*k*Memvisor: Flexible System Wide Memory Mirroring in Virtual Environments

Bin Wang
Zhengwei Qi
Haibing Guan
Haoliang Dong
Wei Sun

Shanghai Jiao Tong University

Yaozu Dong

Intel China Software Center

Is your memory error-prone?

Today's memory do become error-prone

- [B. Schroeder et al. *SIGMETRICS 09*] Memory failures are **common in clusters**
- **8% of DIMMs** have correctable errors per year
- **1.29% uncorrectable errors** in Google testbed

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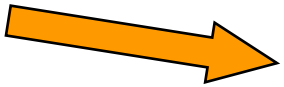

Memory -intensive App.

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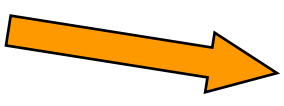

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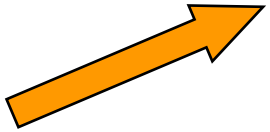

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Memory HA in Cloud Computing

1.29% error rate

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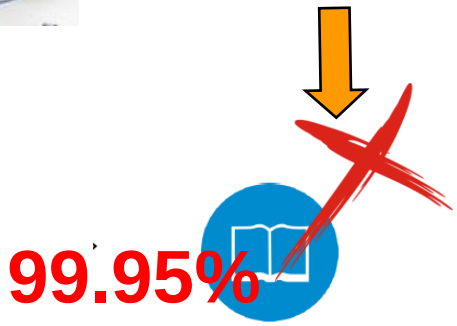

99.95%

Service Level Aggrement

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Service Level Aggrement

4.38 hours downtime per year
21.56 minutes downtime per month
5.04 minutes downtime per day

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Service Level Aggrement

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21.56 minutes downtime per month
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[Andy A. Hwang et al. *ASPLOS 12*] Memory Errors happen at a significant rate in all four sites with **2.5 to 5.5%** of nodes affected per system

Existing Solutions

Hardware

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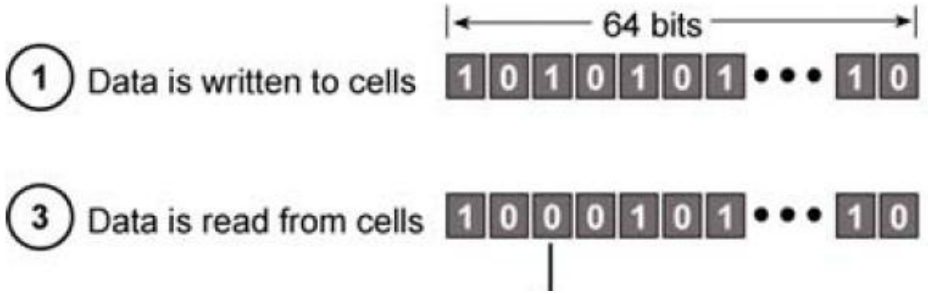
Hardware

ECC (Hp, IBM, Google et al.)



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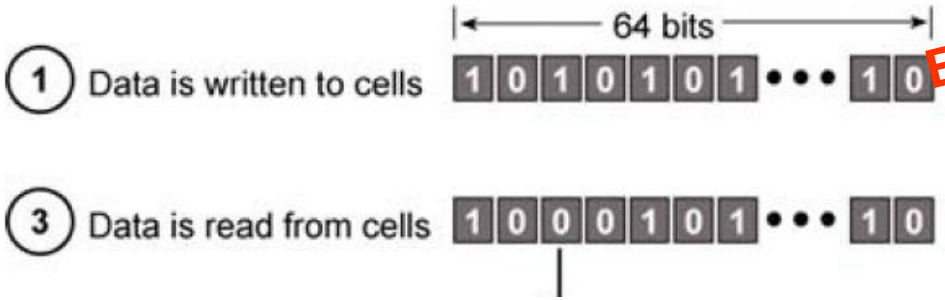

Bit-granularity checking

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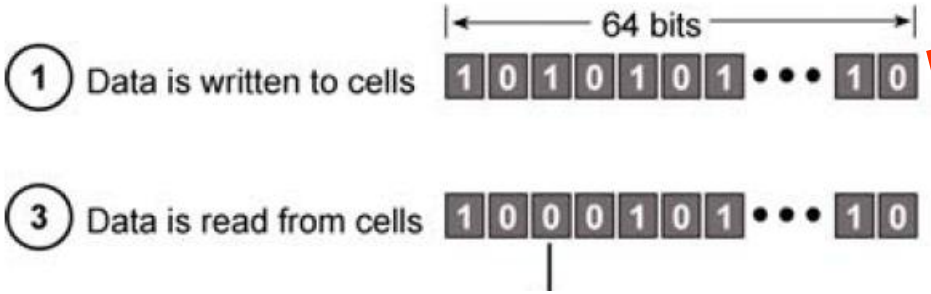
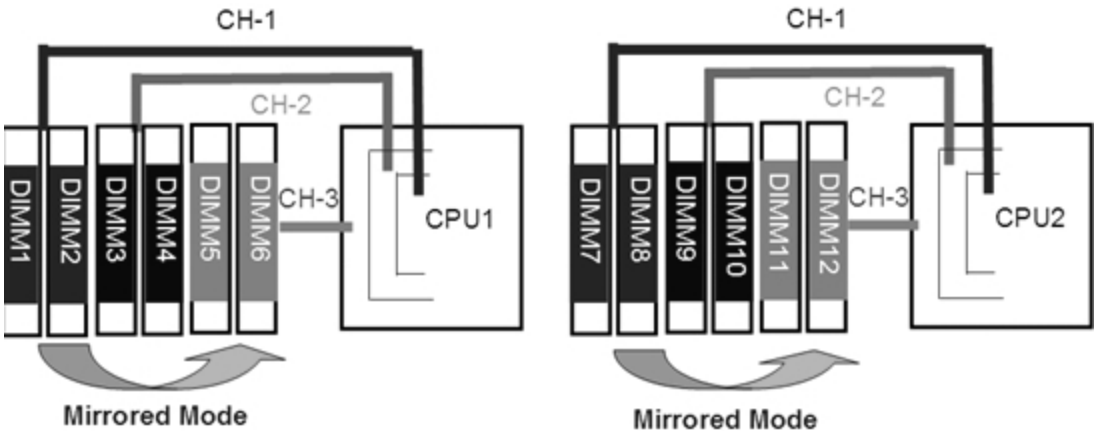


Bit-granularity checking

Mirrored Memory (Hp, IBM, Google et al.)



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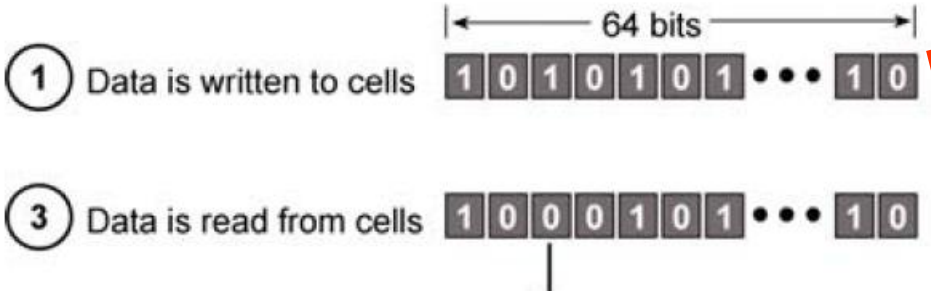

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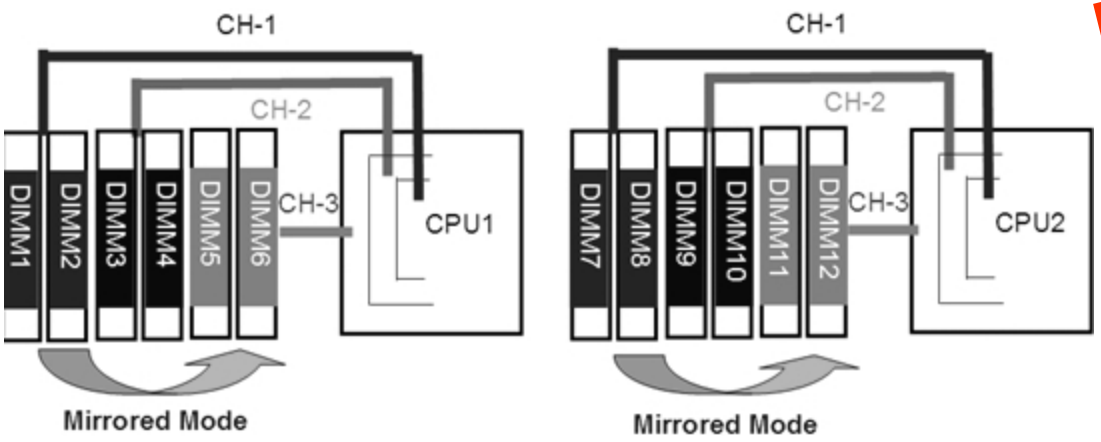

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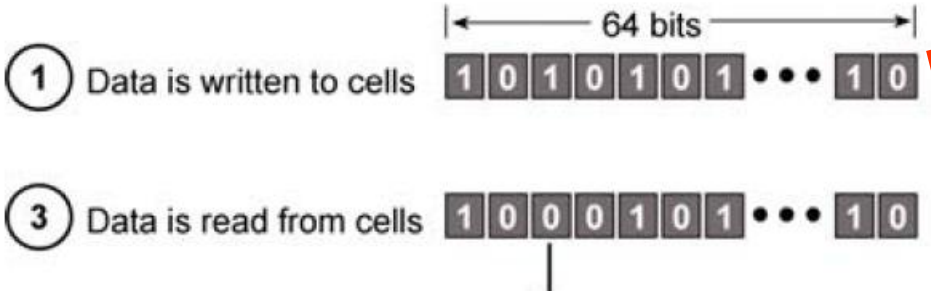

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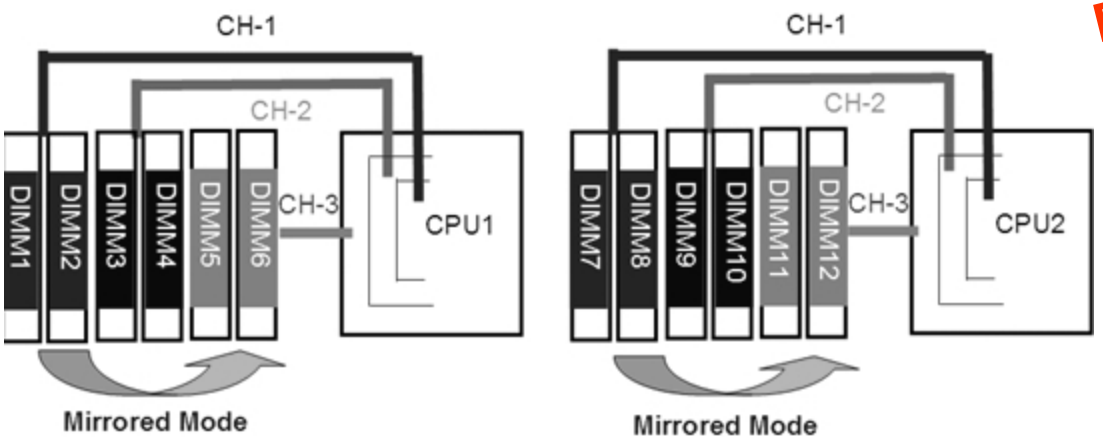

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Low compatibility

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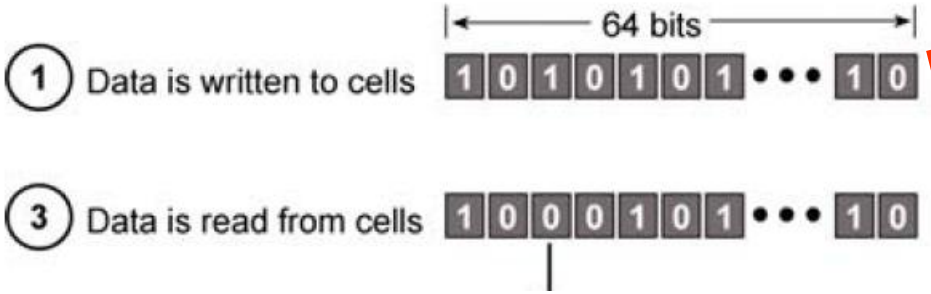

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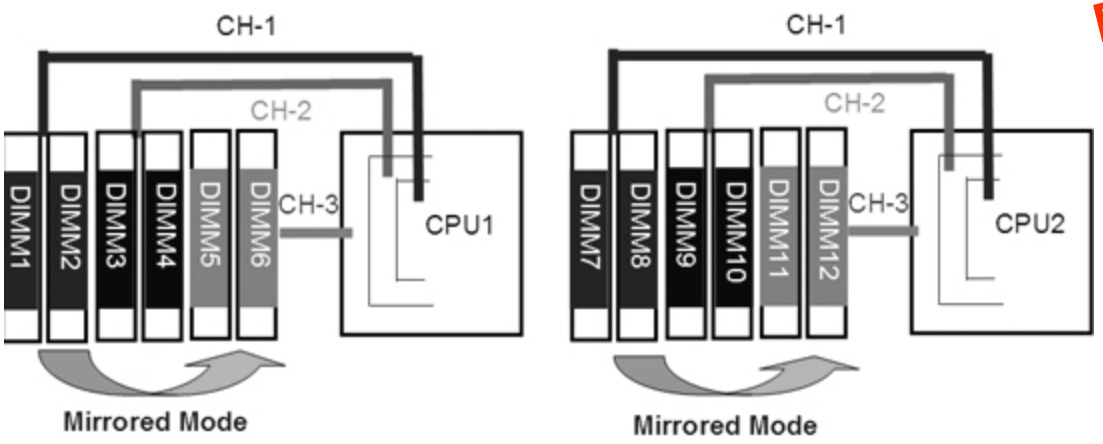

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Low flexibility

Existing Solutions

- Software

- Duo-backup (GFS, Amazon Dynamo)

- Checkpoint, hot spare+ VM migration /replication

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Syetem level tolerance

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Application-Specific and High overhead
(eg. Remus [*NSDI 08*] with **40** Checkpoints/sec, overhead **103%**)

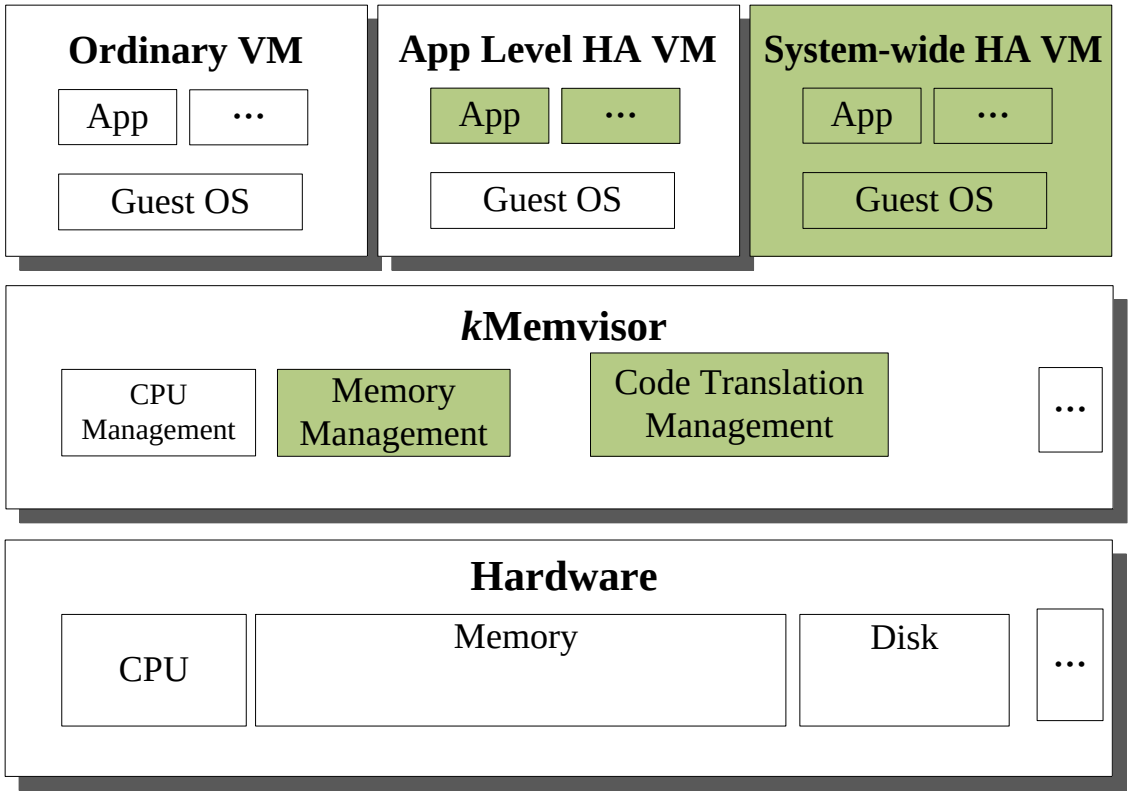
Design Guideline

- Low cost
- Efficiency & compatibility
  - arbitrary platform
  - on the fly+ hot spare
- Low maintaining
  - little impact to others (eg., networking utilization)
  - without migration
- Cloud requirement
  - VM granularity

