Guarded Modules: Adaptively Extending the VMM's Privileges Into the Guest

Kyle C. Hale

Peter Dinda

Department of Electrical Engineering and Computer Science
Northwestern University

http://halek.co
http://presciencelab.org
http://v3vee.org
http://xstack.sandia.gov/hobbes

Palacios
An OS Independent Embeddable VMM

Redefining the boundaries between VMM and guest OS

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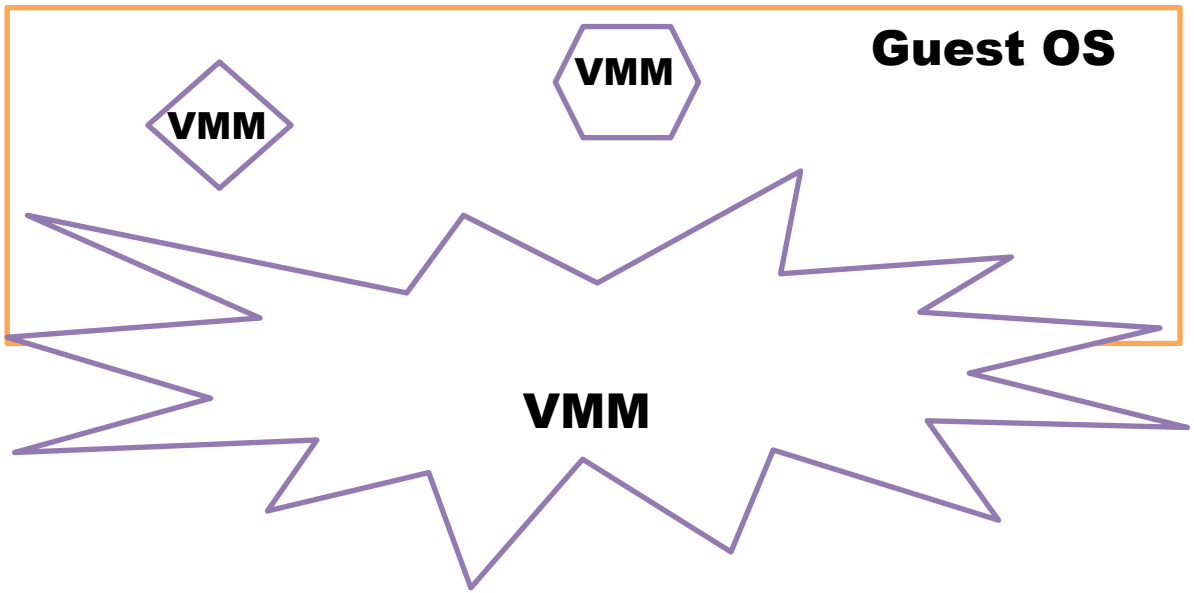


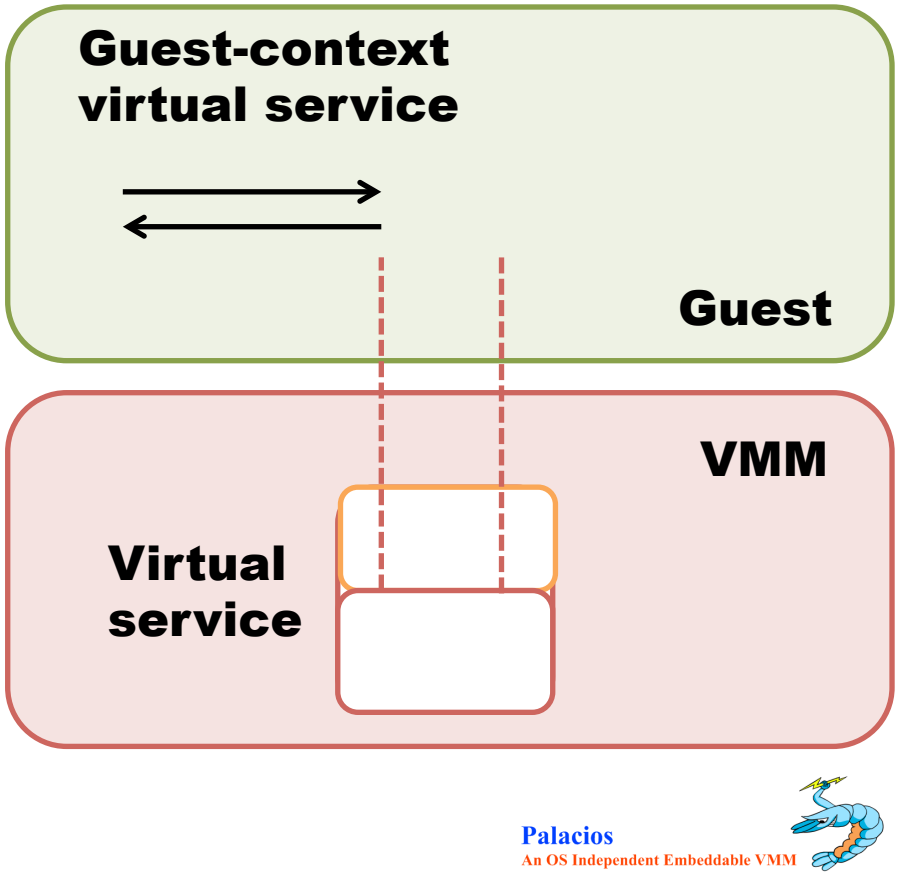
We want to evolve the VMM-guest relationship

…where the interface between the two is more flexible

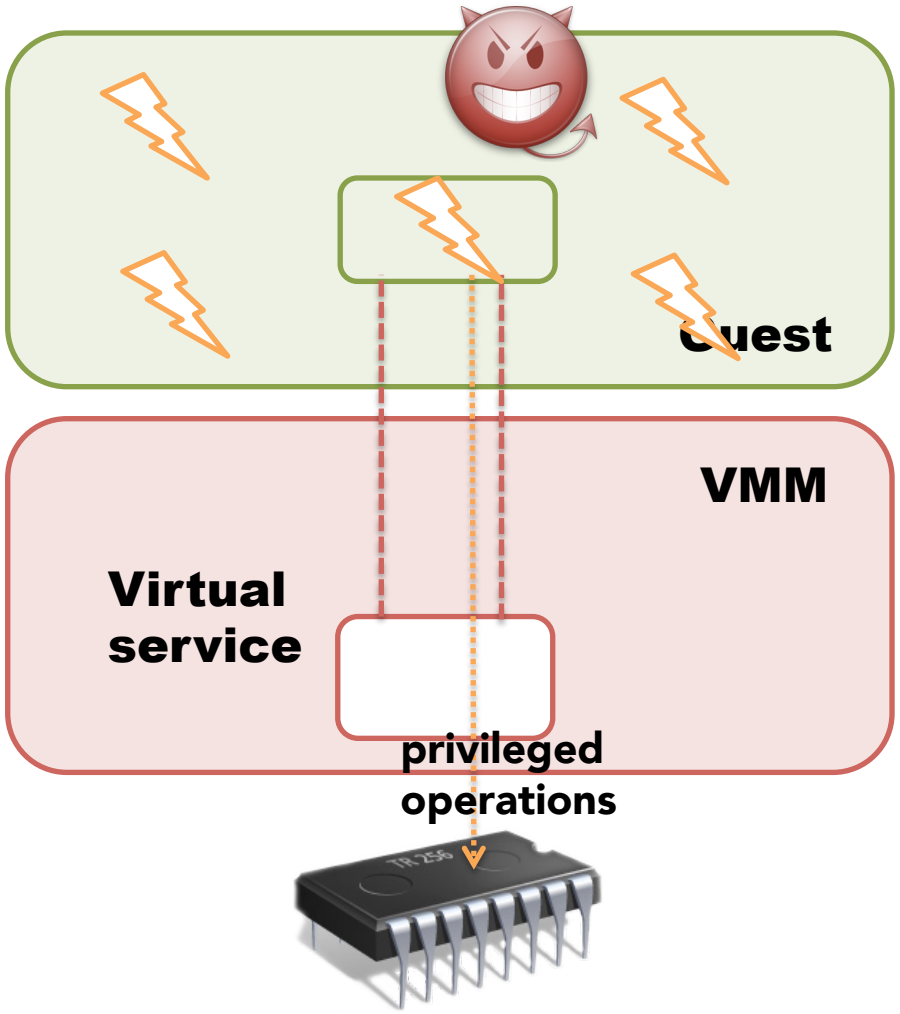
…and where parts of the VMM may actually live inside the guest

