C++ now

Newer Isn't Always Better

Investigating Legacy Design Trends and Their Modern Replacements

Katherine Rocha

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Investigating Legacy Design Trends and Their Modern Replacements

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About Me

- Software Engineer at Atomos Space
- Working in a C++20 Codebase with approximately 100,000 lines of C++
- Previously Worked in a 20+ Year Old Codebase
- “Software Historian/Genealogist”

Initial Discovery

- Understanding the past
- Investigating the new patterns with the same scrutiny as the old
- Tend to make our initial evaluation and stick with it
- Is it a Fad or is it good?

Investigative Process

Timeline

- When was the original trend introduced?
- When did the trend transition?

Original Trend

- What is the original trend?
- Why is it used?

New Trend

- What is the new trend?
- Why did it replace the original?

Original Code

- What is the original solution?
- How elegant is it?
- What are the problems with it?

New Code

- What is the new solution?
- How elegant is it?
- What are the problems with it?

Analysis

- Pros and Cons of the original trend
- Pros and Cons of the new trend
- Comparison of the trends

Global Interfaces/Global State

Use Cases

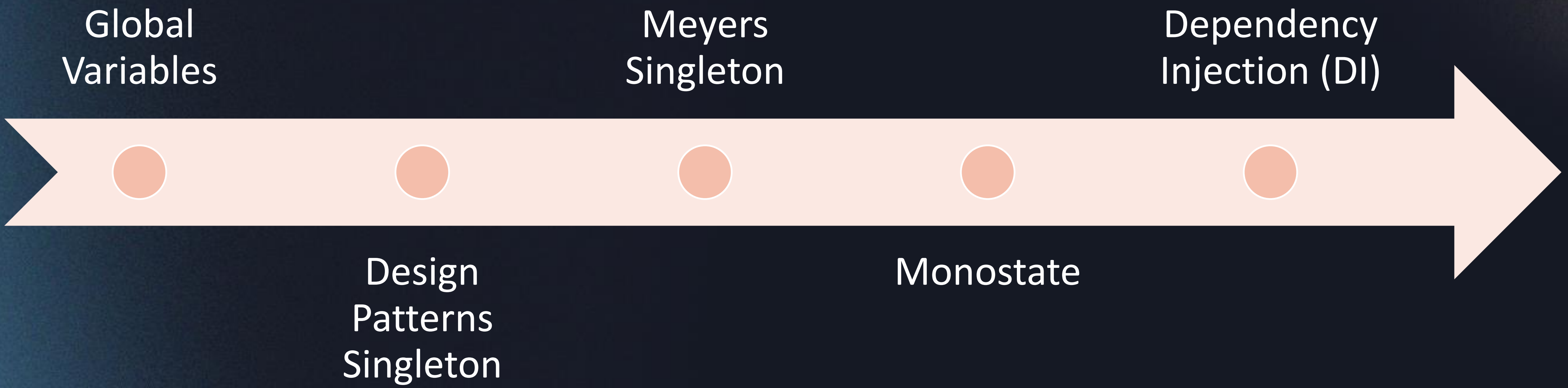
Global Interface

- Logging
- External I/O
- Resource Management
- Plotting

Global Data

- Initial Parameters
- State Parameters

Timeline


Global Variables
Design Patterns Singleton
Meyers Singleton
Monostate
Dependency Injection (DI)

Original Trend - Singleton

- Hold one copy of global data/interface and allow others access
- Usually accessed through a `getInstance()` or `Instance()` function
- Easily accessed
- Identifiable
- Hard to test
- Quintessentially Overused

Original Code – Design Patterns Singleton vs Meyers' Singleton

```cpp
class PlottingSingleton
{
    public:
        static PlottingSingleton* getInstance()
        {
            if (!instance) // race condition
                instance = new PlottingSingleton;
            return instance;
        }

        void plot(double x, double y)
        {
            // ...
        }

    protected:
        PlottingSingleton();

    private:
        inline static PlottingSingleton* instance {NULL};
};
```

```cpp
class PlottingSingleton
{
    public:
        static PlottingSingleton& getInstance()
        {
            static PlottingSingleton instance {};
            return instance;
        }

        void plot(double x, double y)
        {
            // ...
        }

    private:
        PlottingSingleton();
};
```

Original Code – Singleton Wrapper

```cpp
template <typename T>
class Singleton
{
    public:
        static T& getInstance()
        {
            static T instance;
            return instance;
        }

    private:
        Singleton();
};

class Plotting
{
    public:
        void plot(double x, double y)
        {
            // ...
        }
};

using PlottingSingleton = Singleton<Plotting>;
```

New Trend – Monostate

- Make every object in the class static
- Multiple objects all with the same value
- Easy to transition to multiple objects
- May not work well to replace interface singletons

