Design Patterns in C++

Creational Patterns

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Intent

Ensure that a class only has one instance, and provide a global point of access to it

- For some classes it is important to have exactly one instance
  - The should be only one window manager in the system
- Of course, the same can be achieved with a global variable
- However, for complex system we could run in some problems
  - the initialization order
  - the object is created many times by mistake, etc.
- A better solution is to make the class itself responsible for creating and maintaining the instance

Code

```
//include file
class SysParams {
    static SysParams *inst;
    // other non-static members;
    SysParams();
    SysParams(const SysParams &);
public:
    static SysParams &getInstance();
    // other non static members
};
```

pointer to the only instance

constructor made private

copy constructor hidden and not implemented

Code implementation

```
// src (cpp) file
SysParams *SysParams::inst = 0;

SysParams & SysParams::getInstance()
{
    if (inst == 0)
        inst = new SysParams();
    return *inst;
}

SysParams::SysParams() { ... }
```

Lazy initialization

Subclassing and registry

- Sometimes it may be useful to have different subclasses of the class, but only one instance of one of them
- For example, we could chose one of several windows managers
- We can do that at compile/link time by using conditional compilation;
    - In this case, every subclass has its implementation of the `getInstance()` that returns the correct pointer, and the one to compile/link is decided though compilation switches
- We can also do it at run-time (during instantiation), using for example an environment variable
    - In this case, it is necessary to implement the creation code in the `getInstance()` method of the base class

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Concurrency

- If several threads can use the singleton, we must protect the initialization through a mutex semaphore

```
SysParams & SysParams::getInstance()
{
    lock_mutex();
    if (inst == 0)
        inst = new SysParams();
    unlock_mutex();
    return *inst;
}
```

- Notice that every time `getInstance()` gets called, the mutex must be locked and unlocked, even after the object has been created
- To reduce overhead we could use the double checked locking pattern;

Double checked locking

- In this case we perform a double check on the variable

```
SysParams & SysParams::getInstance()
{
    if (inst == 0) {
        lock_mutex();
        if (inst == 0) inst = new SysParams();
        unlock_mutex();
    }
    return *inst;
}
```

- WARNING! This technique may not work on all architectures!
- the problem is with the re-ordering of instructions by the compiler (due to optimizations) or by the hardware (due to instruction re-ordering in the processor)

Solution (correct)

- A **memory barrier** is a processor instruction that guarantees order of instructions
    - All instructions before the barrier must be completed before any instruction after the barrier
- We will also use another helper variable to check initialization

```
SysParams & SysParams::getInstance()
{
    if (val == 0) {
        lock_mutex();
        if (inst == 0) inst = new SysParams();
        unlock_mutex();
        // memory barrier
        val = 1;
        return *inst;
    }
    else {
        // memory barrier
        return *inst;
    }
}
```

When to use singletons

- A Singleton is useful to implement global variables in a safe way
  - For example, it provides a global point of access and an interface to a set of global objects (e.g. system parameters, a window manager, a configuration manager, etc.)
- It may be useful to control the order of initialisation
- The object is not created if not used
- Sometimes this pattern is overused
  - Singletons everywhere!
  - It is not worth to make it for a few primitive global variables that are local to a module

Abstract factory

- A program must be able to choose one of several families of classes
- Example,
  - a program's GUI should run on several platforms
  - Each platform comes with its own set of GUI classes:
    - WinButton, WinScrollBar, WinWindow MotifButton, MotifScrollBar, MotifWindow, pmButton, pmScrollBar, pmWindow
  - Inheritance:
    - Clearly, we can make all “button” classes derive from an abstract button that implements a virtual “draw” function
    - Then, we hold a pointer to button, and assign a specific button object, so that the correct draw() function is invoked each time
  - We probably need to dynamically create a lot of this objects
  - Problem: how can we simplify the creation of these objects?

