CS 241 Honors
Nothing is Ever Random

Kevin Hong

University of Illinois Urbana-Champaign

Feburary 13, 2018

```
int getRandomNumber()
{
    return 4;  // chosen by fair dice roll.
               // guaranteed to be random.
}
```

What is randomness?

- From Wikipedia:

What is randomness?

- From Wikipedia:
- Randomness is the lack of pattern or predictability in events.

What is randomness?

- From Wikipedia:
- Randomness is the lack of pattern or predictability in events.
- A random sequence of events, symbols or steps has no order and does not follow an intelligible pattern or combination.

Why do we care?

- Random numbers are integral to tons of algorithms

Why do we care?

- Random numbers are integral to tons of algorithms
  - Monte Carlo Methods

Why do we care?

- Random numbers are integral to tons of algorithms
  - Monte Carlo Methods
  - Quicksearch

Why do we care?

- Random numbers are integral to tons of algorithms
  - Monte Carlo Methods
  - Quicksearch
  - If you're interested in randomized algorithms, take CS 473!
- Luck in games, etc

Based PRNG

- So we need to generate random numbers?

Based PRNG

- So we need to generate random numbers?
- Methods

Based PRNG

- So we need to generate random numbers?
- Methods
  - Pseudorandom Number Generators (PRNG)
    - Deterministic algorithm for generating a sequence of numbers
    - Relies on a random seed
    - Approximates random numbers well
    - CSPRNG
    - Fast, deterministic, periodic
    - Mersenne Twister, xorshift

Based TRNG

- True Random Number Generators (TRNG)
  - Rely on unpredictable physical phenomena
  - Atmospheric noise, radioactive decay
  - Slow, nondeterministic, non-periodic
  - random.org

Randomness in a computer

- In every laptop . . . there lives a die . . .

Randomness in a computer

- In every laptop . . . there lives a die . . .
- That die is /dev/random and /dev/urandom

Randomness in a computer

- In every laptop . . . there lives a die . . .
- That die is /dev/random and /dev/urandom
- Entropy Pool

Randomness in a computer

- In every laptop . . . there lives a die . . .
- That die is /dev/random and /dev/urandom
- Entropy Pool
  - Your computer grabs physical specs, keyboard input, mouse movements as entropy
  - Supposedly random bits
  - Keep an estimate of the number of unknown bits

Yo dawg . . . I heard you like randomness

- So you want x amount of bits?

