Design Patterns in Modern C++

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What’s In This Talk?

- Examples of patterns and approaches in OOP design
- Adapter
- Composite
- Specification pattern/OCP
- Fluent and Groovy-style builders
- Maybe monad

Adapter

STL String Complaints

- Making a string is easy

```
string s{“hello world”};
```

- Getting its constituent parts is not

```
vector<strings> words;
boost::split(words, s, boost::is_any_of(“ “));
```

- Instead I would prefer

```
auto parts = s.split(“ “);
```

- It should work with “`hello           world`”
- Maybe some other goodies, e.g.
  - Hide `size()`
  - Have `length()` as a property, not a function

Basic Adapter

```
class String {
  string s;
public:
  String(const string &s) : s{ s } { }
};
```

Implement Split

```
class String {
  string s;
public:
  String(const string &s) : s{ s } { }
  vector<string> split(string input)
  {
    vector<string> result;
    boost::split(result, s,
      boost::is_any_of(input), boost::token_compress_on);
    return result;
  }
};
```

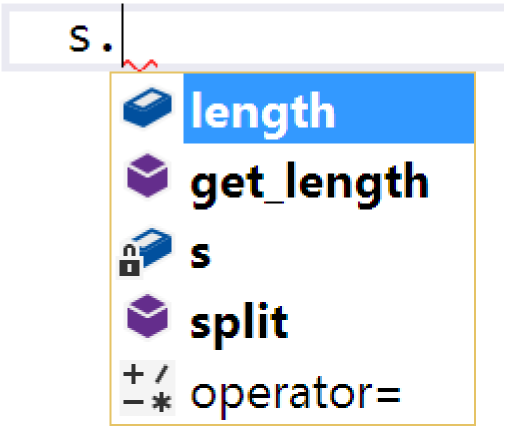
Length Proxying

```
class String {
  string s;
public:
  String(const string &s) : s{ s } { }
  vector<string> split(string input);
  size_t get_length() const { return s.length(); }
};
```

Length Proxying

```
class String {
  string s;
public:
  String(const string &s) : s{ s } { }
  vector<string> split(string input);
  size_t get_length() const { return s.length(); }

  // non-standard!
  __declspec(property(get = get_length)) size_t length;
};
```

String Wrapper Usage




```
String s{ "hello world" };
  cout << "string has " <<
    s.length << " characters" << endl;

  auto words = s.split(" ");
  for (auto& word : words)
    cout << word << endl;
```

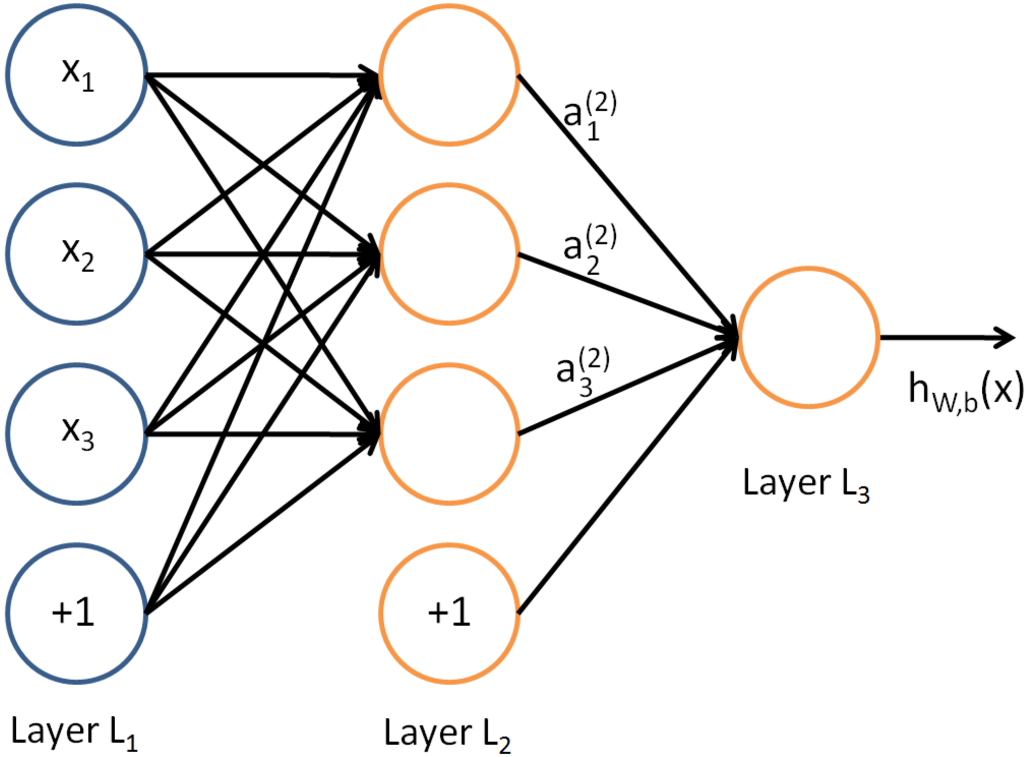
Adapter Summary

- Aggregate objects (or keep a reference)
- Can aggregate more than one
  - E.g., string and formatting
- Replicate the APIs you want (e.g., length)
- Miss out on the APIs you don't need
- Add your own features :)

