Looking to the Future

decreasing trust in dom0, and *client virtualization on ARM*

Kyle J. Temkin
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OpenXT Summit, June 7th 2016

Who am I?

devastating capability, revolutionary advantage

Kyle J. Temkin

- Security Researcher at AIS, Inc.
- Open source contributor, maintainer
- Low-level hardware guy:
  - Hardware design for security
  - Hypervisor/VMM-based security
  - Kernel/driver work

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Talk format

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This talk will have a slightly unusual format.

This is really a pair of ~10 minute "lightning talks":

- **Reducing Trust in "dom0"**
  in which we re-explore disaggregate models made easier by modern Xen
- **Client Virtualization for ARM**
  in which we explore the challenges of creating OpenXT-like functionality on ARM

Important note:
I don't claim to be a definitive source, especially in terms of past disaggregation work. My goal is to encourage discussion– time is allotted for it tomorrow!

Reducing Trust in "dom0"

establishing a trusted foundation for *OpenXT*

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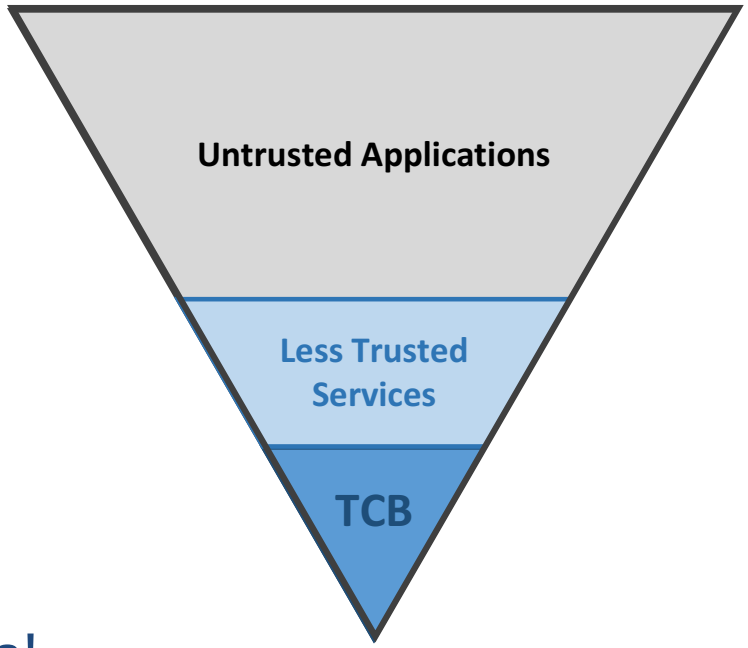
Background: Trusted Computing Base

Limitation:

It's not possible to audit and trust all components of a complex system. Instead, we trust a minimal selection of hardware and software—our trusted computing base—and build complex systems on top of it.

General Goals:

- TCB should be kept as small as possible.
- Platform services should have the least privilege possible.



Compromise of the TCB typically leads to compromise of the entire platform and its data!

OpenXT: Trusted Computing Base

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Unfortunately, pragmatism often leads to large TCBs.

- Together, the *Xen hypervisor*, *dom0 kernel*, and OpenXT toolstack comprise more than 1M SLoC.
  - A meaningful audit of this much security-critical code is intractable.

Existing mitigation technologies (Flask/XSM, SELinux) aren't enough:

- Compromising a privileged component yields all of its privileges.
  - dom0 is currently a trusted domain; the OpenXT *Flask/XSM* policy provides it enough privilege that it can easily compromise every VM on the system
  - The OpenXT toolstack requires similar privileges to do its job: as it acts as the loader for every non-dom0 VM on the system, it is currently granted arbitrary memory access privileges (`map_foreign`).
- dom0 kernel vulnerabilities **do exist**, and they're often **not obvious**!

Example Vulnerability:
Double Fetches in the dom0 kernel

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Description:

special case of TOCTTOU in which shared memory is inappropriately considered static, despite changes being possible from the "other side"

Example:

```
//Synthetic example
if(vm_authorized_for_command(shared_memory_buffer)) { //1
    time_consuming_prepatory_task();
    execute_command(shared_memory_buffer);            //2
} else {
    pr_warn("Access denied!\n");
}
```

Double fetch bugs have been around for a while; and were recently leveraged against Xen in Felix Wilhelm (@_fel1x)'s *XenPwn* talk.

