On the Effectiveness of Kernel Debloating via Compile-time Configuration

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The problem of bloated software

- High complexity: more vulnerabilities
- Unused interfaces: an attacker can use
- Unused code: more ROP gadget

Linux kernel is bloated

- Driving a variety of devices from servers to embedded
  - Server-friendly features
  - Embedded-only features

- Keep adopting new features
  - Support for new hardware
  - Performance optimizations

Problem of bloated kernel: avoidable bugs

- Linux distributions conservatively enable many features
  - Just in case a user wants them

- A system ends up suffering from a bug (vulnerability) in a feature that it never uses
  - which we should avoid

Example: X32 ABI

- Use x86_64 ISA: more registers than i386 (IA-32).
- Keep pointer size 32-bit: smaller memory footprints.
- Rarely used but enabled by default by popular distributions.
  - OpenSuse, Ubuntu, Solus.
- Related to a security-critical bug: CVE-2014-0038.
  - Local privilege escalation.

Example: CVE-2014-0038

- x32 ABI uses `compat_sys_recvmmsg` to implement `recvmmsg`.
- Incorrect casting at line 7 enables arbitrary memory write.
- Only the kernels that `CONFIG_X86_X32` enabled is vulnerable.

```
asmlinkage long compat_sys_recvmmsg(int fd, struct compat_mmsghdr __user *mmsg,
                                    unsigned int vlen, unsigned int flags,
                                    struct compat_timespec __user *timeout)
{
        //...
          if (COMPAT_USE_64BIT_TIME)
                  return __sys_recvmmsg(fd, (struct mmsghdr __user *)mmsg, vlen,
                                        flags | MSG_CMSG_COMPAT,
                                        (struct timespec *) timeout); /* bug here!!*/
```

Background: Linux kernel config. system

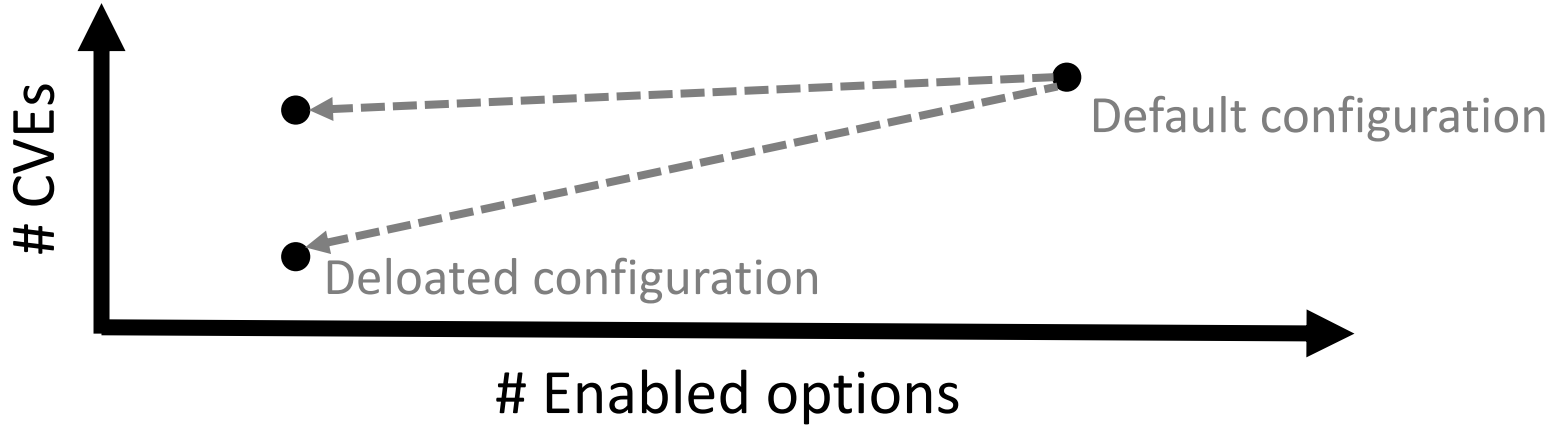
- Configuration options
  - E.g., CONFIG_NET, CONFIG_X86_X32
  - Determine if each source file/line is compile or not
- Configuration: a list of configuration options with the values

```
…
CONFIG_X86_X32=y
CONFIG_COMPAT_32=y
CONFIG_COMPAT=y
CONFIG_COMPAT_FOR_U64_ALIGNMENT=y
CONFIG_SYSVIPC_COMPAT=y
CONFIG_X86_DEV_DMA_OPS=y
CONFIG_NET=y
CONFIG_COMPAT_NETLINK_MESSAGES=y
…
```

