Siemens Corporate Technology | October 2014

Real-Time Virtualization – How Crazy Are We?

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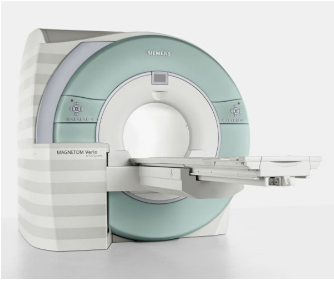
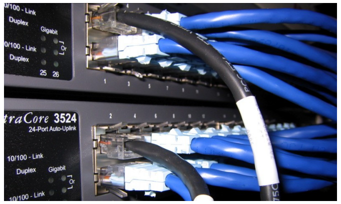
Real-Time Systems Can Benefit from Virtualization

Virtualizable real-time systems

- **Possible scenarios**
  - Control systems
    (industry, healthcare, automotive etc.)
  - Communication systems
    (media streaming & switching, etc.)
  - Trading systems (stocks, goods, etc.)
  - …
- **Primary drivers**
  - Consolidation, include mixed criticality
  - Legacy system migration
  - [Development & test]





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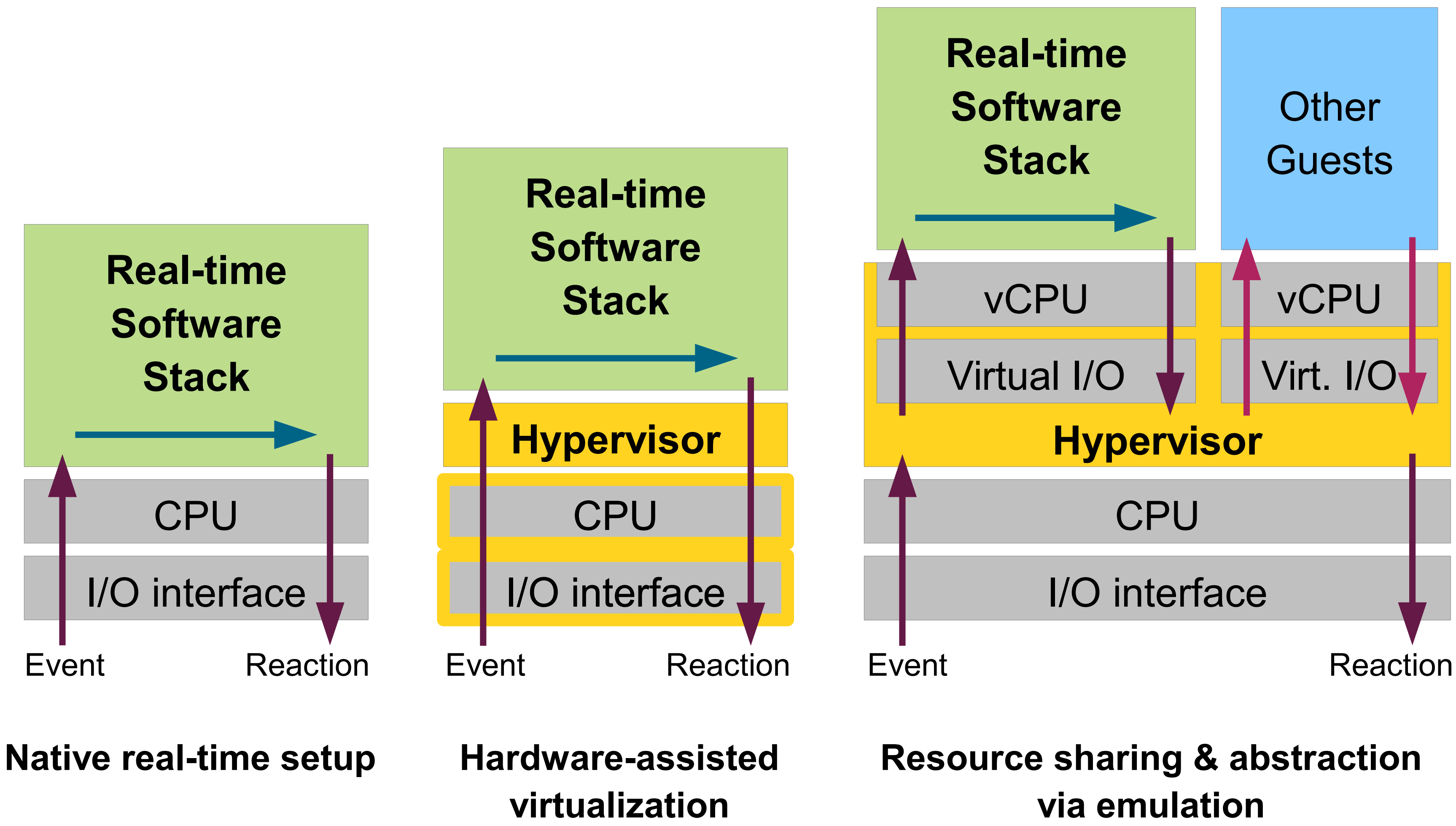
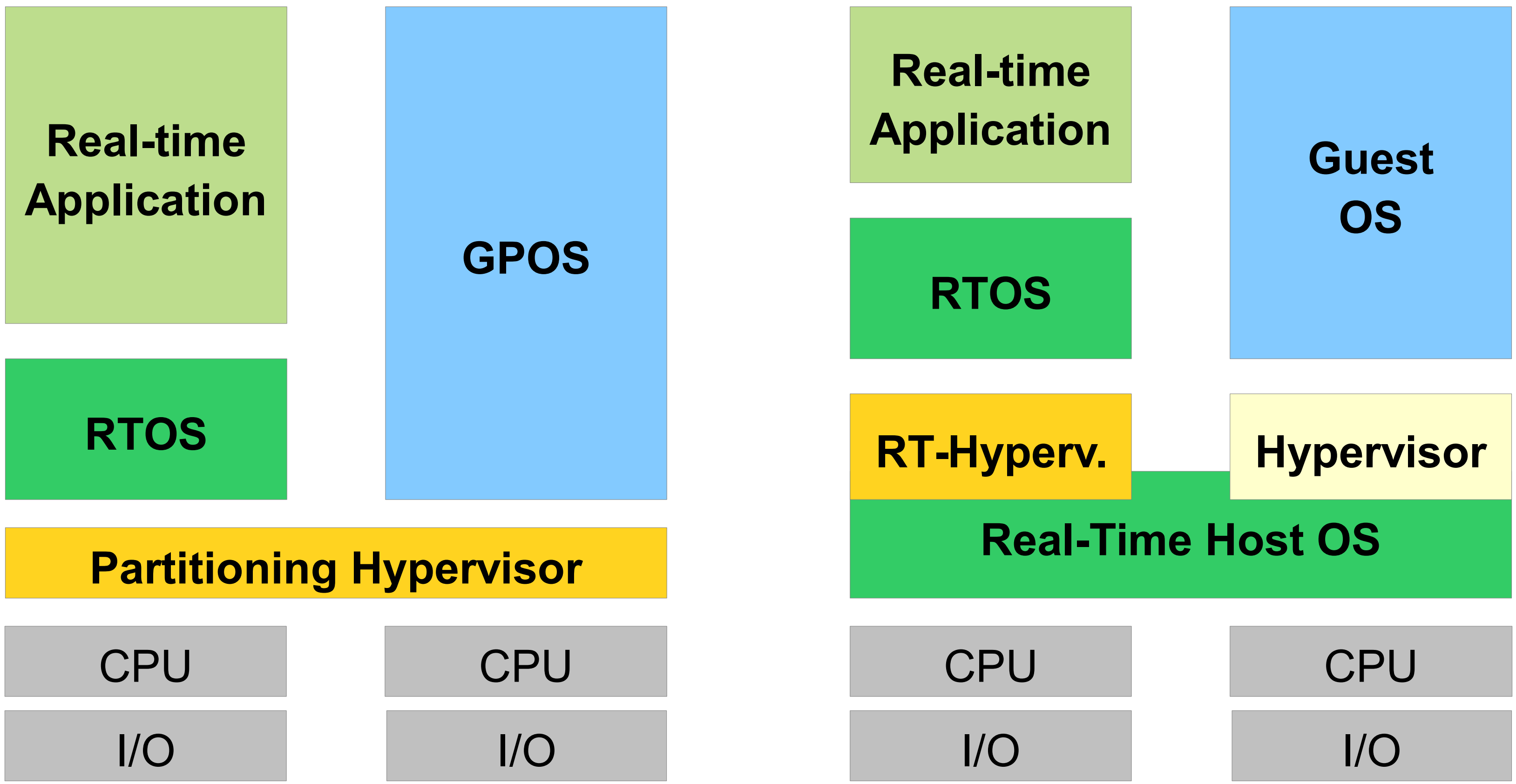
Virtualization ≠ acceleration

