Security types to the rescue

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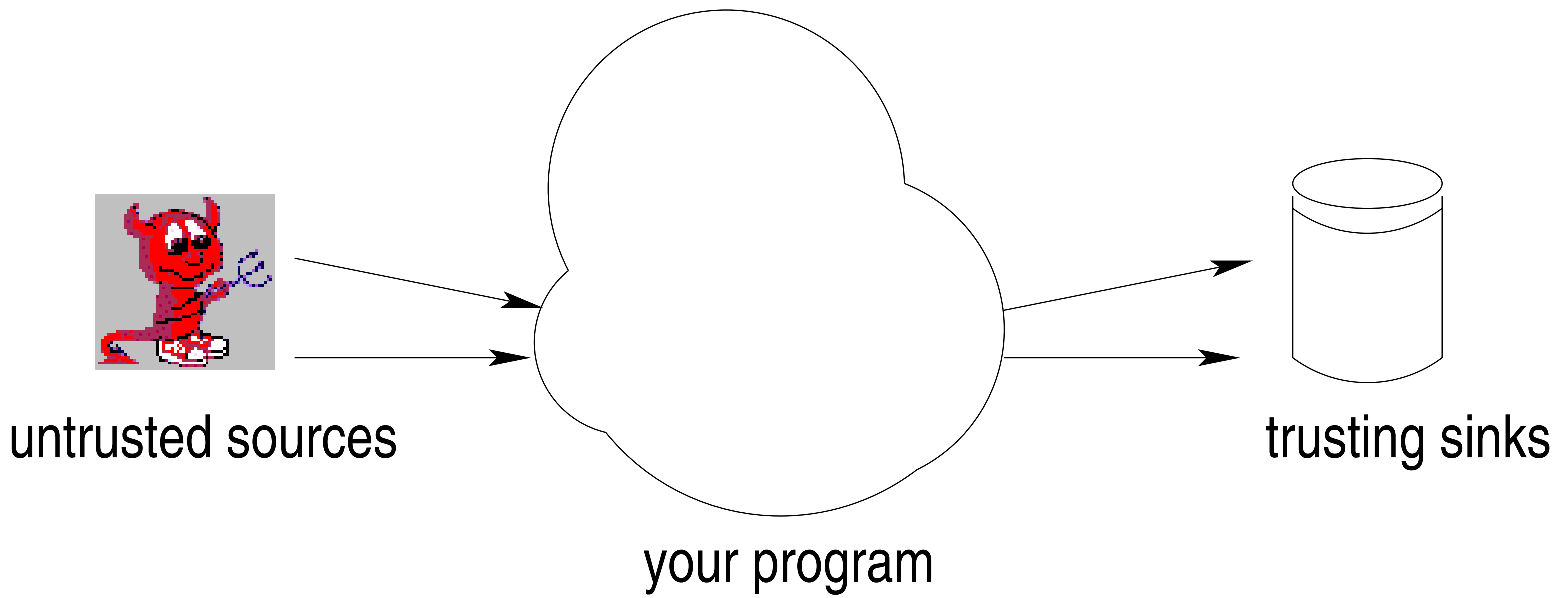
Problem statement

- Attackers may feed us untrustworthy inputs
- We must be careful to never trust those inputs, lest terrible things happen