*k*Memvisor

- A hypervisor providing system-wide memory mirroring based on hardware virtualization
- Supporting VMs with or without mirror memory feature on a same physical machine
- Supporting *NModularRedundancy* for some special mission critical applications

*k*Memvisor High-level Architecture



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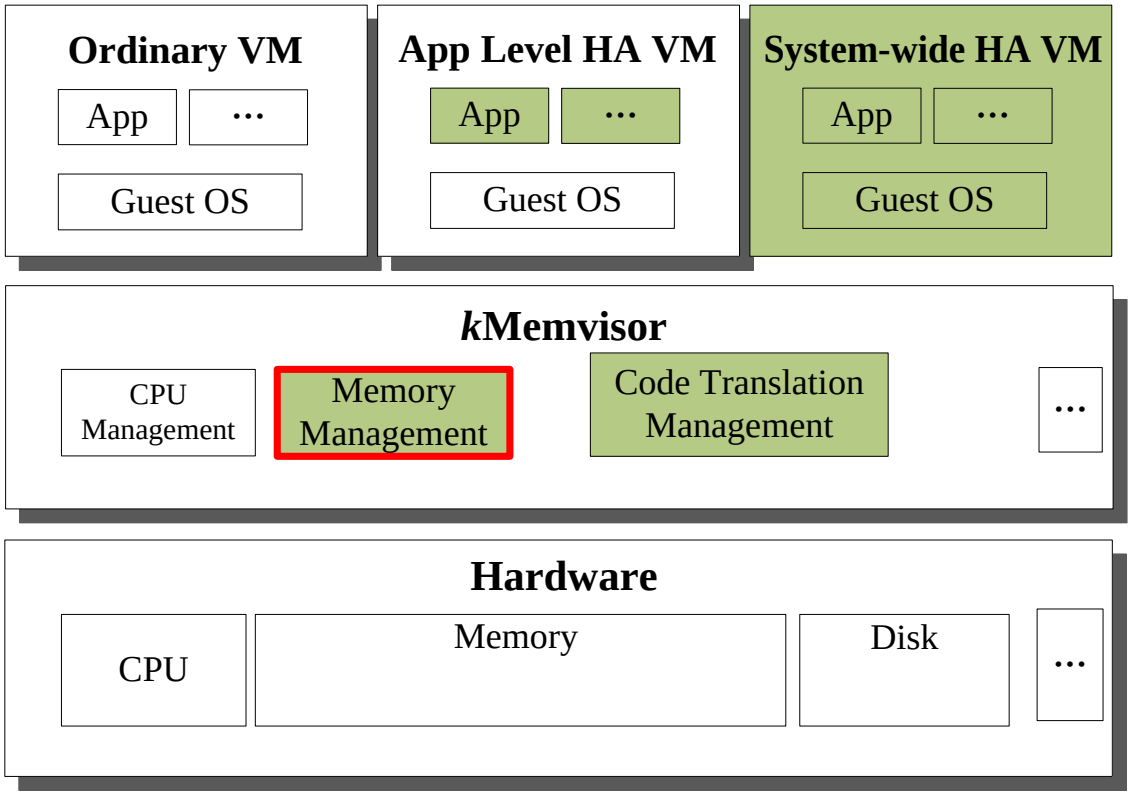

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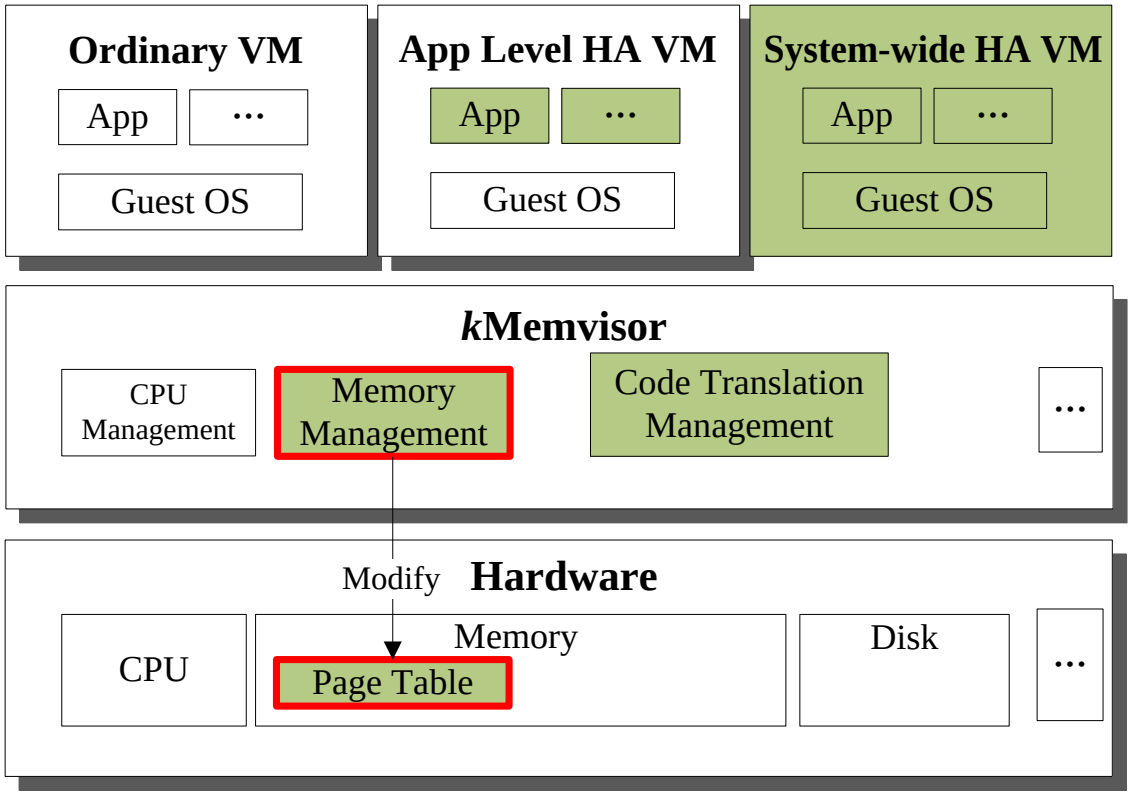

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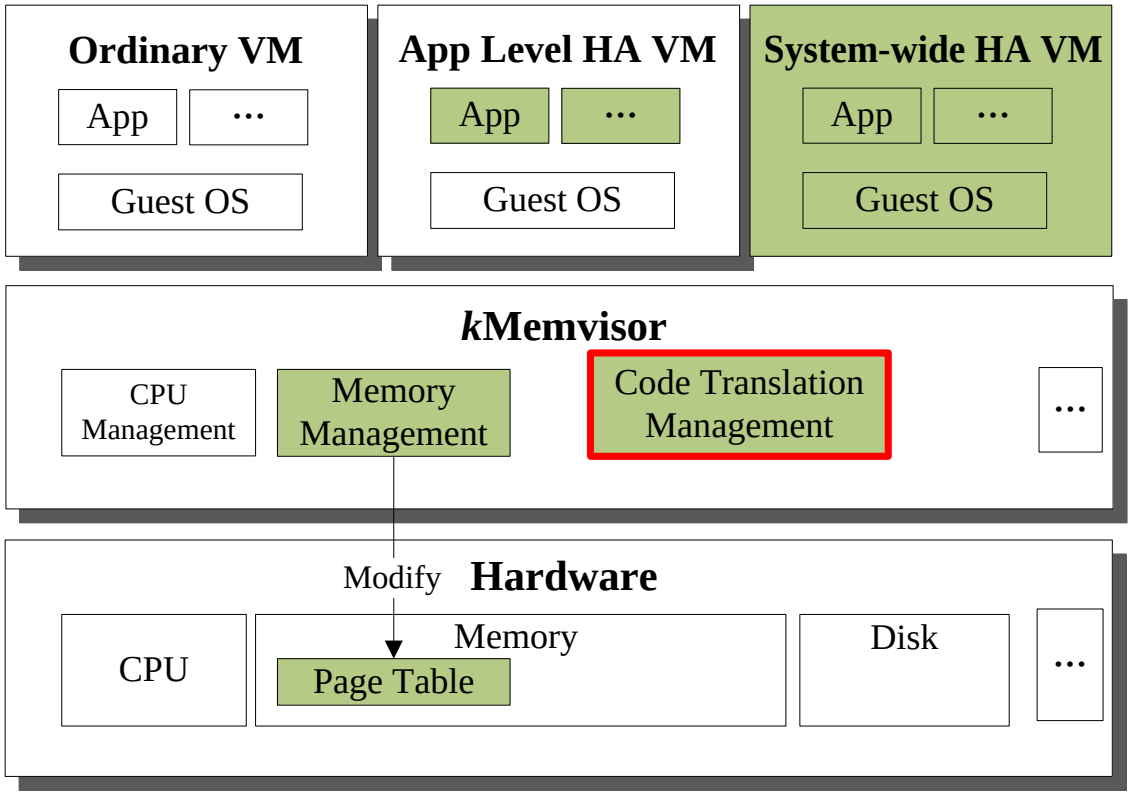

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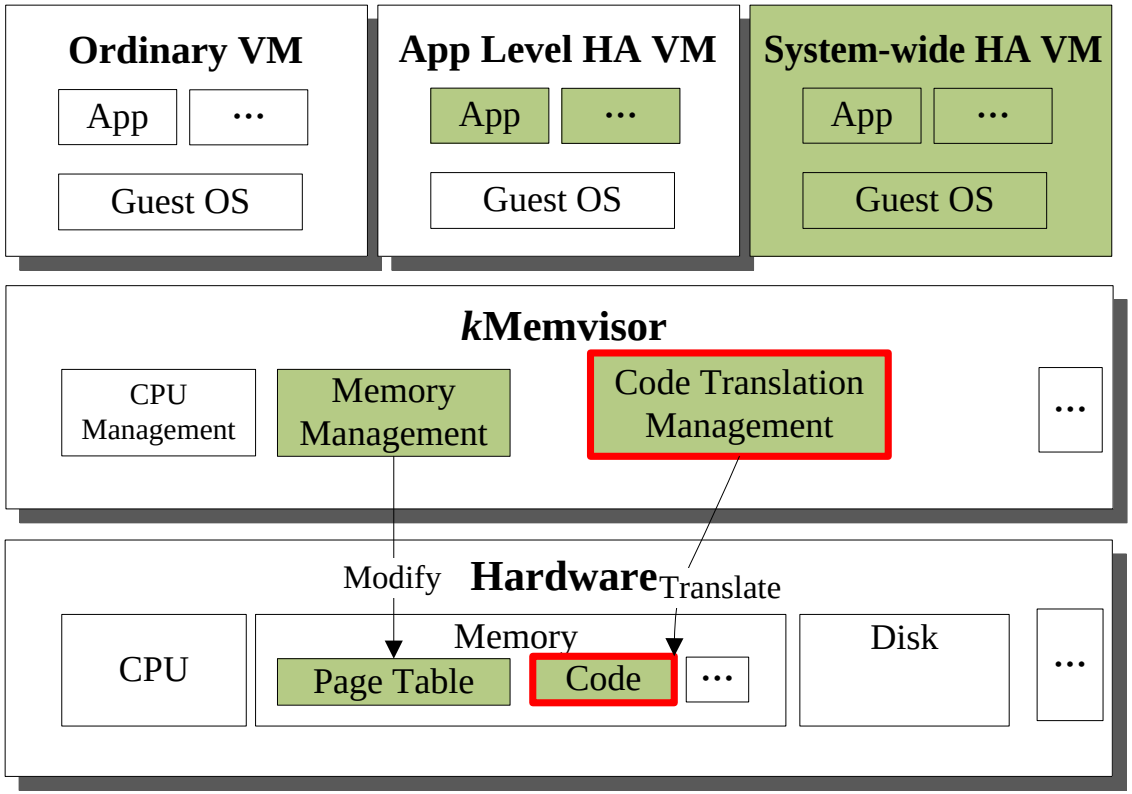

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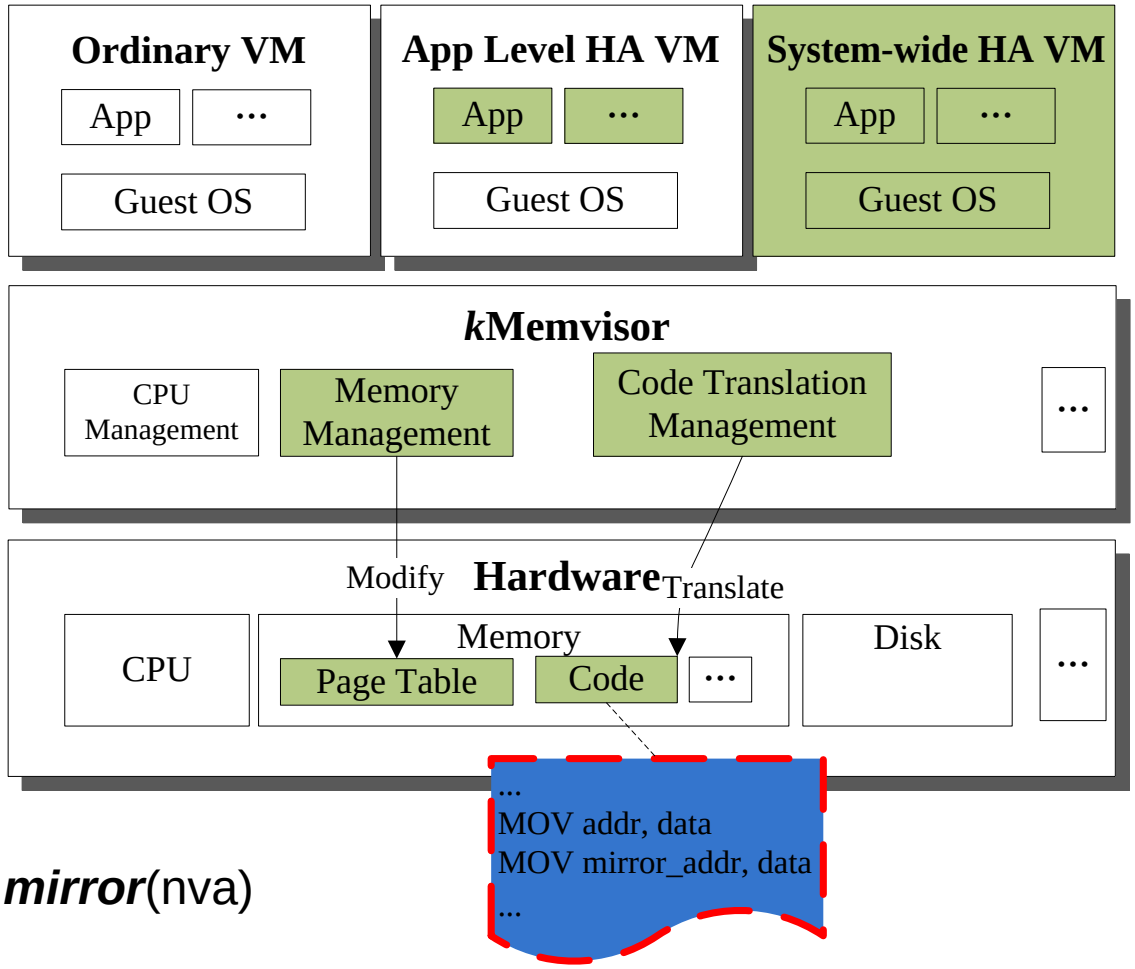

mva = ***mirror***(nva)

