Orchestra: Intrusion Detection Using Parallel Execution and Monitoring of Program Variants in User-Space

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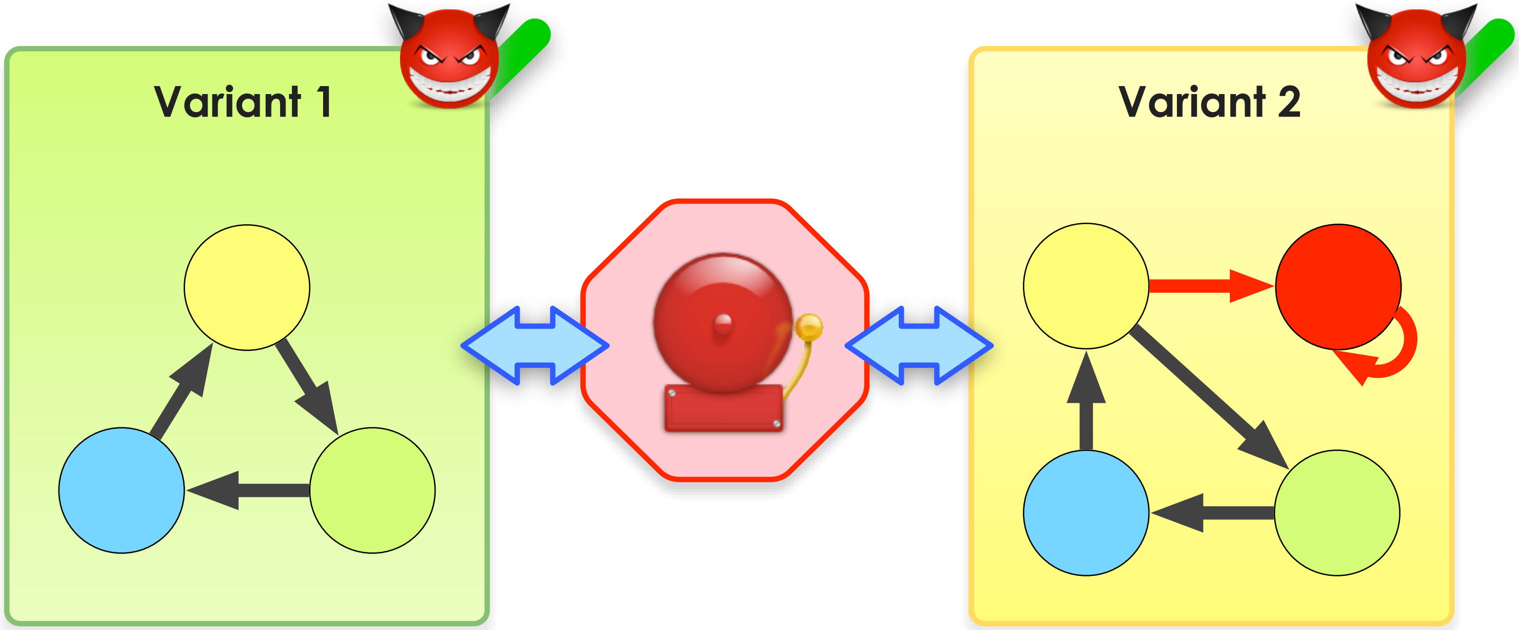
Multi-Variant Execution

