# Object Oriented Programming in C: A Case Study

Git and Kernel Linux

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# Introduction

# OO Techniques in non-OO Languages

**Motivation:** Combine good features of a language with good but absent techniques from other languages.

> *No programming technique solves all problems.*
> *No programming language produces only correct results.*
>
> *— Schreiner, Axel T (1993). Object-Oriented Programming With ANSI-C*

# Content

We'll see the following concepts implemented in C:

- Private attributes
- Private methods
- "Public" Inheritance
- "Private" Inheritance
- Multiple inheritance
- Abstract Classes and Polymorphism
- Metaprogramming
- Design Pattern: Iterator

In particular, we'll talk about implementation examples of these concepts in the **Git** and **Kernel Linux IIO** codebases.

# Kernel Linux IIO

# Linux IIO

- `iio_dev`: Industrial Input/Output Device
- `ad7780_state`: Analog to Digital Sigma-Delta Converter Device


- `struct ad7780_state` specialization of `struct iio_dev`.
- In other words, `ad7780_state` is a **subclass** of `iio_dev`.

# Inheritance

**Inheritance by composition**

Let $S$ be the superclass, and $C$ a subclass of $S$. Assume $n$ and $m$, $S$ and $C$'s memory size in bytes. We create an object of $C$ in the following way:

1. Allocate a block $B$ of size $n + m + a$ (in bytes);
2. Save first $n$ bytes $[0, n]$ for $S$;
3. Save last $m$ bytes $[n + a, n + a + m]$ for $C$;
4. Return a pointer to block $B$ of type $*S$.

$C$ is now a "private" object of $S$.

# Inside the Kernel

## Definitions

$S :=$ `iio_dev`

$C :=$ `ad7780_state`

$n :=$ `sizeof(struct iio_dev)`

$m :=$ `sizeof(struct ad7780_state)`

Function `devm_iio_device_alloc` allocs block $B$ and returns a pointer `struct iio_dev*` to the beginning of the block.

- `drivers/iio/adc/ad7780.c:ad7780_state`
- `include/linux/iio/iio.h:iio_dev`

# Access to the subclass

How to access *c* from an *s* pointer given the address of a block *B*?

```
#define ALIGN(x, a) ALIGN_MASK(x, (typeof(x))(a)-1)
#define ALIGN_MASK(x, mask) (((x) + (mask)) & ~(mask))
#define ALIGN_BYTES CACHE_BYTES_IN_POWER_OF_2

static inline void *priv(const struct S *s) {
  /* Returns a pointer to c "hidden" in s. */
  return (char*) s + ALIGN(sizeof(struct S), ALIGN_BYTES);
}
```

- `include/linux/kernel.h:ALIGN`
- `include/linux/iio/iio.h:iio_priv`
- `include/uapi/linux/kernel.h:__ALIGN_KERNEL_MASK`

# Understanding `ALIGN`

`ALIGN` is a function parameterized by the size of $S$ and some power of two.

**Recall from CS101...**

Access to memory is faster when address is a power of two.

We want to access an address of the alloc'ed memory somewhere near `s+sizeof(S)`, and it must be a power of two.
(see next slide)

**Claim**

`ALIGN(x, a)` is **the smallest multiple of** `a` **greater than** `x`.

`ad7780_state* = priv(iio_dev*) = iio_dev* + ALIGN(...)`

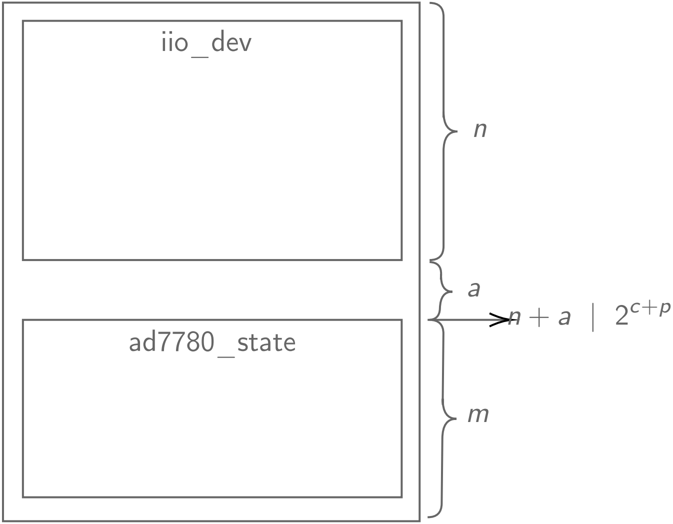



Figure: “Private” inheritance. Given `iio_dev*`, how do we find `ad7780_state*` in a fast, memory efficient way?