XSA-155:
Double Fetches in e.g. *pciback* (dom0 kernel)

Felix Wilhelm was able to exploit a subtle double fetch in *pciback* to gain significant control over the dom0 kernel.

- This kind of attack could be leveraged from an NDVM against *pciback in dom0*.
  - This hurts one of our nicer properties: ideally, a compromised NDVM wouldn't be able to impact other platform components.
- This kind of attack is made easier by a privileged domain that provides services directly to a guest.
- **This doesn't have to be the case: we can design systems to be resilient!**

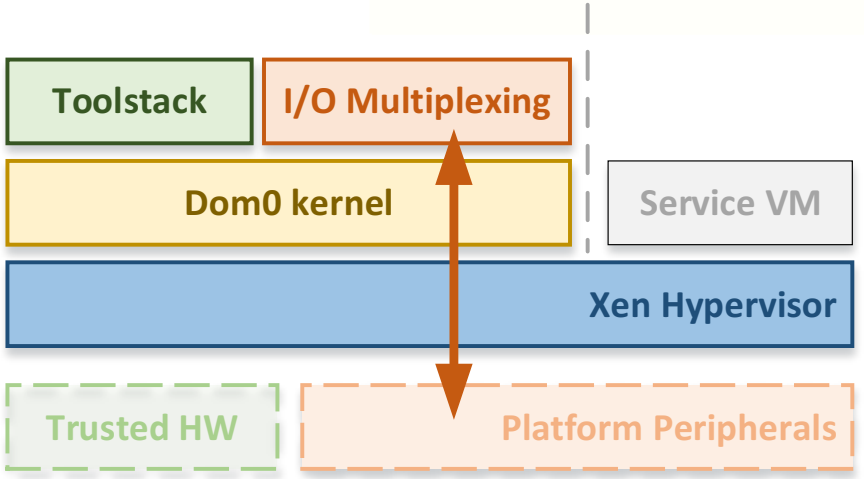
```
switch (op->cmd) {
    case XEN_PCI_OP_conf_read:
            op->err = xen_pcibk_config_read(dev,
                      op->offset, op->size, &op->value);
            break;
    case XEN_PCI_OP_conf_write:
            //...
    case XEN_PCI_OP_enable_msi:
            //...
    case XEN_PCI_OP_disable_msi:
            //...
    case XEN_PCI_OP_enable_msix:
              //...
    case XEN_PCI_OP_disable_msix:
            //...
    default:
            op->err = XEN_PCI_ERR_not_implemented;
            break;
}
```

The non-obvious vulnerable section in pciback.
Source: XenPwn, Felix Wilhelm, Infiltrate 2016

Core Issue: 'polymath' dom0

In this case, the current OpenXT architecture enables the attacker:

- dom0 has too many responsibilities:
  - Hosts drivers for interfacing with most platform hardware.
  - Provides services (e.g. PV backends) to guest domains.
  - Manages and controls all other domains, and thus requires significant privileges.



Core idea: Components with significant privileges shouldn't aggregate responsibilities; and shouldn't share attack surfaces with untrusted guests, or untrusted world-facing hardware.

First-step solution: disaggregation

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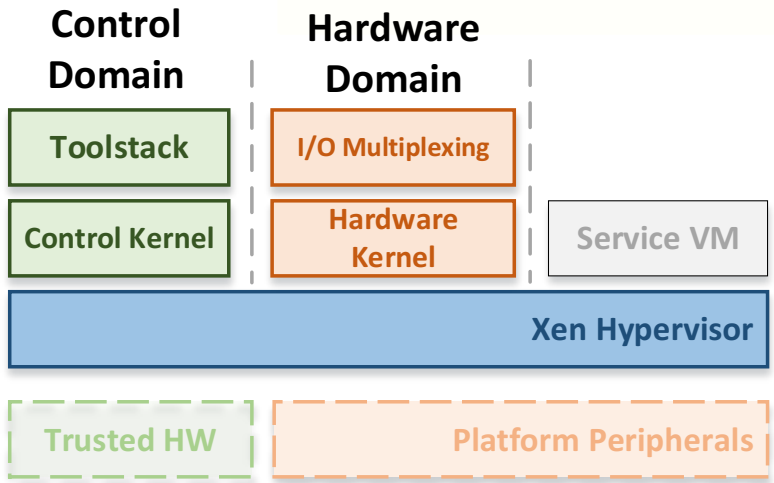
Disaggregation distributes responsibilities between **multiple dedicated domains**.

