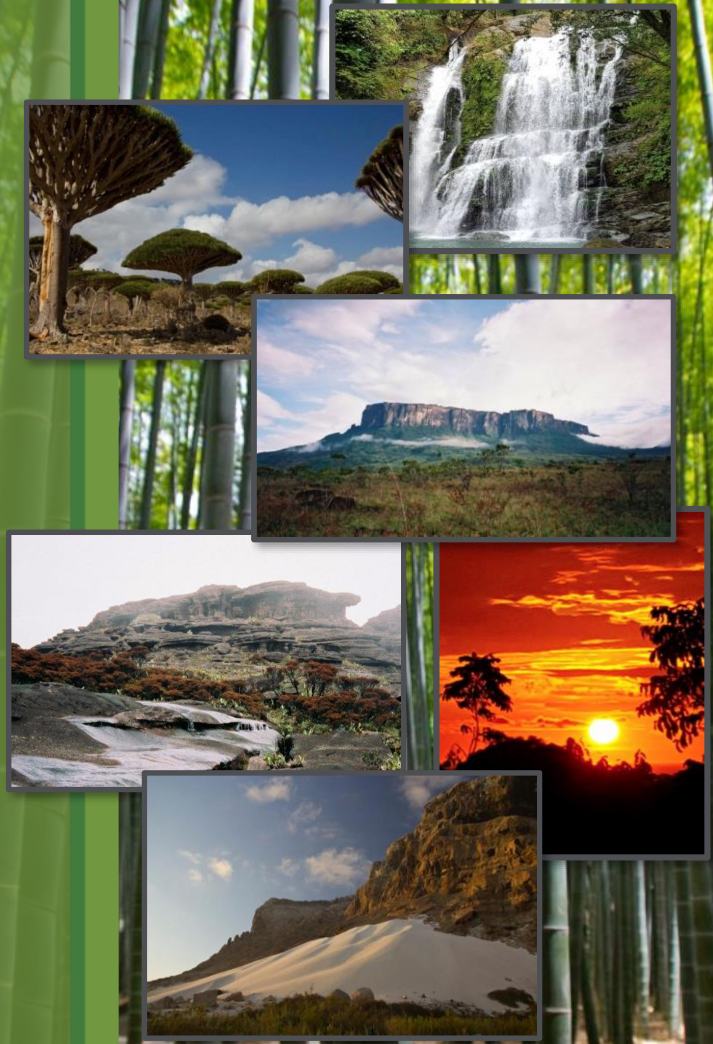
An Introduction to Xen Project Virtualization

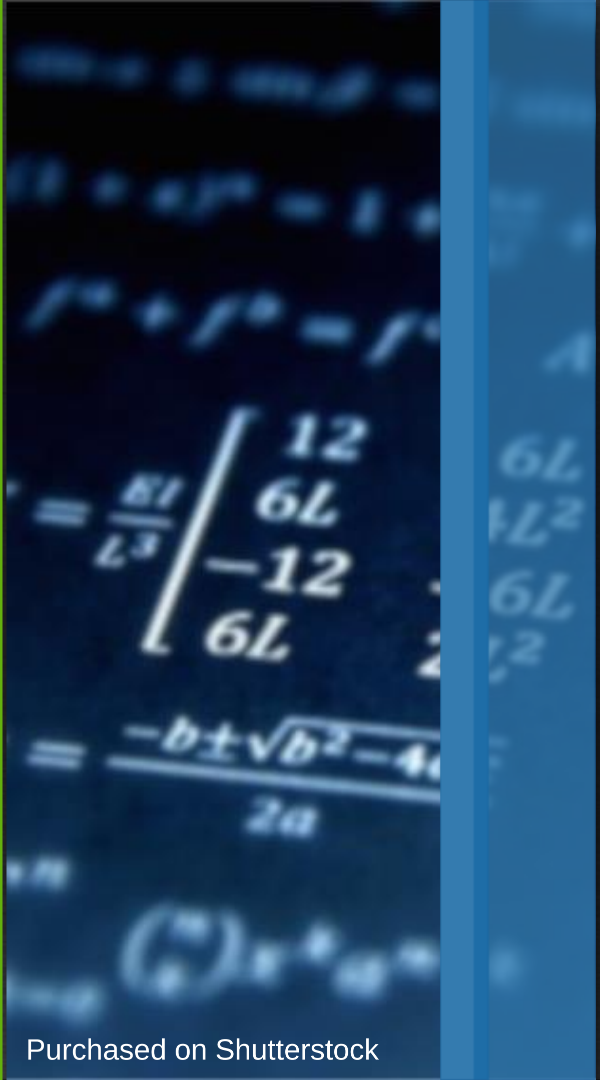
Lars Kurth
Community Manager, Xen Project
Chairman, Xen Project Advisory Board
Director, Open Source, Citrix

IRC lars_kurth

About Me

- Was a contributor to various projects
- Worked in parallel computing, tools, mobile and now virtualization
- Community guy for the Xen Project
  - Working for Citrix
  - Accountable to the Xen Project Community
  - Chairman of Xen Project Advisory Board




Purchased on Shutterstock

Why Virtualize?

Consolidation (Cut Costs)

Servers/Equipment, Cooling, Floor space

Faster provisioning

Flexibility

Less dependency on specific Hardware

Co-existing OS environments

Increased uptime

Live migration, storage migration, fault tolerance, HA

Enhanced security

Strong Isolation

Architecture provides strong isolation

Grant tables

System Partitioning

Disaggregation: sandboxing parts of the system

Fine-grain control of VM capabilities

Secure I/O

Sandboxing disk, memory, etc. drivers

New classes of threat detection

Virtual Machine Introspection, alt2pm

Consolidation

Single SoC

Maintainability, BoM

Flexibility

Less dependency on specific Hardware

Co-existing OS environments

Additional Requirements

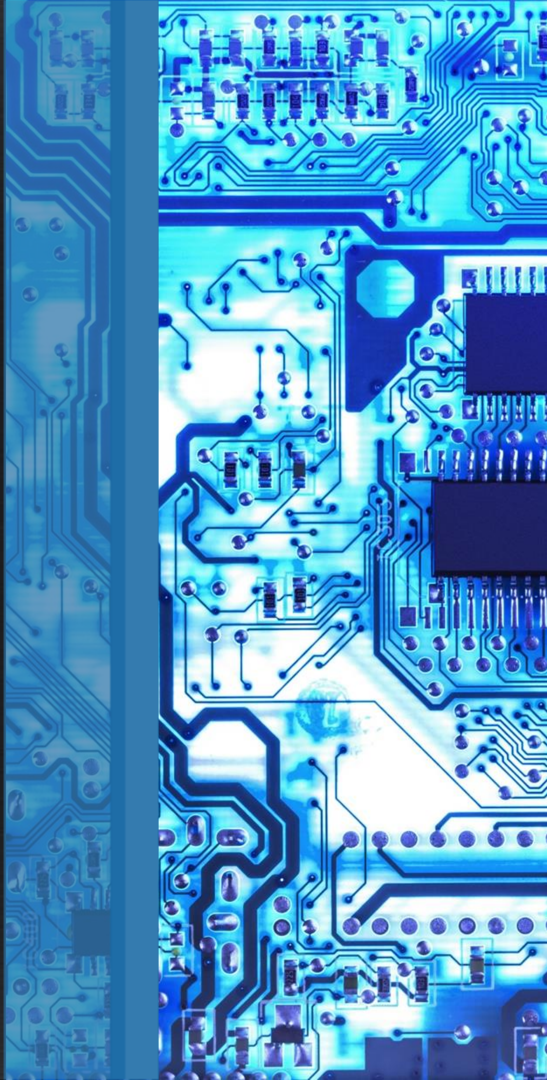
Security requirements (same as on previous slide)

Minimal IRQ latency

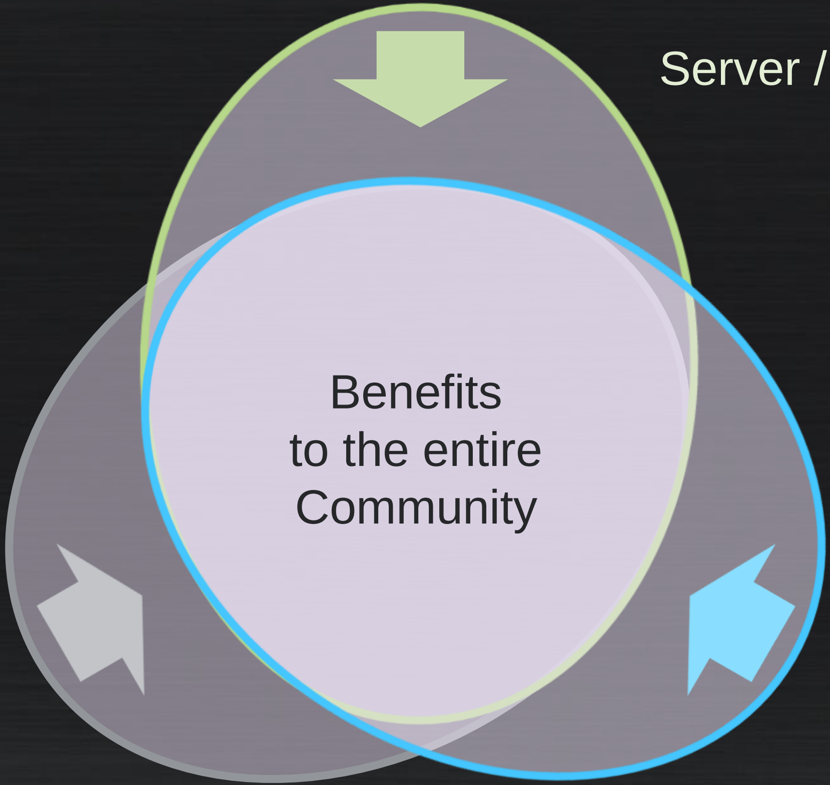
Safety Certification

Low or 0 scheduling overhead

Drivers for special I/O devices



Increasing alignment of Needs



Server / Cloud

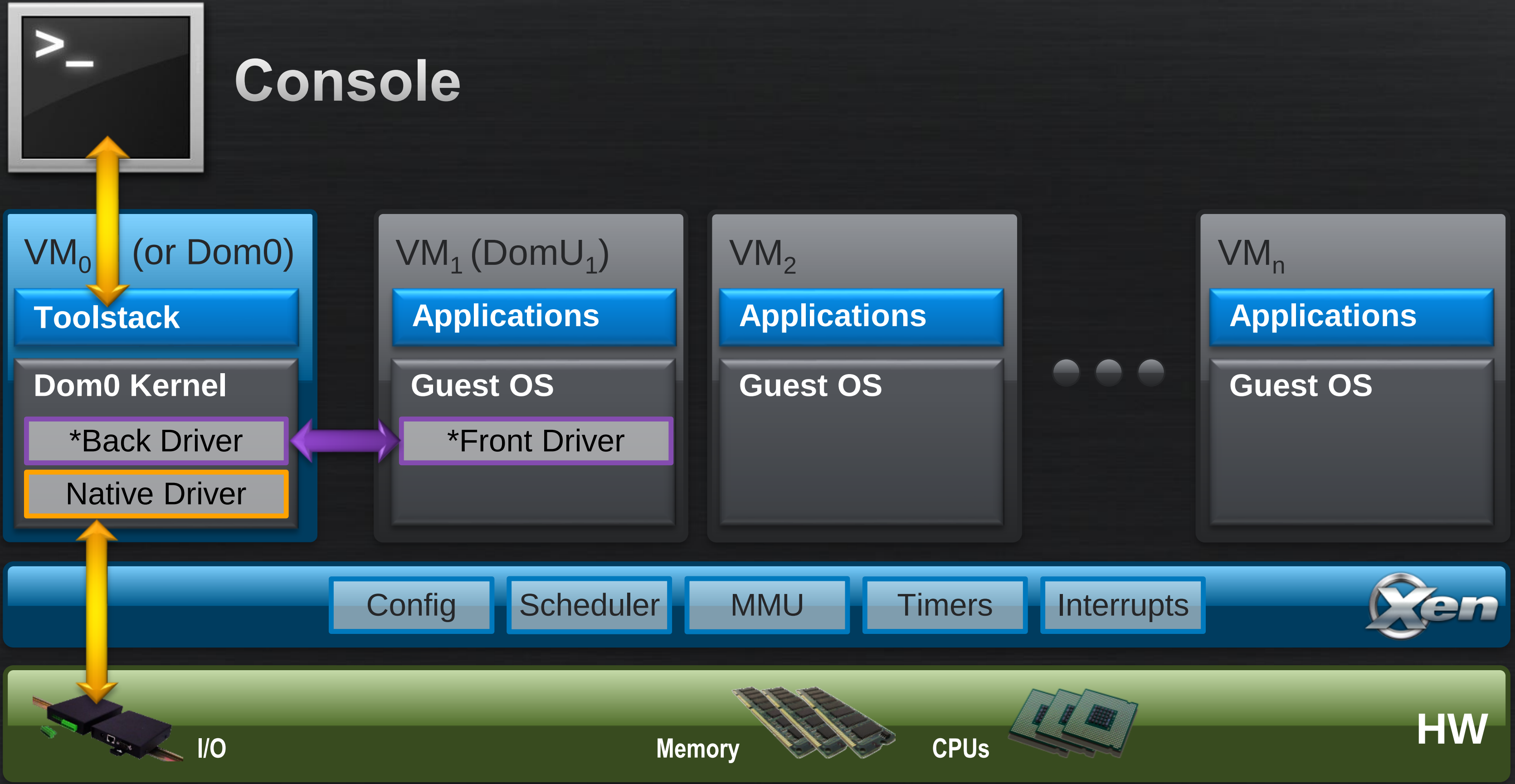
Benefits
to the entire
Community

Security
Applications

Embedded /Automotive
Applications

Xen, a type-1 Hypervisor with a twist

Introduction of key concepts


>_
Console
VM$_0$ (or Dom0)
Toolstack
Dom0 Kernel
*Back Driver
Native Driver
VM$_1$ (DomU$_1$)
Applications
Guest OS
*Front Driver
VM$_2$
Applications
Guest OS
VM$_n$
Applications
Guest OS
Config
Scheduler
MMU
Timers
Interrupts
Xen
I/O
Memory
CPUs
HW

Virtualization Modes (x86 & ARM)

Shortcut	Mode	With	Disk and Network	Interrupts & Timers	Emulated Motherboard, Legacy Boot	Privileged Instructions, Page Tables	
HVM / Fully Virtualized	HVM		Qemu	Qemu	Qemu	HW	Windows
HVM + PV drivers	HVM	PV Drivers	PV	Qemu	Qemu	HW	
PVHVM	HVM	PVHVM Drivers	PV	PV	Qemu	HW	Linux, BSDs, …
PVH	PV	pvh=1	PV	PV	PV	HW	
PV	PV		PV	PV	PV	PV	
ARM	N/A		PV	PV	PV	HW	

Why is PVH & PVH Dom 0 important?

