Effective Virtual CPU Configuration in Nova

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OpenStack Summit

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Timeline of recent CPU flaws, 2018 (a)

Jan 03 — **Spectre v1**: Bounds Check Bypass

Jan 03 — **Spectre v2**: Branch Target Injection

Jan 03 — **Meltdown**: Rogue Data Cache Load

May 21 — **Spectre-NG**: Speculative Store Bypass

Jun 21 — **TLBleed**: Side-channel attack over shared TLBs

Timeline of recent CPU flaws, 2018 (b)

Jun 29	**NetSpectre**: Side-channel attack over local network
Jul 10	**Spectre-NG**: Bounds Check Bypass Store
Aug 14	**L1TF**: “L1 Terminal Fault”
Nov 01	**PortSmash**: Impacts SMT processors
...	?

What this talk is not about

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Out of scope:

- Internals of various side-channel attacks
- How to exploit Meltdown & Spectre variants
- Detailed performance analysis

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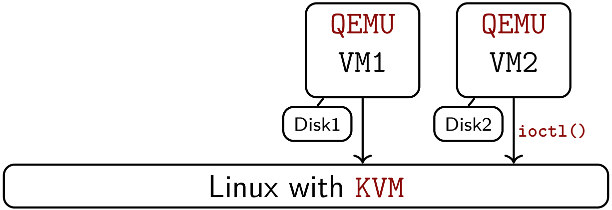
⇝ **Related talks in the ‘References’ section**

KVM-based virtualization components

Linux with `KVM`

KVM-based virtualization components



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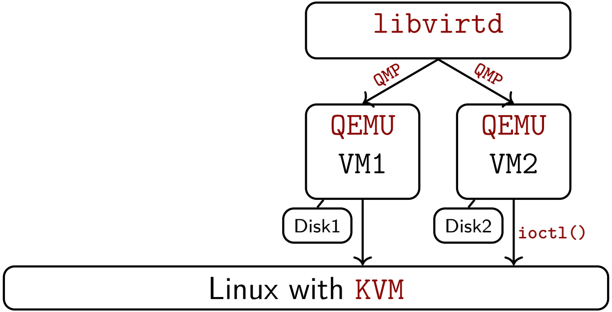

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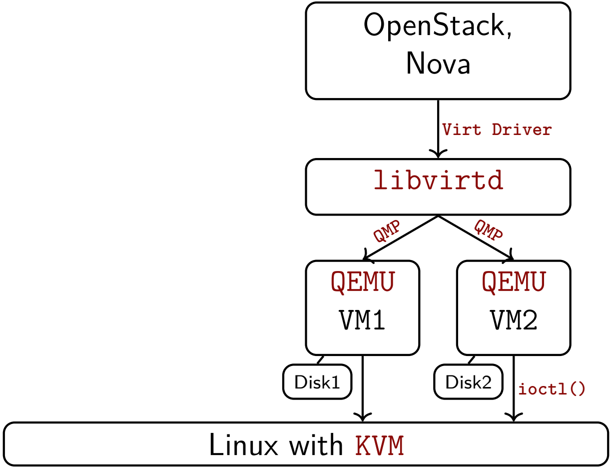