- OpenXT already separates network hardware into its own NDVM; and PCI passthrough allows similar treatment for other devices (USB, storage, display*).
- As of Xen 4.5, Xen finally separates the concept of the *initial domain* (dom0) from the idea of a *hardware domain* and a *control domain*. This allows us some significant new freedoms!

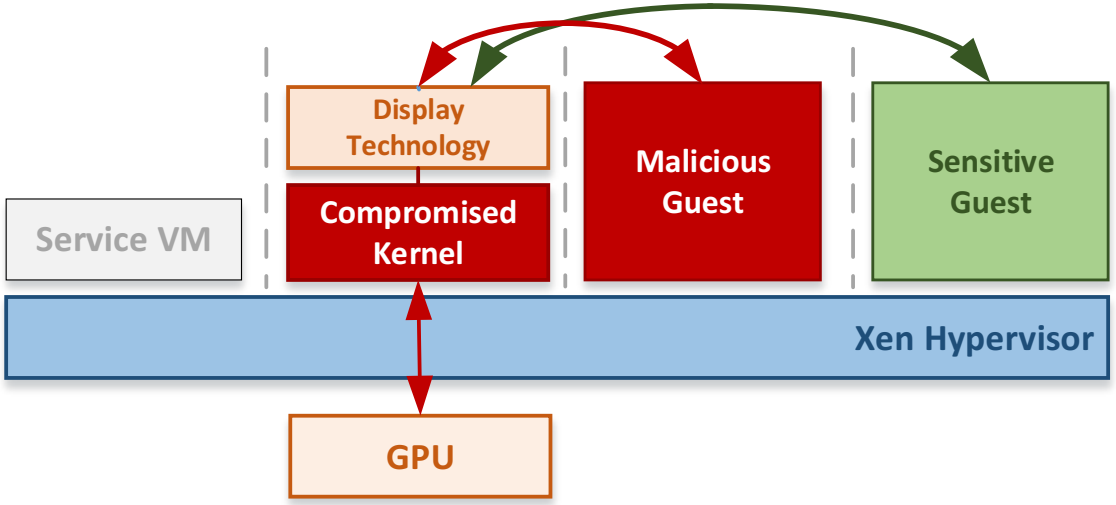


- Software components (e.g. the toolstack, the xenstore) can be further broken into multiple domains, allowing further compartmentalization and increase FLASK/XSM granularity.

Warning: Disaggregation compartmentalizes, reduces *shared* attack surface, and allows for finer-grained permissions, but doesn't automatically reduce the size of the TCB.

Disaggregation: limitations

Disaggregation can significantly limit the scope of an attack, but it doesn't automatically solve existing problems.



- Vulnerable components will likely remain vulnerable even in a disaggregate model—limited scope attacks are still attacks!
- Deprivileging components doesn't remove them from the TCB: sensitive data may still be passing through them!

“Advanced Techniques”

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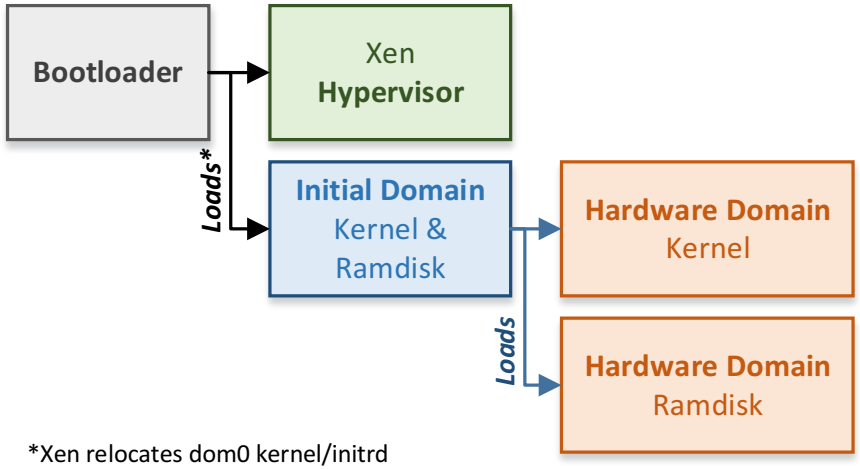
Techniques from other areas of trusted computing can significantly augment disaggregation:

- **Preventing or limiting persistence can further limit the scope of an exploit.** Virtual machines that exist only for the duration of a request, or which are restarted or refreshed periodically (as in the Xoar/Bear architectures) significantly limit the scope of a compromise. These benefits are compounded when service VMs self-diversify.
- **Replacing complex “full-distribution” systems with unikernels can significantly reduce the size of the trusted computing base.** This technique comes with a trade-off: replacing general-purpose software with purpose-built equivalents can significantly reduce attack surface, but often significantly reduces real-world testing.