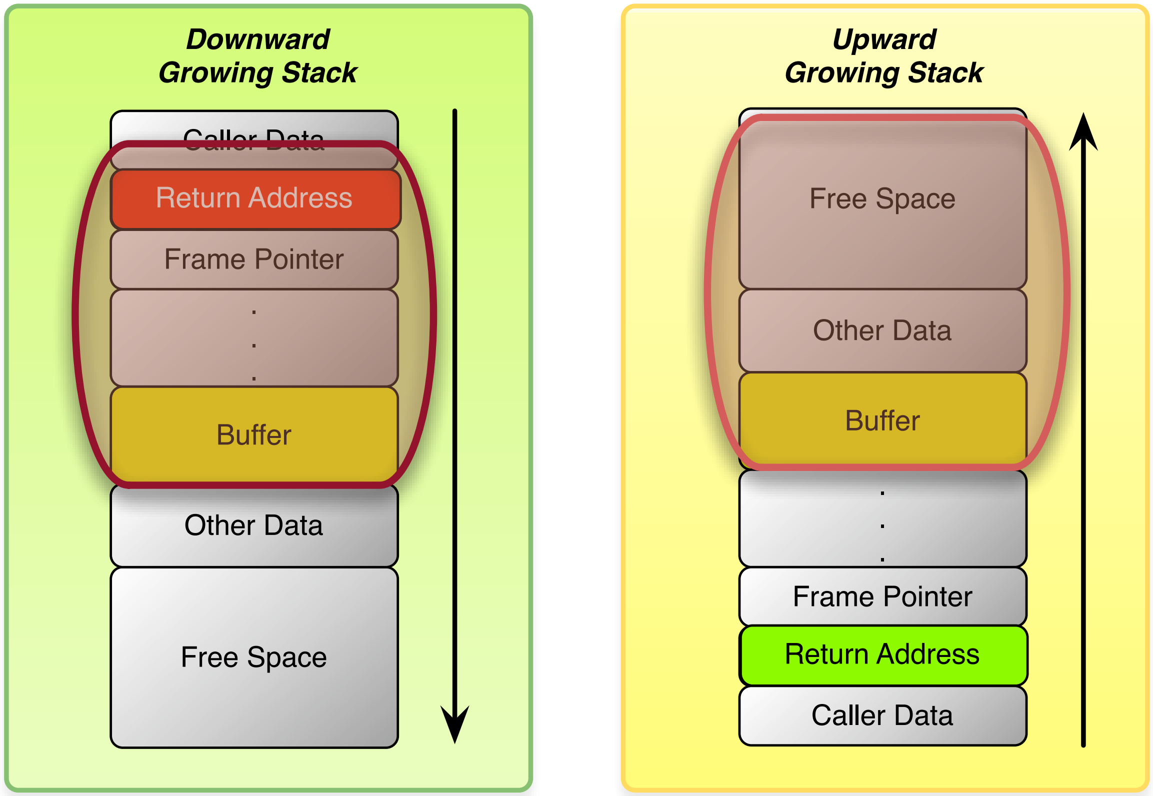


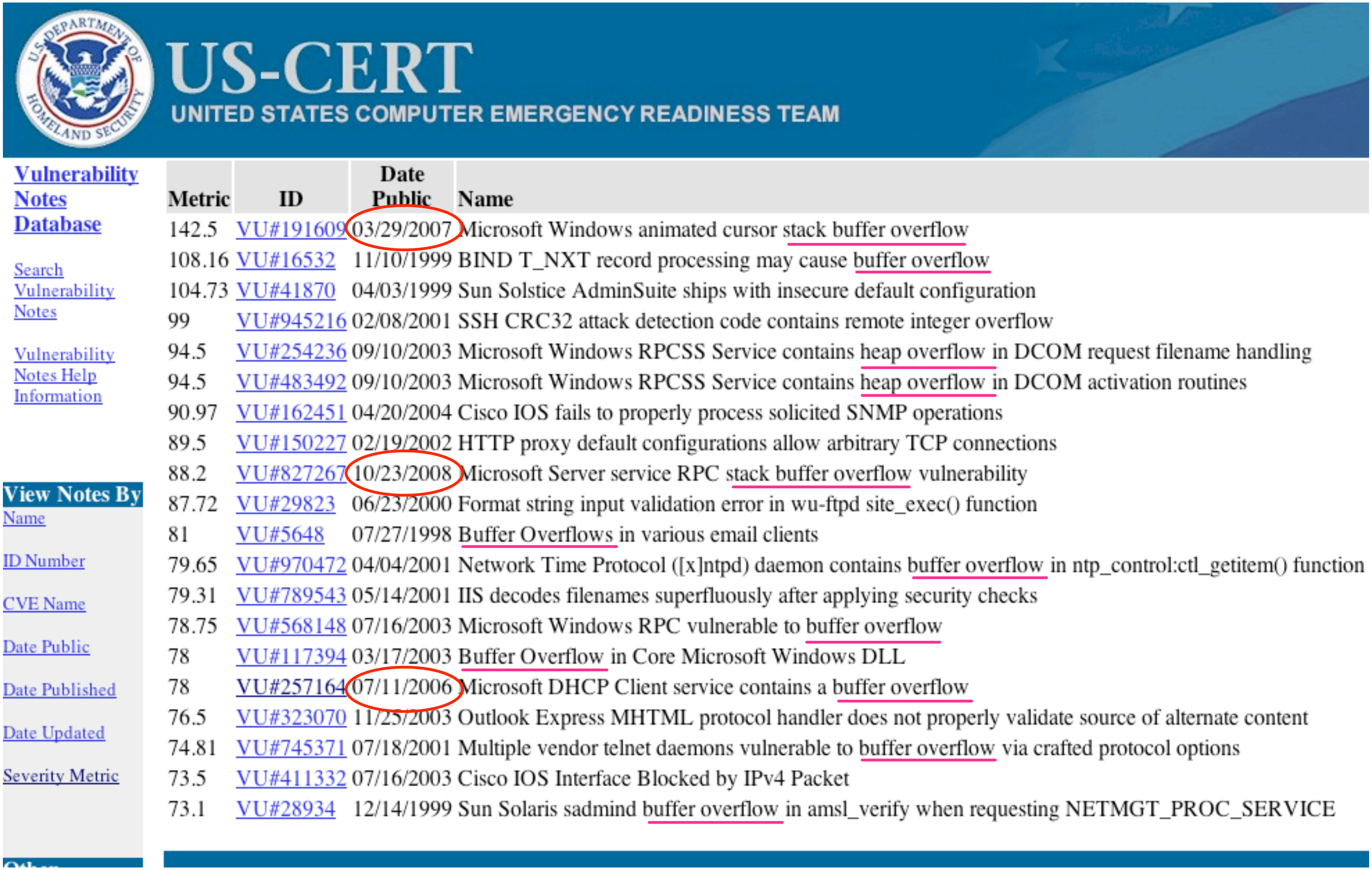
Detection Requirements

- Lock-step execution
- Feed all variants with identical input
- Variants which behave differently when attacked

Reverse Stack Growth Direction

- Stack objects are located in opposite positions





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Vulnerability Notes Database

