15-410

"...1337C0DE..."

Project 4 - "PebPeb"
Apr. 15, 2024

[Squashed edition]

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Synchronization

Deadline reminders

- P3extra deadline != P4 deadline
  - This is for real, not a bureaucratic oversight
- Don't forget about the book report...
  - Hand-in directories have been created

Acknowledgments

Leadership

- Joshua Wise, Wes Filardo, Ben Blum, Reid Long

Reference host, reference guests

- Elly Jones, Michael Sullivan, Reid Long

Payloads

- Josiah Boning, Matt Schnall, Ryan Pearl, Reid Long, Axel Feldman, Jack Duvall

Inspirational artwork

- Chris Lu

Inspirational quote

- "The most fun I've had doing systems programming since I took 410." – Jacob Potter (perpetrator, "SML on Stilts")

Outline

P4

- Write a hypervisor!

Impossible!?!?

- “Some restrictions apply”

“A picture is worth 1000 words”

- I'll still need to talk fast

Component inventory

Suggestions

Scope

How can 2 students re-invent VMware in 10 days??

- Page-table tracing
- Page-table *shadowing*
  - Shadow page-table *caching*
- Binary translation of POPF
- Decoding/simulation of key instructions
  - MOVL %EAX, %CR3
  - MOVL %EBX, %CR3
  - ...etc.
- Virtual interrupts and exceptions
- Decoding I/O port operations into device-I/O requests

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- Hey, remind me what are the *kinds* of virtualization?

Paravirtualization is smaller!

~~Virtualization~~ **Paravirtualization**

- **Page-table conversion**
- ~~Page-table *shadowing*~~
  - ~~Shadow page-table *caching*~~
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  - ~~MOVL %EAX, %CR3~~
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  - ~~...etc.~~
- **Virtual interrupts and exceptions**
- ~~Decoding I/O port operations into device-I/O requests~~

  I/O hypercalls

Paravirtualization

Paravirtualization

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- Virtual interrupts and exceptions
- I/O hypercalls
  - Ok, “miscellaneous” hypercalls too

Paravirtualization

The game

- **Host kernel will execute guest kernel in user mode**

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    - » After all, user programs always run in user mode

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  - Guest user programs will be unaware of the deception
    - » After all, user programs always run in user mode
- Guest kernel won't manipulate hardware directly
  - It will politely ask the host kernel (hypervisor) to manipulate hardware for it
- You will write the host kernel (hypervisor)
  - You will continue to support Pebbles system calls
    - » Shell can fork() and exec() guest kernels
  - You will also support *"PebPeb" hypercalls*
    - » Guest kernels can launch user programs and switch among them
  - You will provide *virtual I/O devices* to guest kernels
    - » Including virtual interrupts

Paravirtualization

Paravirtualization - “PebPeb” Hypercalls

- Page-table tracing
  - hv_setpd(), hv_adjustpg()
- Virtual interrupts and exceptions
  - hv_setidt(), hv_disable_interrupts(), hv_enable_interrupts()
  - hv_iret()
- I/O hypercalls
  - hv_print(), hv_cons_set_cursor_pos(), ...
- Ok, “miscellaneous” hypercalls too
  - hv_magic()
  - hv_exit()

Virtual interrupts

- Timer, keyboard

Picture Time!