## Lemma 1

*Let* $n, m \in \mathbb{Z}_k$*, st* $m = 2^c - 1$ *for some* $c \in \mathbb{N}, c < k$*. Then*

$$(n + m) \ \& \ \sim (m) \mid 2^{c+p}, \text{ for some } p \in \mathbb{N}.$$

**Proof.**

First note that $m = 2^c - 1 = (0 \dots 01 \dots 1)_2$, so $(\sim m) = (1 \dots 10 \dots 0)_2$. Therefore $(n + m) \ \& \ \sim (m)$ are the most significant bits of $n + 2^c - 1$ starting from the $c$-th bit. But that's exactly taking $n + m$ and "subtracting" all the least significant bits starting from $c - 1$. More formally,

$$(n + m) \ \& \ \sim (m) = (n + m) - ((n + m) \ \& \ (2^c - 1)).$$

The right-hand term on the right side of the equality can be rewritten as

$$((n+m)\ \&\ (2^c-1)) \equiv (n+m) \mod 2^c.$$

In other words, taking the $c-1$ least significant bits is equivalent to taking the remainder of the division by $2^c$. To give some intuition, note that the $2^i$ bits for all $i > c$ are all multiples of $2^c$, and therefore equivalent to zero. From that

$$\begin{aligned}(n+m)\ \&\ \sim(m) &= (n+m) - ((n+m) \mod 2^c)\\ &= (n+2^c-1) - ((n+2^c-1) \mod 2^c)\\ &= (n+2^c-1) - ((n-1) \mod 2^c).\end{aligned}$$

If $n < 2^c$, then $(n+2^c-1) - n + 1 = 2^c \mid 2^c$ and therefore the hypothesis is trivially true. The same can be said when $n = 2^c$. Now, assuming $n > 2^c$, let's analize the two possible cases for $n$.

**Case 1:** $2^c \mid n$

$$\begin{aligned}(n+m) \mathbin{\&} \sim(m) &= (n+2^c-1) - ((n-1) \mod 2^c) \\ &= (n+2^c-1)+1 \\ &= (n+2^c) \mid 2^{c+p}. \quad \text{(by assumption)}\end{aligned}$$

**Case 2:** $2^c \nmid n$

$$\begin{aligned}(n+m) \mathbin{\&} \sim(m) &= (n+2^c-1) - ((n-1) \mod 2^c) \\ &= (n-r+r+2^c-1) - ((r-1) \mod 2^c),\end{aligned}$$

where $r = n \mod 2^c$, that is, the "remainder" of $n/2^c$.

We get two subcases: when $0 \equiv r - 1 \mod 2^c$, and thus

$$\begin{aligned}(n + m) \ \& \ \sim (m) &= (n + 2^c - 1) - ((r - 1) \mod 2^c) \\ &= (n - r + r + 2^c - 1) \\ &= ((n - r) + (r - 1) + 2^c) \mid 2^{c+p},\end{aligned}$$

Note that $n - r = 2^c$, since $r = n \mod 2^c$; and $r - 1 = 0$, as $r \equiv 1 \mod 2^c$ and $r < 2^c$ by definition. This means $(n - r) + (r - 1) = 2^c$, and thus $(2^c + 2^c) = 2^{c+1} \mid 2^{c+p}$.