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Name

ID Number

CVE Name

Date Public

Date Published

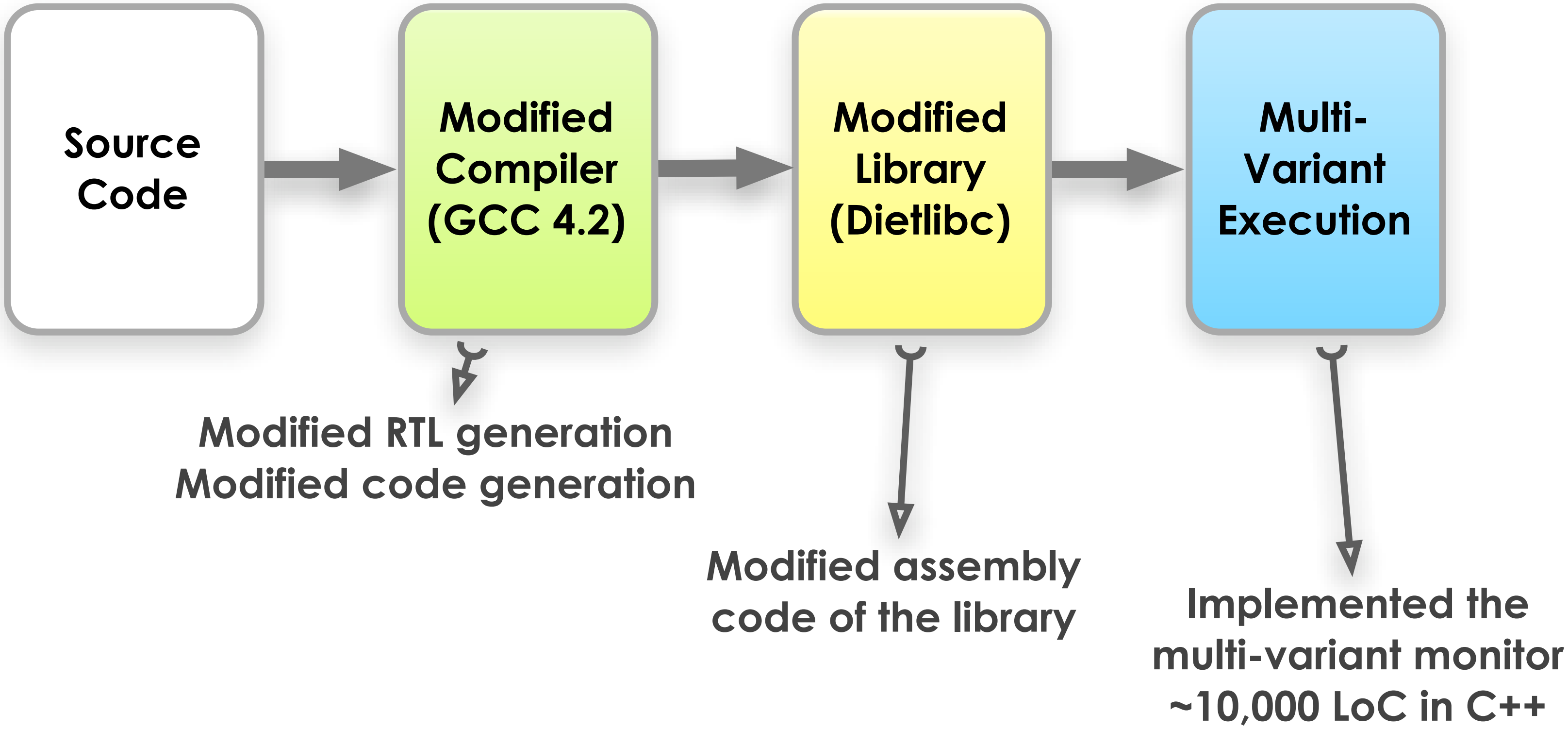
Date Updated

Severity Metric

Other

Metric	ID	Date Public	Name
142.5	VU#191609	03/29/2007	Microsoft Windows animated cursor stack buffer overflow
108.16	VU#16532	11/10/1999	BIND T_NXT record processing may cause buffer overflow
104.73	VU#41870	04/03/1999	Sun Solstice AdminSuite ships with insecure default configuration
99	VU#945216	02/08/2001	SSH CRC32 attack detection code contains remote integer overflow
94.5	VU#254236	09/10/2003	Microsoft Windows RPCSS Service contains heap overflow in DCOM request filename handling
94.5	VU#483492	09/10/2003	Microsoft Windows RPCSS Service contains heap overflow in DCOM activation routines
90.97	VU#162451	04/20/2004	Cisco IOS fails to properly process solicited SNMP operations
89.5	VU#150227	02/19/2002	HTTP proxy default configurations allow arbitrary TCP connections
88.2	VU#827267	10/23/2008	Microsoft Server service RPC stack buffer overflow vulnerability
87.72	VU#29823	06/23/2000	Format string input validation error in wu-ftpd site_exec() function
81	VU#5648	07/27/1998	Buffer Overflows in various email clients
79.65	VU#970472	04/04/2001	Network Time Protocol ([x]ntpd) daemon contains buffer overflow in ntp_control:ctl_getitem() function
79.31	VU#789543	05/14/2001	IIS decodes filenames superfluously after applying security checks
78.75	VU#568148	07/16/2003	Microsoft Windows RPC vulnerable to buffer overflow
78	VU#117394	03/17/2003	Buffer Overflow in Core Microsoft Windows DLL
78	VU#257164	07/11/2006	Microsoft DHCP Client service contains a buffer overflow
76.5	VU#323070	11/25/2003	Outlook Express MHTML protocol handler does not properly validate source of alternate content
74.81	VU#745371	07/18/2001	Multiple vendor telnet daemons vulnerable to buffer overflow via crafted protocol options
73.5	VU#411332	07/16/2003	Cisco IOS Interface Blocked by IPv4 Packet
73.1	VU#28934	12/14/1999	Sun Solaris sadmind buffer overflow in amsl_verify when requesting NETMGT_PROC_SERVICE

From Source to Execution



Source Code

Modified Compiler (GCC 4.2)

Modified Library (Dietlibc)

Multi-Variant Execution

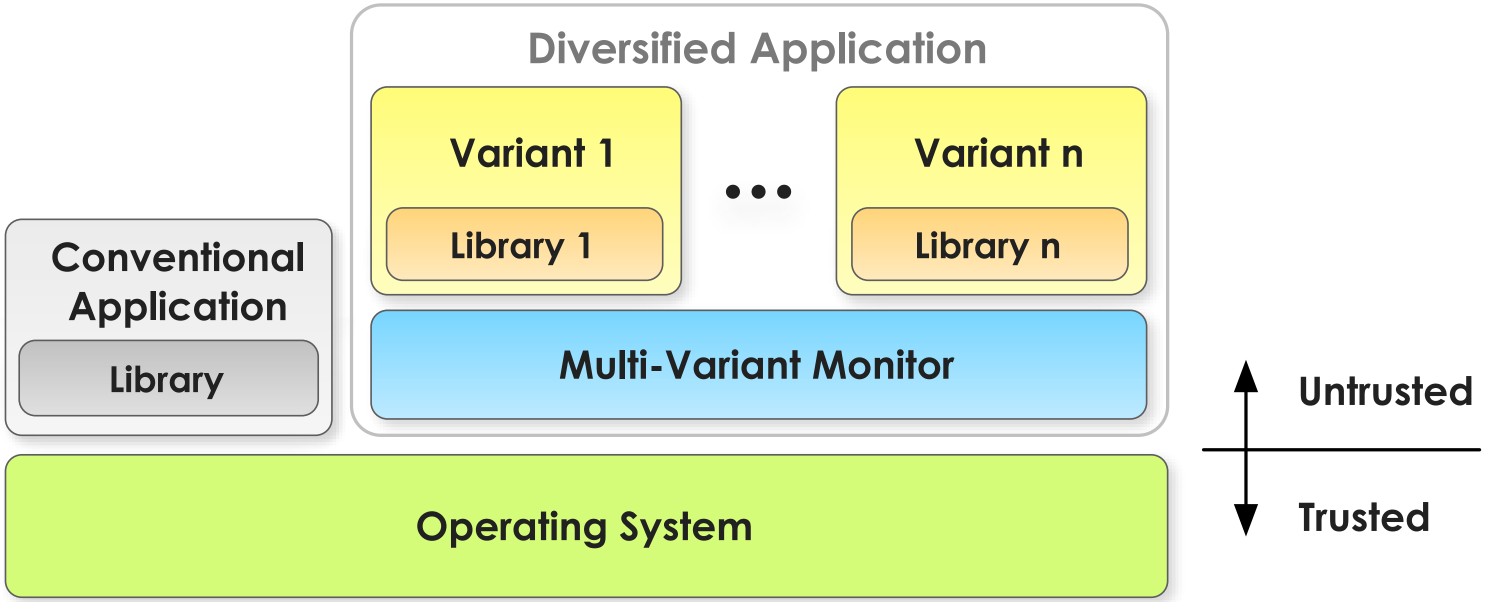
Modified RTL generation
Modified code generation

Modified assembly code of the library

Implemented the multi-variant monitor
~10,000 LoC in C++

Orchestra Architecture

- The monitor is a user-space application

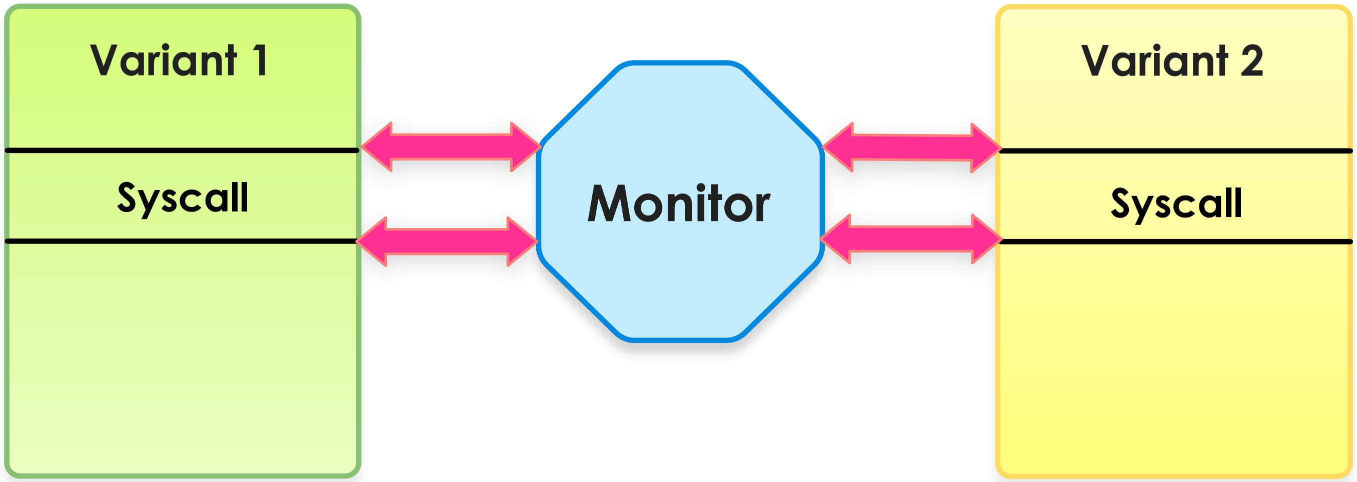


Granularity of Monitoring

- Granularity of monitoring and Synchronization
  - Ideally after each instruction
  - Not always possible
  - Performance issues
- Synchronize and monitor at system calls
  - No harm is done without invoking a system call
  - All instances must invoke the same syscall with equivalent arguments

