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Fine-Grained User-Space Security Through Virtualization

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Motivation

- Applications often vulnerable to security exploits
- Solution: restrict application access to the minimum amount of data needed
  - Least privilege principle

In a nutshell

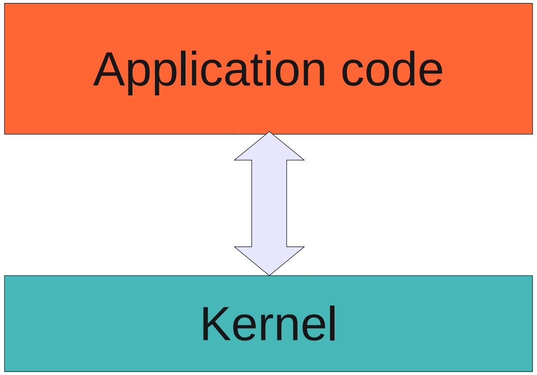
- Fine-grained *virtualization* layer confines security threats
  - All executed code is verified
  - Additional security guards are added to the runtime image
  - All system calls are verified according to a tight policy

Outline

- Introduction
- Security architecture
  - Security through virtualization
  - Software-based fault isolation (SFI)
  - System call interposition
- Evaluation
- Related work
- Conclusion

Introduction

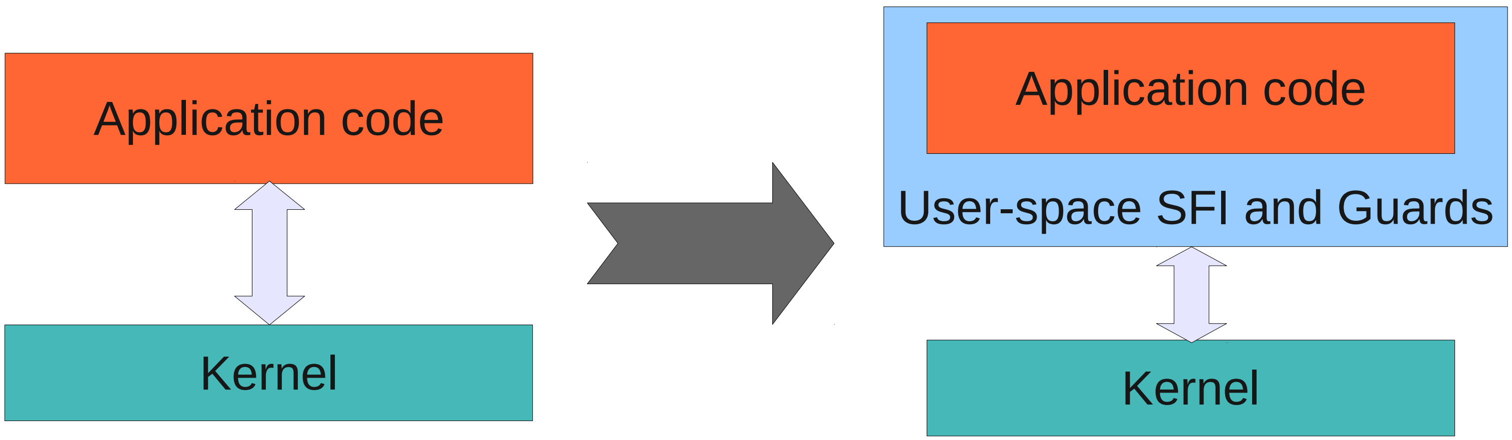
- Software security is a challenging problem
  - Many different forms of attacks exist
  - Low-level bugs are omni-present
  - Current security practice is reactive
- We present a pro-active approach to security
  - Catch exploits before they can cause any harm