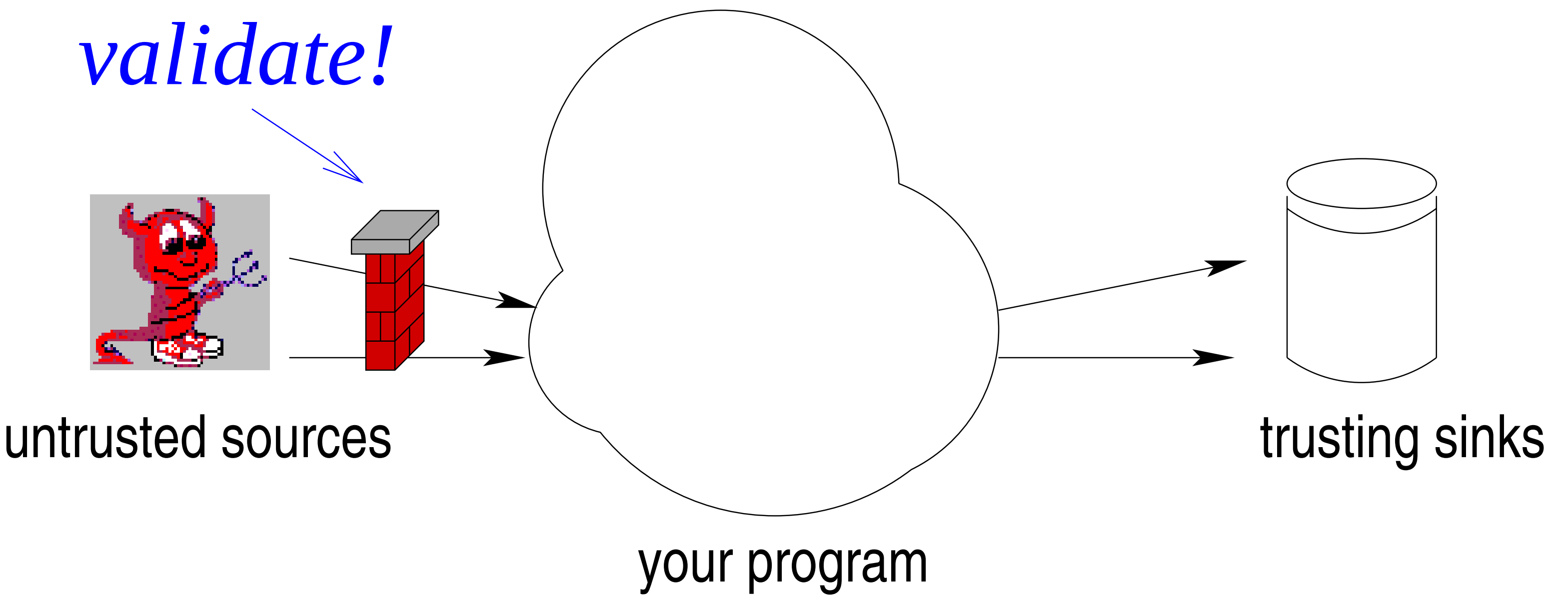
How do we ensure proper **input validation**?

Input validation is tricky



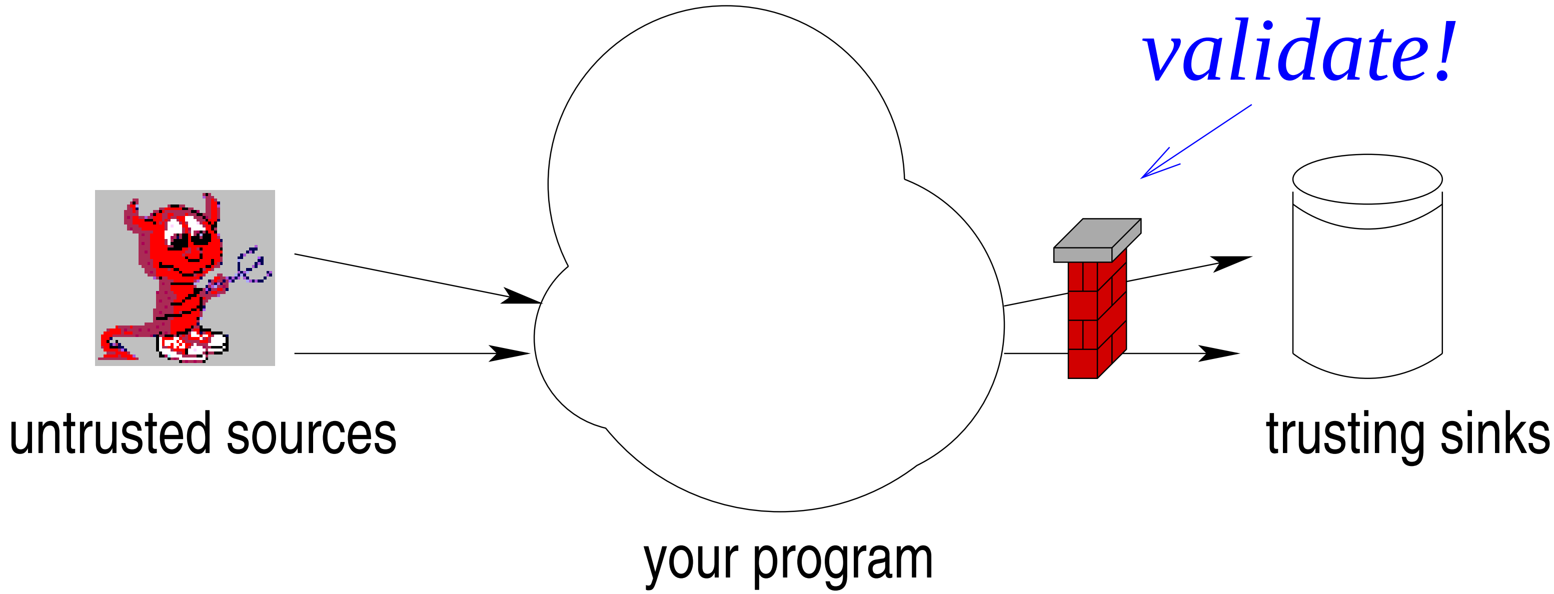
- All untrusted data must get validated somewhere on the path from source to sink
- Sources of untrusted data can be far from the sinks