System Call Monitoring

- Debugging facility of Linux (ptrace) is used to build the monitor
- The monitor is notified twice per system call

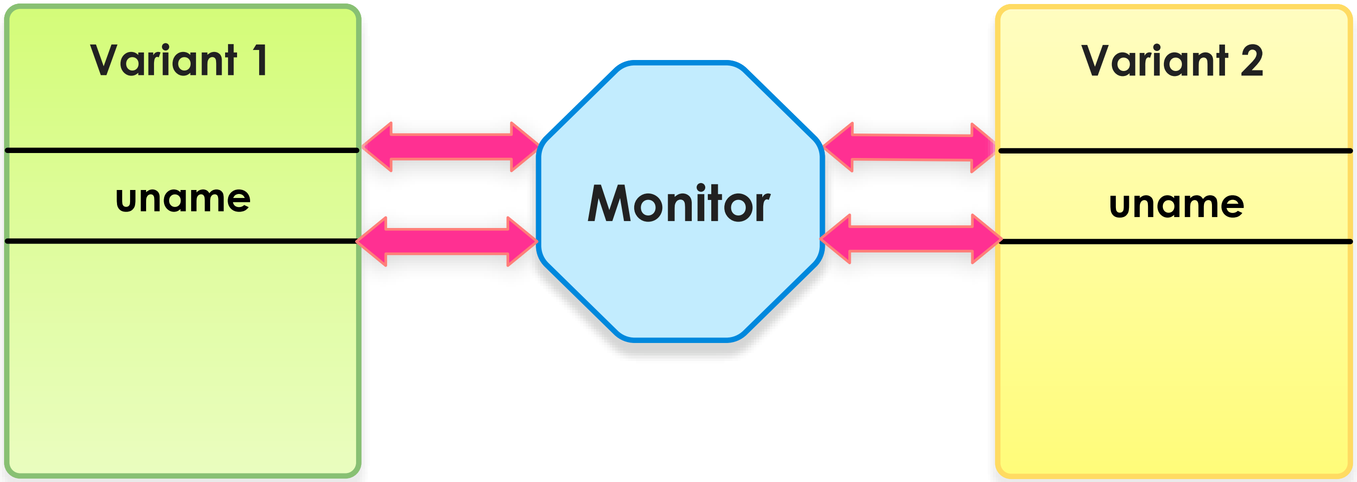


System Call Monitoring (cont.)

- Equivalency is checked at the beginning of a system call
  - The system calls must be the same
  - Arguments must be equivalent
    - Pointers (buffers) have the same content
    - Values are identical
- Results of the system call are written back to the variants at the end of the system call if needed

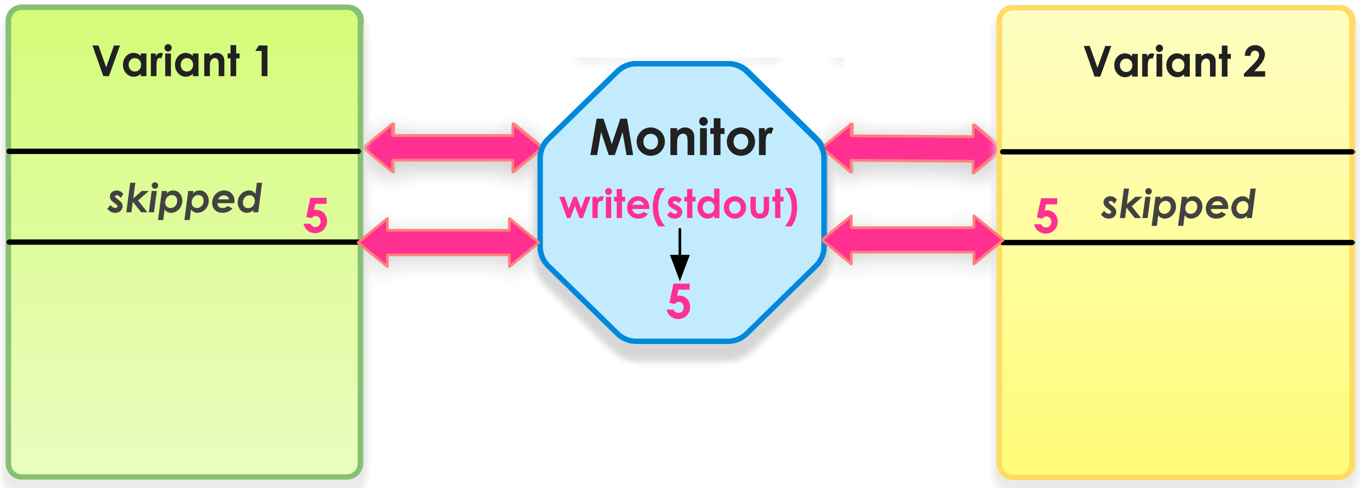
System Call Execution

- Non-state changing system call that produce immutable results are executed by all



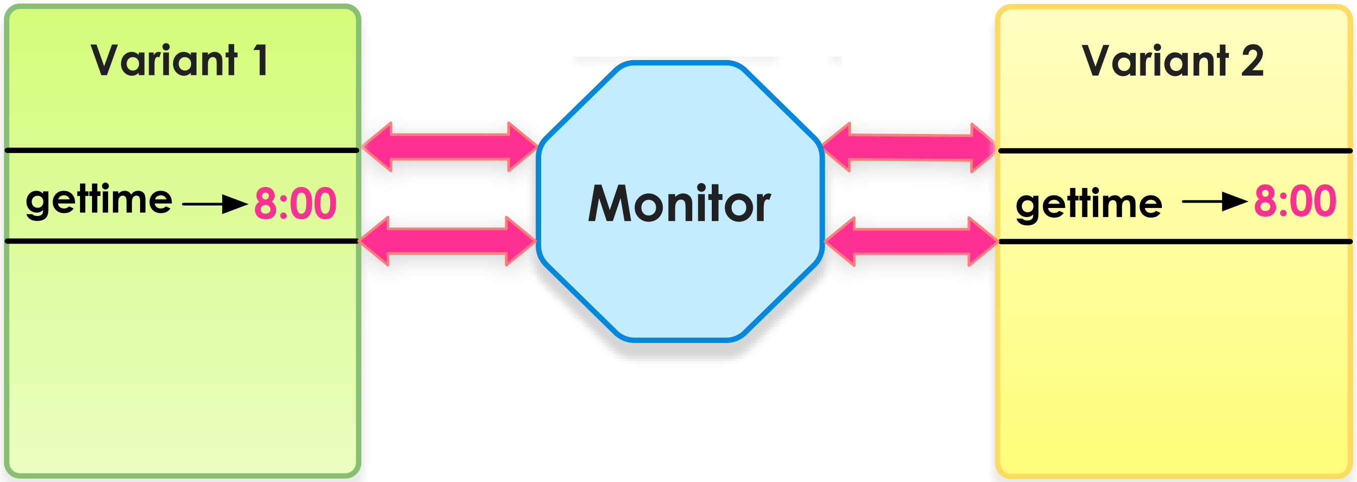
System Call Execution (cont.)

