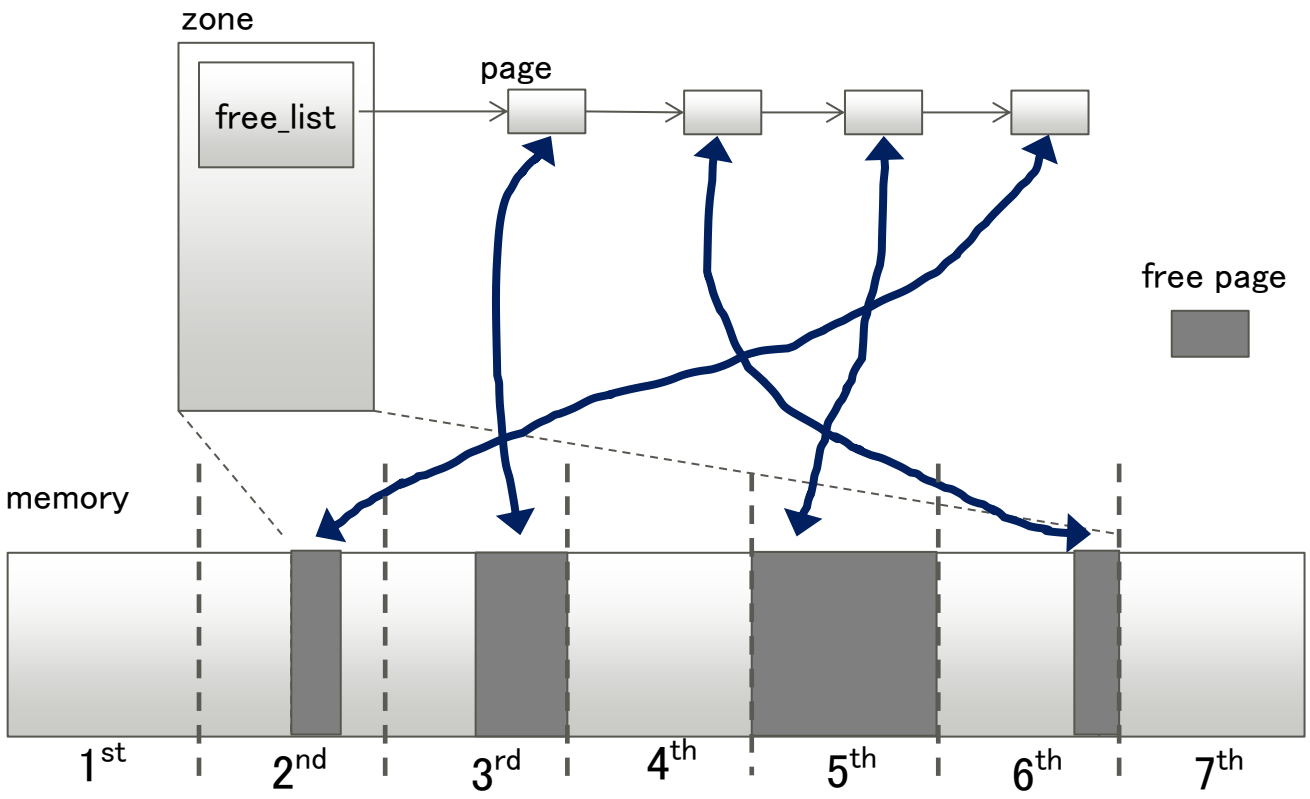
Solution: divide process into cycles

- If N-cycles, bitmap size on memory is reduced to 1/N.
  - Repeat the following processing N-cycles:
    - Create bitmap
    - Write the corresponding pages in crash dump



free_list cannot be divided into cycles

- All the processing in makedumpfile needs to be divided into cycles
- Unfortunately, current method of filtering free pages cannot be divided into cycles
  - Free_list is not sorted: linear search costs O(memory size ^2)