Research goal

- The vulnerability-configuration option dependency

- Potential effectiveness of configuration option-grained tuning



Summary of results

- Dependency
  - ∃options that many vulnerabilities depend on.
  - ∃many options that at least one vulnerability depends on.

- Tuning
  - Popular programs do not need many options.
  - Disabling inessential options make the kernel less likely to have vulnerabilites.

Rest of this talk

- Dependency
  - Collecting the kernel vulnerabilities.
  - Locating the patches.
  - From a patch to the dependency.
- Tuning
  - Indirect study with existing configurations.
  - Direct study with hand-crafted configurations.
- Conclusion

Collecting the kernel vulnerabilities

- CVE data from National Vulnerability Database (NVD).
  - De facto standard, since 1999

→ 2046

- Vulnerabilities found 2005 or after.
  - For easy access to patch: when the git was out

→ 1773

- Only the upstream vulnerabilities.
  - For fair comparison between different distributions or forks
  - E.g., Ubuntu, Fedora or Android

→ 1530 vulnerabilities collected

Locating the patches from NVD entries

- The NVD entry for CVE-2014-0038

```
"cve" : {
        "data_type" : "CVE",
        "data_format" : "MITRE",
        "data_version" : "4.0",
        "CVE_data_meta" : {
              "ID" : "CVE-2014-0038",
            "ASSIGNER" : "cve@mitre.org"
        },
…
        "url" : "https://github.com/torvalds/linux/commit/2def2ef2ae5f3990aabdbe8a755911902707d268"
         }
```

→ Located patches for 1242 entries

A patch example

```
+++ b/net/compat.c
asmlinkage long compat_sys_recvmmsg(int fd, struct compat_mmsghdr __user *mmsg,
-       if (COMPAT_USE_64BIT_TIME)
-               return __sys_recvmmsg(fd, (struct mmsghdr __user *)mmsg, vlen,
-                                     flags | MSG_CMSG_COMPAT,
-                                     (struct timespec *) timeout);
        if (timeout == NULL)
                return __sys_recvmmsg(fd, (struct mmsghdr __user *)mmsg, vlen,
                                      flags | MSG_CMSG_COMPAT, NULL);
-       if (get_compat_timespec(&ktspec, timeout))
+       if (compat_get_timespec(&ktspec, timeout))
                return -EFAULT;
        datagrams = __sys_recvmmsg(fd, (struct mmsghdr __user *)mmsg, vlen,
                                   flags | MSG_CMSG_COMPAT, &ktspec);
-       if (datagrams > 0 && put_compat_timespec(&ktspec, timeout))
+       if (datagrams > 0 && compat_put_timespec(&ktspec, timeout))
                datagrams = -EFAULT;
```

→ Gives the change set

From a patch to the dependencies (1)

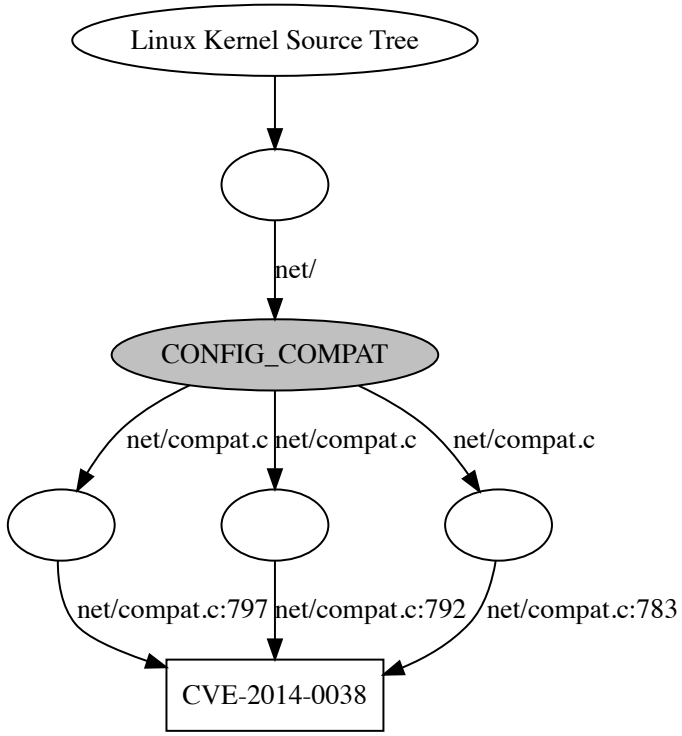
- Find the options that determines if the patched lines are compiled
- Assumption: no change required → no bug