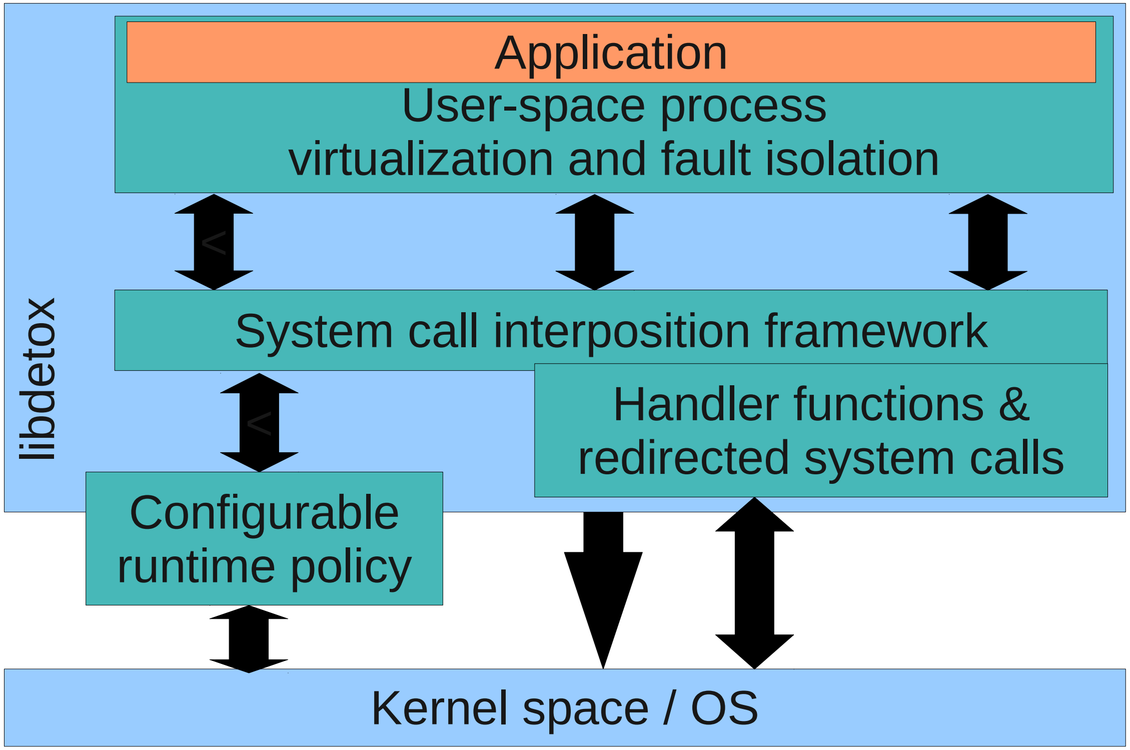
Protection through virtualization

- Virtualization confines and secures applications

- Use a user-space virtualization system
  - Secure all code and authorize all system calls



Security Architecture



- Layered security concept
  - User-space software-based fault isolation
  - System call interposition framework
  - System call authorization

Software-based fault isolation

- SFI implemented as a user-space library

- All code is translated before it is executed
  - Code is checked and verified on the fly
  - All unsafe instructions are encapsulated or rewritten
    - Check targets and origins of control flow transfers
    - Illegal instructions halt the program

SFI: Additional guards

- Translator adds guards that protect from malicious attacks against the SFI platform and enhance security guarantees
  - Secure control flow transfers
  - Signal handling
  - Executable bit removal
  - Address space layout randomization
  - Protecting internal data structures

SFI: Control transfers

- Verify return addresses on stack
  - Use a shadow stack to store original/translated addresses
  - Protects from Return Oriented Programming
- Secure control flow transfers
  - Check target and source locations for valid transfer points
  - Protects from code injection through heap-based/stack-based overflows

SFI: Signal handling

- Catch signals and exceptions
  - Redirect to installed handlers if signal is valid
  - Protects from break-outs out of the sandbox

SFI: Executable bit removal

- Executable bit removed for libraries and application
  - Only libdetox and code-cache contains executable code

- Part of the protection against code-injection

SFI: ASLR

- Address space layout randomization randomizes the runtime memory image
  - Probabilistic measure that makes attack harder

SFI: Internal data structures

- All internal data structures are protected
  - Context transfer to (translated) application code protects all internal data structures
  - Write permissions to all internal memory is removed
- Protects from code-injection and attacks against the virtualization platform

SFI: Added protection

- These additional guards protect from
  - Code injection (stack-based / heap-based)
  - Return-oriented programming
  - Execution of illegal code
  - Attacks against the virtualization platform

System call interposition

- Implemented on top of SFI platform
- All system calls & parameters are checked
  - Dangerous system calls are redirected to a special implementation inside the virtualization library
- System call authorization
  - System calls are authorized based on a user-definable per-process policy
- Protects from data attacks

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libdetox

- Approach implemented as a prototype
- Built on top of fastBT system
  - Additional security hardening
  - Guards implemented in the translation process
  - Dynamic guards extend the dynamic control flow transfer logic

Evaluation

- SPEC CPU2006 benchmarks used to evaluate overheads
- Apache plus policy used to evaluate server performance

- All benchmarks were executed on Ubuntu 9.04 on an E6850 Intel Core2Duo CPU @ 3.00GHz, 2GB RAM and GCC version 4.3.3

SPEC CPU2006

- Benchmarks executed with well-defined policy
- Three configurations:
  - Binary translation (BT) only
    - no security extensions
    - shows cost of translation & control flow transfers
  - libdetox
    - standard security features
  - libdetox + internal memory protection
    - securing internal data structures
    - all transfers from the application code to the libdetox code are protected