Look up mem_map for free page filtering

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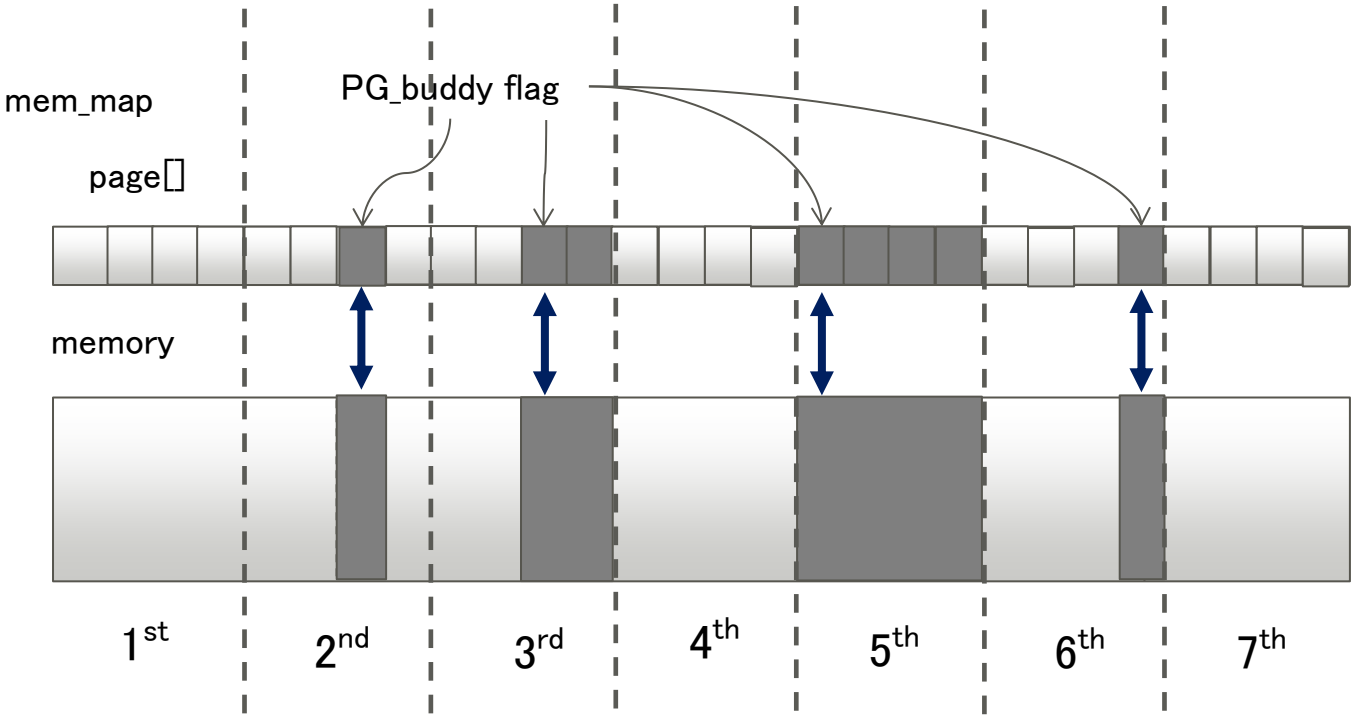
- Like other memory types, looking up mem_map array (page descriptors) in case of free pages
  - Each page descriptor is sorted w.r.t. page frame numbers



Further merits of mem_map array logic

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- More robust against data corruption
  - If free_list is corrupted, cannot follow anymore.
  - Infinite loop at worst case.

Supported versions and usage

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- Supported versions
  - v1.5.0: Cyclic-mode, by Atsushi Kumagai
    - **default mode**
  - v1.5.1: New free pages filtering logic, by HATAYAMA
- Usage
  - --cyclic-buffer <memory in kilobytes>
    - 80% of free memory is specified at default
  - --non-cyclic
    - Switch back to the original mode

Support for above-4GiB bzImage load

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- Yinghai Lu at kernel v3.9
- There is no longer 896MiB limit
- Kernel parameter
  - crashkernel=size[KMG],high
  - crashkernel=size[KMG],low
- Each component needs to support new bzImage protocol
  - System kernel: v3.9~
  - Kexec: v2.0.4~
  - Capture kernel: v3.9~

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Recently fixed issues for “mini dump”

- Memory consumption issue
- Dump filtering performance degradation issue

Dump filtering performance degradation issue

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- Dump filtering time becomes no longer ignorable on terabyte-scale memory

  Memory: 2TiB

makedumpfile	kernel	Dump filter (s)	Copy data (s)	Total (s)
1.5.1	3.7.0	470.14	1269.25	1739.39

