LinuxCon Japan 2016

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Address Range Memory Mirroring

July 13, 2016
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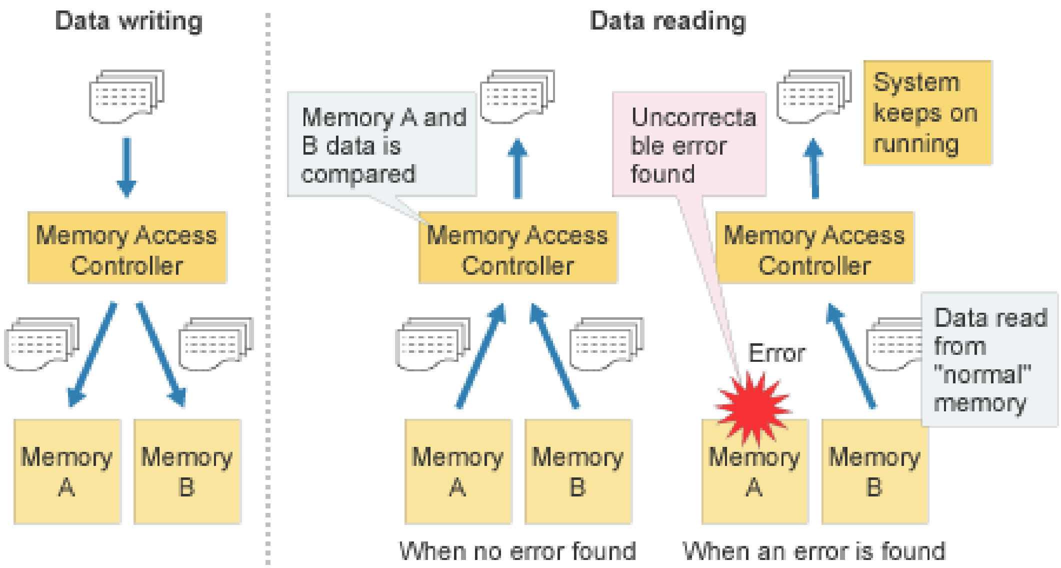
Table of Contents