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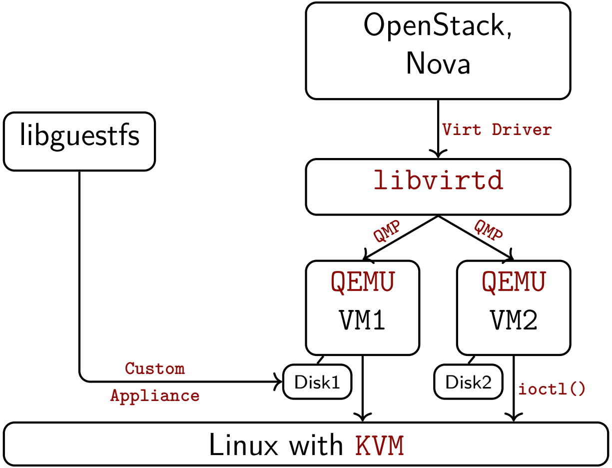
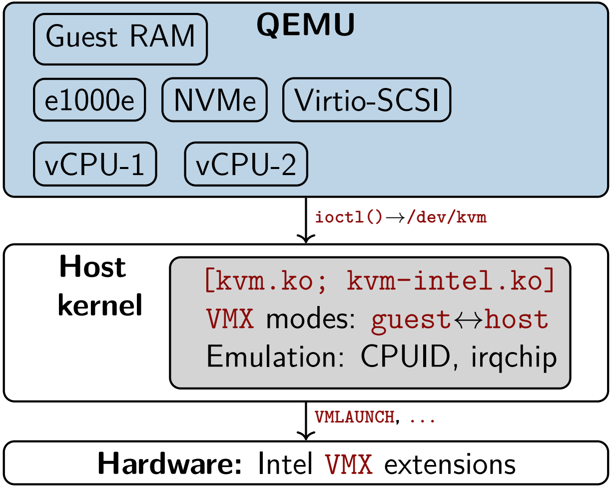
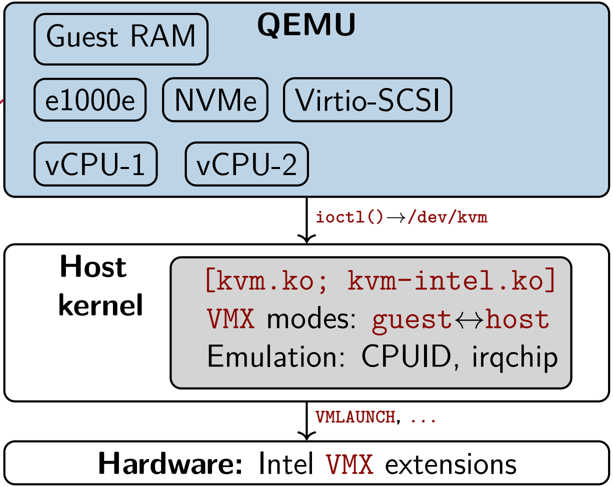
KVM-based virtualization components



QEMU and KVM

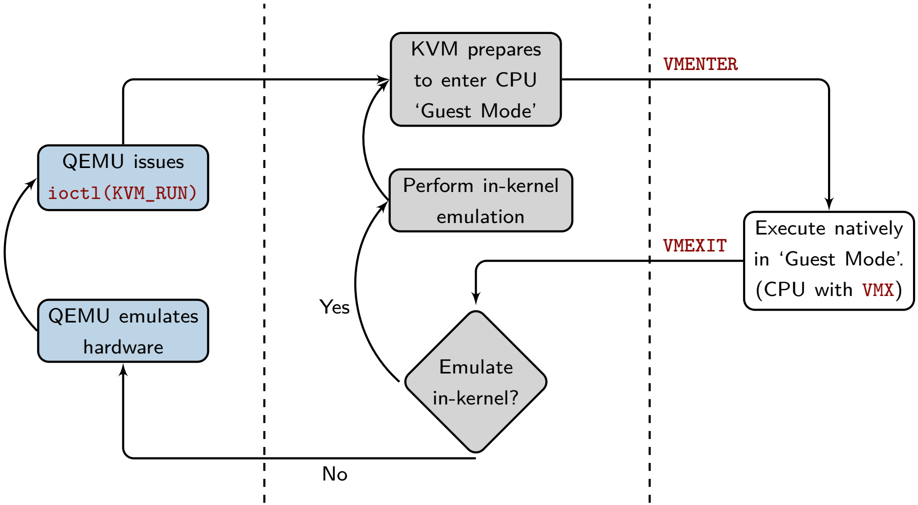

QEMU
Guest RAM
e1000e
NVMe
Virtio-SCSI
vCPU-1
vCPU-2
ioctl()→/dev/kvm
Host kernel
[kvm.ko; kvm-intel.ko]
VMX modes: guest↔host
Emulation: CPUID, irqchip
VMLAUNCH, ...
Hardware: Intel VMX extensions

QEMU and KVM



To inspect, use Linux tools: `top`, `kill`, ...