Strategy #1: Validate at the sources



- A good choice when:
  proper validation depends on where data came from, rather than how it will be used

Strategy #2: Validate at the sinks



- A good choice when:
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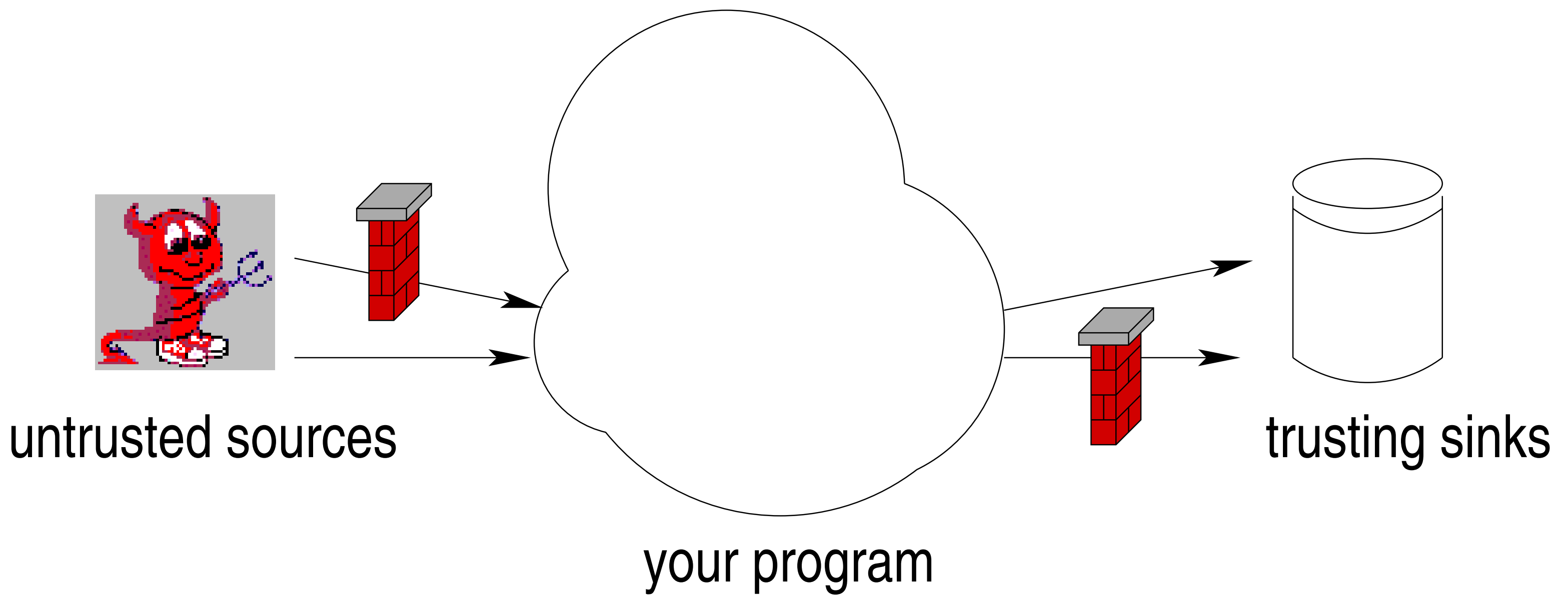
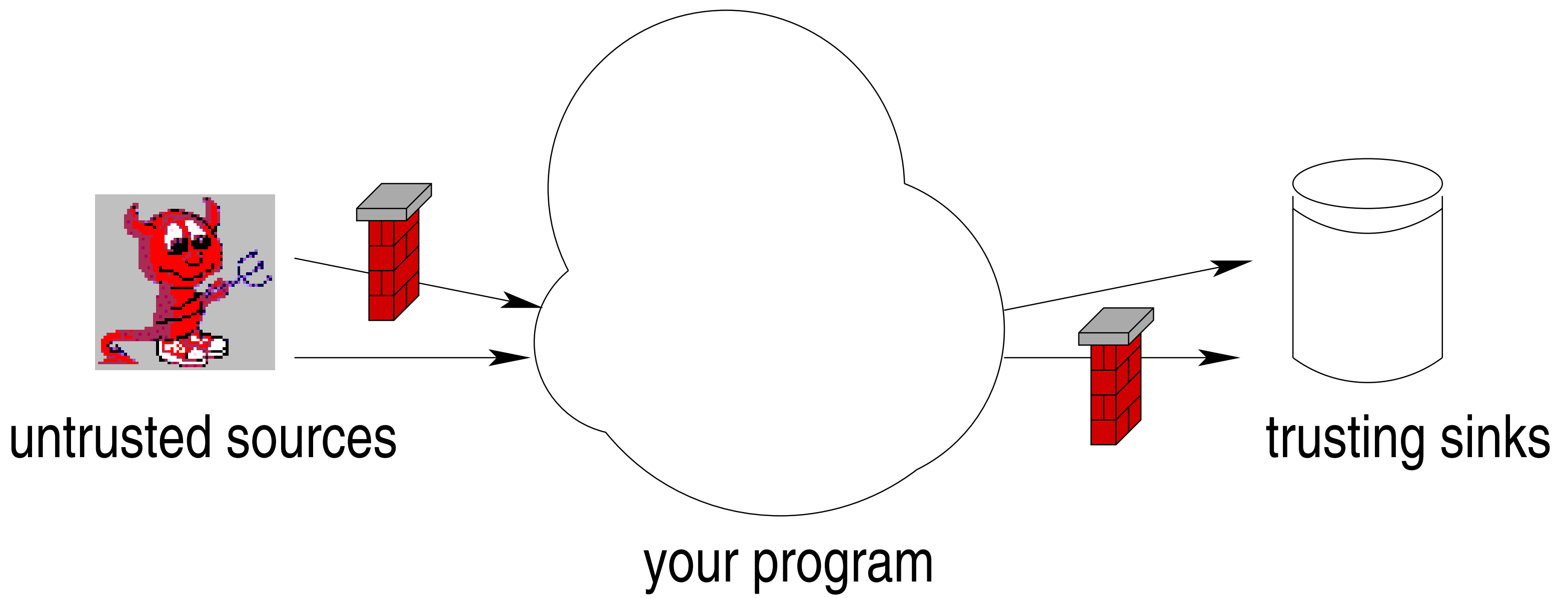
A hybrid strategy