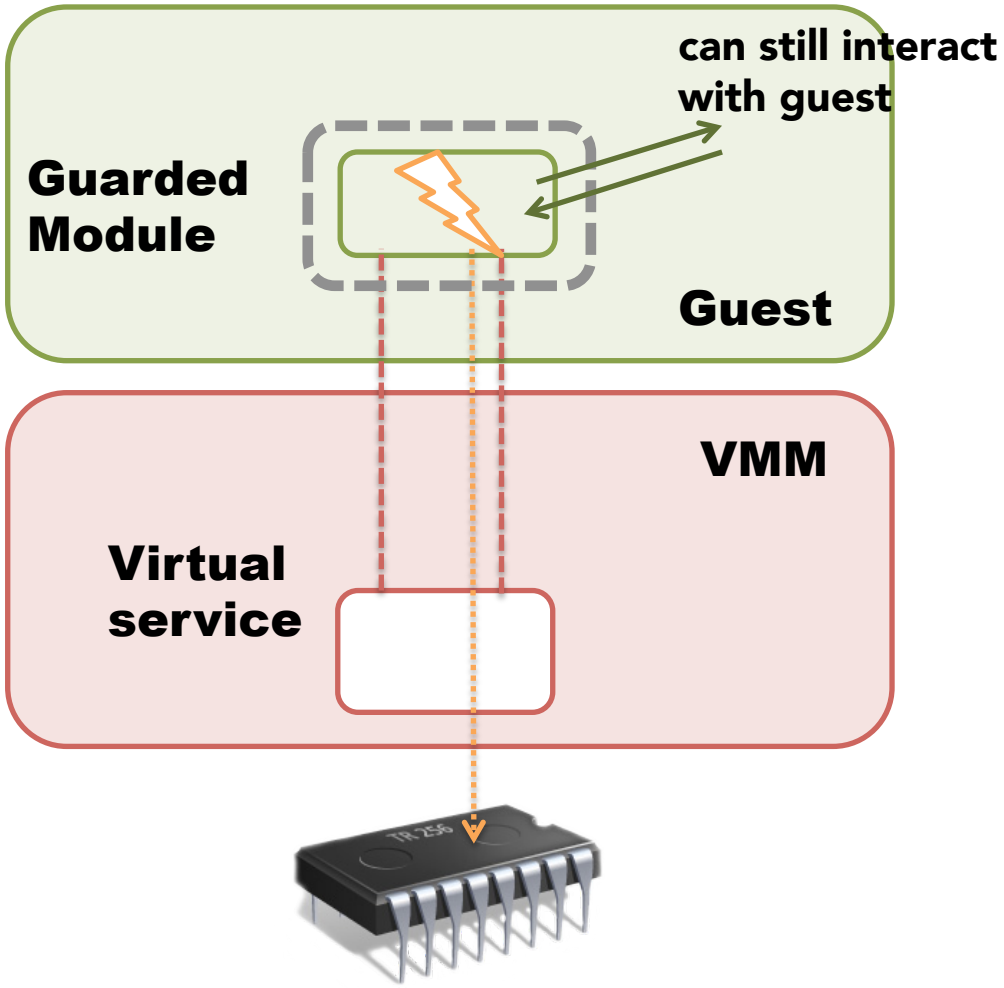
The latter is the focus of this work

GEARS*



* K. Hale, P. Dinda. *Shifting Gears to Enable Guest-context Virtual Services, ICAC 2012*


Guest
VMM
Virtual service
privileged operations


can still interact
with guest
Guarded
Module
Guest
VMM
Virtual
service

How can we isolate and protect pieces of code in a guest OS that run at higher privilege than the rest of the guest?

How can we allow legacy code continue to use guest functionality?

We show how with two examples

Palacios VMM

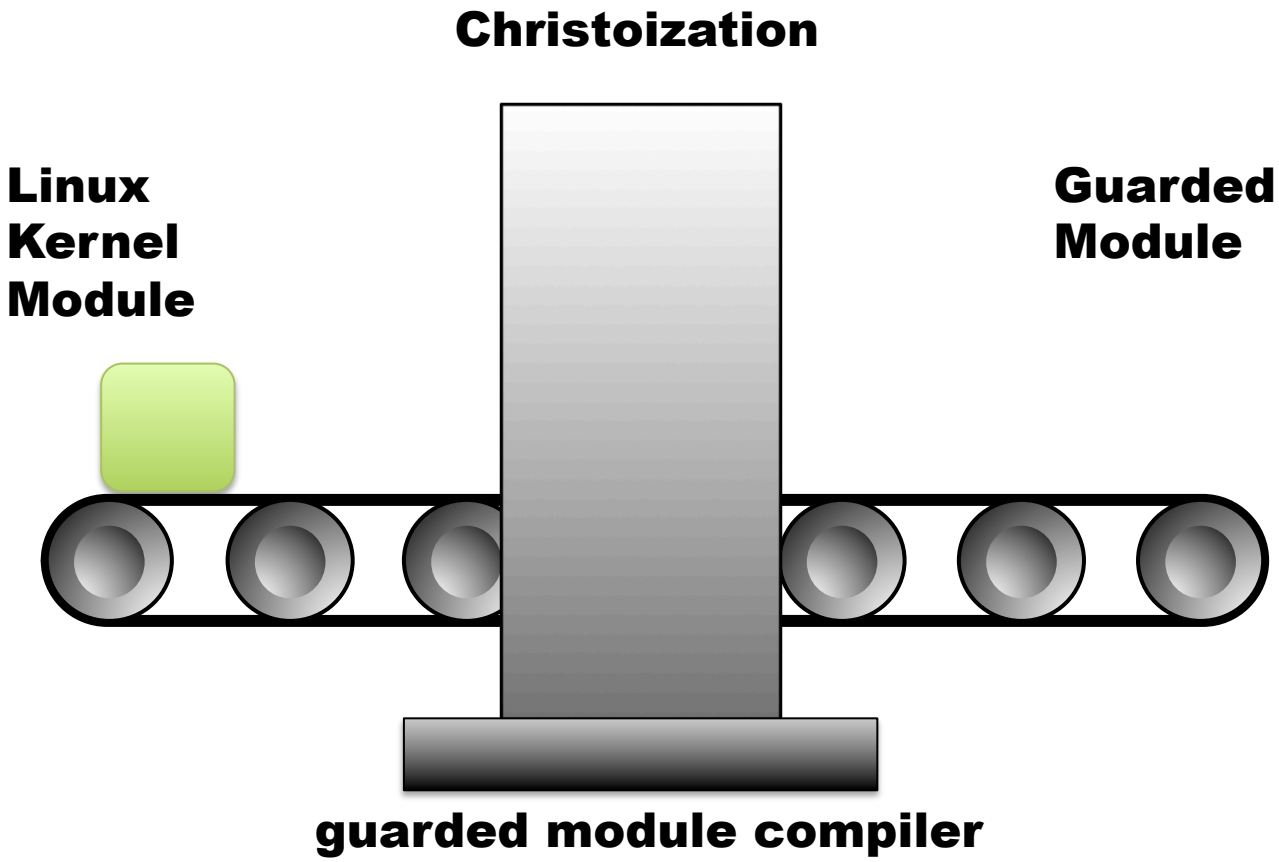
- OS-independent, embeddable VMM
- Support for multiple host OSes (Linux, Kitten LWK)
- Open source, available at
  http://v3vee.org/palacios

