System call tracing overhead

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Introduction

- System call tracing is a common used technique for debuggers or applications which enforce security policies.
- For debugging purposes the tracing is often done *step-by-step* or in conjunction with breakpoints.
- For enforcing security policies usually the interception of system calls is required.
  - → modify, forbid or allow system calls.
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system call interception requires at least a kernel based implementation and an user space process to trace

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  → gives the possibility to modify arguments or even modify the data pointed to by arguments
Overview

- System call interception requires at least a kernel-based implementation and an user space process to trace.
- Usually, there is another process which triggers the tracing and does some actions before and maybe after the system call.
- In addition, the triggering requires some kind of registration at the kernel implementation, at least the PID of the application to trace is required.
- Commonly, kernel implementations provide mechanisms for reading processor registers.
  - Gives the possibility to modify arguments or even modify the data pointed to by arguments.
Overhead

- Intercepting system calls involves additional overhead.
- Additional overhead can be ignored for the purpose of debugging *but* should be considered for security enforcing applications and other kinds of applications.

→ Determine the additional overhead through measurements.
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trace socket system calls of processes on backend servers to determine useful metrics and values for load balancing
Background: server load balancing

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System call

- Interface between operating system kernel and user space programs is defined by a set of system calls [Tan01]
- System calls vary from OS to OS but concepts tend to be similar
- System calls transfer the control to the OS similar to a function call which enters the kernel

→ System calls are a universal and fundamental mechanism
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System call implementation

- system call tracing implementations are usually use system calls too, for registering of PIDs from user space
- implementing a system call requires control transfer, often done through interrupts or traps
- modern architectures provide `SYSCALL/SYSCALL` or `SYSENTER/SYSEXIT` instructions for fast control transfer [BC05]
- system call implementations have to take care about restricted rights and access control
  
  → e.g. `open()` has to check whether the file permissions and the owner match the issuing process
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Three approaches for system call interception mentioned in [Pet97]:

1. kernel based system call interception implemented through a modified system kernel

2. using a modified system library to *replace* the default system calls (maybe using shared libraries and *preload* mechanisms)

3. using a trace process and a debugging interface like ptrace or systrace for system call interception of applications
Focus

→ focus on stable implementations of the third approach in standard kernels on Linux and OpenBSD, namely ptrace and systrace

→ microbenchmarks to determine overhead, issued through context switches between traced process and application

→ kernel tracer like ktrace are out of scope caused by background of server load balancing
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Related work

Usage of system call tracing

Debugging applications using system call tracing

- well known GDB
- ftrace based on frysk
- DTrace on Solaris
- strace based on ptrace
- truss (FreeBSD/SunOS/System V)

→ various commonly used applications for debugging and tracing other processes are available
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Security applications using system call tracing

- AppArmor
- SELinux
- grsecurity
- systrace

→ various commonly used applications to limit application access and achieve Mandatory Access Control (MAC) are available
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Performance system call interception

The performance overhead of a system call interception can be split into the following two parts [Chu]:

- cost of system call interception, for example passing control to the tracing process at every system call of the traced process
- cost of the analysis performed by the tracing process, for example determining whether the reported request for kernel service should be allowed every time the tracing process get invoked
## Performance studies systrace

<table>
<thead>
<tr>
<th>Command</th>
<th>Real</th>
<th>User</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>find /usr/src/ &gt;/dev/null</td>
<td>30</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>systrace find /usr/src/ &gt;/dev/null</td>
<td>42</td>
<td>1.2</td>
<td>3.8</td>
</tr>
<tr>
<td>gzip -9 test.bin</td>
<td>2.0</td>
<td>1.7</td>
<td>0.1</td>
</tr>
<tr>
<td>systrace gzip -9 test.bin</td>
<td>1.9</td>
<td>1.6</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table: Systrace overhead from [Pro02].
Other approaches

- reducing the overhead of ptrace through subsets of system calls (policies)
- utrace and uprobe as replacement for ptrace
- lbox framework (more efficient than ptrace or systrace)

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Ptrace system call and kernel implementation is available on Linux and OpenBSD and on various further operating systems.