Finally, we analyze the last case: $0 \not\equiv r - 1 \mod 2^c$. In this subcase, since $r < 2^c$, $(r - 1 \mod 2^c) = r - 1$ so:

$$\begin{aligned}
(n + m) \,\&\, \sim (m) &= (n + 2^c - 1) - ((r - 1) \mod 2^c) \\
&= (n - r + r + 2^c - 1) - r + 1 \\
&= ((n - r) + 2^c) \mid 2^{c+p}.
\end{aligned}$$

And therefore $(n + m) \,\&\, \sim (m) \mid 2^{c+p}$, for some integer $p$. $\square$

### Lemma 2

*Let $n, m \in \mathbb{Z}_k$, st $m = 2^c - 1$ for some $c \in \mathbb{N}, c < k$. Then*

$$t = (n + m) \ \& \ \sim (m)$$

*Is the smallest multiple of $2^c$ greater than $n$.*

**Proof.**

We will show by exaustion that $t$ is in fact the minimum candidate multiple of $2^c$ with respect to $n$. Recall the cases shown in Lemma 1's proof. When $n < 2^c$,

$$\begin{aligned}
(n + m) \ \& \ \sim (m) &= (n + 2^c - 1) - ((n - 1) \mod 2^c) \\
&= n + 2^c - 1 - n + 1 \\
&= 2^c = t
\end{aligned}$$

and therefore $t$ is the smallest multiple of $2^c$ greater than $n$.

For $n = 2^c$,

$$\begin{aligned}(n+m)\ \&\ \sim(m) &= (n + 2^c - 1) - ((n-1) \mod 2^c) \\ &= 2^c + 2^c - 1 + 1 \\ &= 2^c + 2^c = t,\end{aligned}$$

again $t$ is the "minimum" multiple. Recall the two cases when $n > 2^c$.

**Case 1:** $2^c \mid n$

$$\begin{aligned}(n+m)\ \&\ \sim(m) &= (n + 2^c - 1) - ((n-1) \mod 2^c) \\ &= (n + 2^c - 1) + 1 \\ &= n + 2^c = t\end{aligned}$$

If $n$ is a multiple of $2^c$, then the next multiple greater than $n$ is $n + 2^c$.

**Case 2:** $2^c \nmid n$

When $0 \equiv r - 1 \mod 2^c$, $r = 1$, since $r < 2^c$ by definition.

$$\begin{aligned}(n+m) \ \& \ \sim(m) &= (n + 2^c - 1) - ((r-1) \mod 2^c) \\ &= n - 1 + 2^c = t\end{aligned}$$

But if $r = 1$, then $n - 1$ is a multiple of $2^c$, and therefore the smallest multiple greater than $n$, which is exactly $n - 1 + 2^c$.

For the last subcase, take $0 \not\equiv r - 1 \mod 2^c$. Then

$$\begin{aligned}(n+m) \ \& \ \sim(m) &= (n + 2^c - 1) - ((r-1) \mod 2^c) \\ &= (n - r + r + 2^c - 1) - r + 1 \\ &= n - r + 2^c. = t\end{aligned}$$

Again, $n - r$ is a multiple of $2^c$ by definition, and therefore the next candidate is $n - r + 2^c$. $\square$

**Claim**

`ALIGN(x, a)` is **the smallest multiple of** `a` **greater than** `x`.

Our claim, but fancier:

**Theorem 3**

*The function* `ALIGN(sizeof(struct S), ALIGN_BYTES)` *returns the smallest address of memory multiple of* `ALIGN_BYTES` *greater than* `sizeof(struct S)`*.*

**Proof.**

Follows directly from Lemma 1 and Lemma 2.

□

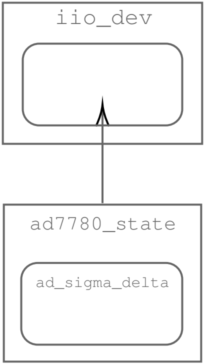
# ALIGN in the wild

```
static int ad7780_probe(struct spi_device *spi) {
  struct ad7780_state *st;
  struct iio_dev *indio_dev;

  indio_dev = devm_iio_device_alloc(&spi->dev, sizeof(*st));
  if (!indio_dev) return -ENOMEM;

  st = iio_priv(indio_dev);
  st->gain = 1;
  ...
}
```

- drivers/iio/adc/ad7780.c:ad7780_probe

# Multiple inheritance

- `ad7780_state` child of `iio_dev` (**“private” inheritance**);
- `ad7780_state` child of `ad_sigma_delta` (**“public” inheritance**).




Both use inheritance by composition, but in different ways.

# “Public” vs “private” inheritance

## Private inheritance

As seen on `iio_dev` and `ad7780_state`.