Palacios
An OS Independent Embeddable VMM

Outline

- Motivation
- Christoization
- Threat Model and Runtime Invariants
- Runtime System and Border Crossings
- Examples
  - Selectively Privileged PCI Passthrough
  - Selectively Privileged `MONITOR/MWAIT`
- Conclusions

Guarded Module Transformation



Christoization

Compile-time and link-time *wrapping*

we use gcc toolchain to instrument (wrap) all calls out of and into the module

Christo and Jeanne-Claude wrap the Reichstag, Berlin, 1995

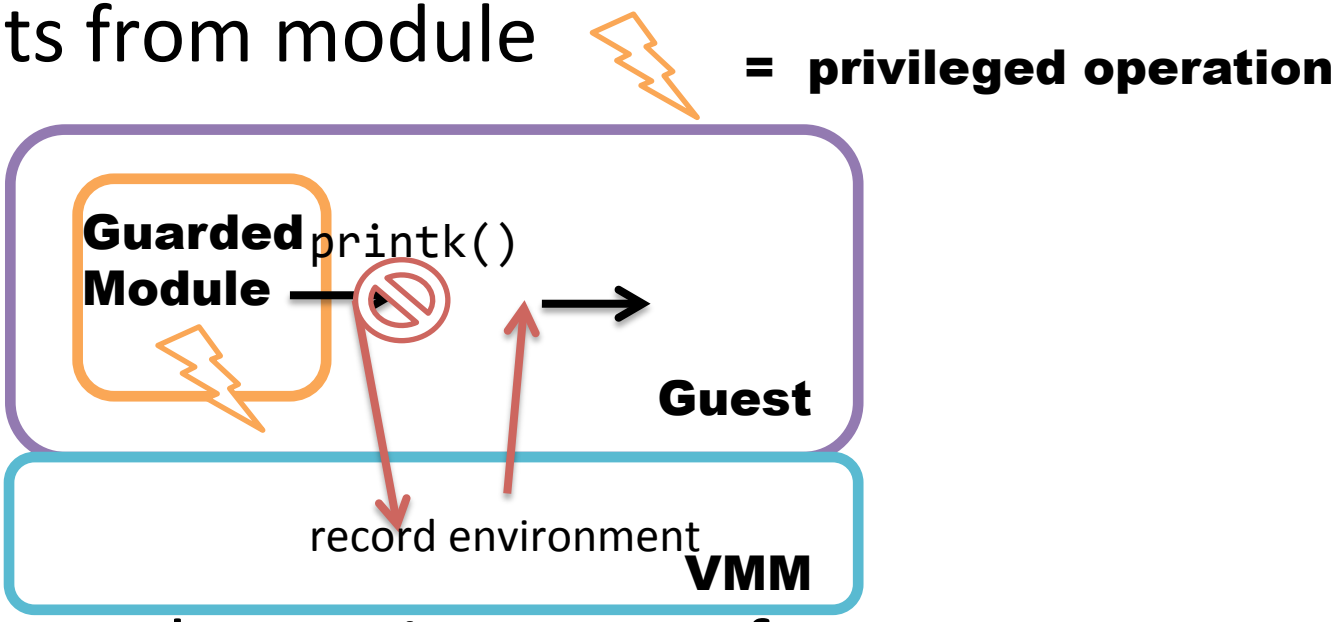
The guest is not to be trusted

We assume a threat model in which a malicious kernel wants to hijack a service's privilege

Execution paths entering and leaving the guarded module **must be checked**

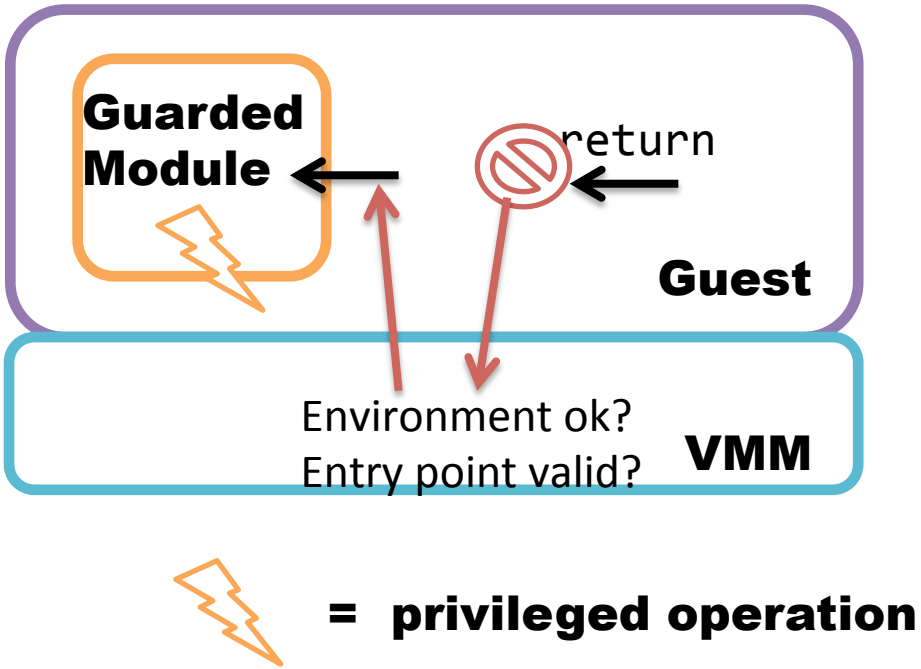
We maintain control flow integrity

Christoization allows VMM to trap all entries into and exits from module

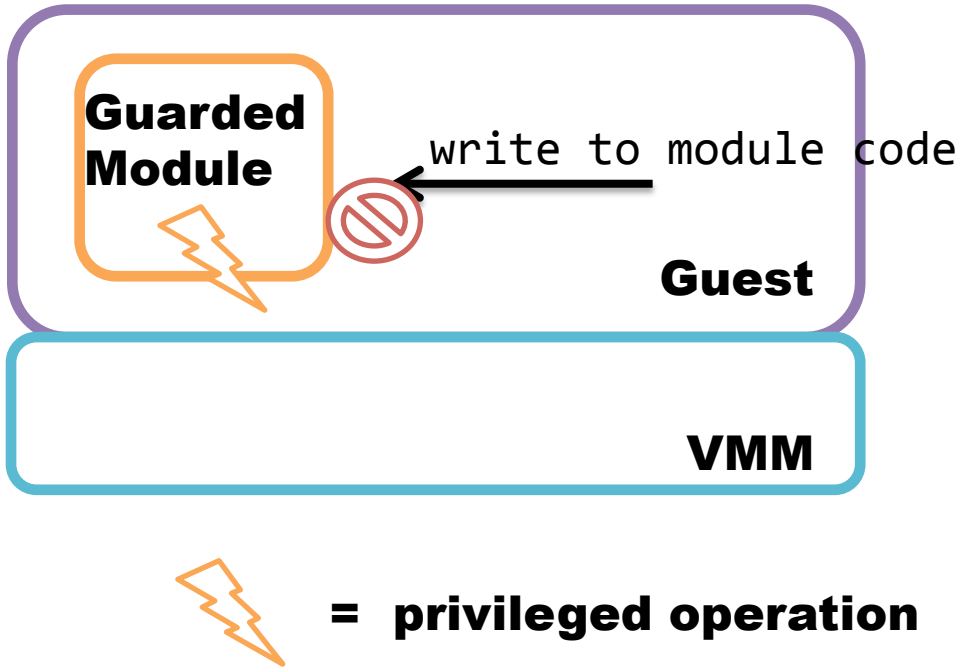


VMM validates the environment for unauthorized changes to execution path (e.g. return oriented attacks)