New Code – Monostate

```cpp
class Plotting
{
    public:
        void plot(double x, double y)
        {
            // ...
        }
    private:
        static std::queue plottingQueue;
};
```

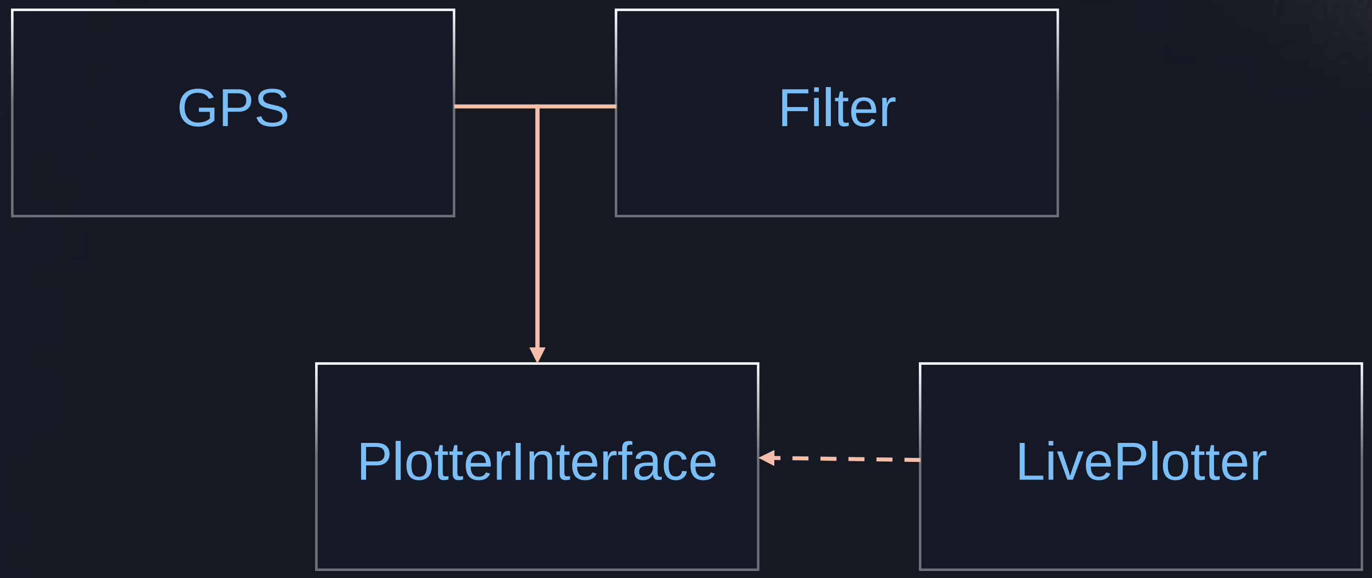
New Trend – Dependency Injection

- Not a global object
- Injects the dependency into each of the using objects

Aside: Dependency Injection (DI) Vs Dependency Inversion Principle (DIP)

Dependency Inversion Principle (DIP)

- Eliminates the dependency by inverting and adding an interface class
- Reduces volatility due to implementation
- Allows for testing and mocking



Dependency Injection (DI)

- Inject the dependency into the object
  - Injected 3 ways
    - Interface/Template Parameter Injection (Type 1)
    - Setter (Type 2)
    - Constructor (Type 3)
  - One Object being shared

New Code – Dependency Injection

```
class Plotting
{
    public:
        void plot(double x, double y)
        {
            // ...
        }
};

class Gps
{
    public:
        Gps(Plotting plotter&);
        void setPlotter(Plotting plotter&);
        void getPositionVelocityAcceleration(Plotting plotter&);
    private:
        Plotting& plotter;
};
```

Comparison

Singleton	Monostate	Dependency Injection (DI)
• Easy to Recognize • Easy Access	• Non-Intuitive Shared Access • Easy Transition to Individual Objects • Less Powerful than the Singleton?	• Explicit Access

SFINAE & Concepts

Use Case

- Function Requirements
- Breaking SOONER in compile time

Usage Example

Runge-Kutta 4 – approximate solution to nonlinear equations

```
inline constexpr double runge_kutta4(std::function<double(double, double)> fun,
                                     double time,
                                     double y0,
                                     double timestep)
{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}
```

```
double stateOut = common::math::runge_kutta4<double, double>(derivFun, currTime, stateIn, dt);
```

Usage Example Continued

```cpp
inline constexpr Eigen::Matrix<double, 1, 6> runge_kutta4(std::function<Eigen::Matrix<double, 1, 6>(double, Eigen::Matrix<double, 1, 6>)> fun,
                                                          double time,
                                                          Eigen::Matrix<double, 1, 6> y0,
                                                          double timestep)
{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}

Eigen::Matrix<double, 1, 6> stateOut = common::math::runge_kutta4<double, Eigen::Matrix<double, 1, 6>>(derivFun, currTime, stateIn, dt);
```