Daniel De Graaf's HWDOM Patchset…

Xen's **initial domain** (dom0) is unique in that it is constructed **by Xen**.
By default, it is granted all hardware resources and significant privilege.



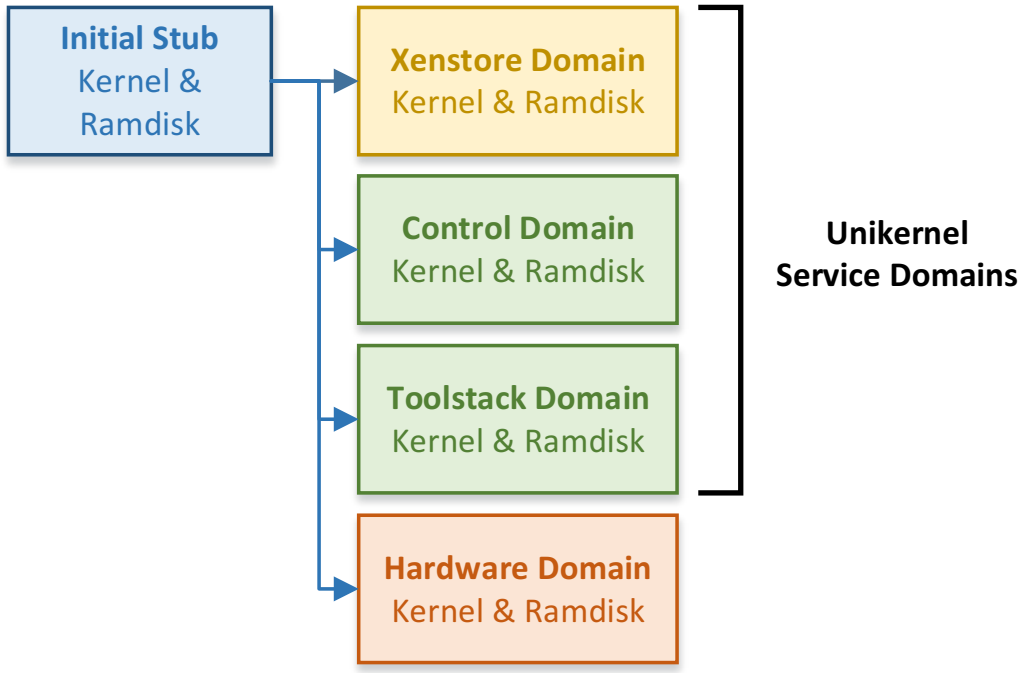
*Xen relocates dom0 kernel/initrd

Included in Xen 4.5, a **NSA patchset** allows deferred construction of the hardware domain, with the intention of enabling disaggreate models.

In this model, a privileged domain can be constructed by Xen without implied hardware access; this domain can later construct the hardware domain.

… and associated domain builder.

Included with the patch set was a **reference domain builder**, which serves to bootstrap a disaggregated system.



This domain builder provides an example of several **unikernel service domains**, providing purpose-built environments for e.g. the XenStore.