Logical ("marketing") pictures

- Lots of colored boxes, everybody's happy

Illogical ("physical") pictures

- Maybe too many boxes

Familiar Things

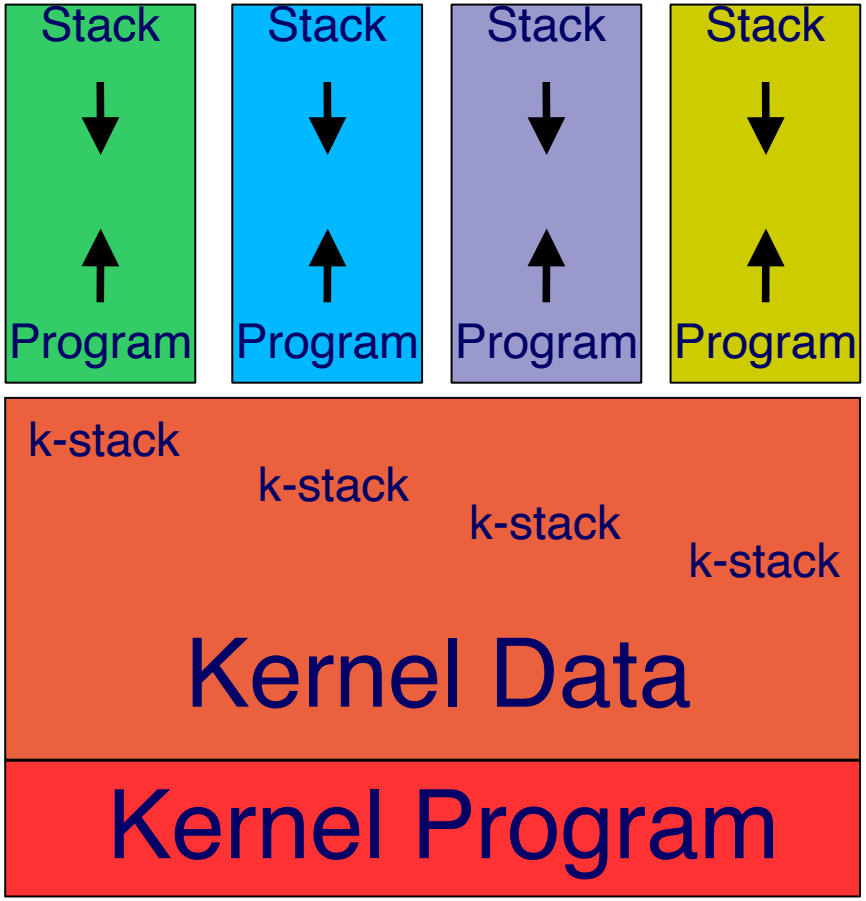
User

Kernel

Virtual

Physical

15-410 Virtual Memory Layout

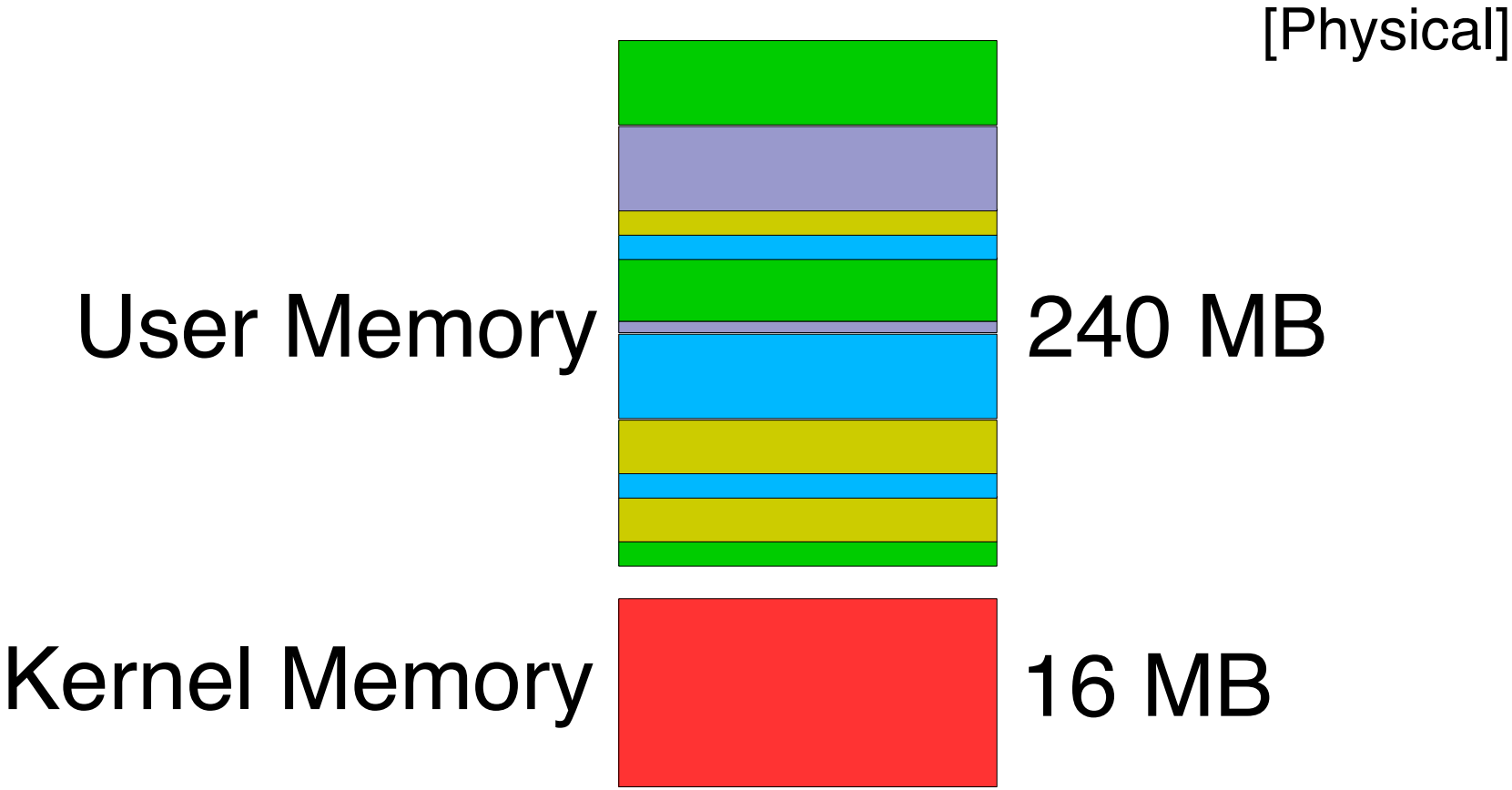


[Logical]

