Asynchronous page faults

Aix did it

Red Hat

Author Gleb Natapov

August 10, 2010

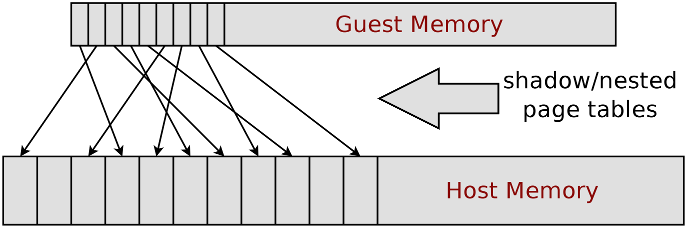
Abstract

Host memory overcommit may cause guest memory to be swapped. When guest vcpu access memory swapped out by a host its execution is suspended until memory is swapped back. Asynchronous page fault is a way to try and use guest vcpu more efficiently by allowing it to execute other tasks while page is brought back into memory.

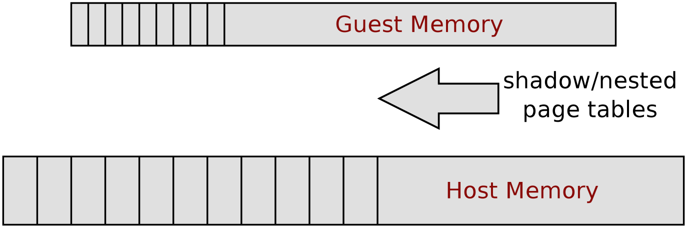
Part I

How KVM Handles Guest Memory and What Inefficiency it Has With Regards to Host Swapping

Mapping guest memory into host memory



But we do it on demand

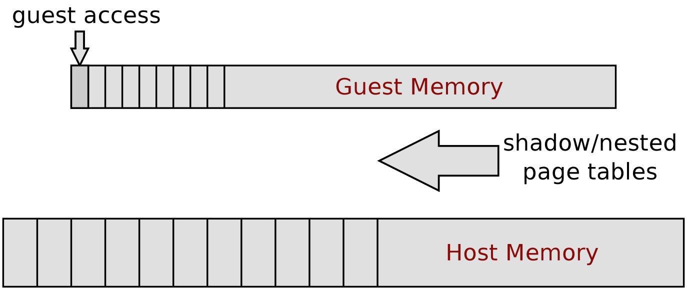


Guest Memory

shadow/nested
page tables

Host Memory

Page fault happens on first guest access



What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
    - no previously mapped page and no swap entry found
    - empty page is allocated
5. page is added into shadow/nested page table

What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
   - no previously mapped page and no swap entry found
   - empty page is allocated
5. page is added into shadow/nested page table

What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()

   no previously mapped page and no swap entry found

   empty page is allocated
5. page is added into shadow/nested page table

What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
    - no previously mapped page and no swap entry found
    - empty page is allocated
5. page is added into shadow/nested page table

What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
    - no previously mapped page and no swap entry found
    - empty page is allocated
5. page is added into shadow/nested page table

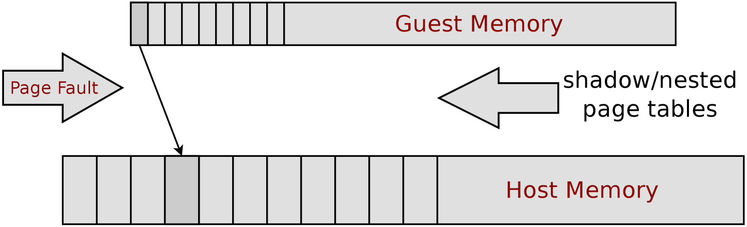
What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
   - no previously mapped page and no swap entry found
   - empty page is allocated
5. page is added into shadow/nested page table

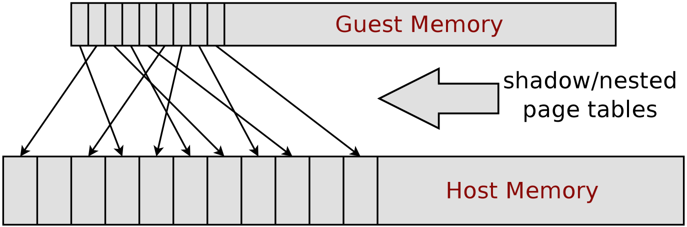
What happens on a page fault?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
   - no previously mapped page and no swap entry found
   - empty page is allocated
5. page is added into shadow/nested page table