SOLID & Non-Traditional Tunneling

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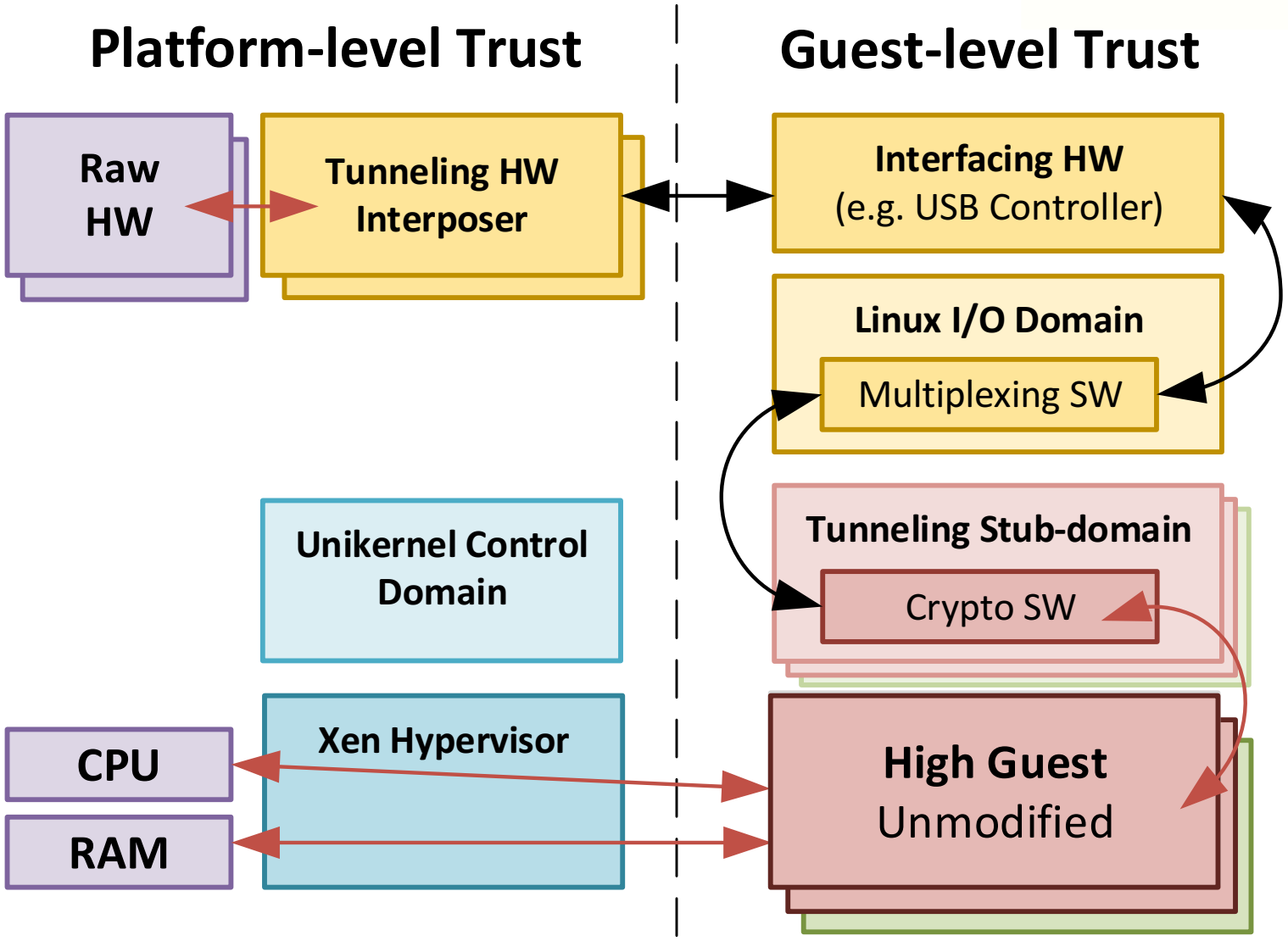

Question Break

Client Virtualization on ARM

towards virtualization for cell phones, tablets, and embedded

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Client Virtualization for Mobile Devices

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The rise of mobile processors with virtualization extensions presents new opportunities for client virtualization.

- If anything, the benefits of client virtualization (consolidation, isolation) are more important on mobile.
  - While it's often practical to own multiple computers, carrying multiple phones or tablets quickly reduces portability.
- In the private sector, organizations often have difficulty separating personal and 'official' data and applications.
  - especially difficult for BYOD ('Bring your own device') IT
- In the government sector, mobile devices can provide portable access solutions.