4080 MB

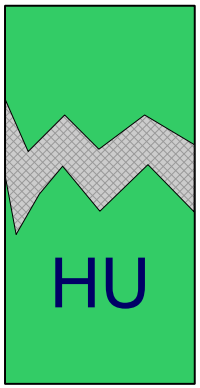
16 MB

15-410 Physical Memory Layout



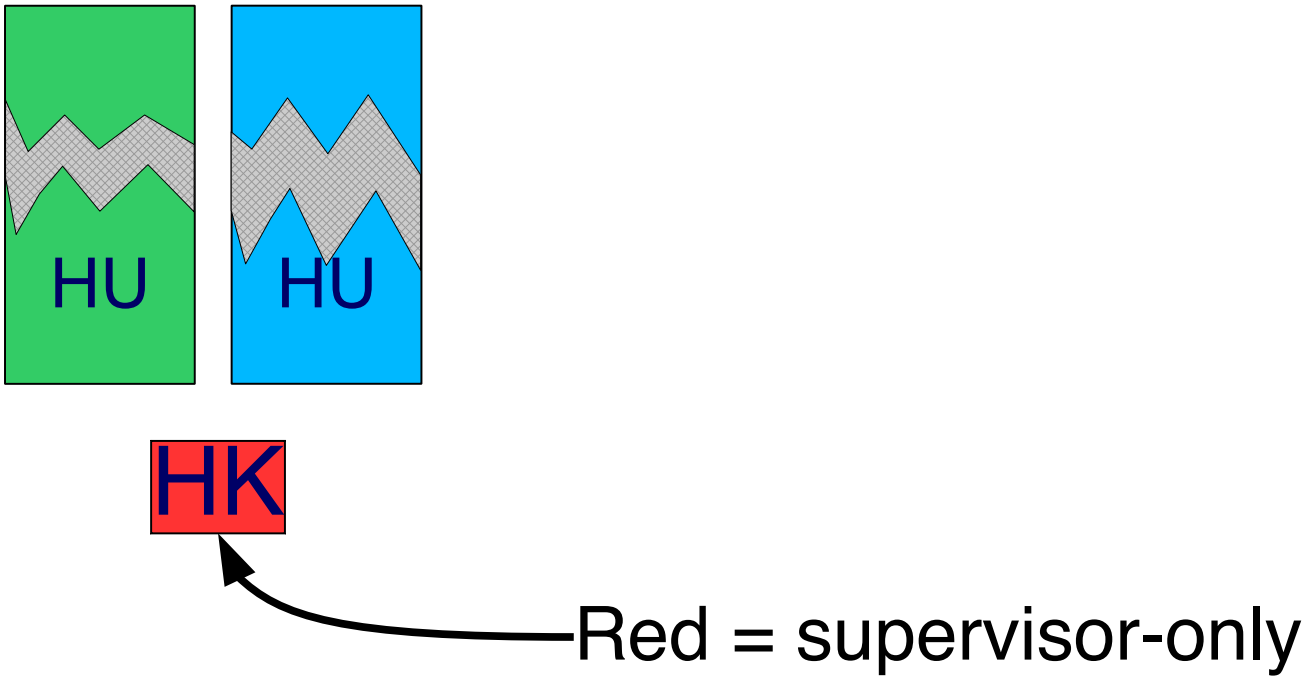
Host User Stands Alone

[Logical]



Host Kernel, Host User Programs

[Logical]



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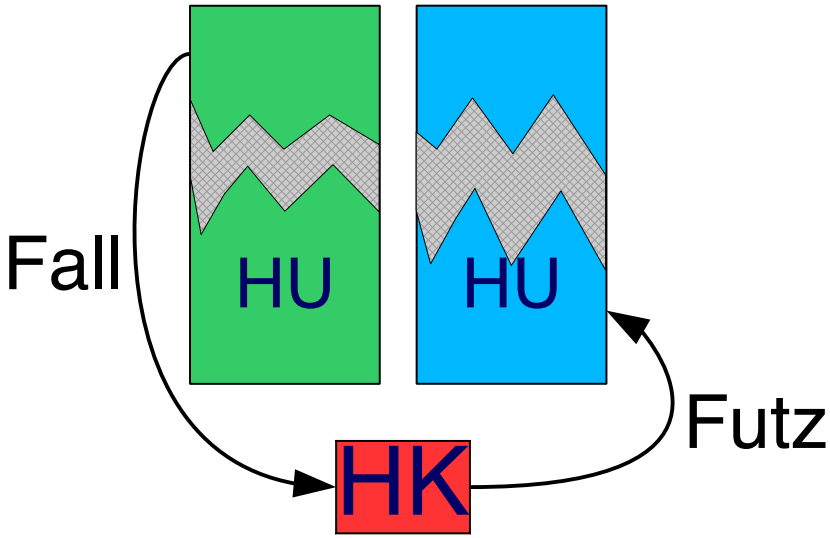