Address Range Mirroring overview

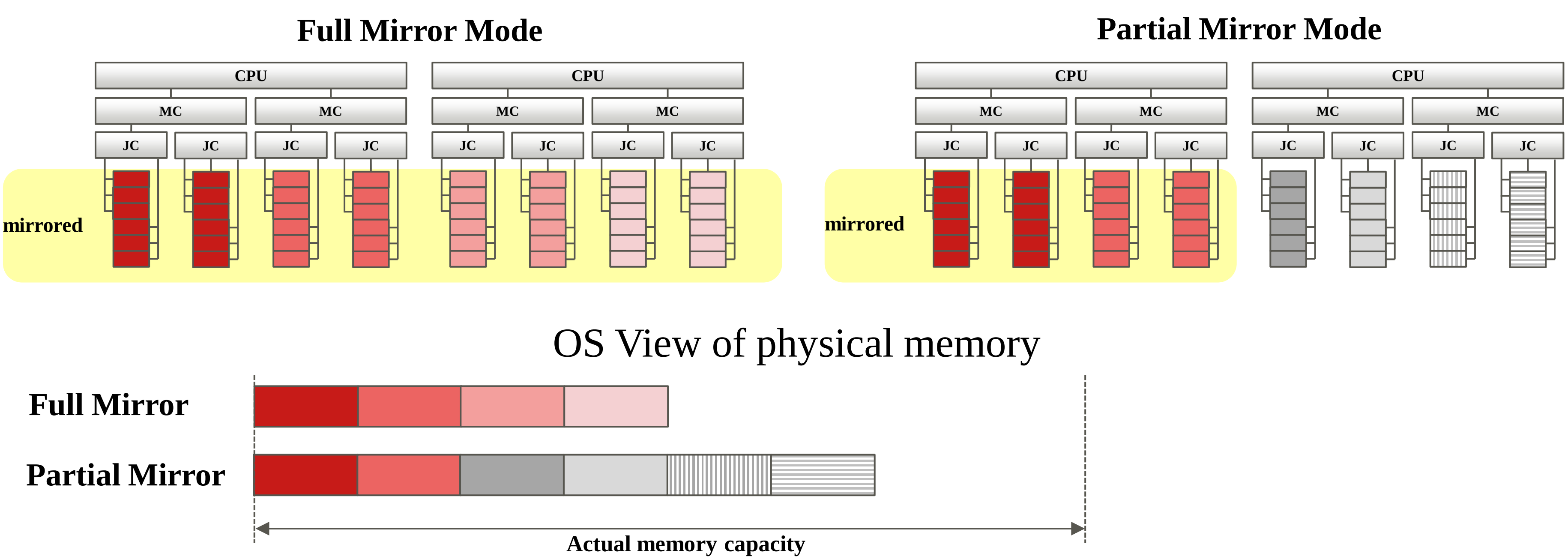
Memory Mirroring

- Memory RAS feature on Xeon family-based systems
- Provides memory redundancy
  - Data writing
    - written to both sides of the memory mirror at the same time (Memory A & B)
  - Data reading
    - Memory Controller reconfirms data validity by comparing data
    - If an uncorrectable error is detected in Memory A, data in Memory B is used for the read operation [tolerance for UCE]



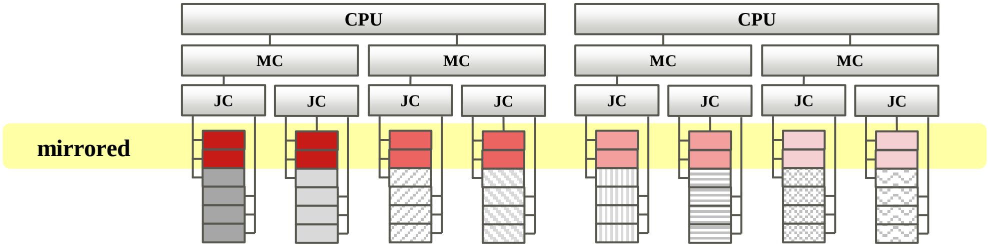
Traditional Memory Mirroring

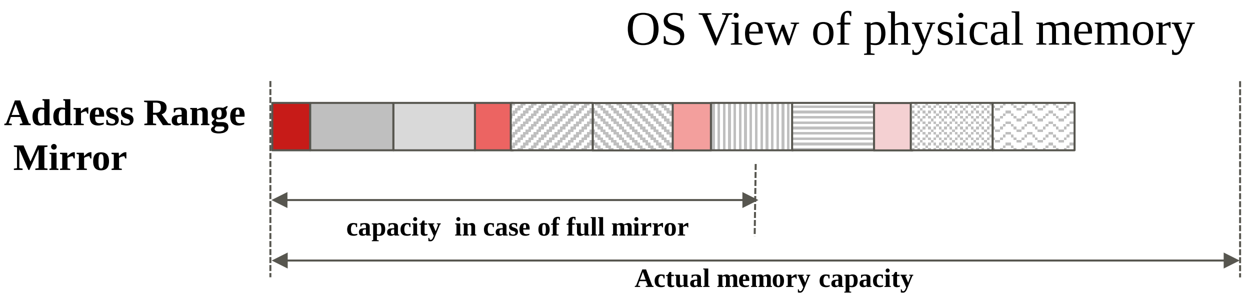
- Full Mirror Mode
  - Pros: Transparent to OS
  - Cons: Halves memory capacity available to OS
- Partial Mirror Mode
  - Pros: Transparent to OS and Keep More capacity than Full Mirror Mode
  - Cons: Mirrored range is one-sided



Address Range Mirroring

- New memory RAS feature on Haswell EX based systems
- Allows high granularity of mirroring
  - Configurable the amount of mirrored memory size
    - optimize total available memory while keeping highly reliable memory range
- Distributes mirrored memory range on each NUMA node
  - Keeps NUMA performance





Address Range Mirroring cont.