- State changing system calls are executed by the monitor



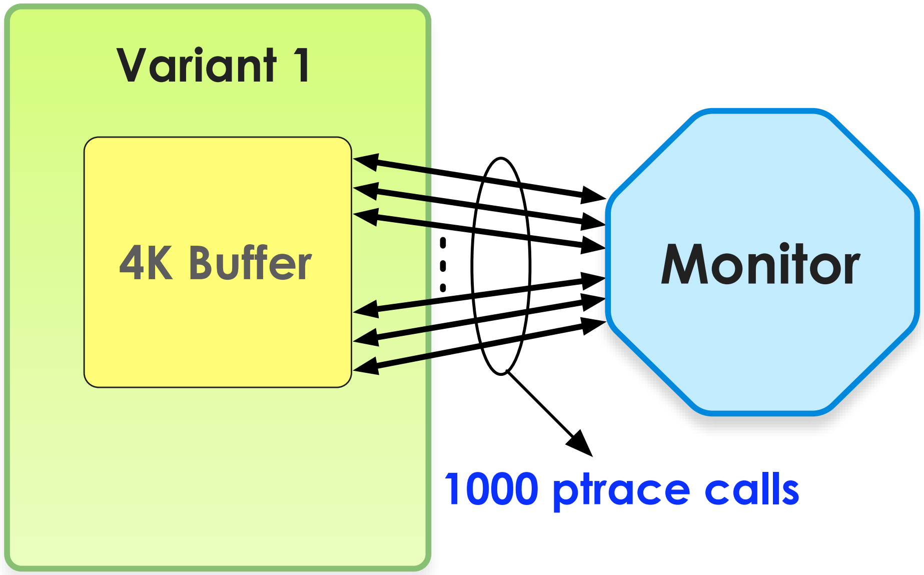
System Call Execution (cont.)

- Non-state changing system call that produce non-immutable results are executed by all, results are copied from the first variant to all



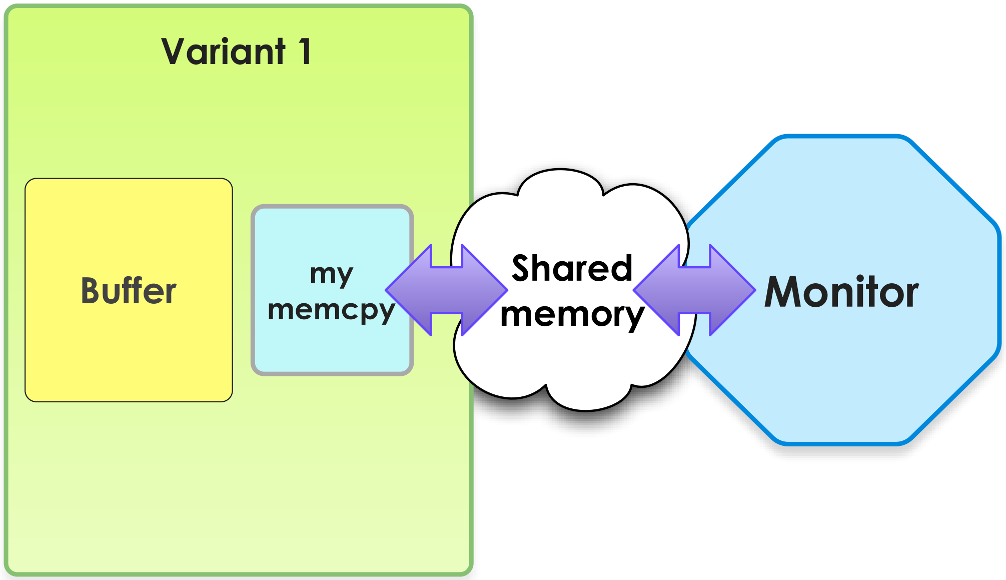
Data Transfer

- ptrace transfers only 4 bytes at a time
  - very slow in transferring large buffers



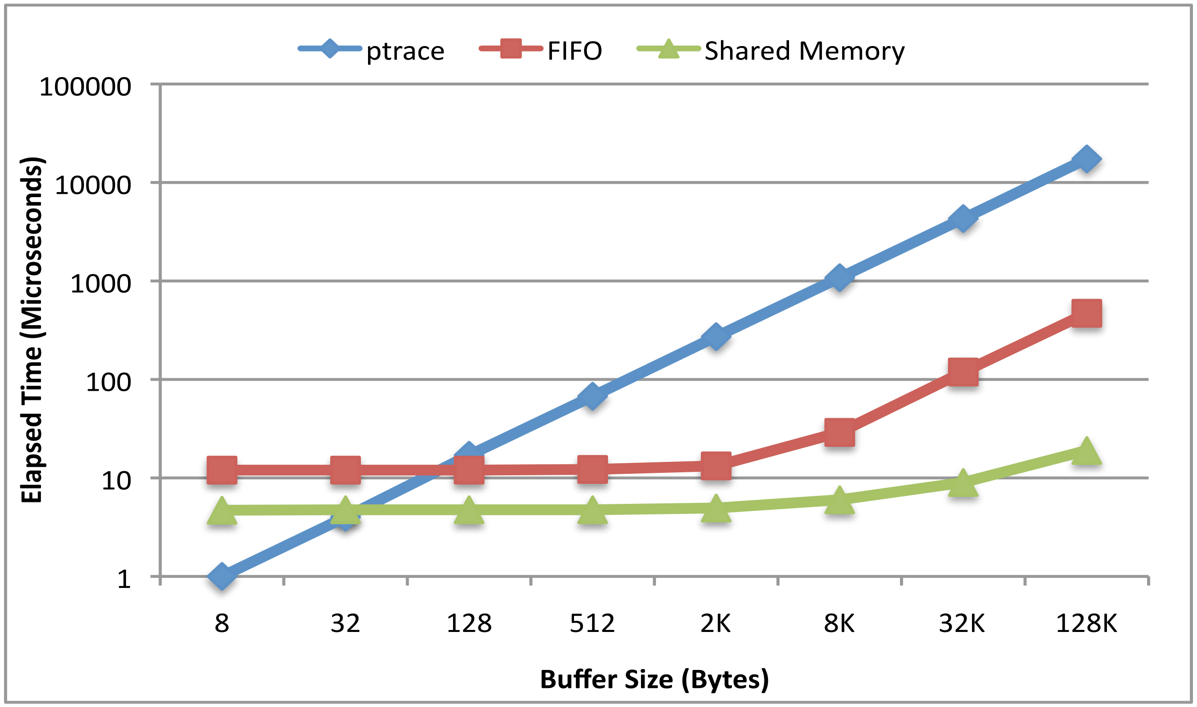
Data Transfer (cont.)