ARM	N/A	PV	PV	PV	VH
PVH	PV	PV	PV	PV	VH
PV	PV	PV	PV	PV	P

This is the most complex part of Xen today!

Simplicity: Less code & fewer Interfaces in Linux/FreeBSD

Security : smaller TCB and attack surface, fewer possible exploits
Clean-up : simplify Xen-Linux kernel, Xen-Any-OS interface

Better Performance & Lower Latency

Dom0 must be a PV guest: PVH allows us to run Dom0 as PVH guest
32 bit: PV guest kernels were run in ring 1, userspace in ring 3 (HW isolation)
64 bit: no ring 1 & 2 ➔ kernel & user space must share ring 3 (TLB flushes)

Why PVH v2?

Remove Limitations, Simplicity, Code-sharing (ARM & HVM)

PVH v1 inherits all the **PV limitations**

Took the PV execution path and added HW support

Separate implementation to HVM: *pass-through*, APIC, APIC config, ACPI
Restrictions: Paging restrictions (4K ➔ 2M+), no access to emulated devices

PVH v2

Reimplementation that Behaves exactly like PVH (minus restrictions)
Uses the same interfaces and execution path as Xen on ARM
Reuses much more HVM code than PVH v1
No dependency on QEMU

www.slideshare.net/xen_com_mgr/towards-a-hvmlike-dom0-for-xen

Virtualization Modes: Future

Shortcut	Mode	With
HVM / Fully Virtualized	HVM	
HVM + PV drivers	HVM	PV Drivers
PVHVM	HVM	PVHVM Drivers
PVH v2	PV	pvh=1
~~PV~~	~~PV~~	
ARM	N/A	

2017

Complete PVH v2
for Dom0 and DomU

Add capability to run classic unmodified PV kernels, in an HVM or PVH v2 domain.

Later: Deprecate PV

With a view to removing PV mode and thus simplifying Linux / BSD / … - Xen interface

Server Virtualization & Cloud Computing

Recent and upcoming developments

The gears of the Cloud

Large User Base
>10M Users

Powers the largest clouds in production

Commercial Xen based products from
Citrix
Huawei
Inspur
Oracle

Alibaba Cloud
aliyun.com

amazon
web services

Amazon Lightsail

ORACLE
CLOUD

rackspace
the open cloud company

SOFTLAYER
an IBM Company

Tencent 腾讯

Live Patching

A tale of improved collaboration within the Xen Project Community

2015
2016
2017
reboot
reboot
D
4.7
4.8
P

Why did we develop Live Patching?

Affected AWS, Rackspace, IBM SoftLayer and many others

Deploying security patches may require reboots; Inconveniences users

How did we fix this?

2015: Design with input from AWS, Alibaba, Citrix, Oracle and SUSE

Replace functions while running (old with new) in a payload

Stackable payloads can be applied and removed

2016: Xen 4.7 came with Live Patching for x86

2016: Xen 4.8 added extra x86 use-cases and ARM support

2017: XenServer 7.1 releases Live Patching in first commercial product

…

If you want to know more …

Specification & Status

xenbits.xen.org/docs/unstable/misc/livepatch.html
wiki.xenproject.org/wiki/LivePatch

Presentations, Videos, Demos

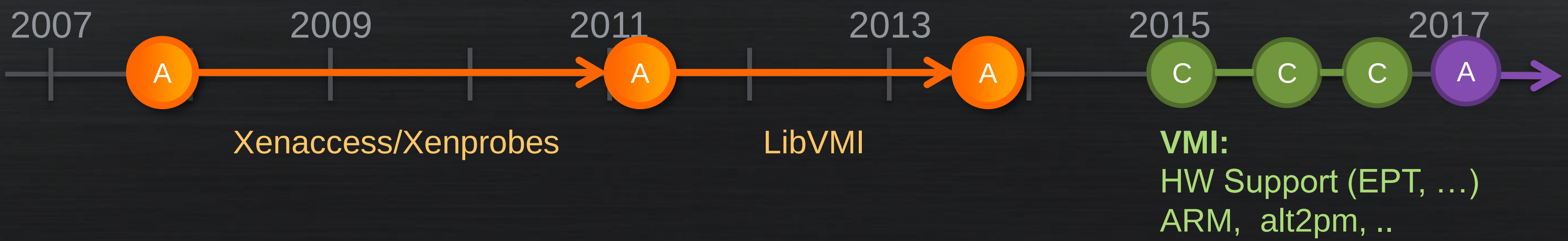
bit.do/live-patch-detailed-ppt
bit.do/live-patch-detailed-video

bit.do/live-patch-short-ppt
bit.do/live-patch-short-video

Pratap Sankar @ Flickr

Virtual Machine Introspection

A new way to protect against malware



Xenaccess/Xenprobes

LibVMI

VMI:
HW Support (EPT, …)
ARM, alt2pm, ..

Enablers: from xenaccess/xenprobes to LibVMI

Interesting research topic

Originally used for forensics (too intrusive for server virt)

VMI: enabling commercial applications

Hardware assisted VMI solves the intrusion problem

Collaboration between: Zentific, Citrix, BitDefender, Intel and others

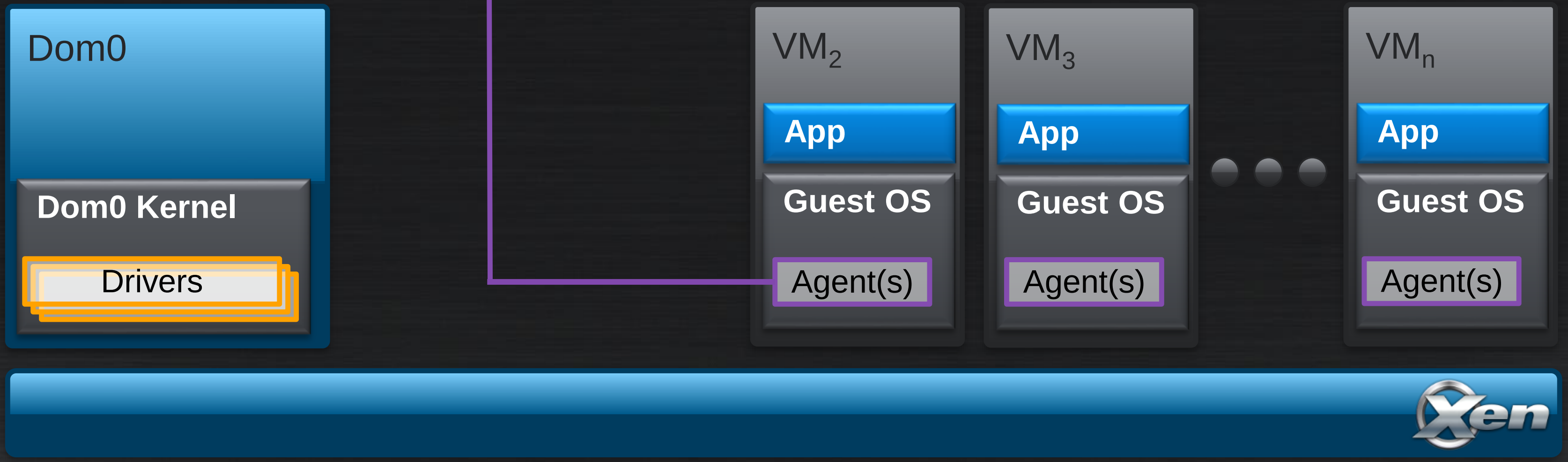
Products

AIS Introvirt, BitDefender Hypervisor Introspection, Zentific Zazen

Traditional Cloud Security

Installed in-guest agents, e.g. anti-virus software, VM disk & memory scanner, network monitor, etc.

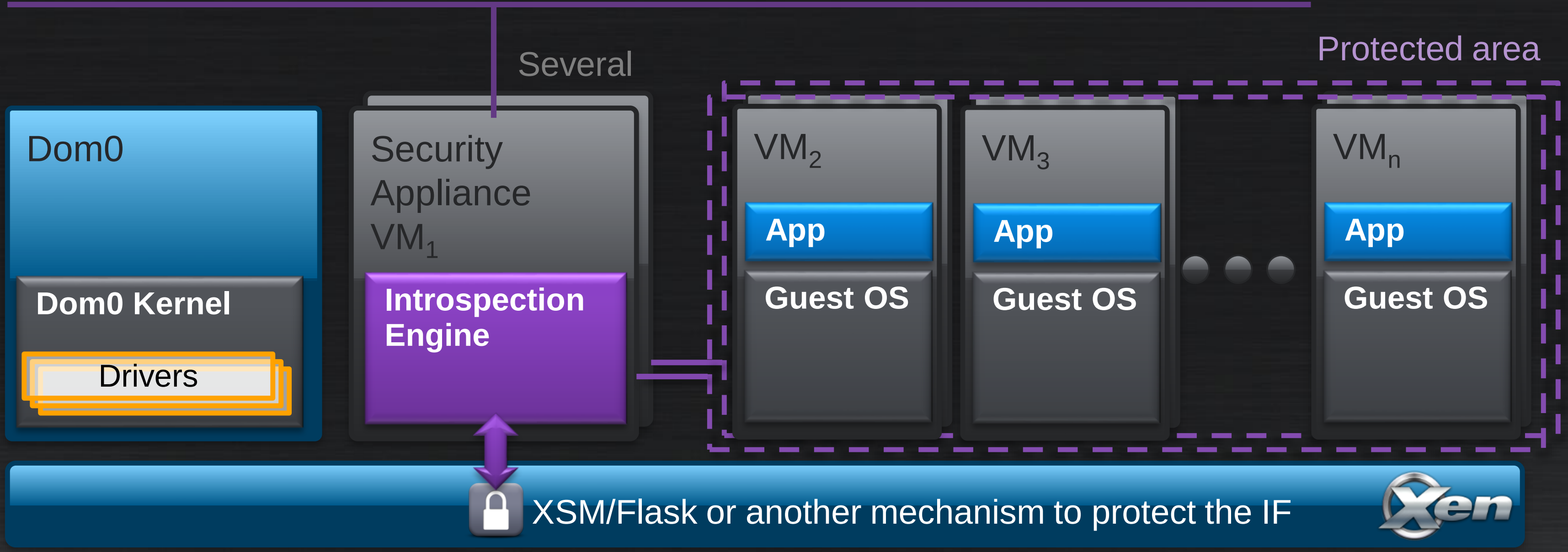
Can be disabled by rootkits and advanced persistent threats (APT)



A new model for Cloud Security?

Uses HW extensions to monitor memory (e.g. Intel EPT) ➔ Low Intrusion

Register rules with Xen to trap on and inspect suspicious activities (e.g. execution of memory on the dynamic heap)



Protection against attack techniques

All malware need an attack technique to gain a foothold
Attack techniques exploit specific software bugs/vulnerability

The number of available attack techniques is small
Buffer Overflows, Heap Sprays, Code Injection, API Hooking, …

Because VMI protects against attack techniques
It can protect against entirely new malware

Verified to block these advanced attacks in real-time
APT28, Energetic Bear, DarkHotel, Epic Turla, Regin, ZeuS, Dyreza, …
solely by relying on VMI

Protection against rootkits & APTs

Rootkits & APTs

Exploit 0-days in Operating Systems/System Software
Can disable agent based security solutions (mask their own existence)

VMI solutions operate from outside the VM

Thus, it cannot be disabled using traditional attack vectors

BUT:

VMI is not a replacement, for traditional security solutions
It is an extra tool that can be used to increase protection

If you want to know more …

Documentation

wiki.xenproject.org/wiki/Virtual_Machine_Introspection

Products

AIS Introvirt
XenServer
www.ainfosec.com

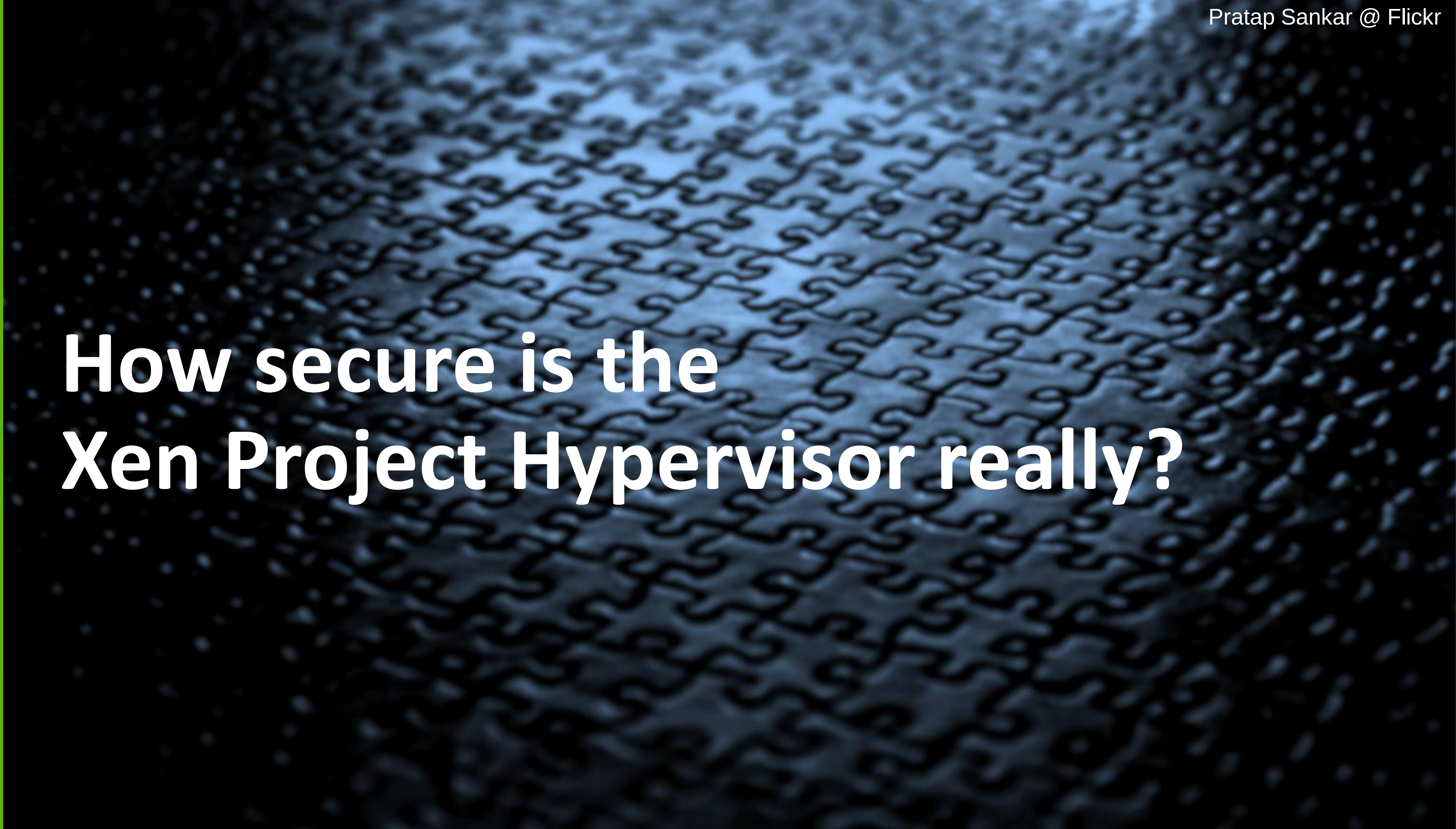
BitDefender HVI
XenServer
www.bitdefender.com