Exciting New Things

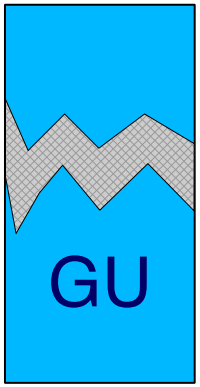
Guest User

Guest Kernel

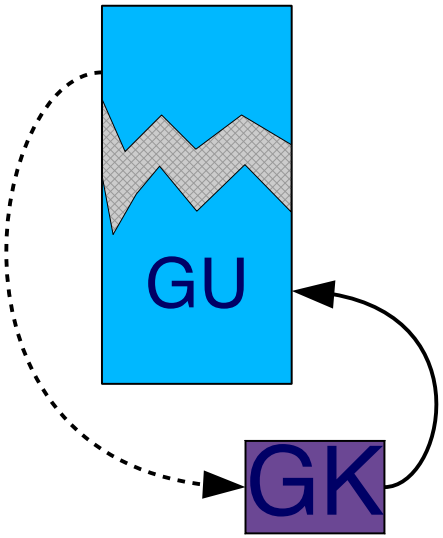
Two kernels

Guest Surprises

Guest User Stands Alone

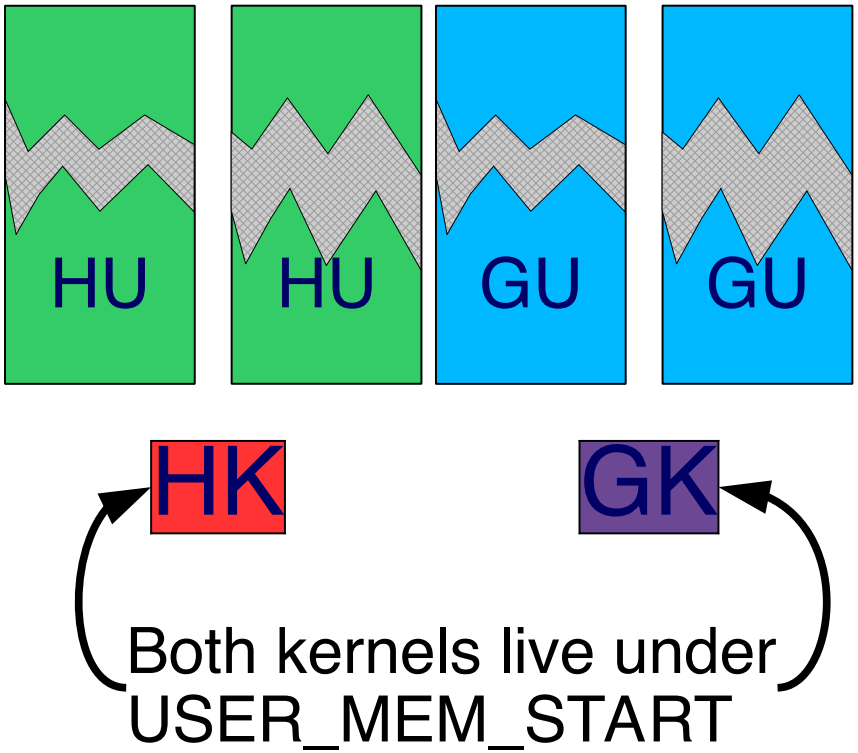


Guest Kernel “Sees” Guest User

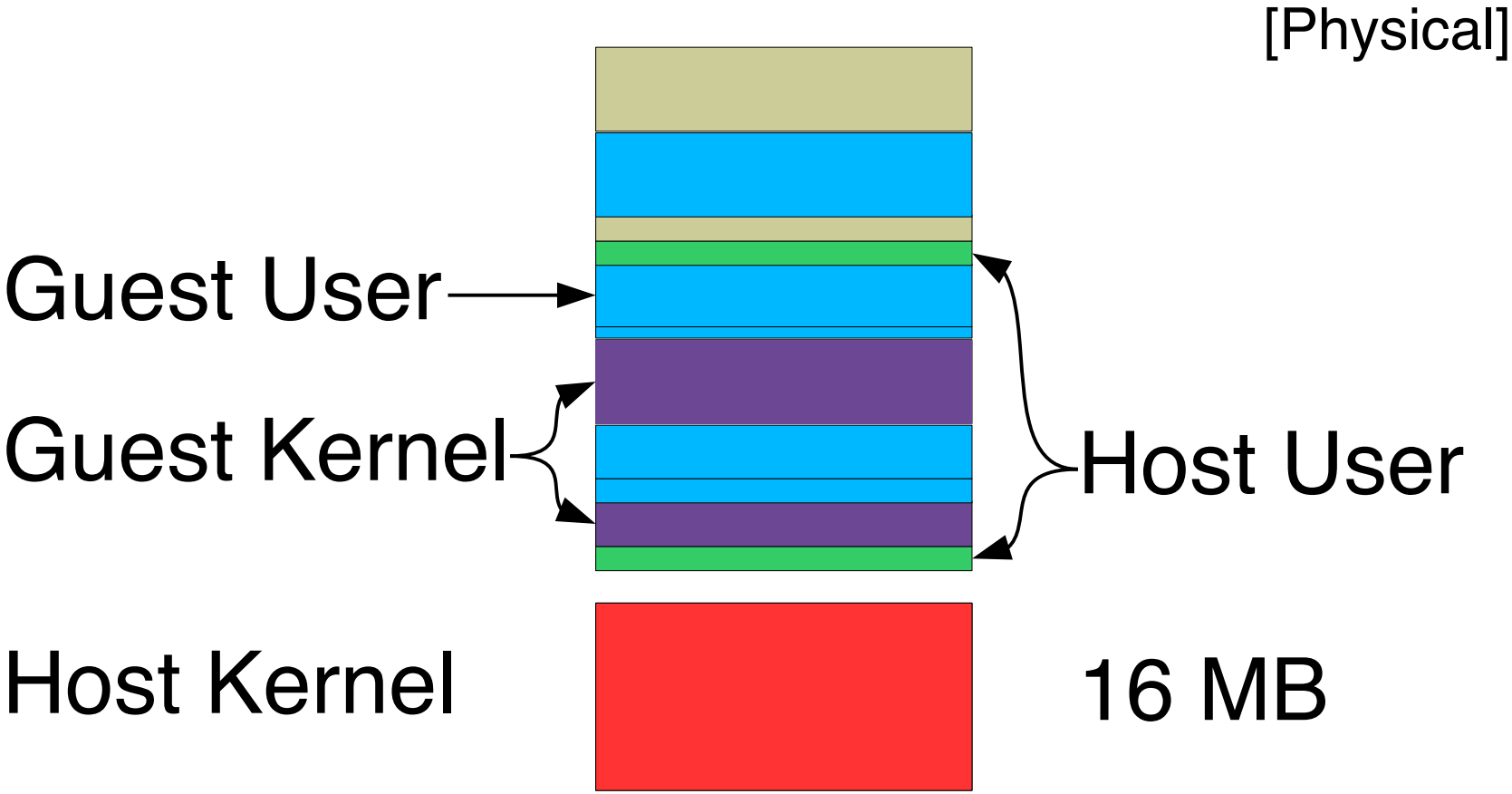