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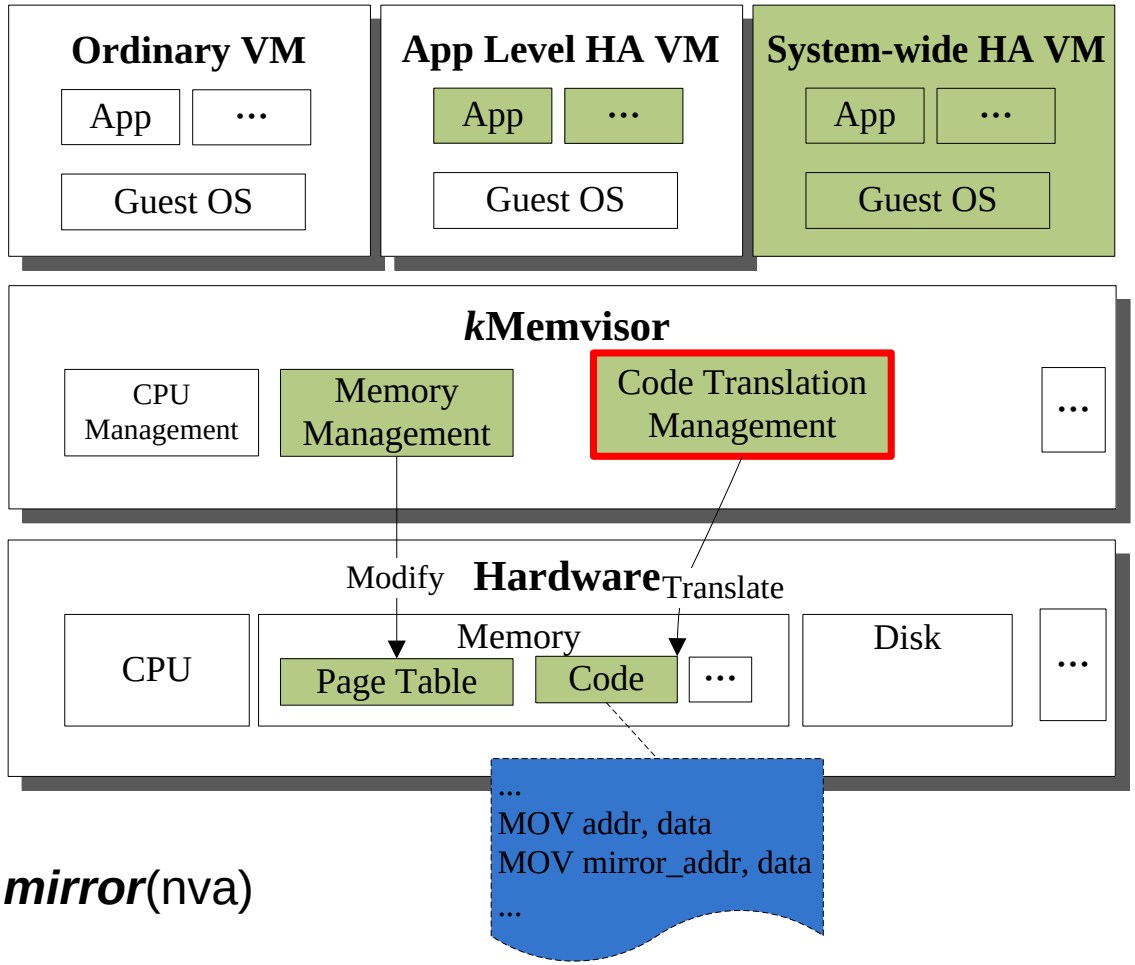

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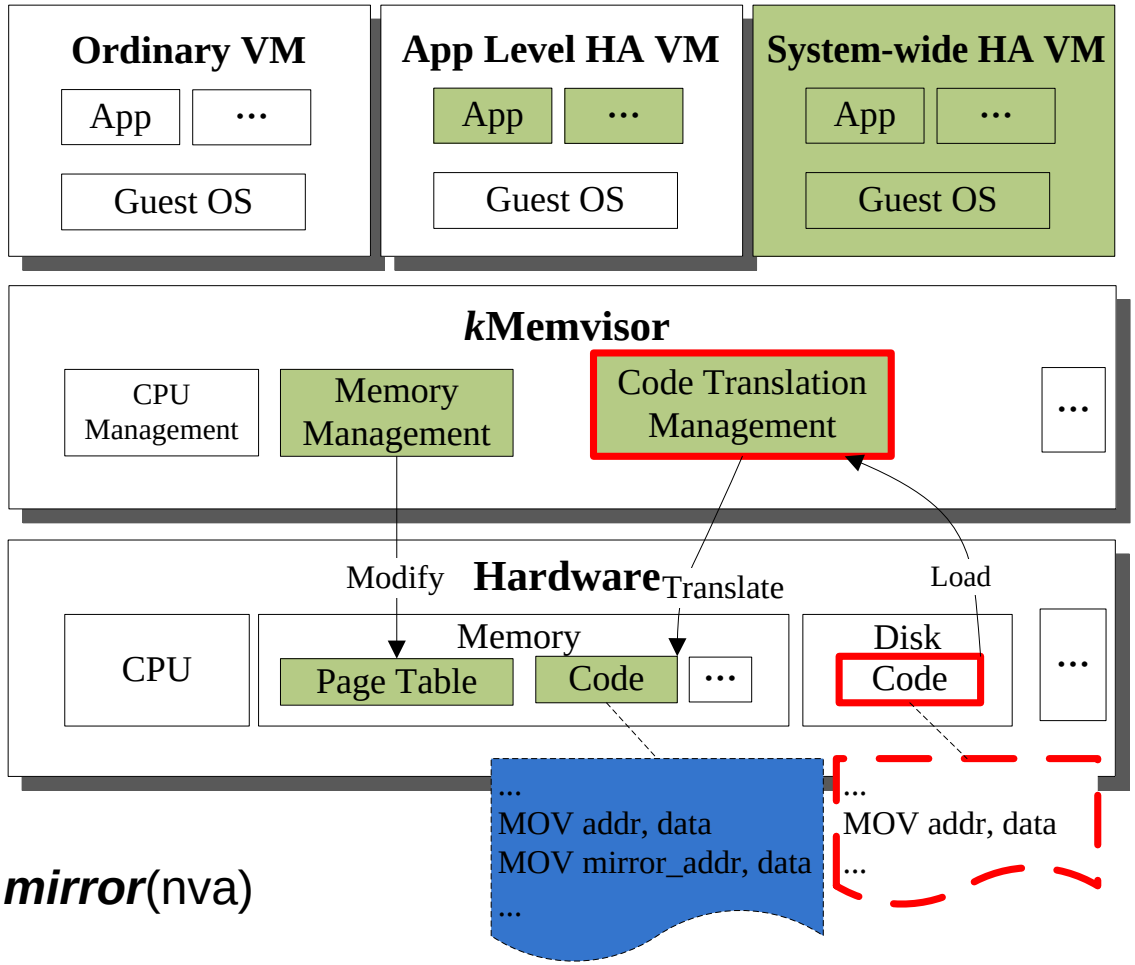

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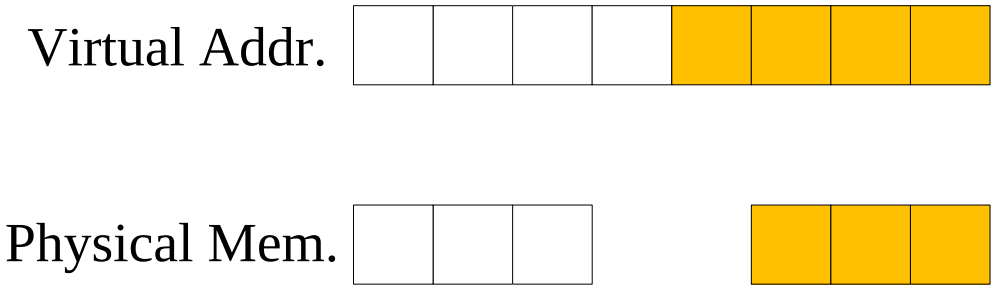
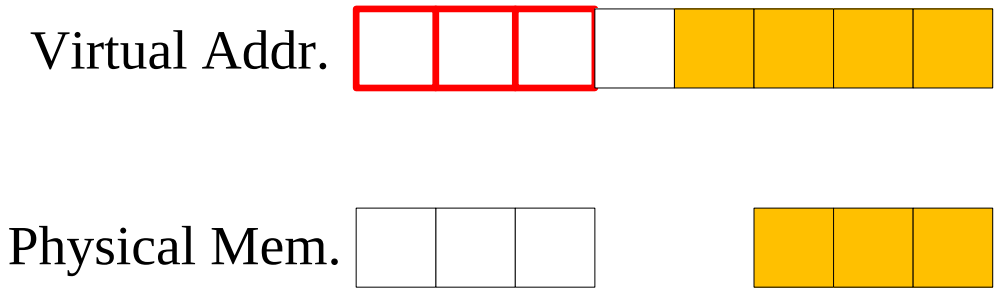


Retrieve Memory Failure

Create native PTE



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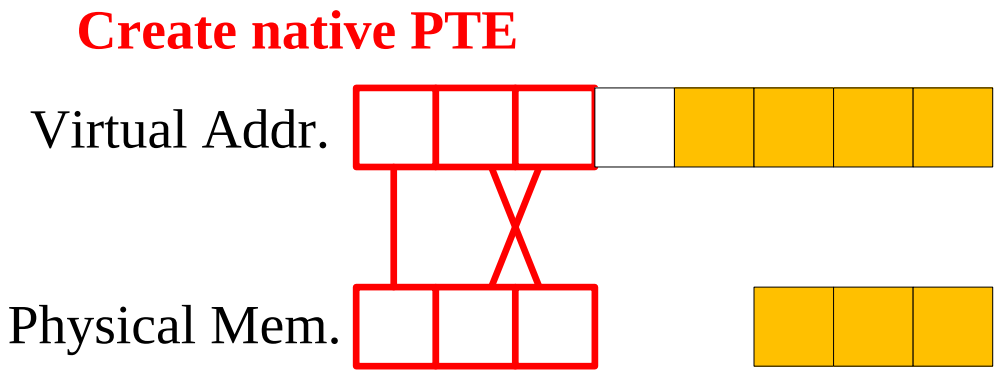

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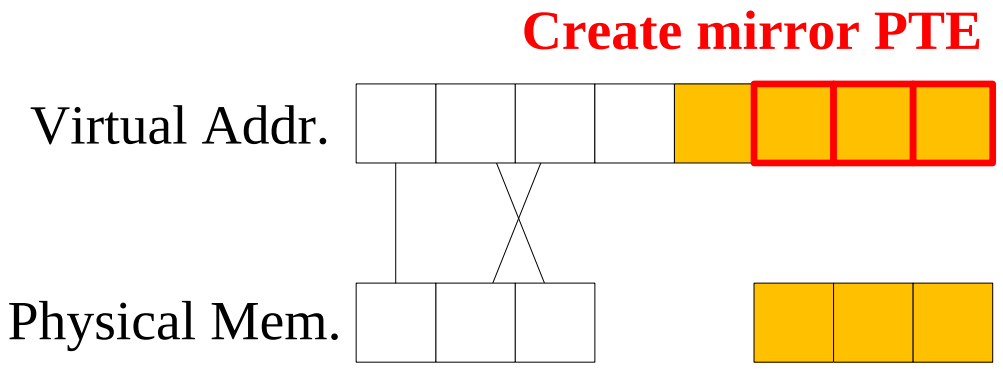

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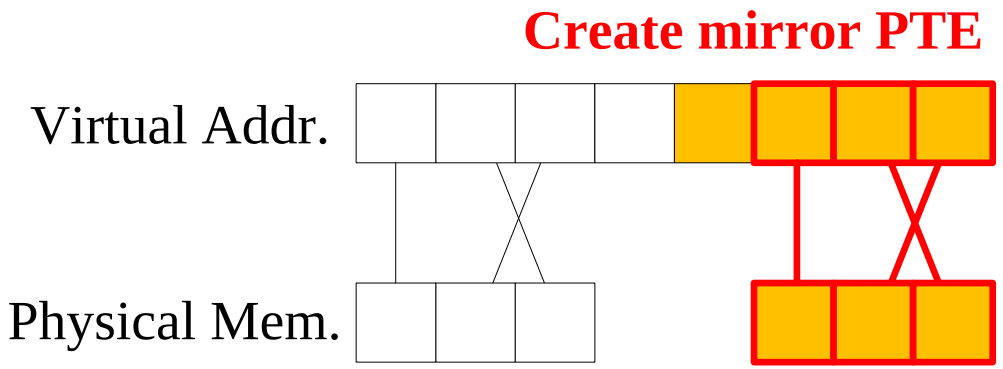

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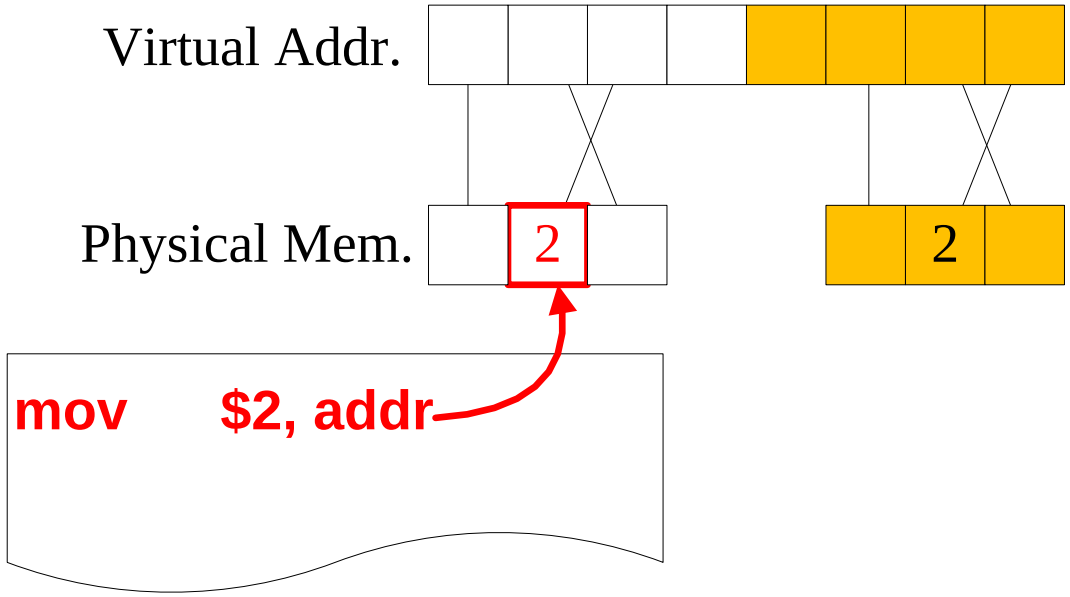

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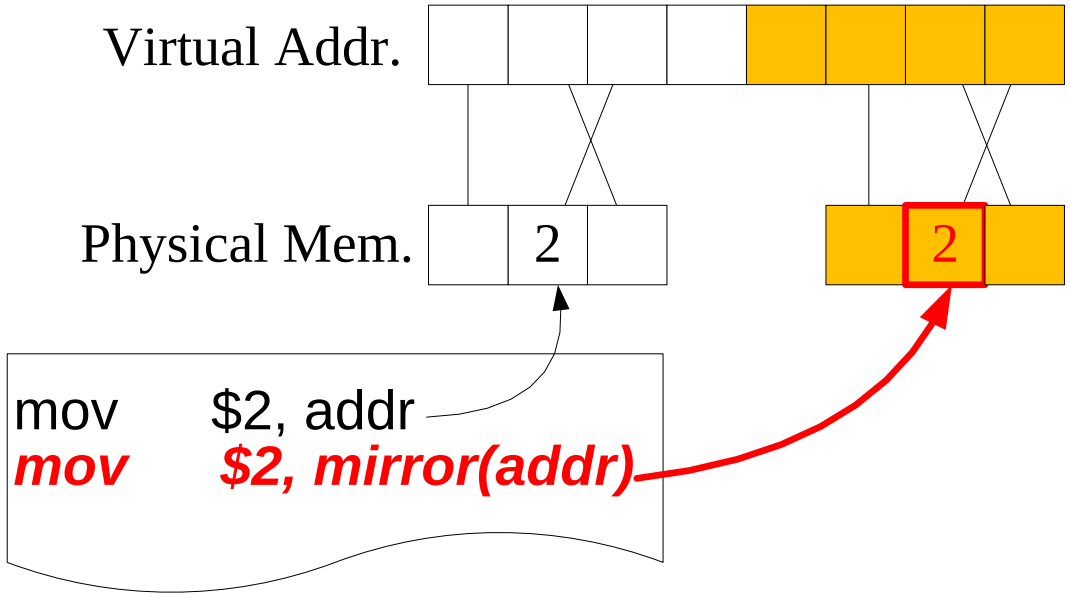

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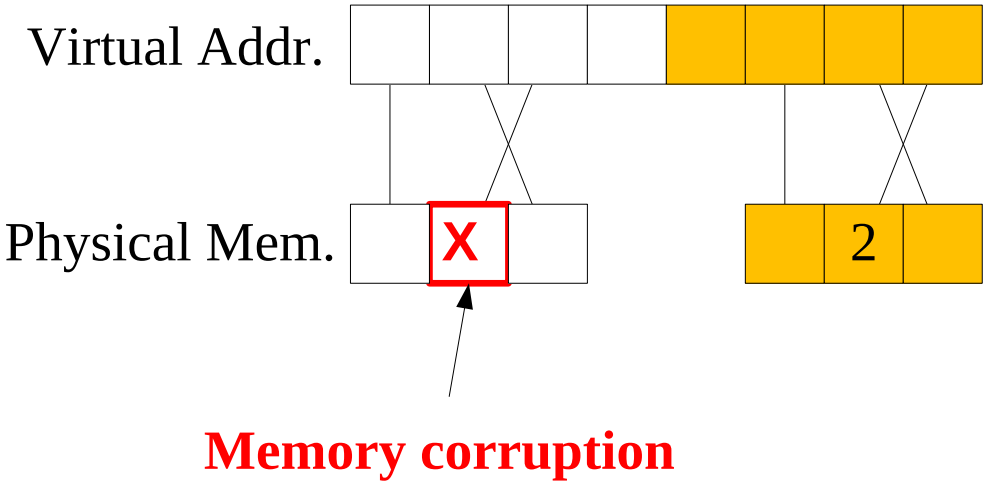