Yo dawg . . . I heard you like randomness

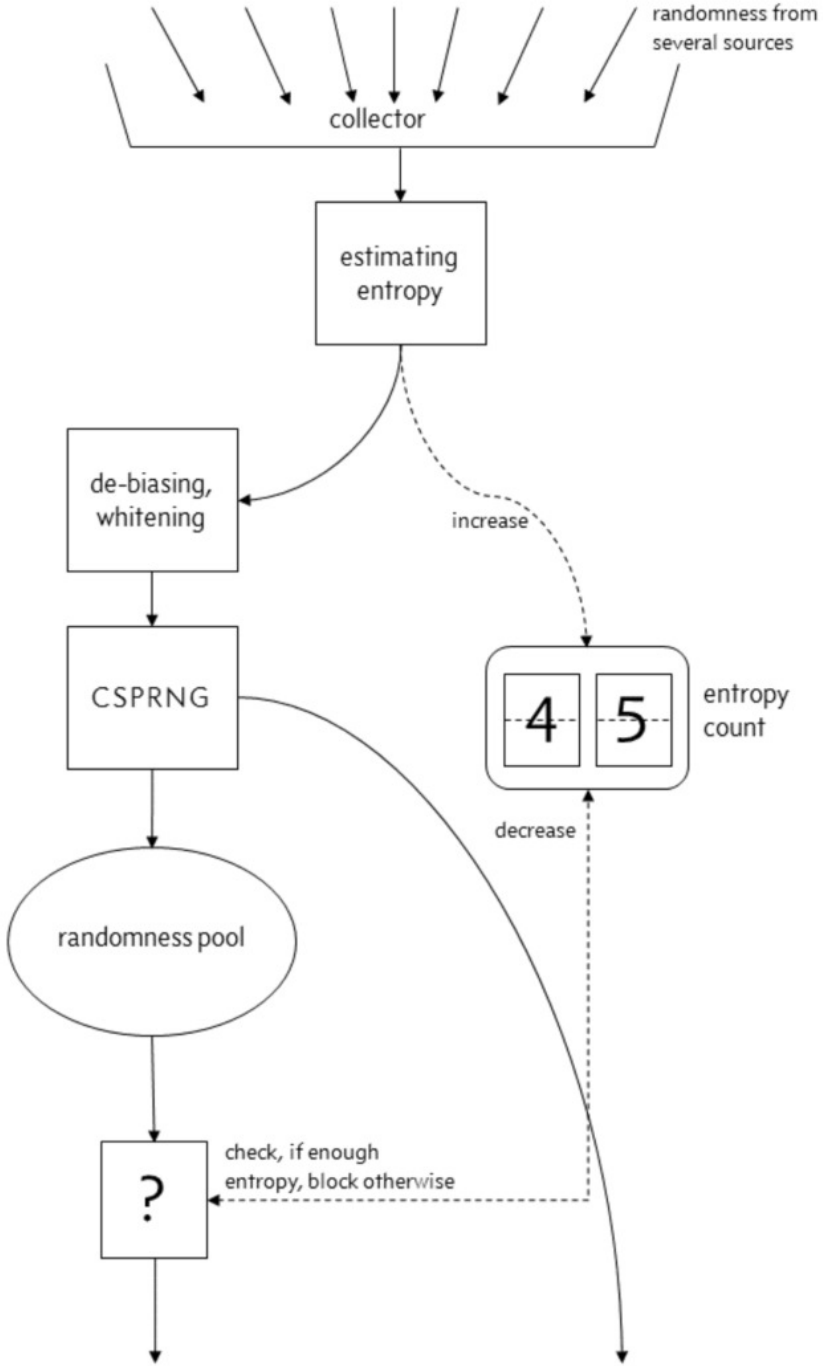
- So you want x amount of bits?
- Pull x number of bits from your entropy pool

Yo dawg . . . I heard you like randomness

- So you want x amount of bits?
- Pull x number of bits from your entropy pool
- Hash it using any good hashing algorithm

Yo dawg . . . I heard you like randomness

- So you want x amount of bits?
- Pull x number of bits from your entropy pool
- Hash it using any good hashing algorithm
- Enjoy your new random number/


randomness from
several sources
collector
estimating
entropy
de-biasing,
whitening
increase
CSPRNG
4
5
entropy
count
decrease
randomness pool
?
check, if enough
entropy, block otherwise

/dev/random? /dev/urandom?

- You may notice there's a difference

/dev/random? /dev/urandom?

- You may notice there's a difference
- Random vs unlimited random

/dev/random? /dev/urandom?

- You may notice there's a difference
- Random vs unlimited random
- Do you need unlimited random?

Further Topics

- Cryptography and CS461
- Randomized Algorithms in CS473 and 498/598

CS 241 Honors
The ~~cake~~ CPU is a lie

Aneesh Durg

University of Illinois Urbana-Champaign

February 13, 2018

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.
- Problem: Modern world demands high computing powers

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.
- Problem: Modern world demands high computing powers
  - Servers handling many users
  - Enterprise software
  - Crysis 3

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.
- Problem: Modern world demands high computing powers
  - Servers handling many users
  - Enterprise software
  - Crysis 3
- Solution: Virtual Machines!

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.
- Problem: Modern world demands high computing powers
  - Servers handling many users
  - Enterprise software
  - Crysis 3
- Solution: Virtual Machines!
  - Legacy Apps!

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.
- Problem: Modern world demands high computing powers
  - Servers handling many users
  - Enterprise software
  - Crysis 3
- Solution: Virtual Machines!
  - Legacy Apps!
  - What if we had more power than we need?