Naive approach

- We keep a global variable (or object) that represents the current window manager and “look-and-feel” for all the objects
- Every time we create an object, we execute a switch/case on the global variable to see which object we must create

```
enum {WIN, MOTIF, PM, ...} lf;
...
// need to create a button
switch(lf) {
case WIN:   button = new WinButton(...);
            break:
case MOTIF: button = new MotifButton(...);
            break;
case PM:    button = new PmButton(...);
            ...
}
```

Problems with the naive approach

- What happens if we need to add a new look-and-feel?
  - We must change lot of code (for every creation, we must add a new case)
- How much code must we link?
  - Assuming that each look and feel is part of a different library, all libraries must be linked together
  - Large amount of code
- This solution is not compliant with the open/closed principle
  - Every time we add a new look and feel, we must change the code of existing functions/classes
- This solution *does not scale*

Requirements

- Uniform treatment of every button, window, etc.
    - Once you define the interface, you can easily use inheritance
- Uniform object creation
- Easy to switch between families
- Easy to add a family

Solution: Abstract factory

- Define a *factory* (i.e. a class whose sole responsibility is to create objects)

```
class WidgetFactory {
    Button* makeButton(args) = 0;
    Window* makeWindow(args) = 0;
    // other widgets...
};
```

- Define a concrete factory for each of the families

```
class WinWidgetFactory : public WidgetFactory {
    Button* makeButton(args) {
        return new WinButton(args);
    }
    Window* makeWindow(args) {
        return new WinWindow(args);
    }
};
```

Solution - cont.

- Select once which family to use:

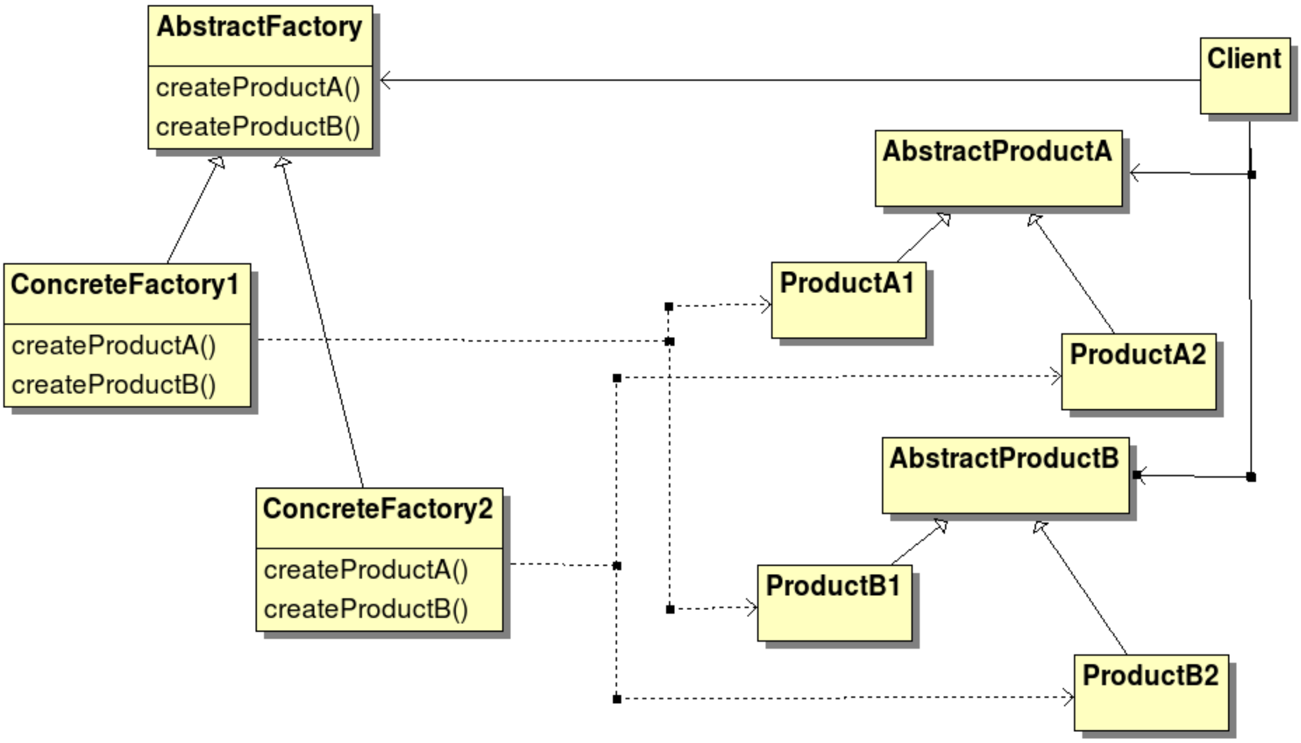
```
WidgetFactory* wf;
switch (lf) {
case WIN:     wf = new WinWidgetFactory();
              break;
case MOTIF:   wf = new MotifWidgetFactory();
              break;
...
}
```