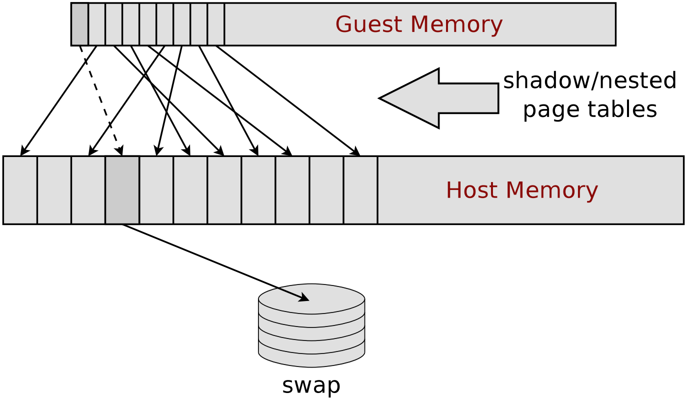
On each page fault one page is mapped



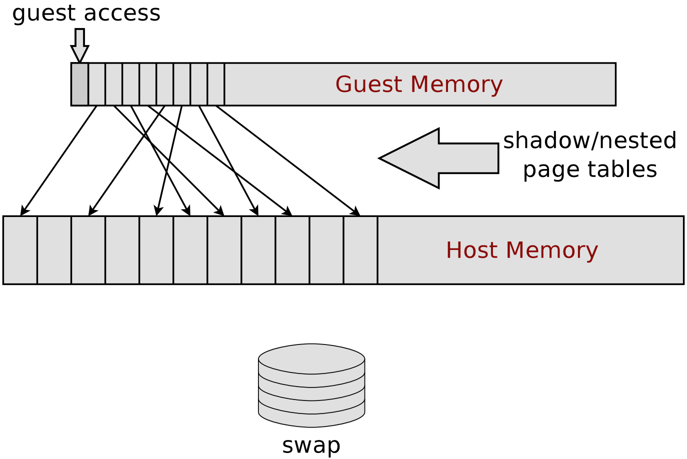
At the end all used pages are mapped



Swapped out page is removed from shadow pt



Page is accessed again



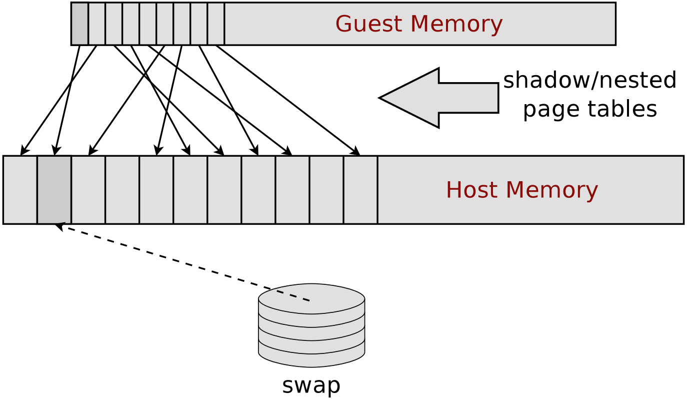
What happens on a page fault now?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
   - swap entry is found
   - page swap-in process is initiated
   - vcpu thread goes to sleep until page is swapped in
5. page is added into shadow/nested page table

What happens on a page fault now?

1. VMEXIT
2. kvm_mmu_page_fault()
3. gfn_to_pfn()
4. get_user_pages_fast()
   - swap entry is found
   - page swap-in process is initiated
   - vcpu thread goes to sleep until page is swapped in
5. page is added into shadow/nested page table