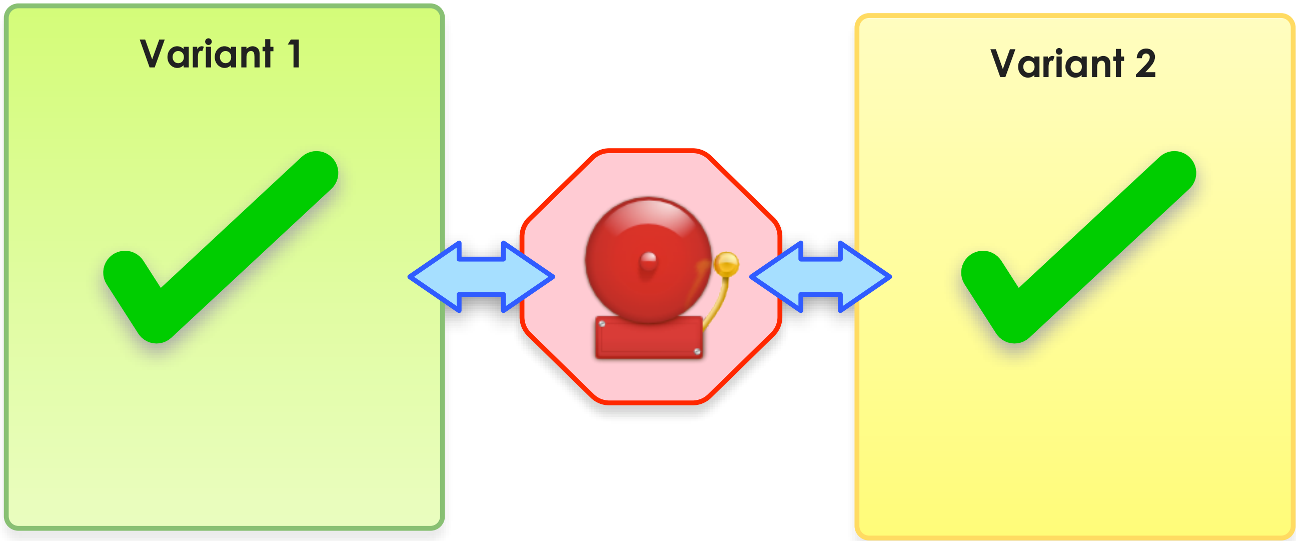
- We tried using named pipes, but they cannot transfer more than 4K bytes at a time
- Shared memory is fast and can transfer mega bytes



Data Transfer Performance

Shared memory is about 1000 times faster than ptrace and 20 times faster than FIFO in transferring a 128K buffer