- When creating objects in the code, don’t use “new” but call:

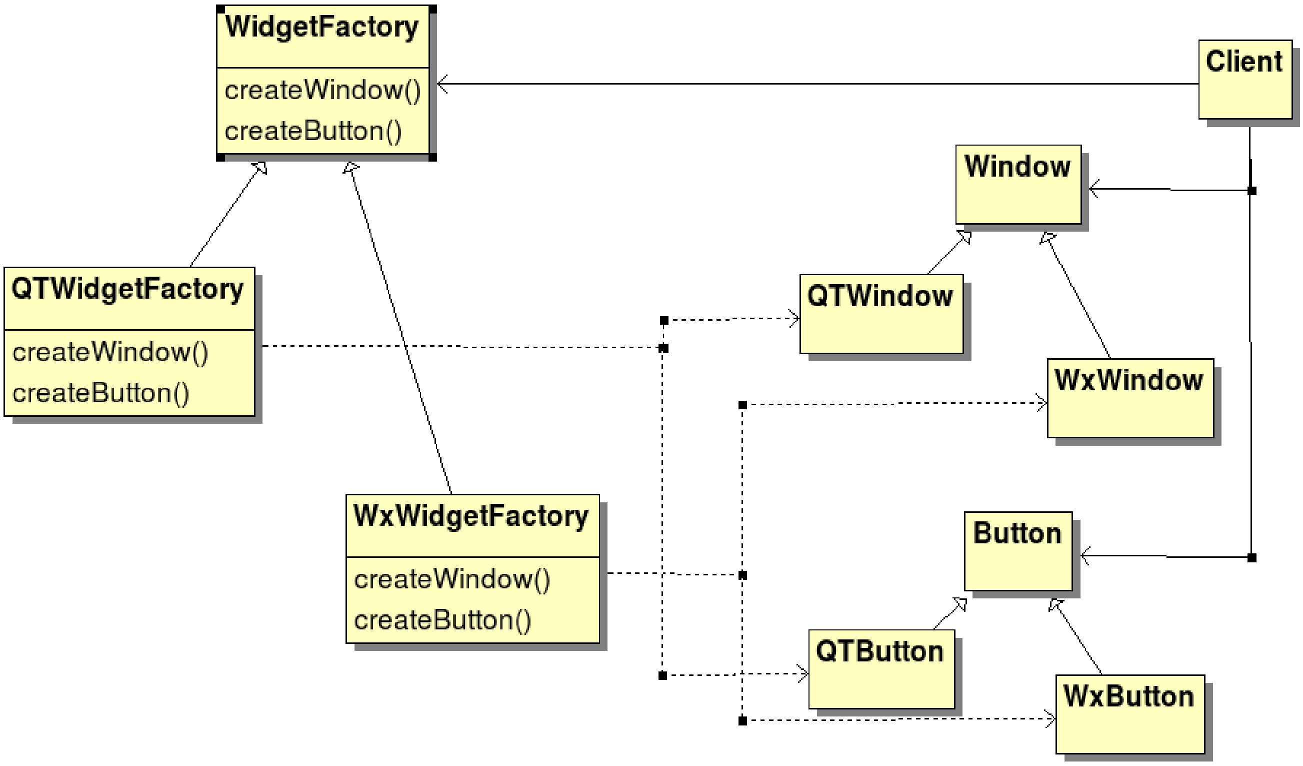
```
Button* b = wf->makeButton(args);
```

