(Advanced) C++ Design Patterns

C++ User Group Frankfurt

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Introduction

- Computer scientist (about 13 years work experience) working as an independent Software Consultant in last years
- Mainly in the following areas
  - Computer Vision / Image Processing
  - Machine Learning / Deep Learning
  - Mobile Computing / Embedded
  - Software Architecture / Build Systems / DevOps
  - Performance Optimizations
- Clients coming from a wide range of sectors such as
  - Automotive
  - Technology provider
  - Medicine
  - Startups
  - B2B, Software companies in general

Outline of this talk

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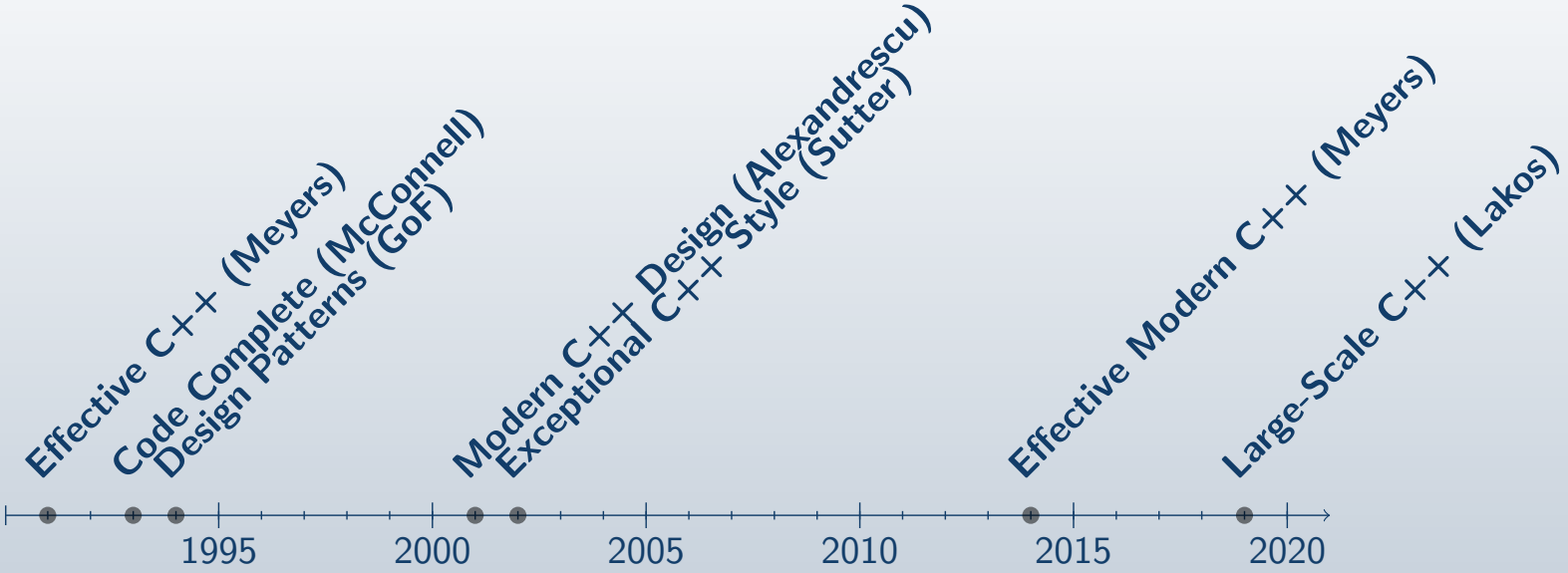
  - Observer, Command, Visitor (Hey compiler hackers), ...
- No **in-depth** review of existing/well-established solutions
- Rather an overview with applicable examples
- Approaches that seem to work in production code (based on my project experience)

Once upon a time



Preamble

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- Design patterns describe working, reusable solutions to common software programming problems
- There exist patterns for recurring problems on different parts of software development
  - resource management, container, concurrency, architecture, distribution, ...
- This talk will only cover some topics on interface design and modularization