Usage Example Continued

```
template <typename Time, typename OutputType>
inline constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
                                         Time time,
                                         OutputType y0,
                                         Time timestep)
{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}

Eigen::Matrix<double, 1, 6> stateOut = common::math::runge_kutta4<double, Eigen::Matrix<double, 1, 6>>(derivFun, currTime,
stateInOut, dt);
```

Compiler Error Output

```
double stateOut = common::math::runge_kutta4<double, std::string>(fun, currTime, std::string(), dt);
```

```
[build] runge_kutta4.hpp:16:50: error: invalid operands to binary expression ('std::basic_string<char>' and 'double')
[build]    16 |     auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
[build]       |                                          ~~ ^ ~~~~~~~~~
[build] example.cpp:145:23: note: in instantiation of function template specialization 'common::math::runge_kutta4<double,
std::basic_string<char>>' requested here
[build]   145 |         common::math::runge_kutta4<double, std::string>(derivFun, currFiltTime, std::string(), dt);
[build]       |                       ^
[build] /usr/bin/../lib/gcc/x86_64-linux-gnu/12/../../../../include/c++/12/complex:392:5: note: candidate template ignored: could not
match 'complex' against 'basic_string'
[build]   392 |     operator*(const complex<_Tp>& __x, const complex<_Tp>& __y)
[build]       |     ^
[build] /usr/bin/../lib/gcc/x86_64-linux-gnu/12/../../../../include/c++/12/complex:401:5: note: candidate template ignored: could not
match 'complex' against 'basic_string'
[build]   401 |     operator*(const complex<_Tp>& __x, const _Tp& __y)
[build]       |     ^
[build] /usr/bin/../lib/gcc/x86_64-linux-gnu/12/../../../../include/c++/12/complex:410:5: note: candidate template ignored: could not
match 'complex<_Tp>' against 'double'
[build]   410 |     operator*(const _Tp& __x, const complex<_Tp>& __y)
[build]       |     ^
[build] example.cpp:144:12: error: no viable conversion from 'std::basic_string<char>' to 'double'
[build]   144 |     double stateOut =
[build]       |            ^
[build]   145 |         common::math::runge_kutta4<double, std::string>(derivFun, currFiltTime, std::string(), dt);
[build]       |         ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[build] /usr/bin/../lib/gcc/x86_64-linux-gnu/12/../../../../include/c++/12/bits/basic_string.h:944:7: note: candidate function
[build]   944 |       operator __sv_type() const noexcept
[build]       |       ^
[build] 2 errors generated.
```

Timeline

SFINAE

- ~2002

Type Traits Introduced

- C++11

Concepts

- C++20

Original Trend (SFINAE)

- Substitution Failure Is Not An Error
- Constraints on templates
- Known for difficult to read errors
- Difficult to constrain

Original Code - SFINAE

```
template <typename Time, typename OutputType, typename = std::enable_if_t<std::is_arithmetic_v<Time>>>
inline constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
                                         Time time,
                                         OutputType y0,
                                         Time timestep)
{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}
```

We also want to constrain OutputType…

Original Code – SFINAE Continued

```cpp
#include <boost/type_traits/has_operator.hpp>

template <typename Time,
          typename OutputType,
          typename = std::enable_if_t<std::is_arithmetic_v<Time>>,
          typename = std::enable_if_t<std::is_arithmetic_v<OutputType> ||
                                      (boost::has_multiplies<OutputType, Time>::value &&
                                       boost::has_plus<OutputType>::value)>>
inline constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
                                         Time time,
                                         OutputType y0,
                                         Time timestep)
{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}
```

Compiler Error Output

```
double stateOut = common::math::runge_kutta4<double, std::string>(fun, currTime, std::string(), dt);

[build] example.cpp:144:9: error: no matching function for call to 'runge_kutta4'
[build]   144 |         common::math::runge_kutta4<double, std::string>(fun, currTime, std::string(), dt);
[build]       |         ^~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[build] runge_kutta4.hpp:16:22: note: candidate template ignored: requirement 'std::is_arithmetic_v<std::basic_string<char,
std::char_traits<char>, std::allocator<char>>> || (boost::has_multiplies<std::basic_string<char, std::char_traits<char>,
std::allocator<char>>, double, boost::binary_op_detail::dont_care>::value && boost::has_plus<std::basic_string<char,
std::char_traits<char>, std::allocator<char>>, std::basic_string<char, std::char_traits<char>, std::allocator<char>>,
boost::binary_op_detail::dont_care>::value)' was not satisfied [with Time = double, OutputType = std::string, $2 =
std::enable_if_t<std::is_arithmetic_v<double>>]
[build]    16 | constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
[build]       |                      ^
```