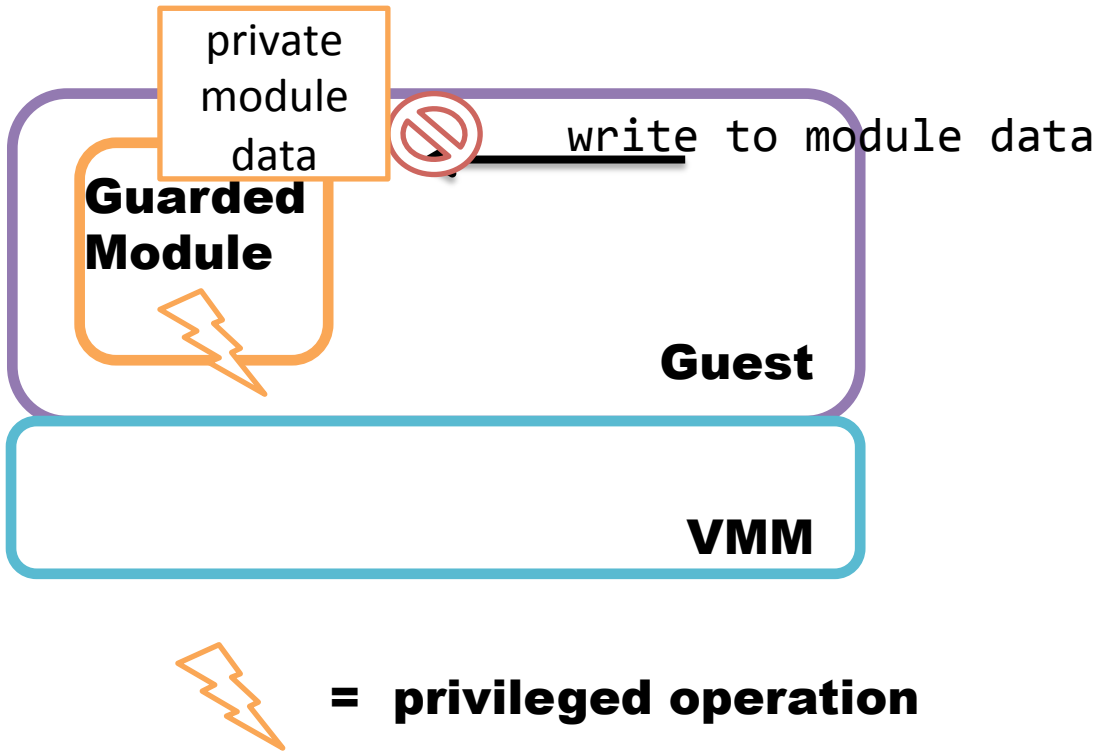
We maintain control flow integrity



…and code integrity



…and data integrity



What we don't provide

Parameter checking

Module cloaking

Currently no support for interactions between guarded modules

Programmer's perspective

1. Write a Linux kernel module (or use an existing one)
2. Run it through our guarded module compiler (christoization)
3. Optional: verify identified module entry points
4. Pass to administrator, who registers guarded module with VMM at runtime

RECAP: Guarded Modules are guest context virtual services

…that can have elevated privilege, are protected from the untrusted guest that they run in, yet can still use its functionality

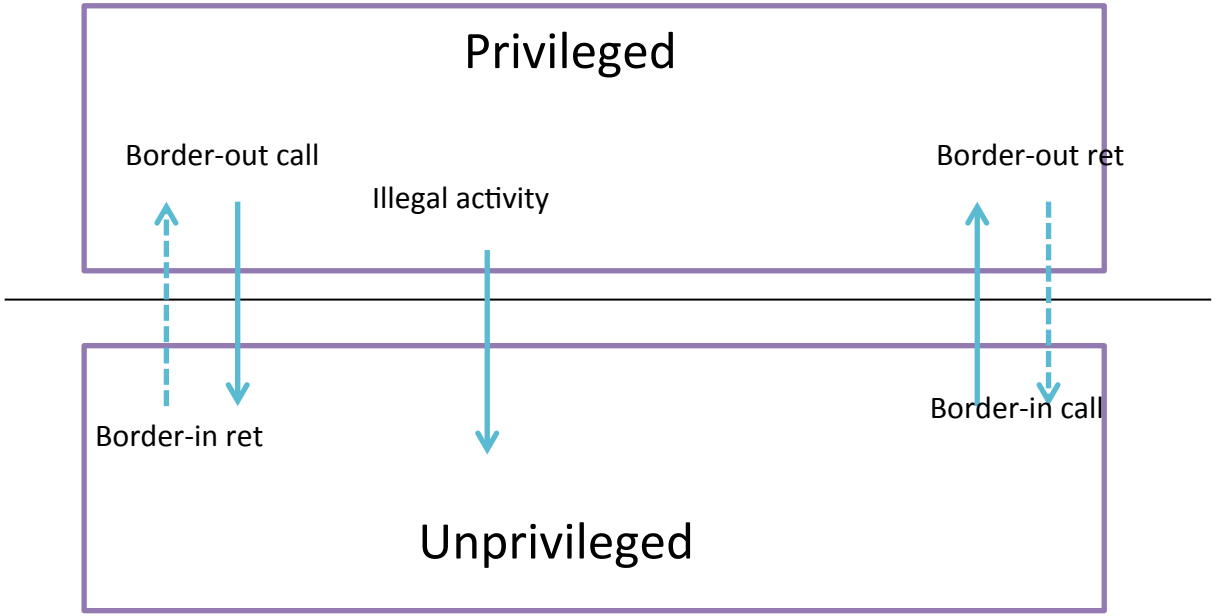
The implementation is small: ~220 lines of Perl, ~260 lines of Ruby, and ~1000 lines of C

(includes both the GM compilation toolchain and runtime system)