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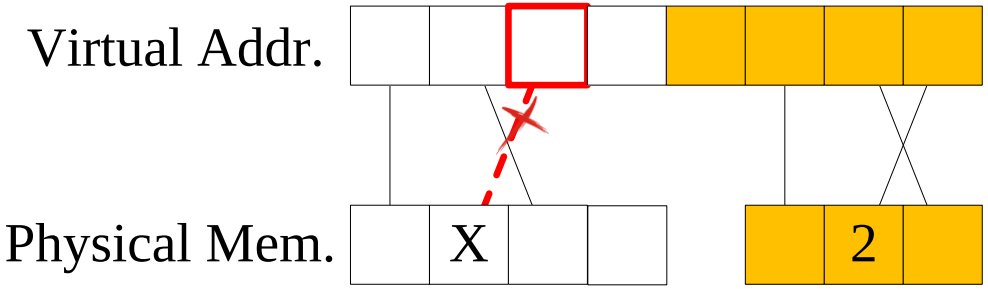

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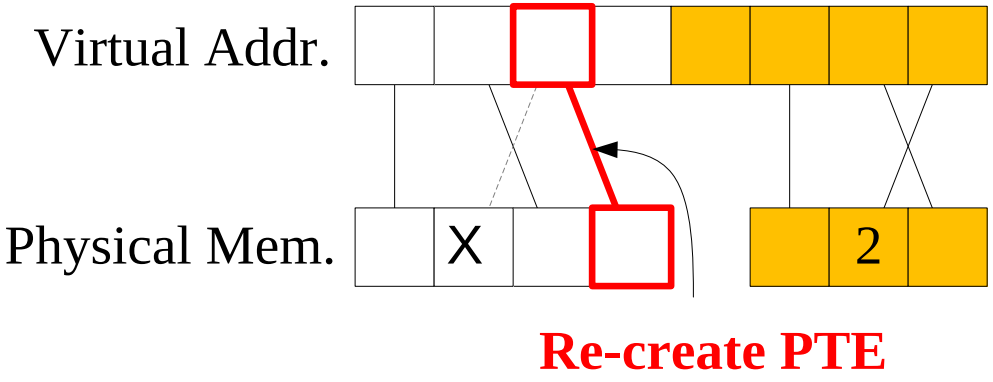

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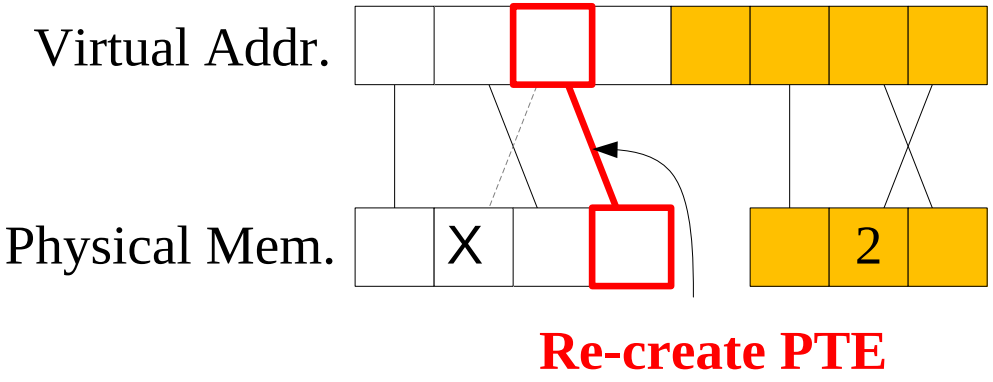

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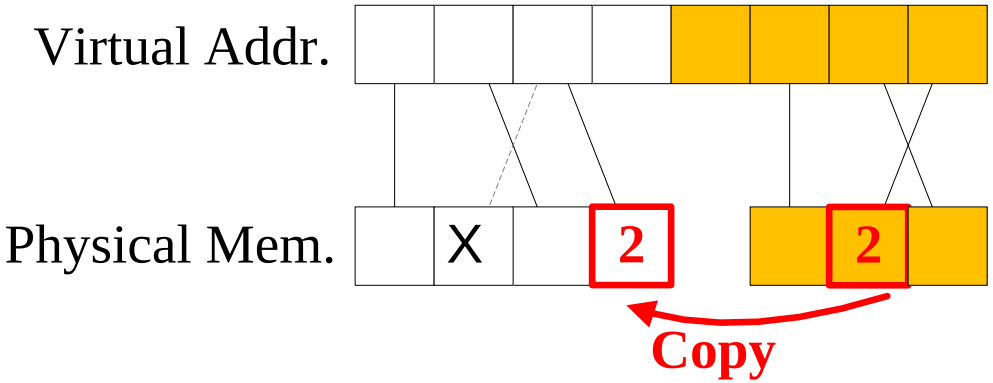
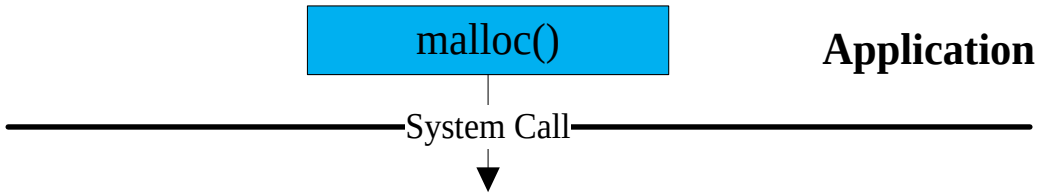


Create Mirror Page Table



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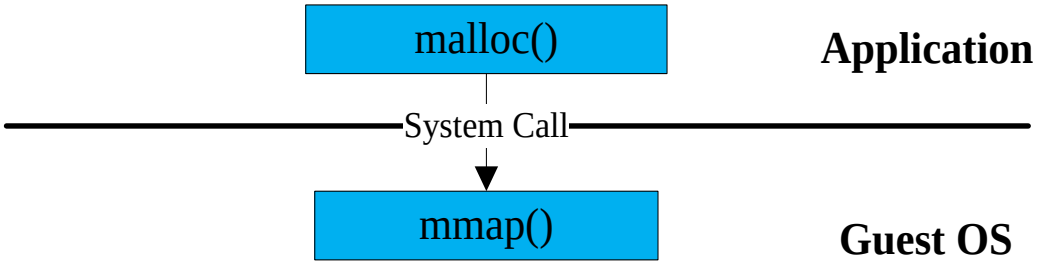

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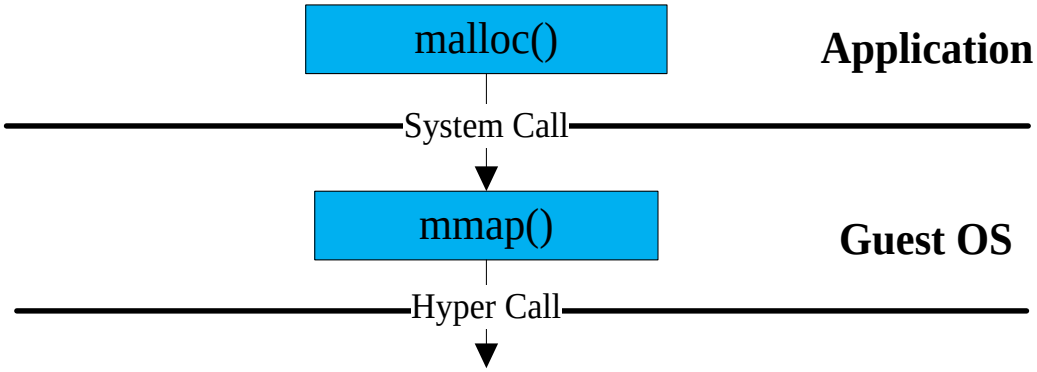

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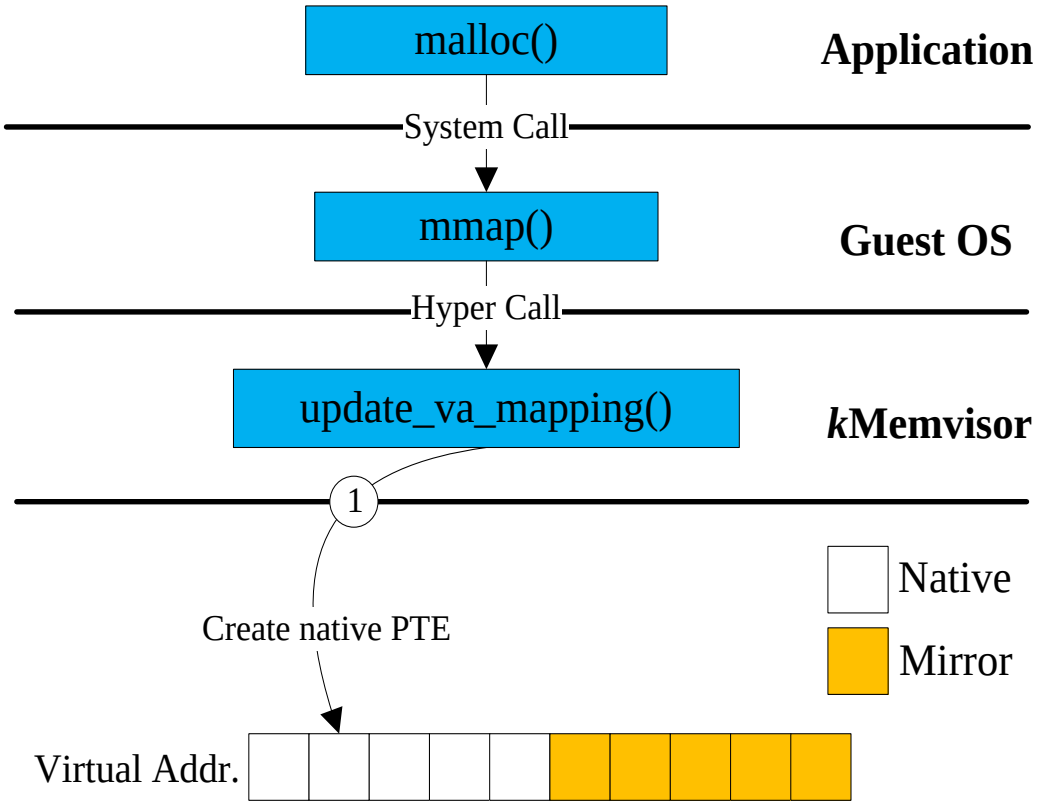

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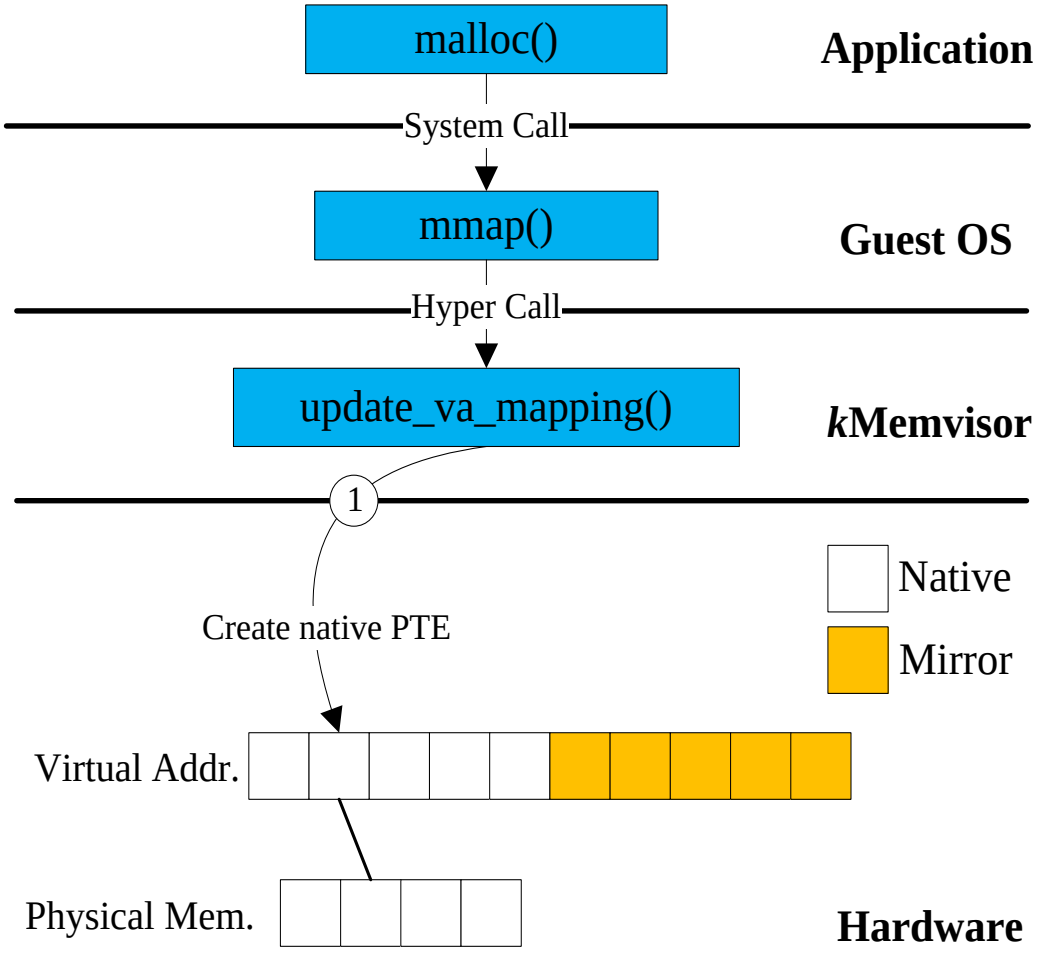

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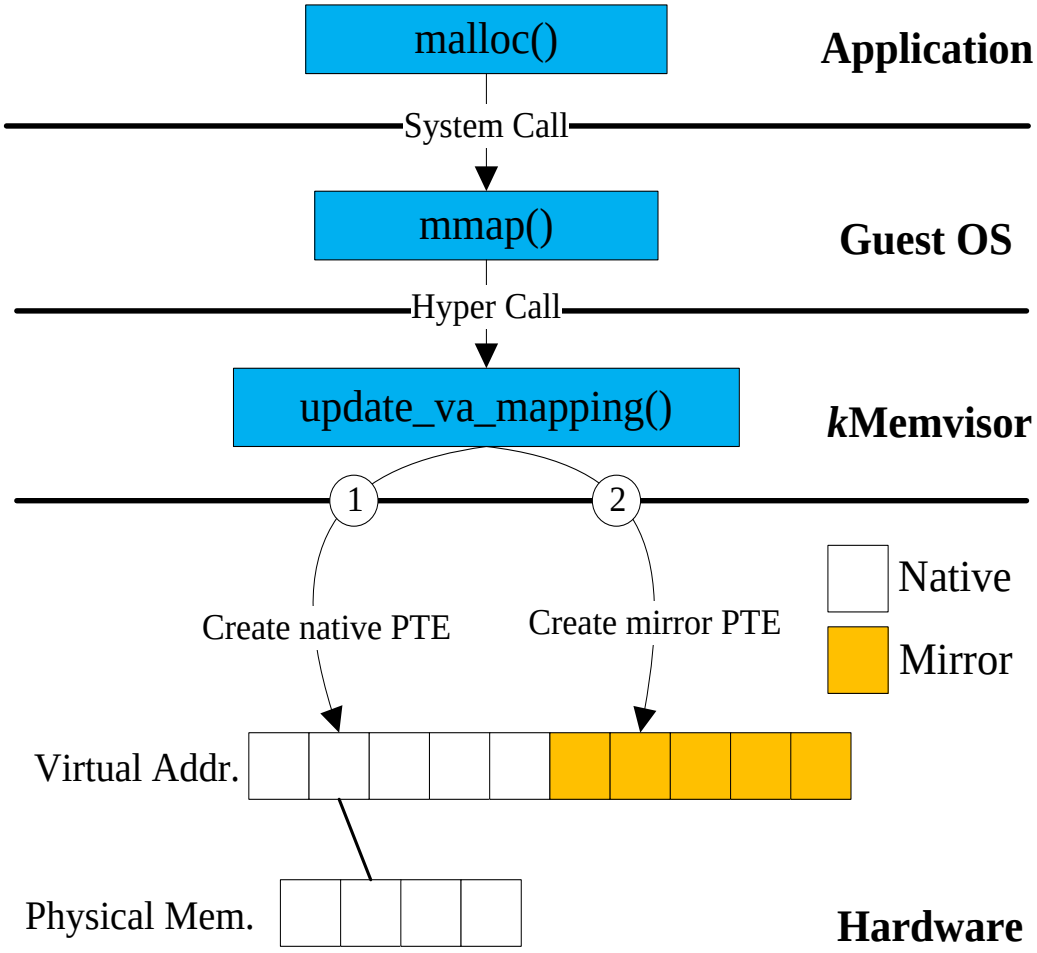