New Trend (Concepts)

- Compile Time constraints
- Named set of requirements
- Improved compiler errors
- Easier to create custom constraints for

New Code - Concepts

```cpp
template<typename T>
concept arithmetic = std::integral<T> || std::floating_point<T>;

template <arithmetic Time, typename OutputType>
inline constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
                                         Time time,
                                         OutputType y0,
                                         Time timestep)
{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}
```

New Code – Concepts Continued

```
template<typename T>
concept arithmetic = std::integral<T> || std::floating_point<T>;

template<class T, typename Num>
concept add_multiply = requires(T t, Num num)
{
    t * num;
    t + t;
};

template <arithmetic Time, typename OutputType>
requires (add_multiply<OutputType, Time>)
inline constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
                                         Time time,
                                         OutputType y0,
                                         Time timestep)

{
    auto k1 = fun(time, y0);
    auto k2 = fun(time + timestep * 0.5, y0 + k1 * timestep * 0.5);
    auto k3 = fun(time + timestep * 0.5, y0 + k2 * timestep * 0.5);
    auto k4 = fun(time + timestep, y0 + k3 * timestep);

    return (y0 + (k1 + 2 * k2 + 2 * k3 + k4) * timestep / 6);
}
```

Compiler Error Output

```cpp
double stateOut = common::math::runge_kutta4<double, std::string>(derivFun, currTime, std::string(), dt);
```

```
[build] example.cpp:144:9: error: no matching function for call to 'runge_kutta4'
[build]   144 |         common::math::runge_kutta4<double, std::string>(derivFun, currTime, std::string(), dt);
[build]       |         ^~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[build] runge_kutta4.hpp:22:29: note: candidate template ignored: constraints not satisfied [with Time = double, OutputType =
std::string]
[build]    22 | inline constexpr OutputType runge_kutta4(std::function<OutputType(Time, OutputType)> fun,
[build]       |                             ^
[build] runge_kutta4.hpp:21:11: note: because 'add_multiply<std::basic_string<char>, double>' evaluated to false
[build]    21 | requires (add_multiply<OutputType, Time>)
[build]       |           ^
[build] runge_kutta4.hpp:16:7: note: because 't * num' would be invalid: invalid operands to binary expression
('std::basic_string<char>' and 'double')
[build]    16 |     t * num;
[build]       |       ^
[build] 1 error generated.
```

Comparison

SFINAE

- Hard to Read Error Messages
- Difficult to Make Complicated Checks

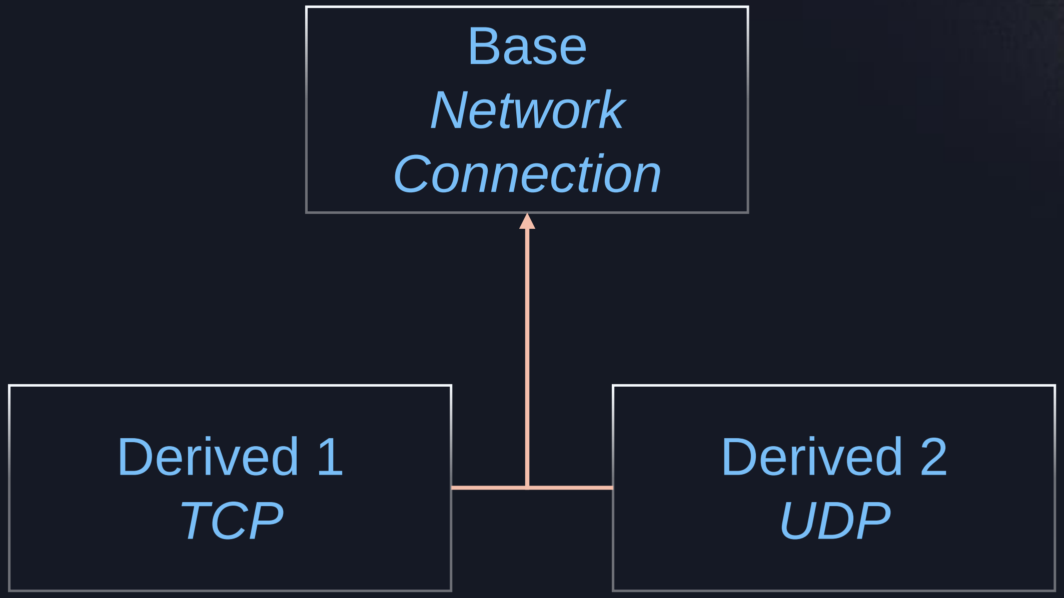
Concepts

- Replaced SFINAE
- Easy to Read Error Messages
- Easy to Make Custom Checks
- Easy to Read Checks