- Subclass attributes are private;
- Runtime inheritance;
- Subclass could be of any type (`ad7780_state`, `ad7793_state`, `mcp3422`, etc).

We shall now see “public” inheritance.

## Public inheritance

To be seen on `ad_sigma_delta` and `ad7780_state`.

- Attributes of superclass and subclass are public;
- Compile-time inheritance;

`ad_sigma_delta`: Analog-Digital Sigma-Delta Converter (ADSD)
`ad7780_state`: ADSD Converter for AD7170/1 and AD7780/1

```
struct ad7780_state {
  const struct ad7780_chip_info *chip_info;
  struct regulator *reg;
  struct gpio_desc *powerdown_gpio;
  ...
  unsigned int int_vref_mv;

  struct ad_sigma_delta sd;
}
```

In private inheritance, the **superclass (**`iio_dev`**) contains the subclass (**`ad7780_state`**)**.

In public inheritance, the **subclass (**`ad7780_state`**) contains the superclass (**`ad_sigma_delta`**)**.

# Access to the subclass

How to access object *c* of subclass *C* when object *s* of type *S* is *inside C*?

```
#define container_of(ptr, type, member) \
  (type*)((void*)(ptr) - ((size_t)&((type*)0)->member)

static struct ad7780_state *ad_sigma_delta_to_ad7780(
  struct ad_sigma_delta *sd) {
    return container_of(sd, struct ad7780_state, sd);
}
```

- `drivers/iio/adc/ad7780.c:ad_sigma_delta_to_ad7780`
- `include/linux/kernel.h:container_of`
- `include/linux/stddef.h:offsetof`

# Understanding container_of

We want to access the "outer" pointer, that is, find the pointer `struct ad7780_state*` that contains `struct ad_sigma_delta*`.

```
#define container_of(ptr, type, member) \
  (type*)((void*)(ptr) - ((size_t)&((type*)0)->member)

static struct ad7780_state *ad_sigma_delta_to_ad7780(
  struct ad_sigma_delta *sd) {
    return container_of(sd, struct ad7780_state, sd);
}
```

## Trick

`&((type*)0)->member`: returns the address of `member` as if `type*` were allocated to the zero-address. In other words, the size (in bytes) of `type` *up to* variable `member`. (see next slide)

```
container_of(p, C, p)=(C*)((void*)p-((size_t)&((C*)0)->p))
```

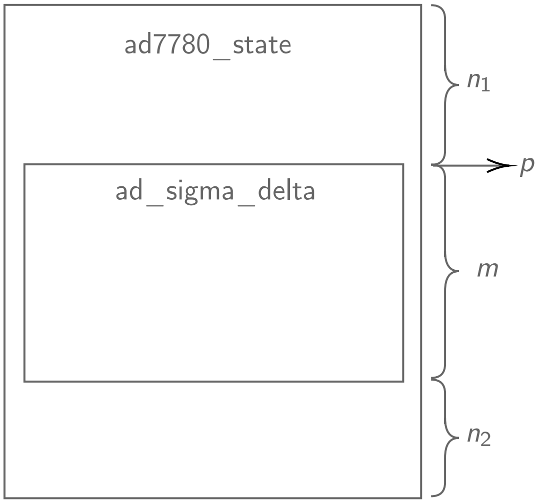



Figure: “Public” inheritance. Given `ad_sigma_delta*`, how do we find `ad7780_state*`?

# Summary

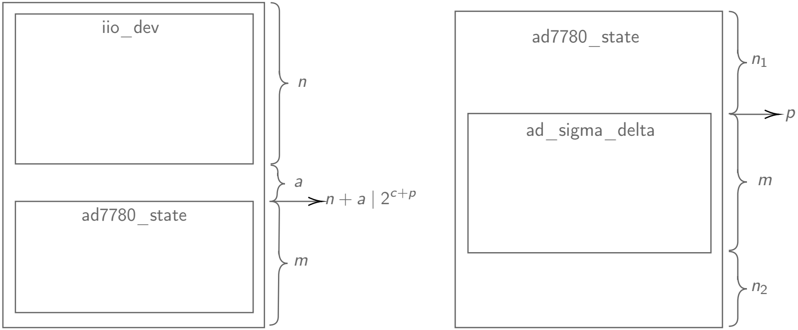



Figure: Different approaches for different uses. Which one is better? Depends on what you need.