From a patch to the dependencies (2)

- Kernel Makefiles determine if each file is included or not

Patch for CVE-2014-0038

net/compat.c:783
net/compat.c:792
net/compat.c:797



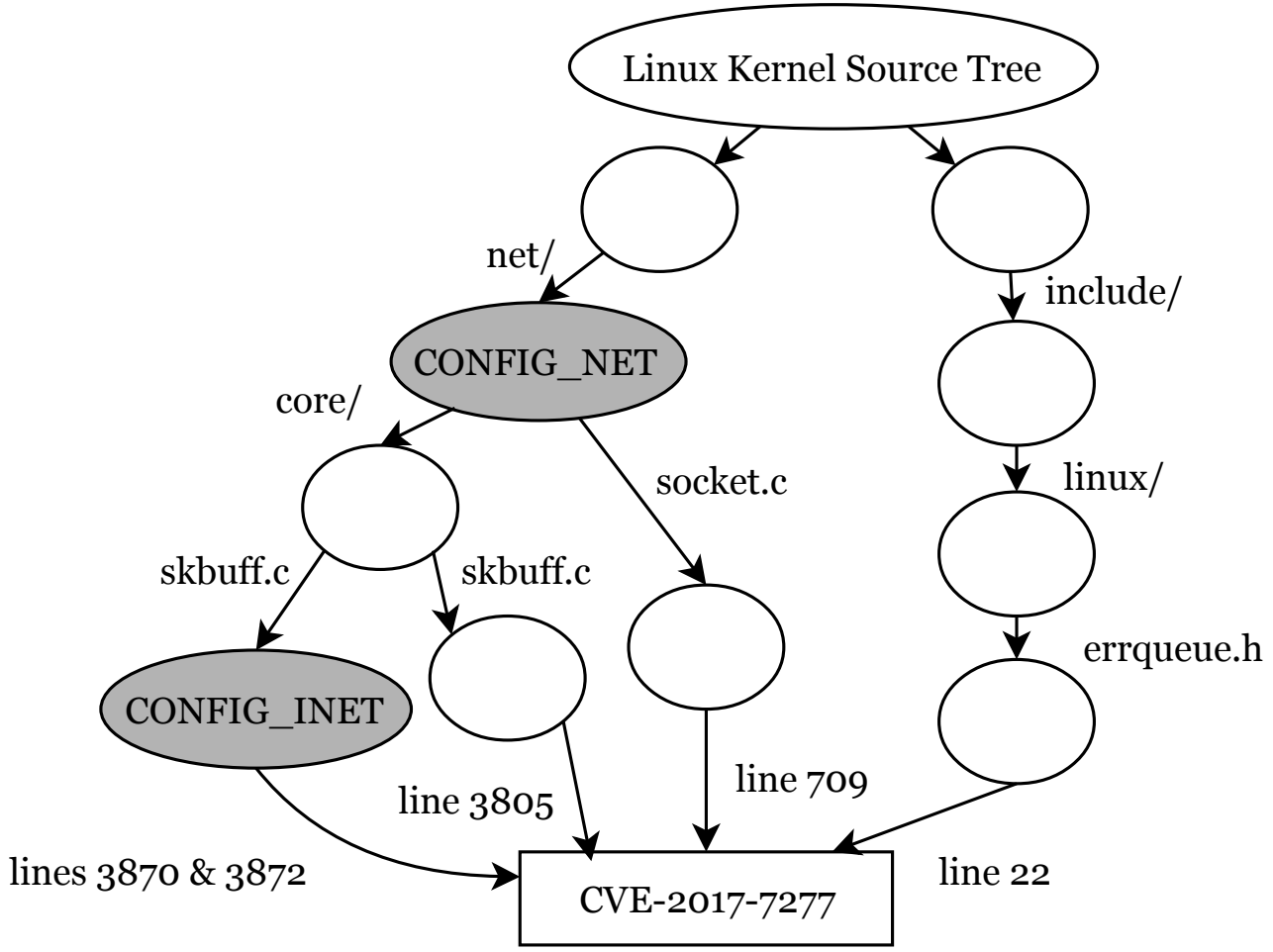

```
 := socket.o core/

 := compat.o
 += $(tmp-y)

e the files in net/802/
 += llc/
 += ethernet/ 802/ sched/ netlink/
```

