CSC 256/456: Operating Systems

Attacks on Operating System Kernels

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aka

The “we’re doing it wrong” Lecture

Operating Systems as the Security Foundation

- Process abstraction provides isolation
- I/O abstractions control access to devices
- Access controls control sharing

Ideal Application Design

- Small programs with least privilege
  - Smaller programs less likely to be exploitable
  - Least privilege limits damage done by an attack

Monolithic Operating System is BAD Design

- OS kernel is *very* large
- OS kernel is *very* privileged
- OS kernel is written in C

If the operating system kernel is exploited, all security guarantees are *null* and *void*.

Methods of Exploitation

- Kernel bugs
  - Missing access control checks
  - Memory safety errors
- Exploitation of privileged programs
  - Load malicious code into kernel
  - Access kernel internal memory
  - Modify OS kernel image on disk

Kernel Bugs

Missing Access Control Checks

- OS kernel fails to check process/thread credentials
  - Permits processes to perform privileged operations
  - Potentially modify OS kernel behavior
    - Has occurred in the "real world"
- Static analysis solutions exist
  - Not used in practice

Memory Safety

- Generally speaking, accessing the "wrong" memory
  - Similar to a "segmentation fault" in applications
- Corrupt important kernel data structures
- Modify kernel code
- Change kernel control flow
  - Trick kernel into performing arbitrary computation

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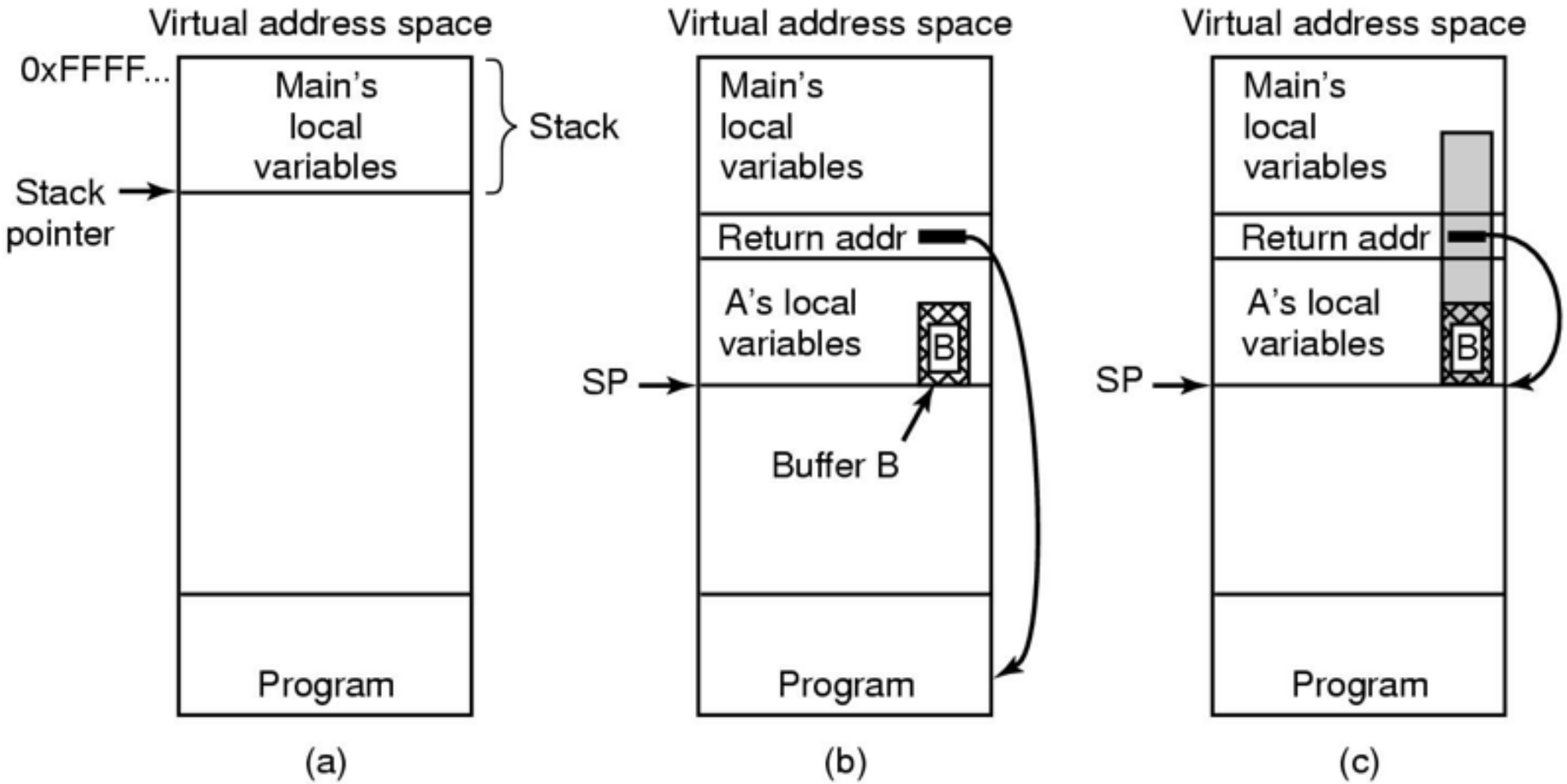
- State manipulation errors
  - Signal handler dispatch on interrupted kernel state
- Hardware configuration errors
  - Mapping code memory into the kernel heap