SPEC CPU2006

Benchmark	BT	libdetox	+ mprot
400.perlbench	55.97%	59.88%	74.69%
401.bzip2	3.89%	5.39%	5.54%
429.mcf	-0.49%	0.49%	0.25%
464.h264ref	6.17%	9.20%	9.20%
483.xalancbmk	23.72%	27.22%	31.27%
454.calculix	-1.68%	-0.56%	-1.12%
Average*	**6.00%**	**6.39%**	**8.21%**

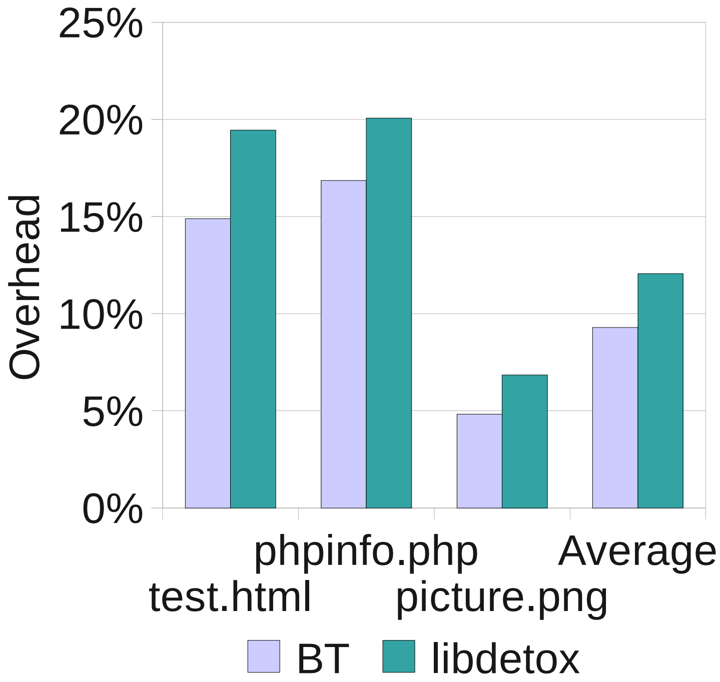
- Average overhead is low
- Most overhead comes from the BT
- Even worst-case behavior (perlbench) is manageable

* Average is calculated over all 28 SPEC CPU2006 benchmarks

Apache2

- Fully protected Apache 2.2.11 is evaluated using the ab benchmark
  - Each file is received 1'000'000 times
    - test.html (static, 1.7kB)
    - phpinfo.php (small, dynamic PHP file)
    - picture.png (static, 242 kB)

Apache2



Throughput [mB/s]	native	BT	libdetox
test.html	22.5	19.6	18.8
phpinfo.php	3.28	2.80	2.73
picture.png	945	902	885
Average overhead	-	9.3%	12%

- Low overhead for real-world server application
- Throughput highly depends on payload
  - Both for virtualized and native executions

Related Work

- Full system translation (VMWare, QEMU, Xen)
  - Virtualizes a complete system, management overhead, data sharing problem
- System call interposition (Janus, AppArmor)
  - Only system calls checked, code is unchecked
- Software-based fault isolation (Vx32, Strata)
  - Only a sandbox is not enough, additional guards and system call authorization needed
- Static binary translation (Google's NaCL)
  - Limits the ISA, special compilers needed

Conclusions

- Combining SFI and policy-based system call authorization builds low overhead virtualization platform
  - Virtualization based on programs, not systems
  - System image is shared with a single configuration
- Fine-grained access control to data / properties
- Opens door to new approaches of security
  - Highly customizable and dynamic

Questions

?

- Libdetox as an implementation prototype supports full IA-32 ISA without kernel module
  - Source: http://nebelwelt.net/projects/libdetox/

Policy

System call definition:

.
.
.
5: open(string, int)
6: close(int)
.
.
.

open:

("/etc/apache2/*", *): allow
("/var/www/*", *): allow
("*", *): deny

close:

(*): allow

Policy: nmap

```
mode:whitelist /* not listed: abort program */
brk(*):allow /* memory management */
mmap2(*,*,*,*,*,*):allow
munmap(*,*):allow
close(*):allow
ioctl(*, TIOCGPGRP, *):allow
open("/dev/tty",*):allow
open("/etc/host.conf",*):allow
open("/etc/hosts",*):allow
open("/usr/share/nmap/nmap-services",*):allow
...
read(*,*,*):allow
stat64("/etc/resolv.conf",*):allow
stat64("/home/test/.nmap/nmap-services",*):allow
...
write(*,*,*):allow
socketcall(PF NETLINK, SOCK RAW, 0):allow /* net */
socketcall(PF INET, SOCK STREAM, IPPROTO TCP):allow
socketcall(PF FILE, SOCK STREAM | SOCK CLOEXEC | SOCK NONBLOCK, 0):allow
...
```

SFI in a nutshell