Protection & Remedial
Monitoring & Admin

Zentific Zazen (Apr 17)
Xen & XenServer & …
www.zentific.com

Protection & Remedial
Monitoring & Admin
Forensics & Data gathering
Malware analysis

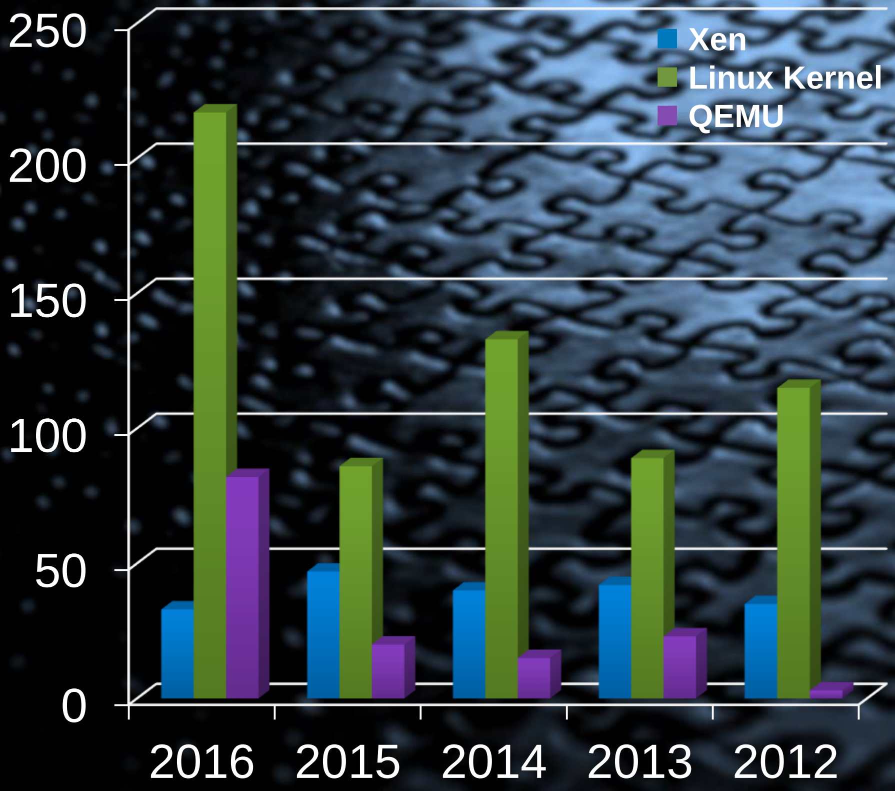
Pratap Sankar @ Flickr



Pratap Sankar @ Flickr

How secure is the Xen Project Hypervisor really?

All CVE’s (change time)



2015+

Active initiatives to find bugs

XTF to help find bugs

Fuzzing of some components

Very few ARM issues

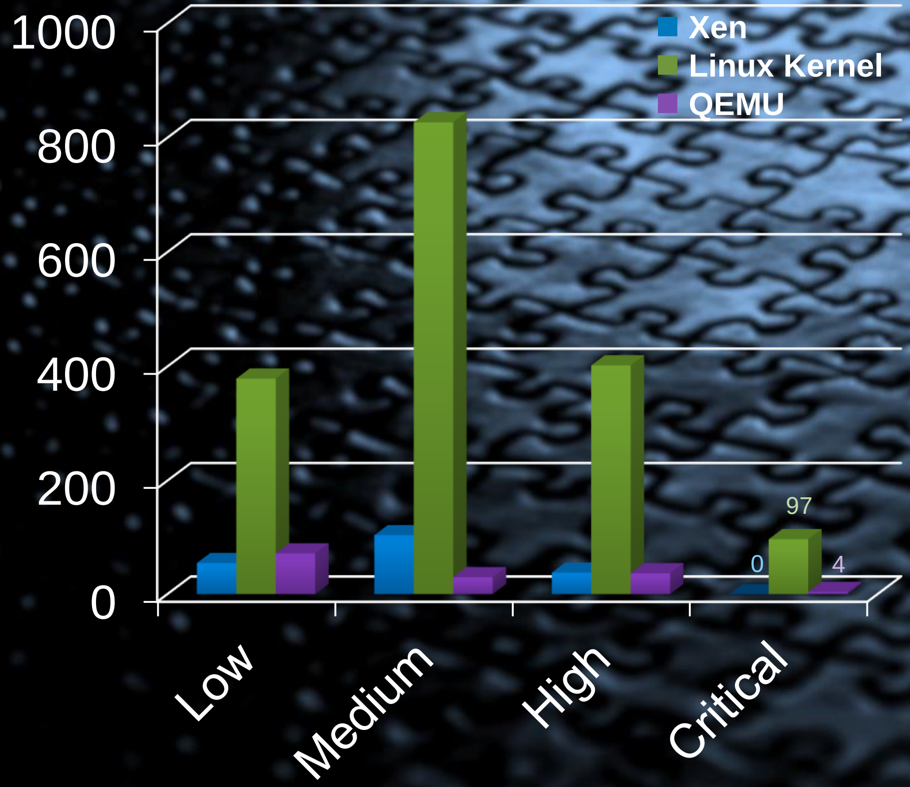
2016: 2/33

2015: 6/47

Does not use QEMU

Vulnerability data from cvdetails.com

CVE’s by CVSS Severity



Average CSSV Scores

Xen: 4.7

Linux Kernel: 5.9

QEMU: 4.3

Known 0-Day Exploits

Xen: 0

Linux Kernel: 18

QEMU: 0

Low = 0.1-3.9; Medium = 4.0-6.9; High = 7.0-8.9; Critical = 9.0-10.0

Vulnerability Process Comparison

	Team	Process	Type	CVEs	Days [1]	Who? [2]	For Severity [3]
Xen Hypervisor Includes Linux & QEMU vulnerabilities in supported Xen configurations	Yes	Yes	Responsible	Yes	14	D, S, P	All
OpenStack OSSA	Yes	Yes	Responsible	Yes	3-5	D, S, P	> Low
OpenStack OSSN	Yes	Yes	Full, post-fix	No			<= Low
Linux Kernel via	Yes	Partly [4]					
OSS security distros	Yes	Yes	Responsible	Yes	14-19	D	> Low
OSS security		No	Full	Some			<= Low
QEMU [5] via	Yes	Partly [4]				D	
OSS security distros			Responsible	Yes	14-19		> Low
OSS security			Full	Some			<= Low
Jailhouse	No	No					

[1] Days embargoed

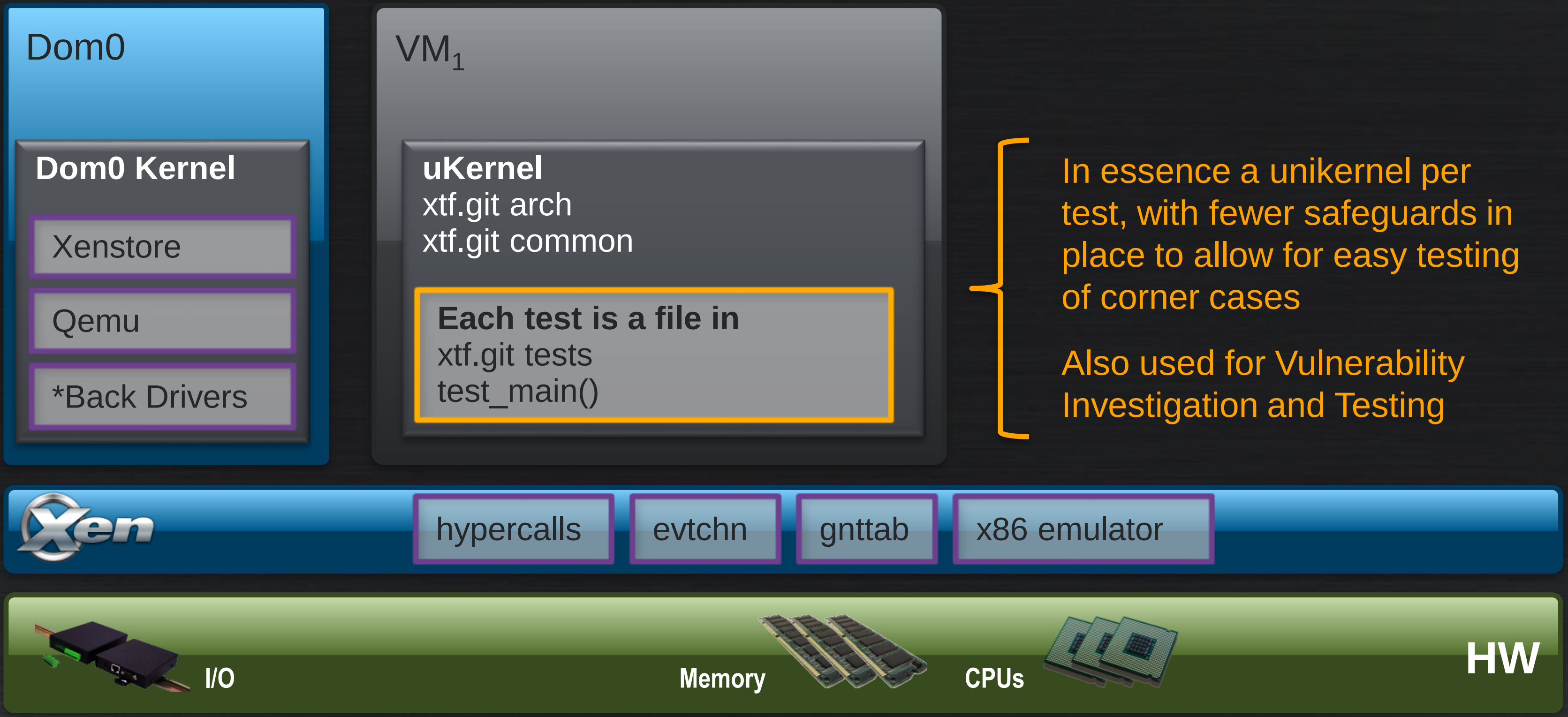
[2] D = Distros/Products, S = Public Service, P = Private

[3] Is the CVE severity used as cut-off for the process

[4] No own pre-disclosure list

[5] Only handles x86 KVM bugs, no own pre-disclosure list

XTF: Testing API behavior



Dom0

Dom0 Kernel

Xenstore

Qemu

*Back Drivers

VM$_1$

uKernel
xtf.git arch
xtf.git common

Each test is a file in
xtf.git tests
test_main()

hypercalls

evtchn

gnttab

x86 emulator

I/O

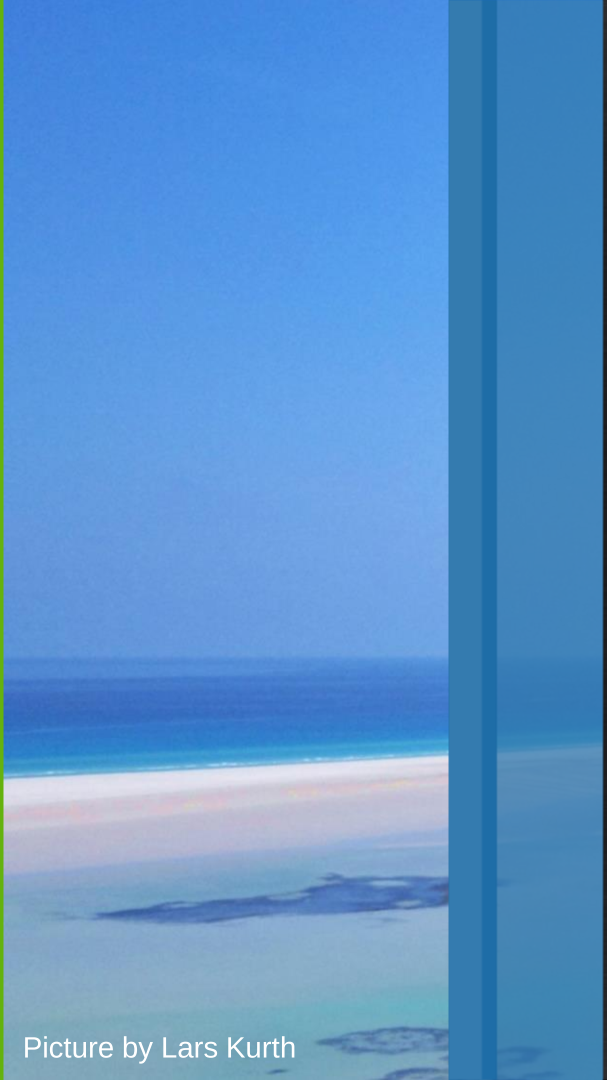
Memory

CPUs

HW

In essence a unikernel per test, with fewer safeguards in place to allow for easy testing of corner cases

Also used for Vulnerability Investigation and Testing



Picture by Lars Kurth

Summary on Security

Track Record

81% of Vulnerabilities Low and Medium

Average severity of vulnerabilities getting lower

Hardening Activities

Security Audits by Cloud and Product Vendors

Testing (fuzzing, XTF, code inspection, …)