available online at http://v3vee.org/palacios

Runtime: module entries/exits trap to the VMM

We call these trapped events *border crossings*

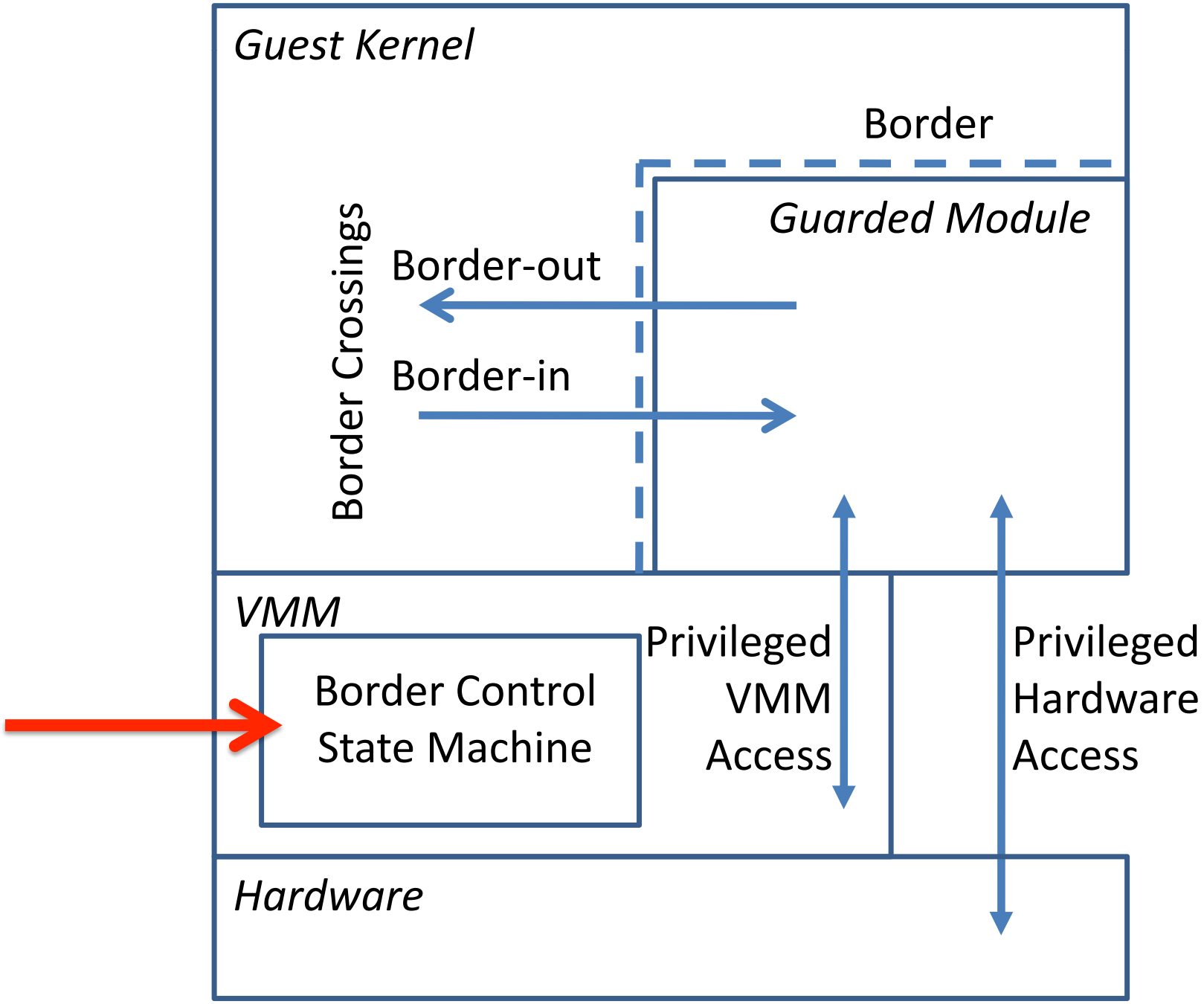


Wrapper stubs

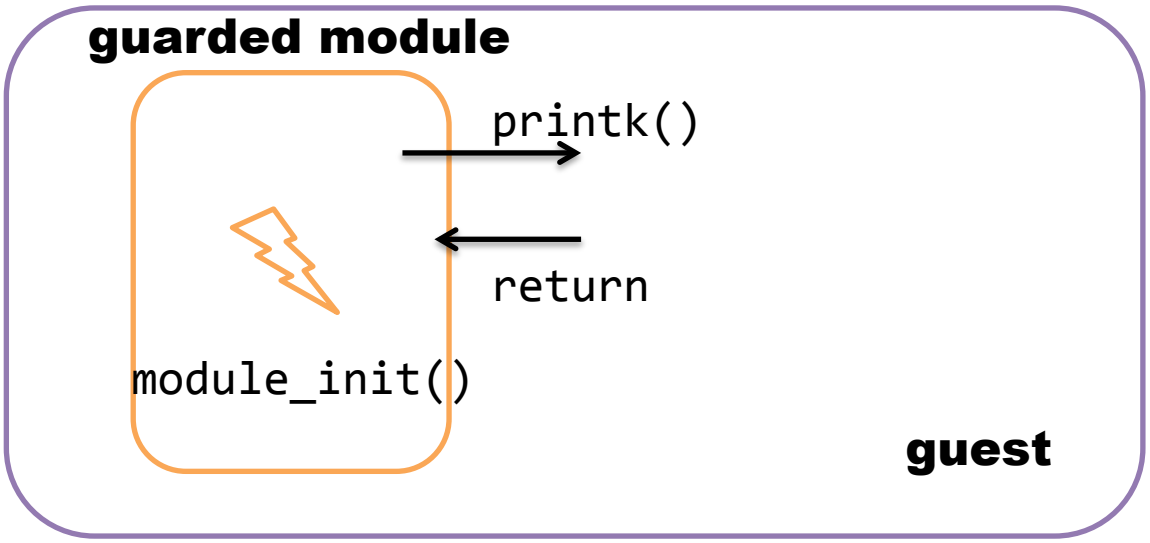
```
exit_wrapped:
    popq %r11
    pushq %rax
    movq $border_out_call, %rax
    vmmcall
    popq %rax
    callq exit
    pushq %rax
    movq $border_in_ret, %rax
    vmmcall
    popq %rax
    pushq %r11
    ret (to into guarded module)
```

Trap to VMM, record environment

Trap to VMM, Check integrity of environment

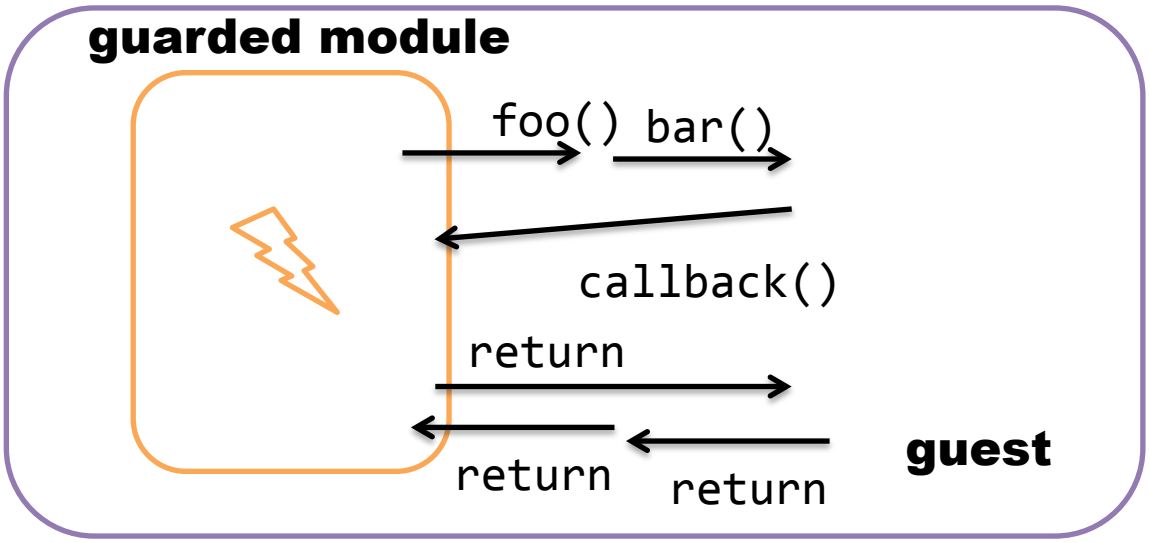

Guest Kernel
Border
Guarded Module
Border Crossings
Border-out
Border-in
VMM
Border Control
State Machine
Privileged
VMM
Access
Privileged
Hardware
Access
Hardware