# Git

# The dir-iterator object

Usage example (simplified):

```
struct dir_iterator *iter = dir_iterator_begin(path);

while (dir_iterator_advance(iter) == ITER_OK) {
  if (want_to_stop_iteration()) {
    dir_iterator_abort(iter);
    break;
  }

  // Access information about the current path:
  if (S_ISDIR(iter->st.st_mode))
    printf("%s is a directory\n", iter->relative_path);
}
```

# API: public attributes and methods

```c
// The current iteration state, with path,
// basename and etc.
struct dir_iterator {
  struct strbuf path;
  const char *relative_path;
  const char *basename;
  struct stat st;
};

struct dir_iterator *dir_iterator_begin(const char *path);
int dir_iterator_abort(struct dir_iterator *iterator);
int dir_iterator_advance(struct dir_iterator *iterator);
```

- dir-iterator.h

# Full declaration and constructor

```
struct dir_iterator_int {
  struct dir_iterator base;

  size_t levels_nr;
  size_t levels_alloc;
  struct dir_iterator_level *levels;
};
```

```
struct dir_iterator {
  struct strbuf path;
  const char *relative_path;
  const char *basename;
  struct stat st;
};
```

```
struct dir_iterator *dir_iterator_begin(const char *path) {
  struct dir_iterator_int *iter = xcalloc(1, sizeof(*iter));
  struct dir_iterator *dir_iterator = &iter->base;
  ... /* Initialize fields. */
  return dir_iterator;
}
```

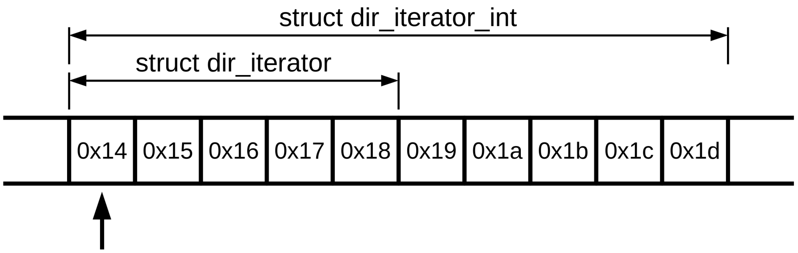
- dir-iterator.c

# How to access private attributes?

```
int dir_iterator_advance(struct dir_iterator *dir_iterator)
{
        struct dir_iterator_int *iter =
                (struct dir_iterator_int *)dir_iterator;
        // Use iter as needed
        ...
}
```

- dir-iterator.c

# Private attributes: how it works




- Use this technique with caution:
  - `memcpy` and others:
    `sizeof(struct dir_iterator) != sizeof(struct dir_iterator_int)`
  - arrays and initializations out of `dir_iterator_begin()`

# What about private methods?

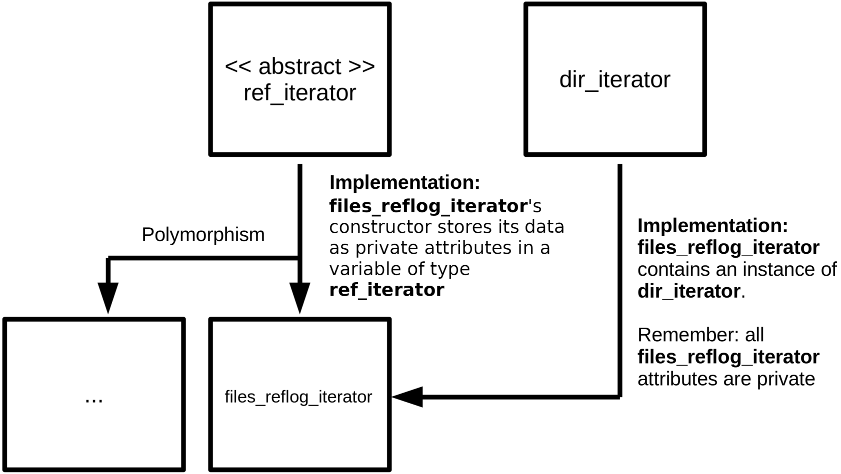
```
int dir_iterator_advance(struct dir_iterator *dir_iterator)
{
        struct dir_iterator_int *iter =
                (struct dir_iterator_int *)dir_iterator;

        if (/* ... */ && push_level(iter))
        ...
}

static int push_level(struct dir_iterator_int *iter)
{
        // Use iter as needed
}
```