- Switch families – once in the code
- Add a family – one new factory, no effect on existing code

UML diagram



UML diagram, applied



Participants

- **AbstractFactory** (WidgetFactory)
  - declares an interface for operations that create abstract product objects.
- **ConcreteFactory** (MotifWidgetFactory, PMWidgetFactory)
  - implements the operations to create concrete product objects.
- **AbstractProduct** (Window, ScrollBar)
  - declares an interface for a type of product object.
- **ConcreteProduct** (MotifWindow, MotifScrollBar)
  - defines a product object to be created by the corresponding concrete factory.
  - implements the AbstractProduct interface.
- **Client**
  - uses only interfaces declared by AbstractFactory and AbstractProduct classes.

Comments

- Pros:
  - *It makes exchanging product families easy*. It is easy to change the concrete factory that an application uses. It can use different product configurations simply by changing the concrete factory.
  - *It promotes consistency among products*. When product objects in a family are designed to work together, it's important that an application uses objects from only one family at a time time.
  - AbstractFactory makes this easy to enforce.
- Cons:
  - Not easy to extend the abstract factory's interface
- Other patterns:
  - Usually one factory per application, a perfect example of a singleton

Known uses

- Different operating systems (could be Button, could be File)
- Different look-and-feel standards
- Different communication protocols

Builder

- Separate the specification of how to construct a complex object from the representation of the object
- The same construction process can create different representations
- Example:
  - A converter reads files from one file format (i.e. RTF)
  - It should write them to one of several output formats (ascii, LaTeX, HTML, etc.)
- No limit on the number of possible output formats
  - It must be easy to add a new “conversion” without modifying the code for the reader

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Requirements

- Single Responsibility Principle
  - Same reader for all output formats
  - Output format chosen once in code
- Open-Closed Principle
  - Easy to add a new output format
  - Addition does not change old code
- Dynamic choice of output format

Participants

- The reader: reads the input file, and invokes the converter to produce the output file
- The output file is the *final product* of the construction
- The converter is the *builder* that builds the final product in a complex way

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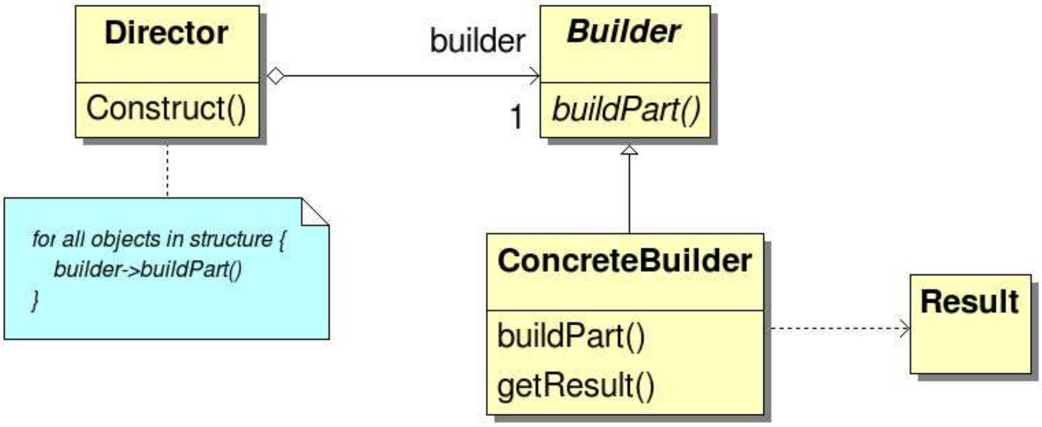
The solution