This is what results when:

- Developer Dave validates at the sources
- Coder Courtney validates at the sinks
- Dave & Courtney work together

Challenges in input validation



- There are many data flow paths through the program that require checks
- *How can we be sure we got them all?*

Overview

In this talk:

Q: How can we verify complete input validation?

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A: Type systems

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Q: How can we verify complete input validation?

A: Type systems

Defn: *Security types* are types that record security claims.

Static taint analysis

The idea:

- Extend the C type system with type qualifiers
- Qualified types express security annotations; e.g., `$tainted char *` is an untrusted string
- Type checking enforces safe usage
- Type inference reduces the annotation burden

Benefits:

- verify complete input validation
- eliminate error-prone mental "bookkeeping"

Spot the bug

```
char *s;
s = read_from_network();
syslog(s);
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$\longrightarrow$ untrusted source

$\longrightarrow$ trusting sink

Spot the bug

```
char *s;
s = read_from_network();    ⟶ untrusted source
syslog(s);          ⟶ trusting sink
```

Format string bug!
`syslog()` trusts its first argument.

Types, and the example

```
void printf($untainted char *, ...);
$tainted char * read_from_network(void);
```

```
char *s;
s = read_from_network();
syslog(s);
```

where $\texttt{\$untainted}\ T \leq \texttt{\$tainted}\ T$

Types, and the example

```
void printf($untainted char *, ...);
$tainted char * read_from_network(void);
```

$\hookrightarrow$ a trust annotation

