Operating System Virtualization: Practice and Experience

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Virtualization

"All problems in computer science can be solved with another layer of indirection"

-- (attributed to) David Wheeler

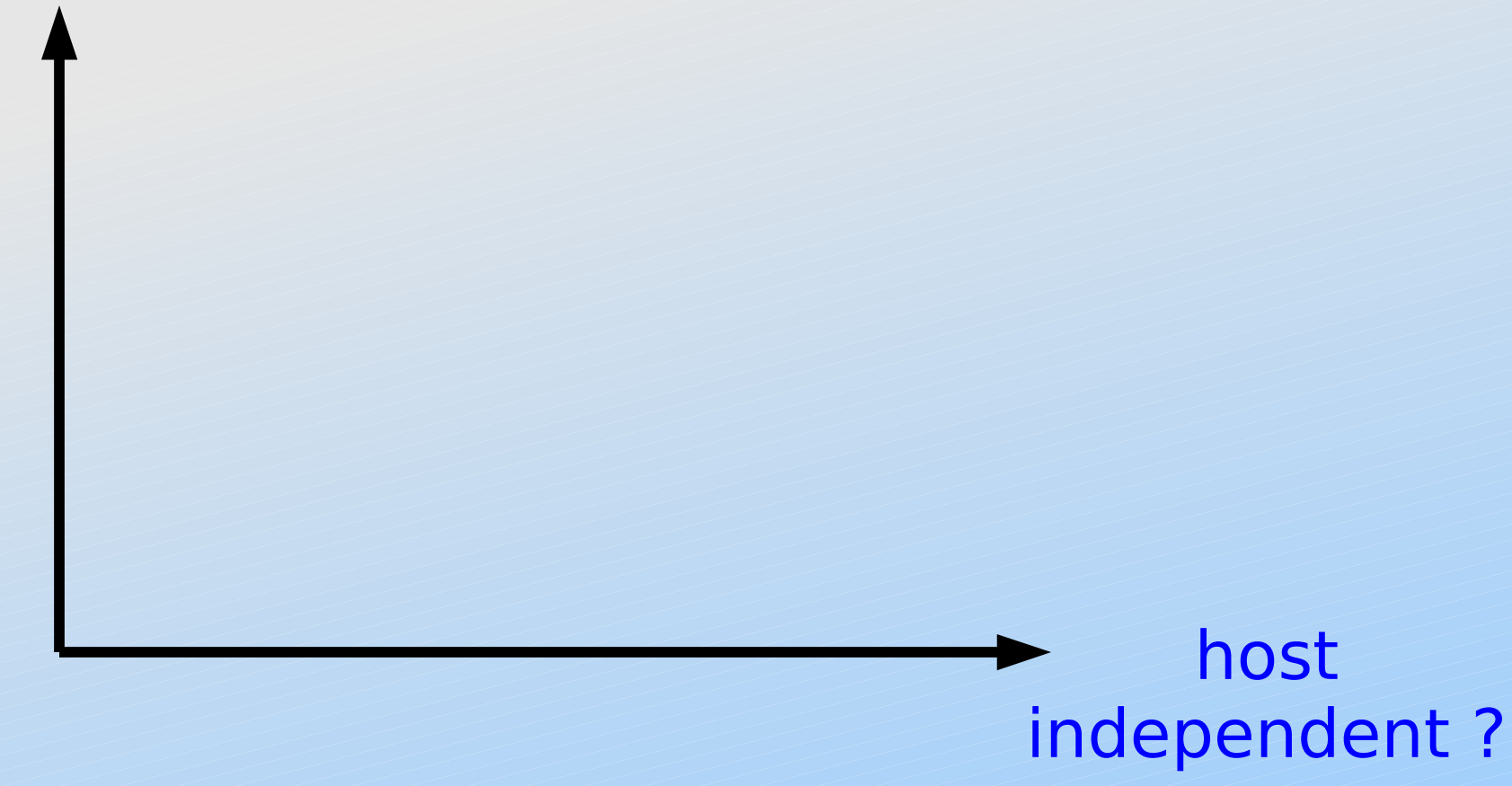
Virtualization - Why

- Computers are faster, cheaper, more connected
- (Re)Emerged to address management complexity and security hazards
- Provides isolation and mobility
  - consolidation, security
  - fault tolerance, load balancing, availability

Virtualization - Where

- Hardware or Operation system ?
  - HW: decouple entire operating system
  - OS: decouple individual applications

OS Virtualization - Taxonomy



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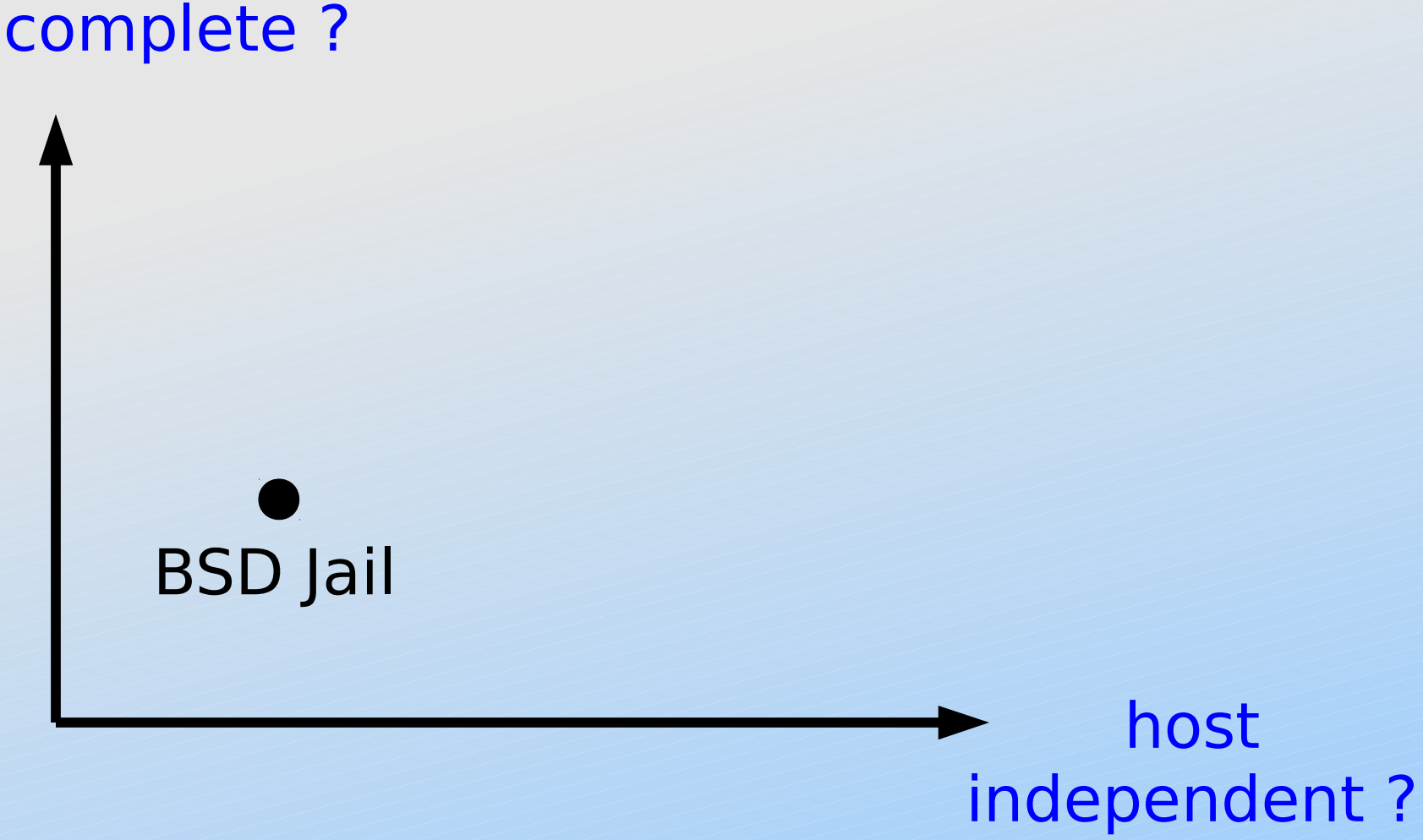