Composite

Scenario

- Neurons connect to other neurons
- Neuron *layers* are collections of neurons
- These two need to be connectable



Scenario

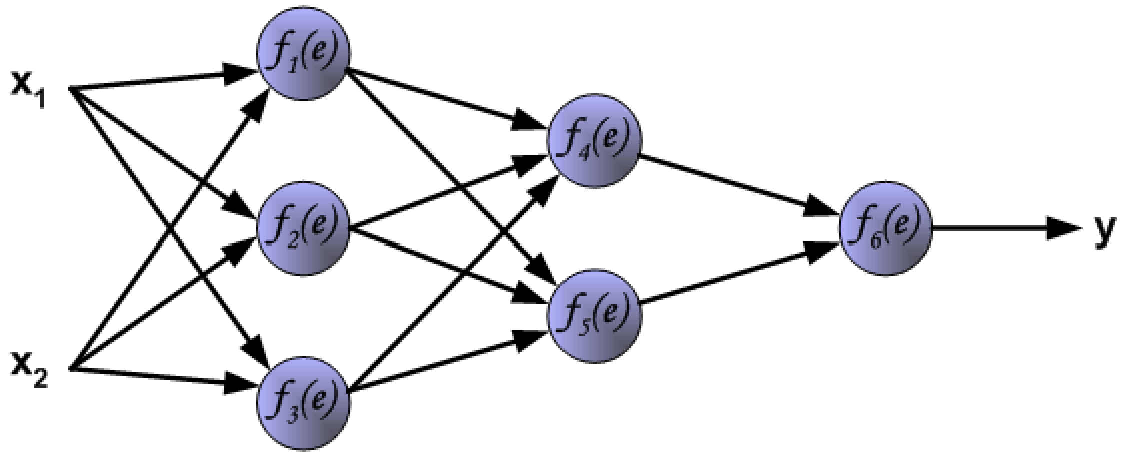
```
struct Neuron
{
  vector<Neuron*> in, out;
  unsigned int id;

  Neuron()
  {
    static int id = 1;
    this->id = id++;
  }
}
```

Scenario

```
struct NeuronLayer : vector<Neuron>
{
  NeuronLayer(int count)
  {
    while (count-- > 0)
      emplace_back(Neuron{});
  }
}
```

State Space Explosition

- ```
  void connect_to(Neuron& other)
  {
    out.push_back(&other);
    other.in.push_back(this);
  }
  ```
- Unfortunately, we need 4 functions
  - Neuron to Neuron
  - Neuron to NeuronLayer
  - NeuronLayer to Neuron
  - NeuronLayer to NeuronLayer


  ```

One Function Solution?

- Simple: treat Neuron as NeuronLayer of size 1
  - Not strictly correct
  - Does not take into account other concepts (e.g., NeuronRing)
- Better: expose a single Neuron in an iterable fashion
- Other programming languages have interfaces for iteration
  - E.g., C# `IEnumerable<T>`
  - `yield` keyword
- C++ does duck typing
  - Expects begin/end pair
- One function solution not possible, but…

Generic Connection Function

```
struct Neuron
{
  ...
  template <typename T> void connect_to(T& other)
  {
    for (Neuron& to : other)
      connect_to(to);
  }
  template<> void connect_to<Neuron>(Neuron& other)
  {
    out.push_back(&other);
    other.in.push_back(this);
  }
};
```

Generic Connection Function

```
struct NeuronLayer : vector<Neuron>
{
  …
  template <typename T> void connect_to(T& other)
  {
    for (Neuron& from : *this)
      for (Neuron& to : other)
        from.connect_to(to);
  }
};
```

How to Iterate on a Single Value?