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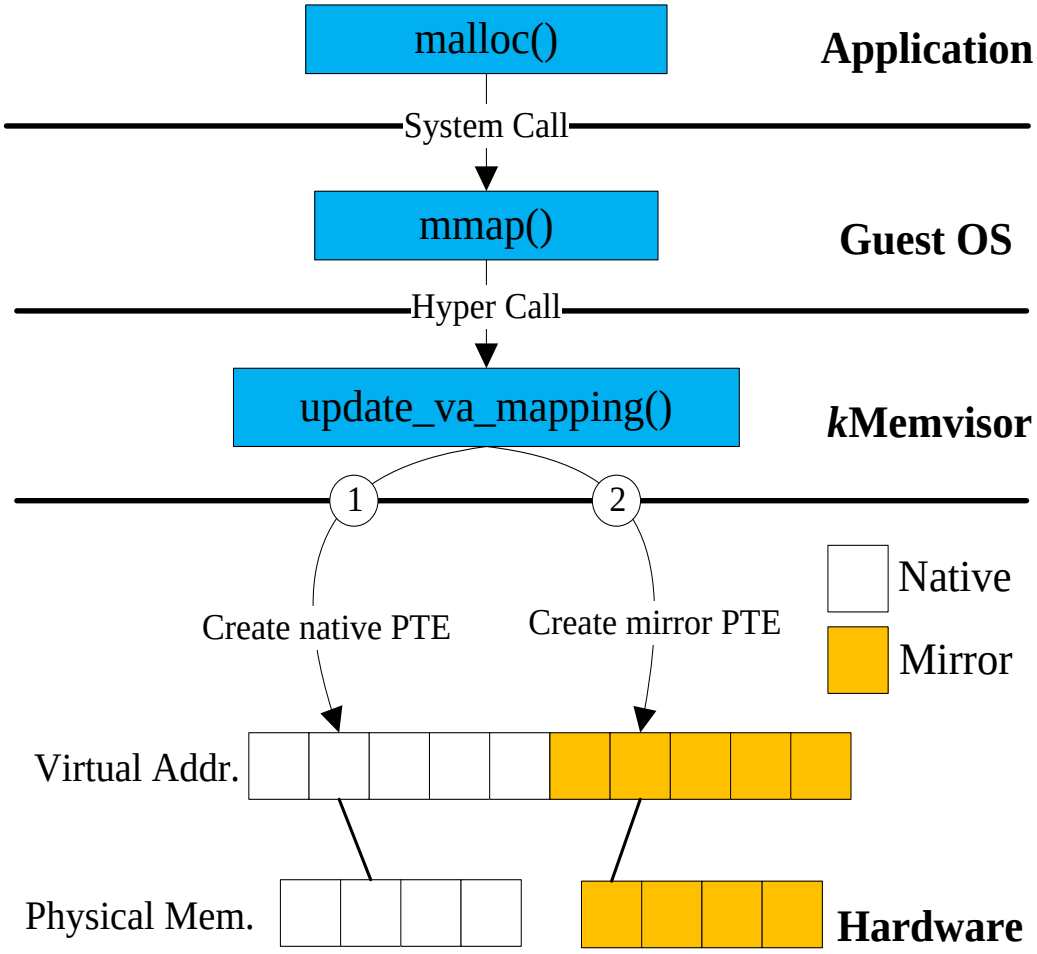
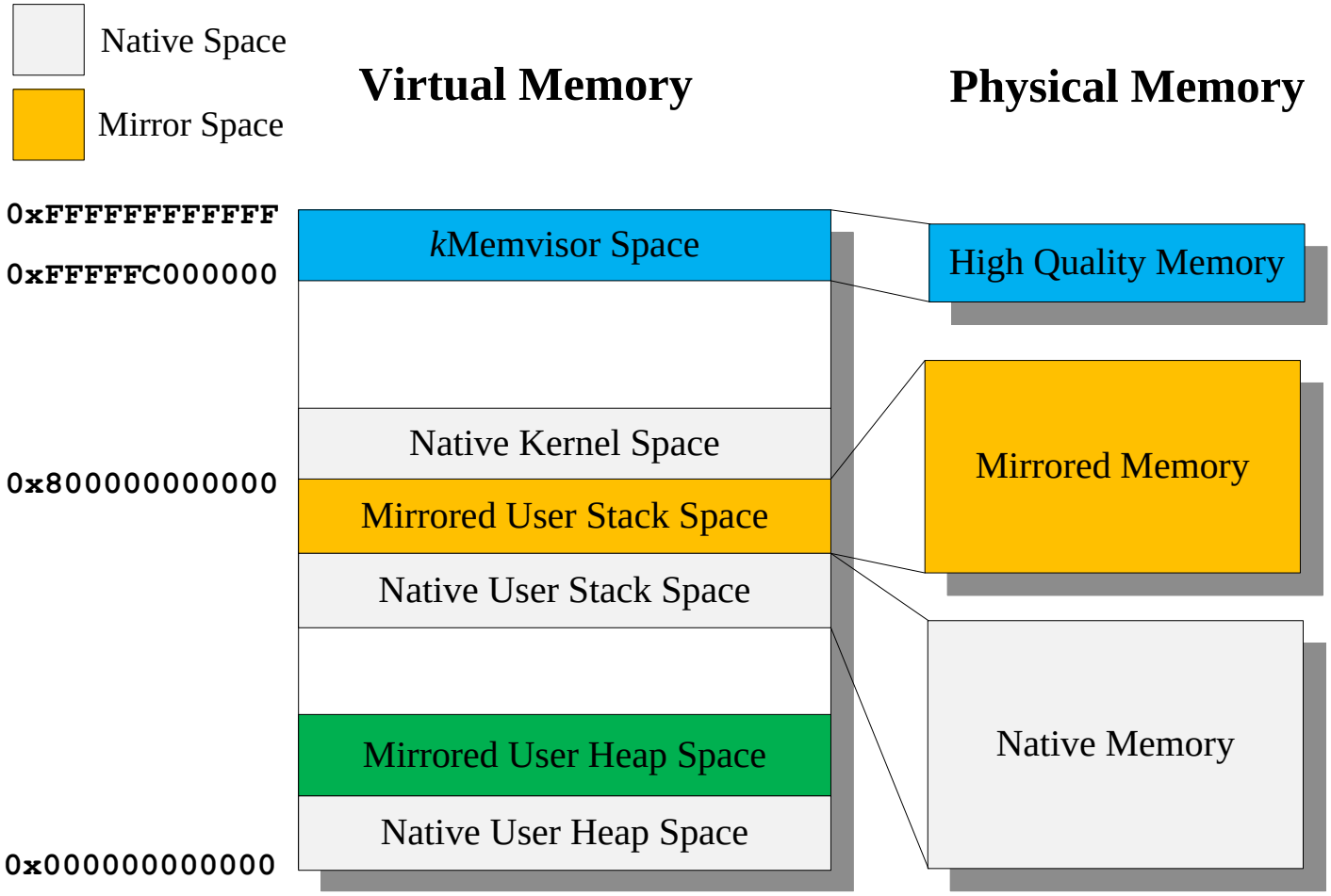


Modification

- Direct page table
  - Write the page table using a **hypercall**
  - Intercept the hypercall & Fill in the PTE
- Modify Guest OS
  - Guest OS has no awareness of iteration with the help of *vm_struct.*
  - Ignore mirror PTE

Modified Memory Layout



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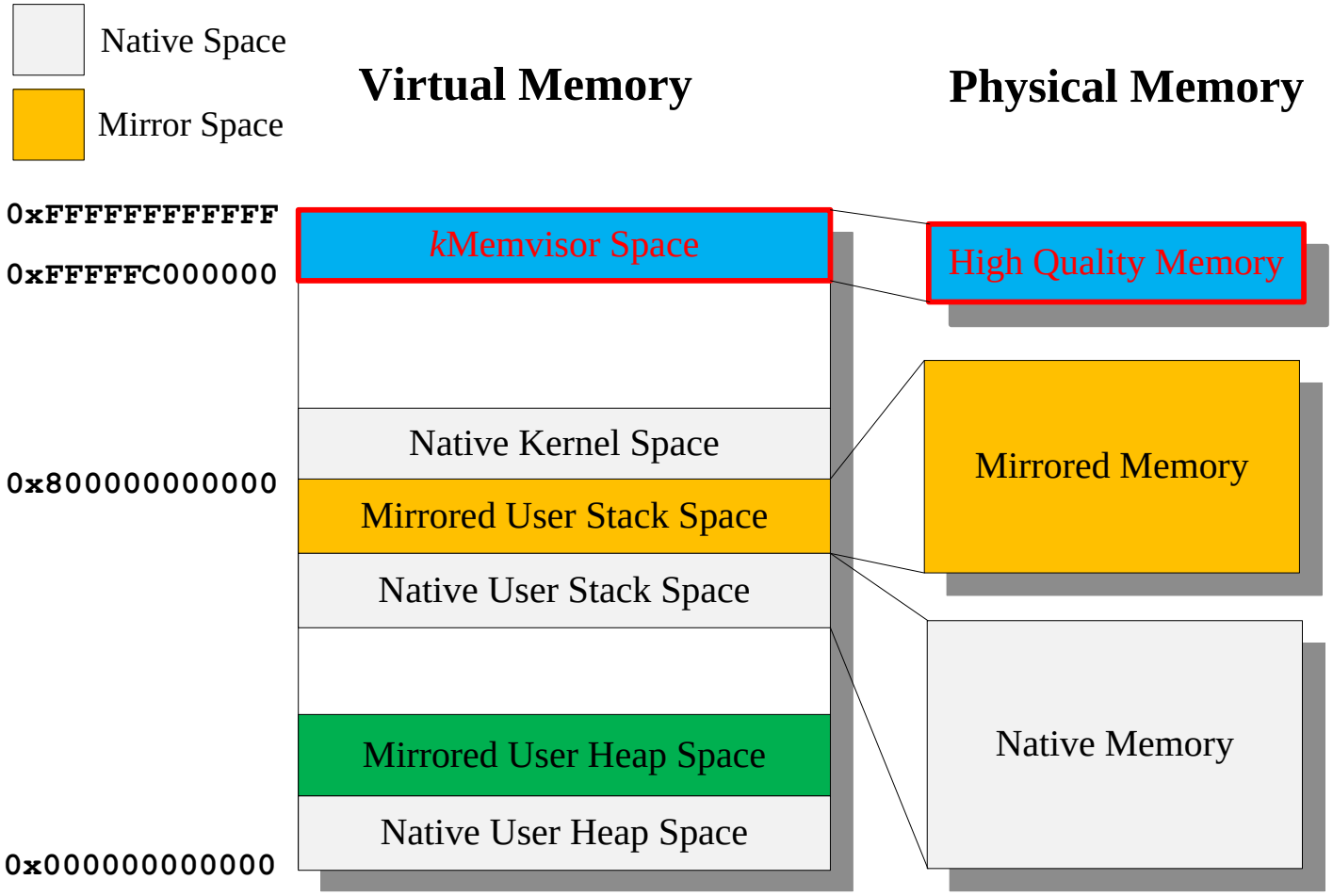

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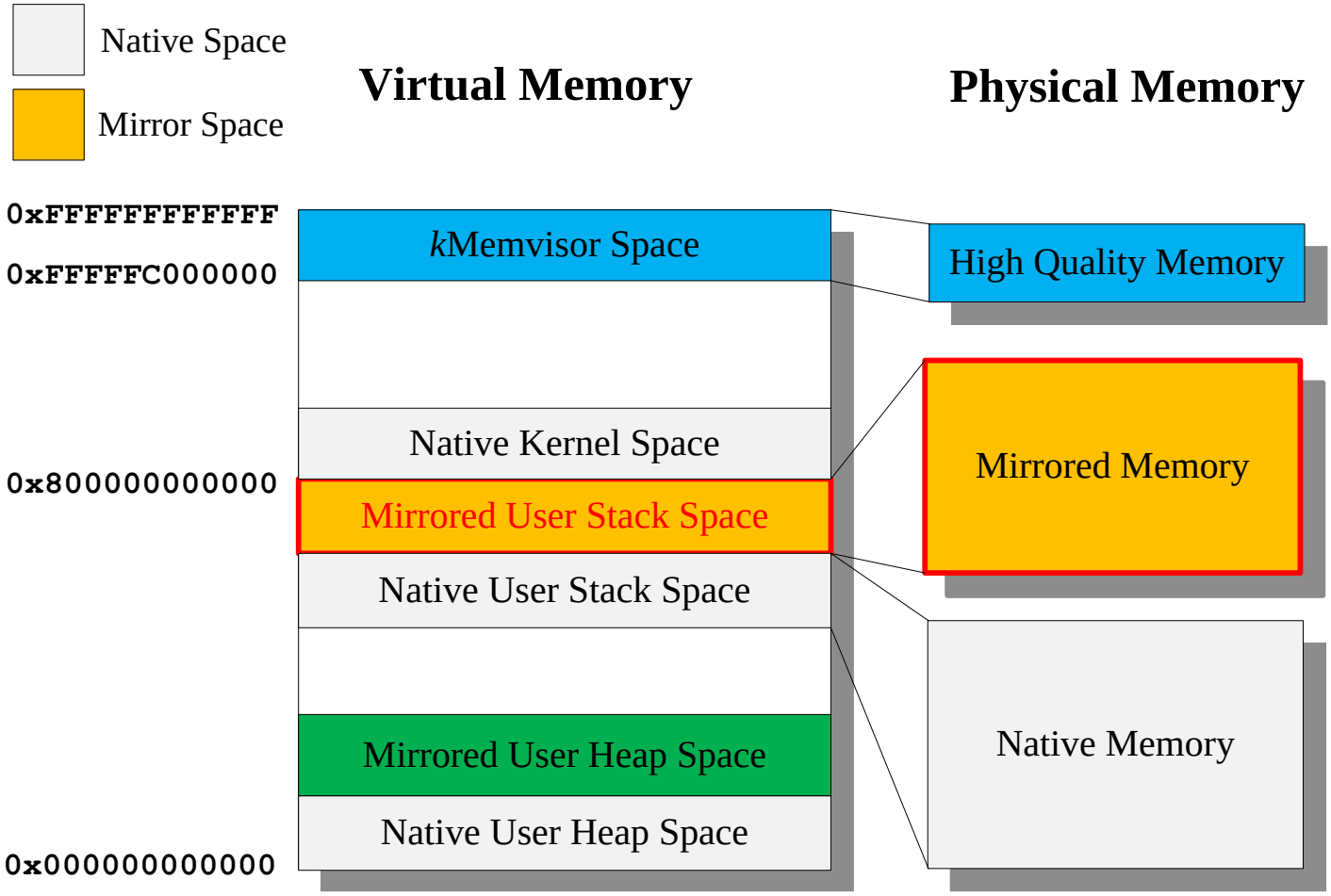

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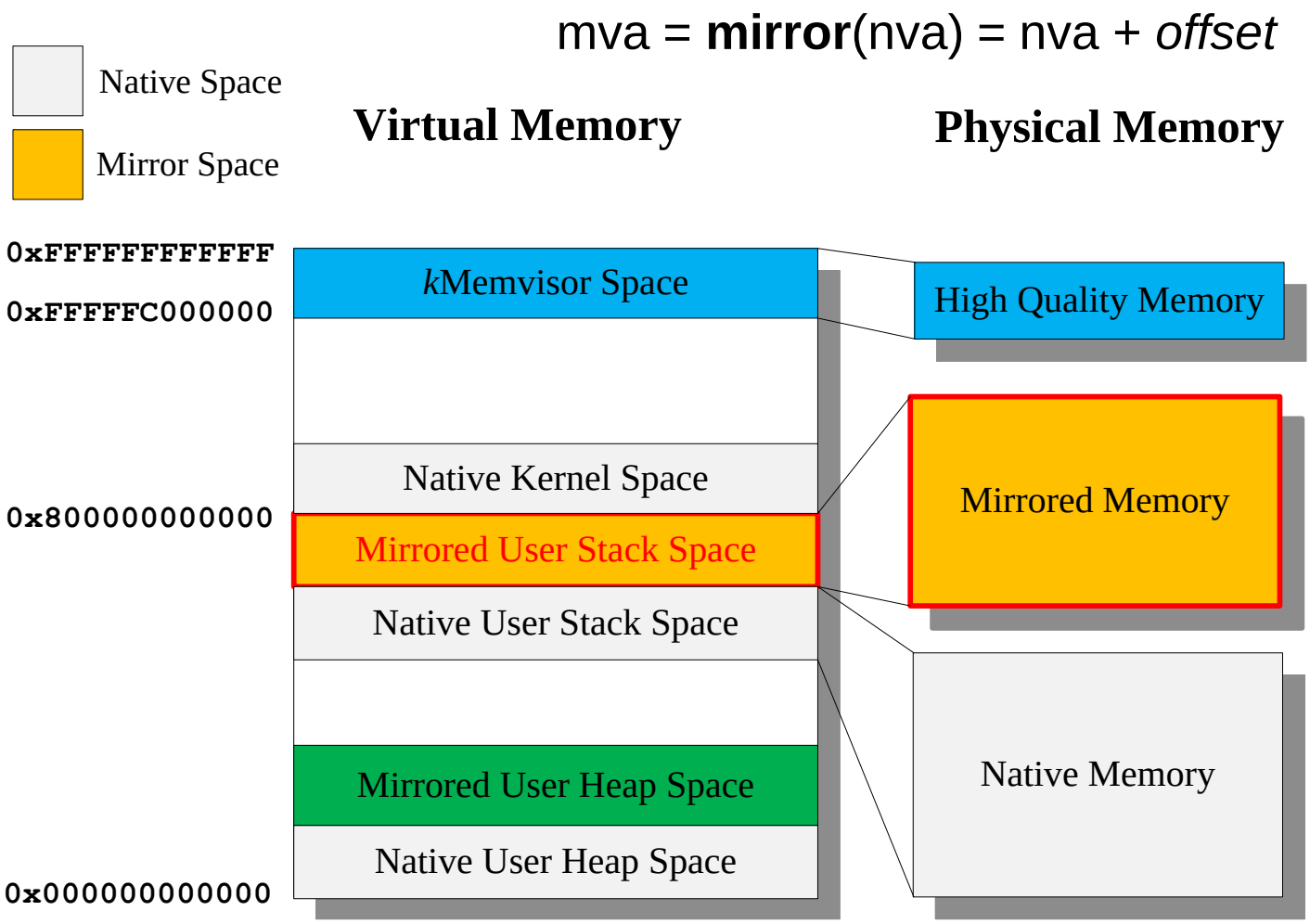