- Requires OS support to fully utilize Address Range Mirroring
  - Necessary to be aware of mirrored region

- Provides Firmware-OS interface
  - UEFI Variables
    - A method to request the amount of mirrored memory
  - UEFI Memory map
    - Presents mirrored memory range on the platform

Mirrored memory size configuration

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- UEFI variable is used to configure mirroring
  - MirrorRequest
    - Written by the OS to request a new mirror configuration on the next boot
  - MirrorCurrent
    - Written by the firmware and read by the OS to communicate the current status of Address Range Mirroring

```
Shell> dmpstore MirrorRequest
Dump Variable MirrorRequest
Variable NV+RT+BS '7B9BE2E0-E28A-4197-AD3E-32F062F9462C:MirrorRequest' DataSize = 5
  00000000: 01 01 C4 09 00                                          *.....*
Shell> dmpstore MirrorCurrent
Dump Variable MirrorCurrent
Variable NV+RT+BS '7B9BE2E0-E28A-4197-AD3E-32F062F9462C:MirrorCurrent' DataSize = 5
  00000000: 01 01 C4 09 00                                          *.....*
```

```
typedef struct  {
   UINT8         MirrorVersion;
   BOOLEAN       MirrorMemoryBellow4GB;      // set to true to mirror memory below 4 GB
   UINT16        MirroredAmountAbove4GB;     // percentage of memory to mirror above 4GB
   UINT8         MirrorStatus;
} ADDRESS_RANGE_MIRROR_VARIABLE_DATA
```

Mirrored memory size configuration cont.

- latest efibootmgr(8) supports UEFI variables for Address Range Mirroring
  - -m: set ‘t’ to mirror memory below 4GB
  - -M: percentage memory to mirror above 4GB

```
# efibootmgr -m t -M 25.00
```

- Confirm current settings of mirroring

```
# efibootmgr
BootCurrent: 0002
Timeout: 10 seconds
BootOrder: 0002,0001,0000
Boot0000* EFI SCSI Device
Boot0001* EFI Internal Shell
Boot0002* opensuse-secureboot
MirroredPercentageAbove4G: 25.00
MirrorMemoryBelow4GB: true
```

Presentation method of mirrored range

- The information which address range is mirrored is passed via EFI memory map

```
Shell> memmap
Type       Start             End                # Pages          Attributes
BS_data    0000000000000000-0000000000000FFF  0000000000000001 000000000001000F
available  0000000000001000-000000000003FFFF  000000000000003F 000000000001000F
BS_data    0000000000040000-000000000009FFFF  0000000000000060 000000000001000F
BS_data    0000000000100000-0000000000FFFFFF  0000000000000F00 000000000001000F
available  0000000001000000-0000000035FC5FFF  0000000000034FC6 000000000001000F
RT_data    0000000035FC6000-0000000035FCCFFF  0000000000000007 800000000001000F
...
BS_data    0000000047ED2000-0000000048013FFF  0000000000000142 000000000001000F
available  0000000100000000-000000203FFFFFFF  0000000001F40000 000000000000000F
available  0000002040000000-000000302FFFFFFF  0000000000FF0000 000000000001000F
available  0000003030000000-000000304FFFFFFF  0000000000020000 000000000000000F
reserved   000000005FC00000-000000005FFFFFFF  0000000000000400 0000000000000001
reserved   0000000060000000-000000008FFFFFFF  0000000000030000 8000000000000001
```

EFI_MEMORY_MORE_RELIABLE attribute: 0x10000

- EFI_MEMORY_MORE_RELIABLE attribute in EFI Memory descriptor indicates mirrored range
  - Defined in UEFI spec 2.5

Motivation

- **Background**
  - Linux can process memory errors in user space memory
    - Just kill the affected processes, even recover if the broken page can be replaced by reading from disk
    - Avoid broken page in the future
  - Linux has no recovery path for errors encountered during kernel code execution
    - Uncorrectable Error in kernel memory would crash the system
  - Full memory mirroring is a good approach, however, as system memory capacity grows, the amount of memory lost for redundancy also grows

- **Motivation**
  - Improve high availability by avoiding uncorrectable errors in kernel memory
    - Allocate all kernel memory from mirrored memory