```
struct Neuron
{
  …
  Neuron* begin() { return this; }
  Neuron* end()   { return this + 1; }
};
```

API Usage

```
Neuron n, n2;
NeuronLayer nl, nl2;

n.connect_to(n2);
n.connect_to(nl);
nl.connect_to(n);
nl.connect_to(nl2);
```

Specification Pattern and the OCP

Open-Closed Principle

- Open for extension, closed for modification
- Bad: jumping into old code to change a stable, functioning system
- Good: making things generic enough to be externally extensible
- Example: product filtering

Scenario

```
enum class Color { Red, Green, Blue };
enum class Size { Small, Medium, Large };

struct Product
{
  std::string name;
  Color color;
  Size size;
};
```

Filtering Products

```
struct ProductFilter
{
  typedef std::vector<Product*> Items;
  static Items by_color(Items items, Color color)
  {
    Items result;
    for (auto& i : items)
      if (i->color == color)
        result.push_back(i);
    return result;
  }
}
```

Filtering Products

```
struct ProductFilter
{
  typedef std::vector<Product*> Items;
  static Items by_color(Items items, Color color) { … }
  static Items by_size(Items items, Size size)
  {
    Items result;
    for (auto& i : items)
      if (i->size == size)
        result.push_back(i);
    return result;
  }
}
```

Filtering Products

```
struct ProductFilter
{
  typedef std::vector<Product*> Items;
  static Items by_color(Items items, Color color) { … }
  static Items by_size(Items items, Size size) { … }
  static Items by_color_and_size(Items items, Size size, Color color)
  {
    Items result;
    for (auto& i : items)
      if (i->size == size && i->color == color)
        result.push_back(i);
    return result;
  }
}
```

Violating OCP

- Keep having to rewrite existing code
  - Assumes it is even possible (i.e. you have access to source code)
- Not flexible enough (what about other criteria?)
- Filtering by X or Y or X&Y requires 3 functions
  - More complexity -> state space explosion
- Specification pattern to the rescue!

ISpecification and IFilter

```
template <typename T> struct ISpecification
{
  virtual bool is_satisfied(T* item) = 0;
};
template <typename T> struct IFilter
{
  virtual std::vector<T*> filter(
    std::vector<T*> items,
    ISpecification<T>& spec) = 0;
};
```

A Better Filter

```
struct ProductFilter : IFilter<Product>
{
  typedef std::vector<Product*> Products;
  Products filter(
    Products items,
    ISpecification<Product>& spec) override
  {
    Products result;
    for (auto& p : items)
      if (spec.is_satisfied(p))
        result.push_back(p);
    return result;
  }
};
```

Making Specifications

```
struct ColorSpecification : ISpecification<Product>
{
  Color color;
  explicit ColorSpecification(const Color color)
    : color{color}  { }

  bool is_satisfied(Product* item) override {
    return item->color == color;
  }
}; // same for SizeSpecification
```

Improved Filter Usage

```
Product apple{ "Apple", Color::Green, Size::Small };
Product tree { "Tree", Color::Green, Size::Large };
Product house{ "House", Color::Blue, Size::Large };

std::vector<Product*> all{ &apple, &tree, &house };

ProductFilter pf;
ColorSpecification green(Color::Green);

auto green_things = pf.filter(all, green);
for (auto& x : green_things)
  std::cout << x->name << " is green" << std::endl;
```

Filtering on 2..N criteria

- How to filter by size **and** color?
- We don’t want a SizeAndColorSpecification
  - State space explosion
- Create combinators
  - A specification which *combines* two other specifications
  - E.g., AndSpecification

AndSpecification Combinator

```
template <typename T> struct AndSpecification : ISpecification<T>
{
  ISpecification<T>& first;
  ISpecification<T>& second;

  AndSpecification(ISpecification<T>& first,
                   ISpecification<T>& second)
    : first{first}, second{second}  { }

  bool is_satisfied(T* item) override
  {
    return first.is_satisfied(item) && second.is_satisfied(item);
  }
};
```

Filtering by Size AND Color

```
ProductFilter pf;
ColorSpecification green(Color::Green);
SizeSpecification big(Size::Large);
AndSpecification<Product> green_and_big{ big, green };

auto big_green_things = pf.filter(all, green_and_big);
for (auto& x : big_green_things)
  std::cout << x->name << " is big and green" << std::endl;
```

Specification Summary

- Simple filtering solution is
  - Too difficult to maintain, violates OCP
  - Not flexible enough
- Abstract away the specification interface
  - bool is_satisfied_by(T something)
- Abstract away the idea of filtering
  - Input items + specification → set of filtered items
- Create combinators (e.g., AndSpecification) for combining multiple specifications

Fluent and Groovy-Style Builders

Scenario

- Consider the construction of structured data
  - E.g., an HTML web page
- Stuctured and formalized
- Rules (e.g., P cannot contain another P)
- Can we provide an API for building these?

Building a Simple HTML List