Hardware-based virtualization with KVM



Part I

Interfaces to configure vCPUs

x86: QEMU's default CPU models (a)

The default models (`qemu32`, `qemu64`) work on any host CPU

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The default models (`qemu32`, `qemu64`) work on any host CPU

But they are dreadful choices!

- No `AES` / `AES-NI`: critical for TLS performance
- No `RDRAND`: important for entropy
- No `PCID`: performance- & security-critical (thanks, Meltdown)

x86: QEMU's default CPU models (b)

```
$ cd /sys/devices/system/cpu/vulnerabilities/
$ grep . *
l1tf:Mitigation: PTE Inversion
meltdown:Mitigation: PTI
spec_store_bypass:Vulnerable
spectre_v1:Mitigation: __user pointer sanitization
spectre_v2:Mitigation: Full generic retpoline
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On a guest running with qemu64

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Spectre-NG

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```

⇝ **Always specify an explicit CPU model; or use Nova’s default, `host-model`**

Defaults of other architectures?

AArch64: Doesn't provide a default guest CPU

```
$ qemu-system-aarch64 -machine virt -cpu help
```

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Default CPU depends on the machine type

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ppc64 — `host` for KVM; `power8` for TCG (pure emulation)

s390x — `host` for KVM; `qemu` for TCG

Configure CPU on the command-line

On **x86**, by default, the `qemu64` model is used:

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Specify a particular CPU model:

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$ qemu-system-x86_64 -cpu IvyBridge-IBRS [...]
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Named CPU model

Control guest CPU features

Enable or disable specific features for a vCPU model:

```
$ qemu-system-x86_64 \
   -cpu Skylake-Client-IBRS,vmx=off,pcid=on [...]
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Granular CPU flags

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$ qemu-system-x86_64 \
   -cpu Skylake-Client-IBRS,vmx=off,pcid=on [...]
```

For a list of supported vCPU models, refer to:

```
$ qemu-system-x86_64 -cpu help
```

Or libvirt's — '`virsh cpu-models x86_64`'

QEMU's CPU-related run-time interfaces

Granular details about vCPU models, their capabilities & more:

- `query-cpu-definitions`
- `query-cpu-model-expansion`
- `query-hotpluggable-cpus`
- `query-cpus-fast`; `device_{add,del}`

⇝ **libvirt runs some of these at its daemon start-up time, and caches the results**

Run-time: E.g. probe for CPU model specifics

Executed at `libvirtd` start-up:

```
(QMP) query-cpu-definitions
    ...
    "return": [
        {   "typename": "Westmere-IBRS-x86_64-cpu",
            "unavailable-features": [],
            "migration-safe": true,
            "static": false,
            "name": "Westmere-IBRS" }]
    ... # Snip other CPU variants
```

Part II
CPU modes, models and flags

Host passthrough

Exposes the host CPU model, features, etc. as-is to the VM

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$ qemu-system-x86_64 -cpu host [...]
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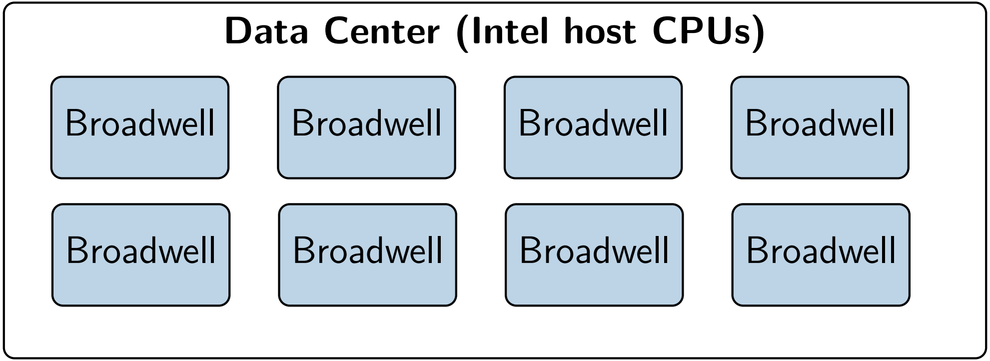
⇝ **Most performant; ideal if live migration is not required**

Host passthrough – when else to use it?



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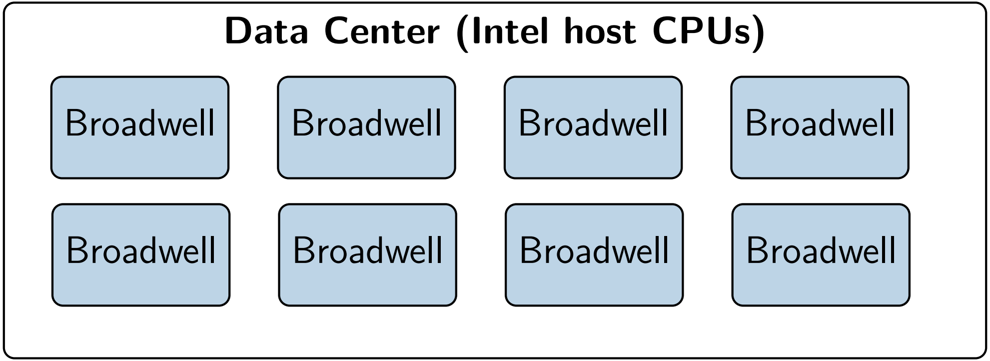

⇝ **Along with identical CPUs, identical kernel and microcode are a <u>must</u> for VM live migration!**

QEMU's named CPU models (a)

Virtual CPUs typically model physical CPUs

From a Nova instance's QEMU log:

```
[...] qemu-system-x86_64 -cpu Broadwell-IBRS,\
vme=on,f16c=on,rdrand=on, \
tsc_adjust=on,xsaveopt=on,\
hypervisor=on,arat=off,   \
pdpe1gb=on,abm=on [...]
```

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hypervisor=on,arat=off,   \
pdpe1gb=on,abm=on [...]
```

⇝ **More flexible in live migration than 'host passthrough'**

QEMU's named CPU models (b)

QEMU is built with a number of pre-defined models:

```
$ qemu-system-x86_64 -cpu help
Available CPUs:
...
x86 Broadwell-IBRS         Intel Core Processor (Broadwell, IBRS)
...
x86 EPYC                   AMD EPYC Processor
x86 EPYC-IBPB              AMD EPYC Processor (with IBPB)
x86 Haswell                Intel Core Processor (Haswell)
...
Recognized CPUID flags:
amd-ssbd apic arat arch-capabilities avx avx2 avx512-4fmaps
...
```

‘`host-model`’ – a libvirt abstraction

Tackles a few things:

- Maximum possible CPU features from the host
- Live migration compatibility—with caveats
- Auto-adds critical guest CPU flags (e.g. `spec-ctrl`)

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⇝ **Targets for the best of ‘host passthrough’ & named CPU models; it’s the <u>default of Nova</u>**

‘host-model’ – example libvirt config

From a Nova guest definition:

```
<cpu mode='host-model'>
  <feature policy='require' name='vmx'/>
  <feature policy='disable' name='pdpe1gb'/>
  ...
</cpu>
```

⇝ **libvirt will translate it into a suitable CPU model; based on:** `/usr/share/libvirt/cpu_map/*.xml`

‘`host-model`’ and live migration

As done by libvirt:

- Source vCPU definition is transferred as-is to the target
- On target: Migrated guest sees the *same* vCPU model

‘`host-model`’ and live migration

As done by libvirt:

- Source vCPU definition is transferred as-is to the target
- On target: Migrated guest sees the *same* vCPU model
- But: When the guest ‘cold-reboots’, it may pick up *extra* CPU features—prevents migrating back to the source host

⇝ **Use `host-model`, if live migration in both directions is not a requirement**

Nova and CPU models

Provides relevant config attributes:

- `cpu_mode`
  - Can be: `custom`, `host-passthrough`, or `host-model`
- `cpu_model` & `cpu_model_extra_flags`
  - Refer to libvirt's `/usr/share/libvirt/cpu_map/*.xml`
  - Or QEMU's: '`qemu-system-x86_64 -cpu help`'

⇝ **Refer to the docs of the above config attributes**
https://docs.openstack.org/nova/rocky/configuration/config.html

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Nova and CPU models – example config

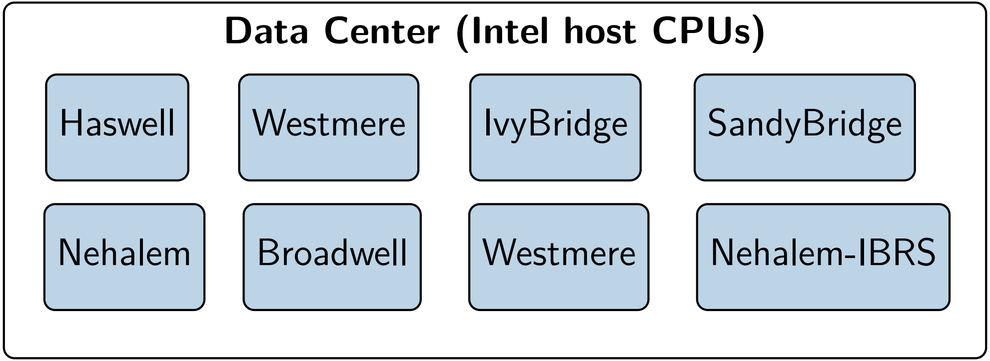
On a Compute node:

```
$ cat /etc/nova/nova.conf
...
[libvirt]
cpu_mode = custom
cpu_model = IvyBridge-IBRS
cpu_model_extra_flags = ssbd, pdpe1gb
...
```

Part III

Choosing CPU models & features

Finding compatible CPU models



Finding compatible CPU models

Problem: Determine a compatible model among CPU variants

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Enter libvirt's APIs:

- `compareCPU()` and `baselineCPU()`
- `compareHypervisorCPU()` and `baselineHypervisorCPU()`

New in libvirt 4.4.0

TODO: Make Nova use these

Intersection between these two host CPUs?

```
$ cat Multiple-Host-CPUs.xml
<cpu mode='custom' match='exact'>
  <model fallback='forbid'>Haswell-noTSX-IBRS</model>
  <vendor>Intel</vendor>
  <feature policy='require' name='vmx'/>
  <feature policy='require' name='rdrand'/>
</cpu>
<!-- Second CPU -->
<cpu mode='custom' match='exact'>
  <model fallback='forbid'>Skylake-Client-IBRS</model>
  <vendor>Intel</vendor>
  <feature policy='disable' name='pdpe1gb'/>
  <feature policy='disable' name='pcid'/>
</cpu>
```

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</cpu>
```

Two CPU models

Use baselineHypervisorCPU() to determine it

```
$ virsh hypervisor-cpu-baseline Multiple-Host-CPUs.xml
<cpu mode='custom' match='exact'>
  <model fallback='forbid'>Haswell-noTSX-IBRS</model>
  <vendor>Intel</vendor>
  <feature policy='require' name='rdrand'/>
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Intersection between our Haswell & Skylake variants

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</cpu>
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⇝ **A “baseline” CPU model that permits live migration**

x86: QEMU’s “machine types”

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Two main purposes:

- Emulate different chipsets (and related devices)—e.g. Intel's `i440FX` (a.k.a `'pc'`) and `Q35`