Current Status of linux

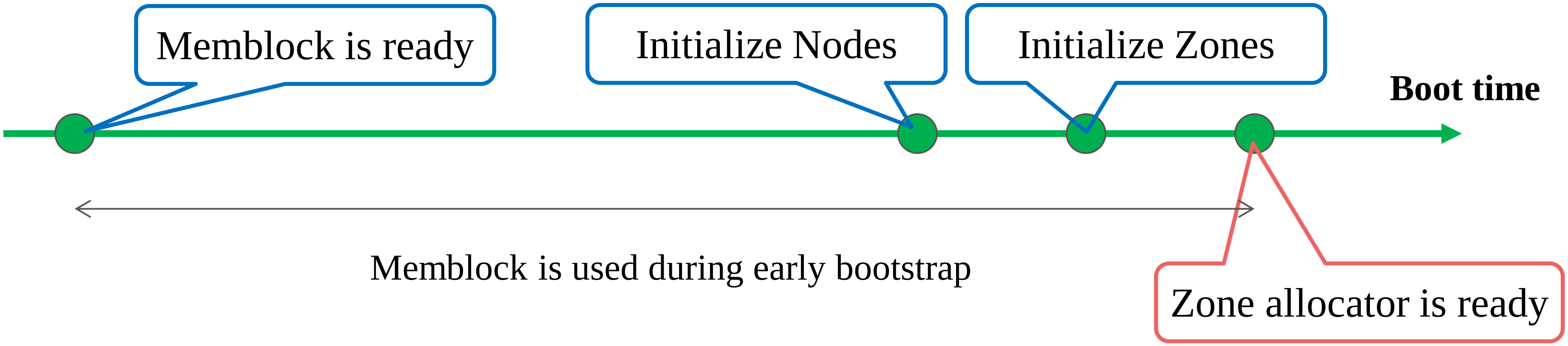
Physical memory management

Memblock

- Manage memory blocks during early bootstrap period
- Discarded after initialization and take over to Zone allocator