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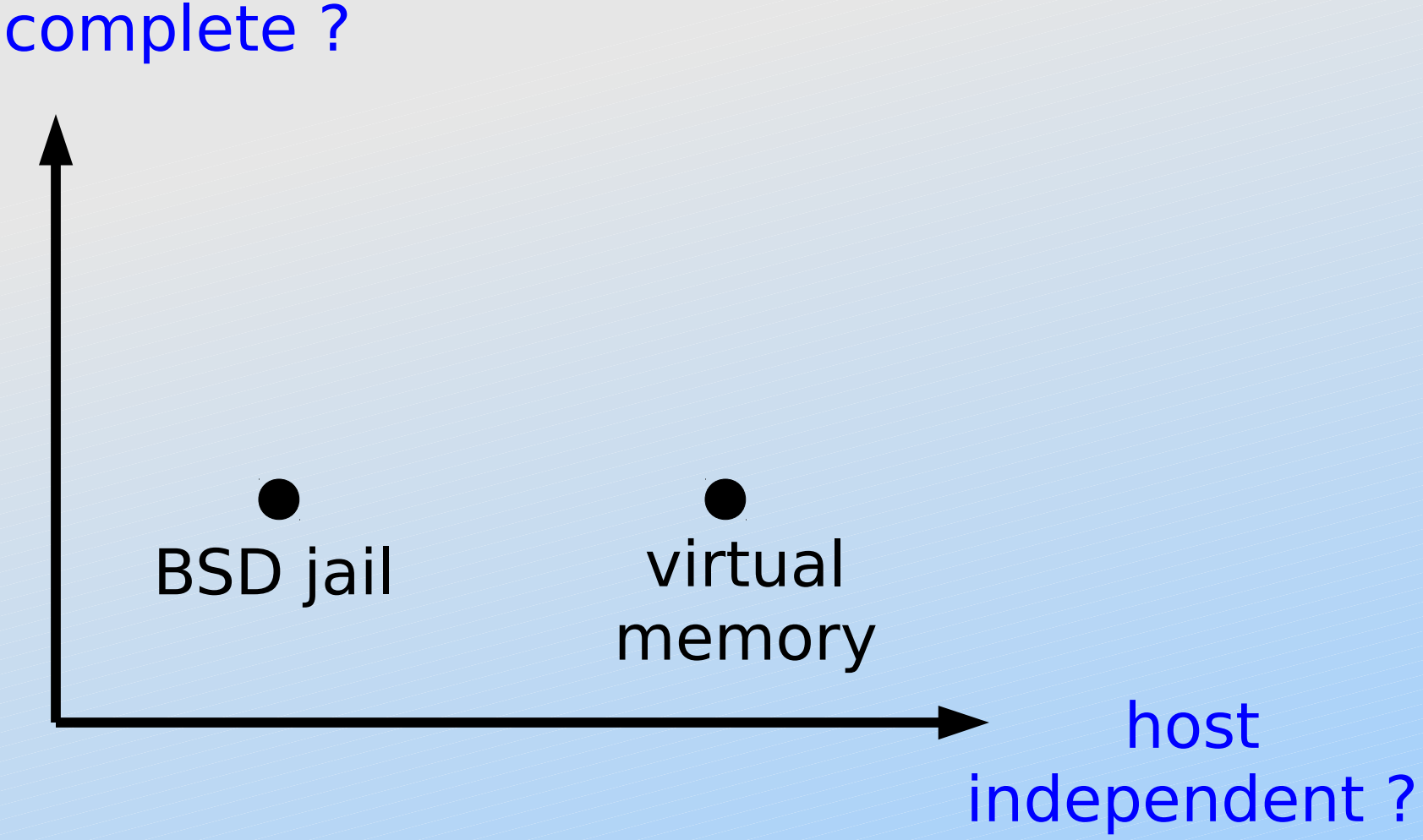

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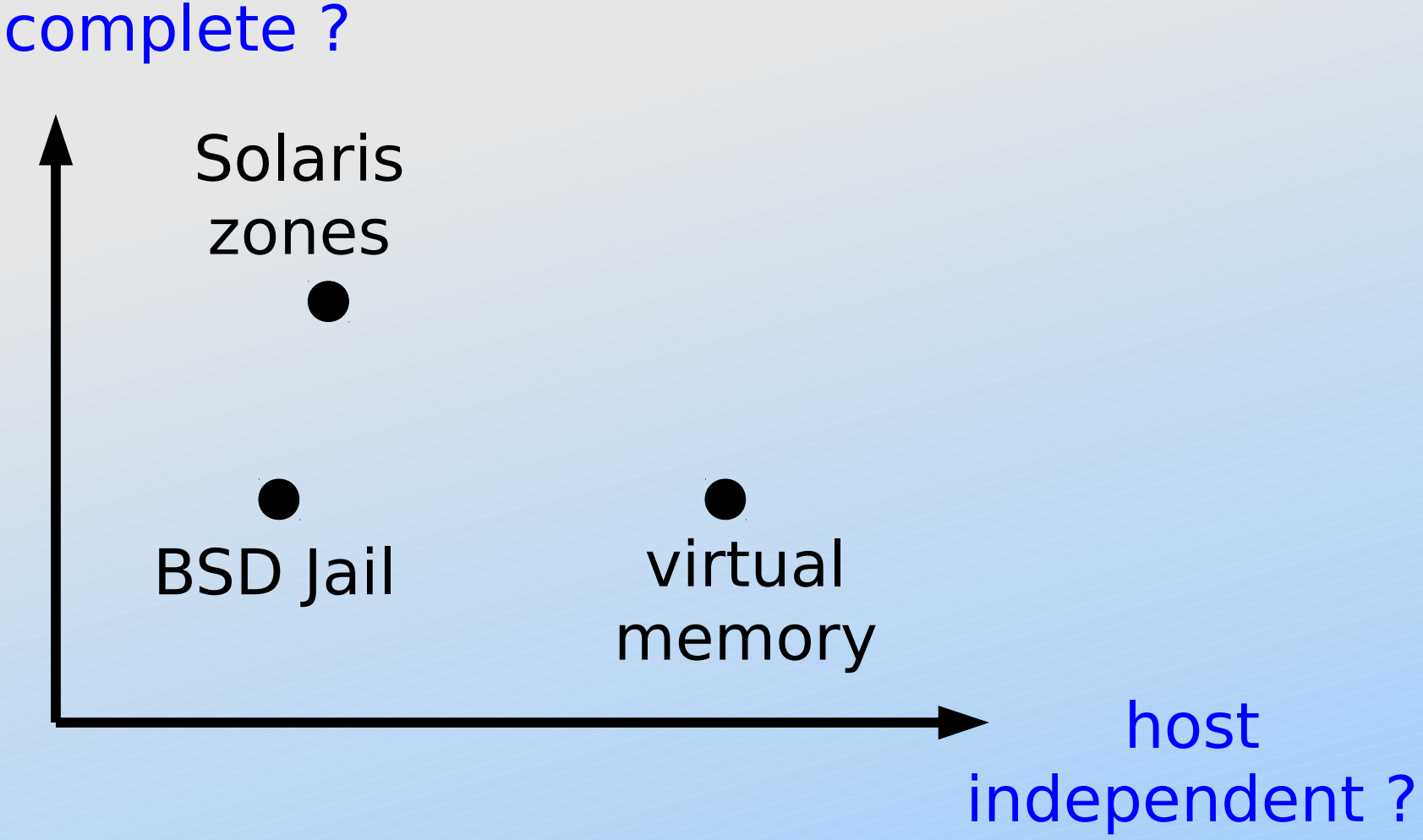

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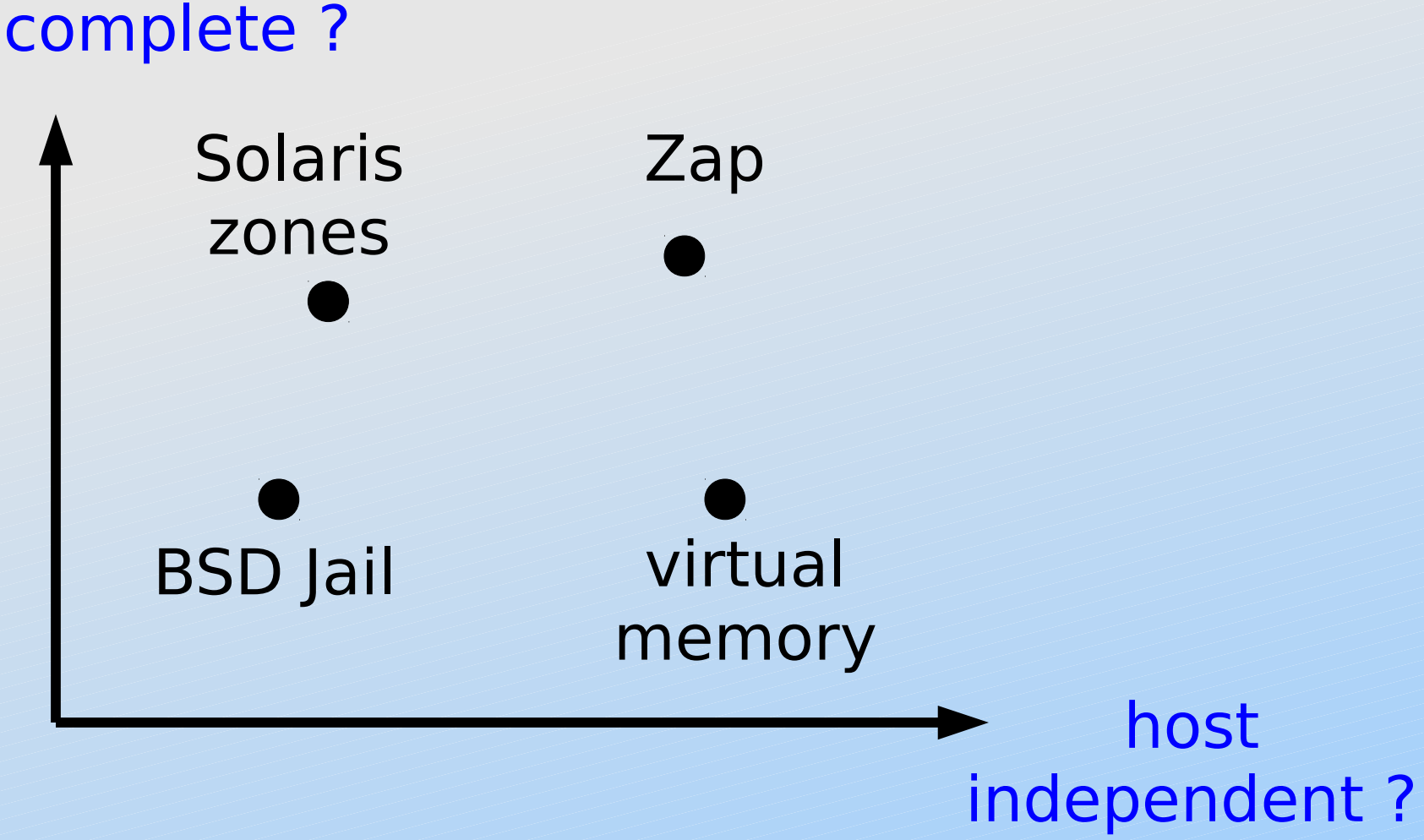