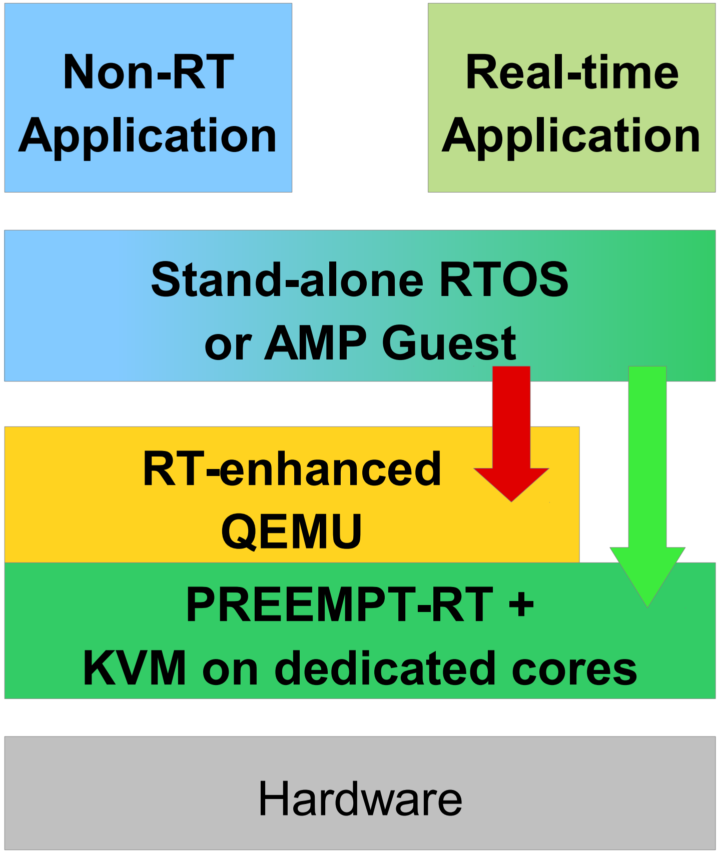
The critical data path with and without virtualization