Secure Phones/Tablets: Ideal Case

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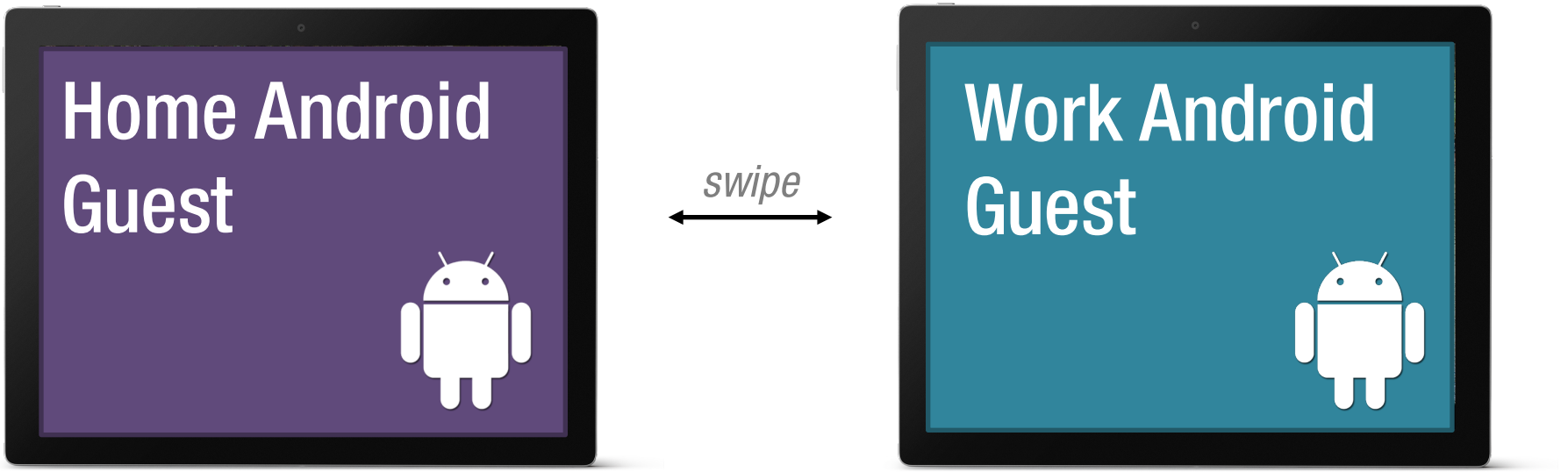
An ideal **client virtualization solution** would provide the an experience consistent with a baremetal mobile device, but will allow VM switching.

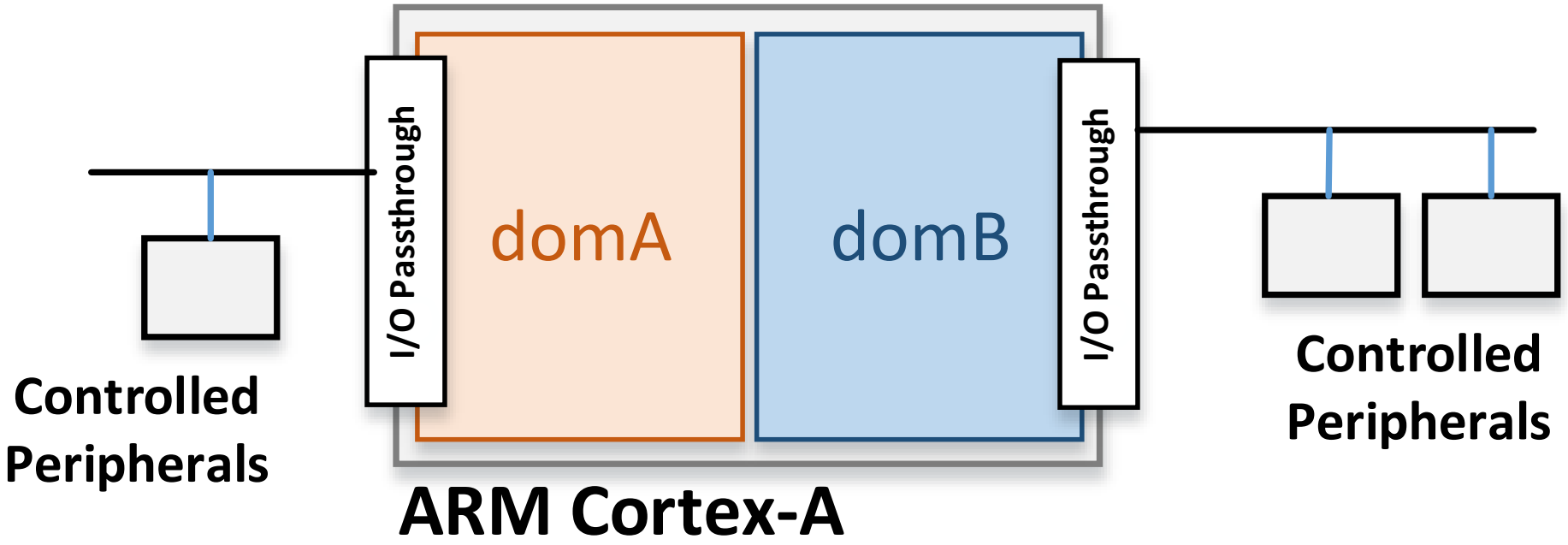


Pictured: *Google Pixel C*

Several companies have phone/tablet hypervisor platforms (e.g. VMware), but no commercial or open-source offering is currently available.