Buffer Overflow



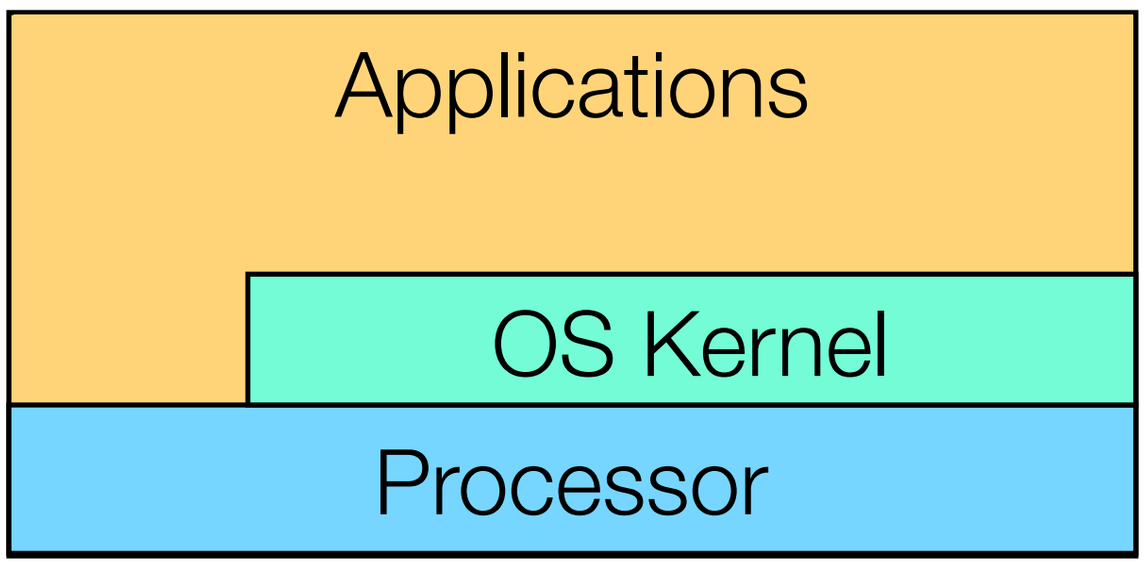
Two General Solutions

- Write OS code in type-safe programming language
- Instrument C code to detect errors at run-time

Writing OS in Type-Safe Language

- Can be done (e.g., Singularity, Verve, SPIN, KaffeOS)
- Need to rewrite entire OS
- Need to deal with garbage collection
  - Can't "stop the world" during an interrupt
  - Ensure that garbage collection doesn't trap
  - May consume more resources
- Some code still written in C and assembler

Secure Virtual Architecture (SVA)



- Compile OS to virtual instruction set
  - Designed to be easy to analyze and instrument
  - Low-level instructions (SVA-OS) replace inline assembly
- Translate ahead-of-time, boot-time, or run-time