{Host,Guest} × {Kernel,User}

[Logical]



The “Real” (not Virtual) Picture



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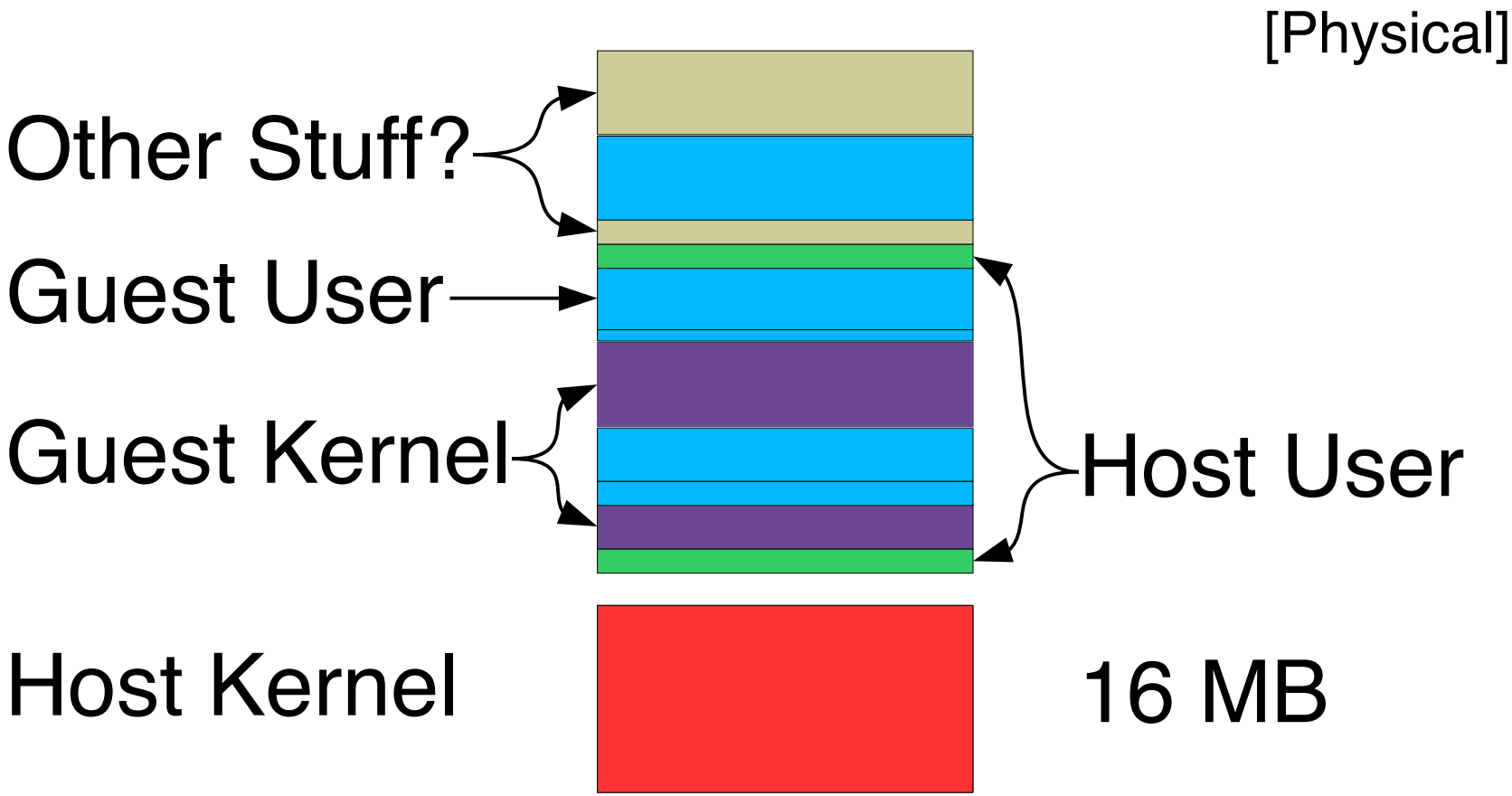

PebPeb Address Spaces

Host kernel

- All of kernel is mapped (0..15M)
- One user program is mapped (16..4095M)