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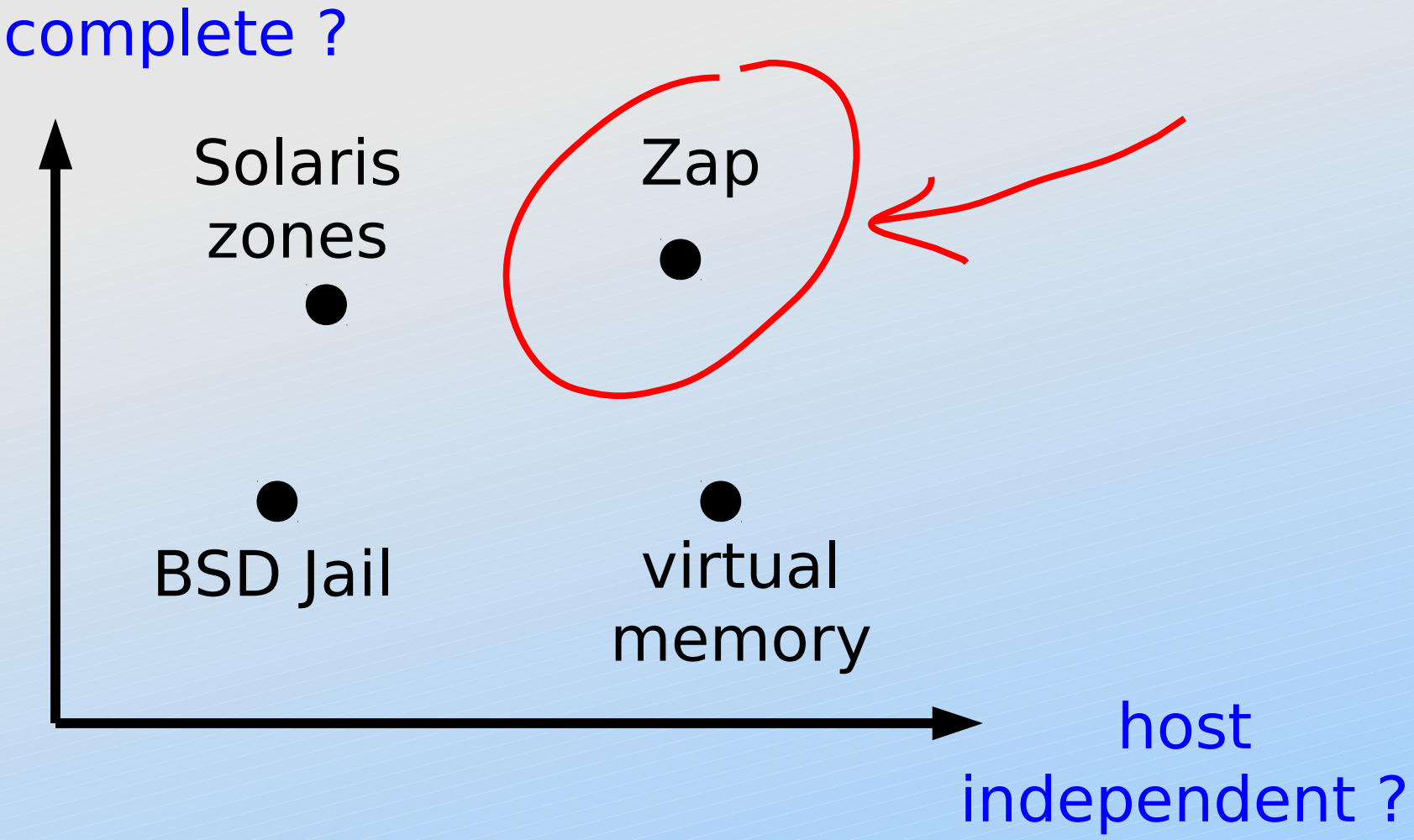
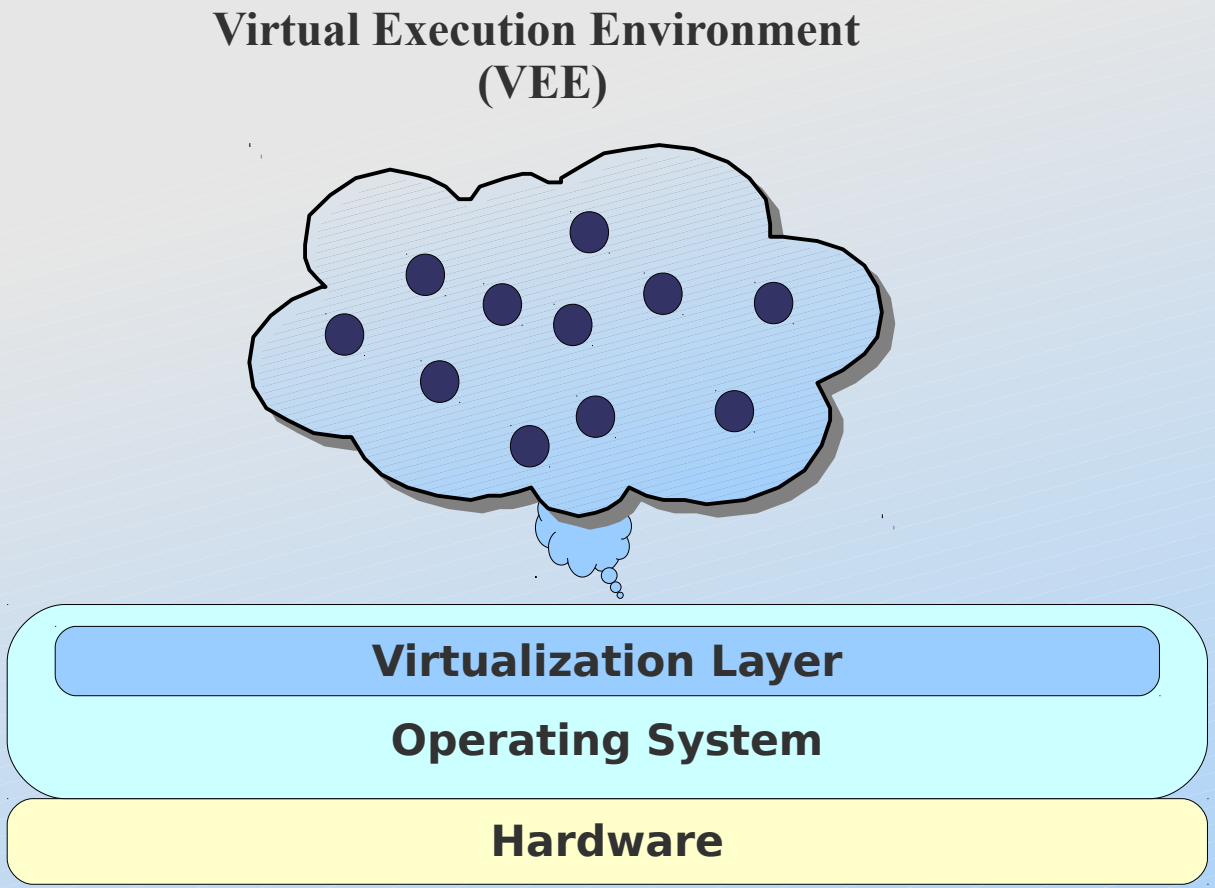