Typical Border Crossing



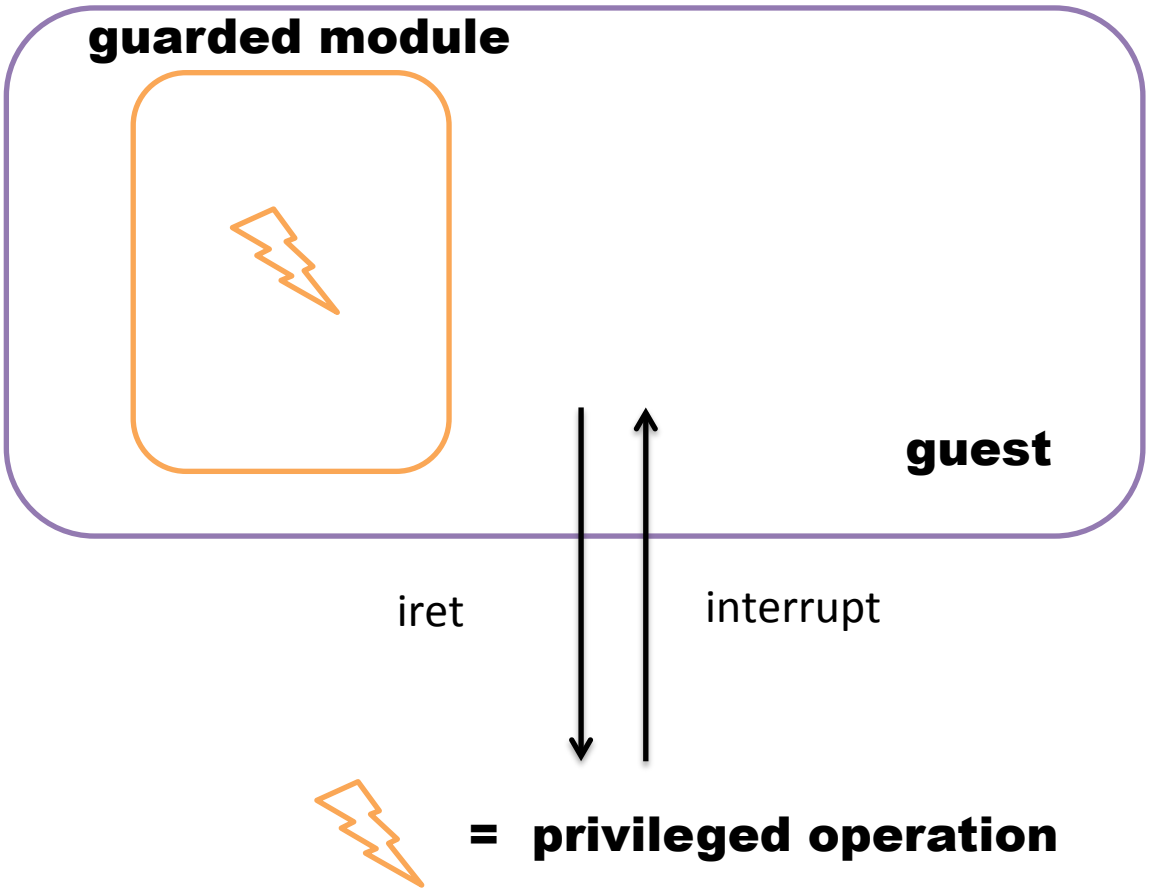
= privileged operation

Nested Border Crossings



= privileged operation

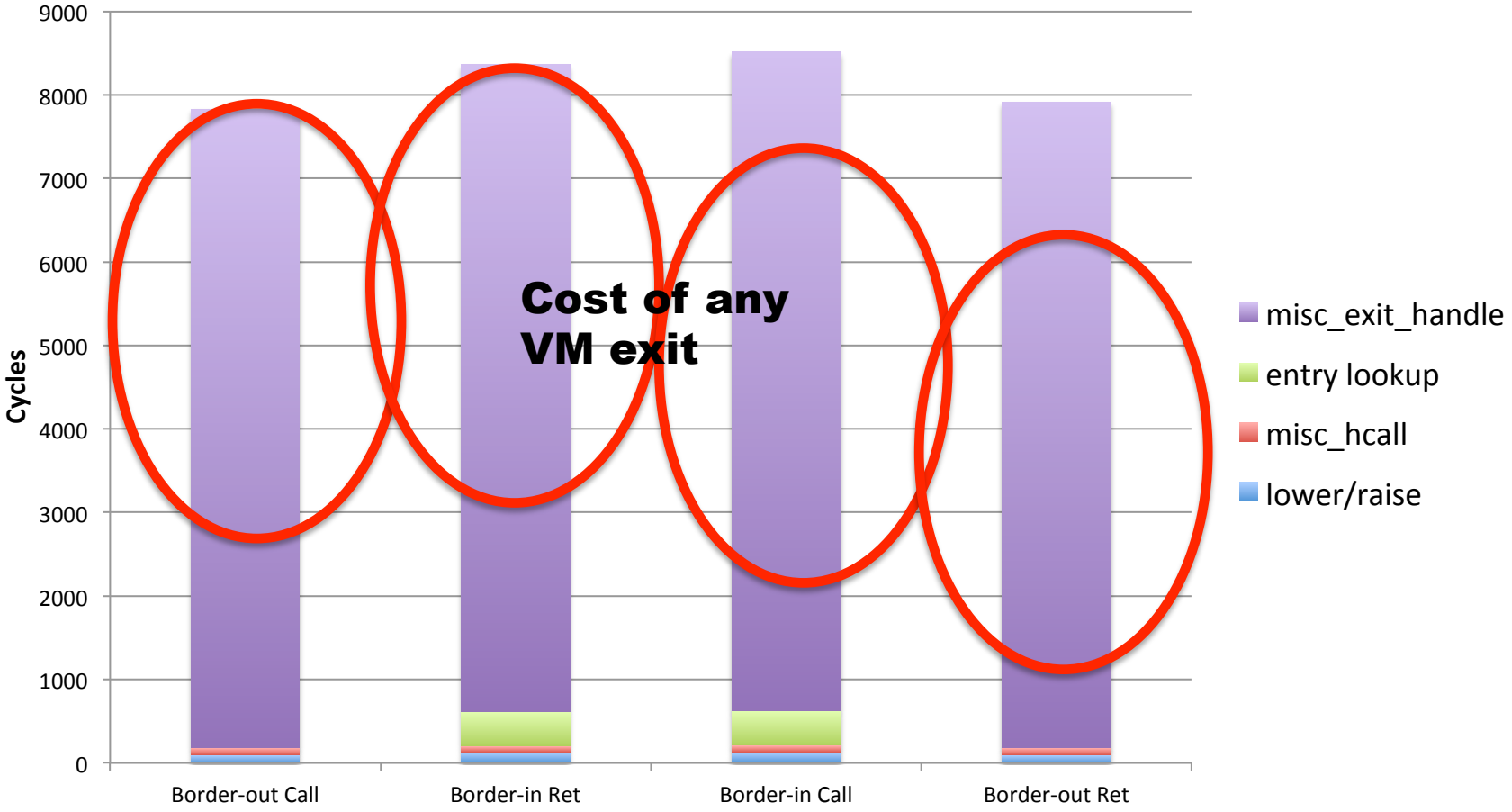
Border Crossing from External Event



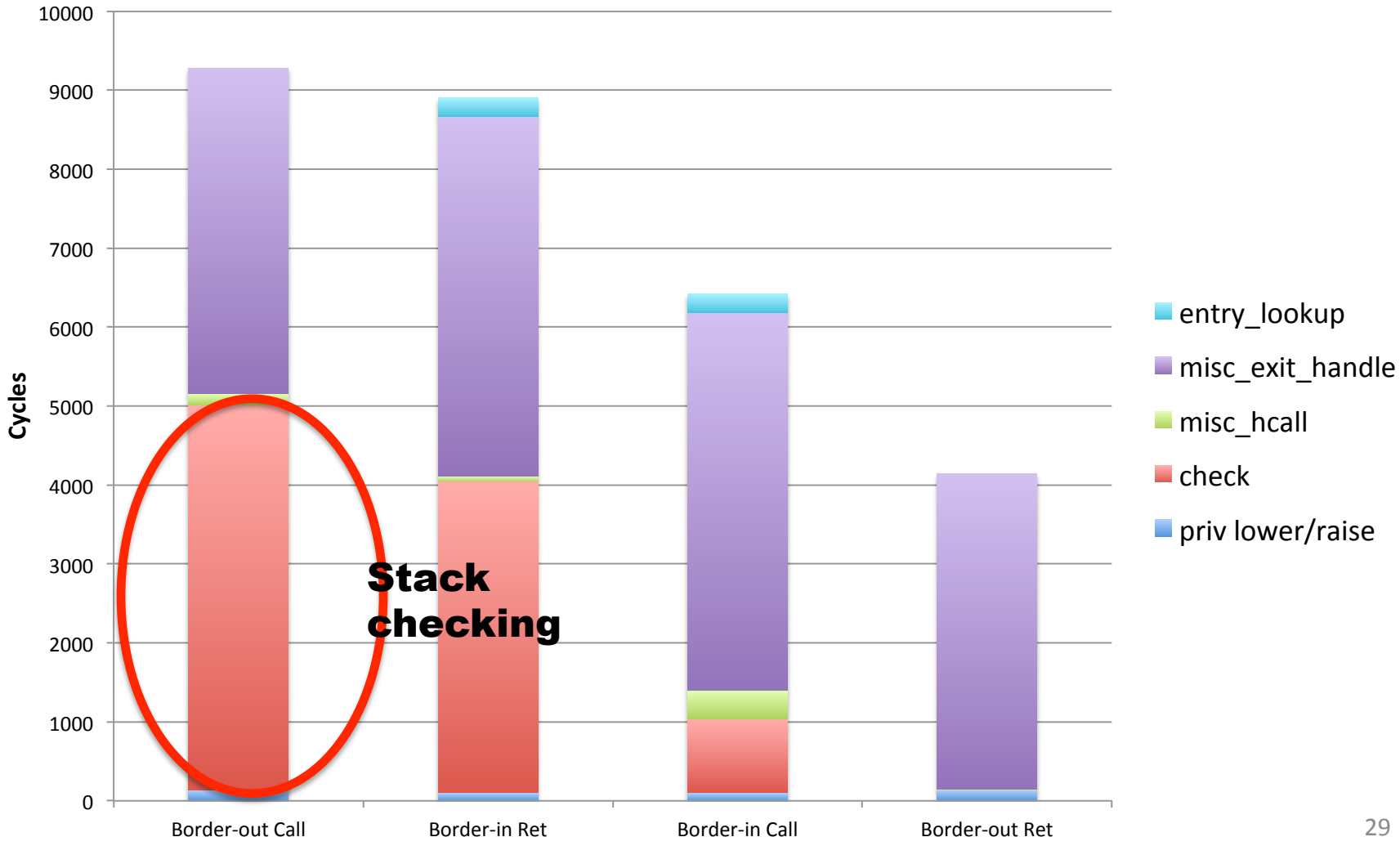
Experimental Setup

- Dell PowerEdge R415
  - 2 sockets, 4 cores each => 8 total cores
  - 2.2 GHz AMD Opteron 4122