```
char *s;
s = read_from_network();
syslog(s);
```

where `$untainted` $T \leq$ `$tainted` T

Types, and the example

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void printf($untainted char *, ...);
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char /* $tainted */ *s;
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void printf($untainted char *, ...);
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char /* $tainted */ *s;
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syslog(s);
```

$\longrightarrow$ an inferred type

where $\texttt{\$untainted}\ T \leq \texttt{\$tainted}\ T$

Types, and the example

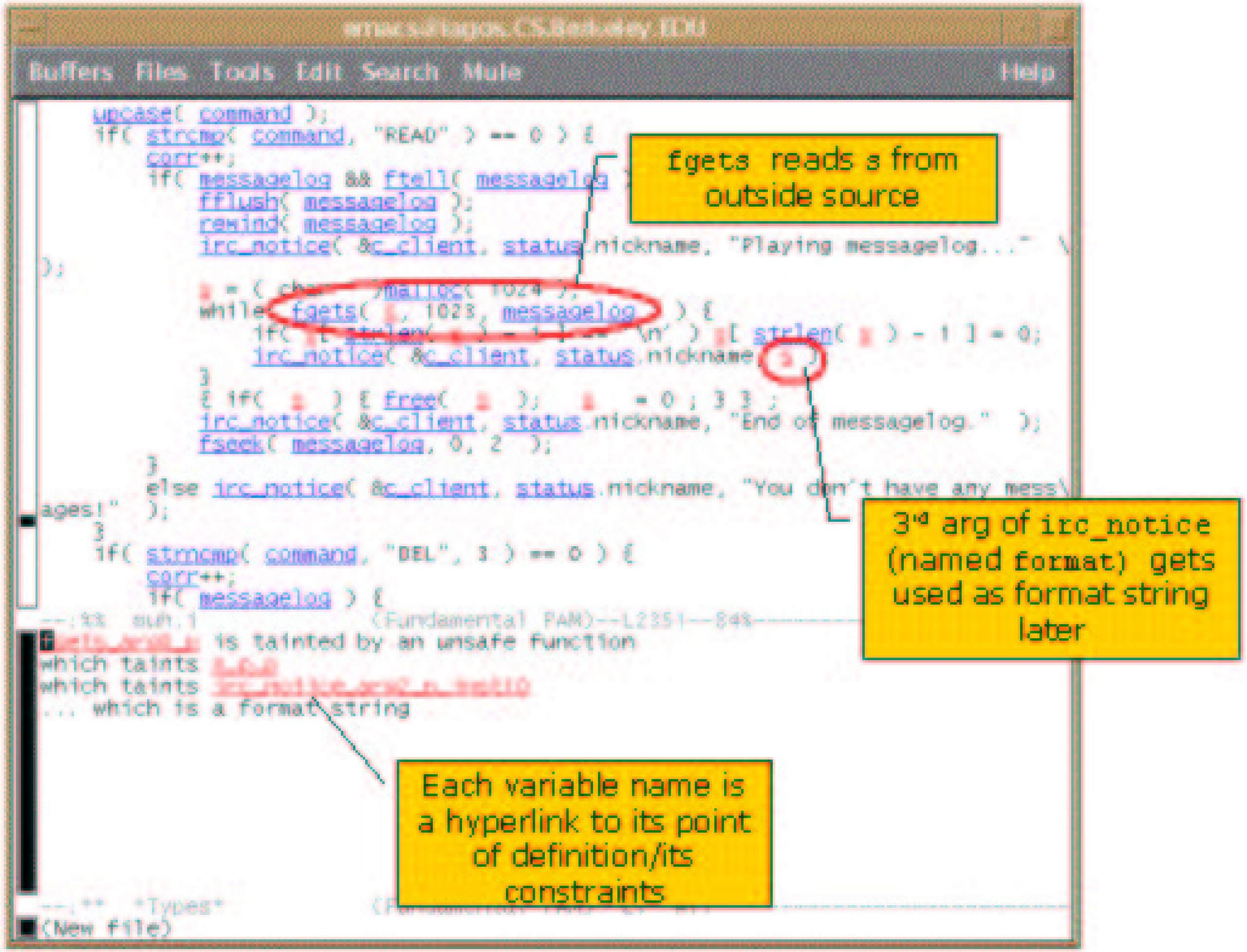
```
void printf($untainted char *, ...);
$tainted char * read_from_network(void);
```

```
char /* $tainted */ *s;
s = read_from_network();
syslog(s);
```

$\hookrightarrow$ Doesn't type-check! A security hole.

where `$untainted` $T \leq$ `$tainted` T

Case study #1: Format string bugs



- Successful at finding bugs in real programs
- Cost: 10–15 minutes per application

Case study #2: the Linux kernel

- Risk: TOCTTOU bugs
  - Some syscalls pass values by reference, rather than by value
- Current approach: manual emulation of pass-by-copy
  - Problematic; it's easy to forget to make a copy
- Types can help. . .