  - 27% of Total is used for dump filtering
- Causes are in
  - makedumpfile
  - /proc/vmcore

makedumpfile: paging was bottleneck

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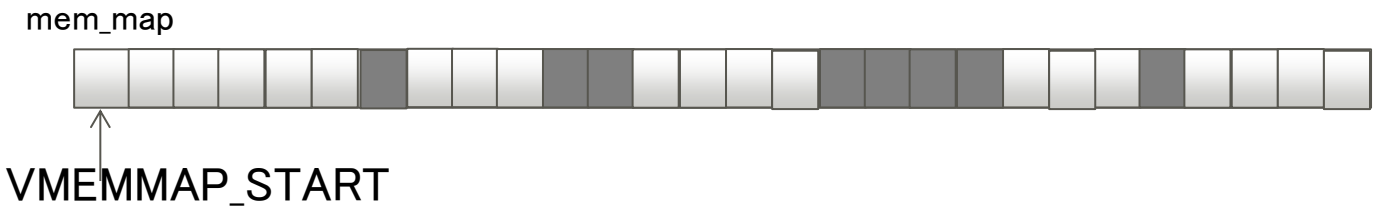
- Problem: on 4-level paging, reads /proc/vmcore 5 times
  - 4-level page walk + target memory access
  - mem_map is mapped in VMEMMAP area, not direct mapping area



- Solution: add cache for /proc/vmcore
  - By Petr Tesarik
  - Keep previously read 8 pages
    - Reduce the number of reads to /proc/vmcore for page table access
  - Simple but very effective

/proc/vmcore: ioremap/iounmap was bottleneck

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- Problem:
  - ioremap/iounmap is called per a single page
  - TLB flush is called on each iounmap call
- Solution: Support mmap() on /proc/vmcore
  - Reduce the number of TLB flush by large mapping size
    - Both mem_map for dump filtering and page frames are consecutive data
  - No copy from kernel-space to user-space

Filtering Benchmark (2TB, 1CPU) [1/2]

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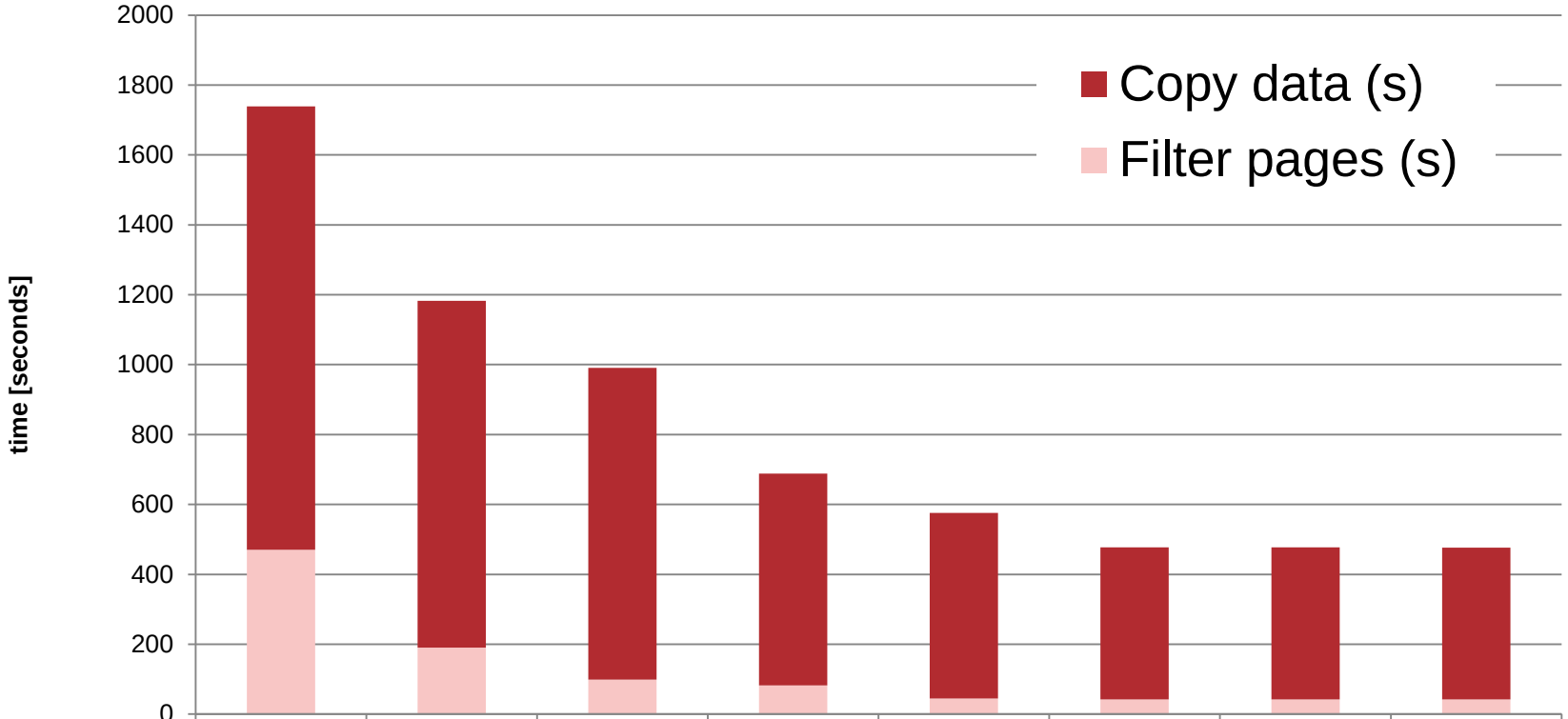
- Smaller is better