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x86: QEMU's "machine types"

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- Emulate different chipsets (and related devices)—e.g. Intel's `i440FX` (a.k.a `'pc'`) and `Q35`
- Provide a stable guest ABI—virtual hardware remains identical *regardless* of changes in host software / hardware

x86: QEMU's "machine types" – versioned

```
$ qemu-system-x86_64 -machine help
...
pc              Standard PC (i440FX + PIIX, 1996) (alias of pc-i440fx-3.0)
pc-i440fx-3.0   Standard PC (i440FX + PIIX, 1996) (default)
pc-i440fx-2.9   Standard PC (i440FX + PIIX, 1996)
...
q35             Standard PC (Q35 + ICH9, 2009) (alias of pc-q35-3.0)
pc-q35-3.0      Standard PC (Q35 + ICH9, 2009)
pc-q35-2.9      Standard PC (Q35 + ICH9, 2009)
pc-q35-2.8      Standard PC (Q35 + ICH9, 2009)
...
```

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Recommended

⇝ **Versioned machine types provide stable guest ABI**

Machine types and CPU features

Changing machine types is guest-visible

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- Explicitly request Nova to change machine type

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$\rightsquigarrow$ **Change machine types only after guest workload evaluation—CPU features & devices can differ**

x86: Updating to patched vCPU models

- First, update microcode, host & guest kernels; refer to—`/sys/devices/system/cpu/vulnerabilities/`

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- First, update microcode, host & guest kernels; refer to—`/sys/devices/system/cpu/vulnerabilities/`
- Next, update libvirt & QEMU
- Then explicitly tell Nova to update guest CPUs to their patched variants—e.g. the `*-IBRS` models
- Cold-reboot the guests—to pick up new `CPUID` bits

⇝ **Guidance:** `qemu/docs/qemu-cpu-models.texi`

x86: Important CPU flags

To mitigate guests from multiple Spectre & Meltdown variants:

- Intel: `ssbd`, `pcid`, `spec-ctrl`
- AMD: `virt-ssbd`, `amd-ssbd`, `amd-no-ssb`, `ibpb`

Some are built into QEMU's `*-IBRS` & `*-IBPB` CPU models

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⇝ **Details:**

`qemu/docs/qemu-cpu-models.texi`

https://www.qemu.org/2018/02/14/qemu-2-11-1-and-spectre-update

'Expectations' from applications like Nova?

> "QEMU and libvirt took the joint decision to stop adding new named CPU models when CPU vulnerabilities are discovered from this point forwards. Applications / users would be expected to turn on CPU features explicitly as needed and are considered broken if they don't provide this functionality."
>
> — "CPU model versioning separate from machine type versioning"
> From '`qemu-devel`' & libvirt mailing lists

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Summary

- Identical host CPUs? Go with "host passthrough"
- With mixed host CPUs: if `host-model` doesn't suit, work out a custom 'baseline' model
- Evaluate workloads before changing machine types
- Systematically update all relevant host & guest components—only *then* update guest CPU models+flags

References

- CPU model configuration for QEMU/KVM x86 hosts, by Daniel Berrangé

  https://www.berrange.com/posts/2018/06/29/cpu-model-configuration-for-qemu-kvm-on-x86-hosts

- Mitigating Spectre and Meltdown (and L1TF), by David Woodhouse

  https://kernel-recipes.org/en/2018/talks/mitigating-spectre-and-meltdown-vulnerabilities/

- Exploiting modern microarchitectures—Meltdown, Spectre, and other hardware attacks, by Jon Masters

  https://archive.fosdem.org/2018/schedule/event/closing_keynote

- KVM and CPU feature enablement, by Eduardo Habkost

  https://wiki.qemu.org/images/c/c8/Cpu-models-and-libvirt-devconf-2014.pdf

Questions?

E-mail: `kashyap@redhat.com`
IRC: `kashyap` – Freenode & OFTC