From a patch to the dependencies (3)

- Kernel sour fig options.

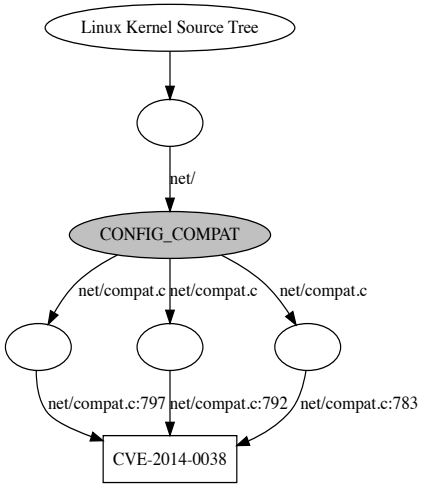
Patch for CVE-2

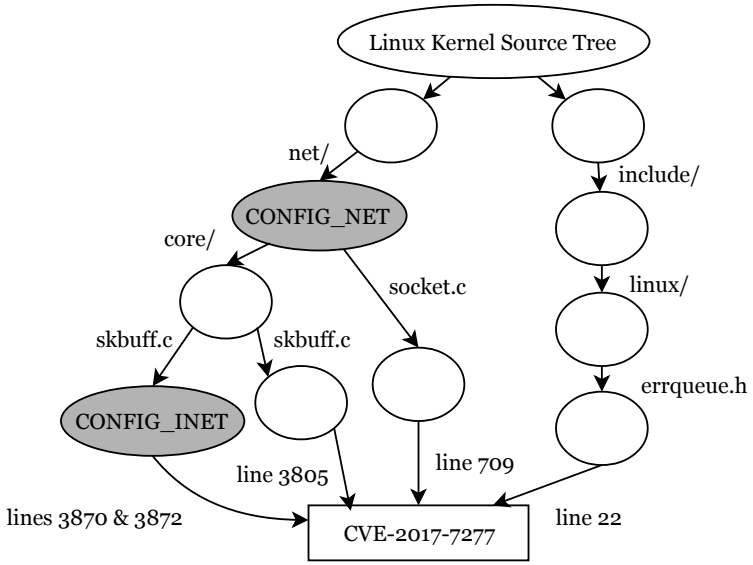
net/core/skbuf
net/core/skbuf
net/core/skbuf
net/socket.c
Include/linux/errq



Observations from the graphs

- Case 1 (e.g., CVE-2014-0038):
  - Disabling one or more option completely discards all patches line.
- Case 2 (e.g. CVE-2017-7077):
  - There exists a patched line that is never discarded.





Inferring the number of active vulnerability

- Optimistic:
  - Discarding any of the patched line deactivates the vulnerability.
  - “OR” operation when inferring the numbers

- Conservative:
  - We must discard all patched lines to deactivate the vulnerability.
  - “AND” operation when inferring the numbers