RT Virtualization – Two Architectural Options



Architecture of a KVM-based RT-Hypervisor



PREEMPT-RT enables RT-Virtualization

Role of Linux extension PREEMPT-RT

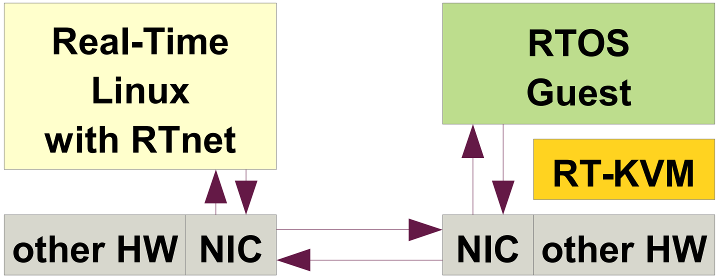
- **Reduce worst-case event delivery latencies**
- **Integrates KVM support**
  - Original use-case: virtualization + native RT applications
- **Allows to prioritize virtualization workload over uncritical tasks**
- **Can be combined with CPU isolation**
  - 1:1 assignment: host CPU – RT guest CPU
  - Off-load all non-RT tasks
    (including low-priority QEMU threads)
  - Warning: No 100% guest CPU load feasible!
    - NO_HZ_FULL extensions work toward enabling this

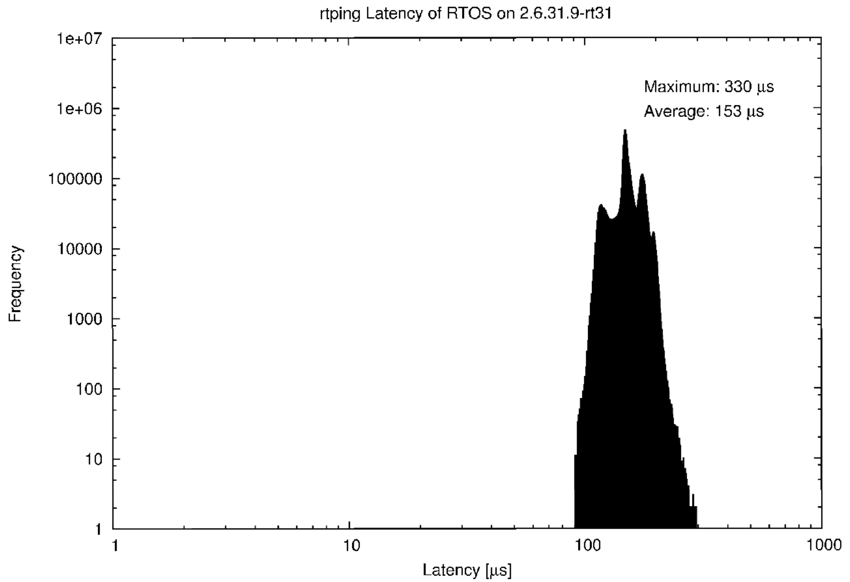
Decent Latencies Achievable in KVM-only Setups

Measuring I/O latency of an RT Guest

- **Host setup**
  - KVM on x86 PREEMPT-RT Linux
  - Virtual machine on dedicated core
  - Intel NIC (E1000 family) as I/O device, directly assigned to guest
  - Permanent disk I/O load
- **Guest setup**
  - Proprietary RTOS
  - Real-time network stack
- **Measurement setup**
  - Linux/Xenomai (native installation)
  - Real-time network stack RTnet
  - Periodic ICMP ping messages sent to target
  - Recorded round-trip latency (error <50 µs)