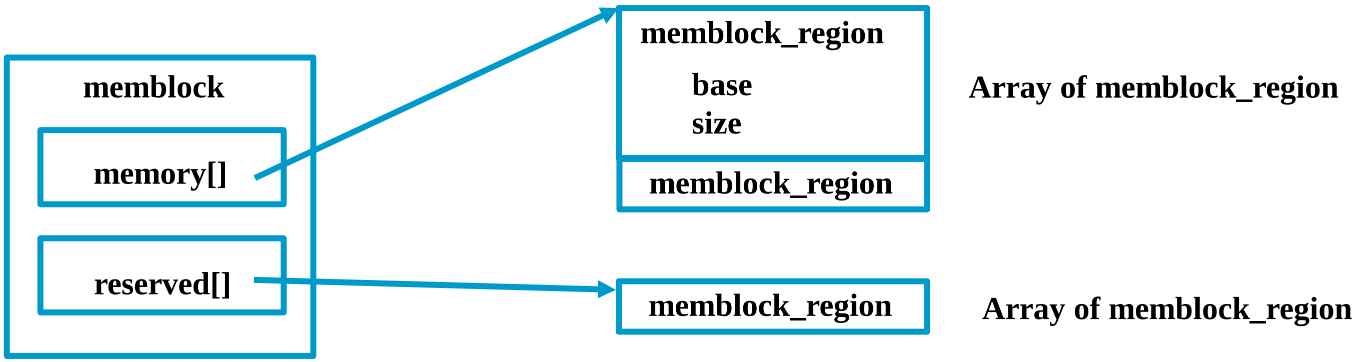
Zone Allocator

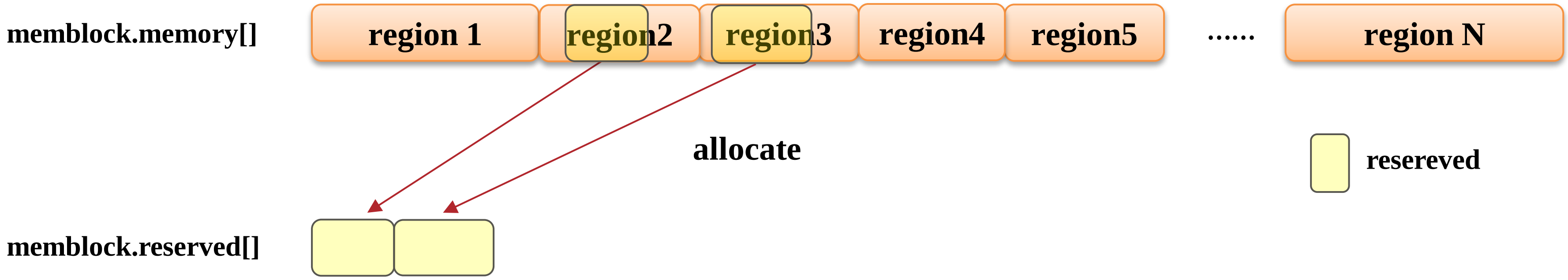
- Usual kernel memory allocator



Memblock

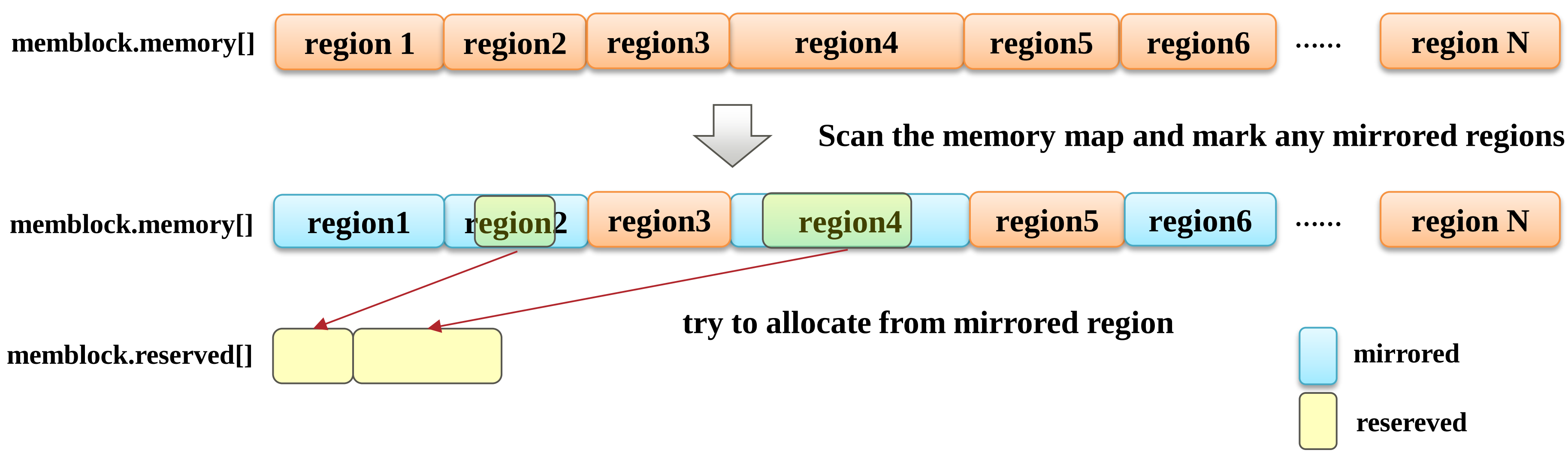
- Simply manages memory blocks
  - Consists of two arrays
    - memory: All the present memory in the system
    - reserved: Allocated memory ranges
  - Allocate by finding regions in memory && !reserved