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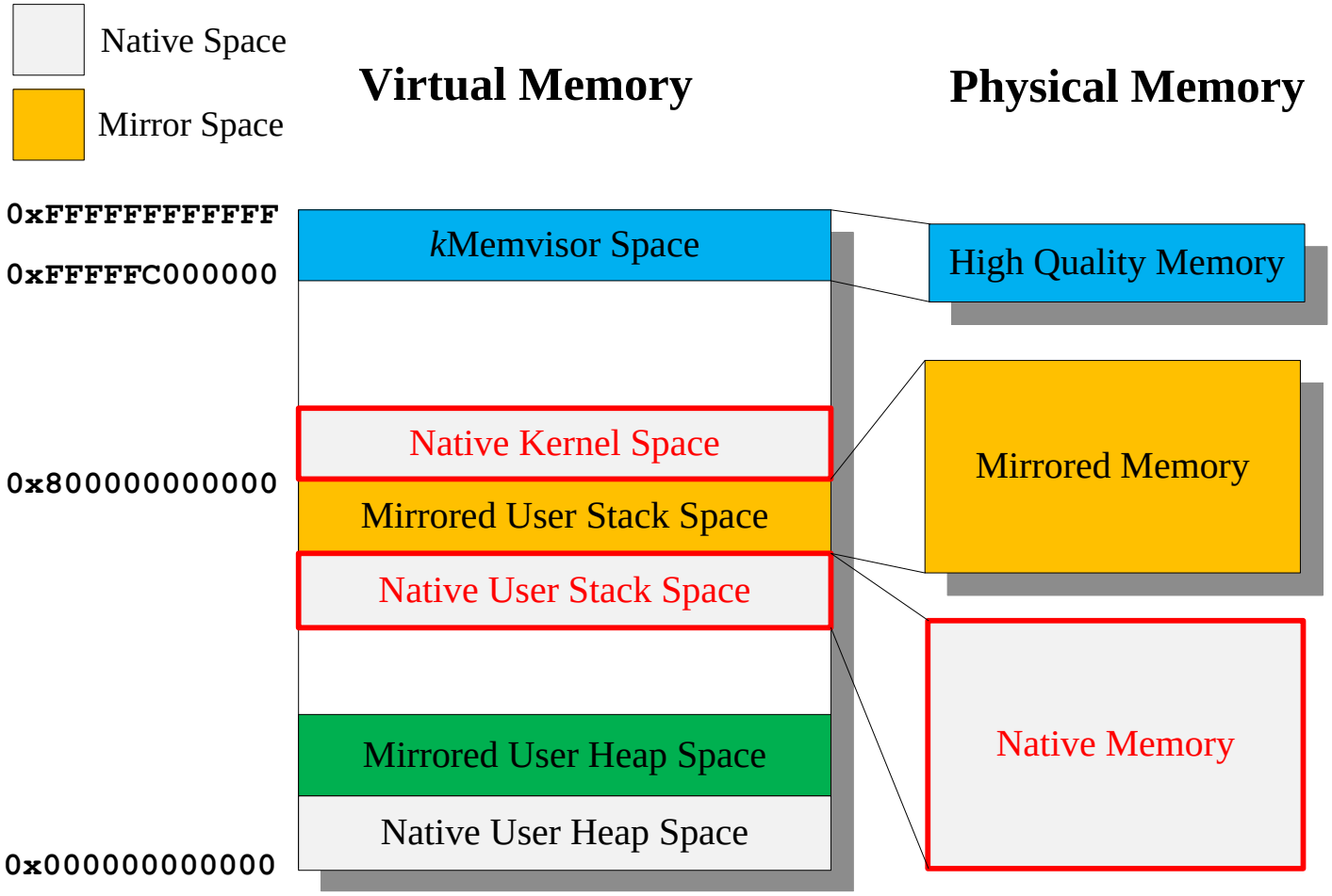
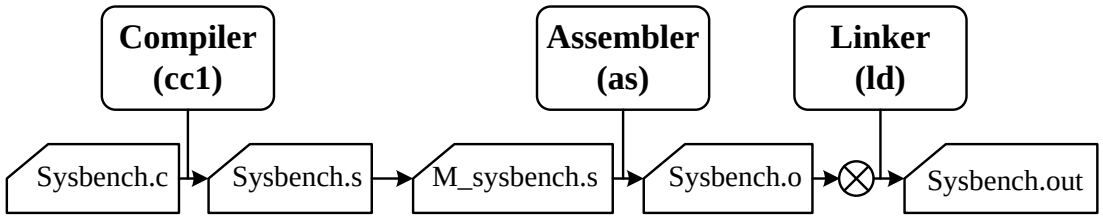


Memory Synchronization



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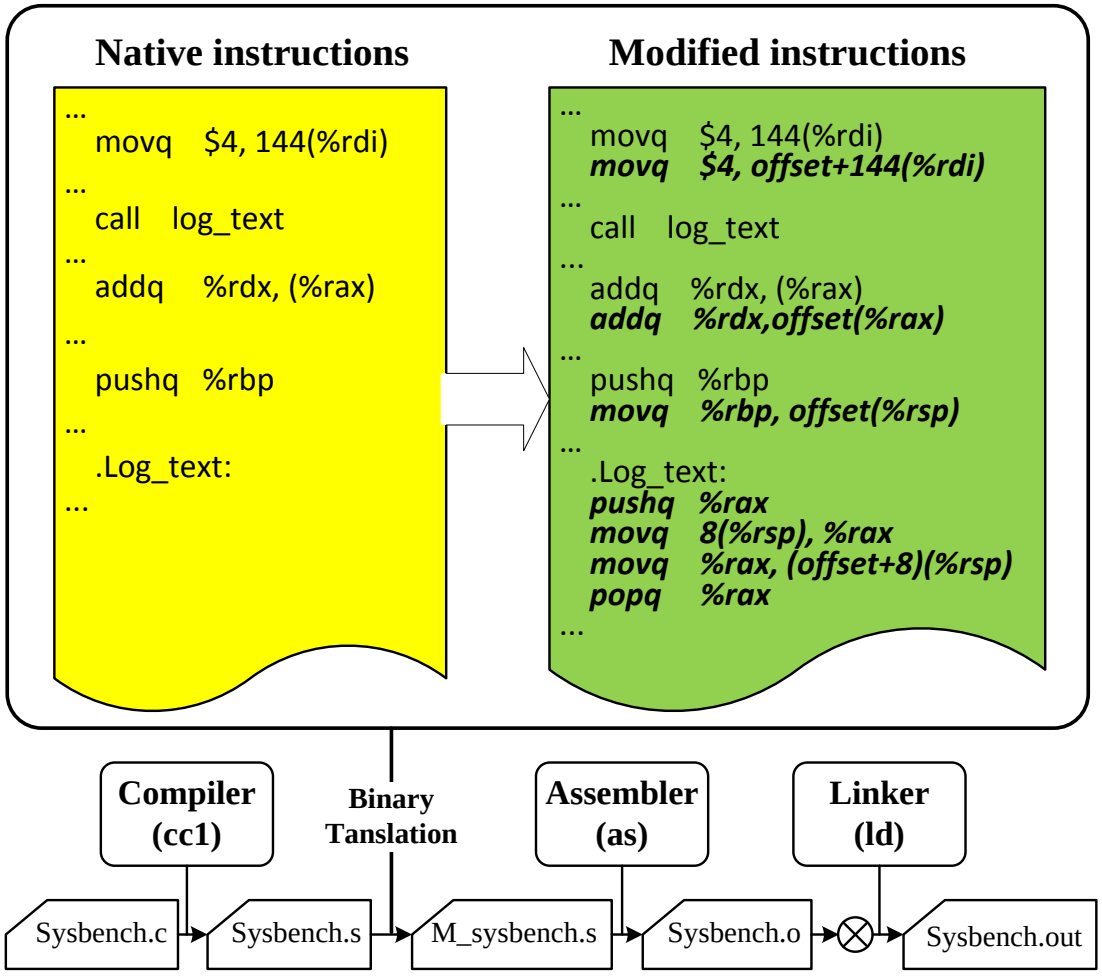

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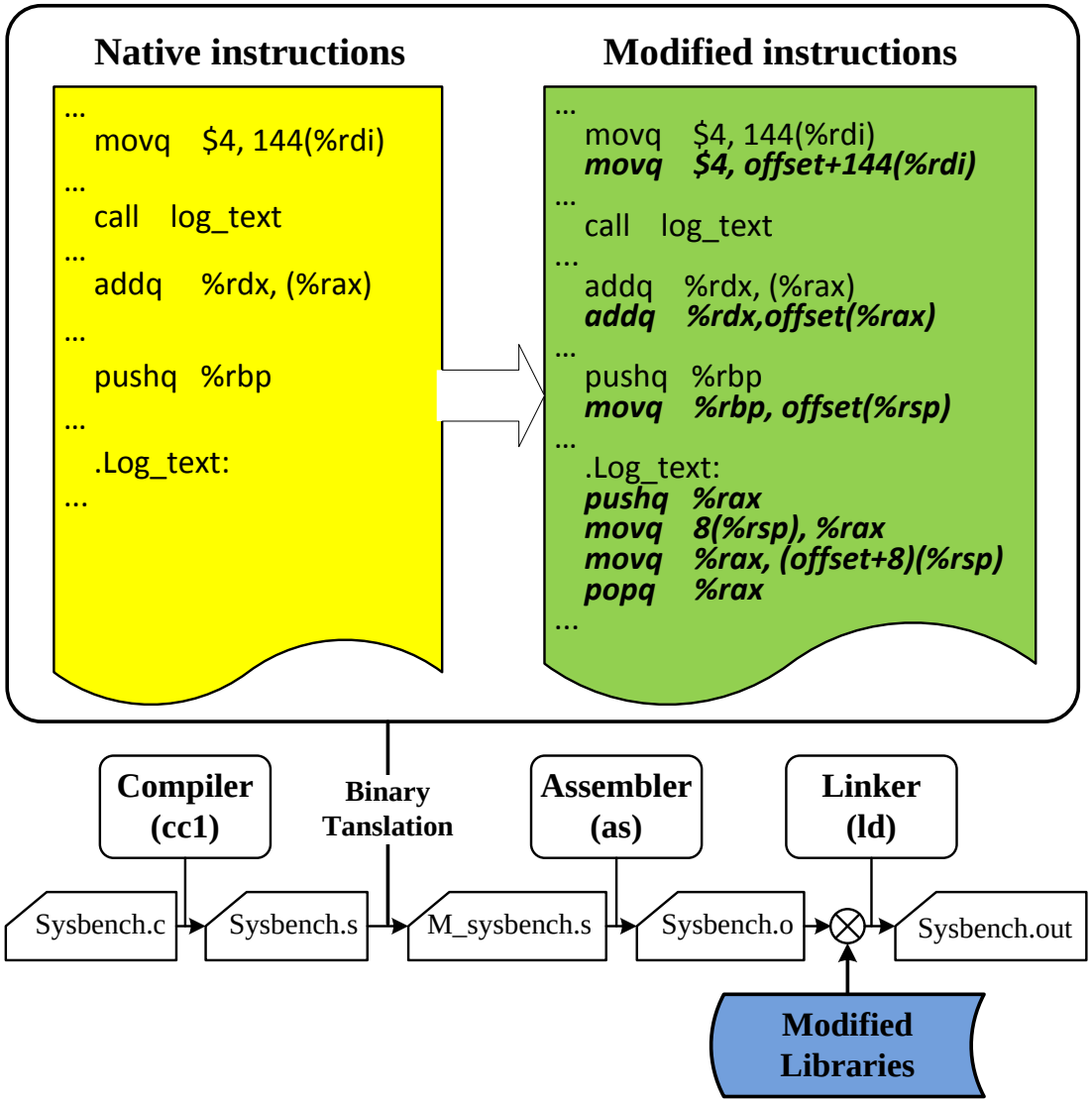

Explicit and Implicit Instructions

```
……
call    grep
pushl   %eax
movl    %eax, offset(%esp)
movl    4(%eax), %eax
movl    %eax, offset+4(%esp)
popl    %eax
……
```

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Would not be executed untill call returns causing data inconsistence

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grep:
pushl   %eax
movl    %eax, offset(%esp)
movl    4(%eax), %eax
movl    %eax, offset+4(%esp)
popl    %eax
…...
```

Would not be executed untill call returns causing data inconsistence

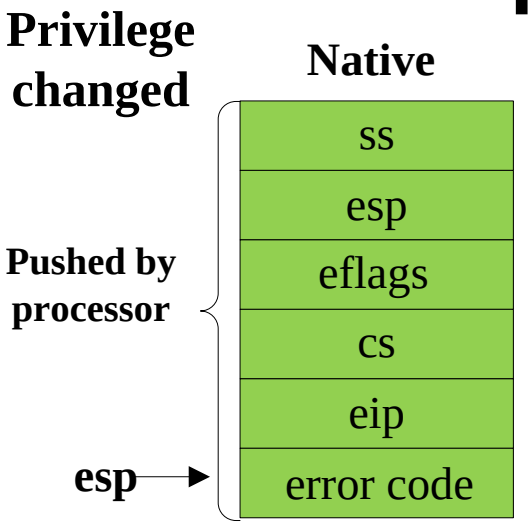
Explicit and Implicit Instructions