Host user

- One user program is mapped
- Kernel is present but invisible until a surprise

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Host user

- One user program is mapped
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Guest kernel

- All of guest kernel is mapped (0..15M)
- One guest user program is mapped (16..*4079*M)

Guest user

- One guest user program is mapped
- Guest kernel is [somewhere] until a surprise
- Host kernel is present but invisible until a surprise

PebPeb Address Spaces

Host kernel

- [You know how to do this]

Host user

- [You know how to do this]

Guest kernel

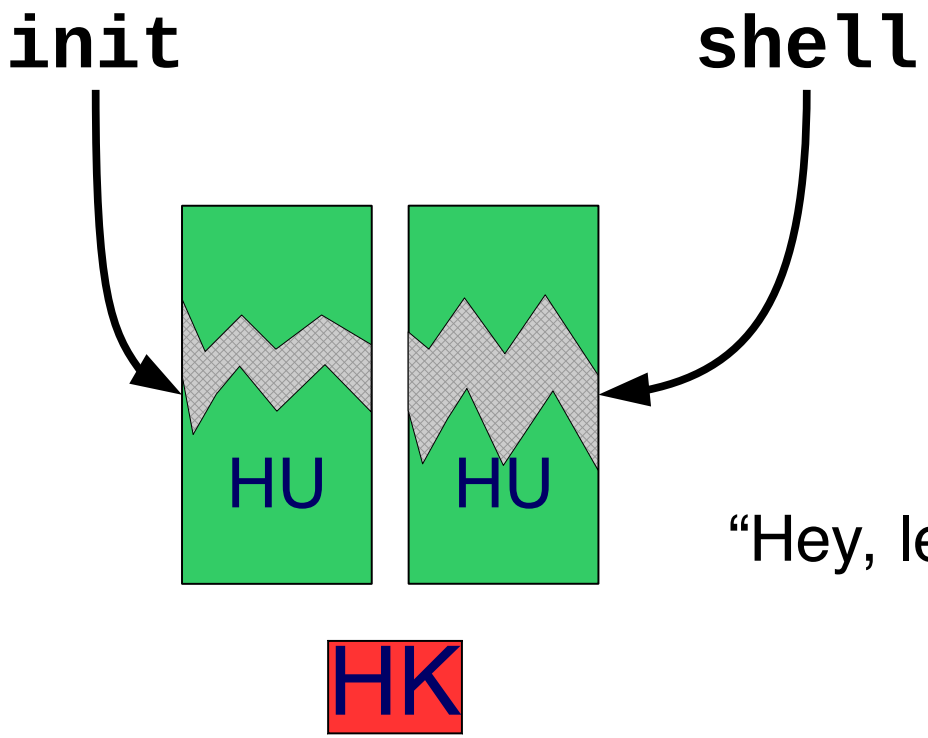
- How can the guest kernel occupy 0..15M?
  - That range is used by the host kernel!

Guest user

- When a guest user program is running, and a surprise happens, hardware will fall into *host* kernel mode
  - How do we get into *guest* kernel mode?

Once Upon a Time...

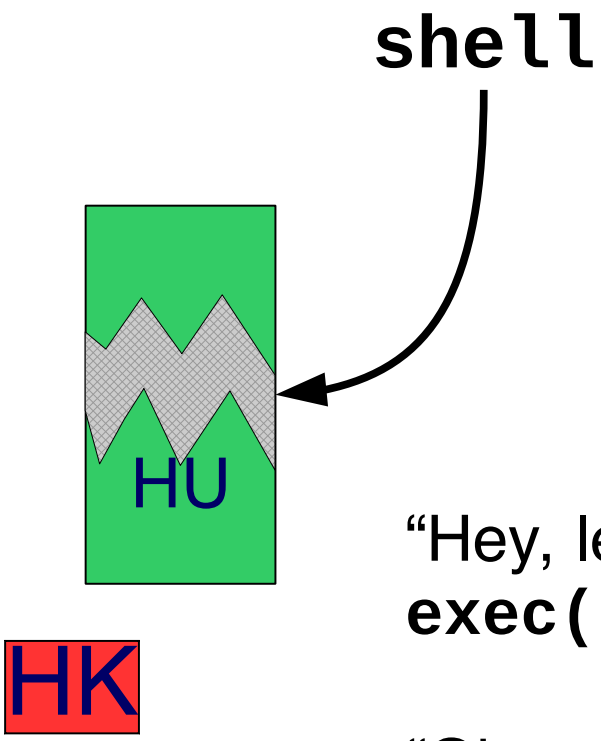
[Logical]



“Hey, let's launch a guest kernel!”

Once Upon a Time...