	1.5.1	1.5.3	1.5.3	1.5.3+mmap	1.5.3+mmap	1.5.3+mmap	1.5.3+mmap	1.5.3+mmap
Copy data (s)	1269.25	992.77	892.27	606.06	531.77	435.4	435.49	434.64
Filter pages (s)	470.14	190.05	98.885	82.44	44.3	41.83	41.72	41.92

Contributed by Jingbai Ma (https://lkml.org/lkml/2013/3/27/19)

Filtering Benchmark (2TB, 1CPU) [2/2]

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- Two experimental kernel-side filtering work
  - Cliff's 240 seconds on 8TiB memory system http://lists.infradead.org/pipermail/kexec/2012-November/007177.html
  - Ma's 17.50 seconds on 1TB memory system https://lkml.org/lkml/2013/3/7/275
- Rough comparison

	Filter pages [sec/TiB]	
Cliff	30	Kernel-side at capture kernel
Ma	18	Kernel-side at system kernel
This work	21	User-side at capture kernel

Community development status

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- Kernel
  - Mmap support on /proc/vmcore, v3.10-rc2 mmotm by HATAYAMA
- makedumpfile
  - Cache for /proc/vmcore, v1.5.2, by Petr Tesarik
  - Mmap support, v1.5.3-devel, by Atsushi Kumagai

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Ongoing and future work for “full dump”

Importance of full crash dump

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- Bug on modern system is complicated
- Failure analysis by experienced developers with full dump is a must
  - dump filtering could lost important data
- E.g. qemu/KVM system
  - Communication between guests and host
  - Virtualization assist features
    - Transparent hugepage, compaction
  - ➔full dump including qemu guests' images
    ➔view from guests helps failure analysis