=> Worst-case latency after 16h: 330 µs

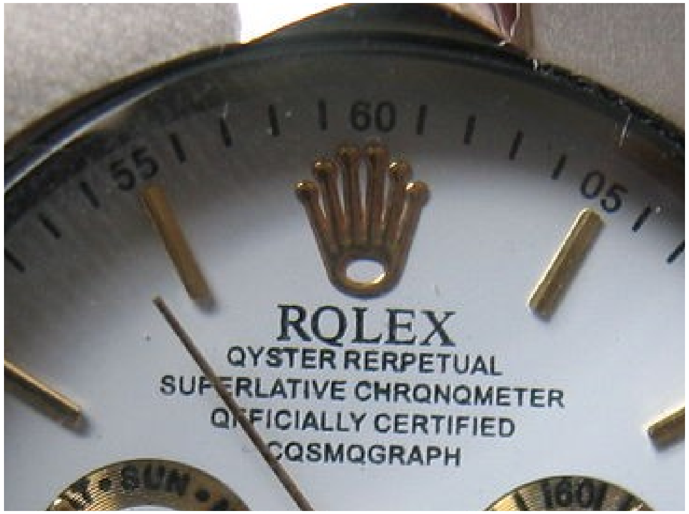




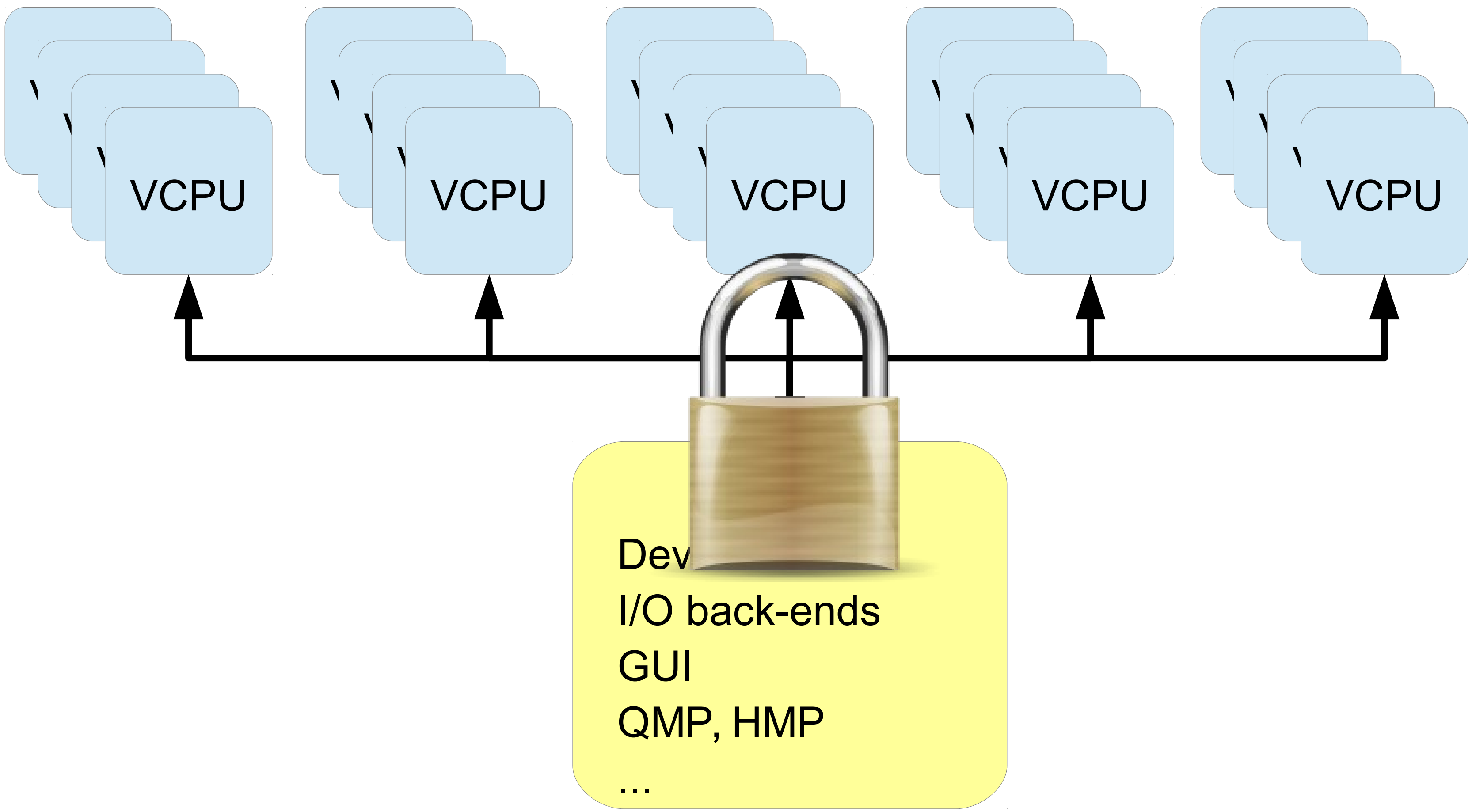
RT-QEMU is Required for Emulating in Real-Time