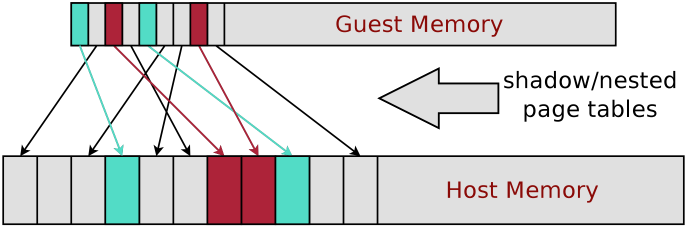
New shadow pt mapping is created



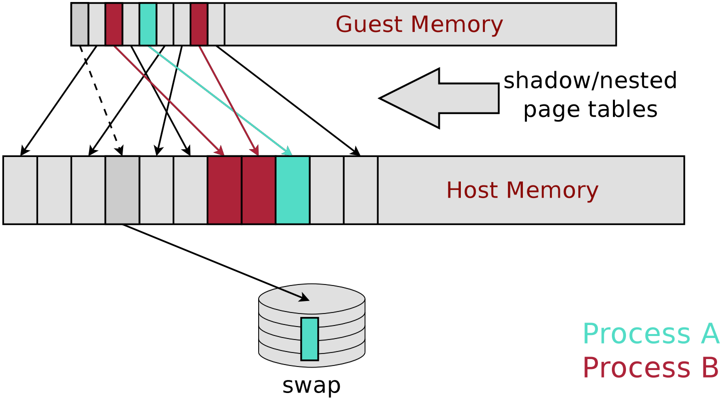
Part II

Lets take close look inside a guest

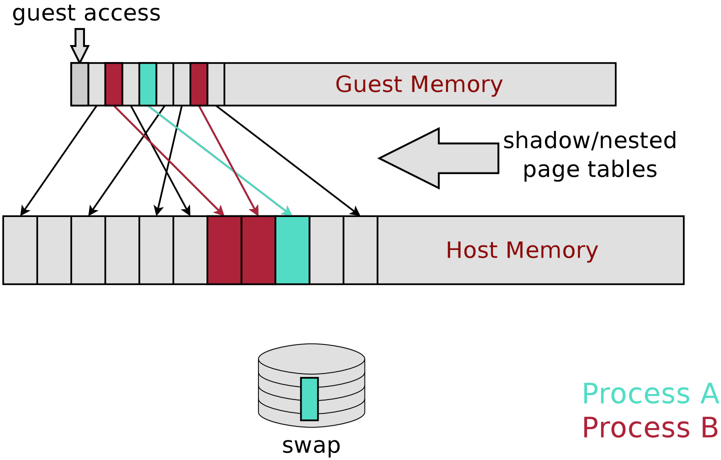
Different pages belong to different processes



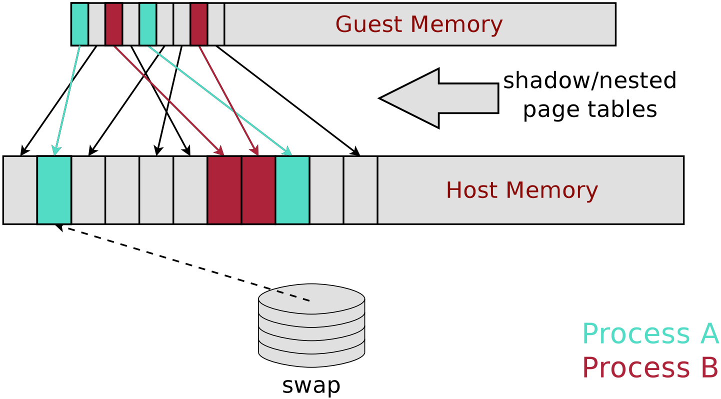
Page belonging to Process A is swapped out



Process A tries to access its page again



New shadow pt mapping is created



Part III

What is Asynchronous Page Fault and How it Can Help us

Asynchronous Page Fault (APF)

New kind of exception

Actually it is not one, but two kind of exceptions:

APF: Page not Present

Guest tried to access page which is swapped out by a hypervisor.

APF: Page Ready

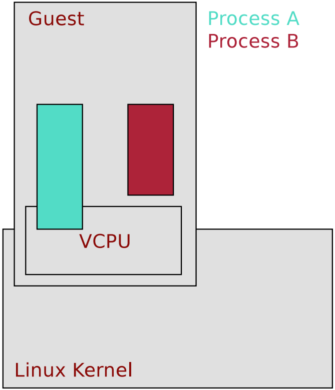
Page is now swapped in and can be accessed from a guest

APF shares exception vector with regular #PF

PV guest can distinguish between regular page fault and APF by checking fault reason in per cpu memory location. It would be nice to have one exception vector to be reserved for virtualization purposes by Intel and AMD.

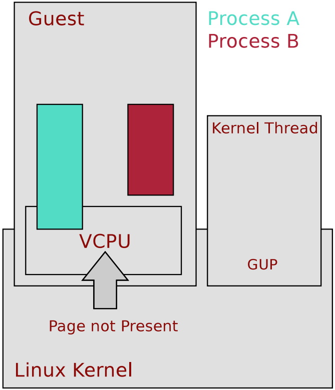
How it Work

- Process A accesses page swapped out by the host.
- GUP is done by dedicated thread. Vcpu gets “Page not Present” exception.
- Guest puts Process A to sleep and schedule another process.
- Page is ready. Vcpu gets “Page Ready” exception.
- Guest can schedule Process A back to run on vcpu.