- We should return a different object depending on the output format:
  - HTMLDocument, RTFDocument, . . .
- Separate the building of the output from reading the input
- Write an interface for such a builder
- Use inheritance to write different concrete builders

UML representation



Director

Construct()

builder

1

Builder

buildPart()

for all objects in structure {
builder->buildPart()
}

ConcreteBuilder

buildPart()
getResult()

Result

The solution – code

- Builder interface

```
class Builder {
    virtual void writeChar(char c) { }
    virtual void setFont(Font *f)  { }
    virtual void newPage() { }
};
```

- Here's a concrete builder:

```
class HTMLBuilder : public Builder
{
private:
    HTMLDocument *doc;
public:
    HTMLDocument *getDocument() {
        return doc;
    }
    void writeChar(char c) {...}
    void setFont(Font *f)  {...}
    void newPage() {...}
}
```

Converter

- The converter uses a builder:

```
class Converter
{
    void convert(Builder *b) {
        while (t = read_next_token())
            switch (o.kind) {
            case CHAR: b->writeChar(o);
                       break;
            case FONT: b->setFont(o);
                       break;
         // other kinds
        }
     }
};
```

- And this is how the converter is used

```
RTFBuilder *b = new RTFBuilder;
converter->convert(b);
RTFDocument *d = b->getDocument();
```

Comments

- This pattern is useful whenever the creation of an object is complex and requires many different steps
  - In the example, the creation of `HTMLDocument` is performed step by step as the tokens are read from the file
  - Only at the end the object is ready to be used
- Therefore, we separate the creation of the object from its use later on
- The final object is created with one single step at the end of the creation procedure
  - In this case, it is easier to check consistency of the creation parameters at once
  - example: create a Square, using the interface of a Rectangle:
    - The user sets Height and Width in the builder, then tries to build the Square, and if they are different gets an exception telling what went wrong
- Another example later on

Intent

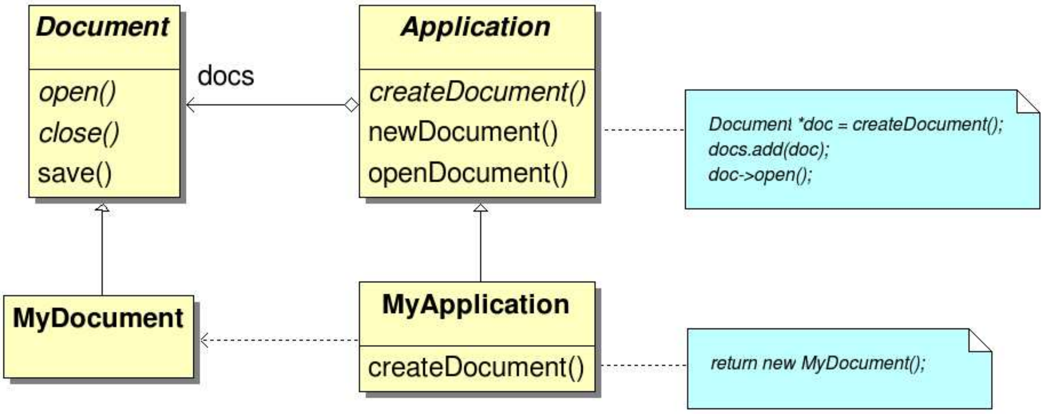
Define an interface for creating an object, but let subclasses decide which class to instantiate

- Also known as *Virtual Constructor*
- The idea is to provide a virtual function to create objects of a class hierarchy
- each function will then know which class to instantiate

