Verifying the Safety of User Pointers Using Static Typing

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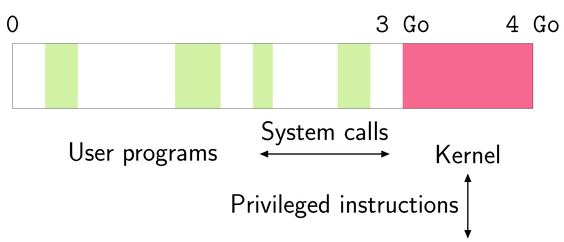
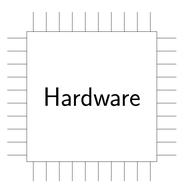
Separation in operating systems



Only the kernel can access the hardware.
User programs have to use *system calls* (`open`, `read`, ...).



Execution of a piece of code:
- with processor at level P
- with privilege level C
- accessing data with level D

is possible iff

$$P \leq \min\{C; D\}$$

On x86, levels are *rings*:
Kernel $= 0$ and User $= 3$.

P	C	D	Access
Kernel	Kernel	Kernel	OK
Kernel	Kernel	User	OK
Kernel	User	Kernel	OK
Kernel	User	User	OK
User	Kernel	Kernel	–
User	Kernel	User	–
User	User	Kernel	–
User	User	User	OK

The confused deputy problem

User programs can pass structures to system calls by pointer:

```
struct timeval tv;
int z = gettimeofday(&tv, NULL);
```

The kernel fills in `tv` with its own privileges (not the caller's).
A user can write the current time of the day at any address.
This is *the confused deputy problem*.
The kernel should check at run time that pointers controlled by userspace point to userspace (`copy_{from,to}_user`).
We detect the places where this dynamic check is omitted, using static typing of C code.

Pointer types

Depending on who controls their value, i.e. how they are created:
- kernel pointers: $\&\ x$, etc. They can be dereferenced.

$$\frac{\Gamma \vdash e : t\ *}{\Gamma \vdash *\ e : t}$$

- user pointers: system call arguments . They need a dynamic check.

$$\frac{\Gamma \vdash e_1 : t\ * \qquad \Gamma \vdash e_2 : t\ @}{\Gamma \vdash \texttt{copy\_from\_user}(e_1, e_2) : \textsc{Int}}$$

User pointer sources require annotations: one per system call.

Example: freedesktop.org bug #29340

```
int radeon_info_ioctl(struct drm_device *dev,
                      void *data,
                      struct drm_file *filp) {
    /*!npk userptr_fieldp data value*/
    struct drm_radeon_info *info = data;
    uint32_t *value_ptr = (uint32_t *)
        ((unsigned long)info->value);
    uint32_t value = *value_ptr;
    /* ... */
}
```

Inference output – **error**:

```
05-drm.c:17#10 - Type clash between :
  KPtr (_a15)
  UPtr (_a8)
```

But if we replace last line by the following:

```
if (copy_from_user(&value, value_ptr,
        sizeof(value)))
    return -14;
```

Inference output – **fully annotated program**:

```
(06-drm-ok.c:17#6)^{
  Int tmp_cir!0;
  (06-drm-ok.c:17#6)^tmp_cir!0 <-
    copy_from_user
      ( &(value) : KPtr (d),
        value_ptr_UPtr (d) : UPtr (d),
        4 : Int); }
```

Compilation

```
int f (int* x) {
    return (*x + 1);
}
```

Type erasure →

```
let f =
    fun (x) ->
        return (*x + 1)
```

Type inference →

```
let f : Int* -> Int =
    fun (x : Int) ->
        return ((((*x) : Int)
            + (1 : Int)) : Int)
```

Input is C code.
GNU extensions used in the kernel are handled.

C type annotations are removed.
The intermediate language has first-order functions and left-values (for partial updates).

Every subexpression gets a type.
This is more precise than C types since abstract types (e.g. user pointers) can be inferred.

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