  - 16 GB memory
  - Host kernel: Fedora 15 with Linux 2.6.38
  - Guest: single vcore with Busybox environment, Linux 2.6.38

System-independent overhead is low



…but ensuring control-flow integrity is expensive



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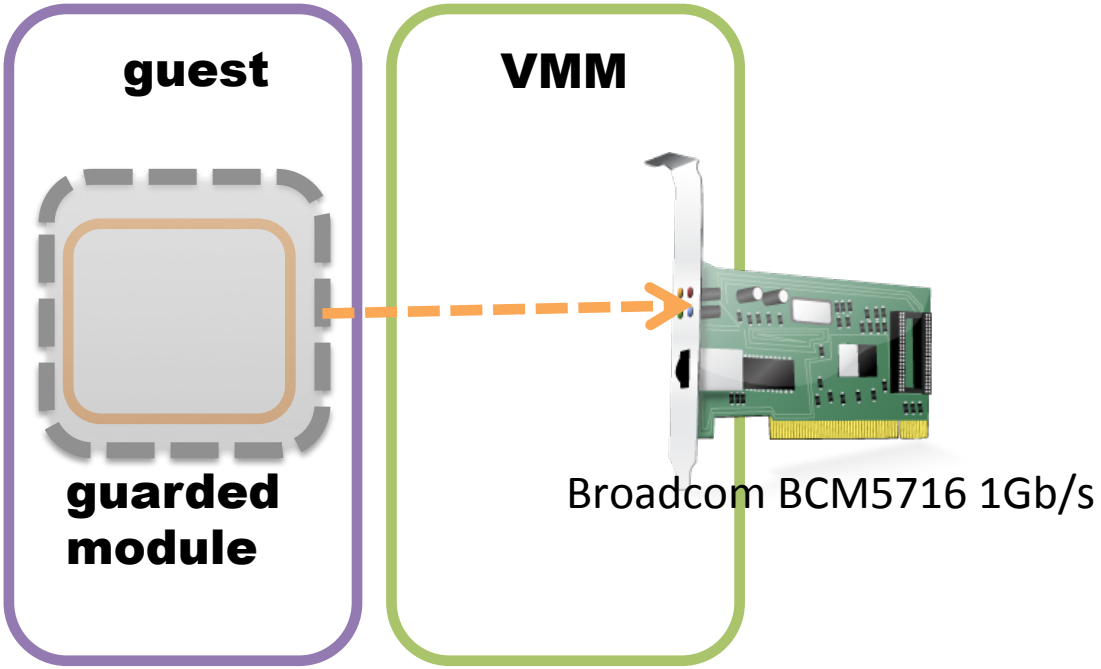
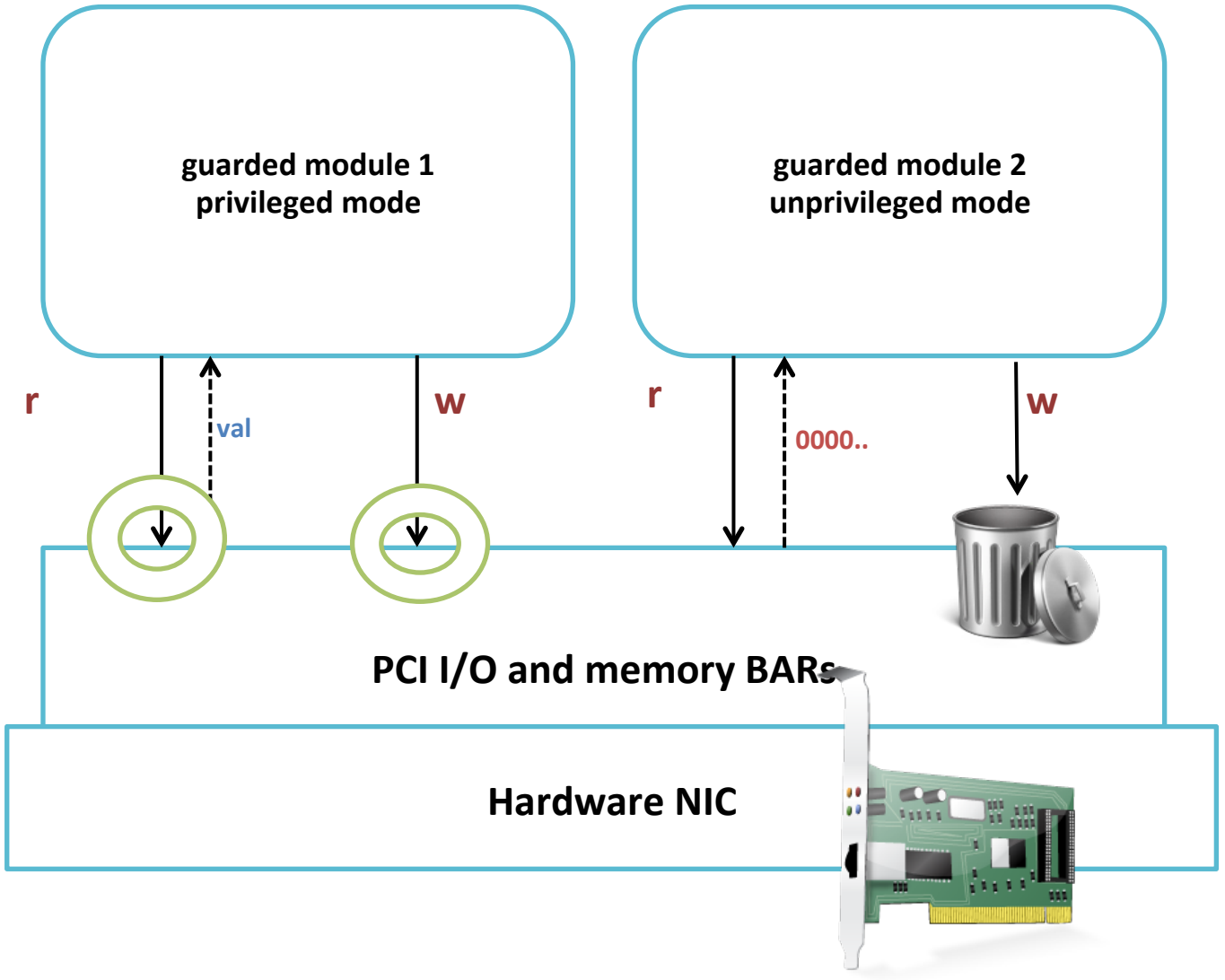
- Related Work and Conclusions