- The system call itself is not part of the POSIX standard.
- Both implementations, Linux and OpenBSD are similar, but the OpenBSD implementations lacks support of features like `PTRACE_SYSCALL` (only `PTRACE_SINGLESTEP`).

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Ptrace sequence

- attach and detach via `PTRACE_ATTACH` and `PTRACE_DETACH` system call arguments
- attach means: tracing application becomes parent of the traced process
- detach restores original parent

→ main idea is: attach to another process identified by PID, start tracing and detach later
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Ptrace capabilities and options

- traced process stops on monitored event (system calls or single step) and sends SIGCHLD signal its parent
- a process can not be traced by two processes at the same time
- CAP_SYS_PTRACE capability flag is required to trace every process in system except init
- without capability flag set only processes of the same owner are allowed to trace

→ tracing parent can read registers and data from the stopped traced process memory
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Ptrace drawbacks

- ptrace does not allow monitoring of specific system calls, instead just all system calls are monitored
  → incurring at least two context switches per traced system call
- blocks the traced process on every system call it makes, therefore the tracing process needs to continue the child each time it is blocked
- considering that a tracing process might monitor more than one process, the overhead on the tracing process increases
Systrace

- developed by Niels Provos
- term systrace refers to the application as well as to the system call and the according kernel implementation
- available for various operating systems, uses different kernel implementations depending on the operating system, for example, the systrace application uses ptrace on Linux

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- enforce policies on system calls
- user space process controls behavior through pseudo-device /dev/systrace and an ioctl based interface
- the ioctl interface together with the defined systrace messages achieve various tracing operations (similar to ptrace), like STRIOCIO for copying data in/out of the process being traced

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- SYSTR_POLICY_PERMIT - immediately allow the system call
- SYSTR_POLICY_NEVER - forbids the system call
- SYSTR_POLICY_ASK - sends a message of the type SYSTR_MSG_ASK and puts the process to sleep until the according answer

→ besides the flexibility of systrace policies, they should be fast since basic policies SYSTR_POLICY_PERMIT and SYSTR_POLICY_NEVER are handled in kernel without asking user space (fast path)
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Measurement environment

- Dual Core Xeon 1.86 GHz in a dual-boot configuration running CentOS 5.2 for ptrace measurements and OpenBSD 4.3 for the systrace measurements
- all measurements gather the number of CPU cycles through the `rdtsc` register and all are repeated 51 times explicitly to avoid cache effects
- the median is used to calculate the result from the 51 repetitions to obviate distortions
Measurement experiments

- first the number of CPU Cycles for the three single plain system calls `open()`, `write()` and `close()` are measured
- then the measurements are done again while tracing these system calls
- additional measurements are done for all three system calls in a sequence and again with an invalid file descriptor
Plain system calls

Figure: System calls with and without valid file descriptors.
Flapping effect

Figure: Flapping for \texttt{write()} and ptrace with invalid file descriptor.
Overhead with valid file descriptors

Figure: Overhead for ptrace and systrace with valid file descriptors.
Overhead with invalid file descriptors

Figure: Overhead for ptrace and systrace with invalid file descriptors.
Conclusion and future work

- System call interception through systrace or ptrace is considered as slow.
- A sequence of system calls is faster than all involved single system calls.
- Ptrace interface measurements show some strange flapping results, which are in the worst case scenario slower than the competitor measurements from systrace.
- Policy concept of systrace is considered to be faster and more flexible than ptrace.
- Overhead looks dramatically high.

→ Can be considered as negligible small for the sake of improved security and flexibility.

→ Further macrobenchmarks measurements in the field of self-adapting server load balancing have shown that the overhead cannot be considered as negligible small therefore.
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Literature I


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