Project Maux Mk.II

"I Own the NIC, now I want a shell!"

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"I have a Cunning Plan"

- Background concepts
- Last year's work (NIC takeover)
- Evolving Project Maux: Project Maux Mk.II
- Identification and defence
- Future work

How to read these slides

- This is not a funded project but personal curiosity-driven what-if research,
- Conceptually similar to the "nth Country Experiment" at LLNL in the 1960s: given open literature how quickly can two Physics PhD candidates develop a working nuke?
- Given no prior knowledge, "the Internet", a cheap 10-pack of NICs and a PC can we develop the ultimate rootkit?

Background concepts

- NICs are becoming more intelligent:
  - firmware is becoming more sophisticated,
  - bugs creep into firmware leading to updates,
  - updates on a deployed card are desirable (especially WiFi...).
- So there must be a firmware loader...

Background concepts

- Video cards are becoming smarter:
  - gamers want a "better experience" therefore accelerated graphics,
  - the GPUs are becoming sophisticated,
  - there is plenty of RAM to play with,
  - a vendor ships a development toolkit...

Project Maux Mk. I (2006-2007)

- A particular PCI NIC (Broadcom "Tigon"-based):
  - MIPS CPU, very little on-board RAM,
  - SDK available on web,
  - Modified Linux drivers courtesy of CERN,
  - Cheap 10-pack available.

Project Maux Mk. I (2006-2007)

- SDK lead to development of "alternative" firmware (aka "Project Maux"):
  - hook to IP checksum routines,
  - add "sniffer" which copies packets into scratch RAM (circular buffer design).
- Only approximately 5s-30s sniffing on loaded NIC then circular buffer fills up.

Project Maux Mk. I (2006-2007)

- Major issues with project Maux:
  - lots of NICs blown in the process,
  - the circular buffer is ridiculously small,
  - loader requires Ring 0,
  - sniffing alone is not very useful.

So what?

- A bit like a ^{235}U device: easy to build but required lots of hardware,
- an excellent proof-of-concept strongly suggesting that the firmware avenue was worthwhile,
- it is an "obvious" entry point into the firmware hacking scenario,
- not that many players cover most hardware (Broadcom, RTL, Intel, Via, etc.).

Defences

- Security through obscurity? Forget it, Google will (eventually) find it,
- Assume your firmware SDK is in hostile hands,
- Think about drivers sanity-checking hardware (need Secure Computing to really work)...
- ...but don't assume PKI will save you...

Evolving Project Maux

- We cannot fix anything at all on the NIC!
  - Blowing NICs is an inevitable consequence of not having documentation,
  - We can't increase the RAM on the MIPS embedded controller,
  - The loader only runs in Ring 0,
  - No RAM means no extra functionality.

Evolving Project Maux

- Look elsewhere given the following constraints:
  - No OS support required,
  - Almost invisible to the CPU,
  - "Remote shell" capability,
  - Must be stealthy!
- This is where we go for the ^{239}Pu design.