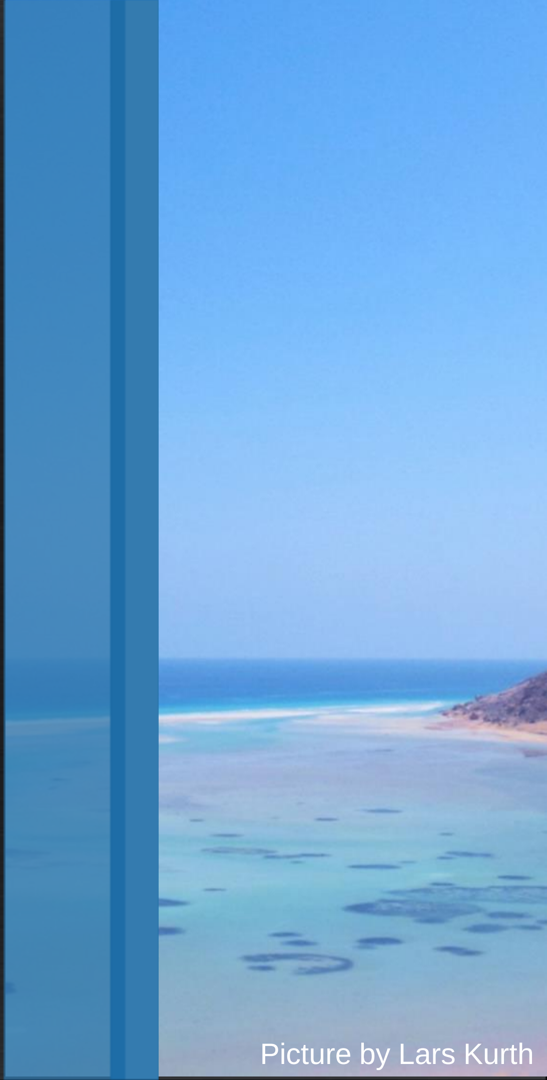
Industry Leading Vulnerability Process

Includes QEMU and Kernel XSAs

Designed with input from Cloud Providers

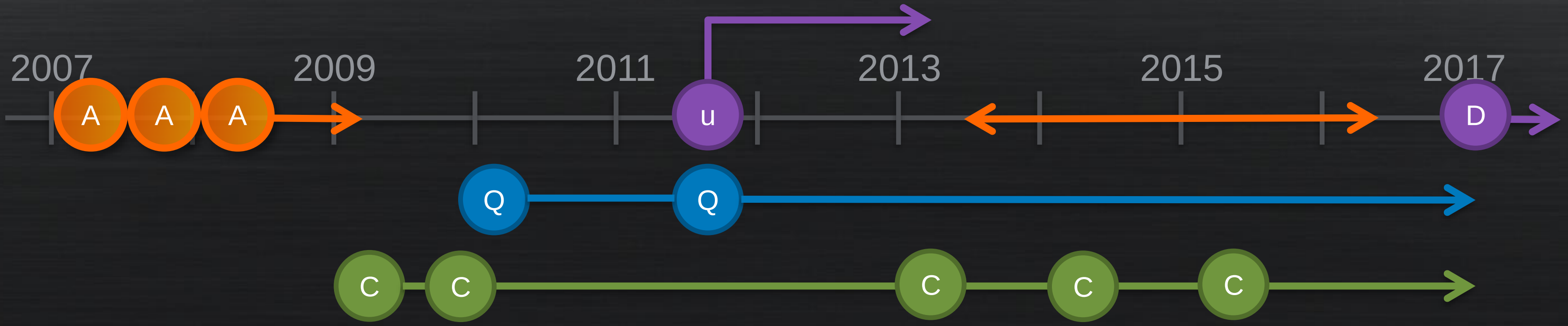
Isolation

Limits impact of exploits



Picture by Lars Kurth

Xen Project in Security Applications



Technology enablers: *XSM*, vTPM & TXT, *Disaggregation & Driver Domains*

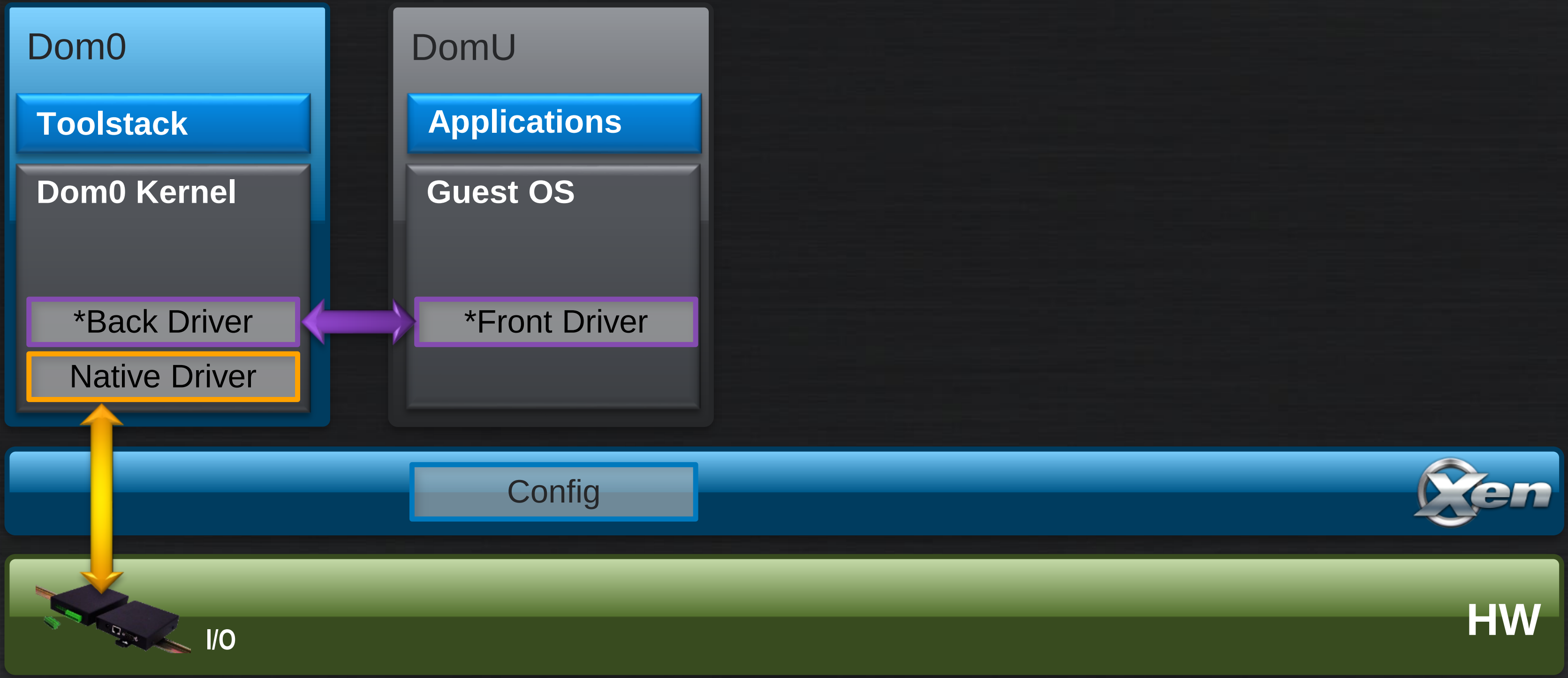
Qubes OS Architecture, Qubes OS 1.0, …

2009: Project Independence (Intel / Citrix)
2010: XenClient 1.0
2013: XenClient XT
2014: Became OpenXT (BAE Systems, Assured Information Security)
2015: Support for Cell Phones, Tablets and Embedded Devices

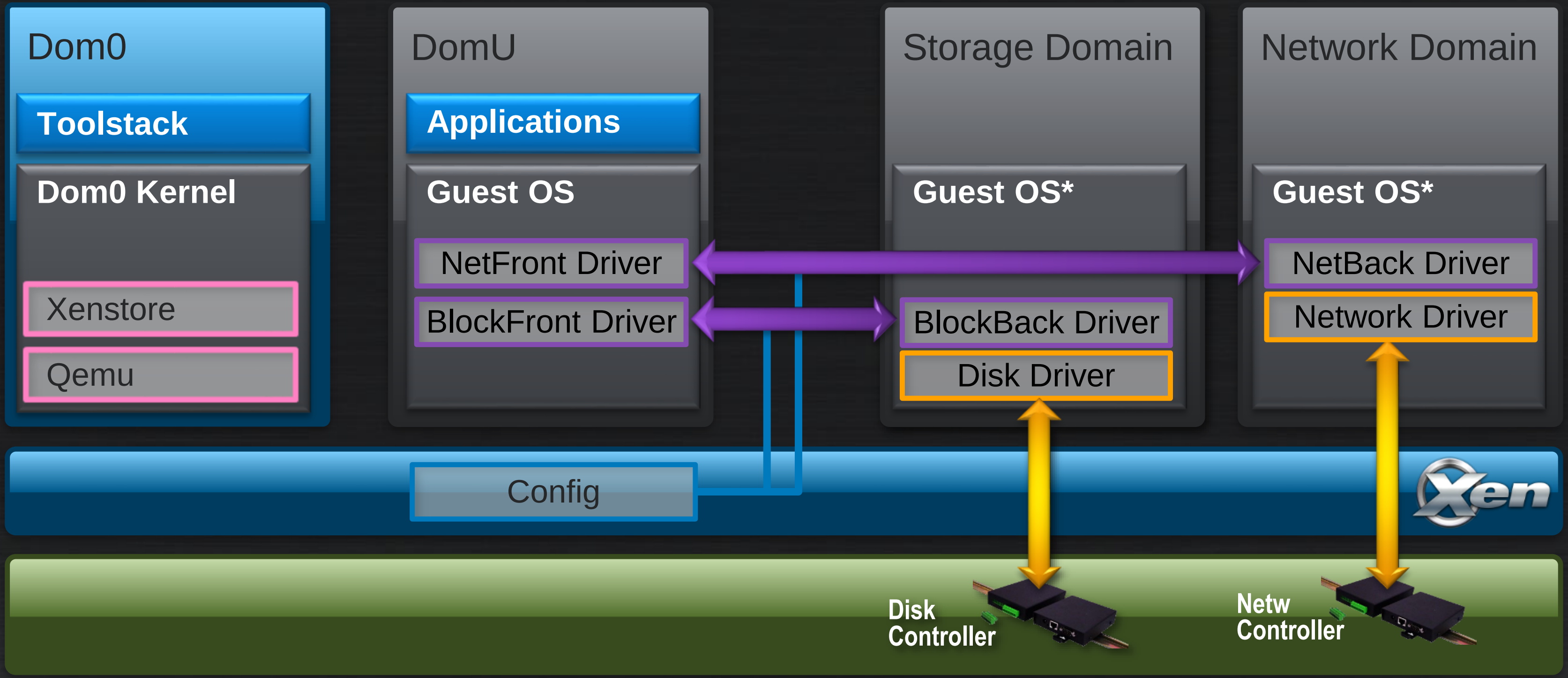
uXen (Bromium) – Windows only, thus never made it upstream

Crucible:Defense

Disaggregation Explained

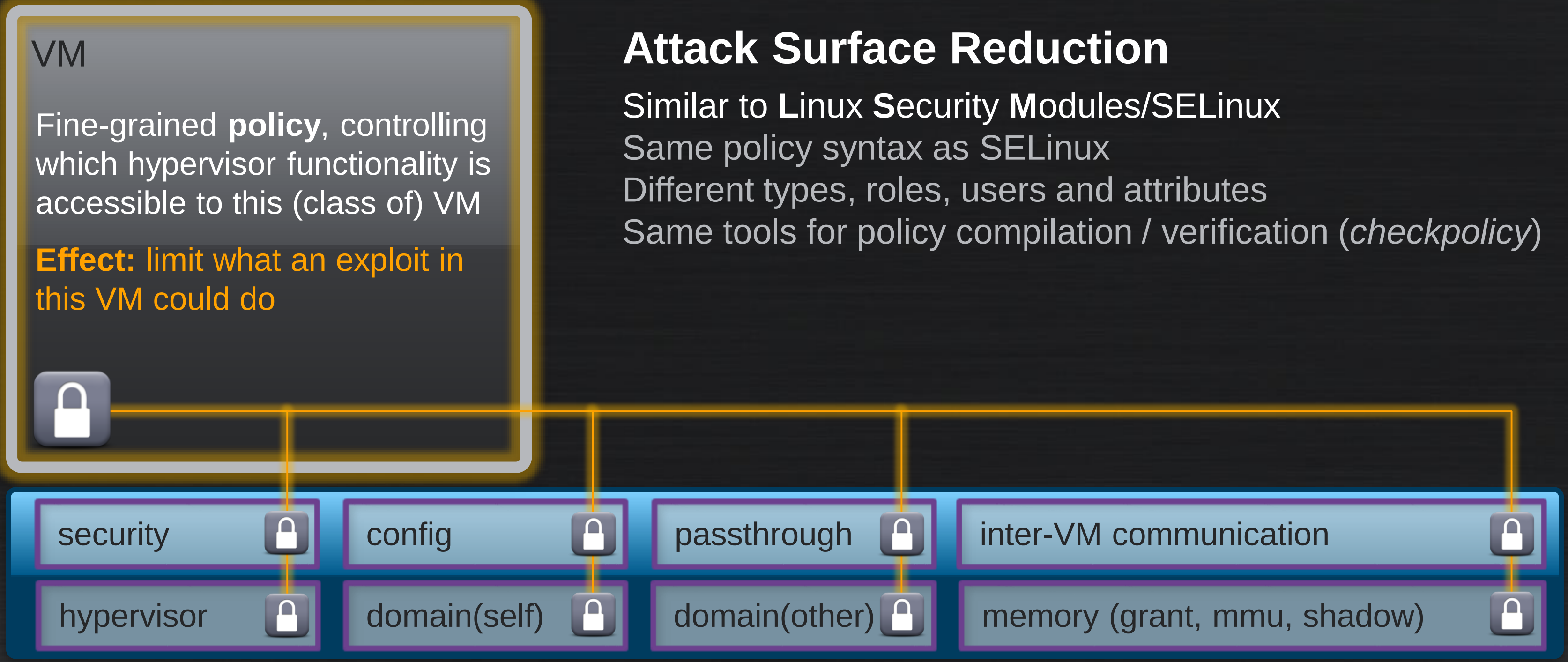


Disaggregation Explained



Driver Domain Guest OS*: Linux, BSD, MiniOS, unikernel, …

XSM/FLASK Explained



VM

Fine-grained **policy**, controlling which hypervisor functionality is accessible to this (class of) VM

