Corporate Technology

KVM in Embedded
Requirements, Experiences, Open Challenges

Jan Kiszka, Siemens AG
Corporate Competence Center Embedded Linux
jan.kiszka@siemens.com

SIEMENS

Agenda

- **Embedded virtualization**
  - What does it mean?
  - Why using KVM?
- **Use case: KVM-hosted enterprise communication**
  - Setup & requirements
  - Virtualization stack experiences
- **KVM and real-time**
  - Host & guest-side RT
  - Possible enhancements
- **Conclusion**

SIEMENS

Embedded Systems, Embedded Virtualization

“Embedded” means

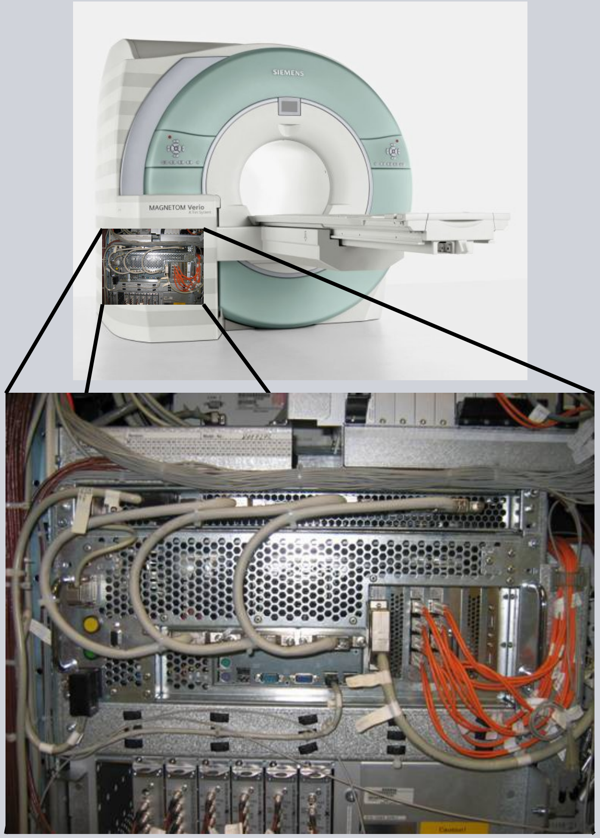
- Small?
- Limited resources?
- No display?
- Hard real-time?
- ...?

More generic definition

- Designed to perform specific, dedicated tasks
- Integrated part of a larger device
- Not recognizable as individual computer system

Embedded Virtualization

- System uses virtualization transparently
- May involve adaptions to system's task



SIEMENS

Embedded Virtualization Benefits

Legacy system migration

- Avoid “divorce” of application and legacy OS
- Single-core software stacks on multicore hosts
- Emulation of discontinued hardware

Consolidation (keeping isolation)

- RTOS aside standard OS
- Multiple virtual boards (or root filesystems) on single silicon

Development environment

- Hardware/software co-development
- Debugging environment
- Virtualization allows speed-up (compared to pure emulation)

SIEMENS

Top Requirements on Embedded Hypervisors

- **Hardware support**
  - CPU architecture
  - Board
  - Virtualization extensions (CPU, I/O)
- **Guest OS support**
- **Isolation**
  - Spatial (license barrier, IPR protection, rarely data security)
  - Temporal (provide real-time guarantees)
- **Customizability**
- **Footprint** (volume markets)

From Enterprise to Embedded Virtualization – Why using KVM?