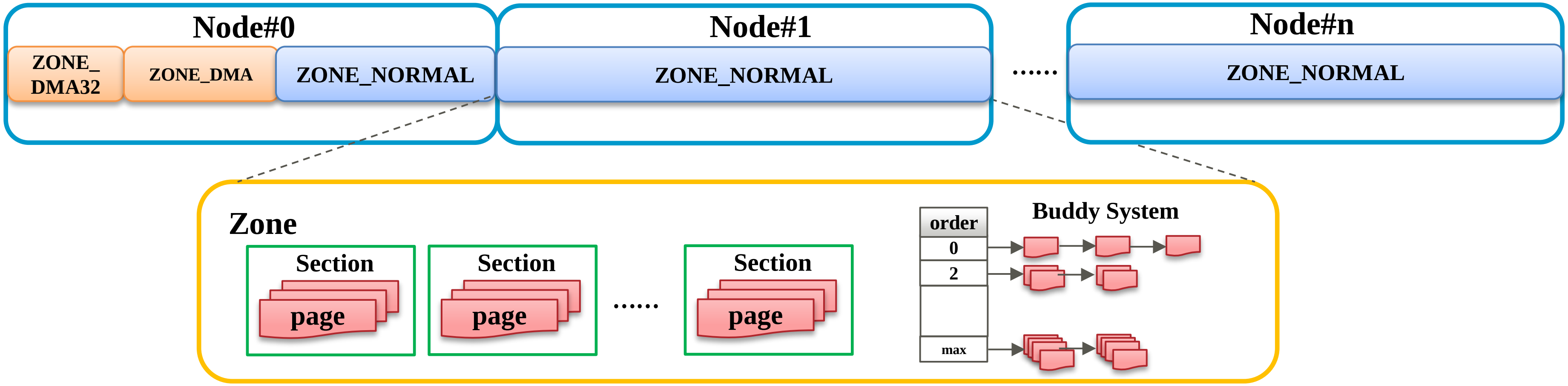
Memblock cont.

- Mirror support of Memblock has been merged into linux-4.3
  - Find mirrored region from EFI memory map information
    - Mark as MEMBLOCK_MIRROR
  - Try to allocate from mirrored region
    - If run out of mirrored memory, fall back to use non-mirrored memory



Zone allocator

- Manages memory areas called zones
  - All pages are managed by Zone
    - ZONE_DMA, ZONE_DMA32
      - used for DMA
    - ZONE_NORMAL
      - memory directly mapped, used by kernel and user space
  - Find zones suitable for memory allocation and allocate memory
- As of linux-4.3, no mirror support for zone allocator
  - Works without any regard to mirrored region