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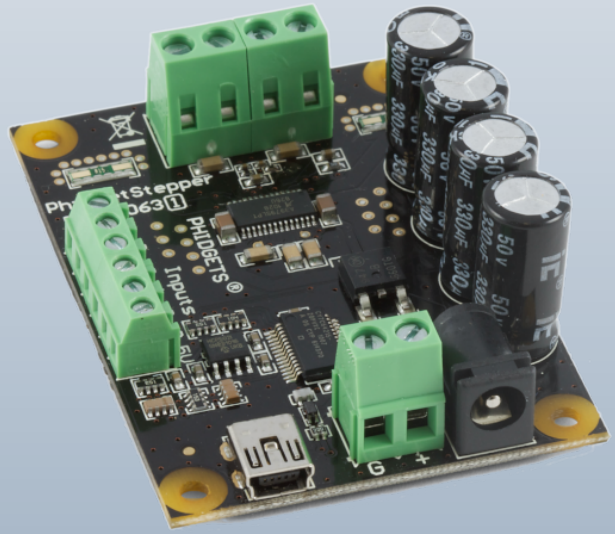
- What exactly *is* a data type?
  - a set of compile-time properties for an object:
    - size and alignment
    - set of valid values
    - set of permitted operations
- We can *exploit* this for constraining our software system under development

Motivating example

Context

In embedded development, hardware is typically controlled (nowadays) via so called memory-mapped devices. Hardware is controlled by flipping bits (register) on certain memory addresses.



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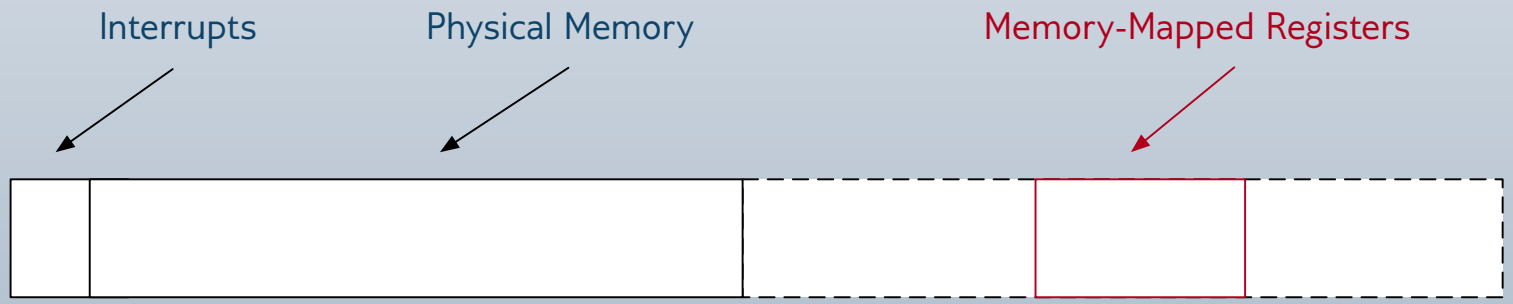
```
#define STROBE1 ((device_reg *)0x1500)
#define STROBE2 ((device_reg *)0x1504)
```