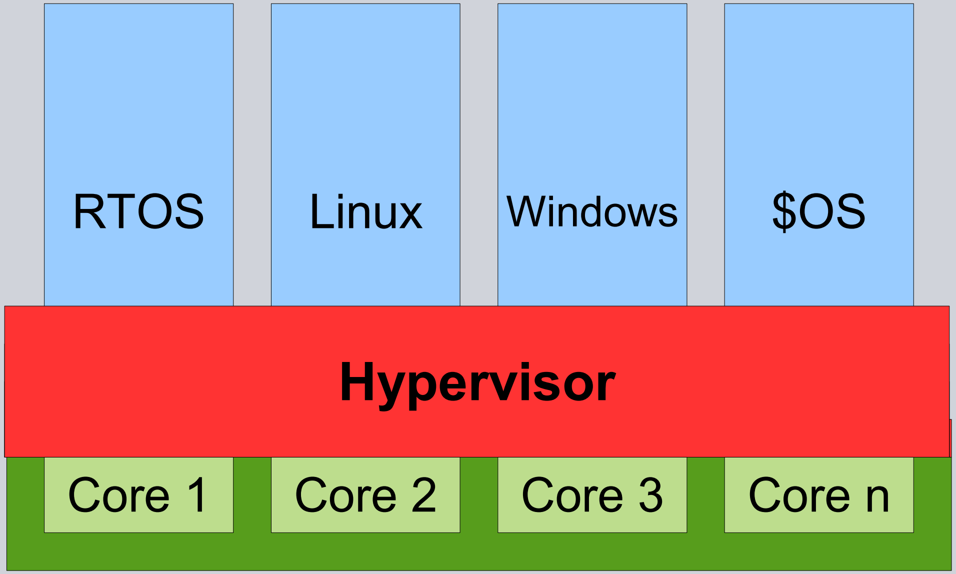
SIEMENS

“We just need a tiny hypervisor to fully exploit this multicore CPU”

- “A few thousand” lines of hypervisor code
- Minimal hardware emulation
- “A bit” paravirtualization
- Devices are passed through

“But it would be nice to...”

- share some devices
- run upstream Linux and latest Windows
- over-commit resources
- manage power
- backup / migrate guests
- use advanced HA features
- ...



Requirements Match

Requirement	**KVM support**
Architecture support	
▪ x86	✓
▪ PowerPC	✓ (Book E&S, no ISA 2.06 yet)
▪ ARM	early stage
▪ Others	?
Board support	✓ (Linux...)
Guest OS support	✓ (broad test bed, virtio drivers, ...)
Customizability	✓
Footprint	*depends on use case*
Isolation	
▪ Spatial	✓ (for most use cases)
▪ Temporal	**improvable**
Future requirements	well prepared

Use Case Example

KVM-hosted Enterprise Communication

Use Case:
KVM-hosted Enterprise Communication

SIEMENS

The user

Siemens Enterprise Communication (SEN)

The mission

Move proprietary RTOS and application stack from custom hardware to standard x86

Requirements

- Low impact on guest
- Preserve (soft) real-time qualities
- Prefer mainline open source technology

Evaluation ruled out

- Invasive paravirtualization (e.g. Xen's PV mode)
- Pure emulation
- Projects with too small communities

Use Case:
KVM-hosted Enterprise Communication (2)

SIEMENS

The choice: QEMU/KVM

- Early proof of concept using QEMU
- ~2500 LoC for custom hardware bits
- KVM acceleration nicely integrates on top
- Upstreamed generic fixes/enhancements since day 1

The new platform:

- QEMU/KVM hosts...
  - proprietary RTOS (multiple instances)
  - formerly stand-alone application stacks (virtual Linux appliances)
- libvirt as hypervisor interface
- Includes high availability stack

Two possible deployments

- Pre-installed on rack system => virtualization is *embedded*
- On customer server => virtual appliances

SIEMENS

SEN Project Experiences

Segmented x86 guests

- 16-bit mode works quite well (despite uncommon use case)
- Task switching required most patching (few issues may remain)

Soft real-time is achievable

- mlockall() + renice -20
- Most latencies were I/O-related
- Decoupled logging and chardev outputs

Board model maintenance

- Out-of-tree enables flexible customizations
- ...but requires custom qemu-kvm package
- Upstream merge appears unrealistic
- 3rd way?
  - Open-Source-only machine plug-ins?
  - Stable API per stable series?