- dir-iterator.c

# Abstract classes, inheritance and polymorphism

- `refs/refs-internal.h`
- `refs/iterator.c`
- `refs/files-backend.c`

# *Big picture*



<< abstract >>
ref_iterator
dir_iterator
Implementation:
files_reflog_iterator's constructor stores its data as private attributes in a variable of type ref_iterator
Polymorphism
Implementation:
files_reflog_iterator contains an instance of dir_iterator.
Remember: all files_reflog_iterator attributes are private
...
files_reflog_iterator

# The abstract class ref_iterator

```
struct ref_iterator {
        struct ref_iterator_vtable *vtable;

        unsigned int ordered : 1;
        const char *refname;
        const struct object_id *oid;
        unsigned int flags;
};
```

- refs/refs-internal.h

# ref_iterator: abstract methods

```
int ref_iterator_advance(struct ref_iterator *ref_iterator)
{
        return ref_iterator->vtable->advance(ref_iterator);
}

int ref_iterator_abort(struct ref_iterator *ref_iterator)
{
        return ref_iterator->vtable->abort(ref_iterator);
}
```

- refs/iterator.c

# The sub-class reflog_iterator

```
static struct ref_iterator *reflog_iterator_begin(struct ref_store *
                                                  ref_store,
                                                  const char *gitdir)
{
        struct files_reflog_iterator *iter = xcalloc(1, sizeof(*iter));
        struct ref_iterator *ref_iterator = &iter->base;
        struct strbuf sb = STRBUF_INIT;

        base_ref_iterator_init(ref_iterator,
                               &files_reflog_iterator_vtable, 0);
        strbuf_addf(&sb, "%s/logs", gitdir);
        iter->dir_iterator = dir_iterator_begin(sb.buf);
        iter->ref_store = ref_store;
        strbuf_release(&sb);

        return ref_iterator;
}
```

- refs/files-backend.c

# Multiple inheritance

```
static int files_reflog_iterator_advance(struct ref_iterator *ref_iterator)
{
	struct files_reflog_iterator *iter =
		(struct files_reflog_iterator *)ref_iterator;
	struct dir_iterator *diter = iter->dir_iterator;
	int ok;

	while ((ok = dir_iterator_advance(diter)) == ITER_OK) {
		int flags;
	...
}
```

- `refs/files-backend.c`

# “Metaprogramming” in Git

# Metaprogramming

```
#include "cache.h"
...

define_commit_slab(blame_suspects, struct blame_origin *);
static struct blame_suspects blame_suspects;
```

- blame.c

# Metaprogramming

```
#define define_commit_slab(slabname, elemtype)   \
        declare_commit_slab(slabname, elemtype); \
        implement_static_commit_slab(slabname, elemtype)
```

- commit-slab.h

# Metaprogramming

```
#define declare_commit_slab(slabname, elemtype) \
                                                \
struct slabname {                               \
        unsigned slab_size;                     \
        unsigned stride;                        \
        unsigned slab_count;                    \
        elemtype **slab;                        \
}
```

- `commit-slab-decl.h`

# Metaprogramming

```
#define implement_static_commit_slab(slabname, elemtype) \
        implement_commit_slab(slabname, elemtype, MAYBE_UNUSED static)

#define implement_commit_slab(slabname, elemtype, scope)       \
                                                               \
scope void init_ ##slabname## _with_stride(struct slabname *s, \
                                           unsigned stride)    \
{                                                              \
        unsigned int elem_size;                                \
        if (!stride)                                           \
                stride = 1;                                    \
                ...                                            \
}                                                              \
...
```

- `commit-slab-impl.h`

# Questions?

# References I


- Git.
  URL: https://git.kernel.org/pub/scm/git/git.git.
- Industrial input/output linux kernel subsystem.
  URL: https://git.kernel.org/pub/scm/linux/kernel/git/jic23/iio.git/.
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