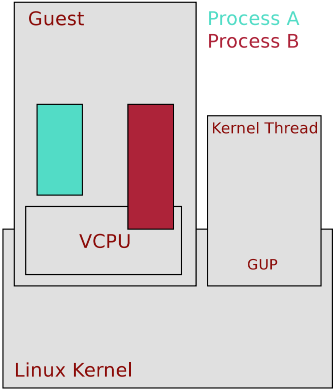
How it Work

- Process A accesses page swapped out by the host.
- GUP is done by dedicated thread. Vcpu gets "Page not Present" exception.
- Guest puts Process A to sleep and schedule another process.
- Page is ready. Vcpu gets "Page Ready" exception.
- Guest can schedule Process A back to run on vcpu.



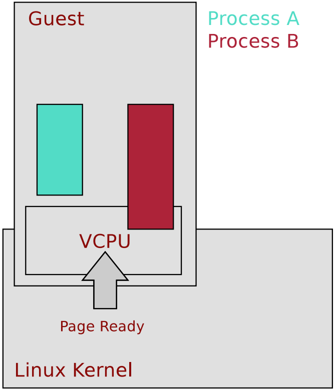
How it Work

- Process A accesses page swapped out by the host.
- GUP is done by dedicated thread. Vcpu gets "Page not Present" exception.
- Guest puts Process A to sleep and schedule another process.
- Page is ready. Vcpu gets "Page Ready" exception.
- Guest can schedule Process A back to run on vcpu.



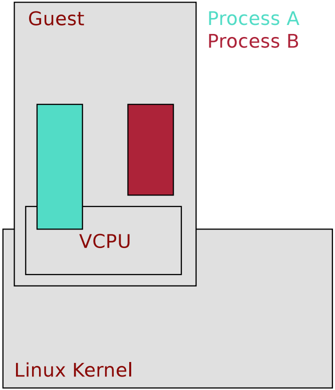
How it Work

- Process A accesses page swapped out by the host.
- GUP is done by dedicated thread. Vcpu gets “Page not Present” exception.
- Guest puts Process A to sleep and schedule another process.
- Page is ready. Vcpu gets “Page Ready” exception.
- Guest can schedule Process A back to run on vcpu.



How it Work

- Process A accesses page swapped out by the host.
- GUP is done by dedicated thread. Vcpu gets "Page not Present" exception.
- Guest puts Process A to sleep and schedule another process.
- Page is ready. Vcpu gets "Page Ready" exception.
- Guest can schedule Process A back to run on vcpu.



Enhancing GUP

- Need GUP version that will succeed only if page can be acquired without IO.
- `__get_user_pages_fast()` is not good enough. Will fail if page is in page or swap cache.
- Introduce new GUP variant: `get_user_pages_noio()`.

Part IV
Test Results

Benchmark

Application:

- 4 threads doing random memory access (faulting threads)
- 4 threads incrementing per thread counter (working threads)
- running for 1 minute
- output per thread counter value and sum of all counters

Execution environment:

- 4 VCPUS
- 2G guest memory
- runs inside 512M memory group *

* $\frac{1}{4}$ overcommit

Results

With async pf:	
worker 0:	63972141051
worker 1:	65149033299
worker 2:	66301967246
worker 3:	63423000989
total:	258846142585

Without async pf:	
worker 0:	30619912622
worker 1:	33951339266
worker 2:	31577780093
worker 3:	33603607972
total:	129752639953

50% improvement!

Perf data from inside the guests

With async pf:

```
97.93%  bm  bm        [.]  work_thread
1.74%   bm  [kernel]  [k] retint_careful
0.10%   bm  [kernel]  [k] _raw_spin_unlock_irq
0.08%   bm  bm        [.]  fault_thread
0.05%   bm  [kernel]  [k] _raw_spin_unlock_irqrestore
0.02%   bm  [kernel]  [k] __do_softirq
0.02%   bm  [kernel]  [k] rcu_process_gp_end
```

Without async pf:

```
63.42%  bm  bm        [.]  work_thread
13.64%  bm  [kernel]  [k] __do_softirq
8.95%   bm  bm        [.]  fault_thread
5.27%   bm  [kernel]  [k] _raw_spin_unlock_irq
2.79%   bm  [kernel]  [k] hrtimer_run_pending
2.35%   bm  [kernel]  [k] run_timer_softirq
1.28%   bm  [kernel]  [k] _raw_spin_lock_irq
```

redhat.

The end.

Thanks for listening.