QEMU as a Real-Time Device Emulator

- **Scenarios**
  - Guest uses NIC A, host has NIC B attached
  - Legacy devices are no longer available on a modern host
  - Multiple guests share single I/O interface
    for talking to different devices (e.g. on a CAN bus)
- **QEMU can handle such scenarios via emulation**
- **Requirements on emulation**
  - Equivalent functional behavior
  - Devices models need to react in time on guest requests
  - Devices models need to deliver external events to the guest timely



Concurrency in QEMU/KVM – The Big QEMU Lock (BQL)



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Critical BQL Zones

CPUState

- Read/write access
- cpu_single_env

Coalesced MMIO flushing

PIO/MMIO request-to-device dispatching

Back-end access

- TX on network layer
- Write to character device
- Timer setup, etc.

Back-end events (iothread jobs)

- Network RX, read from chardev, timer signals, …

IRQ delivery

- Raising/lowering from device model to IRQ chip
- Injection into VCPU (if user space IRQ chips)

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Challenge 1: Management of Task Priorities

There can be many task involved

- VCPU threads
- VIRQ injection threads (QEMU: iothreads)
- Kernel threads (IRQ, worker, RCU, forgot anything?)

Problems

- Wrong configuration destroys RT
- ...or locks up parts or all of your system
- Actually a generic RT Linux issue

Proposals?

- Tool-based dependency discovery?
- Tool-based configuration?
- (More) automatic configuration?

Challenge 2: Management of IRQ Parameters

Relevant IRQ parameters

- CPU affinity
- Thread priority (if any)

How to configure in advance?

- Line-based IRQs may be reachable via /proc/irq
- MSIs are not...
- Dynamic IRQ numbers – how to associate with devices?

Proposals?

- Something like /sys/devices/.../<device>/irq_vector<N>/...?

Safe Isolation via Linux?