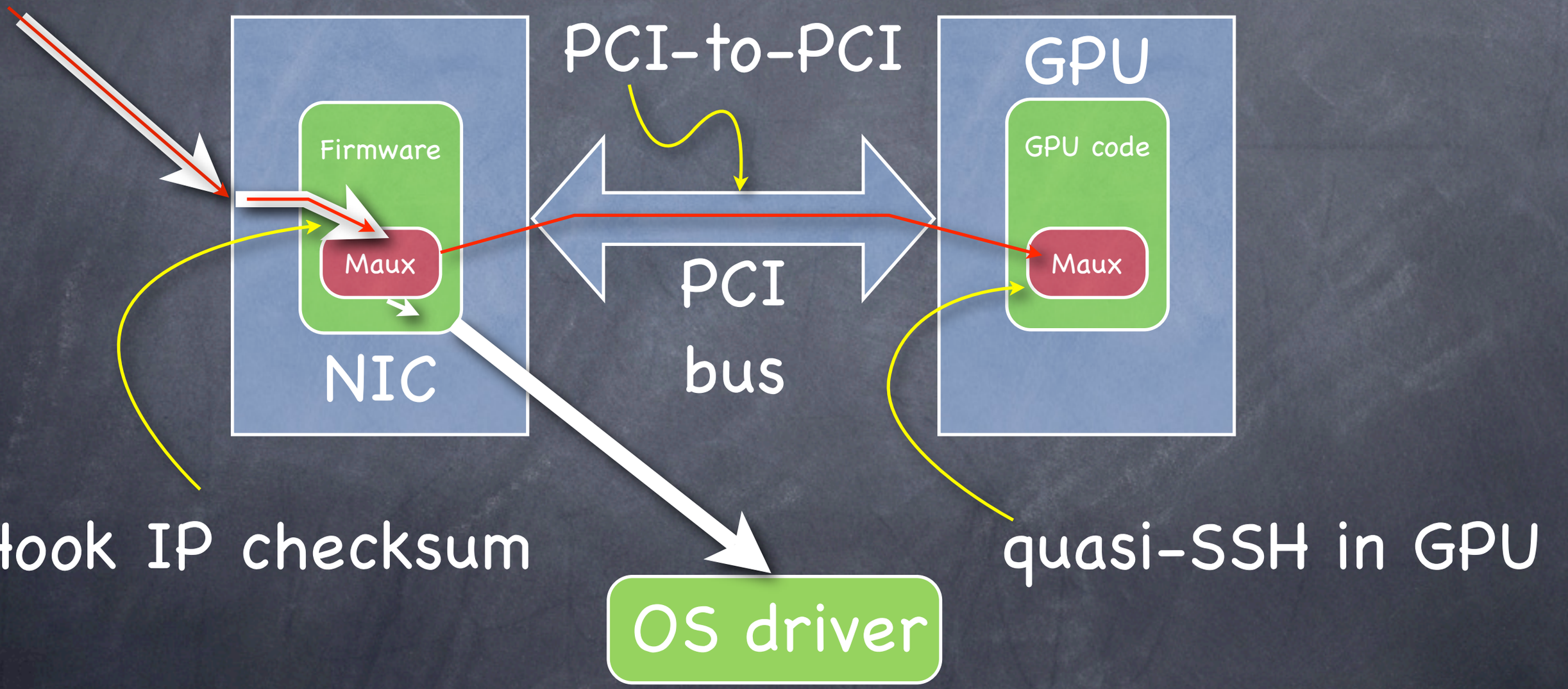
Project Maux Mk.II

- The solution is to look at another PCI board!
- nVidia GPU development kit:
  - not the "OpenGL/Direct X" stuff...
  - but the "GPU computing" kit (aka "CUDA")!
- This gives us access to a CPU with substantial amounts of RAM (128Mb at least)...

Project Maux Mk.II

- Overall design outline:
  - quasi-SSH communications with quasi-SSH daemon running in GPU,
  - NIC filters out "relevant" packets, forwards them to GPU via PCI-to-PCI transfer,
  - quasi-SSH interprets them.

Project Maux Mk.II



Project Maux Mk.II

- NIC firmware modification:
  - same technique as old "sniffer": hook IP checksum (every IP packet triggers it),
  - grab packet, check magic,
  - pass "magic packet" to GPU via PCI-to-PCI transfer

Project Maux Mk.II

- check magic:
  - if the IP ID is 0xbeef **and**
    - the IP timestamp option has a flag value of 0x3, IP address of 0x50b1463d and a timestamp of 0x06026860.
  - this causes the firmware to forward the packet off to the GPU.

Project Maux Mk.II

- GPU gets magic packet:
  - 1st packet seen from this IP? Then send back a "suitable" response to say we are a "Mauxed" system with details of OS and capabilities,
  - otherwise interpret as part of a session.

Project Maux Mk.II

- Introducing nicssh 1.0 (a quasi-SSH daemon):
  - no DH key exchange, in fact no authentication!
  - Blowfish with static 128-bit key (static as in "static in the GPU code being injected"),
  - basic command shell with readline and limited number of commands.

nicssh 1.0

- nicssh handshake:
  - ICMP Echo Request with "magic",
    - respond with correct ICMP Echo Reply, but with "magic" in the header,
    - nicssh waits for 1st session packet.
- Note: the OS is totally oblivious to the above and never sees the ICMP packets.

nicssh 1.0

- nicssh capabilities:
  - memory inspection (GPU RAM and system RAM),
  - sniffer on NIC sending data to VRAM,
  - sending of data via the network,
  - cleanup (extremely flaky),
  - readline (tab completion and history).

nicssh 1.0

- "Stealth" capabilities:
  - if negotiated then use special port for traffic, otherwise default is 80,
  - when using "web ports" (pre-defined to 80, 8080, 3128) then use rwwwshell GET method.
- More planned (Nushu, sniffing backdoor...).

nicssh 1.0

first "magic packet"

"magic packet" back

```
archimede:~/nicssh$ nicssh 10.4.4.233
Connecting to 10.4.4.233
ICMP Echo Reply from OS - no nicfw
archimede:~/nicssh$ nicssh 10.4.4.234
Connecting to 10.4.4.234
ICMP Echo Reply from nicfw (Windows system)
Requesting tcp/80 with cloaking
nicssh> ?
help memory* sniff* send* reboot cleanup quit
nicssh>
```

"stealth" mode

"shell" with basic help

Installation...

- Good question with no good answer at the time (March 2008). Some ideas:
  - fake driver update with phishing website to entice downloaders (think "ehanced driver for gamers"),
  - virus with injection payload,
  - infected Linux distribution.

Installation...