Virtual Private Namespace



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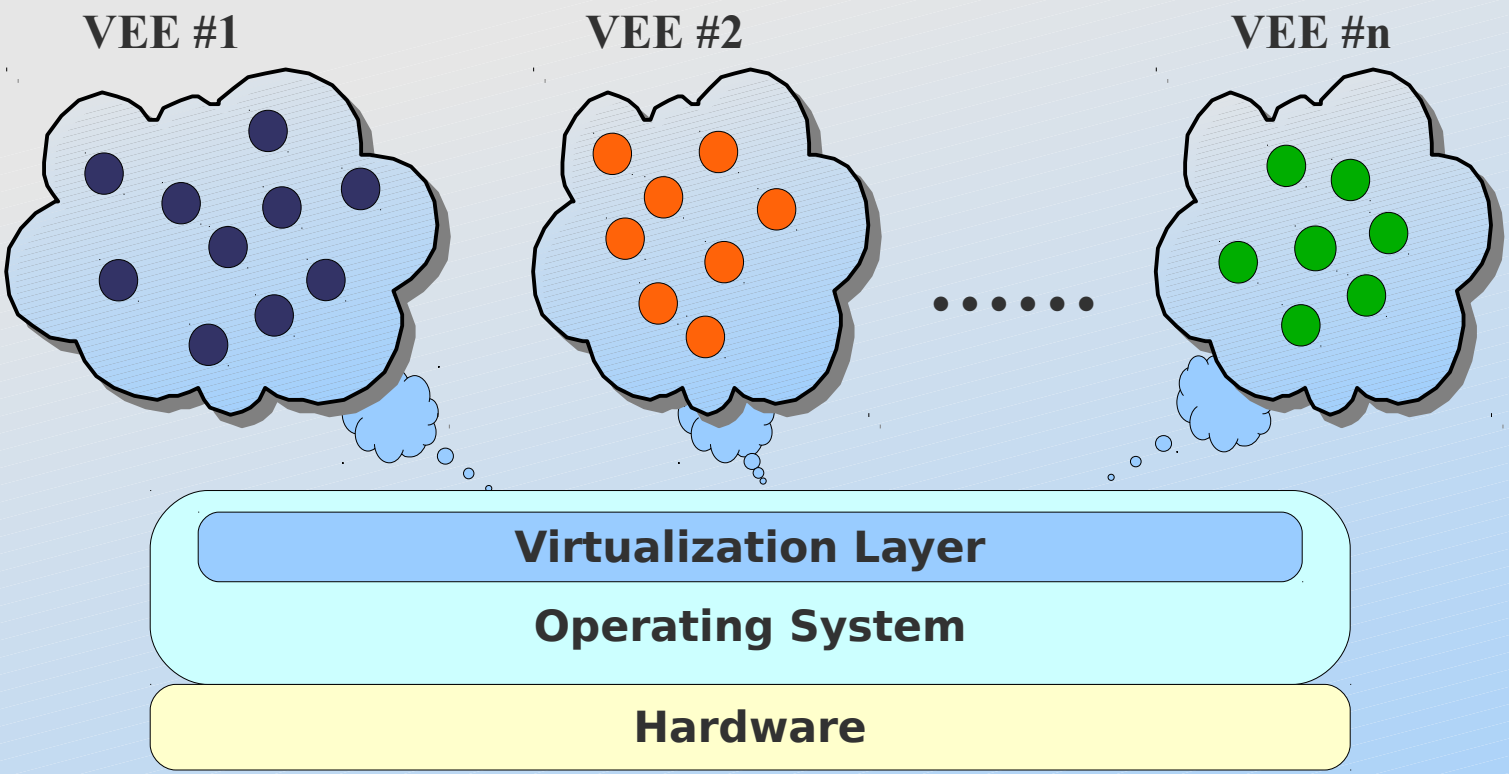
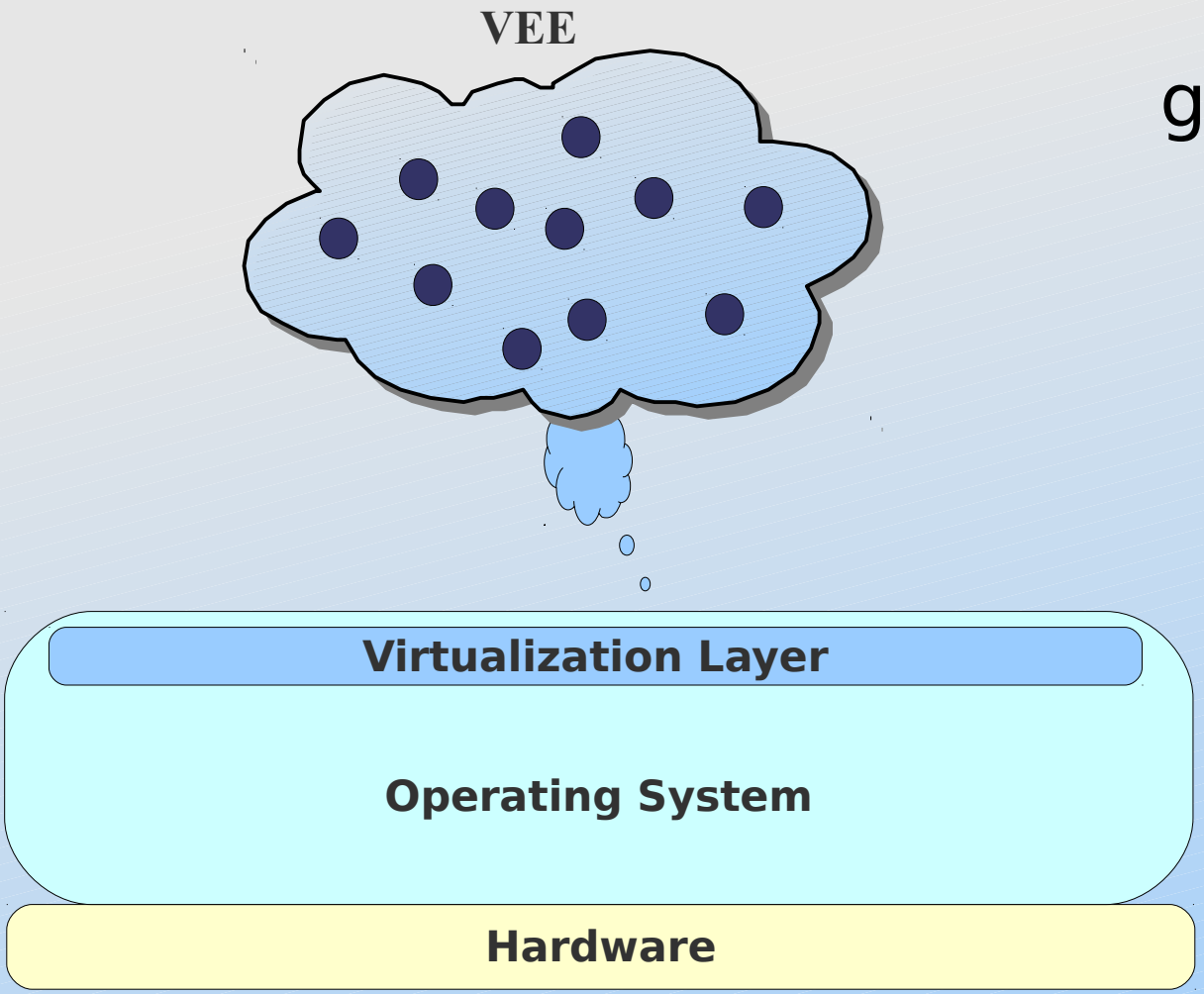


Virtual Namespace



getpid() ?

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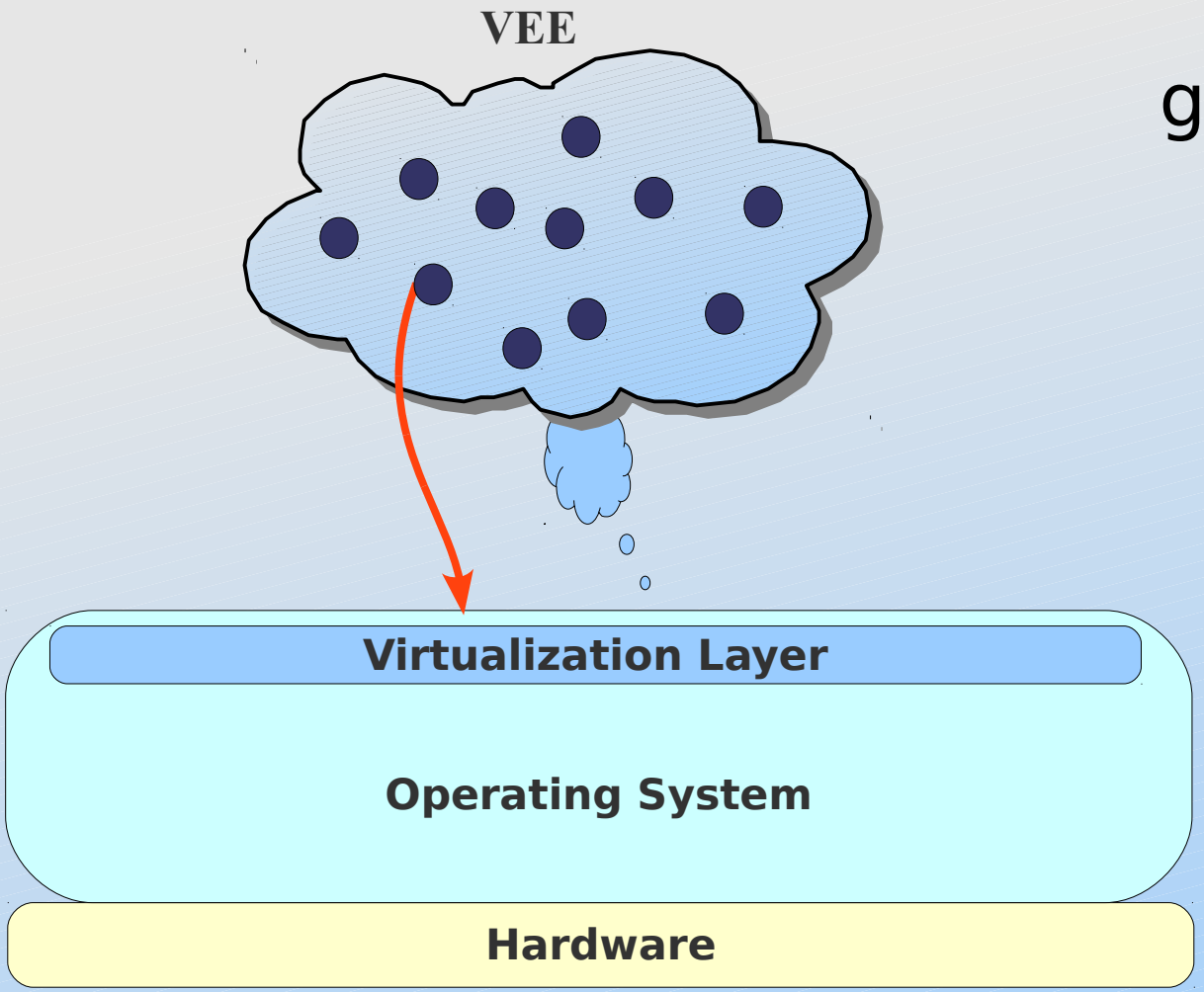

