Moving *from* Logical Sharing of Guest OS
*to* Physical Sharing of Deduplication on Virtual Machine

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Contents

• Vulnerability of logical sharing (Dynamic-Link Shared Library and Symbolic Link)
• Propose replacement of logical sharing by physical sharing
  – Physical sharing
    • Deduplication on Memory and Storage
  – Self-contained binary
    • It is NOT static-Link binary.
• Experimental results
• Conclusions with discussing topics
Logical Sharing

• Logical sharing is OS technique to reduce consumption of memory and storage.
  – “Dynamic-Link Shared Library” for memory and storage
  – “Symbolic Link” for storage

• Unfortunately, they include vulnerability caused by dynamic management.
  – Search Path Replacement Attack
  – GOT (Global Offset Table) overwrite attack
  – Dependency Hell
  – Etc.
Search Path Replacement Attack

• Dynamic-link searches a shared library at run time using a search path.
  – Search path is defined by environment variables.
    • Example: “LD_LIBRARY_PATH”
    – It allows us to change shared libraries in any directories.

• Unfortunately, the search path is easily replaced by an attacker and leads to malicious shared libraries.
  – Caller program has no methods to certify libraries.

• Static-link solves this problem but it wastes memory and storage.
GOT Overwrite Attack

- ELF format has GOT (Global Offset Table) to locate position-independent function address of shared library. The value of GOT is assigned at run time.
  - GOT is created on Data Segment and vulnerable for overwrite attack.
- Static link solves this problem but it wastes memory and storage.
Dependency Hell (DLL Hell in Windows)

- Dependency Hell is a management problem of shared libraries.
  - Package manager maintains versions of libraries. However, the version mismatch may occur, when a user updates a library without package manager.
  - Caller program has no methods to certify libraries.
- Dependency Hell is escalated by symbolic-link, because most shared libraries use symbolic-link to manage minor updates.
  - /lib/libc.so.6 -> libc-2.10.1.so
  - # ln –s libc-2.11.1.so libc.so.6
- Static link solves this problem but it wastes memory and storage.
Solution, and further problems

• The problems are solved by static-link, but it increase consumption of memory and storage.
  – Fortunately, the increased consumption is mitigated by new technique, deduplication.
  – SLINY[USENIX’05] developed deduplication in Linux kernel.
  – It looks the problems are solved ...

• Two trends
  – Current applications assume dynamic-link and are not re-compiled as static-link easily.
  – Current virtualization offers us deduplication.
    • SLINKY uses special Linux kernel. It is not applied on any OSes.
    • Using virtualization, guest OS only has to consider the solution without regard to physical consumption.
Static-Link is not easy

• Current applications deeply depend on dynamic-link shared libraries for flexibility and for avoiding license contamination problems.

• We tried to re-compile /bin, /sbin, /usr/bin, and /usr/sbin dynamic-linked binaries (1,162) with static-link on Gentoo.
  – 185 (15.9%) binaries are re-compiled with static-link.

• Binary packages make it difficult to re-compile, because they are not easy to get all source code.
  – Commercial applications make problem more difficult.
Self-Contained Binaries

• Self-contained binary translator
  • It is developed to bring a binary to another machine.
  • It integrates shared libraries into an ELF binary file.

  – Advantage
    • Prevent Search Path Replacement Attack and Dependency Hell, because it integrates all libraries.
    • Mitigate GOT Overwrite Attack, because the addresses are prefixed for each execution.

  – Disadvantage
    • Consume more memory and storage than static-link

• Tools
  – Statifier, Autopacage, Ermine for Linux
  – VMWare “ThinApps(was Thinstall)” for Windows
Statifier (1/2)

• Statifier includes shared library into an ELF binary.

• On Normal binary
  ① _dl_start() of ld-linux.so
     • Reallocate dynamic link libraries and map them
  ② _dl_start_user() of ld-linux.so
     • Call initialization functions in libraries

• Statifier creates self-contained binary
  – Take snapshot before _dl_start_user() and analyze relocation information of functions of libraries from /proc/PID/maps.
  – The libraries and relocation information are embedded into the binary.
Statifier (2/2)

- **Self-Contained Binary**
  - Relocation information and shared libraries are loaded by the starter of statifier.
  - **Includes special libraries:** `linux-gate.so`, `ld-linux.so`
  - The ELF binary has no **INTERP** segment to call `ld-linux.so`
  - `ldd` command shows no dynamic-link shared libraries

- **However, Statifier makes a larger binary than static link.**
Deduplication

• Technique to share same-content chunks at block level (memory and storage).