Toward fast crash dumping

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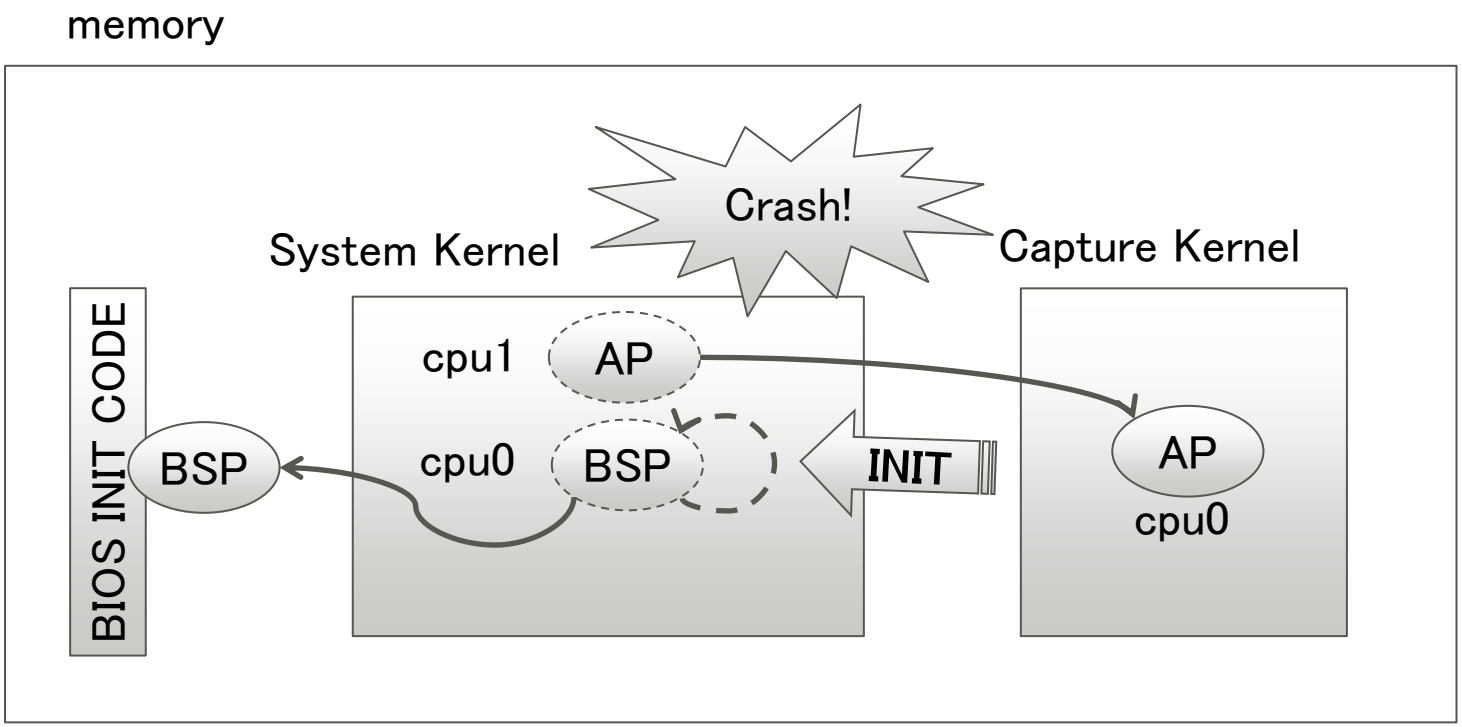
- Goal: Complete **2TiB** full crash dump within an hour
- How:
  - Fast compression algorithm
    - Fast enough even if data is not reduced at all
  - Data striping like RAID0
    - Write data concurrently into multiple disks
- Problem
  - On x86 capture kernel cannot use multiple CPUs now
    - Limited to 1 at default
      - maxcpus=1

x86 boot protocol issue

- If BSP receives INIT IPI, then BSP jumps at BIOS init code
  - System hang or system reset



Experimental benchmark

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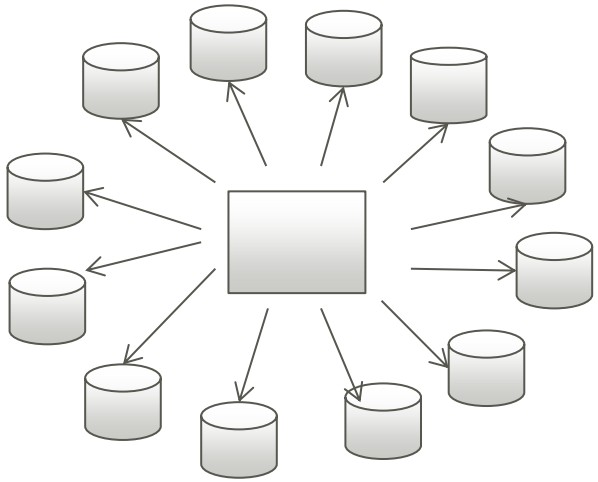
- Purpose: see performance under the configuration with
  - fast compression: LZO, snappy
  - paralell I/O
  - **multiple CPUs**
- How
  - Process 10GiB data in **system kernel**
  - The data is randomized not to be reduced by compression
    - To see if fast compression can be used for free even at worst case

OS	RHEL 6.3
Kernel	2.6.32-279.el6.x86_64
CPU	Intel® Xeon® CPU E7540@2.00GHz
System	PRIMEQUEST1800E
Disk	(147GiB, 6 Gb/s) x 12



Benchmark result (1 CPU)