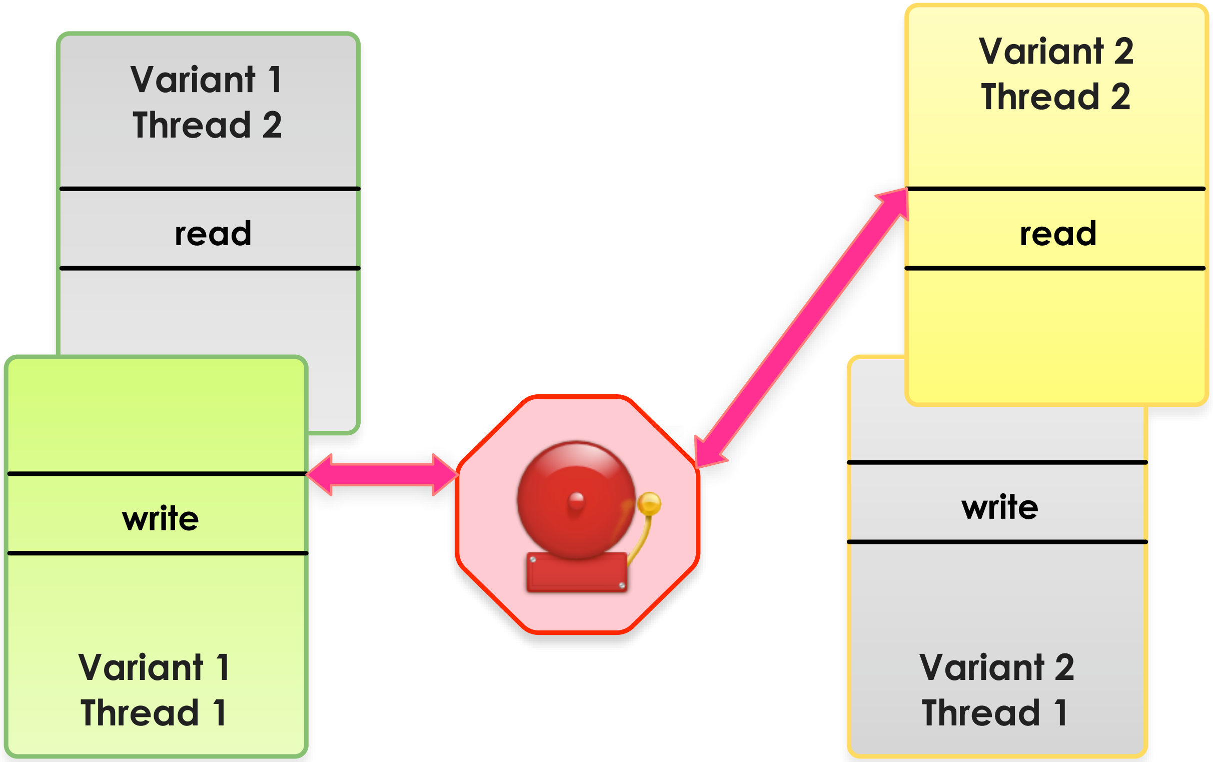


Removing False Positives

False positives are the major practical issue in using multi-variant execution

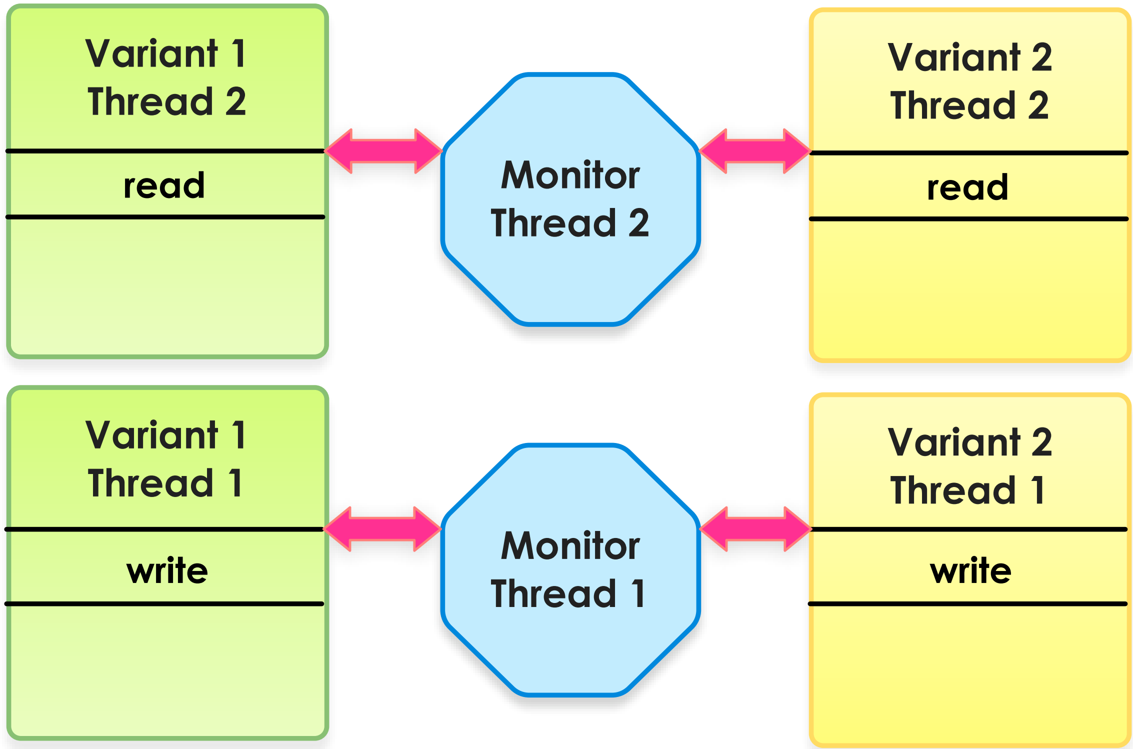
Multi-Threaded Variants

- Different scheduling of multi-threaded or multi-process applications can cause false positives



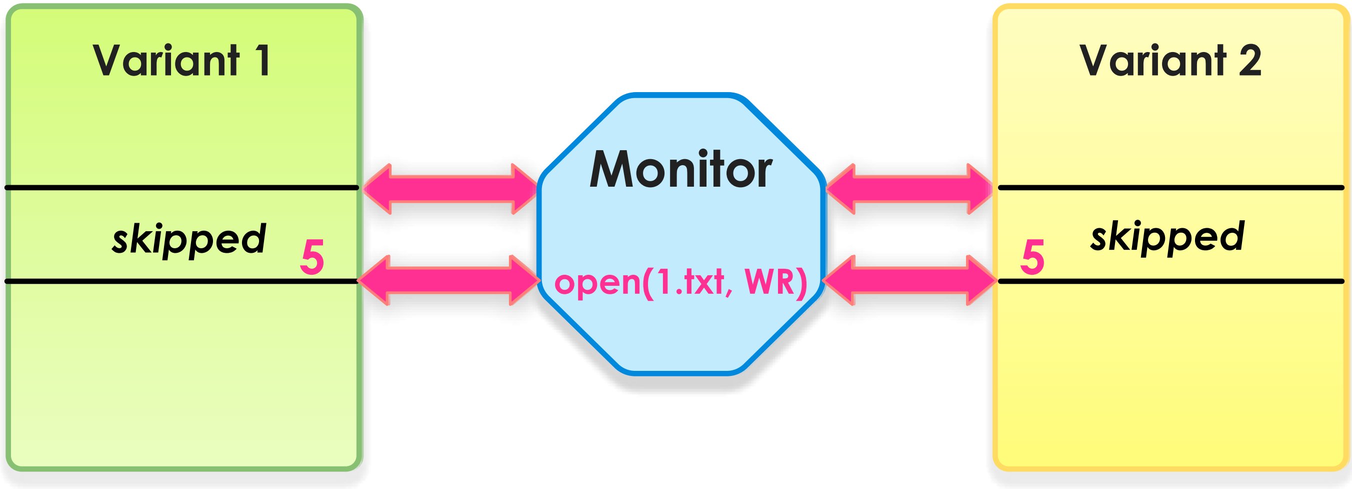
Monitoring multi-threaded variants

- Corresponding threads/processes must be synchronized to each other



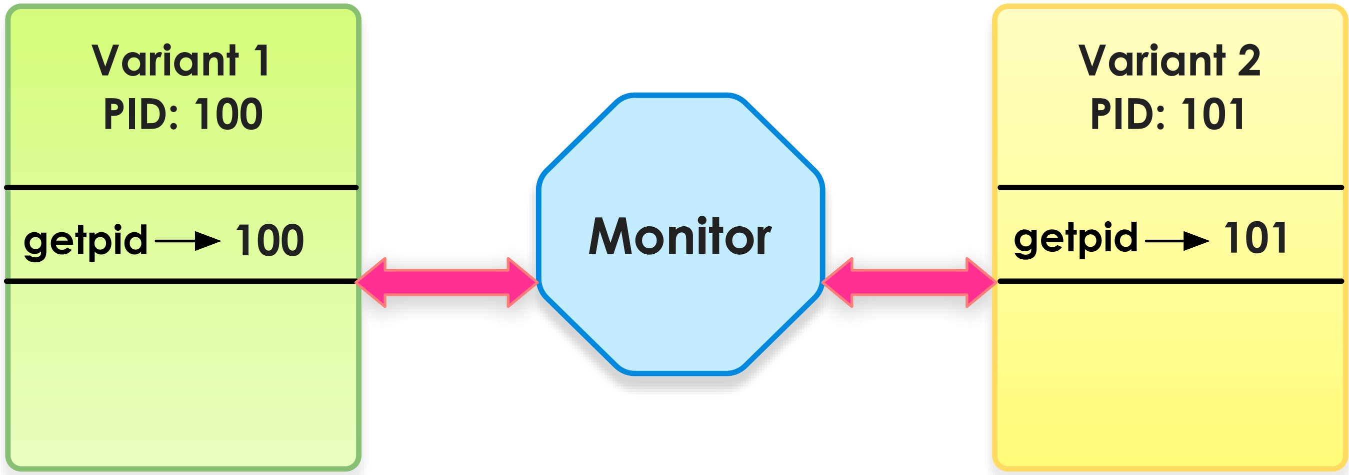
File Descriptors

- The same file descriptor is always reported to all variants when they invoke system calls that return a file descriptor



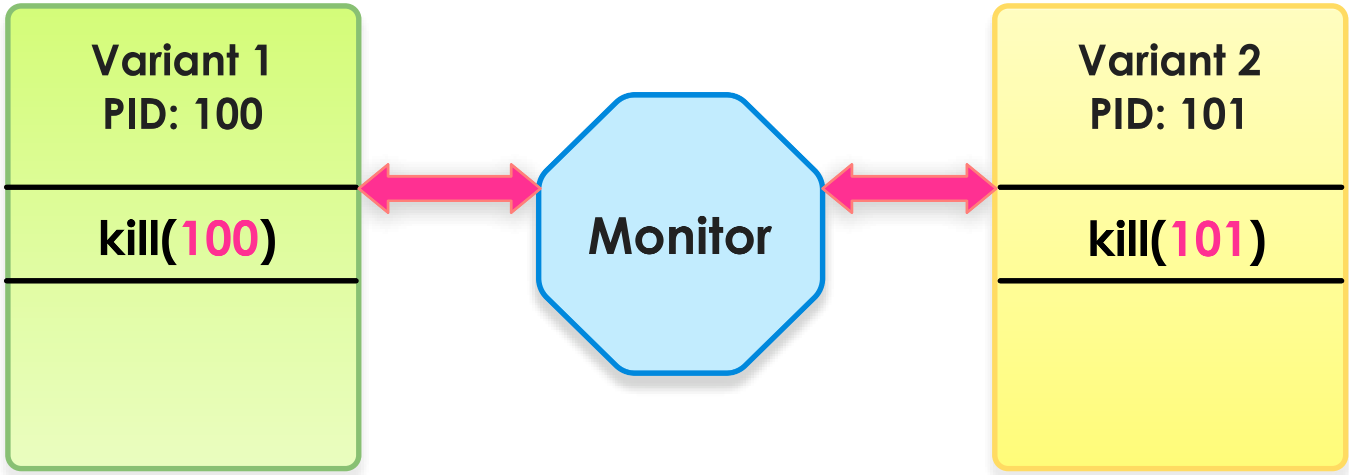
Process ID

- Monitor reports the process ID of the first variant to all
- The PID of the first variant's child process is reported as the result of `fork` or `clone` to all the variants