Polymorphism

Use Case

- One interface with multiple implementations
- Key Object-Oriented Design method
- Implementation for Don’t Repeat Yourself (DRY)



Timeline

Virtual Functions

- ~1986

Curiously Recurring Template Pattern (CRTP)

- ~1995

Deducing This

- C++23

Original Trend – Virtual Functions

- Run-Time Polymorphism
- Quintessential Object Oriented Method
- Overused

Original Code – Virtual Functions

```cpp
struct NetworkConnection
{
    virtual void initializeConfig() = 0; // Pure Virtual

    void init()
    {
        initializeConfig();
        // ...
    };
};
```

```cpp
struct Tcp : public NetworkConnection
{
    void initializeConfig() override
    {
        // ...
    }
};
```

```cpp
struct Udp : public NetworkConnection
{
    void initializeConfig() override
    {
        // ...
    }
};
```

New Trend – Curiously Recurring Template Pattern (CRTP)

- Compile Time Polymorphism
- Force a Downcast from the Parent to Access Child Elements
- Explicit Cast

New Code – CRTP

```
template <class derived>
class NetworkConnection
{
    public:
        void init()
        {
            (static_cast<derived*>(this))->initializeConfig();
            // ...
        };
};
```

```
class Tcp : public NetworkConnection<Tcp>
{
    public:
        void initializeConfig()
        {
            // ...
        }
};
```

```
class Udp : public NetworkConnection<Udp>
{
    public:
        void initializeConfig()
        {
            // ...
        }
};
```

New Trend – Deducing This

- C++23 Feature
- Simplifies Compile Time Polymorphism

New Code – Deducing This

```
struct NetworkConnection
{
    public:
        void init(this auto&& self)
        {
            self.initializeConfig();
            // ...
        };
};

class Tcp : public NetworkConnection
{
    public:
        void initializeConfig()
        {
            // ...
        }
};
```

```
class Udp : public NetworkConnection
{
    public:
        void initializeConfig()
        {
            // ...
        }
};
```

Multi-Level Inheritance – Virtual Attempt

```cpp
// https://godbolt.org/z/T51xE5qbK
struct NetworkConnection
{
    virtual void initializeConfig() = 0; // Pure Virtual

    void init()
    {
        initializeConfig();
        // ...
    };
};


struct Tcp : public NetworkConnection
{
    void initializeConfig() override
    {
        std::cout << "tcp\n";
        // ...
    }
};
```

```cpp
struct Session : public Tcp
{
    void initializeConfig() override
    {
        std::cout << "session\n";
        // ...
    }
};


int main()
{
    Tcp a;
    a.init();

    Session b;
    b.init();
}
```

Output of x86-64 clang (trunk) (Compiler #1)

A Wrap lines Select all

```
ASM generation compiler returned: 0
Execution build compiler returned: 0
Program returned: 0
 tcp
 session
```

Multi-Level Inheritance – CRTP Attempt

```cpp
#include <type_traits>

// https://godbolt.org/z/s3ed4Yorv
template <class derived>
struct NetworkConnection
{
    void init()
    {
        (static_cast<derived*>(this))->initializeConfig();
        // ...
    };
};

template <class T = void>
struct Tcp : public NetworkConnection<Tcp<T>>
{
    void initializeConfig()
    {
        std::cout << "tcp\n";
    }
};
```

```cpp
struct Session : public Tcp<Session>
{
    void initializeConfig()
    {
        std::cout << "session\n";
    }
};

int main()
{
    Tcp a;
    a.init();

    Session b;
    b.init();
}
```

Output of x86-64 clang (trunk) (Compiler #1)

A Wrap lines Select all

```
ASM generation compiler returned: 0
Execution build compiler returned: 0
Program returned: 0
 tcp
 tcp
```

Multi-Level Inheritance – Deducing This Attempt

```cpp
// https://godbolt.org/z/ccsoaf3ec
struct NetworkConnection
{
    void init(this auto&& self)
    {
        self.initializeConfig();
        // ...
    };
};

struct Tcp : public NetworkConnection
{
    void initializeConfig()
    {
        std::cout << "tcp\n";
        // ...
    }
};
```

```cpp
struct Session : public Tcp
{
    void initializeConfig()
    {
        std::cout << "session\n";
        // ...
    }
};

int main()
{
    Tcp a;
    a.init();

    Session b;
    b.init();
}
```

Output of x86-64 clang (trunk) (Compiler #1)