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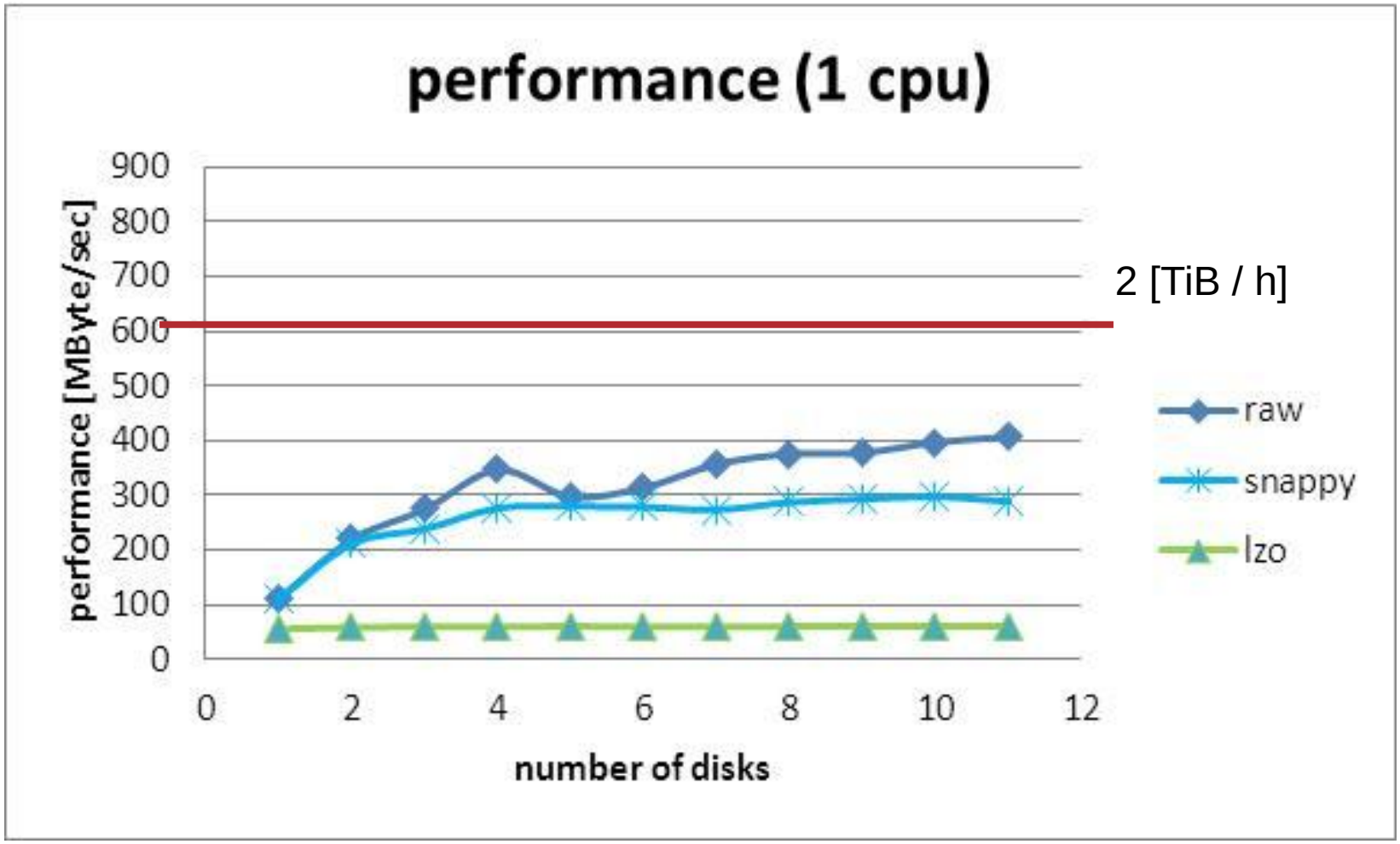
- Larger is better



Benchmark result (12 CPUS)