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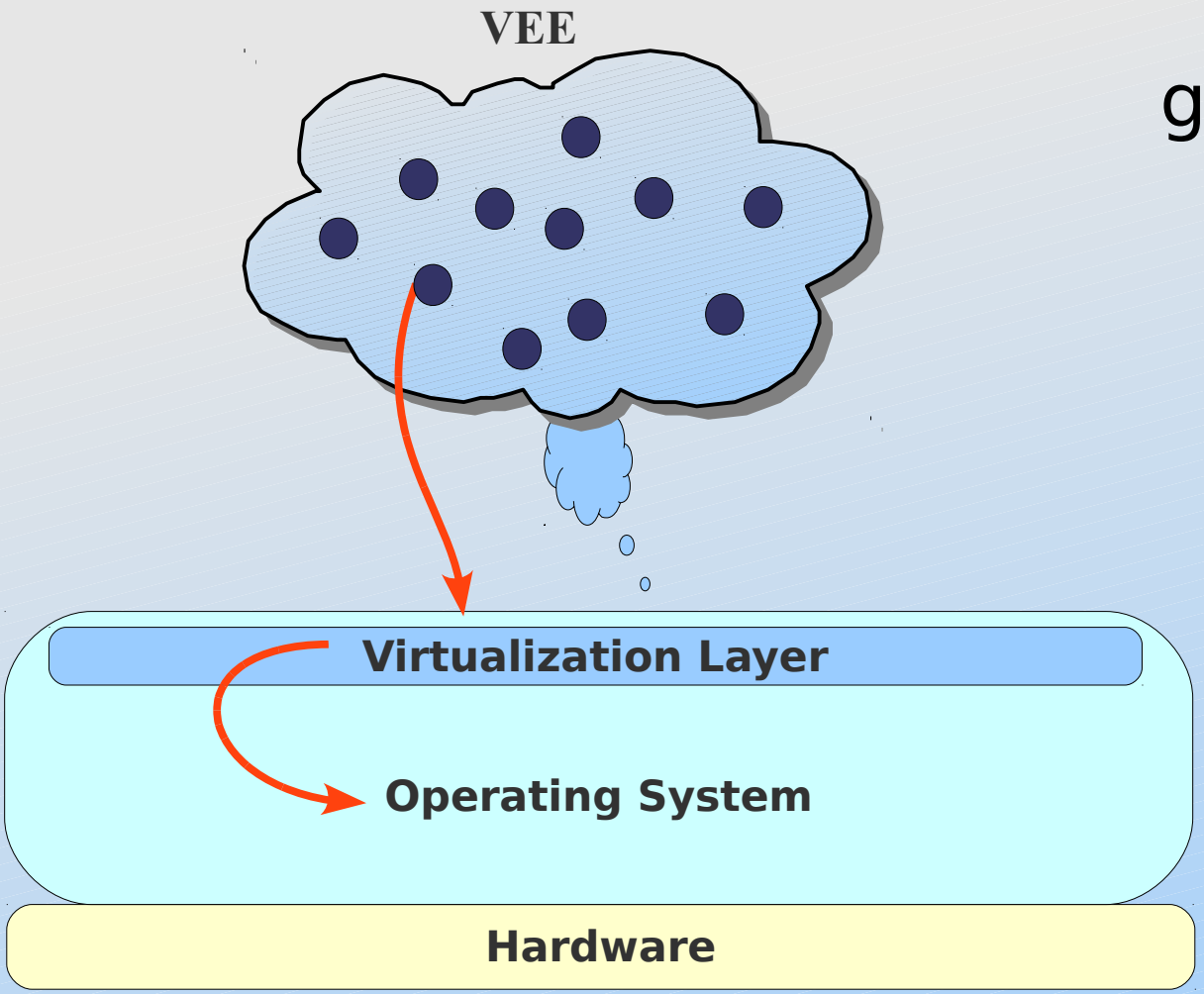

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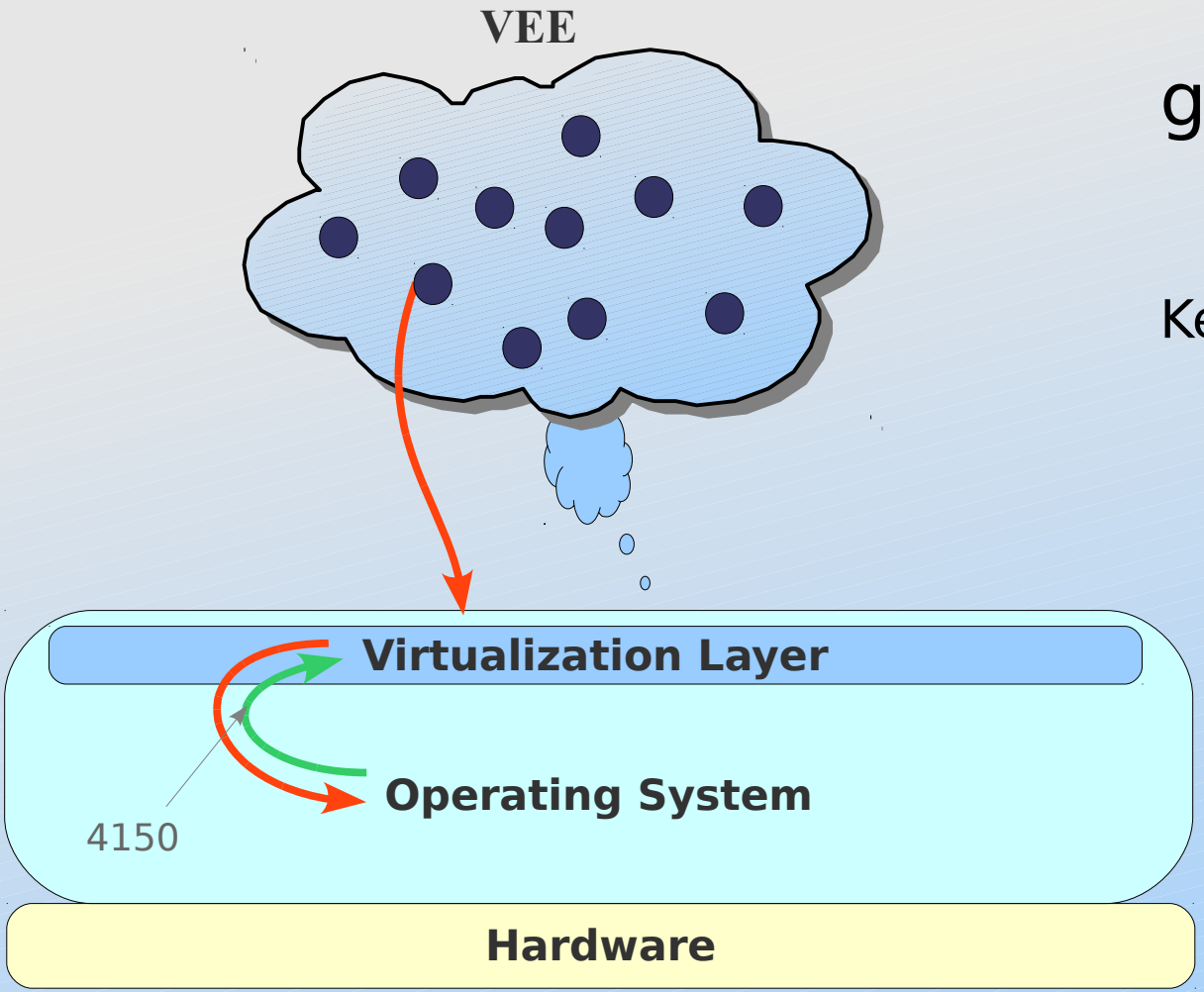