A Wrap lines Select all

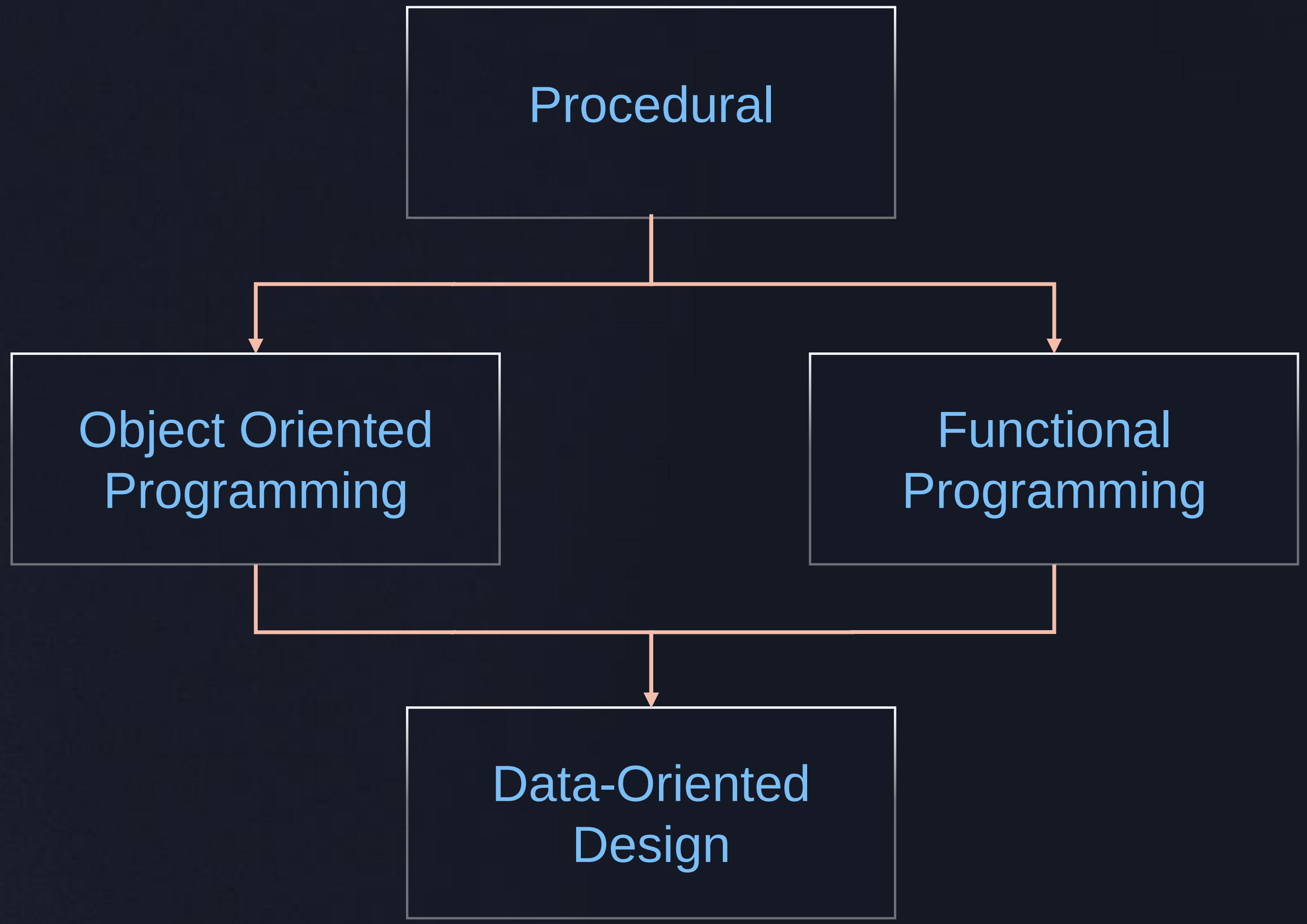
```
ASM generation compiler returned: 0
Execution build compiler returned: 0
Program returned: 0
 tcp
 session
```

Comparison

Virtual Polymorphism	CRTP	Deducing This
• Runtime Polymorphism • Easy to Read and Trace	• Compile Time Polymorphism • Harder to Read • Hard to Trace • Multi-Level Polymorphism is Difficult	• Compile Time Polymorphism • C++23 Feature • Hard to trace