SIL 1..4

ASIL

Code size

Formal Methods

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SIL2Linux

Certification

Legacy Code

Consolidation

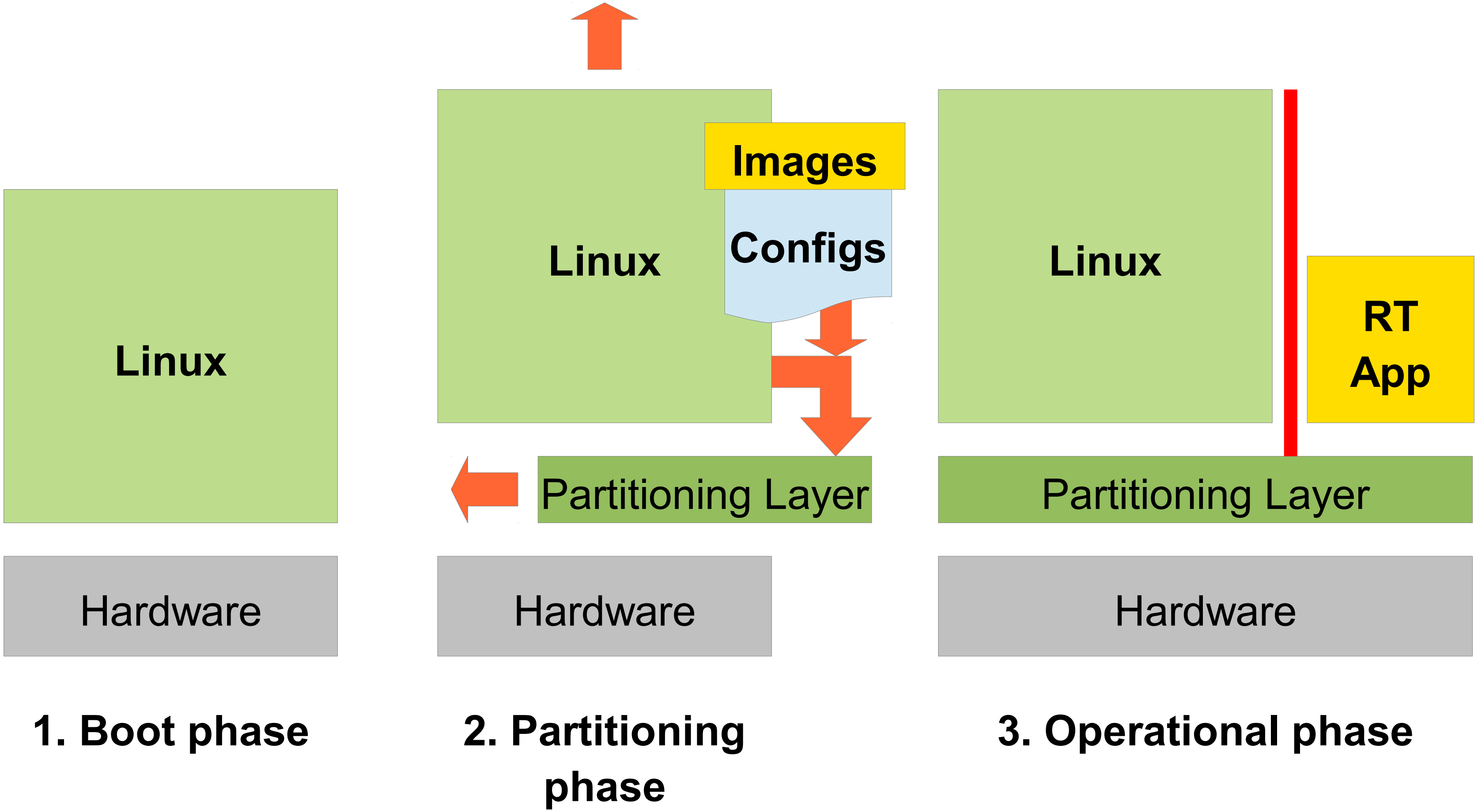
Validation

Mixed Criticality

Multicore

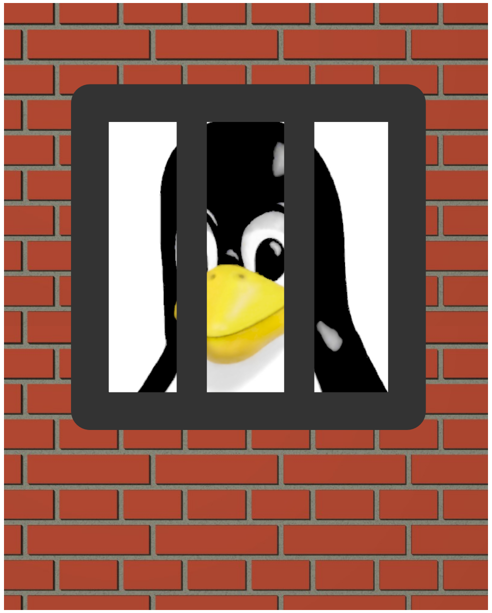
What about postponing the hypervisor start?

Basic concept of late partitioning



Jailhouse: Keep it simple, keep it open

The Philosophy of Jailhouse



- **Avoid emulation, focus on hardware assisted isolation**
  - No overcommitment, no scheduler, static partitioning
  - Directly assign physical devices, do not emulate them
  - You need more? Use KVM!
- **Only expose resources that are required for operation**
  - No boot-up phase virtualization
  - Board initialization done by Linux
- **Off-load uncritical tasks to Linux**
  - Initial setup / image loading
  - Reconfigurations while in non-operational mode
  - Monitoring, logging etc.
- **Released under GPLv2**

=> Minimal-sized certifiable hypervisor
with full CPU assignment and Linux look-and-feel