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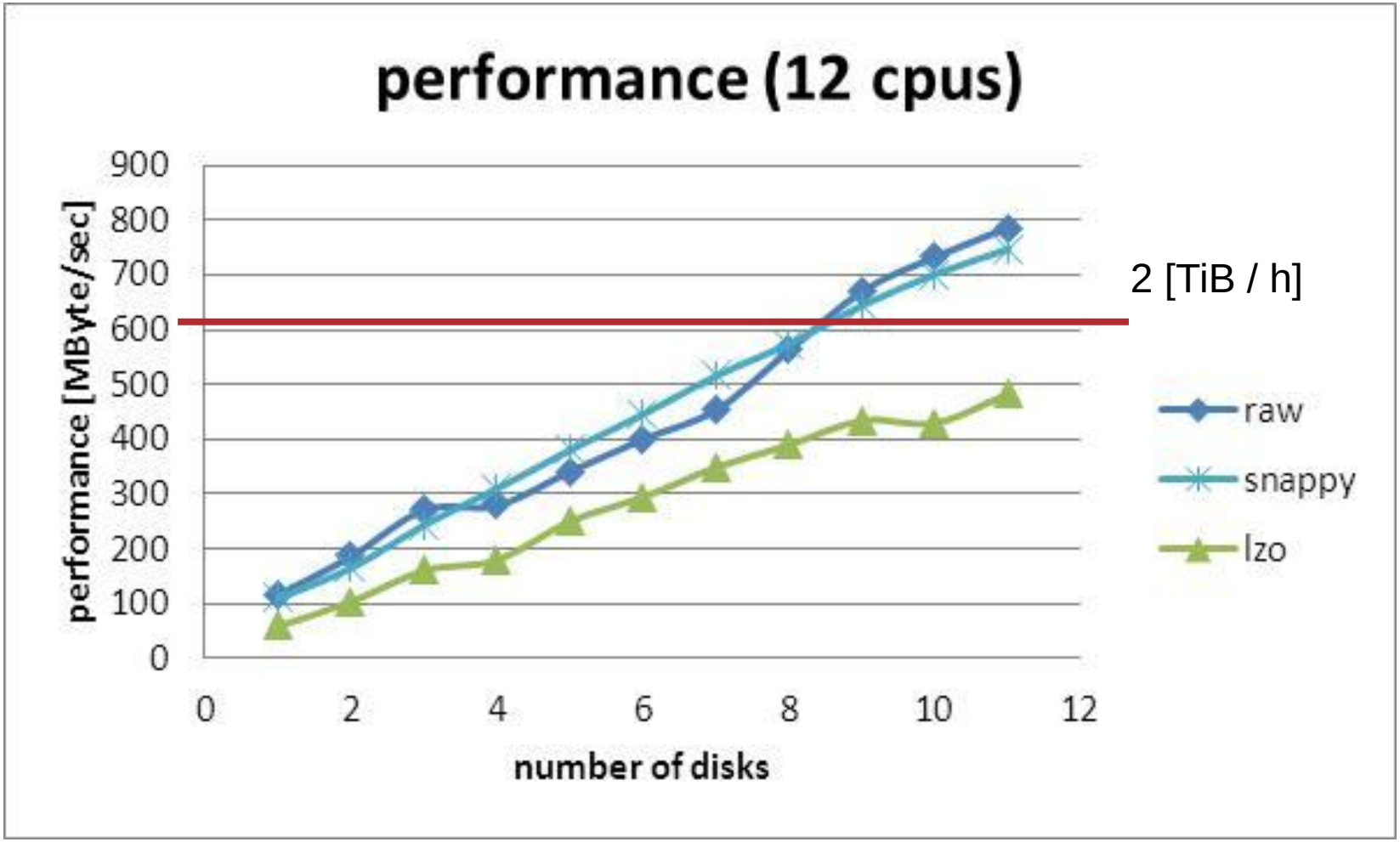
- Larger is better