- Now for something more esoteric:
  - Broadcom firmware has traces of "remote update" functionality...
  - Drive-by injection via WiFi, WiFi driver exploit, PCI-to-PCI into the NIC?
- The second of the two would be lethal for laptops.

Uninstall?

- What if you wish to remove all traces of modification?
- Sorry, no (smart) answer at the moment (March 2008) for the NIC.
- GPU? Just reboot (cold boot perhaps).
- Should drivers always inject fresh firmware?

Is it worth it?

- Short answer: definitely not in 2008.
- In the longer term this is an ideal A-V evasion technique for bots:
  - install bot, zap firmware, disappear. New A-V signatures? Too late. OS reinstall? Irrelevant.
  - bot functionality in VRAM and on GPU! OS is pristine and irrelevant.

Is it worth it?

- What about virtualisation?
  - VM escape: working on something named the "Jedi packet trick"...
  - Smaller number of server NICs make it an attractive "market" from an ROI perspective,
  - Hypervisor is "Just Another OS",
  - "A Hypervisor" allegedly runs "Not Linux"...

Is it worth it?

- What about firewalls?
  - 90+% of world's firewalls run on the PC architecture and therefore...
    - extension of "Jedi packet trick" to NIC-to-NIC transfers!
- This could also extend to IDS/IPS systems... one parser vulnerability, NIC takeover, game over!

Is it worth it?

- Get nastier: what about the highly integrated support chips on the motherboard?
  - MITM of PCI-to-PCI transfers,
    - crypto accelerators need data and key to be sent to them to "accelerate"...
    - grab data being written to SATA...
- Why? ROI for theft looks promising: keylogger++

Is it worth it?

- Two scenarios:
  - Government: exercise for the reader.
  - Criminal organisations:
    - Targeted attacks "for rent",
    - "Transparent" bots,
    - Pre-loaded bots: how difficult is it to attack Dell's pre-loaded image loader?

But we use PKI!

- PKI structure (assumed):
  - signed firmware with a public key embedded in "secure" area of the chip,
  - offer semi-custom parts to OEMs,
  - OEMs roll-out their own modified firmware,
  - so you have multiple public keys on chip.
- One question: how do you push a CRL?

PKI, an interesting note

- In the previous PKI scenario the problem is obviously pushing a CRL off to end-users.
- The scenario was thought up independently and then was discovered to match the concerns of a manufacturer...
- Think back to the Nth Country Experiment... I might not be the only one thinking about it.

Identification

- On the network?
  - Currently as good as your detection of rwwwshell,
    - Can be improved due to "magic" needed for NIC firmware to redirect to GPU.
- On the system?
  - Anyone counting PCI-to-PCI transfers?

Defence

- The marketing defence: JIT manufacturing means different cards in different PCs and "same model different chipset" making targeting extremely difficult,
- Firmware verification during update (c.f. Intel's microcode update vs. AMD microcode update),
- Trusted computing if extended to cover firmware verification (see John Heasman).

Defence

- Learn from OS/VM (now zVM) providing fine virtualisation services since 1968:
  - true hardware-aided virtualisation,
  - protection rings at the hypervisor level,
  - See IBM's research (Karger paper on alpha PALcode and virtualisation).
- "A virtualisation so good you can virtualise it"

Defence

- The Secure Computing Initiative:
  - currently does not appear to cover firmware! Obviously needs extending...
    - the PCI bus could well become the "new Internet" for malicious communications,
    - check all firmware, not just the obvious.
- Interesting question: how do you boot safely?

Project Maux Mk.II unsolved issues

- Elegant installation process:
  - Currently by hand (!!), no automation...
- NIC long-term stability testing:
  - Never ran for more than a week.
- GPU code persistence:
  - Reboot kills us at the moment.

Project cost

- "Another year of Sundays":
  - approximately 100 man/hrs,
  - Project Maux was approx. 150 man/hrs,
  - $0 hardware costs (Project Maux: $100),
  - MVT: Google.

Future work

- GPU code persistence by using John Heasman's ACPI/BIOS work?
- GPU code persistence using hidden sectors on disk loaded at boot via NIC firmware BIOS initialisation routine?
- More sophisticated nicssh functionality (with authentication?)

Jedi packet trick™ spoiler

- Drivers (sometimes) assume hardware is badly designed, perhaps badly behaved, but not malicious...
- NIC takeover followed by driver takeover...
- Driver takeover means Ring 0...
- Ring 0 means kernel...
- Who says that there has to be a single TCP/IP stack in the kernel? "There is no packet here, you will let it through" ☺
- You heard it here first™

Thanks

- My family ∀ their ∞ patience while I play with my toys,
- Toby for keeping the hard questions coming,
- Maya for project naming,
- $C_8H_{10}N_4O_2$

Spoiler: the Nth Country Experiment nuke design by the PhDs would have gone "b00m!" and was indeed initially meant to be tested "for real" at the NTS to validate this.

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