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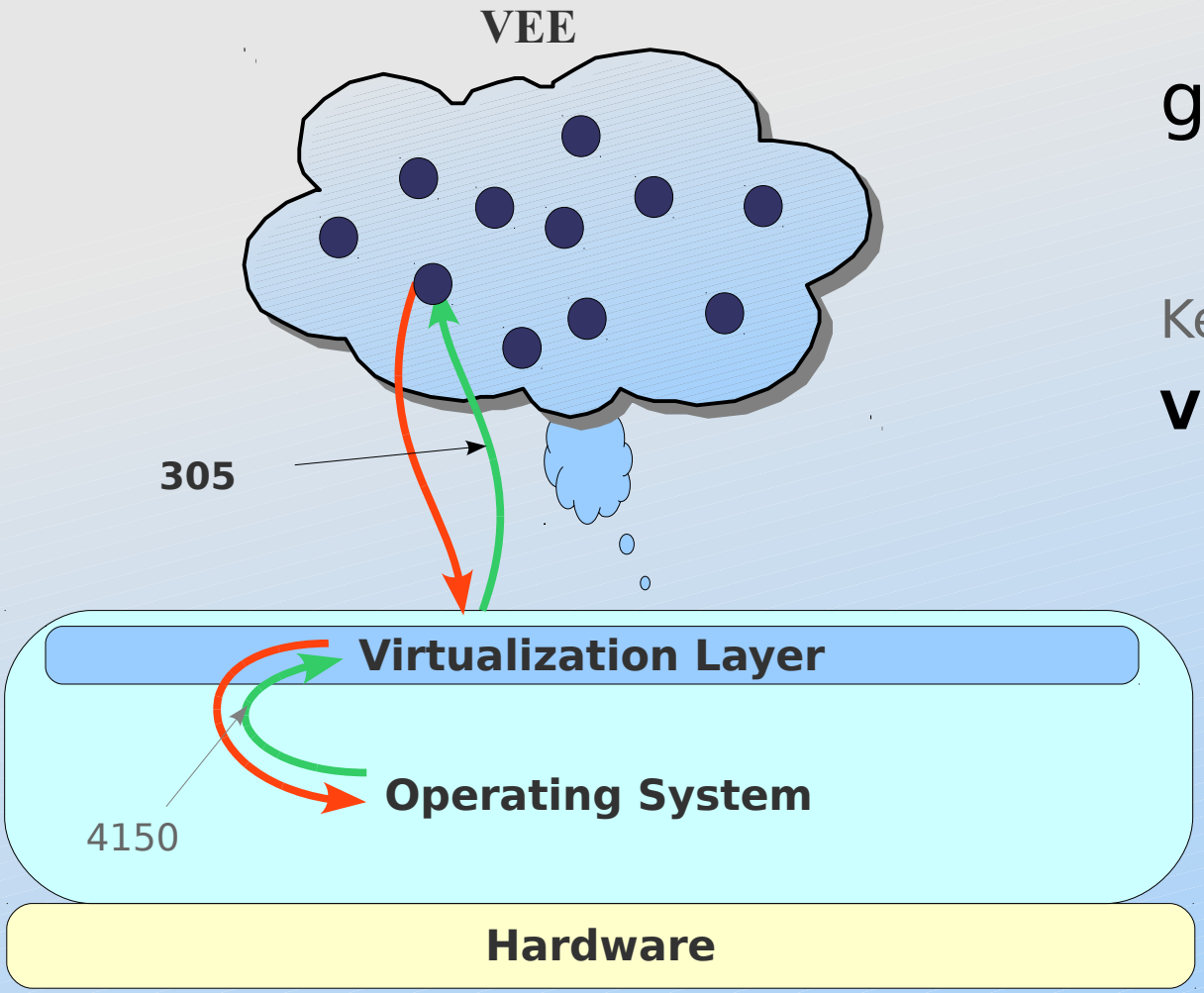
Kernel: 4150 (real)

Virtual Namespace



getpid() ?

Kernel: 4150 (real)

VEE: 305 (virtual)

OS Virtualization - Where

- Interposition
  - user-level
  - process tracing
  - in-kernel

The Virtual Diner...

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- HW or OS ?

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- Complete ? Host independent ?

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- Complete ? Host independent ?

  “I'll have host independent, and add complete on the side.

- Userspace or in-kernel ?
  - “can I have it as a kernel module ?”

Virtualization

"All problems in computer science can be solved with another layer of indirection ...

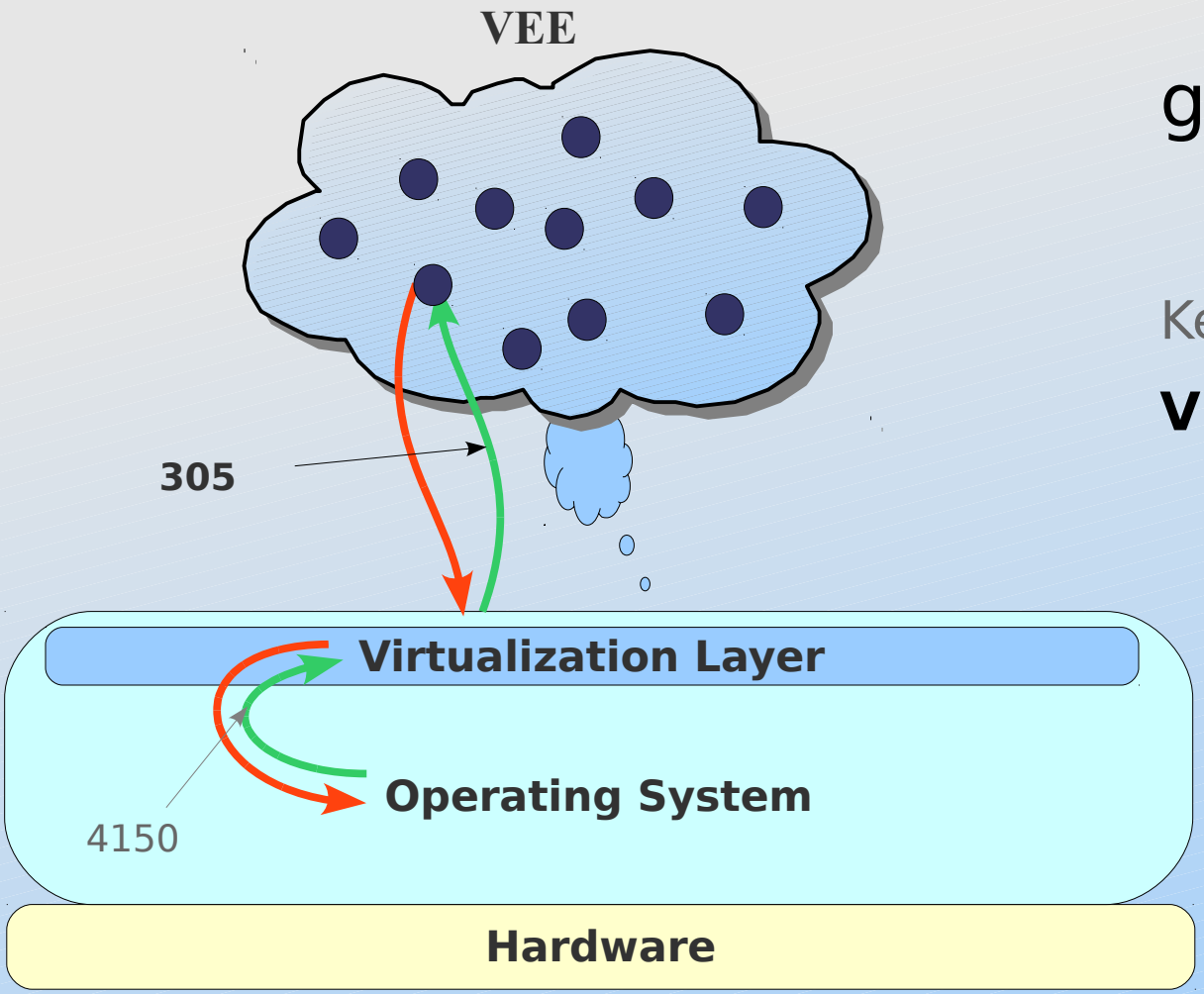
... but that usually will create another problem."

-- (attributed to) David Wheeler

Virtualization - Challenges

- Performance overhead
- Race conditions

Interposition Revisited



getpid() ?

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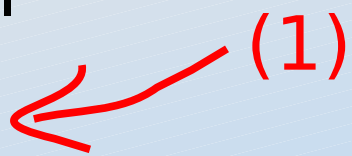
Race Conditions

- syscall wrapper
  - translate virtual → physical
  - invoke kernel system call
  - translate physical → virtual