SIEMENS

SEN Project Experiences (2)

Libvirt

- Feature gap required latest & greatest
- Faced few stability issues (resource management...)
- Suboptimal: QEMU wrapper script workaround
- All in all: benefits outweigh current drawbacks

Current open topic: live backup / snapshot

- Block live migration (yet?) too slow
- QEMU snapshots: longer downtime, qcow2-only
- libvirt-managed file-system / block layer snapshots?

KVM and Real-Time

KVM and Real-Time – Meeting Host Requirements

SIEMENS

Requirement:

Guests must not defer host RT applications

Preemptible KVM

- Problem mostly solved
- The key: preemption notifiers (arch-agnostic concept)
- Keep an eye on preempt/IRQ-disabled paths!
- Known pitfall: wbinvd latencies (x86)

KVM on PREEMPT_RT

- Long supported, but quality varying
- Current 2.6.33.x-rt is fine
- Adoption of raw spinlocks reduced maintenance
- Risk of regressions remain => include in autotest?

KVM and Real-Time –
Meeting Guest Requirements

SIEMENS

Requirement:

Fulfill guest tasks in a timely manner

Precondition

Sufficient host real-time qualities
(PREEMPT_NONE → PREEMPT → PREEMPT_RT)

Already achievable

- Soft real-time
- Moderate guest reaction times
- Example for <1 ms peak latency:

Host timer IRQ →in-kernel APIC model →guest RTOS →guest task

Feasible goals

- Standard KVM architecture: < 200 µs (x86)
- “Dedicated” KVM mode: close to hardware limits (<< 50 µs on x86)

SIEMENS

What Kills Guest Real-Time?

KVM's MMU emulation

- Can contribute several milliseconds guest latency
- EPT/NPT resolves the issue
- Legacy RTOSes may also run MMU-less

