Design Patterns

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This Lecture

- The Creational Patterns
  - Abstract Factory
  - Builder
  - Prototype
  - Factory Method
- Choosing Between Them

Creational Patterns

- Easily Change:
  - What gets created?
  - Who creates it?
  - When is it created?
- Hide the concrete classes that get created from client code
- Competing patterns, each with its own strengths

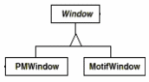
6. Abstract Factory

- A program must be able to choose one of several families of classes
- For 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

The Requirements

- Uniform treatment of every button, window, etc. in the code
  - Easy - Define their interfaces:



- Uniform object **creation**
- Easy to switch between families
- Easy to add a family

The Solution

- Define a Factory - a class that creates objects:

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

The Solution II

- Define a concrete factory for each of the families:

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

The Solution III

- Select once which family to use:

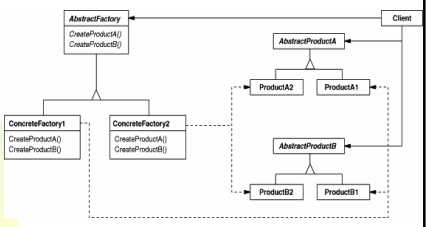
```
WidgetFactory* wf =
  new WinWidgetFactory();
```

- 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!

The Big (UML) Picture



The Fine Print

- The factory doesn't have to be abstract, if we expect a remote possibility of having another family
- Usually one factory per application, a perfect example of a *singleton*
- Not easy to extend the abstract factory's interface

Known Uses

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

7. Builder

- Separate the specification of how to construct a complex object from the representation of the object
- For example, a converter reads files from one file format
- It should write them to one of several output formats

The Requirements

- Single Choice 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

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

The Solution II

- Here's the builder's interface:

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

The Solution III

- Here's a concrete builder:

```
class HTMLBuilder
    : public Builder
{
 private:
    HTMLDocument *doc;
 public:
    HTMLDocument *getDocument() {
          return doc;
    }
    // all inherited methods here
}
```

The Solution IV

- The converter uses a builder:

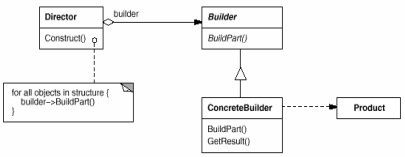
```
class Converter
{
  void convert(Builder *b) {
     while (t = read_next_token())
       switch (o.kind) {
         CHAR: b->writeChar(o);
         FONT: b->setFont(o);
         // other kinds…
       }
  }
}
```

The Solution V

- This is how the converter is used:

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

The UML



The Fine Print

- The builder's interface affects the ease of coding concrete builders
- Kinds of documents don't need a common base class
- Methods in class *Builder* are empty and not abstract
- *getResult()* is not always trivial
  - Optimizations
  - Lazy Creation

Known Uses

- Converting to different formats
- Building a parse tree in a compiler
- Building a normalized database

8. Prototype

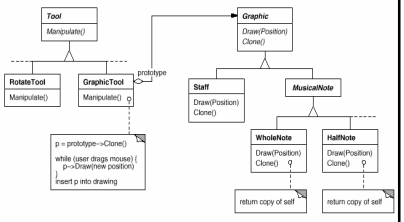
- Specify the kind of object to create using a prototypical instance
- For example, a photo/map editor has a palette of tools and objects that can be created
- How do we have only one class for creations, and parameterize it by the *class* of objects it initializes?

The Requirements

- One class for the creation tool
- Easy to add new objects
- Dynamic toolbox configuration

The Solution

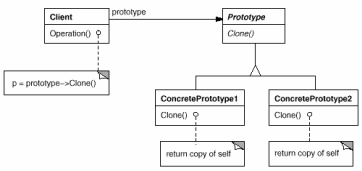
- Hold a prototype of object to create
- Creation is by cloning the prototype



The Solution II

- Less classes in the system
- Can be even less: same *Graphic* object with different properties can be used for different tools
- Tools can be chosen and configured at runtime

The UML



The Fine Print

- Prototype Manager - a runtime registry of prototype can handle dynamically linked classes
- Java, SmallTalk, Eiffel provide a default *clone()* method. C++ has copy constructors
- All of these are shallow by default
- When implementing deep clone, beware of circular references!

Known Uses

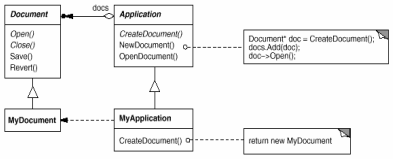
- Toolboxes / Palettes
- Supporting dynamically defined debuggers in a uniform GUI
- EJB / COM Servers
- Basically a plug-in mechanism

9. Factory Method

- Let subclasses decide which objects to instantiate
- For example, a framework for a windowing application has a class *Application* which must create an object of class *Document*
- But the actual applications and documents are not written yet!

The Solution

- Separate creation into a method



Second Variant

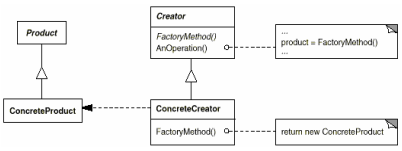
- A remote services package has a *RemoteService* class that returns objects of class *Proxy* to client
- A few clients wish to write a more potent *CachedProxy*
- How do we support this without much hassle?