"I think there is a world market for maybe five computers." - Thomas Watson

- You probably have 5 computers on your right now.
- Problem: Modern world demands high computing powers
  - Servers handling many users
  - Enterprise software
  - Crysis 3
- Solution: Virtual Machines!
  - Legacy Apps!
  - What if we had more power than we need?
  - Offers isolation!

Challenges

- What are sensitive instructions?

Challenges

- What are sensitive instructions?
  - All instructions are equal, but some are more equal than others
  - Requires elevated privilages to execute - can't have everybody breaking the system all the time

Challenges

- What are sensitive instructions?
  - All instructions are equal, but some are more equal than others
  - Requires elevated privilages to execute - can't have everybody breaking the system all the time
- Trap is not just a kind of music

Challenges

- What are sensitive instructions?
  - All instructions are equal, but some are more equal than others
  - Requires elevated privilages to execute - can't have everybody breaking the system all the time
- Trap is not just a kind of music
  - 'trap' the kernel and execute the instruction there

Challenges

- What are sensitive instructions?
  - All instructions are equal, but some are more equal than others
  - Requires elevated privilages to execute - can't have everybody breaking the system all the time
- Trap is not just a kind of music
  - 'trap' the kernel and execute the instruction there
  - e.g. direct access to hardware, enable/disable interrupts, etc.

History time!

- Problem: What happens if a user tries to execute privilaged instructions

History time!

- Problem: What happens if a user tries to execute privilaged instructions
  - You'd hope it traps to kernel

History time!

- Problem: What happens if a user tries to execute privilaged instructions
  - You'd hope it traps to kernel
  - Intel disagrees.

History time!

- Problem: What happens if a user tries to execute privilaged instructions
  - You'd hope it traps to kernel
  - Intel disagrees.
- Solution: Lol just silently ignore those pesky users

History time!

- Problem: What happens if a user tries to execute privilaged instructions
  - You'd hope it traps to kernel
  - Intel disagrees.
- Solution: Lol just silently ignore those pesky users
- Problem: Some architechtures/OSes check have instructions that can do *some* sensitive instructions

History time!

- Problem: What happens if a user tries to execute privilaged instructions
  - You'd hope it traps to kernel
  - Intel disagrees.
- Solution: Lol just silently ignore those pesky users
- Problem: Some architechtures/OSes check have instructions that can do *some* sensitive instructions
  - Different behavior when executed by user vs. kernel

History time!

- Why do we care?

History time!

- Why do we care?
  - This makes virtualization more confusing...

History time!

- Why do we care?
  - This makes virtualization more confusing...
  - What if the OS is in user mode?

10 kinds of people in this world...

- Let's build a hypervisor!

10 kinds of people in this world...

- Let's build a hypervisor!
  - Smaller than a kernel

10 kinds of people in this world...

- Let's build a hypervisor!
  - Smaller than a kernel
  - Allows us to 'virtualize' hardware

10 kinds of people in this world...

- Let's build a hypervisor!
  - Smaller than a kernel
  - Allows us to 'virtualize' hardware
- Type 1 vs Type 2

10 kinds of people in this world...

- Let's build a hypervisor!
  - Smaller than a kernel
  - Allows us to 'virtualize' hardware
- Type 1 vs Type 2
- Pros and cons to each