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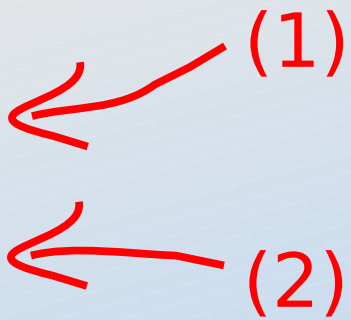
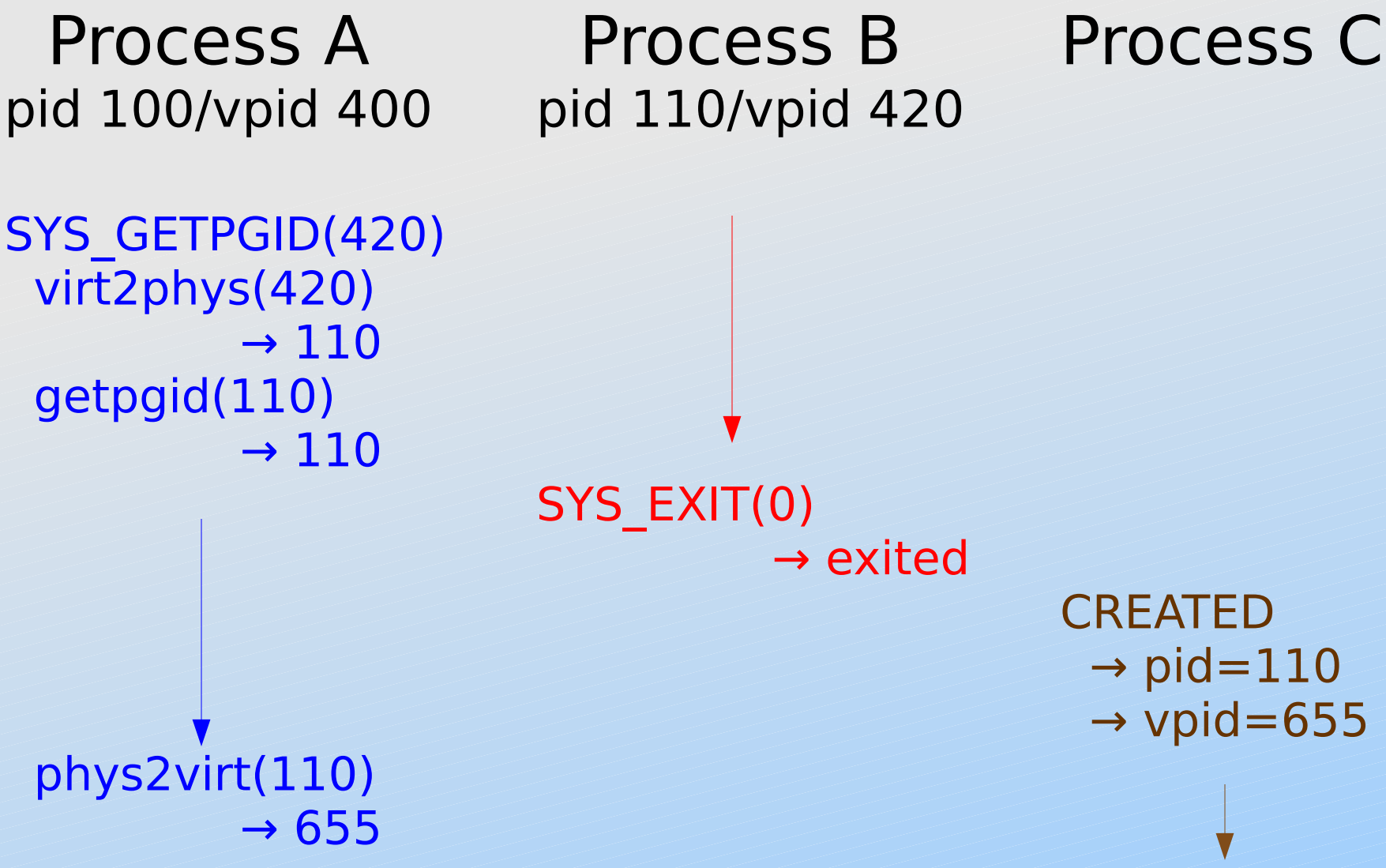


- Wrapper preamble (1), epilogue (2)
- Initialization, deletion, re-use

PID Races - reuse



PID Races - init

Parent

pid 100/vpid 400

SYS_FORK()

fork()

→ pid = 110

→ vpid = 420

Child

CREATED

→ pid = 110

SYS_GETPID()

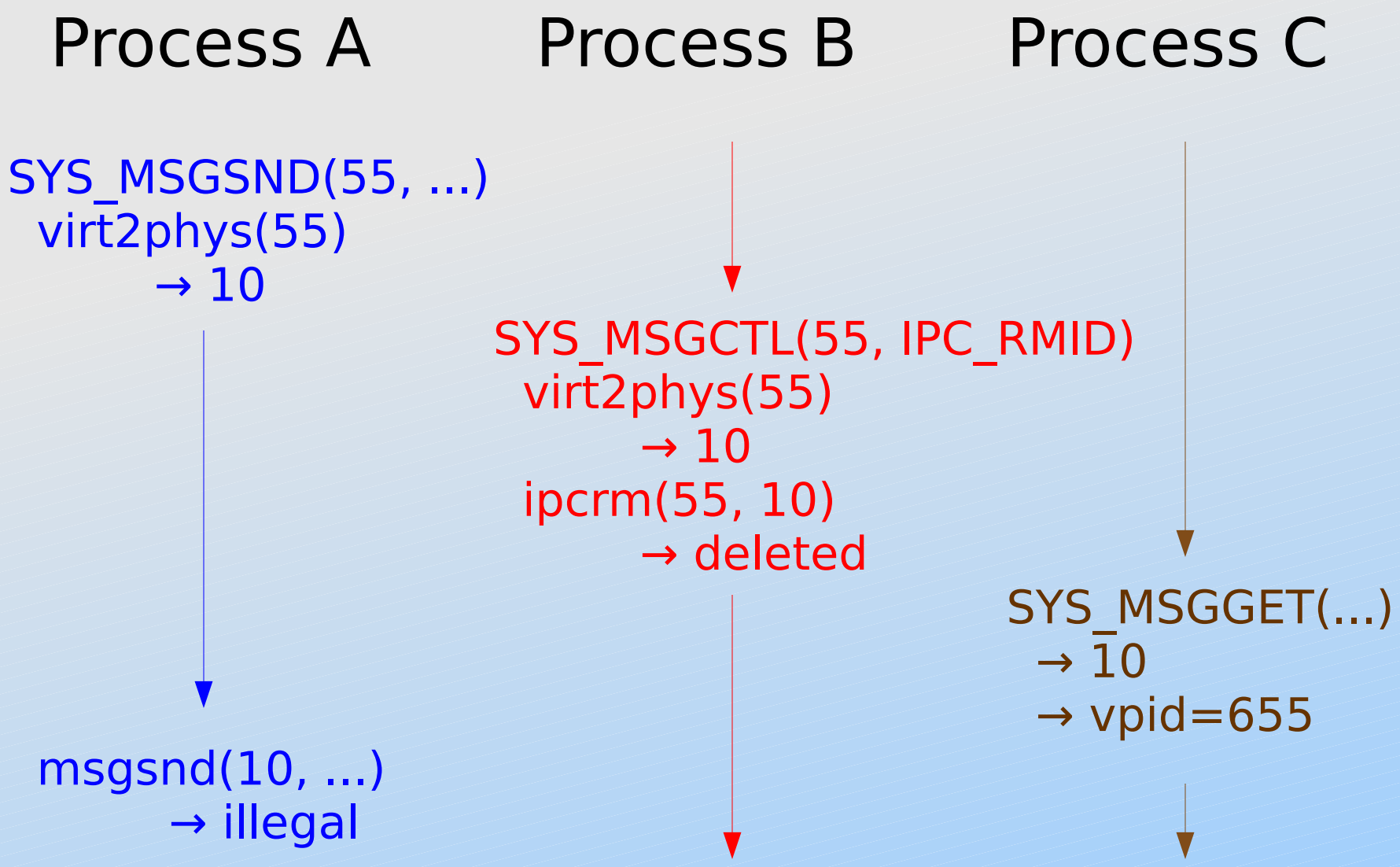
getpid()

→ 110

phys2virt(110)