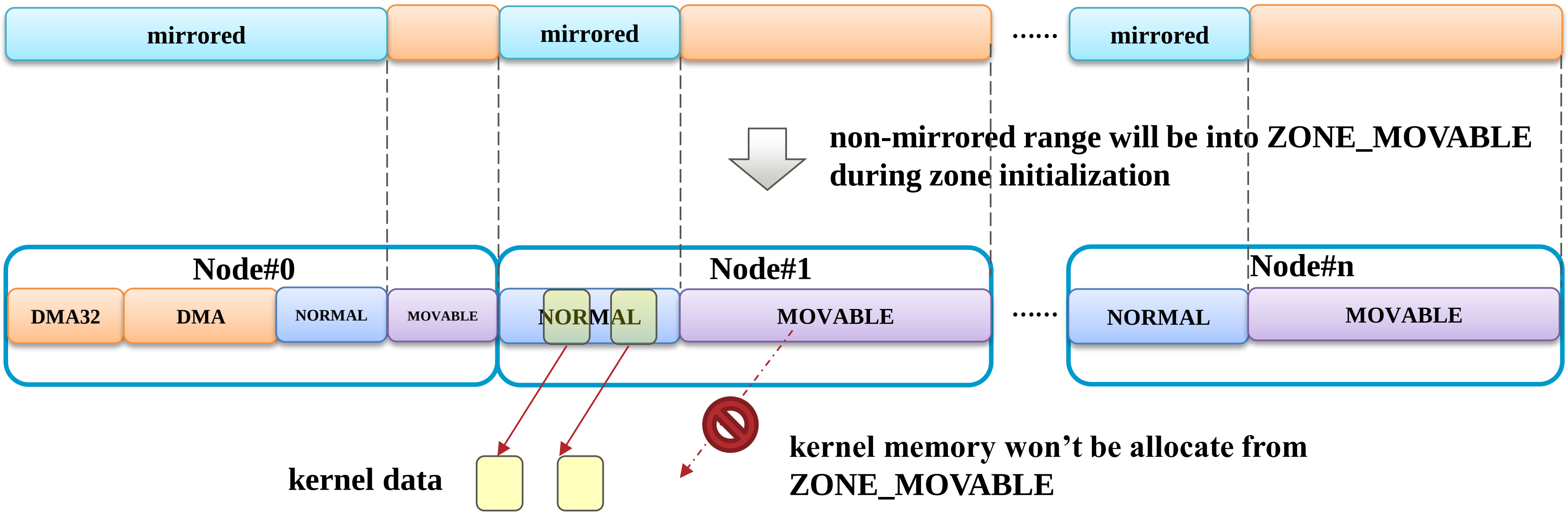


Solution for mirror support of Zone allocator

- Requirement
  - Allocate kernel memory from mirrored region
  - Allocate user memory from non-mirrored region
- Clue
  - ZONE_MOVABLE
    - Not exist by default
      - need to boot with “kernelcore” or “movablecore” specified
    - migratable memory can be allocated = users page only
      - kernel pages won’t be allocated; kernel page is NOT migratable
      - go well together memory hot-remove
- Idea
  - Arrange non-mirrored range into ZONE_MOVABLE

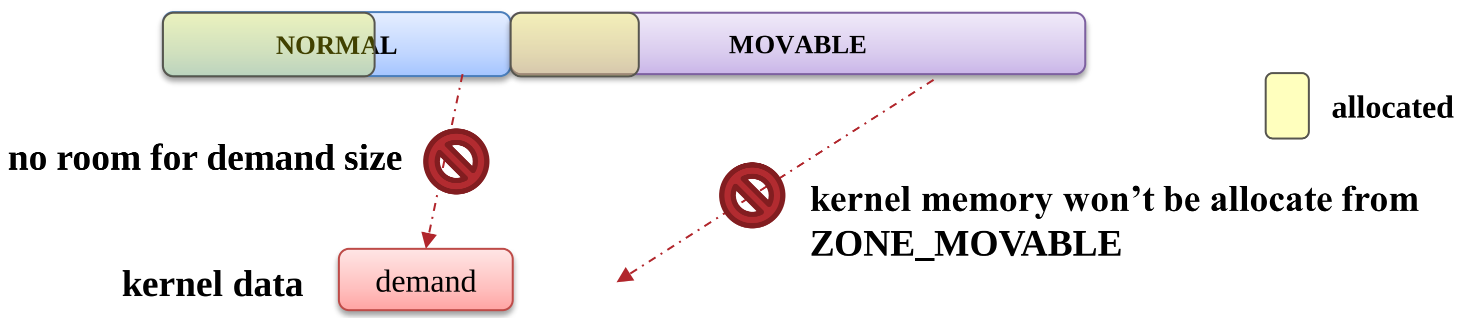
kernelcore=mirror boot option

- New in linux-4.6 for Address Range Mirroring
- By specifying “kernelcore = mirror” boot option,
  - Non-mirrored region will be arranged into ZONE_MOVABLE
  - kernel memory won’t be allocated from ZONE_MOVABLE, so it will be allocated from mirrored region



Drawback of kernelcore=mirror approach

- When running out of mirrored memory, never fall back to use non-mirrored memory
  - Possible that kernel memory is exhausted, though there is non-mirrored memory available
  - This behavior is as planned to protect kernel memory surely
  - Need sizing of total kernel memory



Future Plan

Future plan

- Handling of user’s memory
  - Prevent involuntarily user’s memory allocation from mirrored range
    - Currently user’s memory can be allocated from ZONE_NORMAL
    - Add a new __GFP_NONMIRROR allocation flag to be part of GFP_HIGHUSER_MOVABLE ?
  - Add the method that any user apps’ memory can be allocated from mirrored memory
    - Add a new MADV_MIRROR flag to the madvice(2) ?
- Handling of mirrored memory exhaustion case
  - Add fallback to non-mirrored memory option
    - In my opinion, we should not fallback. Change mirrored size to expand instead