Type 1

- The intuitive, hardware-based approach

Type 1

- The intuitive, hardware-based approach

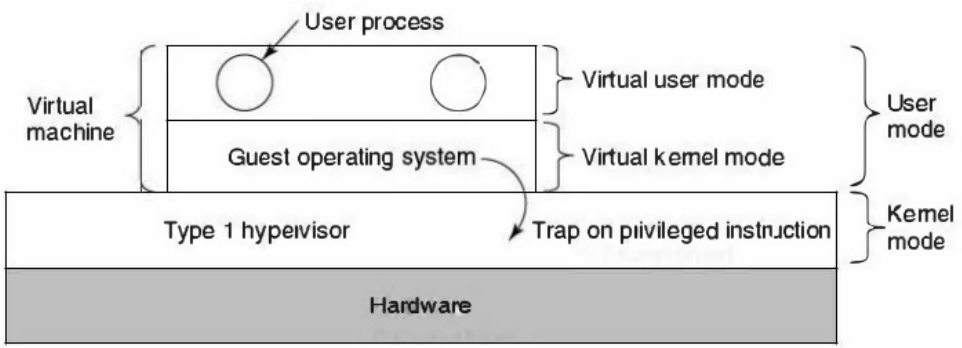


Figure 8-26. When the operating system in a virtual machine executes a kernel-only instruction, it traps to the hypervisor if virtualization technology is present.

Type 1

- The intuitive, hardware-based approach

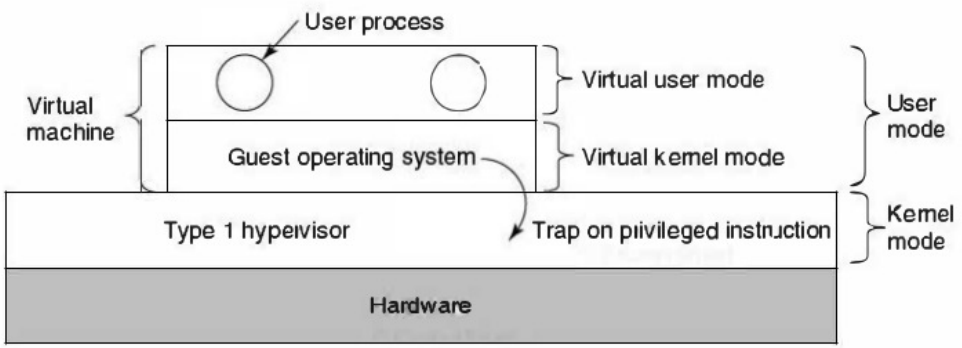


Figure 8-26. When the operating system in a virtual machine executes a kernel-only instruction, it traps to the hypervisor if virtualization technology is present.

- Guest OS/kernel $\rightarrow$ hypervisor

Type 1

- The intuitive, hardware-based approach

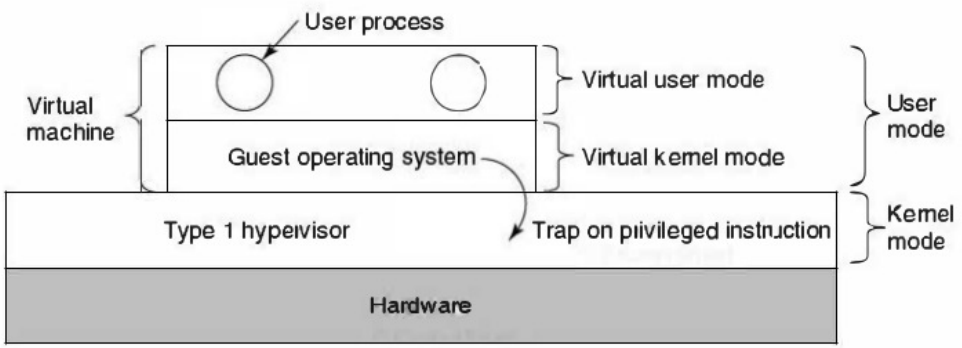


Figure 8-26. When the operating system in a virtual machine executes a kernel-only instruction, it traps to the hypervisor if virtualization technology is present.

- Guest OS/kernel $\rightarrow$ hypervisor
- Guest process $\rightarrow$ CPU

Type 2

- First made by VMWare in 2006

Type 2

- First made by VMWare in 2006
- On first run needs to boot from 'disk' and install the OS to it's own 'disk'
  - The 'disks' are acutally just files

Type 2

- First made by VMWare in 2006
- On first run needs to boot from 'disk' and install the OS to it's own 'disk'
  - The 'disks' are acutally just files
- Emulates sensitive instructions

Type 2

- First made by VMWare in 2006
- On first run needs to boot from 'disk' and install the OS to it's own 'disk'
  - The 'disks' are acutally just files
- Emulates sensitive instructions
- Runs on top of Guest OS!