[Execution]

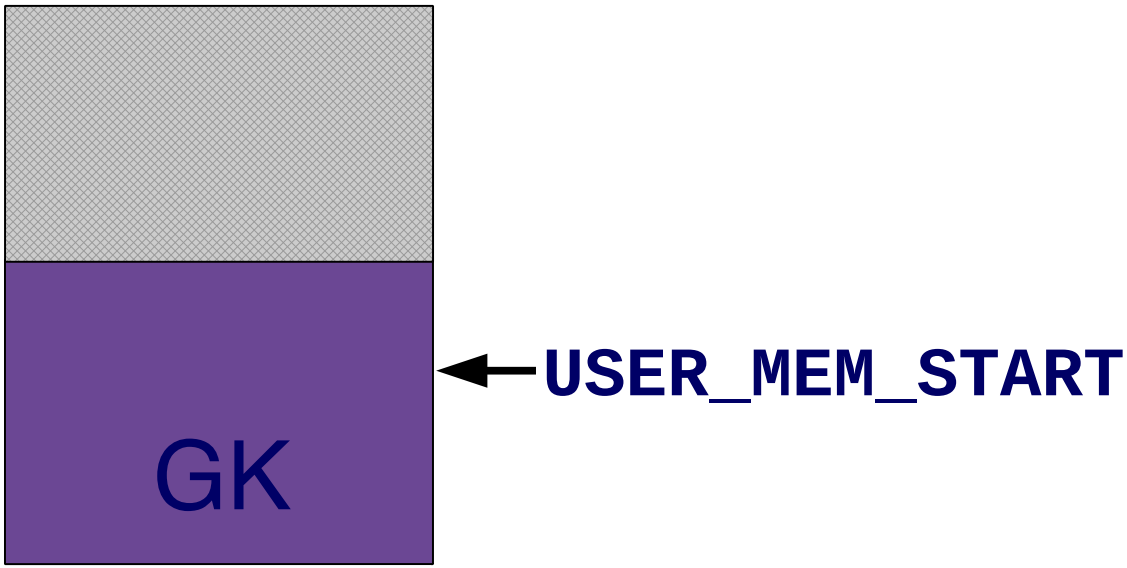


"Hey, let's launch a guest kernel!"
`exec("pathos", argv);`

"Ok, you get 20 'guest MB.'"

Guest Kernel in “Boot VM” Mode

[*LOLgical*]



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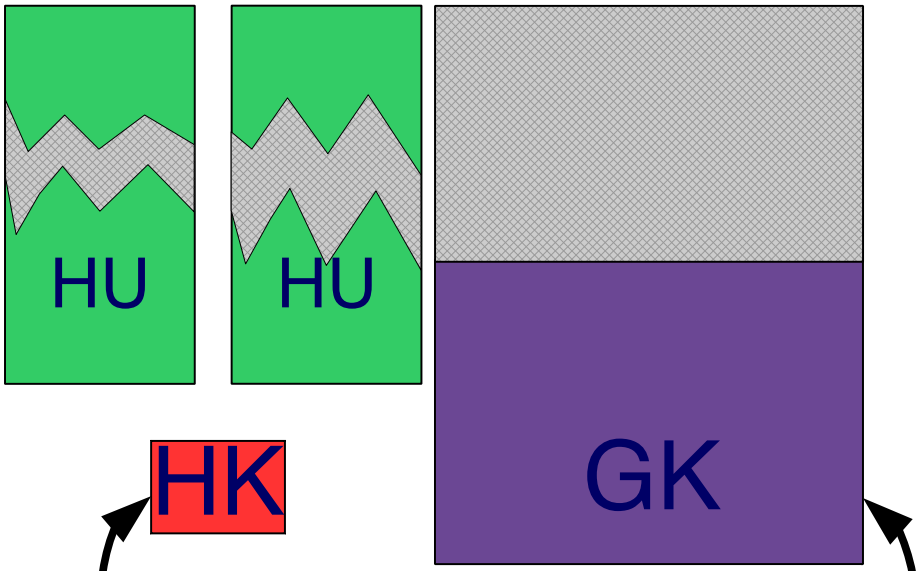

Both kernels live under USER_MEM_START??

Segmentation to the Rescue!

Guest kernel runs in custom segments!

- B: 16M
- L: 4080M
  - (or a bit less)

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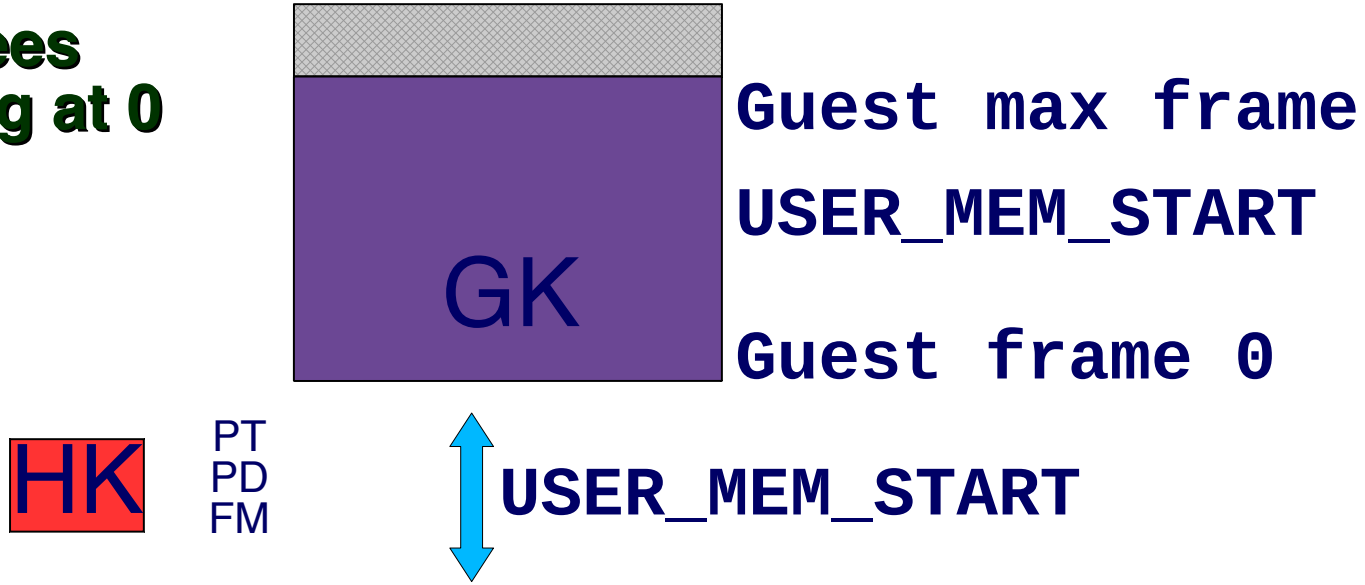