GOOD!

User code

```
int main ()
{
  struct foo *p;
  ...
  ioctl (fd, SIOCGFOO, p);
  ...
}
```

Kernel code

```
int dev_ioctl (int cmd, long arg)
{
  struct foo *q = mkfoo();
  ...
  copy_to_user (arg, q, n);
  return 0;
}
```

BAD!

User code

```
int main ()
{
  struct foo *p;
  ...
  ioctl (fd, SIOCGFOO, p);
  ...
}
```

Kernel code

```
int dev_ioctl (int cmd, long arg)
{
  struct foo *q = mkfoo();
  ...
  memcpy (arg, q, n);
  return 0;
}
```

Type qualifiers to the rescue

The idea:

- Annotate all pointers from user-space as `$user`
- Annotate all kernel pointers as `$kernel`
- Only allow dereferencing of `$kernel` pointers
- Use type qualifier inference (CQUAL)

Example: Type checking

```
struct foo * $kernel mkfoo(void);
int memcpy(void * $kernel dst,
           void * $kernel src, size_t n);


int dev_ioctl (int cmd, long $user arg)
{
    struct foo * $kernel q = mkfoo();
    ...
    memcpy (arg, q, n);
    return 0;
}
```

⟶ Doesn't type-check!

Example: Type inference

```
struct foo * $kernel mkfoo(void);
int memcpy(void * $kernel dst,
           void * $kernel src, size_t n);


int dev_ioctl (int cmd, long $user arg)
{
    struct foo * /* $kernel */ q = mkfoo();
    ...
    memcpy (arg, q, n);
    return 0;
}
```

↪ q's type is inferred automatically

⟶ Doesn't type-check!

Example: Type inference

```
struct foo * $kernel mkfoo(void);
int memcpy(void * dst, void * src, size_t n)
    { while (n-- > 0) *dst++ = *src++; }
```

↪ `memcpy()`'s signature is inferred automatically

```
int dev_ioctl (int cmd, long $user arg)
{
    struct foo * /* $kernel */ q = mkfoo();
    ...
    memcpy (arg, q, n);
    return 0;
}
```

↪ `q`'s type is inferred automatically

⟶ Doesn't type-check!

Experience with user-kernel bugs

- Analyzed 1259 files in Linux 2.4.18
- CQUAL reported errors in 23 files
- One error was genuine, exploitable bug
- Fixed in Linux 2.4.19

- Recent changes to CQUAL
  - Improve bug-finding power
    (pointeral and structureal constraints)
  - Reduce false positive rate
    (polymorphic type inference, separating structure instances)
- Results forthcoming

Spot the bug

```
static int joydev_ioctl(struct inode *inode, struct file *f
                unsigned int cmd, unsigned long arg)
{
  switch (cmd) {
    case JSIOCSAXMAP:
      if (copy_from_user((__u8 *) arg, joydev->abspam,
                         sizeof(__u8) * ABS_MAX))
          return -EFAULT;
      for (i = 0; i < ABS_MAX; i++) {
          if (joydev->abspam[i] > ABS_MAX) return -EINVAL;
          joydev->absmap[joydev->abspam[i]] = i;
      }
  }
}
```

The general picture

Principle: Objects with different security properties should receive different types.

Values under attacker control receive a `$tainted` type:

- Untrusted sources are marked `$tainted`
- Anything that depends on a `$tainted` value is also marked `$tainted`
- Input validation breaks the propagation of `$tainted`
- A `$tainted` value at a trusting sink is an error

Concluding thoughts

- *Security types*: a disciplined style of programming
  - An *enforceable* discipline
  - Detects errors of omission, but not of comission; type system won't let you forget to validate inputs (but did you do the *right* validation checks?)
- Type systems are useful for security engineering
- You can try this at home