6.1800 Spring 2024

Lecture #6: Virtual Machines

even more virtualization, plus kernel designs
The South Pacific island of Niue says it was cheated out of .nu, a domain that turned out to be very lucrative on the other side of the world.

A village on Niue, a South Pacific island of about 100 square miles, roughly the same area as Lincoln, Neb. Jill Ferry/Getty Images
The South Pacific island of Niue is one the most remote places in the world. Its closest neighbors, Tonga and American Samoa, are hundreds of miles away. The advent of the internet promised, in a small way, to make Niue and its 2,000 or so residents more connected to the rest of the world.

In the late 1990s, an American businessman offered to hook up the island to the internet. All he wanted in exchange was the right to control the .nu suffix that Niue was assigned for its web addresses. The domain did not seem as lucrative as .tv — which was slotted to Tuvalu, another South Pacific nation — and the leaders of Niue (pronounced New-ay) signed off on the deal. But the two sides were soon at odds.

Now, after more than two decades of back and forth, the disagreement is finally nearing a resolution in a court of law. Disputes over domain names were not uncommon during the internet’s infancy but experts are hard pressed to recall one that has lasted this long.

It turned out that .nu was, in fact, very valuable. “Nu” means now in Swedish, Danish and Dutch, and thousands of Scandinavians registered websites with that suffix, creating a steady business for Niue’s business partner, Bill Semich.

A village on Niue, a South Pacific island of about 100 square miles, roughly the same area as Lincoln, Neb. Jill Ferry/Getty Images
“We are victims of digital colonialism,” Prime Minister Dalton Tagelagi of Niue said over a crackling video link from his office in the capital of Alofi. “This domain, the .nu, recognizes Niue as a sovereign country. This is how important it is to our identity.”

Critics question that assessment, as there is formally no such thing as sovereignty in cyberspace, only administrative zones that divide the web into domains like .nu and, for instance, the .nz suffix assigned to New Zealand.

Winning the case could help ensure the long-term survival of Niue, Mr. Tagelagi said. The island’s population is now about a third of what it was in the 1960s, and the empty homes that dot the island are a reminder of the people who left for better economic opportunities. A victory could help fund its bid to join the United Nations, similar to how Tuvalu obtained U.N. membership after monetizing .tv.

If Niue manages to get .nu back, it could bring in up to $2 million in revenue a year, according to Par Brumark, a domain name expert who is acting on Niue’s behalf in the Swedish case.
6.1800 in the news

in the case of DNS, names have meaning outside of the system, even if they were only originally intended to denote “administrative zones that divide the web into domains”

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many of the decisions we make when we build our systems impact people who might not even be aware of the system

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Operating systems enforce modularity on a single machine using virtualization in order to enforce modularity and have an effective operating system, a few things need to happen:

1. Programs shouldn’t be able to refer to (and corrupt) each other’s memory

2. Programs should be able to communicate with each other

3. Programs should be able to share a CPU without one program halting the progress of the others

- Virtual memory
- Bounded buffers (virtualize communication links)
- Threads (virtualize processors)
operating systems enforce modularity on a single machine using **virtualization**

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**Today’s goal:** run multiple operating systems at once
A virtual machine monitor (VMM) virtualizes the physical hardware for the guest operating systems (OSes) by running guest OSes inside virtual machines. The physical hardware includes components such as U/K, PTR, page table, etc.
**virtual machine monitor** virtualizes the physical hardware for the guest OSes

guest OSes run in user mode

**virtual machine monitor (VMM)**

physical hardware

U/K, PTR, page table, ...
virtual machine monitor virtualizes the physical hardware for the guest OSes

guest OSes run in user mode

privileged instructions in guest OS will cause an exception, which the VMM will intercept ("trap") and emulate

if the VMM can’t emulate an instruction, it will send the exception back to the guest OS for handling
virtual machine monitor virtualizes the physical hardware for the guest OSes.

Guest OSes run in user mode, and privileged instructions in guest OS will cause an exception, which the VMM will intercept ("trap") and emulate. If the VMM can't emulate an instruction, it will send the exception back to the guest OS for handling.

**First question:** What does it mean to emulate?
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First example: virtualizing memory (again!)

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Virtual hardware

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| U/K, PTR, page table, ... |

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**guest virtual address**

**guest physical address**

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**guest OS**

**virtual hardware**

- U/K
- PTR
- page table

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**guest OS**

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- U/K
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**virtual machine monitor (VMM)**

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**physical hardware**

- U/K, PTR, page table, ...

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**guest virtual address**

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**guest physical address**

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**host physical address**

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    - U/K
    - PTR
    - page table
  - guest virtual address
- **guest OS**
  - virtual hardware
    - U/K
    - PTR
    - page table
  - guest physical address
- **virtual machine monitor (VMM)**
- **physical hardware**
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  - host physical address

**first question:** what does it mean to emulate?

in this example, it means that the VMM needs to step in and translate guest physical addresses to host physical addresses
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**Diagram:**

- **guest OS**
  - virtual hardware
    - PTR
    - guest OS page table

- **guest OS**
  - virtual hardware
    - PTR
    - guest OS page table

- **virtual machine monitor (VMM)**
  - guest virtual → guest physical

- **physical hardware**
  - PTR
virtual machine monitor virtualizes the physical hardware for the guest OSes

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- guest OS page tables are marked as read-only memory so that modifications to these page tables also trigger exceptions (and thus allow the VMM to update the other tables)
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In modern hardware, the physical hardware is aware of both page tables, and performs the translation from guest virtual to host physical itself.
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- **guest OS**
  - virtual hardware
    - U/K
    - PTR
    - page table
    - ...
  - virtual machine monitor (VMM)
  - physical hardware
    - U/K, PTR, page table, ...

- **guest OS**
  - virtual hardware
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Figuring out how to emulate an instruction is not enough; we also need to make sure that the VMM is trapping all relevant instructions.
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second example: virtualizing the U/K bit

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**para-virtualization:** modify guest OS slightly

**binary translation:** VMM replaces problematic instructions with ones that it can trap and emulate

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**second example: virtualizing the U/K bit**

- **guest OS**
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**hardware support**: architecture provides a special operating mode for VMMs in addition to user mode, kernel mode

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VMMs work by **trapping** and **emulating** important instructions.

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The actual **emulation** looks different depending on what we’re trying to do. At times — e.g., in the case of virtual memory — it’s a fairly straightforward extension of what the OS does.
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Modern architectures build support for virtualization into their CPUs, which allow the VMM to operate **efficiently**.

This is all yet another application of **virtualization**. The details change depending on what problem we’re solving, but the goal of virtualization remains the same.
monolithic kernel: no enforced modularity within the kernel itself

application

basic interprocess communication, virtual memory, scheduling, file server, device drivers, network, ...

hardware
monolithic kernel: no enforced modularity within the kernel itself

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application

basic interprocess communication, virtual memory, scheduling, file server, device drivers, network, ...

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microkernels: enforce modularity by putting subsystems in user programs

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application

application IPC

device driver

network

basic interprocess communication, virtual memory, scheduling

hardware
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**monolithic kernel:** no enforced modularity within the kernel itself

**microkernels:** enforce modularity by putting subsystems in user programs

Despite the modularity, it’s not clear that redesigning an operating system from a monolithic kernel to a microkernel is a good idea, in part for reasons of **performance**.
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you have now seen **virtualization** applied as a solution to many different problems. the details change depending on what problem we’re solving, but the goal of virtualization remains the same.