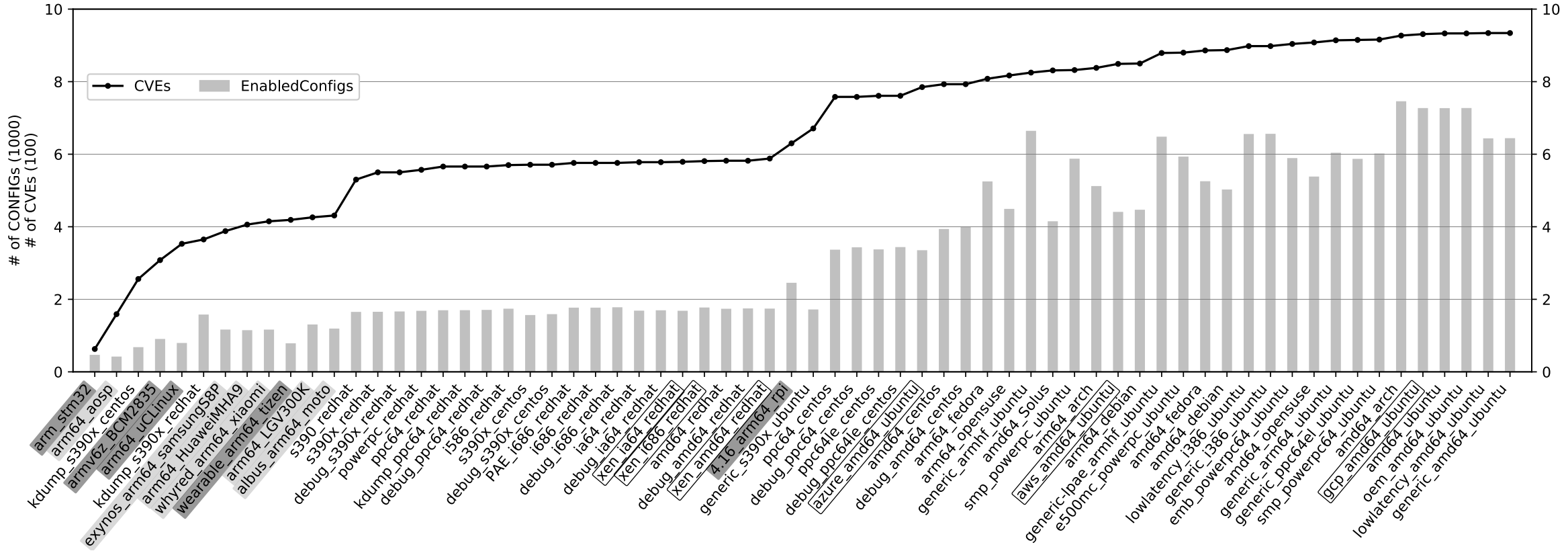
Some numbers from the dependency study

- ∃Potentially *large* configuration options which are related to many vulnerabilities.
  - CONFIG_NET: 100, CONFIG_KVM: 46, CONFIG_PCI: 39
- Many (***701***) configuration options are related to at least one.
- Only **136 (11%)** vulnerabilities have a *“bypass”.*
  - Which debloating cannot deactivate in the worst case.

Can we then tune?

- Indirect study with existing configurations
  - Collected 66 default configurations
- Direct study with manual debloating
  - Created 2 minimal, application-specific configurations

More enabled options → more vulnerabilities



Embedded Mobile (Android) Servers/desktops

Manual debloating

- Minimal web server: nginx
  - Started from Ubuntu for x86
  - Correctness: if it serves a simple web page

- Minimal sensor node: mosquitto
  - Started from Buildroot for aarch64
  - Correctness: if a client can deliver a message to a server

Targeted debloating is effective

Target	Distribution	# Options	# Bugs	Dependency
nginx	Ubuntu	7598 → 1038 (86.3%)	929 → 234 (74.8%)	OR (Optimistic)
			1000→412 (58.8%)	AND
			1006 → 472 (53.1%)	AND with Bypasses (Conservative)
mosquitto	Buildroot	1229 → 581 (52.7%)	281 → 159 (43.4%)	OR (Optimistic)
			472 → 265 (43.9%)	AND
			526 → 347 (34.0%)	AND with Bypasses (Conservative)

Conclusion

- Most (89%) of vulnerabilities can be nullified by configuration.
- Application-specific debloating is effective (34-74% reduction).
- Next steps
  - Splitting large config options (e.g., CONFIG_NET)
  - Automating the configuration-grained debloating

Thank you!

Questions?