• Same-content chunks are shared by indirect link.
  – It is easy to implement when a virtual layer exists to access a block device.
  – Some virtualizations include deduplication mechanism.
Storage Deduplication

- Used by CAS (Content addressable Storage)
  - data is not addressed by its physical location. Data is addressed by a unique name derived from the content (a secure hash is used as a unique name usually)
  - Same contents are expressed by one original content (same hash) and addressed by indirection link.
- Plan9 has Venti [USENIX FAST02]
- NetApp Deduplication (Data Domain) [USENIX FAST08]
- LBCAS (Loopback Content Addressable Storage) [LinuxSymp09]

### Diagram

- **Virtual Disk**
  - Address
    - 0000000–0003FFF 4ad36ffe8...
    - 0004000–0007FFF 974daf34a...
    - 0008000–000BFFF 2d34ff3e1...
    - 000C000–000FFFF 974daf34a...
  - SHA-1
- **Indexing**
  - New block is created with new SHA-1
- **CAS Storage Archive**
  - Sharing
Memory Deduplication

- Memory deduplication is mainly used for virtual machines.
- Very effective when same guest OS runs on several virtual machines.
- On Virtual Machine Monitor
  - Disco[OSDI97] has Transparent Page Sharing
  - VMWare ESX has Content-Based Page Sharing [SOSP02]
  - Xen has Satori[USENIX09] and Differential Engine[OSDI08]
- On Kernel
  - Linux has KSM (Kernel Samepage Merging) from 2.6.32 [LinuxSymp09]
    - Memory of Process(es) are deduplicated
    - KVM uses this mechanism
- These targets are virtual machines, but our proposal uses memory deduplication on a single OS image, which increase same pages with copy of libraries (self-contained binary).
Evaluation

• Evaluate the effect of moving form logical sharing to physical sharing.
  – Effect of Statifier
    • Applied on binaries under /bin,/sbin,/usr/bin,/usr/sbin of Gentoo (installed on 32GB virtual disk for KVM virtual machine)
  – Memory Deduplication
    • KSM (Kernel Samepage merging) of Linux with KVM virtual machine (758MB).
  – Storage Deduplication
    • LBCAS (Loopback Content Addressable Storage)
Static Analysis of Statifier

- Gentoo was customized by statifier.
  - The ELF (1,162) binaries under /bin (82 files), /sbin (74), /usr/bin (912), /usr/sbin (94) were customized by statifier.

<table>
<thead>
<tr>
<th></th>
<th>Original (Dynamic-link)</th>
<th>Statifier</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>87,865,480</td>
<td>3,572,936,704</td>
<td>40.66</td>
</tr>
<tr>
<td>Average</td>
<td>75,615</td>
<td>3,074,816</td>
<td>40.66</td>
</tr>
<tr>
<td>Max (gnome-open)</td>
<td>5,400</td>
<td>8,732,672</td>
<td>1617.16</td>
</tr>
<tr>
<td>Min (qmake)</td>
<td>3,426,340</td>
<td>6,094,848</td>
<td>1.78</td>
</tr>
</tbody>
</table>

- The disk image (includes non-statifiered files) was expanded from 3.75GB to 7.08GB (1.88 times).
Effect of Memory Deduplication

- Memory usage at the end of login
- Statifier expanded memory consumption from the view of GuestOS,
- but Deduplication reduced physical memory consumption.

![Graph showing memory consumption comparison](image-url)
Effect of Storage Deduplication

- Storage usage (static) and total read data at boot (dynamic).
- Statifier expanded storage consumption from the view of GuestOS on both cases, but Deduplication reduced physical storage consumption in static and dynamic.
- Smaller chunk is easy to be deduplicated but time overhead is large.

<table>
<thead>
<tr>
<th></th>
<th>Static</th>
<th>Dynamic (boot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>normal</td>
<td>statifier</td>
</tr>
<tr>
<td>On Loopback</td>
<td>3,754MB</td>
<td>7,075MB</td>
</tr>
<tr>
<td>(Guest OS View)</td>
<td>(1.88)</td>
<td>(2.25)</td>
</tr>
<tr>
<td>LBCAS 16KB</td>
<td>268,454 [4195MB]</td>
<td>4352MB [278,499]</td>
</tr>
<tr>
<td></td>
<td>(1.04)</td>
<td>(1.04)</td>
</tr>
<tr>
<td></td>
<td>(1.12)</td>
<td>(1.12)</td>
</tr>
<tr>
<td></td>
<td>(1.18)</td>
<td>(1.18)</td>
</tr>
</tbody>
</table>
Trace of memory consumption
Time overhead at boot

- Statifier reduced the boot time, because it eliminated dynamic reallocation overhead.
- Deduplication increased the boot time. The overhead of KSM and LBCAS was less than 37%.
  - The overhead is a penalty to remove the vulnerabilities of logical sharing.

<table>
<thead>
<tr>
<th></th>
<th>Without KSM</th>
<th>With KSM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Statifier</td>
</tr>
<tr>
<td>Loopback</td>
<td>95s</td>
<td>84s</td>
</tr>
<tr>
<td>LBCAS (256KB)</td>
<td>107s</td>
<td>108s</td>
</tr>
</tbody>
</table>
Conclusion & Discussion (1/2)

• Self-Contained binaries strengthen OS security.
  – Prevent Search Path Replacement Attack, GOT (Global Offset Table) overwrite attack, Dependency Hell
  – Easy to apply on normal OS. It does not require source code and re-compile.
  – Increase consumption of memory and storage.

• Deduplication mitigates the consumption of memory and storage caused by self-contained binary.
  – Encourage moving from Logical sharing to Physical Sharing

• Deduplication is utilized to increase security on single OS.
Conclusion & Discussion (2/2)

- Deduplication will be mainly used on IaaS type (multi-tenants) Cloud Computing.
- Two directions of research
  - Increase code sharing
    - “Return-Oriented Programming” style becomes popular?
      » Tools: Return Oriented Rootkit [USENIX Security 09]
  - Keep security
    - Code sharing will increase a chance to attack
    - *Attack for deduplication* will be presented in *Rump Session* of USENIX Security.