Design Methodology

Flow of Design Methods



C++ Design Aims – From The Design and Evolution of C++

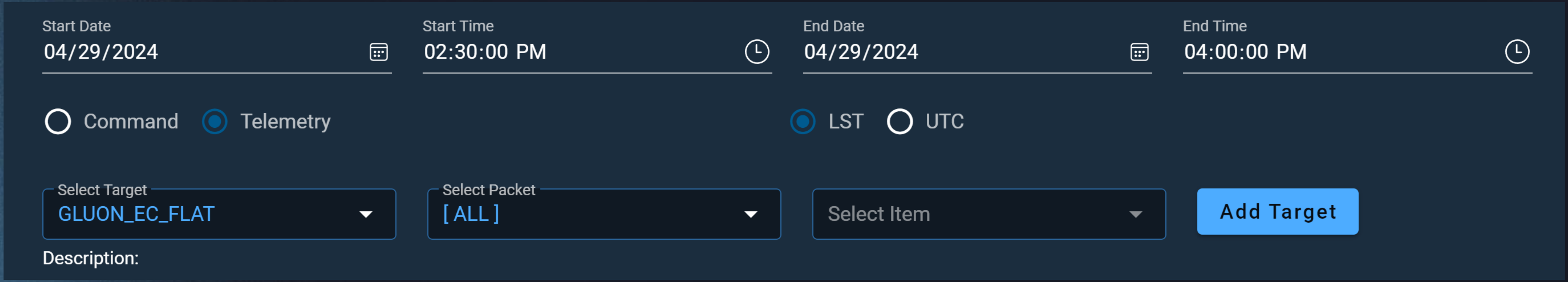
Aims:
C++ makes programming more enjoyable for serious programmers. C++ is a general-purpose programming language that – is a better C – supports data abstraction – supports object-oriented programming – supports generic programming

C++ Design Rules – From The Design and Evolution of C++

General rules:
C++'s evolution must be driven by real problems.
C++ is a language, not a complete system.
Don't get involved in a sterile quest for perfection.
C++ must be useful *now*.
Every feature must have a reasonably obvious implementation.
Always provide a transition path.
Provide comprehensive support for each supported style.
Don't try to force people.

Example Problem Space

- Extract all telemetry packets received during this talk
- Instantaneous and prolonged events



Procedural Programming

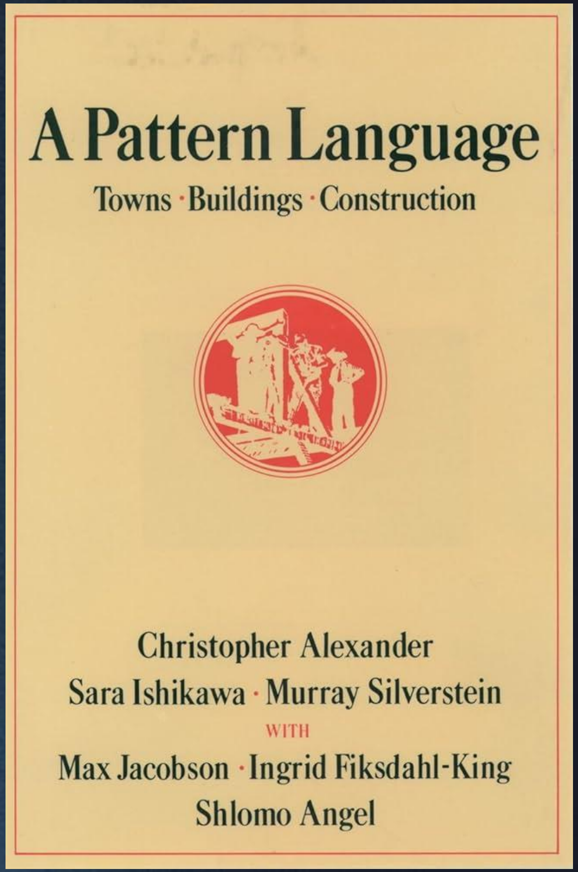
- Original Programming Style
- Think C not C++
- Do A then Do B then Do C