→ undefined

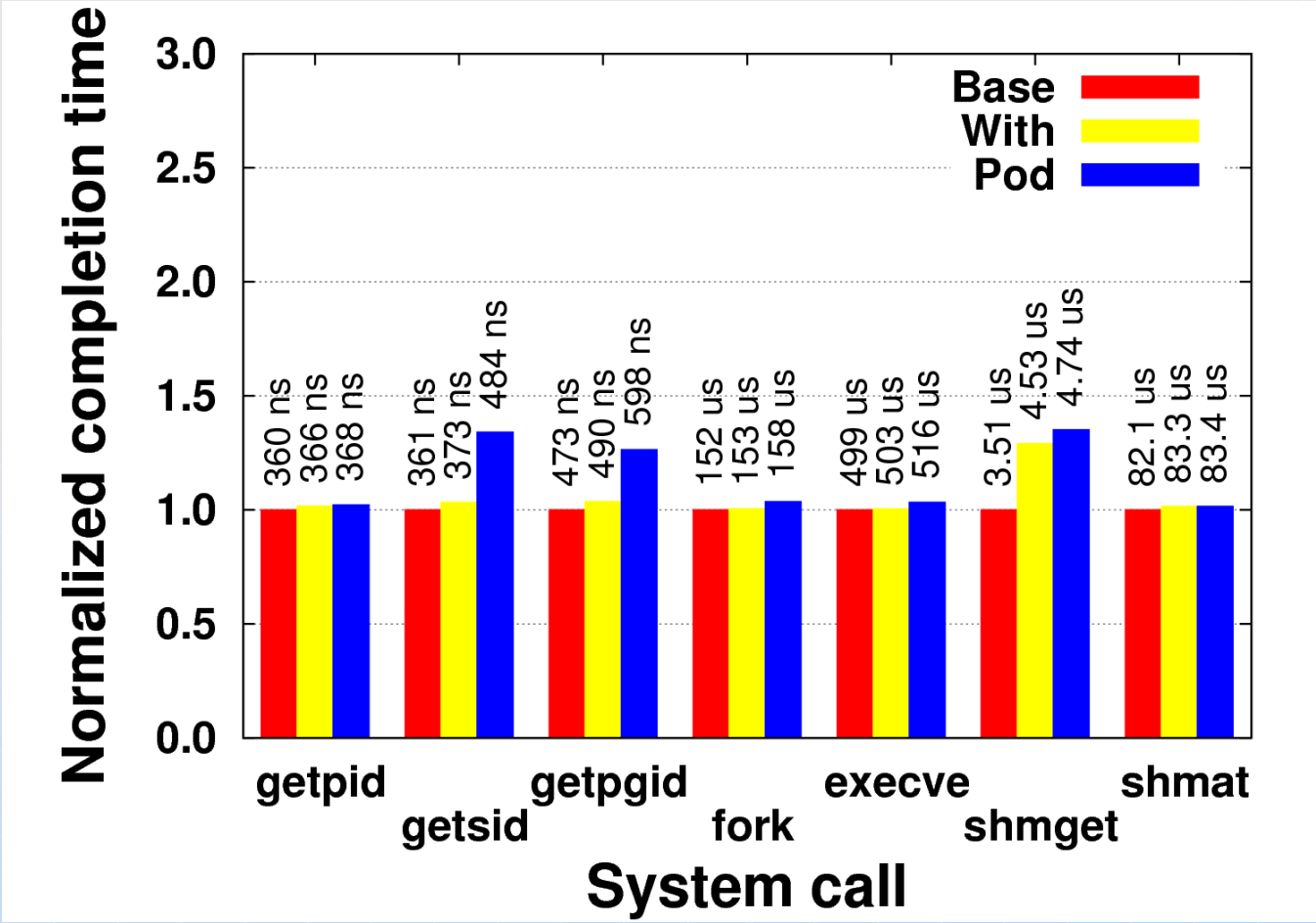
IPC Races - reuse



Experimental Evaluation

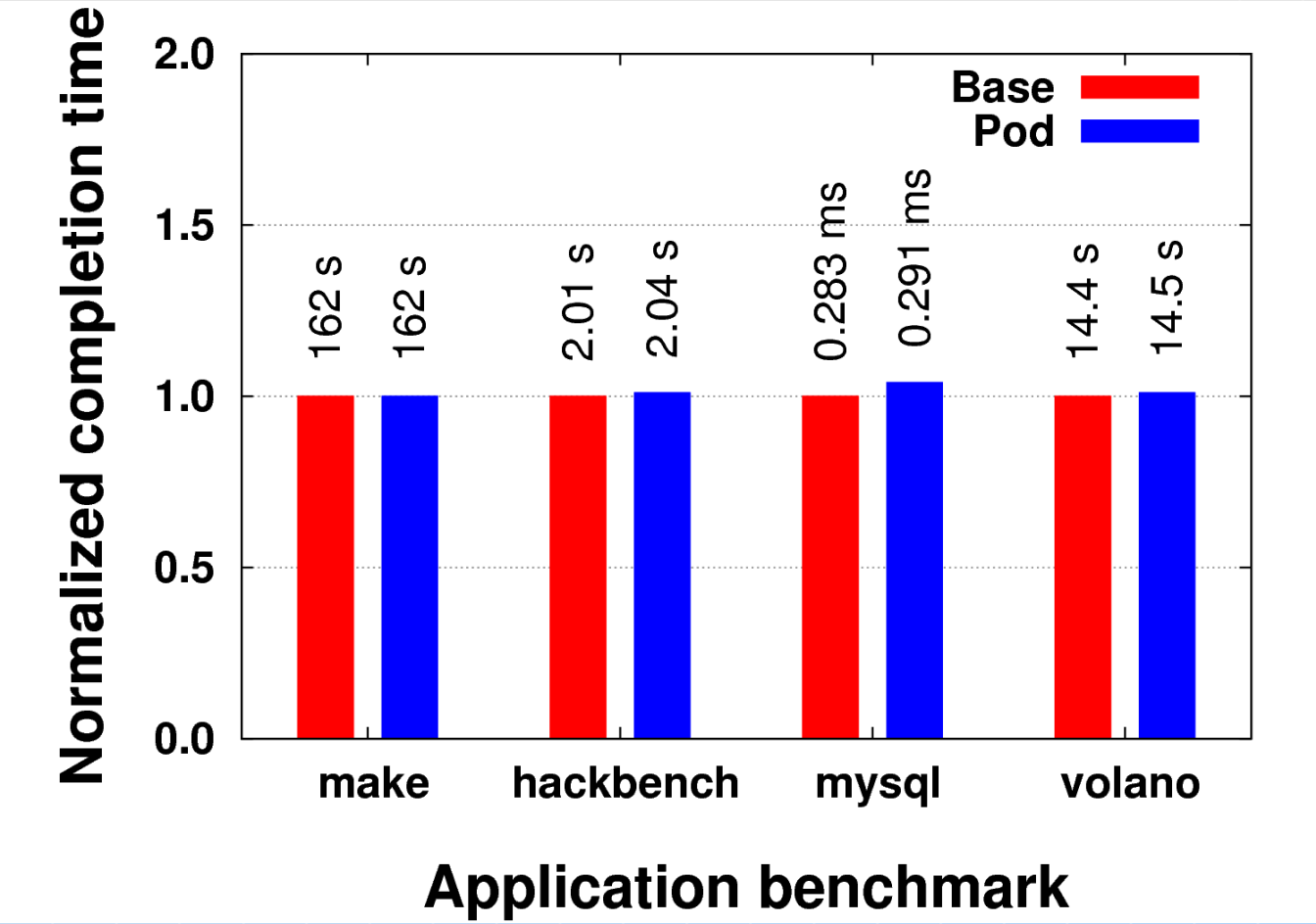
- Micro benchmarks
  - overhead on select system calls
- Macro benchmarks
  - overhead on select applications
- Scalability
  - multiple VEEs running concurrently

Micro-benchmark



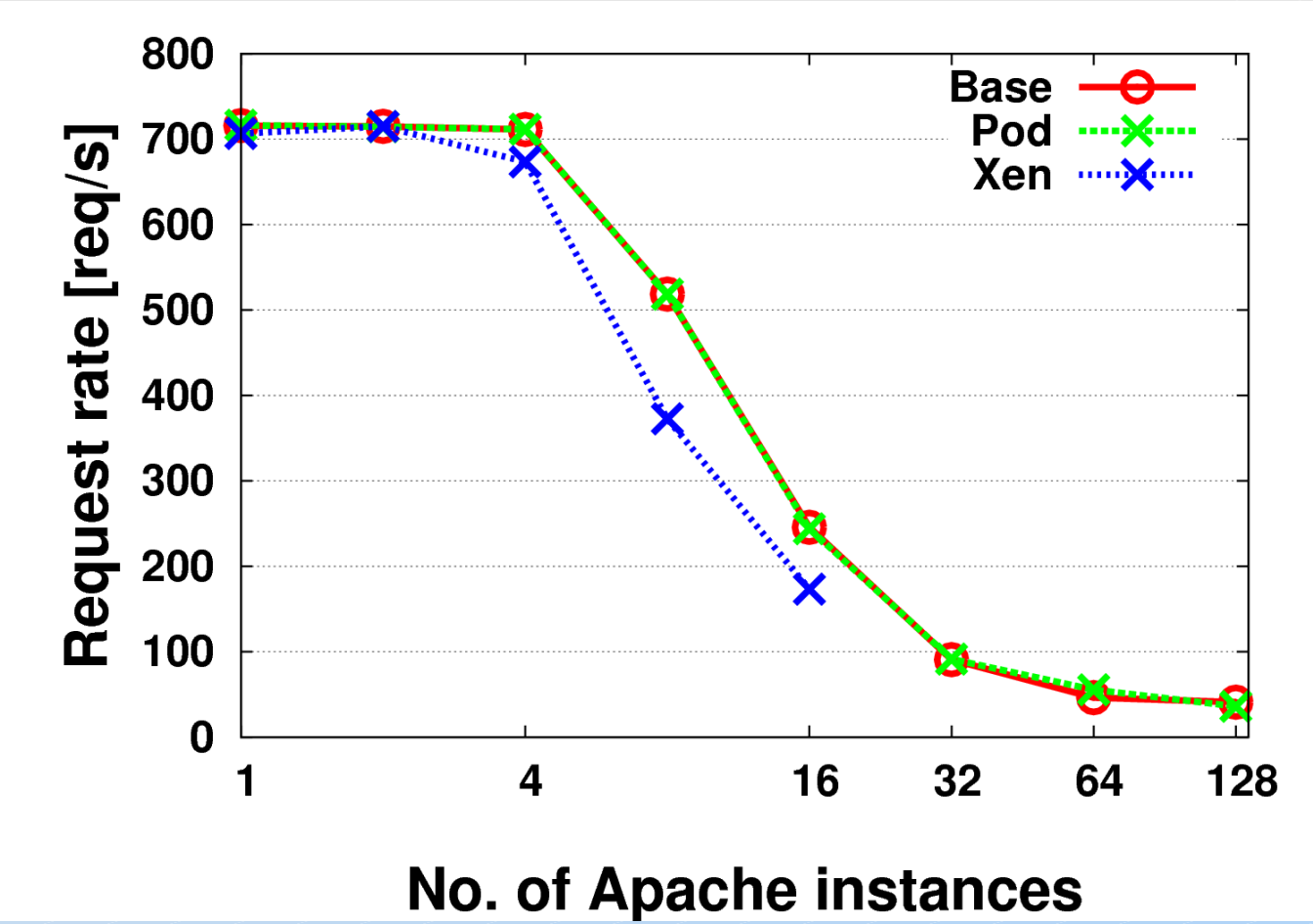
→ Runtime overhead is low

Macro-benchmark



→ Runtime overhead is lower

Scaling-benchmark



→ excellent scalability

Experience

- Application checkpoint-restart (Zap)
  - guarantee same environment at restart
- Application record-replay (Scribe)
  - guarantee same environment at replay

Conclusions

- OS Virtualization
  - useful but challenging
- Virtualization via interposition
  - address race conditions
  - meet performance needs

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Thank You !

Virtualization – How

- Decouple execution from underlying environment
  - execution should exhibit effect identical to un-virtualized system
  - dominant part of the execution should be direct