Effect: limit what an exploit in this VM could do

security

config

passthrough

inter-VM communication

hypervisor

domain(self)

domain(other)

memory (grant, mmu, shadow)

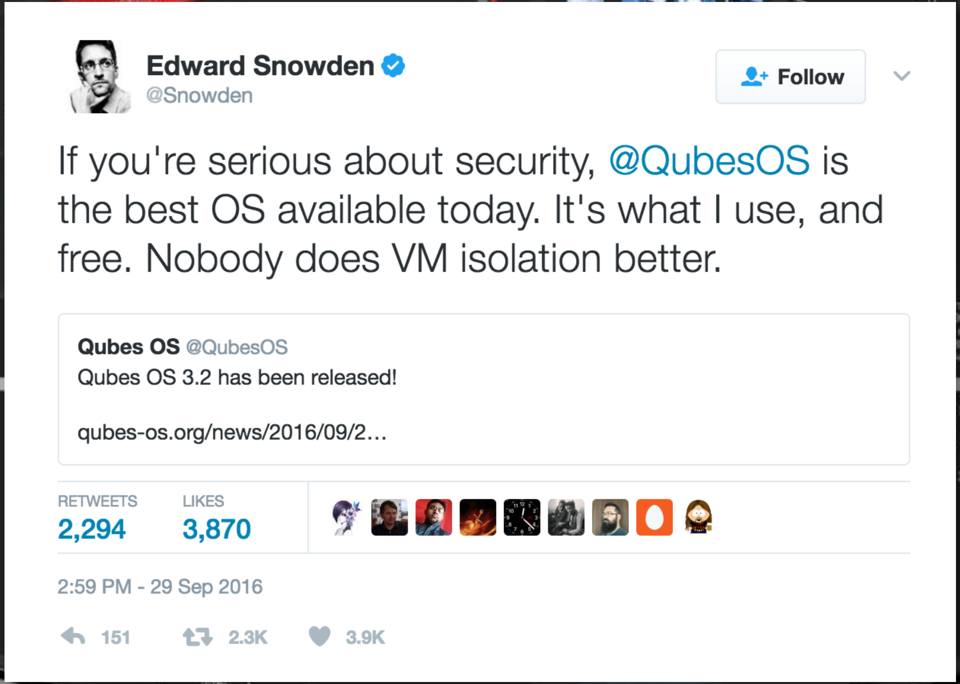
Attack Surface Reduction

Similar to **L**inux **S**ecurity **M**odules/SELinux

Same policy syntax as SELinux

Different types, roles, users and attributes

Same tools for policy compilation / verification (*checkpolicy*)



Edward Snowden
@Snowden

If you're serious about security, @QubesOS is the best OS available today. It's what I use, and free. Nobody does VM isolation better.

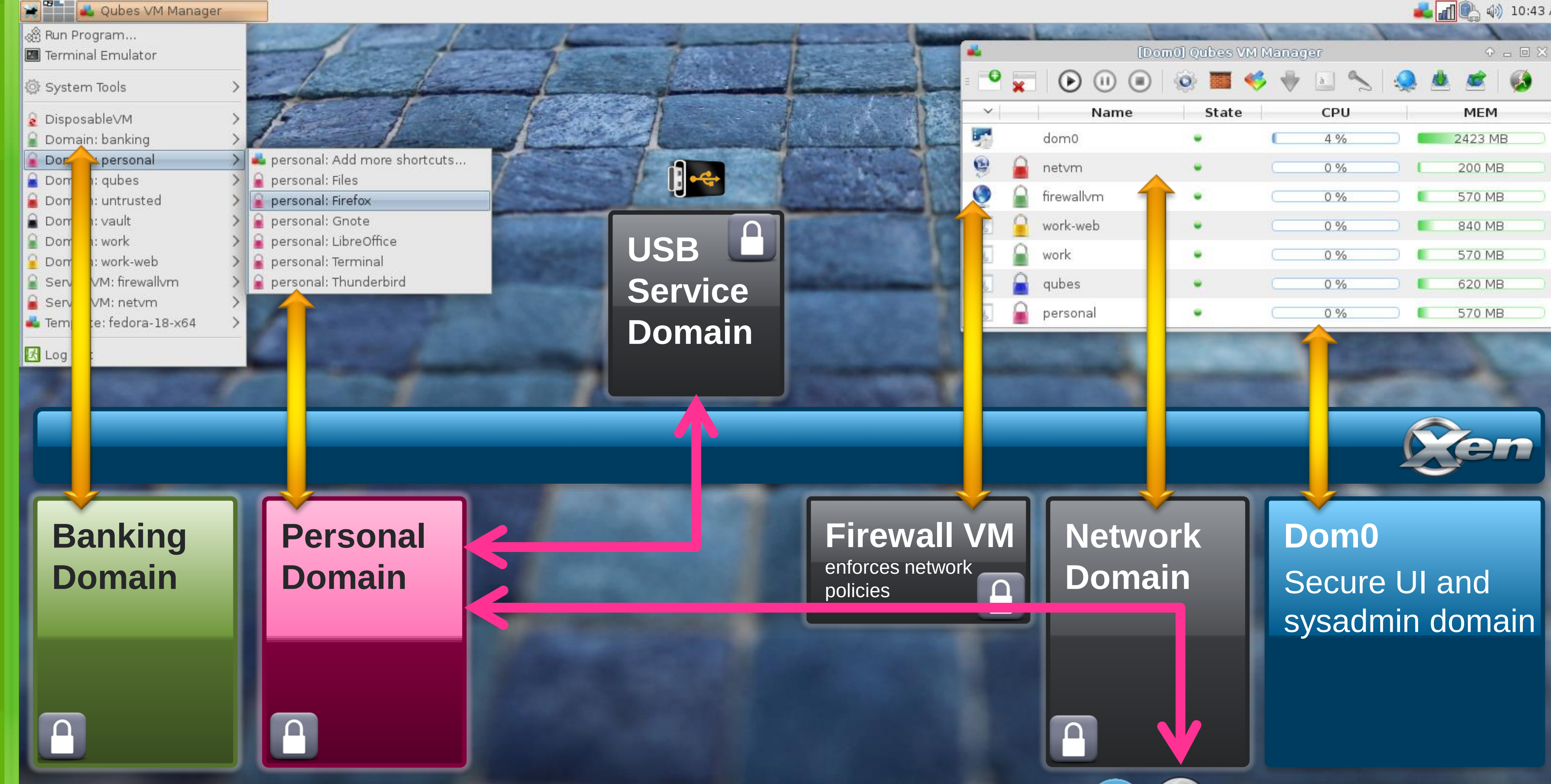
Qubes OS @QubesOS
Qubes OS 3.2 has been released!

qubes-os.org/news/2016/09/2…

RETWEETS	LIKES
2,294	3,870

2:59 PM - 29 Sep 2016

151 2.3K 3.9K



Name	State	CPU	MEM
dom0	●	4 %	2423 MB
netvm	●	0 %	200 MB
firewallvm	●	0 %	570 MB
work-web	●	0 %	840 MB
work	●	0 %	570 MB
qubes	●	0 %	620 MB
personal	●	0 %	570 MB

USB Service Domain

Banking Domain

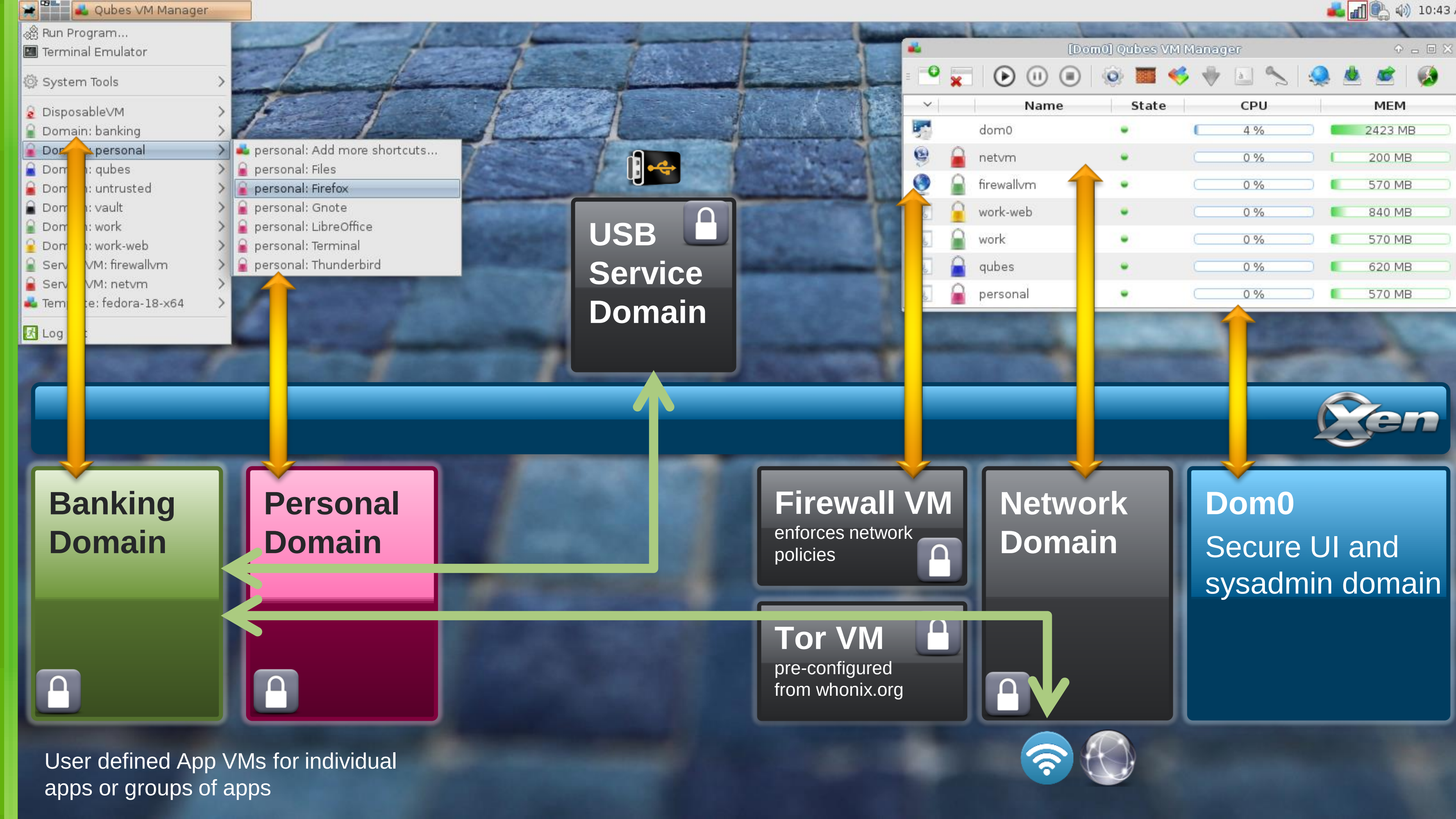
Personal Domain

Firewall VM
enforces network policies

Network Domain

Dom0
Secure UI and sysadmin domain

User defined App VMs for individual apps or groups of apps



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qubes	●	0 %	620 MB
personal	●	0 %	570 MB

USB Service Domain

Banking Domain

Personal Domain

Firewall VM
enforces network policies

Tor VM
pre-configured from whonix.org

Network Domain

Dom0
Secure UI and sysadmin domain

User defined App VMs for individual apps or groups of apps

If you want to know more …

Documentation

wiki.xenproject.org/wiki/Dom0_Disaggregation
wiki.xenproject.org/wiki/Xen_Security_Modules_:_XSM-FLASK

Products & Projects

Qubes OS

www.qubes-os.org

Secure OS

OpenXT

www.openxt.org

FOSS Platform for security research, security application and embedded appliance integration building on Xen & OpenEmbedded

BAE SYSTEMS ais

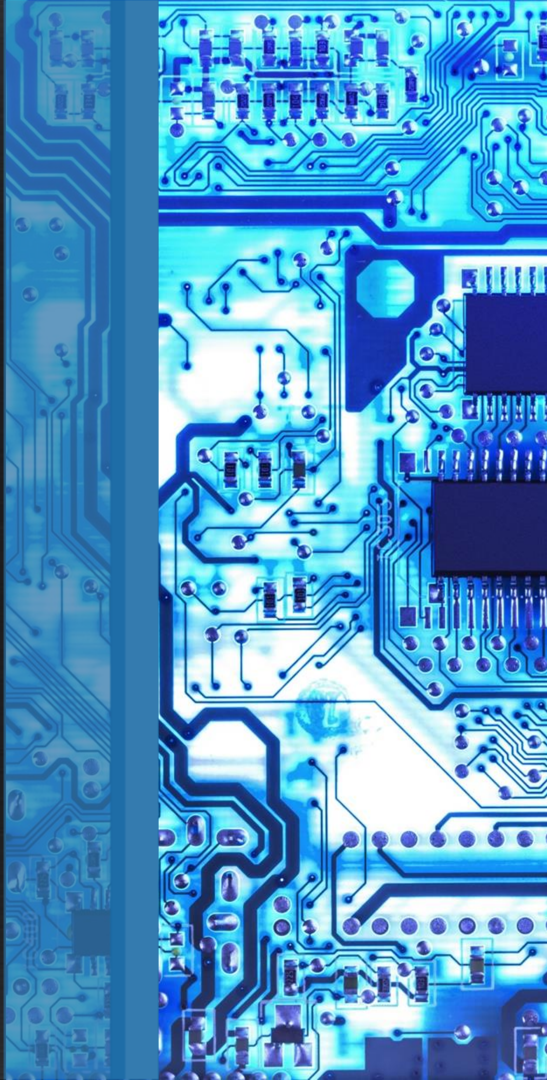
Crucible:Defense

starlab.io

Xen Project based virtualization platform for technology protection, cyber-hardening, and system integrity for aerospace & defense systems

Pratap Sankar @ Flickr

Xen Project in Embedded



Vendors Active in the Community

Dornerworks

dornerworks.com/xen

Consulting
Xen Embedded Distros

Xen for Xilinx Zynq
Xen for NXP i.MX 8

ARLX Hypervisor
DO-178 (EAL6+), IEC 62304, ISO 26262
MILS EAL
FACE, VICTORY, ARINC 653

Starlab

starlab.io

Crucible and Crucible:Defense
Xen embedded hypervisor
In progress: DO-178, MILS EAL