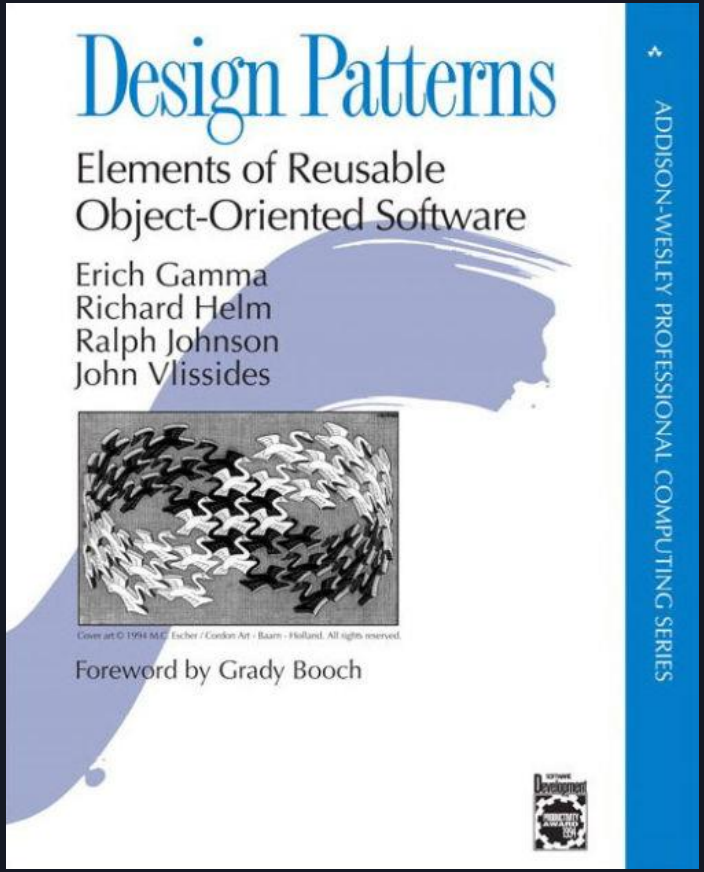
Procedural Programming Example

```cpp
struct Packet
{
    // ...
};

std::vector<Packet> telemetry = getTelemetry();

filterTelemetry(telemetry);
```

```cpp
std::vector<Packet> filterTelemetry(std::vector<Packet> telem)
{
    for (telemetry : telem)
    {
        if (telemetry.durationEvent)
        {
            // ...
        }
        else
        {
            // ...
        }
    }
}
```

Object Oriented Programing History





Note: SmallTalk (an OOP language) was invented before A Pattern Language was published

Common Object Oriented Patterns

- Creational Patterns
  - Factory
  - Builder
  - Prototype
  - Singleton
- Structural Patterns
  - Adapter
  - Bridge
  - Composite
  - Decorator
  - Façade
  - Flyweight
  - Proxy
- Behavioral Patterns
  - Chain of Responsibility
  - Command
  - InterpreterMediator
  - Memento
  - Observer
  - State
  - Strategy
  - Visitor

Object Oriented Programming

```
struct Packet
{
// ...
};

struct FilterTelemetryFacade
{
// ...
};

std::vector<Packet> telemetry = getTelemetry();

auto filter = FilterTelemetryFacade(telemetry);
std::vector<Packet> filter.getFilteredTelemetry();
```

Functional Programming History

- Lambda Calculus (1930s) by Alonzo Church
- Languages such as LISP and Haskell

Functional Patterns

- Functors
- Monads
- Applicatives

Functional Programming

```
struct Packet
{
    // ...
};

std::vector<Packet> telemetry = getTelemetry();

std::vector<Packet> filteredTelemetry;
```

```
auto filter = [](Packet telem)
{
    if (telemetry.durationEvent)
    {
        // ... Return true/false somewhere in here…
    }
    else
    {
        // ... Return true/false somewhere in here…
    }
}

std::copy_if(telemetry.begin(), telemetry.end(),
filteredTelemetry.begin(), filter);
```

Data-Oriented Design History

- Data-Oriented Design (Or Why You Might Be Shooting Yourself in The Foot With OOP) By Noel Llopis 2009
- Game Developer Perspective

Data-Oriented Design

```cpp
struct Packet
{
    // ...
};

std::vector<Packet> durationTelemetry = getDurationTelemetry();
std::vector<Packet> instantTelemetry = getInstantTelemetry();

filterDurationTelemetry(durationTelemetry);
filterInstantTelemetry(instantTelemetry);
```

```cpp
std::vector<Packet> filterDurationTelemetry(std::vector telem)
{
    for (telemetry : telem)
    {
        // ...
    }
}

std::vector<Packet> filterInstantTelemetry(std::vector telem)
{
    for (telemetry : telem)
    {
        // ...
    }
}
```

Pros and Cons

Procedural

- Simplistic
- Old
- Imperative
- Verbose

Object Oriented

- Colloquially Overused
- Heuristically Organize Data
- Pattern Based
- Prone to Anti-Patterns
- From Tony's talk this morning: "Objects are made of Velcro"

Functional

- Pure Functions
- Immutable Data
- Treat Functions as Data
- Describe the what not the how

Data-Oriented

- Hardware Oriented
- Performance Mindset
- Backwards to Traditional Thought

Other Potential Evaluations

- Union vs Variant
- Enum vs Enum Class
- Raw Pointers vs Reference vs Smart Pointers
- Raw Iterators vs Standard Algorithms
- C-Style Casts vs Fancy Casts (static, dynamic, reinterpret, const casts)
- Allocators vs PMR
- printf vs std::cout vs libfmt

Conclusion

- Newer Isn’t Always Better
- Consistently Reevaluate Alternatives
- Use Case Determines Usability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