Second Variant Solution

- Separate creation into a method
- *RemoteService* will have a virtual method called *CreateProxy()*
- Write *CachedProxy*, then write:

```
class CachedRemoteService
    : public RemoteService
{
  Proxy* createProxy(...) {
    return new CachedProxy(...);
  }
}
```

The UML



The Fine Print

- Two Variants: Is the factory method abstract or not?
- Good style to use factory methods even for a slight chance of need
- Parameterized factory methods make it easy to add created products without affecting old code

```
Product* createProduct(int id) {
    switch (id) { ... }
}
```

The Fine Print II

- C++ warning: You can't call a factory method from a constructor!
  - Use lazy initialization instead

```
Product* getProduct() {
  if (_product == NULL)
    _product = createProduct();
  return _product;
}
```

- Use templates to avoid subclassing
  - `Application<ExcelDocument>`
  - `complex<float>, complex<double>`

Known Uses

- A very common pattern
- Framework classes
  - *Application*, *Document*, *View*, ...
- Changing default implementations
  - *Proxy*, *Parser*, *MemoryManager*, ...

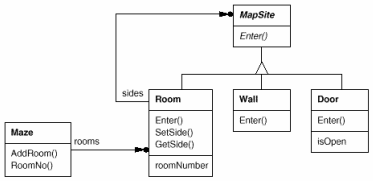
Pattern of Patterns

- Encapsulate the varying aspect
- Interfaces
- Inheritance describes variants
- Composition allows a dynamic choice between variants

Criteria for success:

Open-Closed Principle
Single Choice Principle

A Comparative Example



The Example Problem

```
Maze* MazeGame::CreateMaze () {
  Maze* aMaze = new Maze;
  Room* r1 = new Room(1);
  Room* r2 = new Room(2);
  Door* theDoor = new Door(r1, r2);

  aMaze->AddRoom(r1);
  aMaze->AddRoom(r2);

  r1->SetSide(North, new Wall);
  r1->SetSide(East, theDoor);
  // set other sides, also for r2

  return aMaze;
}
```

Enchanted Mazes

- How do we reuse the same maze with *EnchantedRoom*, *TrapDoor*?
  - Pass *createMaze* an object that can create different maze parts
  - Pass *createMaze* an object that can build a maze and then return it
  - Pass *createMaze* initialized samples of each kind of maze part
  - Move creation with *new* to other methods that descendants redefine

Abstract Factory

- Define a set of interfaces
  - *Door*, *Wall*, *Room*, ...
- Write families of classes
  - *SimpleDoor*, *SimpleRoom*, ...
  - *EnchantedDoor*, *EnchantedRoom*,...
- Define an abstract *MazeFactory*, and a concrete class for each family
  - *SimpleFactory*, *EnchantedFactory*, ...
- Pass *createMaze* a factory

Abstract Factory II

```
Maze* MazeGame::CreateMaze
  (MazeFactory* mf) {
  Maze* aMaze = mf->createMaze();
  Room* r1 = mf->createRoom(1);
  Room* r2 = mf->createRoom(2);
  Door* d  = mf->createDoor(r1,r2);

  // rest is same as before
```

- Families don't have to be disjoint
- Same factory can return variants of the same class

Abstract Factory Cons

- Requires a new factory class for every family
- Families are defined statically
- Parts of the complex maze are returned right after creation
- The client of the factory builds the connections between maze parts
- Maze stands for any complex object

Builder Pros & Cons

- Pros
  - Each builder can create a totally different kind of object
  - Object returned only at the end of construction - enables optimization
  - Especially if object is on network
- Cons
  - Complex Interface to builder

Prototype Pros & Cons

- Pros
  - Less Classes
  - Prototype can be customized between different creations
- Cons
  - Requires memory to hold prototype
  - Many prototypes must be passed
  - *Clone()* may be hard to implement

Factory Method P&C

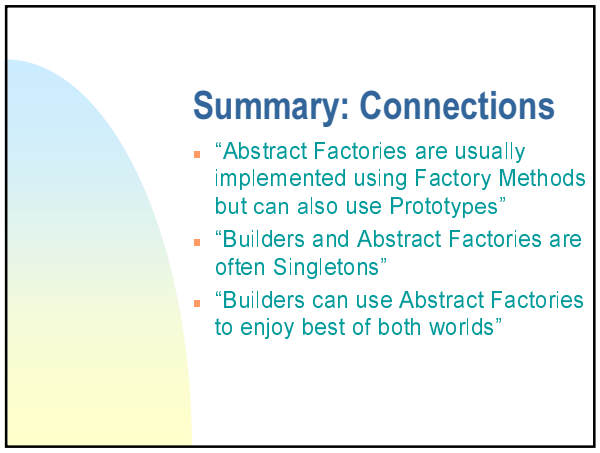
- Pros
  - The simplest design
- Cons
  - Requires a new class for every change in creation
  - Compile-time choice only

The Verdict

- Use Factory Methods when there is little (but possible) chance of change
- Use Abstract Factory when different families of classes are given anyway
- Use Prototype when many small objects must be created similarly
- Use Builder when different output representations are necessary

Some Easy Cases

- Dynamic loading of classes whose objects must be created
  - only Prototype
- Creation can be highly optimized once entire structure is known
  - only Builder


Summary: Connections
"Abstract Factories are usually implemented using Factory Methods but can also use Prototypes"
"Builders and Abstract Factories are often Singletons"
"Builders can use Abstract Factories to enjoy best of both worlds"