Type 2

- First made by VMWare in 2006
- On first run needs to boot from 'disk' and install the OS to it's own 'disk'
  - The 'disks' are acutally just files
- Emulates sensitive instructions
- Runs on top of Guest OS!
  - Scan blocks of code in OS, if a block of kernel code needs a sensitive

Type 2

- First made by VMWare in 2006
- On first run needs to boot from 'disk' and install the OS to it's own 'disk'
  - The 'disks' are acutally just files
- Emulates sensitive instructions
- Runs on top of Guest OS!
  - Scan blocks of code in OS, if a block of kernel code needs a sensitive
  - If it's a user mode, do nothing...

Type 2

- First made by VMWare in 2006
- On first run needs to boot from 'disk' and install the OS to it's own 'disk'
  - The 'disks' are acutally just files
- Emulates sensitive instructions
- Runs on top of Guest OS!
  - Scan blocks of code in OS, if a block of kernel code needs a sensitive
  - If it's a user mode, do nothing...
  - This is called **binary translation**

Why does binary translation work?

- Caching!

Why does binary translation work?

- Caching!
  - Can generate a graph of blocks the OS needs as they are availible by following branches/jumps

Why does binary translation work?

- Caching!
  - Can generate a graph of blocks the OS needs as they are availible by following branches/jumps
  - Once the whole program is caches, should run at native speed

Why does binary translation work?

- Caching!
  - Can generate a graph of blocks the OS needs as they are availible by following branches/jumps
  - Once the whole program is caches, should run at native speed
  - Some optimizations like jumping straight to cached blocks

Which one is better?

- Generally type 2

Which one is better?

- Generally type 2
  - Type 1 causes too many traps :(

Which one is better?

- Generally type 2
  - Type 1 causes too many traps :(
  - This leads to poor MMU performace, CPU caching, and branch prediction

More compilcated than we thought?

- Paravirtualization

More compilcated than we thought?

- Paravirtualization
  - Hypervisor as a microkernel
  - Abstraction around hardware interface
  - Requires modified OS
- Virtualizing IO

More compilcated than we thought?

- Paravirtualization
  - Hypervisor as a microkernel
  - Abstraction around hardware interface
  - Requires modified OS
- Virtualizing IO
  - What about reading and writing from memory?

More compilcated than we thought?

- Paravirtualization
  - Hypervisor as a microkernel
  - Abstraction around hardware interface
  - Requires modified OS
- Virtualizing IO
  - What about reading and writing from memory?
- Licensing?

More compilcated than we thought?

- Paravirtualization
  - Hypervisor as a microkernel
  - Abstraction around hardware interface
  - Requires modified OS
- Virtualizing IO
  - What about reading and writing from memory?
- Licensing?
  - If you have a licence to run an OS on one machine is it one real machine or one machine?

Containerization (The final frontier...)

- Docker!

Containerization (The final frontier...)

- Docker!
- Lots of overlapping features
  - Isolation
  - Low cost
  - Multiple OSes

Containerization (The final frontier...)

- No need to virtualize all the hardware/entire OS

Containerization (The final frontier...)

- No need to virtualize all the hardware/entire OS
- Can share libraries, executables, drives, etc.

Containerization (The final frontier...)

- No need to virtualize all the hardware/entire OS
- Can share libraries, executables, drives, etc.
- Made possible by software like **aufs**
  - Layered FS that can have another 'real' fs underneath.

Containerization (The final frontier...)

- No need to virtualize all the hardware/entire OS
- Can share libraries, executables, drives, etc.
- Made possible by software like **aufs**
  - Layered FS that can have another 'real' fs underneath.
- choose the right tool for the right task.

Sources

- http://searchservervirtualization.techtarget.com/answer/How-is-containerization-different-from-virtualization
- Modern Operating Systems 3^{rd} edition. Andrew S. Tanenbaum