```
// <ul><li>hello</li><li>world</li></ul>
string words[] = { "hello", "world" };
ostringstream oss;
oss << "<ul>";
for (auto w : words)
  oss << "  <li>" << w << "</li>";
oss << "</ul>";
printf(oss.str().c_str());
```

HtmlElement

```
struct HtmlElement
{
  string name;
  string text;
  vector<HtmlElement> elements;
  const size_t indent_size = 2;

  string str(int indent = 0) const; // pretty-print
}
```

Html Builder (non-fluent)

```
struct HtmlBuilder
{
  HtmlElement root;
  HtmlBuilder(string root_name) { root.name = root_name; }
  void add_child(string child_name, string child_text)
  {
    HtmlElement e{ child_name, child_text };
    root.elements.emplace_back(e);
  }
  string str() { return root.str(); }
}
```

Html Builder (non-fluent)

```
HtmlBuilder builder{"ul"};
builder.add_child("li", "hello")
builder.add_child("li", "world");
cout << builder.str() << endl;
```

Making It Fluent

```
struct HtmlBuilder
{
  HtmlElement root;
  HtmlBuilder(string root_name) { root.name = root_name; }
  HtmlBuilder& add_child(string child_name, string child_text)
  {
    HtmlElement e{ child_name, child_text };
    root.elements.emplace_back(e);
    return *this;
  }
  string str() { return root.str(); }
}
```

Html Builder

```
HtmlBuilder builder{"ul"};
builder.add_child("li", "hello").add_child("li", "world");
cout << builder.str() << endl;
```

Associate Builder & Object Being Built

```
struct HtmlElement
{
  static HtmlBuilder build(string root_name)
  {
    return HtmlBuilder{root_name};
  }
};

// usage:
HtmlElement::build("ul")
  .add_child_2("li", "hello").add_child_2("li", "world");
```

Groovy-Style Builders

- Express the *structure* of the HTML in code
- No visible function calls
- ```
  UL {
    LI {“hello”},
    LI {“world”}
  }
  ```
- Possible in C++ using uniform initialization
  ```

Tag (= HTML Element)

```
struct Tag
{
  string name;
  string text;
  vector<Tag> children;
  vector<pair<string, string>> attributes;
protected:
    Tag(const std::string& name, const std::string& text)
      : name{name}, text{text} {  }
    Tag(const std::string& name, const std::vector<Tag>& children)
      : name{name}, children{children} {  }
}
```

Paragraph

```
struct P : Tag
{
  explicit P(const std::string& text)
    : Tag{"p", text}
  {
  }
   P(std::initializer_list<Tag> children)
    : Tag("p", children)
  {
  }
};
```

Image

```
struct IMG : Tag
{
  explicit IMG(const std::string& url)
    : Tag{"img", ""}
  {
    attributes.emplace_back(make_pair("src", url));
  }
};
```

Example Usage

```
std::cout <<

   P {
     IMG {"http://pokemon.com/pikachu.png"}
   }

   << std::endl;
```

Facet Builders

- An HTML element has different facets
  - Attributes, inner elements, CSS definitions, etc.
- A Person class might have different facets
  - Address
  - Employment information
- Thus, an object might necessitate *several* builders

Personal/Work Information

```
class Person
{
  // address
  std::string street_address, post_code, city;

  // employment
  std::string company_name, position;
  int annual_income = 0;

  Person() {} // private!
}
```

Person Builder (Exposes Facet Builders)

```
class PersonBuilder
{
  Person p;
protected:
  Person& person;
  explicit PersonBuilder(Person& person)
    : person{ person } { }
public:
  PersonBuilder() : person{p} { }
  operator Person() {  return std::move(person);  }

  // builder facets
  PersonAddressBuilder lives();
  PersonJobBuilder works();
}
```

Person Builder (Exposes Facet Builders)

```
class PersonBuilder
{
  Person p;
protected:
  Person& person;
  explicit PersonBuilder(Person& person)
    : person{ person } { }
public:
  PersonBuilder() : person{p} { }
  operator Person() {  return std::move(person);  }

  // builder facets
  PersonAddressBuilder lives();
  PersonJobBuilder works();
}
```

Person Builder Facet Functions

```
PersonAddressBuilder PersonBuilder::lives()
{
  return PersonAddressBuilder{ person };
}

PersonJobBuilder PersonBuilder::works()
{
  return PersonJobBuilder{ person };
}
```