Example

- Consider a framework for an office suite
  - Typical classes will be `Document` and `Application`
  - there will be different types of documents, and different types of applications
  - for example: Excel and PowerPoint are applications, excel sheet and presentation are documents
  - all applications derive from the same abstract class *Application*
  - all documents derive from the same abstract class *Document*
  - we have *parallel hierarchies* of classes
  - every application must be able to create its own document object

Example in UML



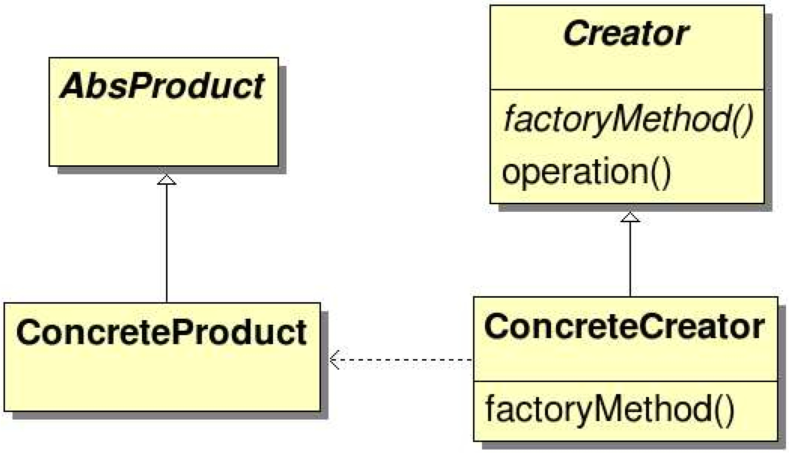
```
Document *doc = createDocument();
docs.add(doc);
doc->open();
```

```
return new MyDocument();
```

Participants

- **Product** (Document)
  - defines the interface of the objects the factory method creates
- **ConcreteProduct** (MyDocument)
  - implements the Product's interface
- **Creator** (Application)
  - declares the factory method
- **ConcreteCreator** (MyApplication)
  - overrides the factory method to return an instance of a ConcreteProduct

UML representation



AbsProduct

Creator

factoryMethod()

operation()

ConcreteProduct

ConcreteCreator

factoryMethod()

Implementation

- It may be useful to add parameters to the factory method, to allow the creation of multiple types of products
    - For example, suppose that you want to save a bunch of different objects on the disk (Triangle, Rectangle, Circle, etc, they are all of type shape)
    - one possibility would be to enumerate the types with an integer `id`, and save the `id` as first element in the disk record
    - when loading the objects again you may read the `id` first, and then pass it to a factory method which creates the correct type of object and loads it from the disk
    - further, to avoid a switch-case in the factory method, we could implement a registry (will see in a little while how to do this)

Using templates to avoid sub-classing

- Sometimes the ConcreteCreator must only implement the factory method
- to avoid writing just a class for this, we could use templates:

```
class Creator {
public:
    virtual Product *createProduct() = 0;
    ...
};

template <class TheProduct>
class StandardCreator : public Creator {
public:
    virtual Product* createProduct() {
        return new TheProduct();
    }
};

StandardCreator<MyProduct> myCreator;
```

How to create objects

- Usually, objects are created by invoking the constructor
- however, sometimes the constructor is not as flexible as we wish
- an alternative technique is to use a static method in the class, whose purpose is to create objects of the class in a more flexible way
- this technique is called *static factory method*
    - has almost nothing to do with the GoF's factory method

```
class MyClass {
public:
    MyClass(int param);                  // std constructor
    static MyClass *create(int param);   // static fact. method
};
```