Community development status

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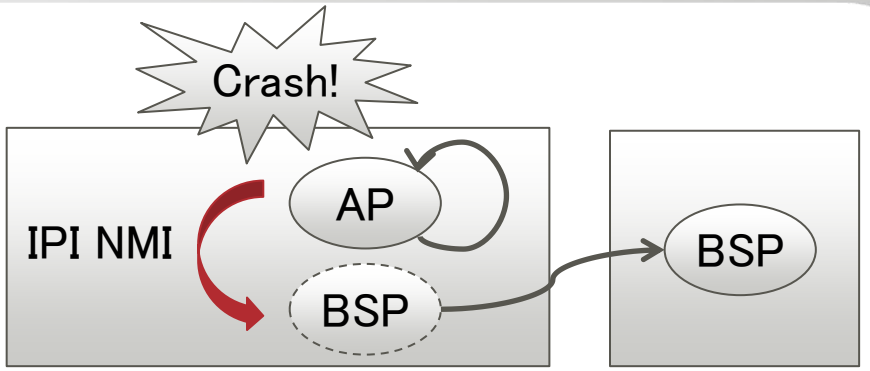
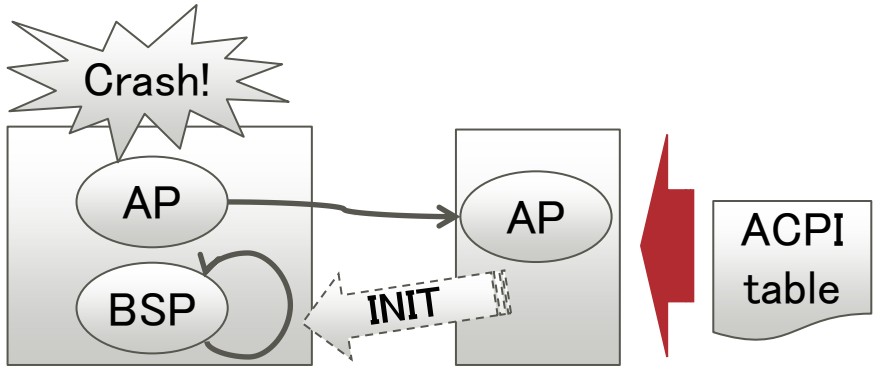
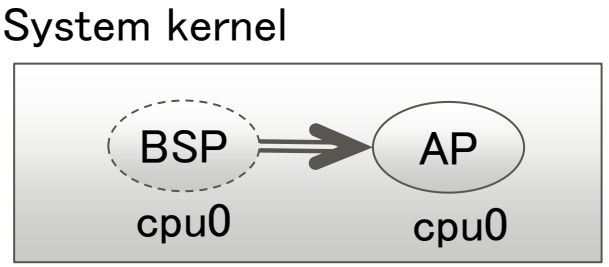
- Enter capture kernel with BSP by switching IPI NMI
  ➔ Nacked
  Depending IPI NMI reduces reliability



- Disable BSP at Capture Kernel
  - Cannot execute rdmsr to read BSP flag bit in MSR for the CPU not running
    - Chicken-and-egg problem
  - Look up APIC/MP table to check if given CPU is BSP



- Unset BSP flag bit in MSR reg using wrmsr instruction in System Kernel
  - Some say there should be firmware assuming BSP flag bit to be kept throughout runtime



Summary

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- Several issues for “mini dump” has been being improved
  - Memory consumption issue
  - Dump filtering performance degradation issue
  - ➔Now mini dump can be collected with no problem
- Ongoing work for “full dump”
  - Multiple CPUs are essential for “full dump” configuration
  - Under discussion in community

Future work

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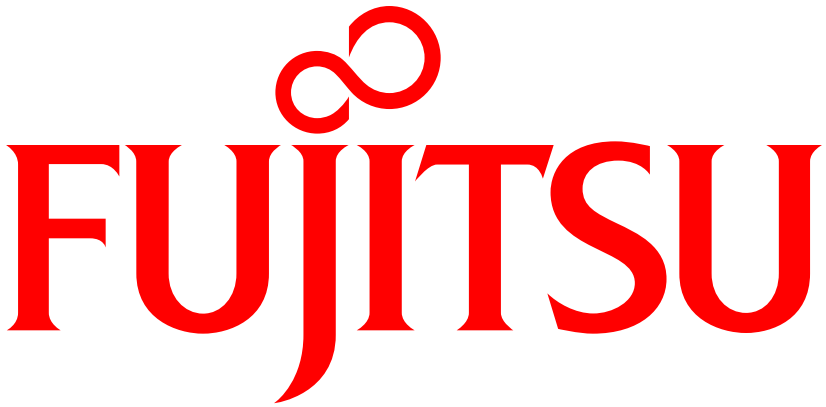
- Improvements for Capture Kernel to show performance like the experimental benchmark
  - Kernel
    - Multiple CPUs on capture kernel
    - Support large pages on remap_pfn_range
  - Makedumpfile
    - Support direct I/O for makedumpfile
    - Make compression block size configurable
- A lot of benchmark



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