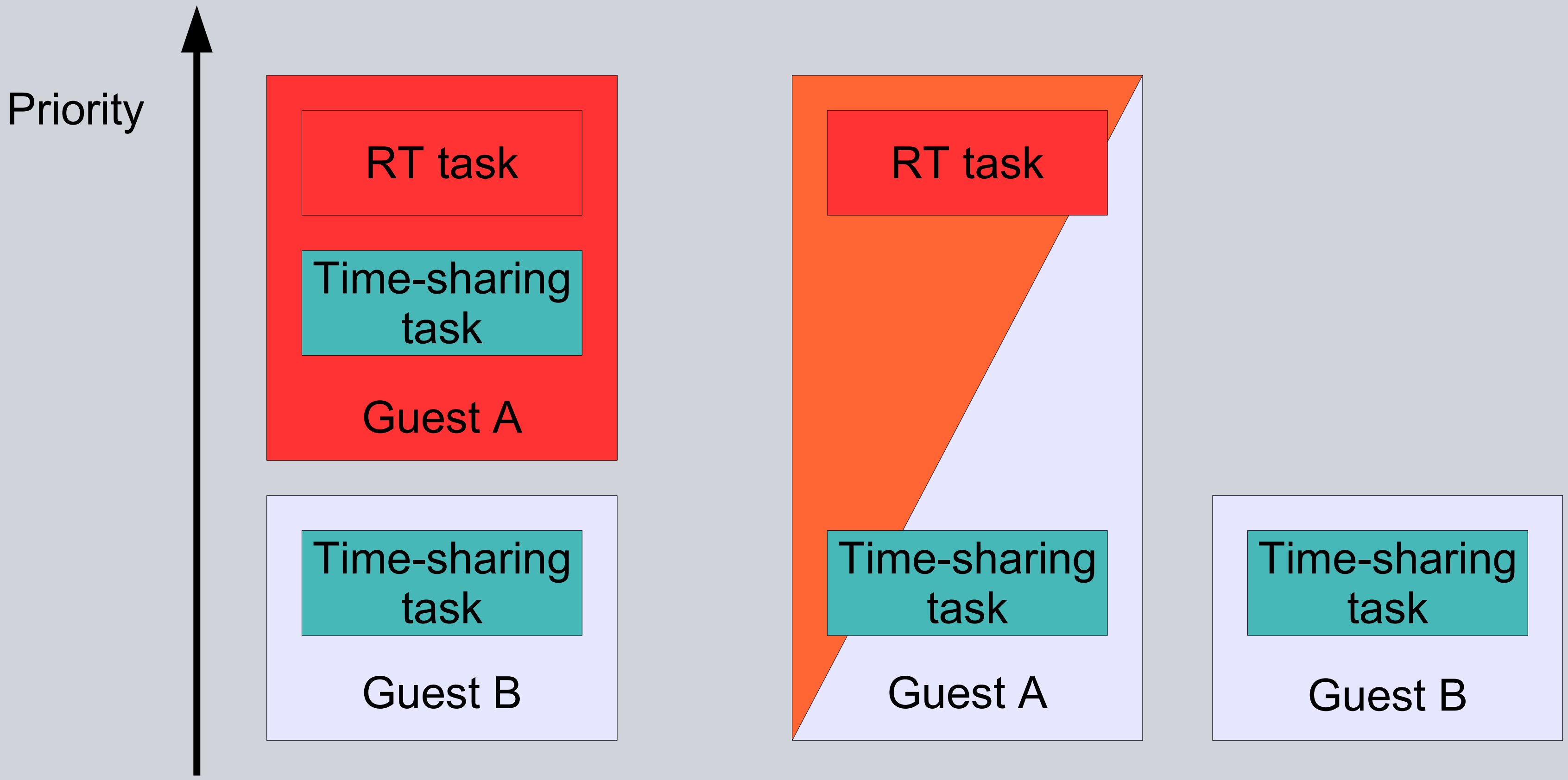
I/O-related priority inversions

- Threaded AIO completions can accumulate long work queues
  => use Linux AIO or lower AIO thread priority
- QCOW2 (contains synchronous write calls)
- SDL graphic output
- Heavy traffic on chardev backends (e.g. virtual serial port)

RT-aware device emulation required

- We already heard about threading it... (→ Anthony's talk)
- No costly synchronous host services in VCPU context!
- Per-device locking will help to avoid priority inversions
- Also relevant for SMP scalability