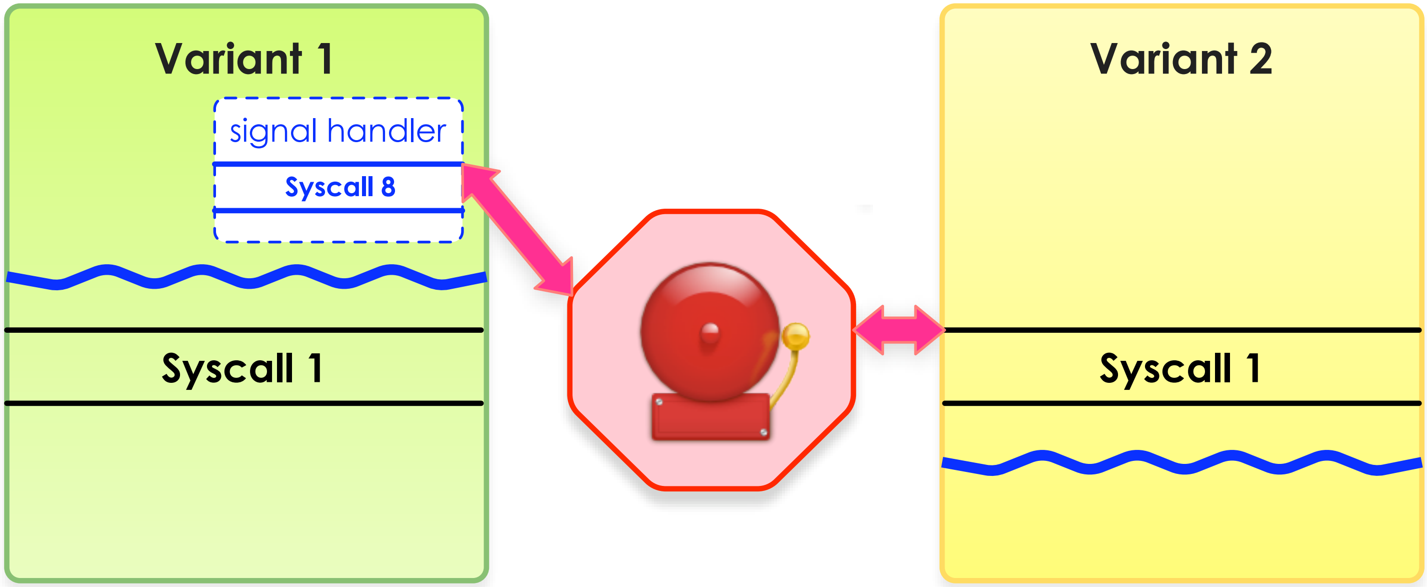
Process IDs in Arguments

- When variants need to run a system call that receives a PID, appropriate PID is restored before the execution of the system call



Asynchronous Signals

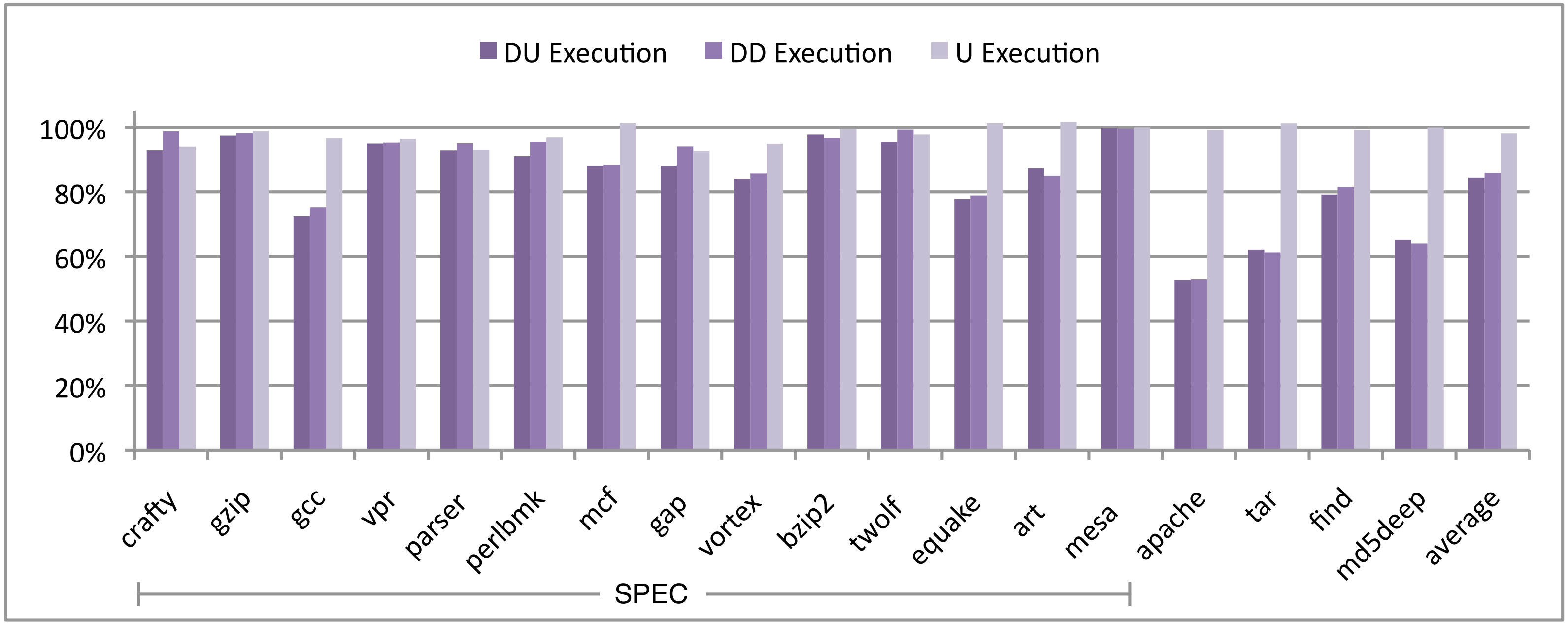
- Signal handlers can cause different sequences of system calls to be executed by the variants



Time and Random Numbers

- System calls that read time (e.g., gettimeofday) are executed by one variant and the result is copied to all
- By providing identical time and other system information to all variants, they likely use the same seed to generate random numbers
- The monitor reads /dev/urandom and copies the result to all variants
- Reading CPU time stamp counters (RDTSC) may still cause false positives

Performance



Summary

- Multi-variant execution is an effective technique in detecting and disrupting attacks
- A reverse stack executable can prevent stack-based buffer overflow vulnerabilities in a multi-variant environment
- Our methods can remove most sources of false positives in multi-variant execution
- Running two parallel variants have about 15% overhead

Thank you

Questions?