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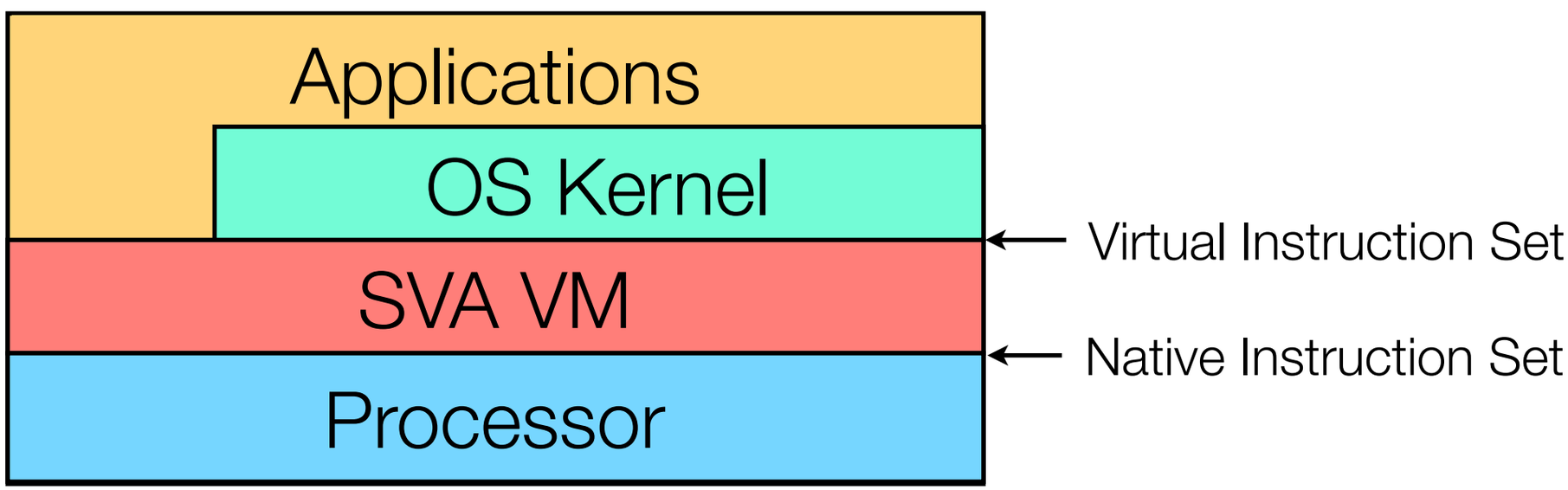

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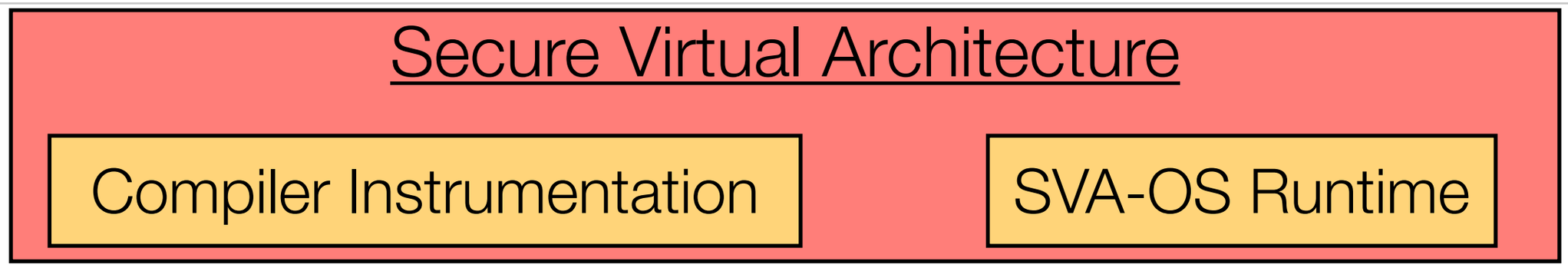
SVA Virtual Instruction Set



- SVA-Core: Compiler Instrumentation
  - Based on LLVM IR: Typed, Explicit SSA form
  - Sophisticated compiler analysis and instrumentation
- SVA-OS: Runtime Library
  - OS-neutral instructions to support a commodity OS
  - Encapsulates & controls hardware and state manipulation
  - Keeps policy decisions within the OS

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- Type-safety for a subset of memory objects
- Dangling pointers made safe; no garbage collection

Memory Safety Compiler Instrumentation

- Add code to track the location of memory objects
  - Record object locations in “per-pool” data structures
  - Take advantage of type-safe memory pools
- Add checks on loads and stores
- Add checks on pointer arithmetic operations

Memory Safety for SVA-OS

- Restrict MMU configuration
  - Prevent double mappings that violate type safety
  - Prevent making code segment writeable
  - Prevent applications from accessing kernel memory
- Restrict state manipulation
  - Generally disallow changes to interrupted kernel state
  - Provide unwinding of interrupted kernel state

Exploitation of Privileged Programs

OS Kernel Configuration/Extension

- Administrator can
  - Load new code into the kernel
  - Write new code into the files containing kernel code
  - Bypass file system by writing to device files
  - Modify kernel memory through /dev/kmem device

Result:

Privileged programs are on par with the kernel!

Kernel-Level Malware

- Malicious code loaded into kernel
- Typically hides processes, files, network connections
  - Has access to all kernel data structures
- Also capable of
  - Snooping on applications
  - Modifying application memory
  - Altering application behavior

Kernel-Level Malware Hooking

- Modify system call table
  - Intercept all desired system calls
- Modify interrupt handler tables
  - Get executed periodically
- Modify function pointers to virtual file system layer
  - Intercept all file system calls

Kernel Level Malware Challenges

- Difficult to classify a kernel driver as “malicious”
- Difficult to control code running in lowest privilege layer
- Kernel-level malware has many, many options

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