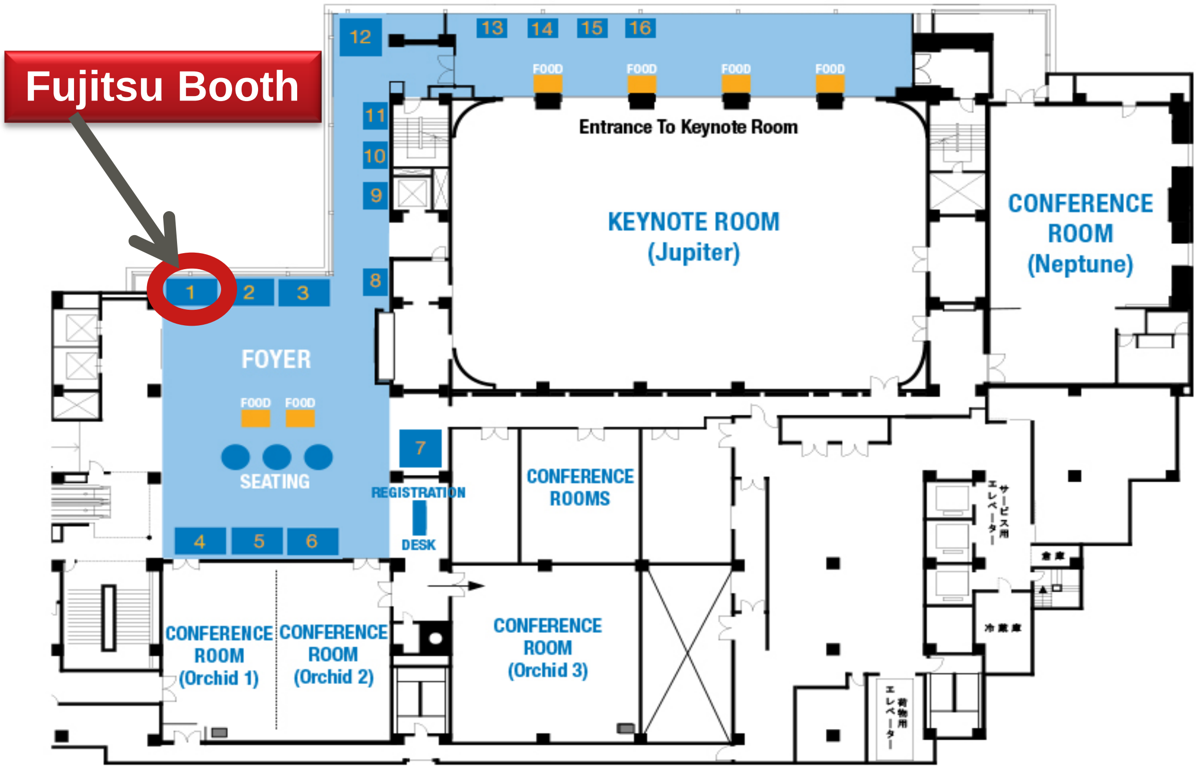
Feedback from MM summit 2016

- Got negative feedback for putting user-space program into mirrored range
  - madvice(2) is wrong interface
    - placement in mirrored memory would be mandatory
    - mirrored memory could be an opt-out resource rather than opt-in
      - But nobody would volunteer to opt-out…
  - A little messy so everything has to go there including shared libraries
    - Need restart apps?
  - Sizing for ZONE_NORMAL becomes difficult
    - second coming of low-memory problem
  - Assuming user-space program can figure the right thing to choose what needs to be mirrored is not safe
    - Security issues: some program can force the exhaustion of mirrored memory
  - Partial mirroring is simply the wrong approach
    - Simply mirroring the entire address space is easy

Summary

- Address Range Mirroring overview
  - What is Address Range mirroring
- Current status of linux
  - Current implementation for Address Range mirroring
- Future plan
  - Feedback from MM summit 2016

[PR] Fujitsu Booth



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