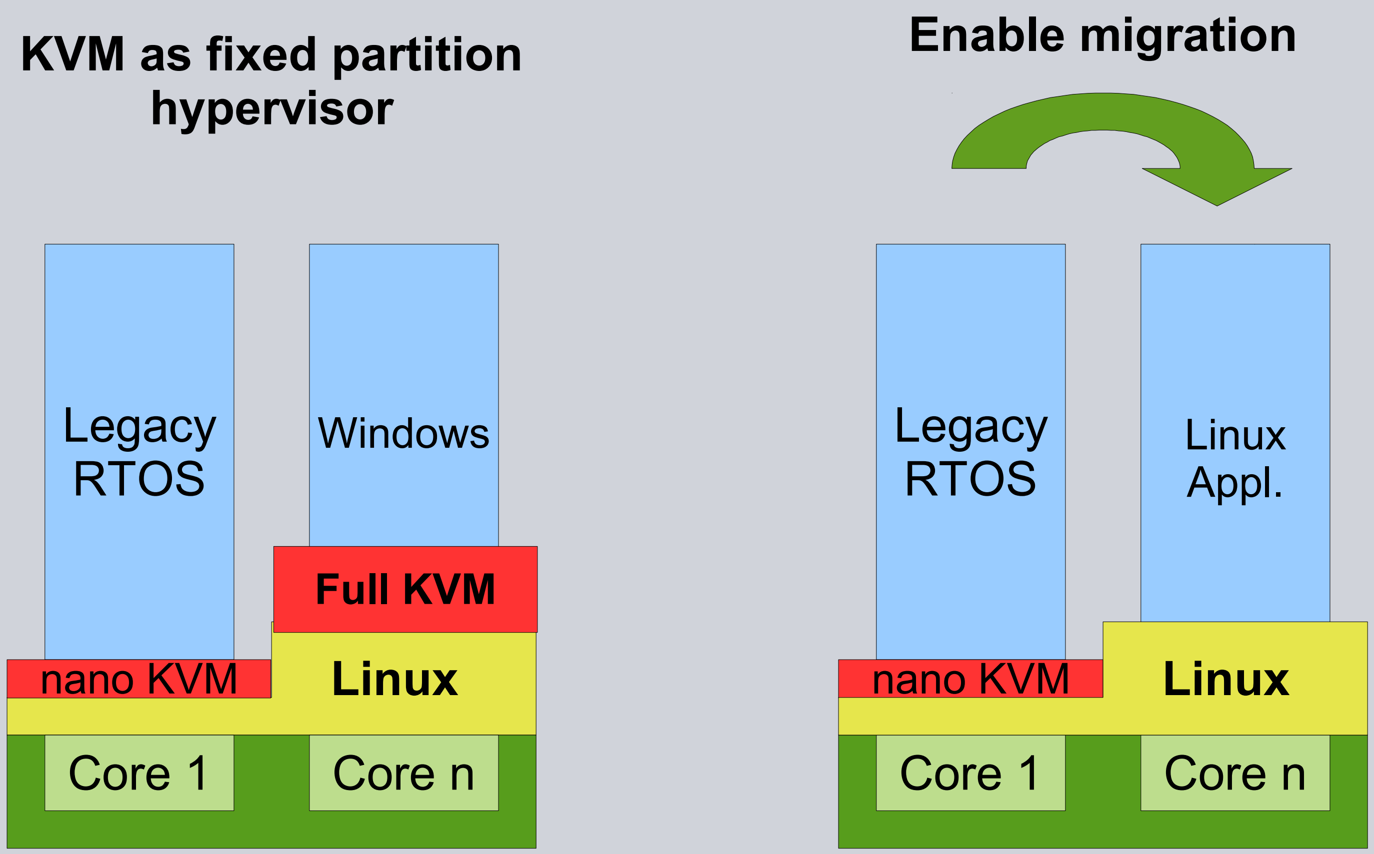
Managing Priorities



Black-Box VM Scheduling

Paravirtual Scheduling

Towards Minimal-Latency KVM



SIEMENS

Conclusion

- **Embedded Virtualization is a broad domain, today focused on multi-core partitioning**
- **KVM already meets many of its key requirements**
- **Well set up for bringing enterprise features to embedded**
- **More work required**
  - Reduce prio-inversions in hypervisor
  - Temporal isolation of guests
  - Paravirtualized scheduling
  - Non-x86 architectures

KVM may never fit all embedded use case, but a significant share

Thank You!

Any Questions?

SIEMENS

Paravirtualized Scheduling

Execution model

- Use POSIX scheduling policies
- Per-VCPU policy/priority
- Map guest on VCPU thread priorities:

$$p = \left\lfloor p_{guest} \frac{p_{max}}{99} \right\rfloor$$

- Boost to maximum priority during interrupt
- Nested boosts for NMI support

Host-guest Interface

- Two hypercalls
  - Set Scheduling Parameters (CPU-ID, policy, priority)
  - Interrupt Done

KVM prototype “just” requires rebase and upstream posting

SIEMENS

Towards Minimal-Latency KVM (2)

Step 1: Advanced CPU isolation

- Single task shall dominate CPU
- Many proposals brought up, none mainline compatible
- Requires iterative approach
  - Migrate timers, disable sched tick
  - Move housekeeping work
  - Exclude CPU from RCU
  - Reduce IPI reasons
- Many folks interested, but no one working on it ATM

Reduce RT-unrelated "noise"

Step 2: Run KVM VCPUs on isolated CPUs

- Goals (guest in operation mode):
  - Zero user space VMM exits
  - Zero host task switches
- In-kernel non-threaded IRQ (re-)injection
- Adopt guest to avoid user space device emulations