Embedded Hypervisors

Embedded hypervisors can be used to support legacy applications in non-user-facing systems, allowing similar consolidation.



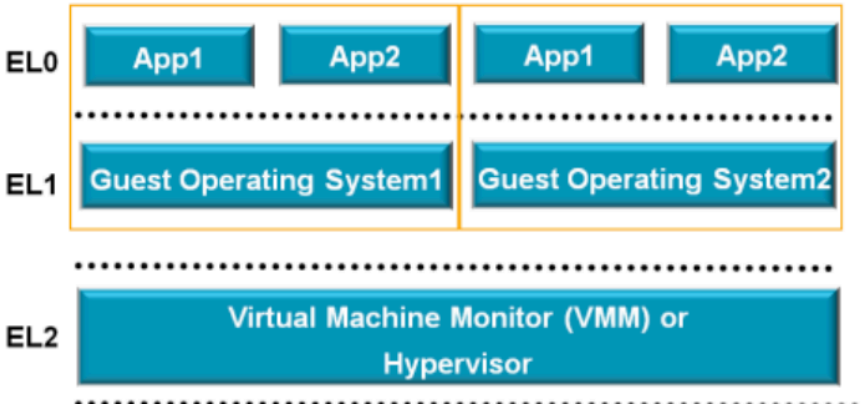
Embedded hypervisors straddle the line between client and server virtualization: while not user-facing, they often support peripheral HW.

ARM Virtualization Extensions

Modern ARMv7-A (32-bit) and ARMv8-A (64-bit) processors support virtualization extensions, which provide VT-x-like hardware support.

ARM's virtualization extensions:

- Provide similar capabilities to Intel's offerings, though with some significantly differing mecahnisms.
- Lack the near-ubiquitous support characteristic of Intel's virtualization tech.
  - Only select cores support the virtualization extensions, and most commercial phones and tablets prohibit you from using them!



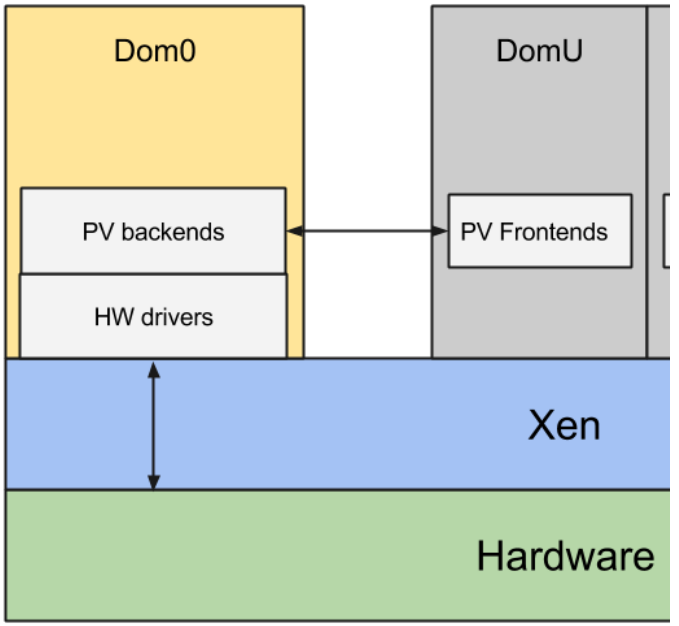
Source: *ARM ARMv8 Whitepaper*

Upstream Xen on ARM

The upstream Xen community has been actively working to support ARM platforms; Xen-on-ARM has been usable since about Xen 4.4.0.