Uses a minimal Dom0 using MiniOS, disaggregation and XSM/FLASK

AIS

ainfosec.com

BAE Systems

baesystems.com

Galois

galois.com

Maintain FreeRTOS Xen Port
Developed and maintain HalVM

Precedents of military grade certification for Xen based systems

www.slideshare.net/xen_com_mgr/art-certification & www.youtube.com/watch?v=UyW5ul_1ct0
www.linux.com/news/xen-project/2017/2/how-shrink-attack-surfaces-hypervisor

Pratap Sankar @ Flickr

Additional Requirements

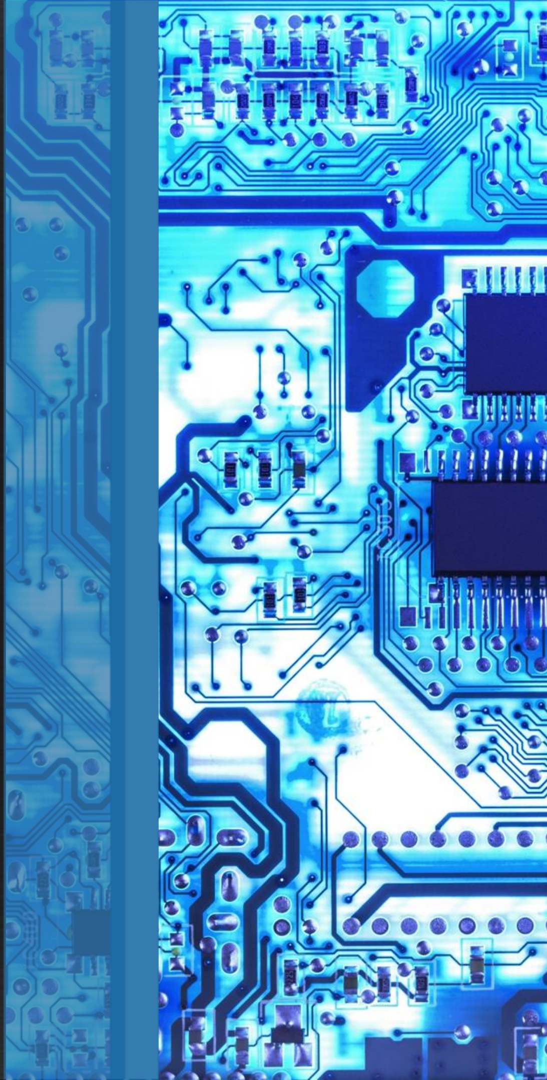
Security requirements ✓

Safety certification ✓

Low or 0 scheduling overhead

Minimal IRQ latency

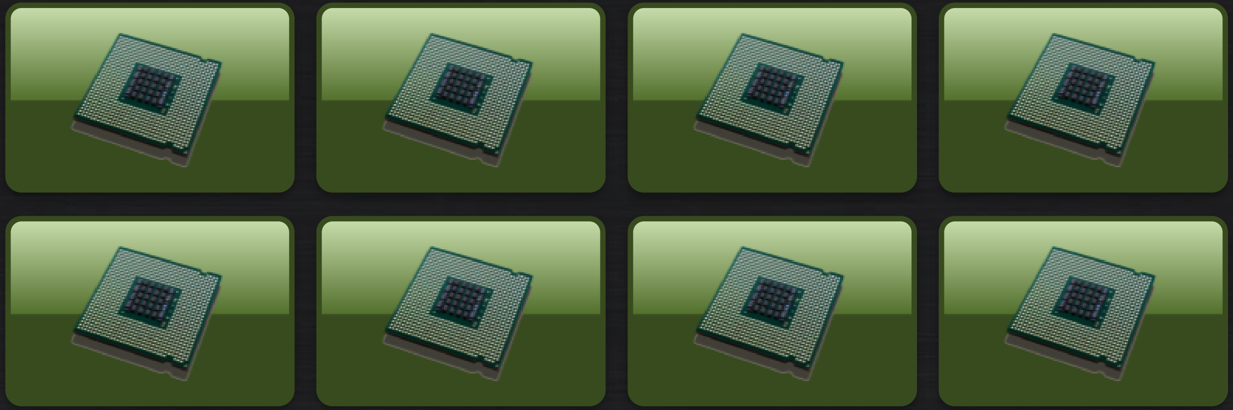
Drivers for special I/O devices



Schedulers & Interrupt Latency

Partitioning the System

Xen supports **several different** schedulers with different properties.



Partitioning the System

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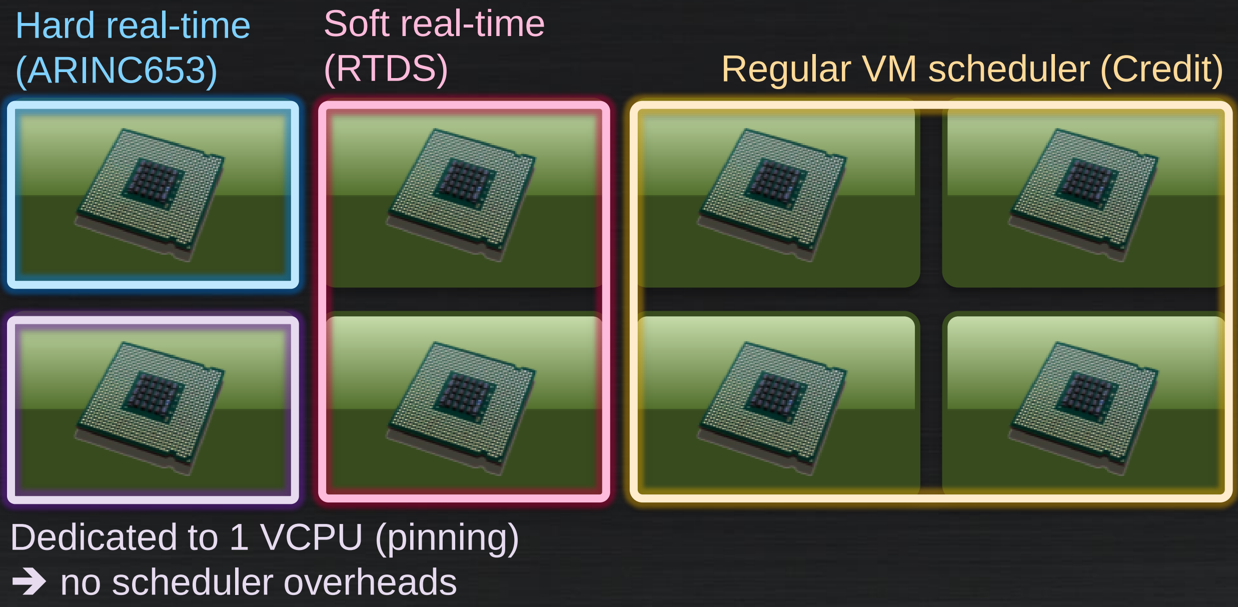


Xen Schedulers

Scheduler	Use-cases	Xen 4.7	Plans for 4.8+
Credit	General Purpose	**Supported** **Default**	Supported Optional
Credit 2	General Purpose Optimized for lower latency, higher VM density	**Supported**	**Default**
RTDS	Soft & Firm Real-time **Multicore** Embedded, Automotive, Graphics & Gaming in the Cloud, Low Latency Workloads	Experimental Better XL support <1μs granularity	Supported (4.9+) Hardening Optimization
ARINC 653	Hard Real-time **Single core** Avionics, Drones, Medical	**Supported** Compile time	

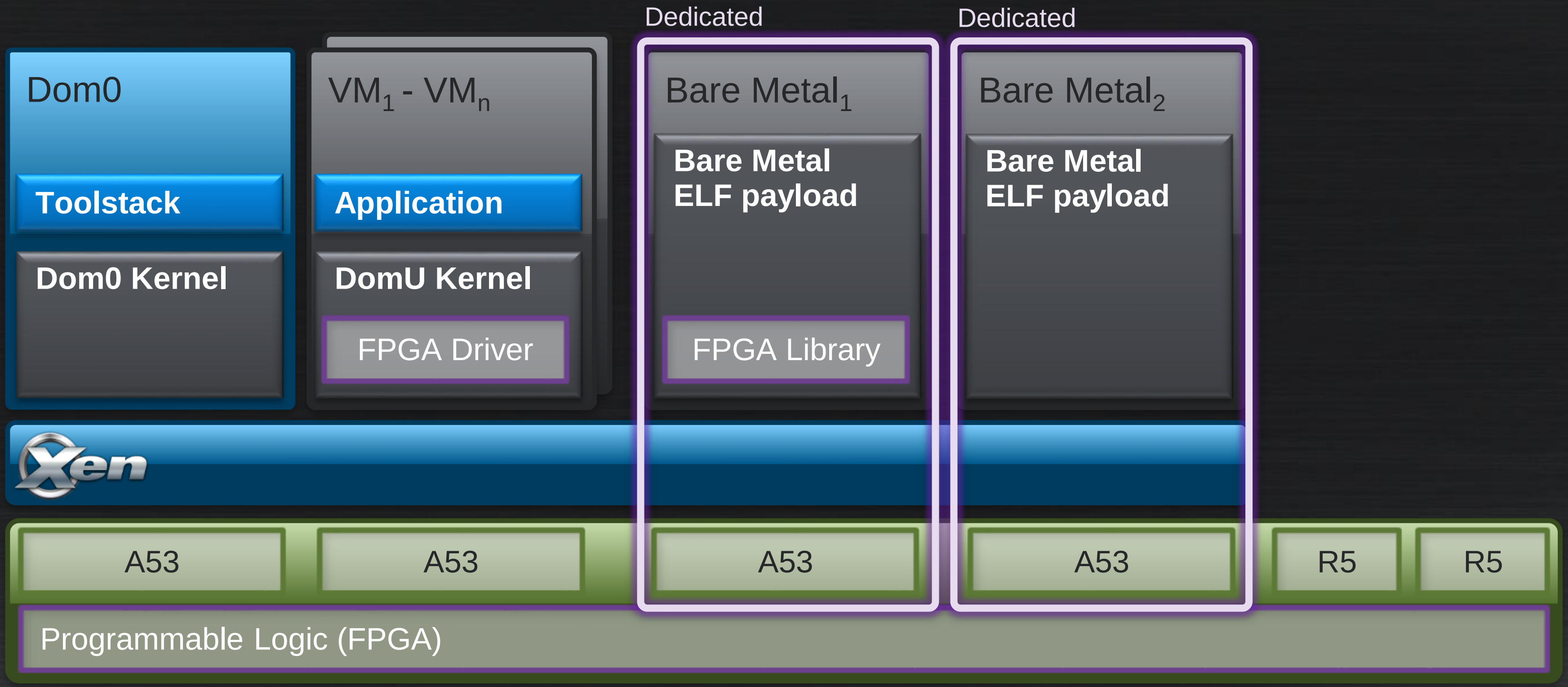
Legend:

Likely in 4.8

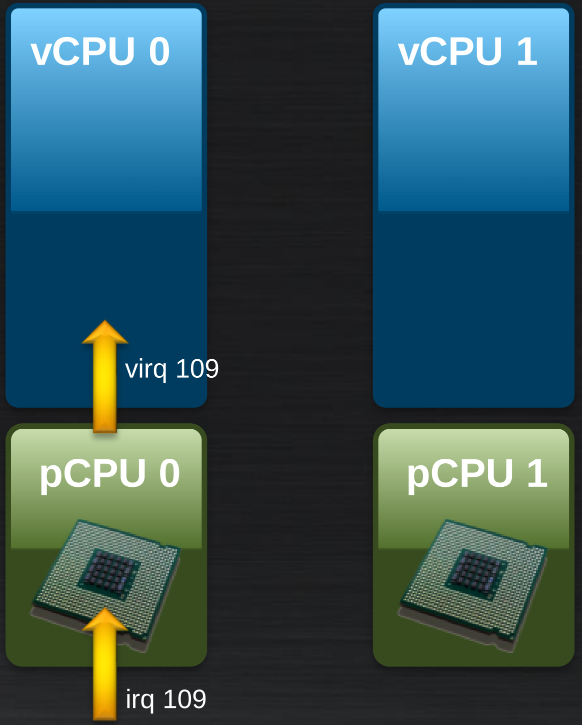
Possible in 4.8

Example: Xilinx Zynq XenZynq

dornerworks.com/wp-content/uploads/2017/01/Xen-Zynq-Distribution-XZD-Users-Manual.pdf



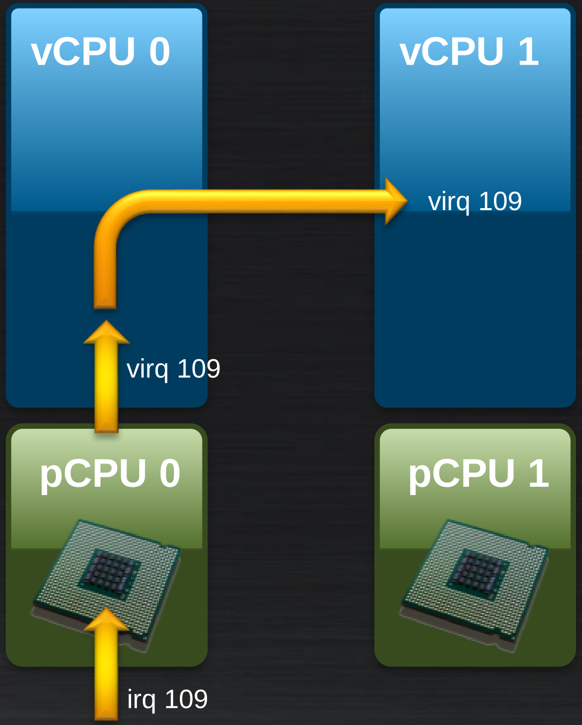
IRQs: Physical follows virtual



IRQ injection

Always on the CPU running the vCPU

IRQs: Physical follows virtual



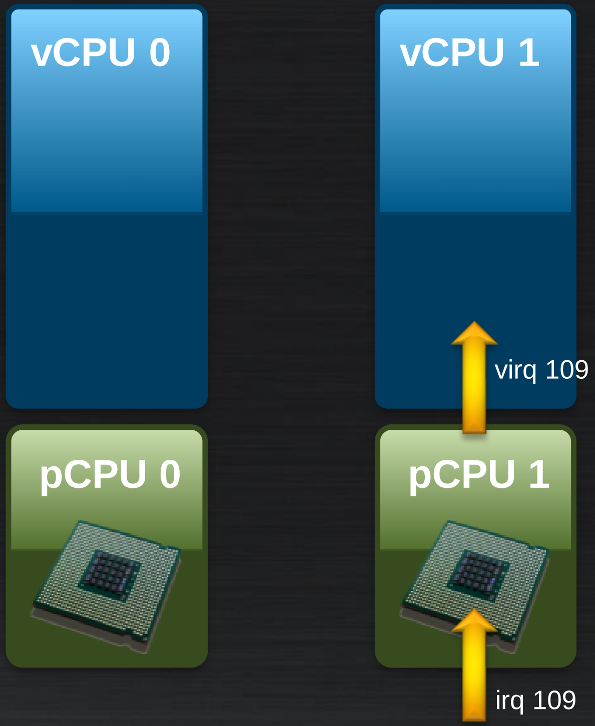
IF

vIRQ target changes or vCPU is moved

THEN

vIRQ is moved immediately

IRQs: Physical follows virtual



Xilinx ZynqMP board
(four Cortex A53 cores, GICv2)