```
……
call    grep
pushl   %eax
movl    %eax, offset(%esp)
movl    4(%eax), %eax
movl    %eax, offset+4(%esp)
popl    %eax
……
grep:
pushl   %eax
movl    %eax, offset(%esp)
movl    4(%eax), %eax
movl    %eax, offset+4(%esp)
popl    %eax
…...
```

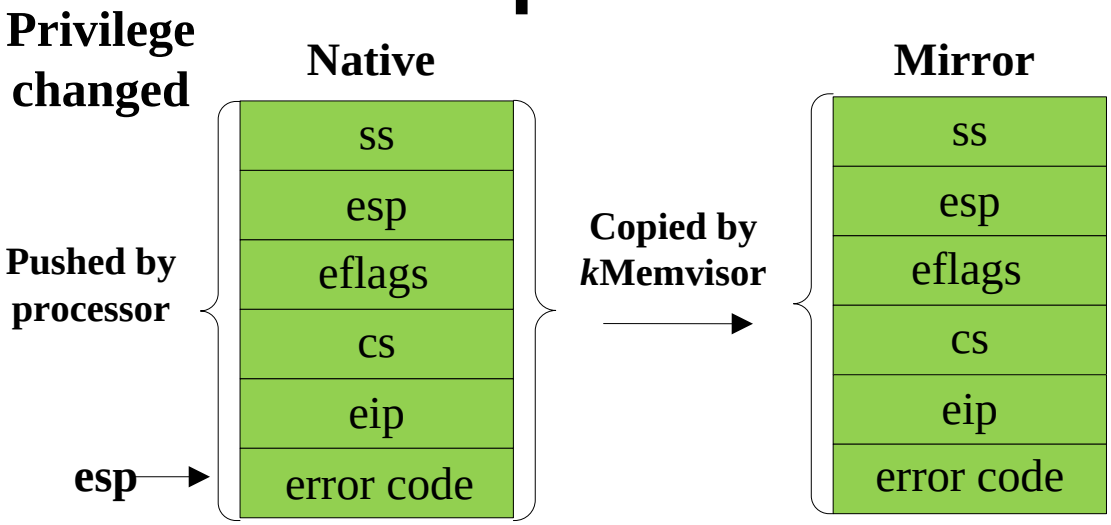
Would not be executed untill call returns causing data inconsistence

Instrumenting mirror instructions at the start of the called procedure

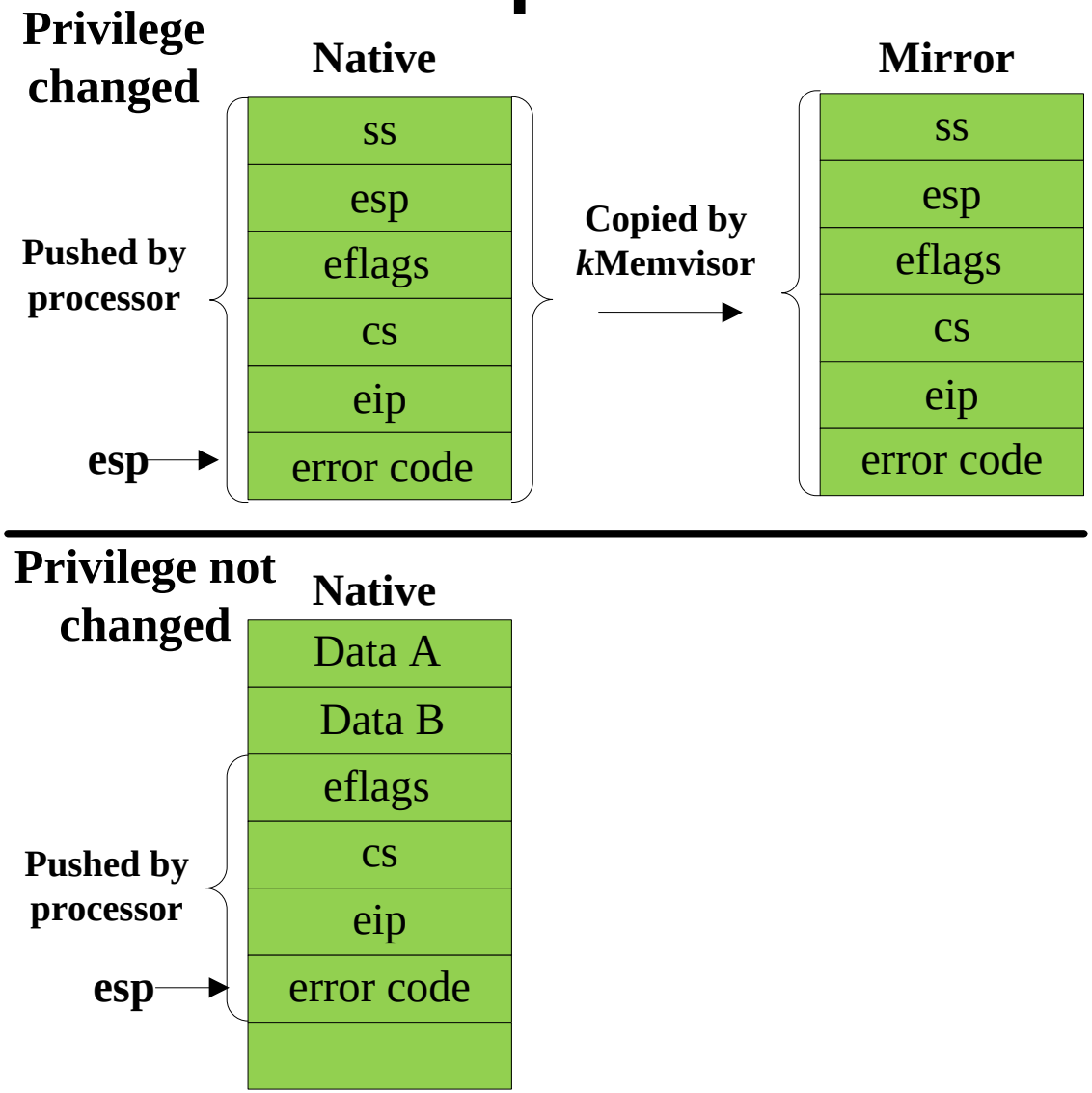
The Stack After An *int* Instruction Completes



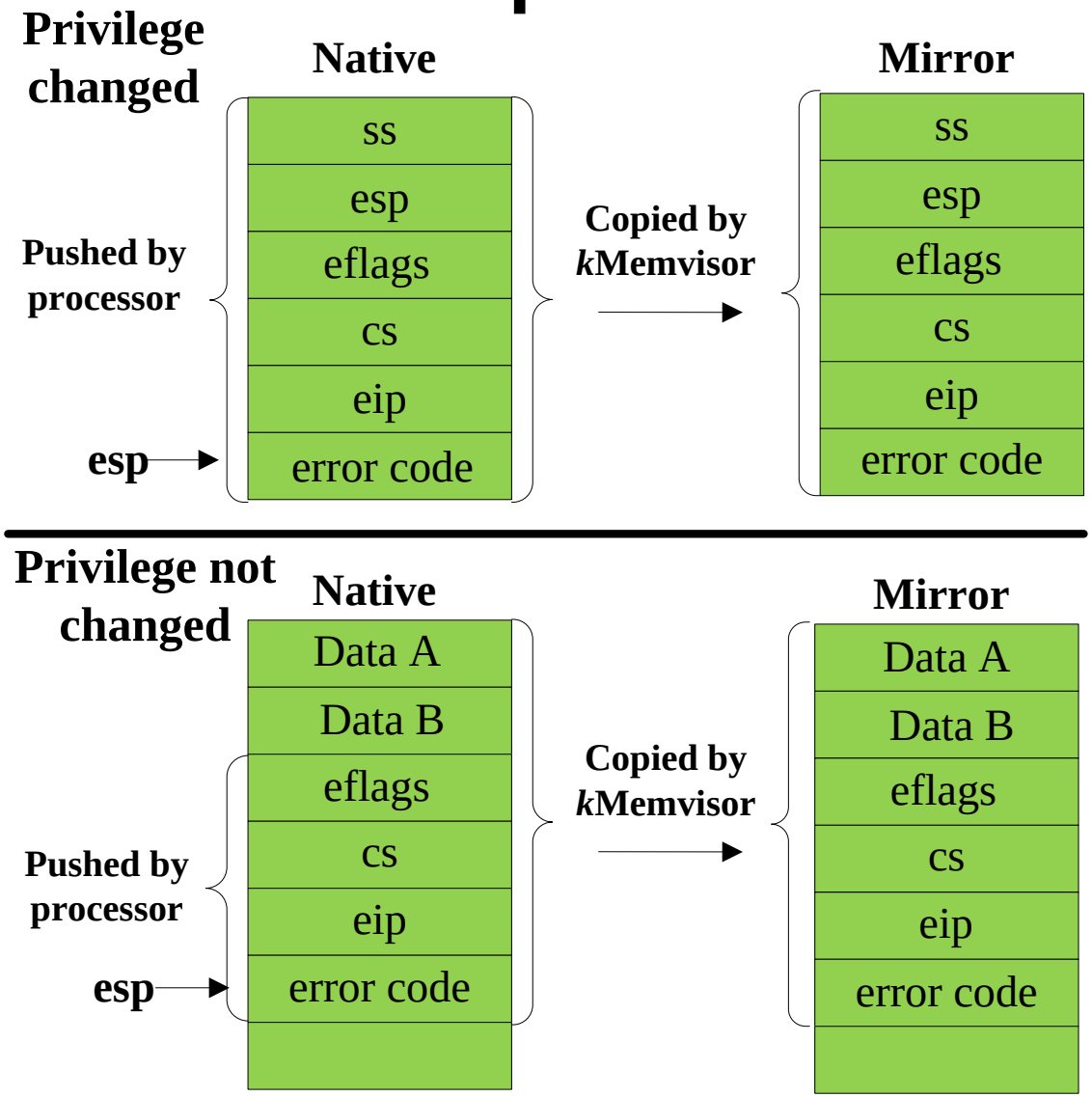
The Stack After An *int* Instruction Completes



The Stack After An *int* Instruction Completes



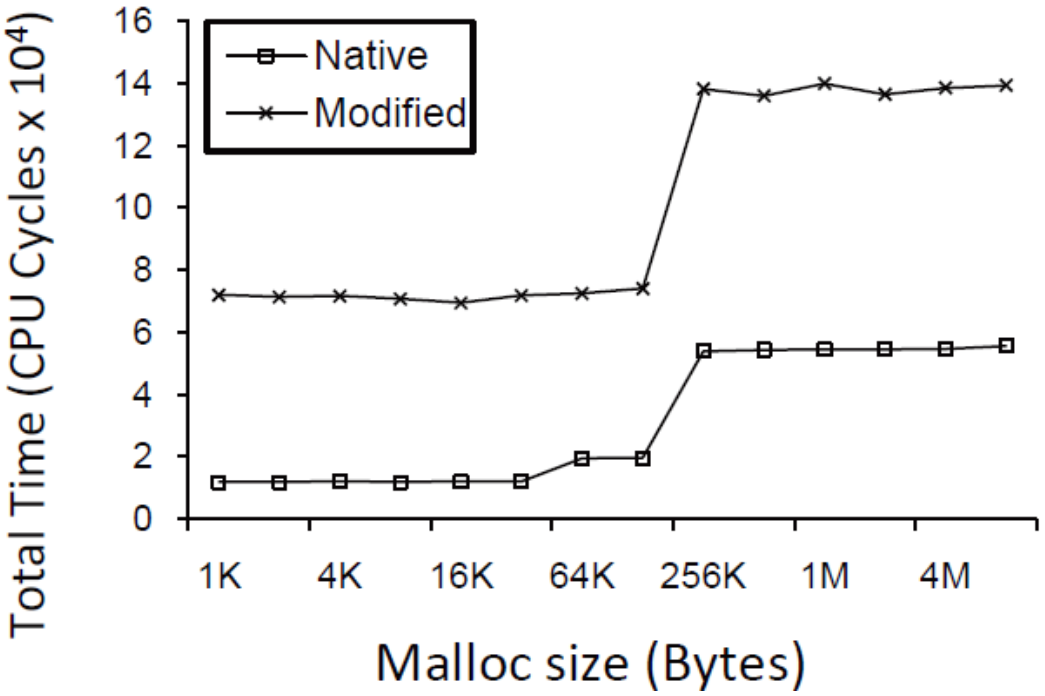
The Stack After An *int* Instruction Completes



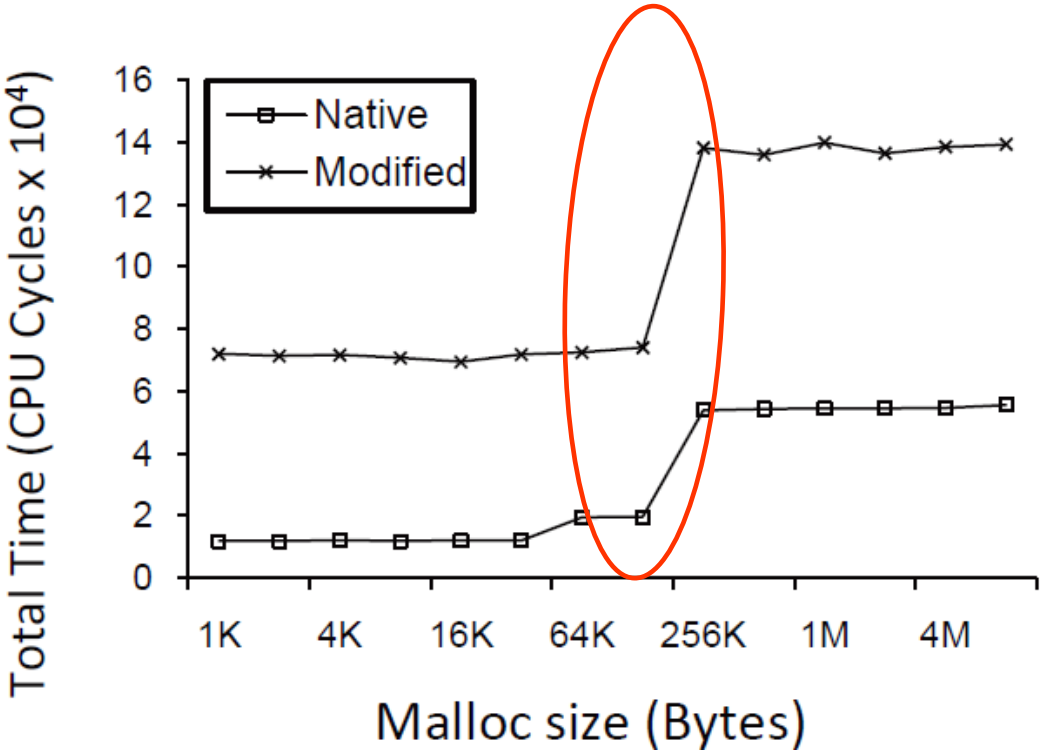
Test Environment

- Hardware
  - *Dell* PowerEdge T610 server：6-core 2.67GHz Intel Xeon CPU with 12MB L3 cache
  - *SamSung* 8 GB *DDR*3 RAMs with ECC and a 148 GB *SATA* Disk
- Software
  - Hypervisor: Xen-3.4.2
  - Kernel: 2.6.30
  - Guest OS: Busybox-1.19.2

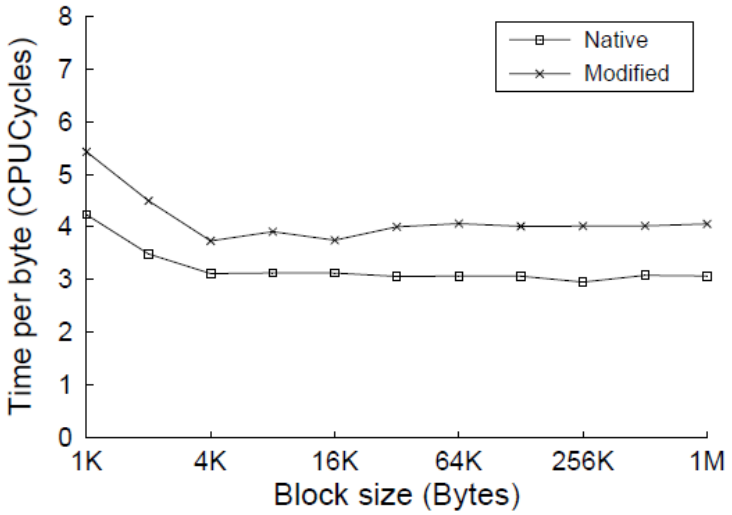
Malloc Micro-test with Different Block Size



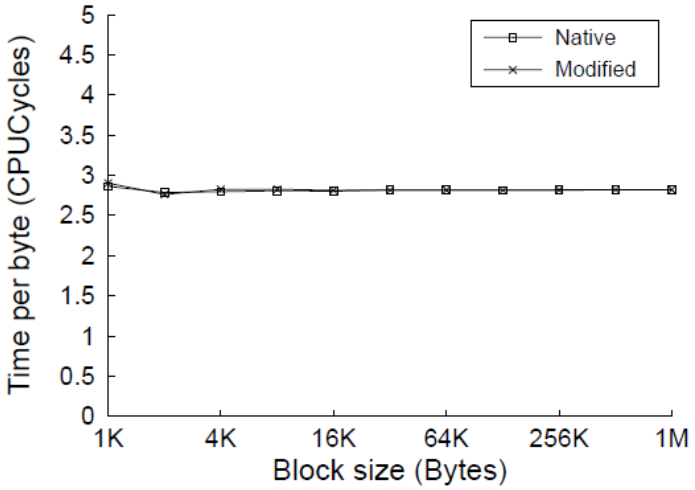
Malloc Micro-test with Different Block Size



Sequential Read & Write

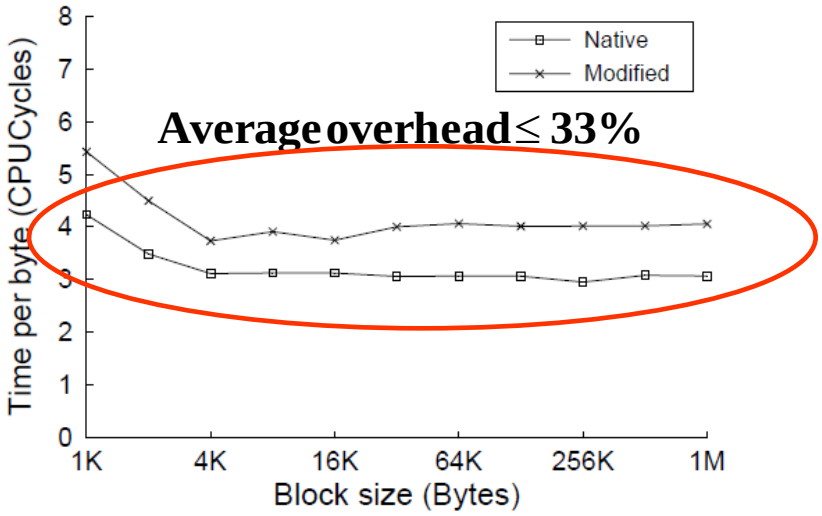


Overhead for sequential memory write

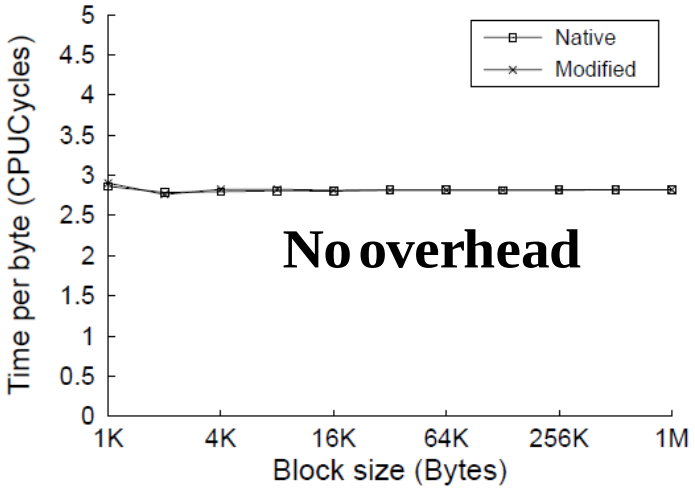


Overhead for sequential memory read

Sequential Read & Write

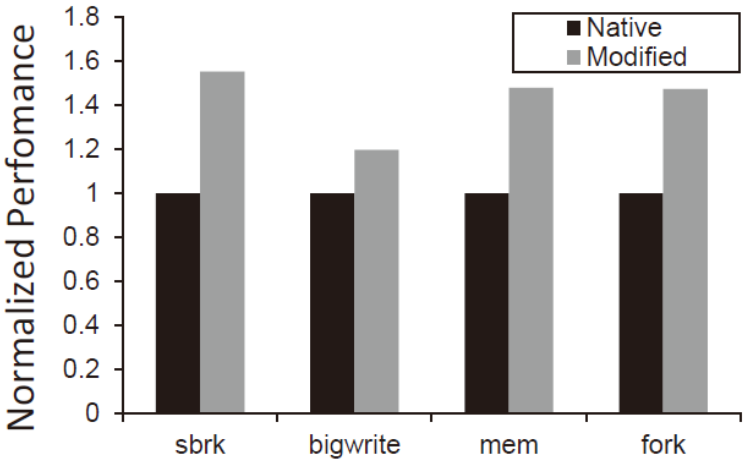


Overhead for sequential memory write

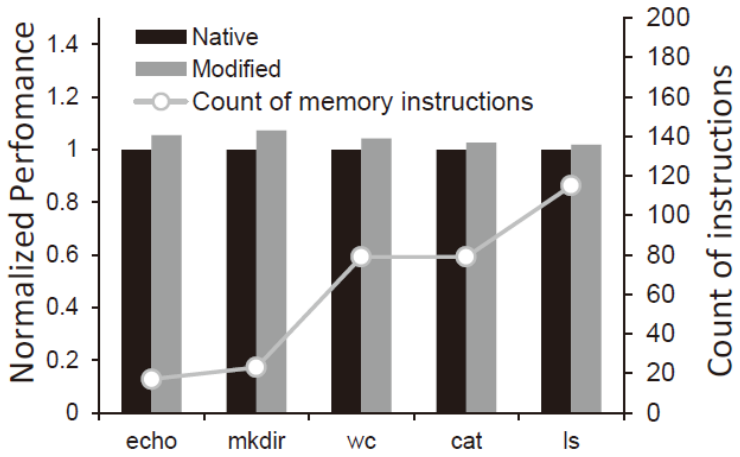


Overhead for sequential memory read

XV6 Benchmark

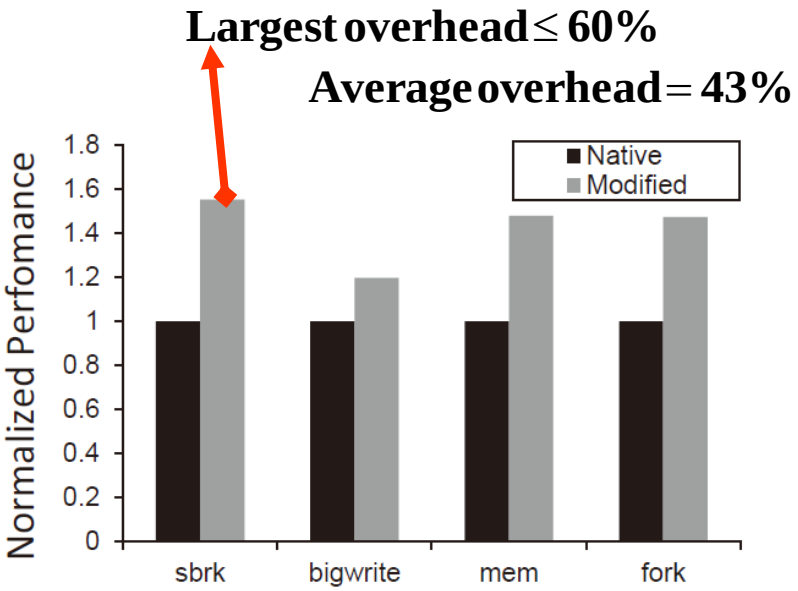