ARM support is a "refinement" of the existing Xen architecture:

- Only one type of guest: PVH.
  - This means no required device models, but drivers must be Xen-aware.
  - Performance-wise, this seeks to be the best of both worlds: hardware-assisted virtualiztaion without emulated devices.
- Unified virtualization support allows for a smaller codebase: 90k SLOC vs 150 k SLOC



Source: *XenProject "Xen on ARM" Whitepaper*

Challenge: Hardware Availability

Only a limited number of commercially available phones and tablets support the ARM virtualization extensions.

It can be challenging to find COTS phones and tablets for ARM development:

- The Google Pixel C (pictured) is an ARMv8 tablet that supports hypervisor applications and has case-closed access to a debug UART.
- Allwinner tablets (inexpensive, insecure) tend to provide simple ARMv7 development boards.
- Many development boards now support hypervisor applications; and OEM partnerships may yield hypervisor-enabling bootloaders.

Challenge: Hardware Support

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The implementation of ARM hardware is significantly more varied than its x86 counterparts, down to the details of individual chipsets.

ARM is an IP vendor, not an IC manufacturer: most IC vendors build their own componentry around an existing ARM core. As a result, Xen modifications are often required to support new SoC families.

Examples:

- The NVIDIA Tegra family (ARMv7, ARMv8) has a special "legacy" interrupt controller that must be correctly programmed by Xen.
  - Not yet supported in upstream Xen; we have a WIP patchset to address this.
- The Exonos family has a non-standard timer architecture; platform quirks exist upstream to get timers working.

Challenge: Android Support

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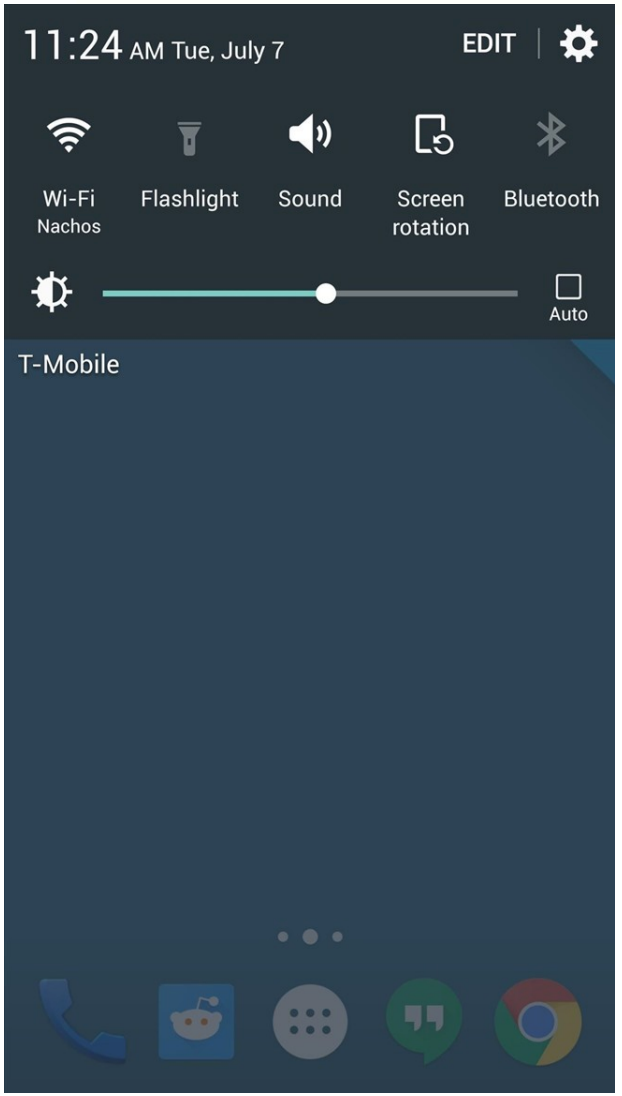
As PVH guests require PV drivers, guest OS builds must be customized to run on Xen.

Android's Linux-kernel core makes support for PV drivers relatively straightforward; but some sections are are more complex.

- Android versions starting with 4.0 technically require a (v)GPU with OpenGL ES support.
  - Out of tree patches enable software rendering; but significant use of transparency leads to poor performance, especially in terms of power.
- Peripheral devices (accelerometers, gyroscopes, light sensors) require new classes of PV driver.



Open Questions

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Questions for community consideration:

- Should OpenXT expand into the ARM arena?
  - If so, how do we want to proceed in the future?
  - Does this provide value to existing derived products?

- How would an ARM project mesh with the OpenXT roadmap?

Questions?

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