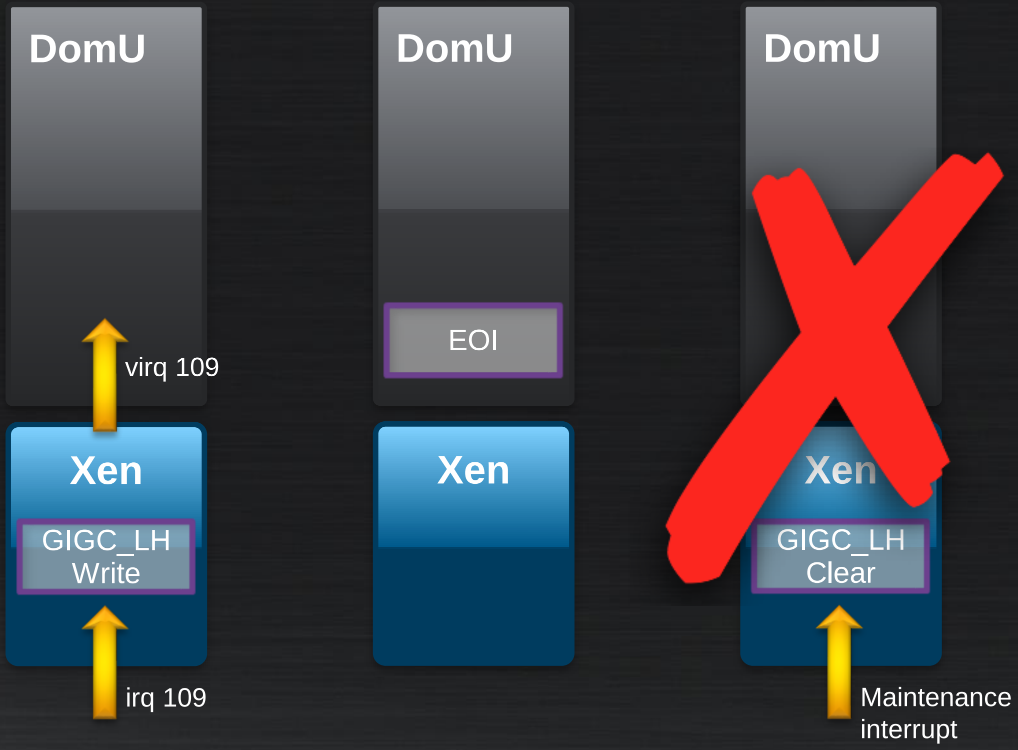
WARM_MAX (excluding the first 3 interrupts): <2000ns

marc.info/?l=xen-devel&m=148778423725945
marc.info/?l=xen-devel&m=148839743820338

IRQs always shadow the vIRQ

➔ minimizes latency

ARM IRQs: no maintenance interrupts



IRQ received by DomU

DomU performs EOI

The guest kernel issues an "EOI" at the end of the interrupt service routine, to notify the HW that the IRQ handling is finished.

No maintenance IRQ

Additional context switch to handle EOI.

Use EOI support in HW to directly EOI the physical IRQ

PV Drivers and Protocols for various use-cases

Existing

net, block, console
keyboard, mouse, USB
framebuffer, XenGT

New

9pfs
PVCalls
MultiTouch, Sound, Display

Developing New Ones

Easy to write (GPL and BSD samples)
Kernel and User Space

Xen Project
in Automotive

Vehicles are becoming the ultimate mobile device

Vendors that we know use Xen

GlobalLogic

Product: Nautilus

bit.do/gl-nautilus

First product in production expected in Q1 2018

Supports:

HW: Renesas R-Car Gen2 & Gen3, TI Jacinto6, Intel Apollo Lake, Qualcomm 410C, Sinlinx A33

Guests: Linux up to 4.9 • Android M, N, N-Car • QNX, ThreadX, FreeRTOS

PV Drivers for: GPU, Audio, HW accelerated Video codecs, DRM, …

Contributions:

27 smaller features from 2013 to 2016

EPAM

Demo

youtube.com/watch?v=jMmz1odBZb8

Interesting Features:

Container based telematics applications running in a Xen VM that can be downloaded from a cloud service

Ongoing Contributions:

ABIs for PV Sound, PV Display & PV DRM

LG Electronics

Demo

bit.do/lg-xen-demo-2016

Bosch Car GmbH

Contributions

10 smaller features in 2016

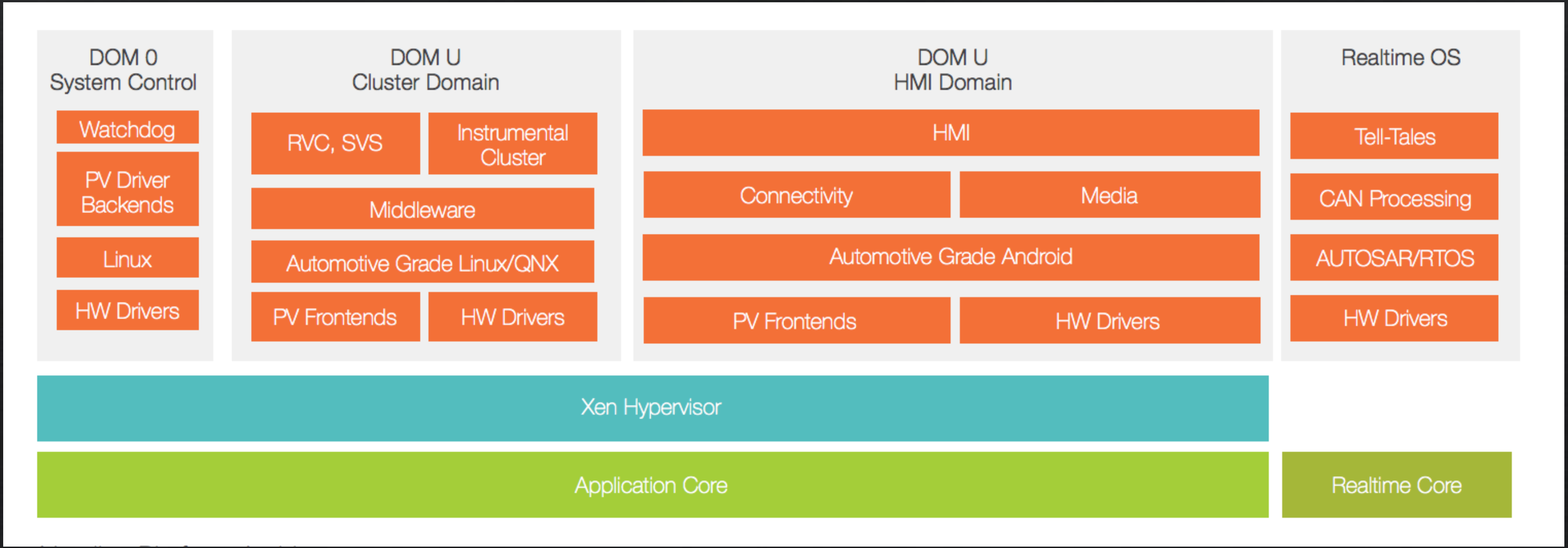
Perseus

Founded by Xen maintainer

bit.do/perseus-2017

Pratap Sankar @ Flickr

TODO: Need a higher res picture



DOM 0
System Control

Watchdog

PV Driver Backends

Linux

HW Drivers

DOM U
Cluster Domain

RVC, SVS

Instrumental Cluster

Middleware

Automotive Grade Linux/QNX

PV Frontends

HW Drivers

DOM U
HMI Domain

HMI

Connectivity

Media

Automotive Grade Android

PV Frontends

HW Drivers

Realtime OS

Tell-Tales

CAN Processing

AUTOSAR/RTOS

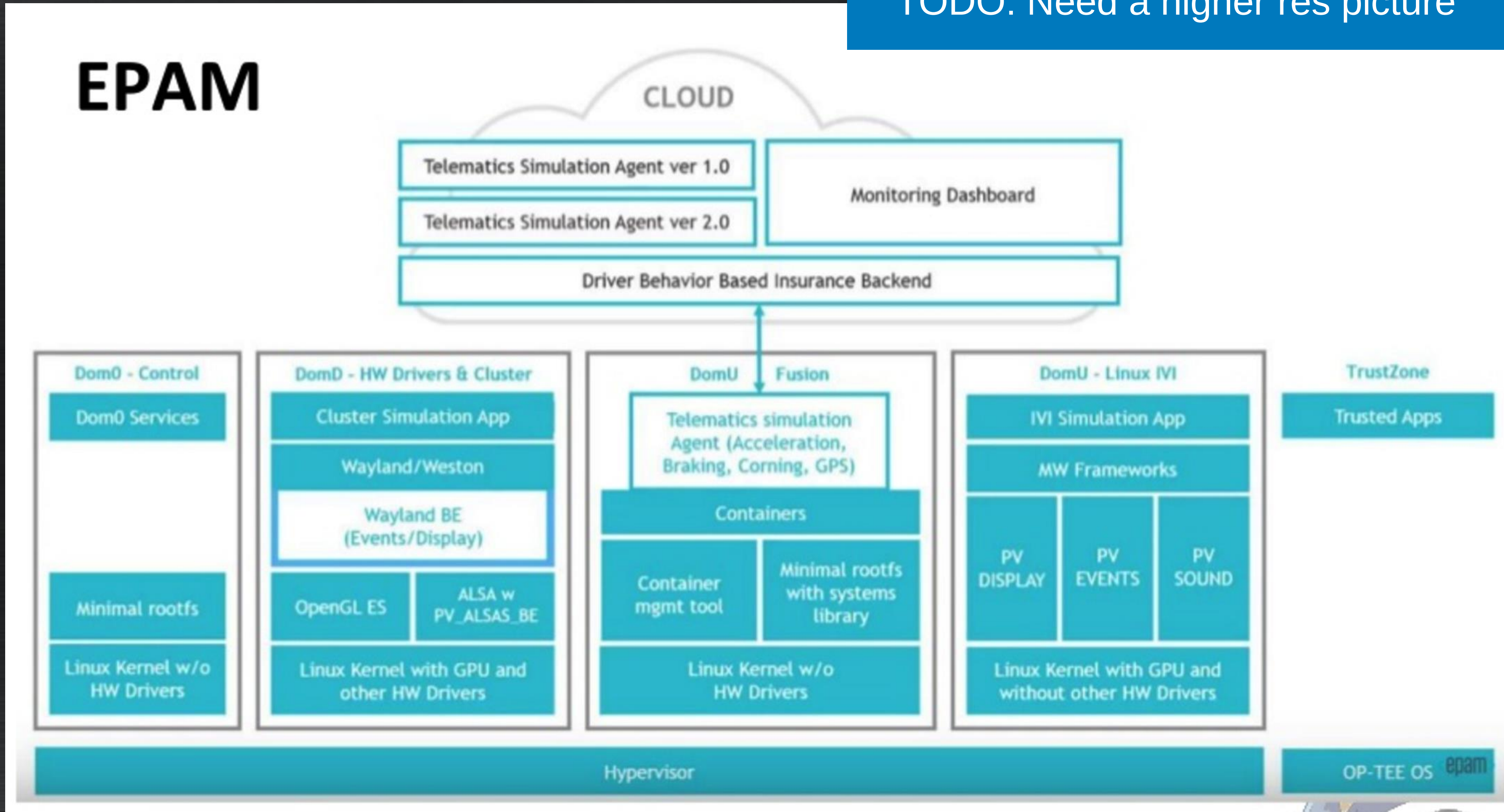
HW Drivers

Xen Hypervisor

Application Core

Realtime Core

TODO: Need a higher res picture



EPAM

CLOUD

Telematics Simulation Agent ver 1.0

Telematics Simulation Agent ver 2.0

Monitoring Dashboard

Driver Behavior Based Insurance Backend

Dom0 - Control
- Dom0 Services
- Minimal rootfs
- Linux Kernel w/o HW Drivers

DomD - HW Drivers & Cluster
- Cluster Simulation App
- Wayland/Weston
- Wayland BE (Events/Display)
- OpenGL ES
- ALSA w PV_ALSAS_BE
- Linux Kernel with GPU and other HW Drivers

DomU Fusion
- Telematics simulation Agent (Acceleration, Braking, Corning, GPS)
- Containers
- Container mgmt tool
- Minimal rootfs with systems library
- Linux Kernel w/o HW Drivers

DomU - Linux IVI
- IVI Simulation App
- MW Frameworks
- PV DISPLAY
- PV EVENTS
- PV SOUND
- Linux Kernel with GPU and without other HW Drivers