Person Address Builder

```
class PersonAddressBuilder : public PersonBuilder
{
  typedef PersonAddressBuilder Self;
public:
  explicit PersonAddressBuilder(Person& person)
    : PersonBuilder{ person } { }
  Self& at(std::string street_address)
  {
    person.street_address = street_address;
    return *this;
  }
  Self& with_postcode(std::string post_code);
  Self& in(std::string city);
};
```

Person Job Builder

```
class PersonJobBuilder : public PersonBuilder
{
  typedef PersonJobBuilder Self;
public:
  explicit PersonJobBuilder(Person& person)
    : PersonBuilder{ person }  {  }

  Self& at(std::string company_name);
  Self& as_a(std::string position);
  Self& earning(int annual_income);
};
```

Back to Person

```
class Person
{
  // fields
public:
  static PersonBuilder create();

  friend class PersonBuilder;
  friend class PersonAddressBuilder;
  friend class PersonJobBuilder;
};
```

Final Person Builder Usage

```
Person p = Person::create()
    .lives().at("123 London Road")
            .with_postcode("SW1 1GB")
            .in("London")
    .works().at("PragmaSoft")
            .as_a("Consultant")
            .earning(10e6);
```

Maybe Monad

Presence or Absence

- Different ways of expressing absence of value
- Default-initialized value
  - string s; // there is no ‘null string’
- Null value
  - Address* address;
- Not-yet-initialized smart pointer
  - shared_ptr<Address> address
- Idiomatic
  - boost::optional

Monads

- Design patterns in functional programming
- First-class function support
- Related concepts
    - Algebraic data types
    - Pattern matching
- Implementable *to some degree* in C++
    - Functional objects/lambdas

Scenario

```
struct Address
{
  char* house_name; // why not string?
}

struct Person
{
  Address* address;
}
```

Print House Name, If Any

```
void print_house_name(Person* p)
{
  if (p != nullptr &&
      p->address != nullptr &&
      p->address->house_name != nullptr)
  {
    cout << p->address->house_name << endl;
  }
}
```

Maybe Monad

- Encapsulate the ‘drill down’ aspect of code
- Construct a Maybe<T> which keeps context
- Context: pointer to evaluated element
  - person -> address -> name
- While context is non-null, we drill down
- If context is nullptr, propagation does not happen
- All instrumented using lambdas

Maybe<T>

```
template <typename T>
struct Maybe {
  T* context;
  Maybe(T *context) : context(context) { }
};

// but, given Person* p, we cannot make a ‘new Maybe(p)’

template <typename T> Maybe<T> maybe(T* context)
{
  return Maybe<T>(context);
}
```

Usage So Far

```
void print_house_name(Person* p)
{
  maybe(p). // now drill down :)
}
```

Maybe::With

```
template <typename T> struct Maybe
{
  ...
  template <typename TFunc>
  auto With(TFunc evaluator)
  {
    if (context == nullptr)
      return ??? // cannot return maybe(nullptr) :(
    return maybe(evaluator(context));
  };
}
```

What is ???

- In case of failure, we need to return Maybe<U>
- But the type of U should be the return type of evaluator
- But evaluator returns U* and we need U
- Therefore…
-
```
return Maybe<
  typename remove_pointer<
    decltype(evaluator(context))
  >::type>(nullptr);
```

Maybe::With Finished

```
template <typename TFunc>
auto With(TFunc evaluator)
{
  if (context == nullptr)
    return Maybe<typename remove_pointer<
      decltype(evaluator(context))>::type>(nullptr);
  return maybe(evaluator(context));
};
```

Usage So Far

```
void print_house_name(Person* p)
{
  maybe(p) // now drill down :)
    .With([](auto x) { return x->address; })
    .With([](auto x) { return x->house_name; })
    . // print here (if context is not null)
}
```

Maybe::Do

```
template <typename TFunc>
auto Do(TFunc action)
{
  // if context is OK, perform action on it
  if (context != nullptr) action(context);

  // no context transition, so...
  return *this;
}
```

How It Works

- `print_house_name(nullptr)`
  - Context is null from the outset and continues to be null
  - **Nothing happens** in the entire evaluation chain
- `Person p; print_house_name(&p);`
  - Context is Person, but since Address is null, it becomes null henceforth
-
```
Person p;
p->Address = new Address;
p->Address->HouseName = “My Castle”;
print_house_name(&p);
```
  - Everything works and we get our printout

Maybe Monad Summary

- Example is not specific to nullptr
  - E.g., replace pointers with boost::optional
- Default-initialized types are harder
  - If s.length() == 0, has it been initialized?
- Monads are difficult due to lack of functional support
  - `[](auto x) { return f(x); }` instead of `x => f(x)` as in C#
  - No implicits (e.g. Kotlin's 'it')

That’s It!

- Questions?
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