We transformed a NIC driver into a guarded module



no manual modifications to NIC driver!

Selectively expose the PCI BARs to the guest



Bandwidth drops, but border crossing count is very high!

Each border crossing is ~16,000 cycles (7.3 µs)

Packet Sends	
Border-in	1.06
Border-out	1.06
Border Crossings / Packet Send	2.12

Packet Receives	
Border-in	4.64
Border-out	4.64
Border Crossings / Packet Receive	9.28

Many of these are leaf functions!

We implemented an adaptive idle loop with selective privilege

MONITOR/MWAIT instructions allow a CPU to go into a low-power state until a write occurs to a region of memory

```
MONITOR [addr]
…
MWAIT
```

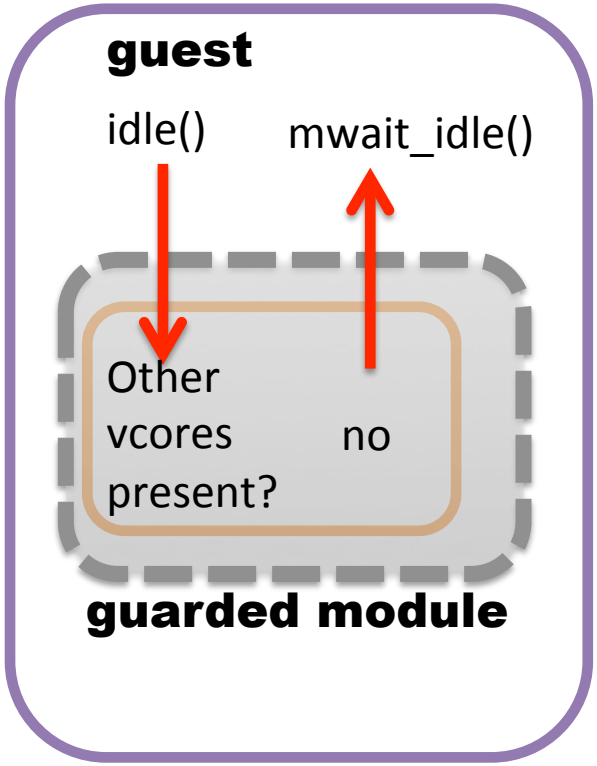
VMs can't typically use these instructions

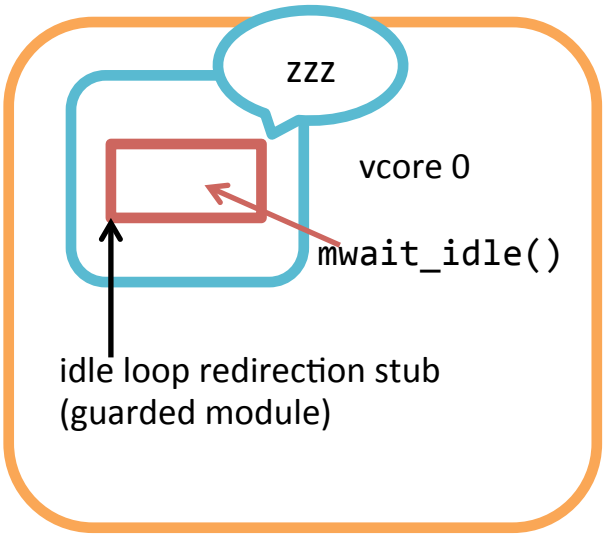
Puts *physical* core to sleep. Other VMs/processes on that core will starve

But if the guest *knows* how many guests are on the machine (VMM state), we can let it run these instructions when idling

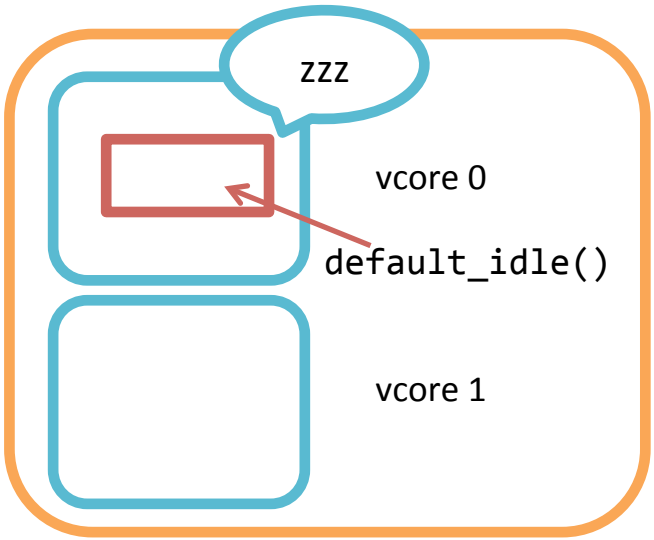
Can't let untrusted parts of guest hijack this capability!

Adaptive mwait_idle() as a guarded module





pcore 0



pcore 1

Scenario 1:

a single vcore

Scenario 2:

vcores sharing a physical core

Guarded Modules as *adaptive, guest-context virtual services*

We're leveraging VMM global information about the environment

That information is *only* exposed to the guarded module—this presents a new way to adapt VMs at runtime

Related Work

Nooks – isolate faulty code in kernel modules with wrappers. Kernel requires modification, protecting guest from modules

[Swift, SOSP '03]

LXFI, SecVisor – protect kernel against attack with VMM-authorized code

[Mao, SOSP '11], [Seshadri, SOSP '07]

SIM – guest-resident VMM code, but special-purpose, uses completely separate address space

[Sharif, CCS '09]

Conclusions

We've shown the feasibility of *adaptively* extending the VMM into the guest with *guarded modules*

General technique to automatically transform kernel modules into guarded modules

Two proof-of-concept examples:

- Selective Privilege for Commodity NIC driver
- Selective Privilege for MONITOR/MWAIT

Future Work

Feasibility of automatically inlining leaf functions into modules (making them more self-contained)

Further motivating examples for guarded modules

Generalization of guarded modules—modules with VMM-controlled, specialized execution modes

We are rethinking system software interfaces

This talk focused on virtualization, but we're thinking bigger (HW/VMM/OS/app)

It's time to reconsider the structure of our system software stacks

We can adapt software services, but can we adapt their organization/structure?

For more info:

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