TrustZone
- Trusted Apps

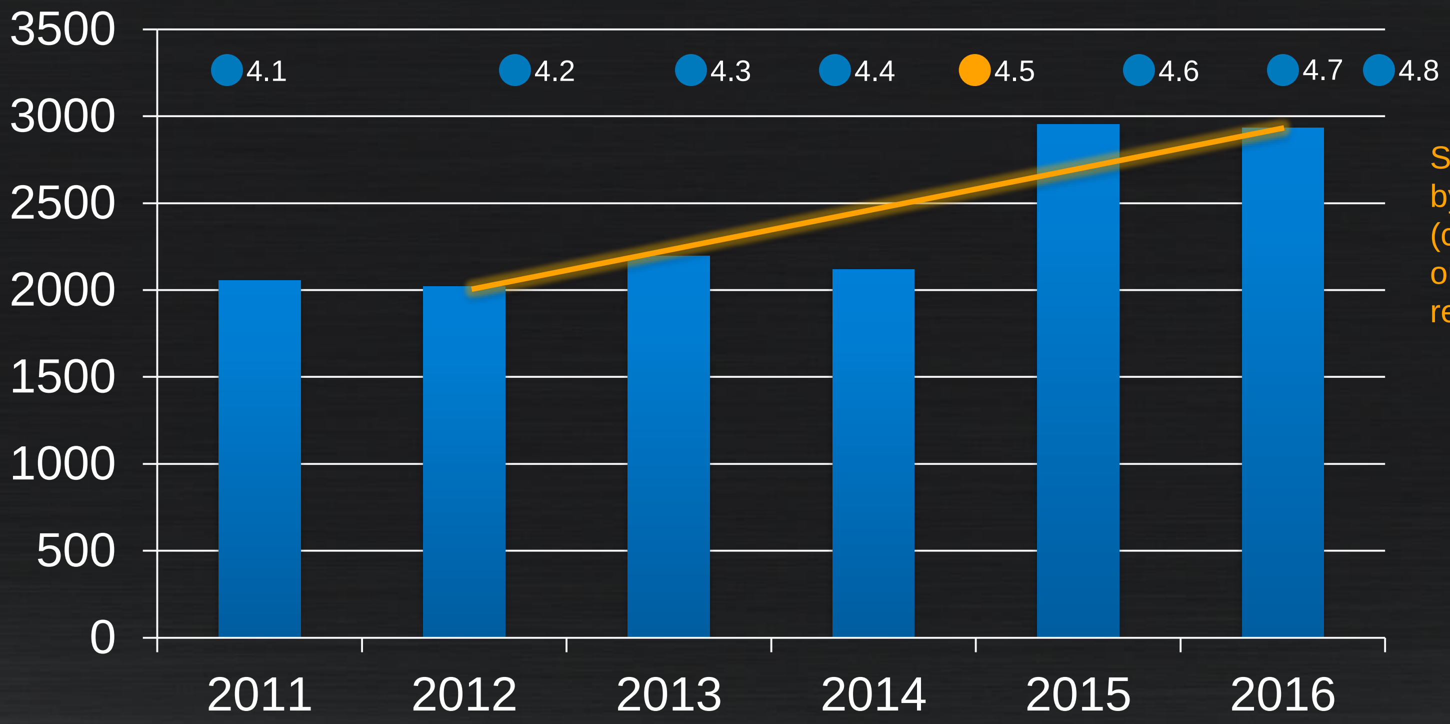
Hypervisor

OP-TEE OS

epam

A diverse, vibrant and growing community

Hypervisor Git Commits

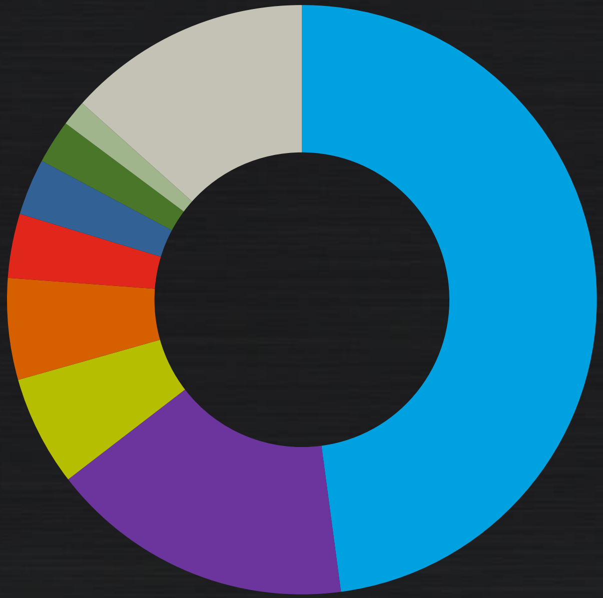


Stats are impacted by release model (code freezes) and our transition to 2 releases per year

2015: Hypervisor Stack Top Players

Top:

Citrix	48%
Suse	17%
Oracle	6%
Intel	6%
Red Hat	4%
Linaro	3%
FreeBSD	2%
Star Lab	1%
Other	13%



Others:

Fujitsu

Invisible Things Lab

BitDefender

Huawei

Zentific

Verizon

Cavium

GlobalLogic

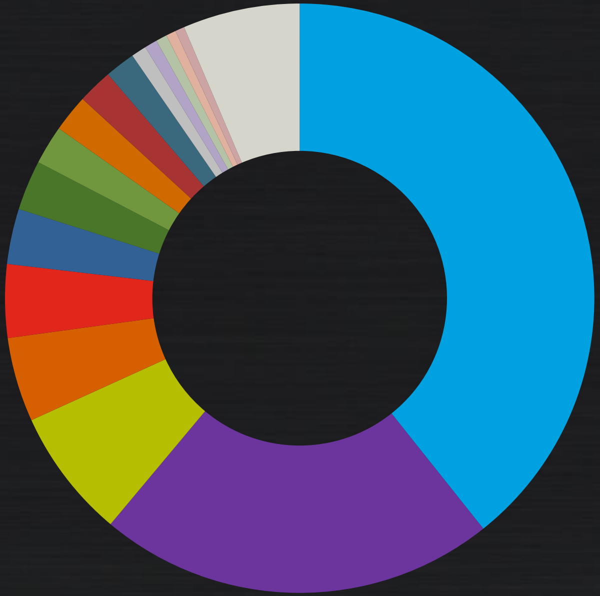
NSA

…

2016: Hypervisor Stack Top Players

Top:

Citrix	39%
Suse	22%
Oracle	7%
ARM	5%
Red Hat	4%
Linaro	3%
Intel	3%
Star Lab	2%
BSD	2%
Fujitsu	2%
Bitdefender	2%
Zentific	1%
NSA	1%
Zentific	1%
Qualcomm	1%
Huawei	1%
Other	6%



First-time contributors in 2016:

ARM

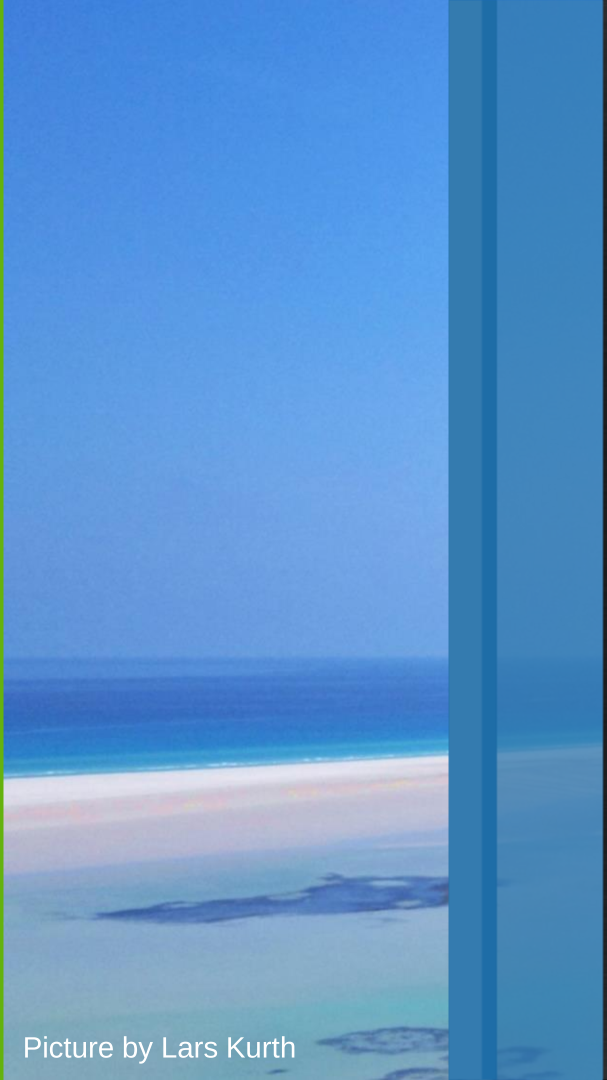
Aporeto

Bosch Car Multimedia Gmbh

Netflix

Qualcomm

Xilinx



Picture by Lars Kurth

Why should I use Xen?

Extremely Flexible and Versatile

Proven in different markets

Security and Resilience

Isolation, Partitioning, Security Features
Track record in handling

Safety

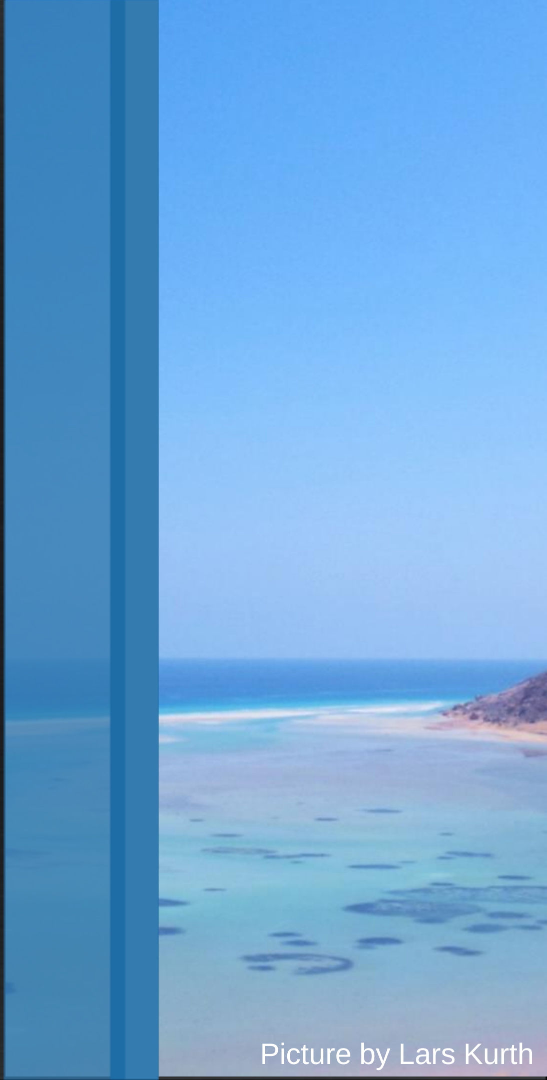
Examples of Military Grade Certification

Portability and Flexibility

Easy to port to new environments
Easy to develop new PV drivers
Highly customizable

Vibrant and Diverse Community

Covering Server, Cloud, Security, Embedded, Automotive



Picture by Lars Kurth

More Resources (ARM Focus)

Port Xen to a new SOC: goo.gl/384aD8
Add Xen support Xen to your OS: goo.gl/3qgqcM

Xen on ARM whitepaper: goo.gl/TcuqXd
Xen on ARM wiki: goo.gl/9qsfMf

Device Passthrough presentation: goo.gl/KM0f8c
OE meta-virtualization Xen recipe: goo.gl/m7GuXR
OpenXT (Xen + OpenEmbedded): openxt.org

Biweekly ARM Community Call: goo.gl/8ULYRn

Engage!

Xen devel ML: xen-devel@lists.xenproject.org
Xen user ML: xen-users@lists.xenproject.org
IRC on freenode: #xenarm or #xen-devel

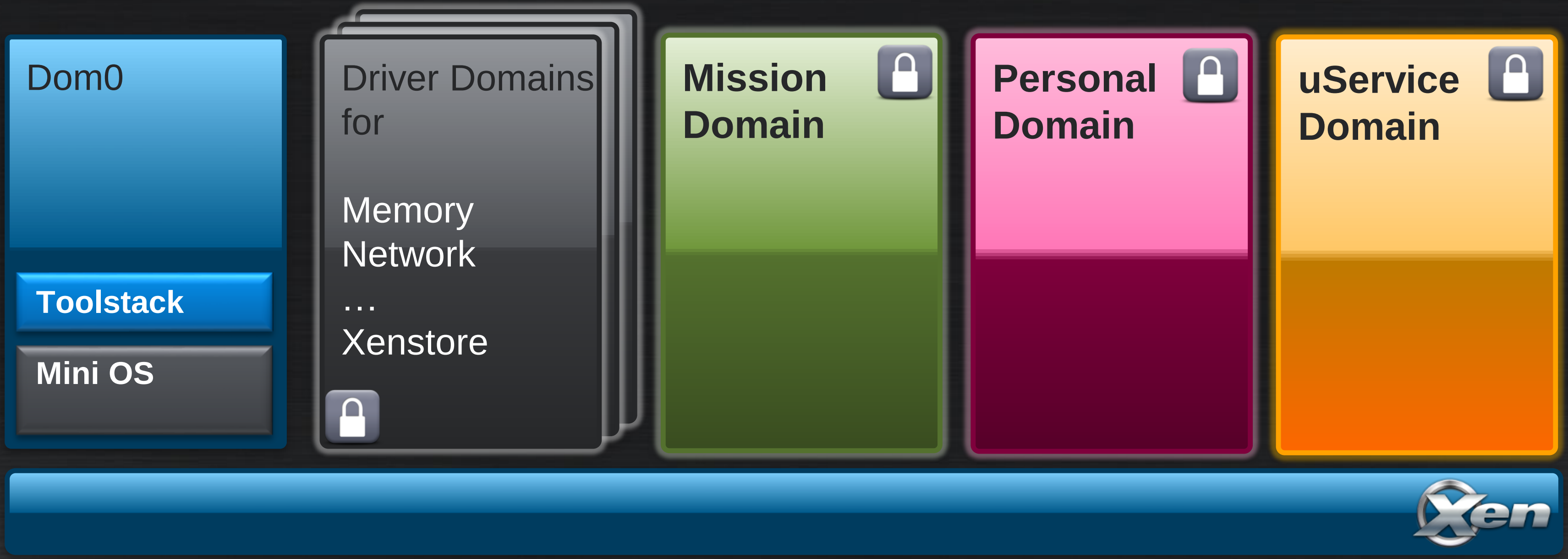
Internships in 2017:
Google Summer of Code
Outreachy (Women and other groups)
wiki.xenproject.org/wiki/Category:Internships

Questions

Picture by Lars Kurth

Example Architecture: Crucible

Leave this put, as it does not add anything



Dom0
Toolstack
Mini OS
Driver Domains for
Memory
Network
…
Xenstore
Mission Domain
Personal Domain
uService Domain
Xen