Usertests performance comparison

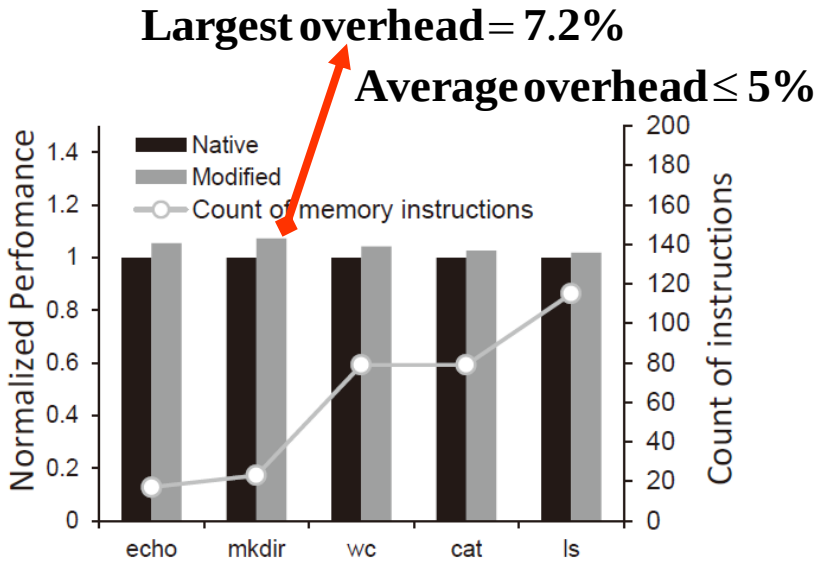


Command performance comparison

XV6 Benchmark

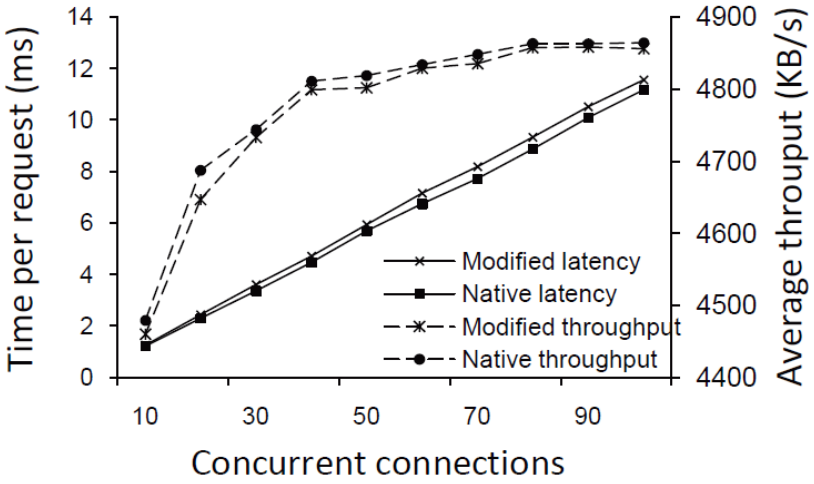


Usertests performance comparison

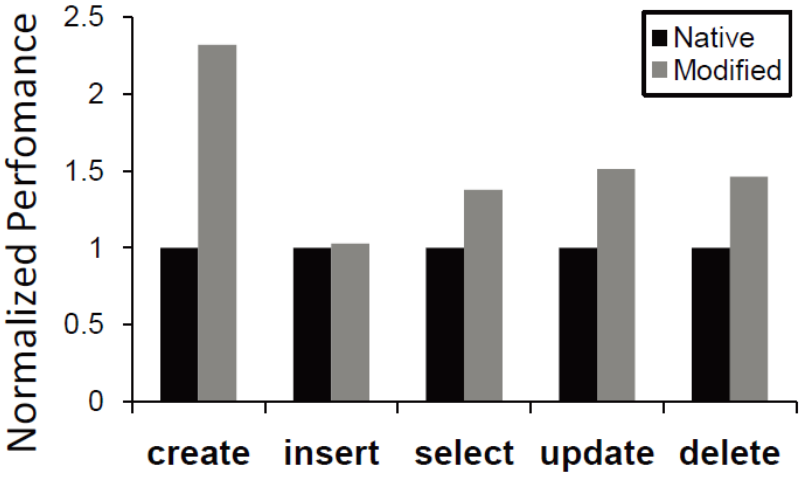


Command performance comparison

Web Server & Database

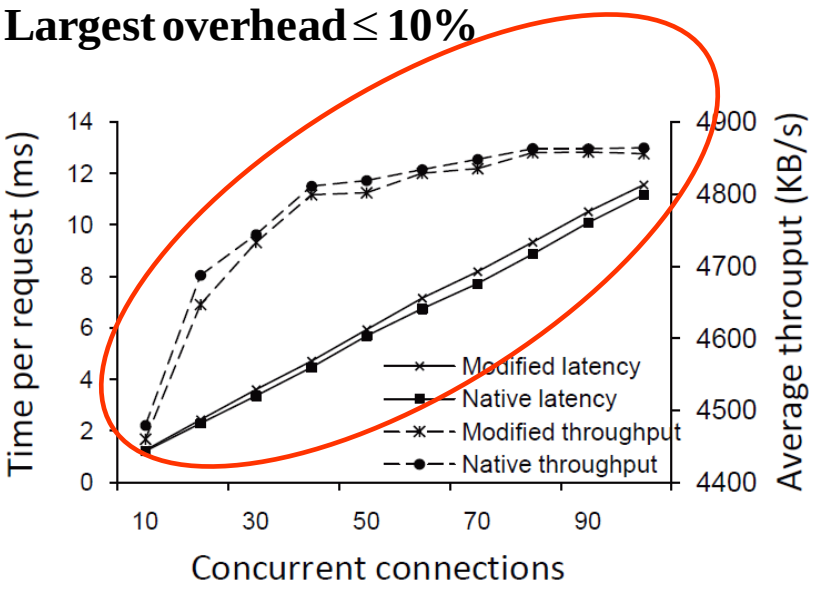


Performance of thttpd

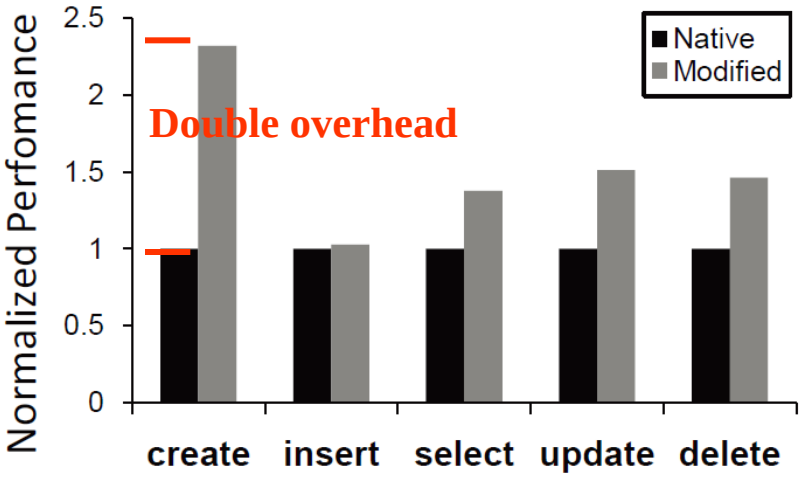


The performance impact for *create, insert, select, update*, and delete in SQLite

Web Server & Database

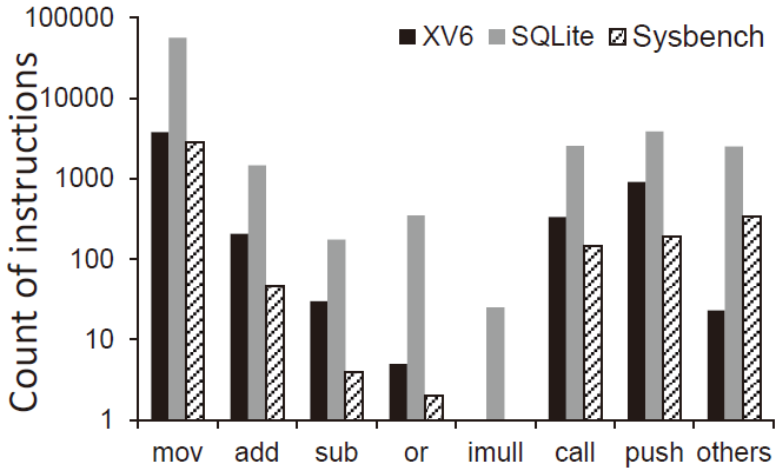


Performance of thttpd

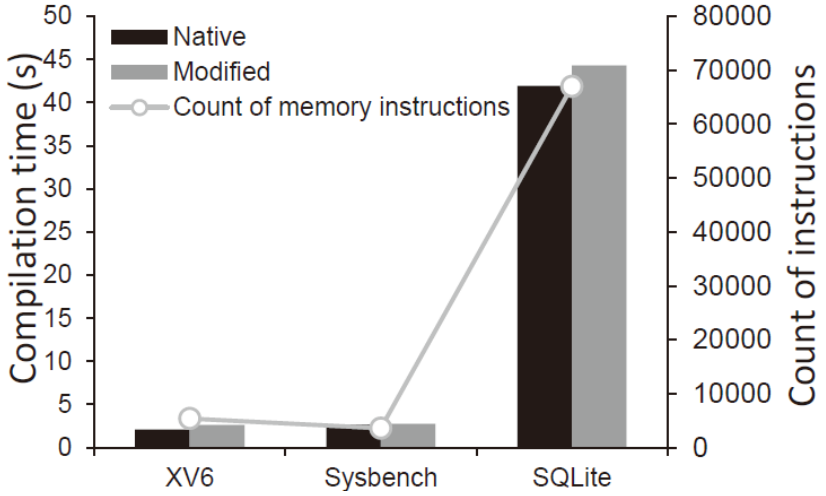


The performance impact for *create, insert, select, update*, and delete in SQLite

Compilation Time

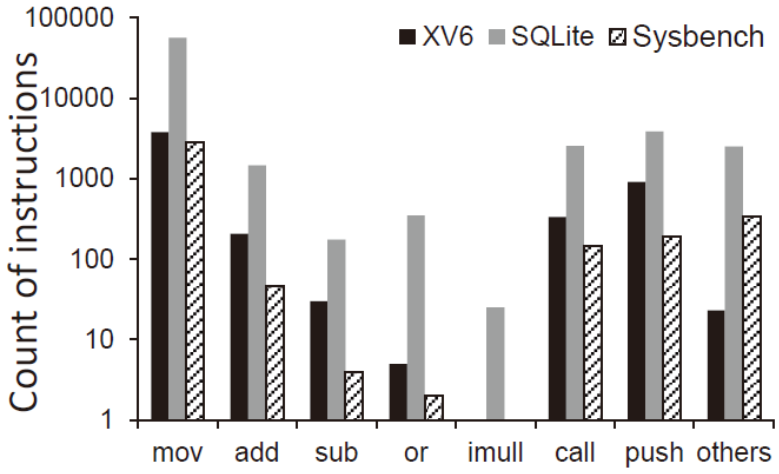


Mirror instructions detail information



Compilation time overhead brought by *k*Memvisor

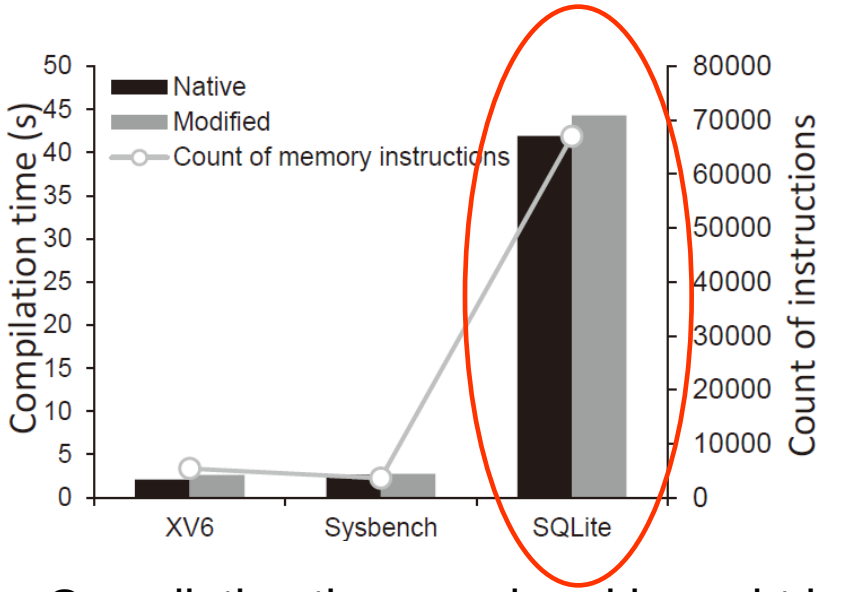
Compilation Time



Mirror instructions detail information

Average overhead = 6%

SQLite overhead = 5.64%



Compilation time overhead brought by *k*Memvisor

Discussion

- Special memory area
  - Page table area& hypervisor
- Other device memory operation
  - IO operation
- Address conflict
  - mva = nva+offset
- Challenge in binary translation
  - Self-modifying code & value
- Multi-threads and multi-cores
  - Multi-thread: emulate mirrored instruction
  - Multi-cores: explicit mutex lock

Conclusion

- A software mirrored memory solution
  - CPU-intensive tasks is almost **unaffected**
  - Our stressful memory write benchmark shows the backup overhead of **55%**.
  - Average overhead in real world applications **30%**

- Dynamic Binary Translation
- Full kernel mirroring