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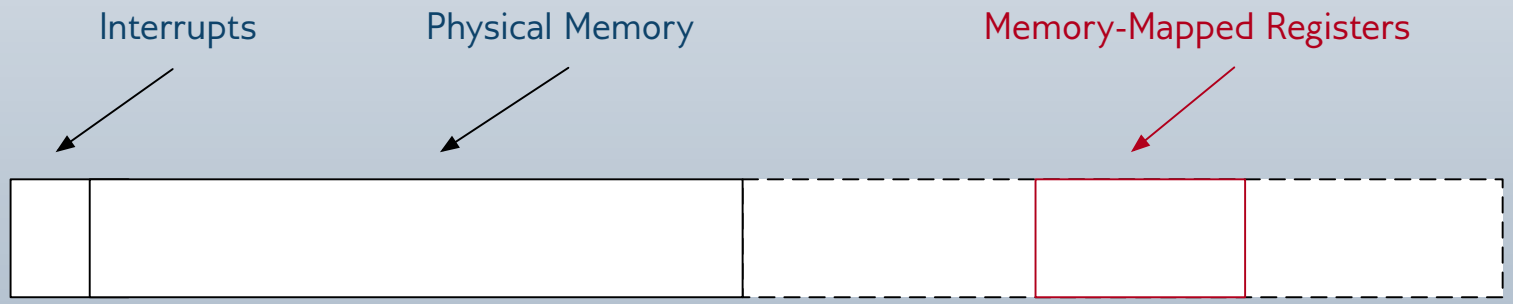

- Modifying the hardware consists of bit shuffling on this particular address:

```
*STROBE1 |= 3;
```

Motivating example (cont.)

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  - False read/writes can be a happy source of debugging

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- This is prone to errors:
  - Often there are registers that are **only** supposed to be read from
  - While other registers are supposed to be write-only
  - False read/writes can be a happy source of debugging
- We want to reduce the number of potential errors by making use of the type system to constrain access to those memory-mapped devices

Motivating example

```
template <typename t>
class WriteOnly {
  public:
    WriteOnly() = default;
    WriteOnly(const t &val) : val_(val) {}
    void operator=(const t &val) { val_ = val; }
    WriteOnly(const WriteOnly &) = delete;
    WriteOnly &operator=(const WriteOnly &) = delete;

  private:
    t val_;
};
```

[0] code::dive conference 2015 - Dan Saks - Sooner rather than later

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Works as advertised

```
WriteOnly<int> strobe(17);
strobe = 23; // assignment works
int foo = strobe; // does not compile
```

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Motivating example

```
template <typename t>
class ReadOnly {
  public:
    ReadOnly() = default;
    ReadOnly(const t &val) : val_(val) {}
    operator const t &() const { return val_; }
    const t *operator&() const { return &val_; }
    ReadOnly(const ReadOnly &) = delete;
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Works as advertised

```
ReadOnly<int> polarity(23);
polarity = 17; // does not compile
int bar = polarity; // reading works
polarity = 23; // does not compile
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- This comes with a (huge) runtime cost:
  - Additional pointer stored per object (8 bytes per object)
  - Extra indirection through pointer deference for each invocation of a virtual method
  - Those virtual methods can hardly be inlined

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- In recent years, compilers ship with a *devirtualization* optimization
  - If an actual type at call site can be determined already at compile-time dynamic dispatch will be resolved statically
  - In my benchmarks, this only works for the simplest cases (and even then not reliably)

Curiously Recurring Template Pattern (CRTP)

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  - Polymorphism provides a single interface or contract for different types
  - CRTP is not related to any interface but a design technique to aid implementation

Curiously Recurring Template Pattern (CRTP)

Motivating Example

```
struct Point {
    explicit Point(int x, int y) : x(x), y(y) {}
    bool operator==(const Point& other) const {
        return x == other.x && y == other.y;
    }
    bool operator!=(const Point& other) const {
        return !(*this == other);
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    int x{0}, y{0};
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struct Rect {
    explicit Rect(int x, int y, int w, int h) : x(x), y(y), w(w), h(h) {}
    bool operator==(const Rect& other) const {
        return x == other.x && y == other.y && w == other.w && h == other.h;
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    int x{0}, y{0}, w{0}, h{0};
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Curiously Recurring Template Pattern (CRTP)

Reducing boilerplate