Segmentation to the Rescue!

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  - **(or a bit less)**

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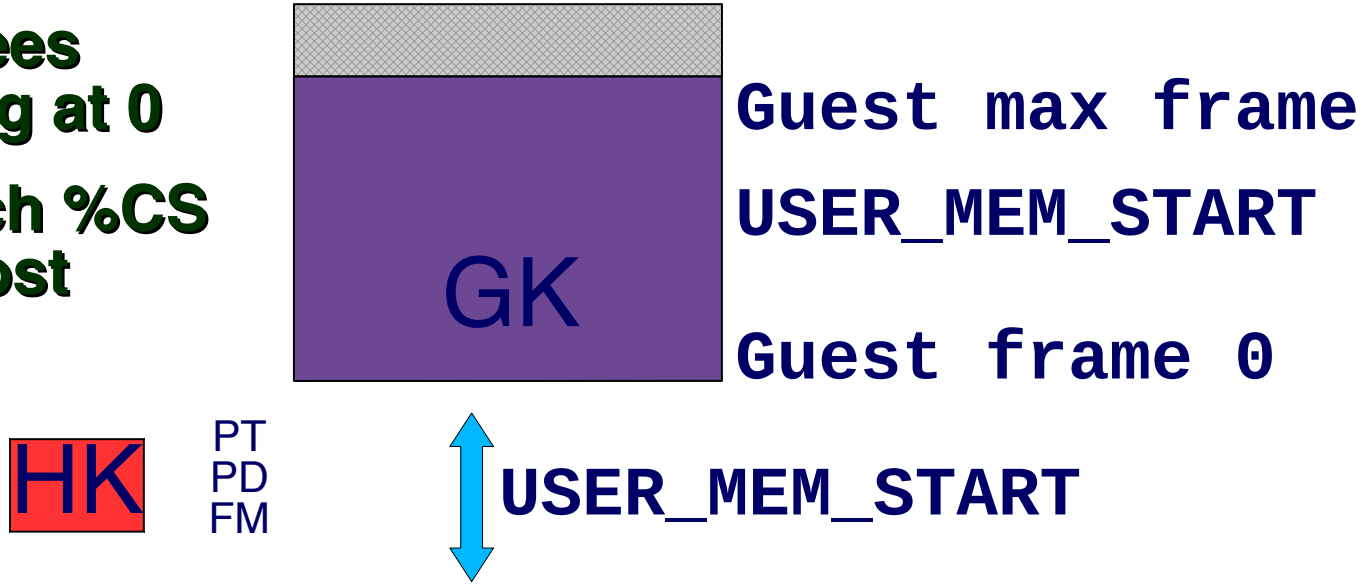
Surprises switch %CS and %SS, so host kernel works



Component Inventory

What are the pieces?

- Virtual consoles – independent, not tricky
- Creating shifted segments – not very hard
- "Boot VM" page-table generator
- Tweaked guest-kernel ELF loader
- HV console-output – straightforward
- Basic hv_iret()
- Delivery of virtual interrupts to guests
  - Timer, then keyboard – this part is significant
  - Result: "P1 guests" run: cool!

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  - Result: "P1 guests" run: cool!
- Page-table compiler
  - Conceptually non-trivial
  - Not huge amounts of code
- Advanced hv_iret(), hv_exit(), "mop up"
  - Result: "P3 guests" run: wow!

Grading

All or nothing???

- P4 is actually two different projects
  - Virtual consoles + hosting P1 guests
  - Virtual consoles + hosting P1 guests + hosting P3 guests

The first version is actually fairly educational!

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- [Squashed edition] Goal will be *P1* guests, not P3 guests
  - No page-table compiler!
  - No guest-user mode (fewer IDT entries, simpler)!
- We expect to award liberal partial credit
  - "Micro-guest" payloads
    - » Mere execution of a guest
    - » Simple hypercall
    - » Printing
    - » Timer, keyboard
  - P1 guests (P3 guests are bonus fun)

Summary

P4 – "PebPeb" paravirtualization

Segmentation to the rescue!

Impossible!?!?

- [Squashed edition]
- Ok to aim for "P1 guests"
- Ok to not achieve 100% of "P1 guests"
  - Delivering virtual interrupts to a guest is quite educational
- Infrastructure is provided for virtual consoles and/or P3 guests if you want to have fun