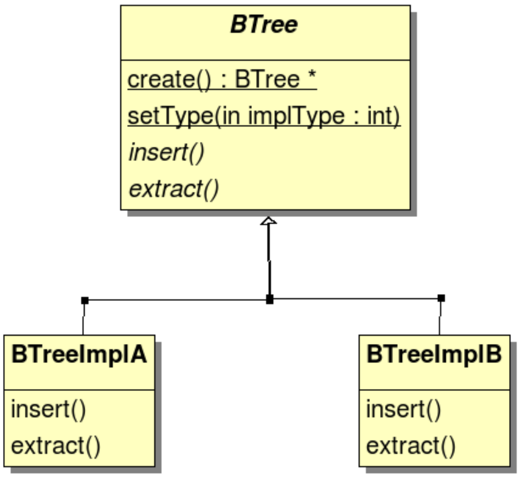
Advantages

- The first advantage is that factory methods can have descriptive names
- This is especially useful when there are many different ways to create an object
  - the standard way is to implement many constructors with different argument lists
  - however, the code readability of this technique is poor: it is difficult to understand what a certain constructor does by just looking at the list of parameters
  - sometimes, constructors differ just in the order of the parameters!
- with static factory methods, instead:
  - It is possible to create different methods with different, more descriptive names

Advantages

- The second important advantage is that, unlike constructors, static factory methods must not necessarily create an object
  - This can be useful for example when you want to control how many objects are around, and eventually reuse them
  - For example, this technique is very useful when implementing an enumeration of constant objects
- The third advantage is the fact that they can create an object of a subtype of the original type, without the client knowing this fact
  - Suppose for example that you implemented a `BTree` class
  - The client code uses the interface of BTree to perform operations like insert/extract
  - Then, you realize that you need different implementation of BTree in different contexts, because of performance / efficiency reasons
  - If the BTree is created with a factory method, you can simply switch between the implementations by configuring the method differently

Implementation



- Notice that the two implementation classes need not to be exposed to the client: they can be completely hidden, and changed at any time without even informing the customer
- the extra function `setType()` can be optionally used to let the client select the preferred implementation
- therefore, we have maximum separation of concerns

Hiding the constructor?

- The static factory method looks similar to the singleton pattern (except that there is no limit to the number of instances)
- You might be tempted to make the constructor private, so the only way to construct an instance is to use the static factory method
- however, keep in mind that, if the constructor is private, the class cannot be sub-classed
    - The derived class cannot call the base class constructor!
- therefore, if you want to sub-class, the constructor must be at least protected

Other advantages

- Another advantage is the fact that you can easily specify default parameters between successive calls
- this reduces the list of parameters of complex constructors
  - This is sometimes called *telescoping constructor*

```
class NutritionFacts {
public:
    NutritionFacts(int servingSize, int servings) {...}
    NutritionFacts(int servingSize, int servings, int calories) {...}
    NutritionFacts(int servingSize, int servings, int calories,
                   int fat) {...}
    NutritionFacts(int servingSize, int servings, int calories,
                   int fat, int sodium) {...}
};
...
NutritionFacts label1(240, 8, 100, 0, 35, 27);
NutritionFacts label2(240, 8, 100, 0, 42, 25);
NutritionFacts label3(300, 10, 100, 0, 42, 25);
```

With static factory method

- see `simple_builder`
- notice how much more readable it is
- Notes:
  - The `auto_ptr<>` is used to guarantee that the builder object is destroyed after the last use
  - once all parameters have been set, they can be checked in the `NutritionFacts` constructor
  - this method can be extended to consistently build more complex objects step by step (see Builder Pattern)

Creating objects by ID

- Sometimes it is necessary to create objects by using an `ID`
- consider a hierarchy of classes, with `Base` as the base class and many different derived classes
- clients use the interface of `Base` to access the object methods
- however, they would like to flexibly create one instance of one of the subclasses depending of an `ID`
  - Could be an integer or a string, or anything else
- Therefore, we need an `AbstractFactory`, with one single create method, which takes a parameter `ID` to decide which type of object to instantiate
- the following structure will combine:
  - AbstractFactory
  - Singleton
  - Static Factory Method