```cpp
template <typename T>
struct Inequality {
    bool operator!=(const T& other) const {
        const auto& derived = static_cast<const T&>(*this);
        return !(derived == other);
    }
};
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struct Point : public Inequality<Point> {
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struct Rect : public Inequality<Rect> {
    explicit Rect(int x, int y, int w, int h) : x(x), y(y), w(w), h(h) {}
    bool operator==(const Rect& other) const {
        return x == other.x && y == other.y && w == other.w && h == other.h;
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    int x{0}, y{0}, w{0}, h{0};
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- Inflexible as we cannot inject further implementation
- Impossible to add additionals to `Point` or `Rect`, e.g. object counter using CRTP

```
template <typename>
struct ObjCounter {
    ObjCounter() { ++size; }
    ObjCounter(const ObjCounter&) { ++size; }
    ~ObjCounter() { --size; }
    static std::size_t size;
};
template <typename T> std::size_t ObjCounter<T>::size = 0;
```

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- With this, `Point` can be specified more freely, e.g.

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Point<ObjCounter> pt1;
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- What about injecting *more than one* features at compile-time?

```
Point<ObjCounter, Inequality, Singular> pt3; // ?
```

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Variadic CRTP

- Using variadic template template parameter packs, we can inject several compile-time features at once
- Interface for `Point` v3

```
template<template <typename> class... Feature>
struct Point : public Feature<Point<Feature...>>... {};
```

- This works now

```
Point<ObjCounter, Inequality> pt3;
```

Variadic CRTP

Motivating example

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We want to implement something as follows:

```
using MyIODevice = IODevice<PullBasedProcessing>;

MyIODevice device;
device.start();
device.process(io_calback);
device.wait();
...
```

Variadic CRTP

Motivating example (Cont.)

Variadic template template parameter packs to the rescue

```
template <template <typename> class... Feature>
struct IODevice : public Feature<IODevice<Feature...>>... {
  void start() {}
  void stop() {}
  ...
};

using Callback = std::function<void()>;

// Typically on any modern desktop system
template <typename T>
struct PushBasedProcessing {
  void connect(Callback&& io_cb) {}
};

// Typically on embedded, where we need to control everything ourselves
template <typename T>
struct PullBasedProcessing {
  void wait() {}
  void process(Callback&& io_cb) {}
};
```

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  - Thus, CRTP can be significantly more efficient than dynamic dispatch
  - Note that CRTP can be used to optimize both runtime performance as well as memory footprint
- Tradeoff between cognitive complexity and performance - productivity gain though
  - May or may not be justifiable depending on team and experience

Tag Dispatching

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- Several ways to call a function or construct object with same types of parameters
- A given tag type determines which overload ends up being called
- Technique used heavily inside STL (e.g. Iterators)

Tag Dispatching

Another motivating example

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Create function to calculate profit independent from the actual car vendor or model being used

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struct Tesla {
    int getFuelConsumption() const { return 0; }
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};


struct BMW {
    int getBarrelOfFuelPerMeter() const { return 42; }
    int getServiceCosts() const { return 33; }
};
```

Tag Dispatching

Implementation

Final dispatch function

```
template <typename T>
float calcProfit(const T& car) {
    return 17.4f * Profit<T>::output(car) / Profit<T>::input(car);
};
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};
```

Implementation details for each car

```
template <typename T>
struct Profit {};

template <>
struct Profit<Tesla> {
    static int input(const Tesla& t) { return t.getInsurancePrice(); }
    static int output(const Tesla& t) { return t.getFunFactor(); }
};

template <>
struct Profit<BMW> {
    static int input(const BMW& b) { return b.getBarrelOfFuelPerMeter(); }
    static int output(const BMW& b) { return b.getServiceCosts(); }
};
```

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- Since, this implementation relies on templates, the compiler can see the function definition and optimize accordingly
- Generally speaking, we are paying with additional compile time for the saved costs in runtime

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  - ...

Commercial Break

Available for consulting services, trainings and workshops. Feel free to contact me at www.kai-wolf.me

Thank you