Factory Patterns:
Factory Method
and
Abstract Factory

Factory Patterns

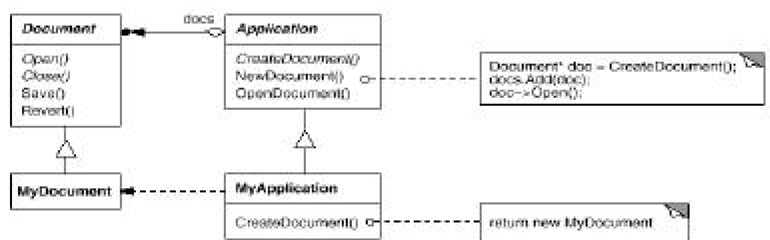
- Factory patterns are examples of creational patterns
- *Creational patterns* abstract the object instantiation process. They hide how objects are created and help make the overall system independent of how its objects are created and composed.
- *Class creational patterns* use inheritance to decide the object to be instantiated
  - ⇨ Factory Method
- *Object creational patterns* delegate the instantiation to another object
  - ⇨ Abstract Factory

Factory Patterns

- All OO languages have an idiom for object creation. In Java this idiom is the *new* operator. Creational patterns allow us to write methods that create new objects without explicitly using the new operator. This allows us to write methods that can instantiate different objects and that can be extended to instantiate other newly-developed objects, all without modifying the method's code! (Quick! Name the principle involved here!)

The Factory Method Pattern

- Intent
  - ⇨ Define an interface for creating an object, but let subclasses decide which class to instantiate. Factory Method lets a class defer instantiation to subclasses.
- Motivation
  - ⇨ Consider the following framework:



  - ⇨ The createDocument() method is a factory method.

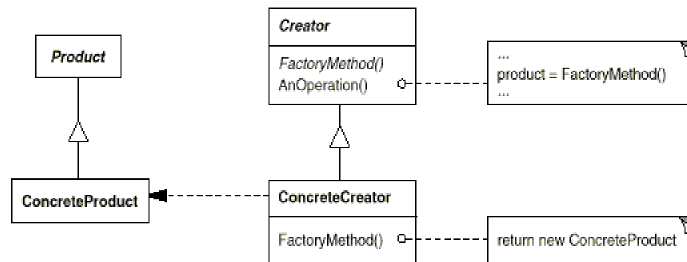
The Factory Method Pattern

- Applicability

  Use the Factory Method pattern in any of the following situations:

  - A class can't anticipate the class of objects it must create
  - A class wants its subclasses to specify the objects it creates

- Structure

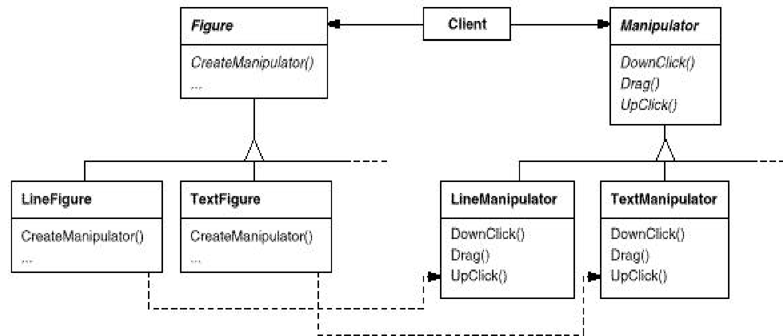


The Factory Method Pattern

- Participants
  - Product
    - Defines the interface for the type of objects the factory method creates
  - ConcreteProduct
    - Implements the Product interface
  - Creator
    - Declares the factory method, which returns an object of type Product
  - ConcreteCreator
    - Overrides the factory method to return an instance of a ConcreteProduct
- Collaborations
  - Creator relies on its subclasses to implement the factory method so that it returns an instance of the appropriate ConcreteProduct

Factory Method Example 1

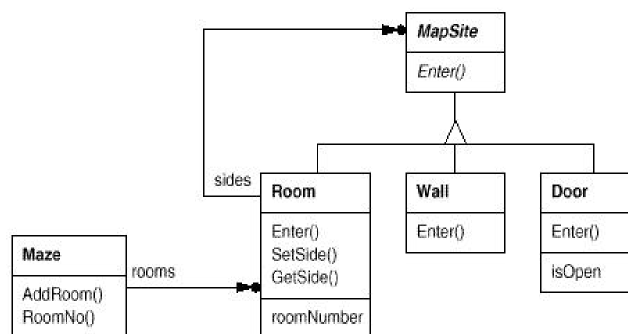
- Clients can also use factory methods:



- The factory method in this case is createManipulator()

Factory Method Example 2

- Consider this maze game:



Factory Method Example 2 (Continued)

- Here's a MazeGame class with a createMaze() method:

```
/**
  * MazeGame.
*/
public class MazeGame {

  // Create the maze.
  public Maze createMaze() {
    Maze maze = new Maze();
    Room r1 = new Room(1);
    Room r2 = new Room(2);
    Door door = new Door(r1, r2);
    maze.addRoom(r1);
    maze.addRoom(r2);
```


Factory Method Example 2 (Continued)

```
    r1.setSide(MazeGame.North, new Wall());
    r1.setSide(MazeGame.East, door);
    r1.setSide(MazeGame.South, new Wall());
    r1.setSide(MazeGame.West, new Wall());
    r2.setSide(MazeGame.North, new Wall());
    r2.setSide(MazeGame.East, new Wall());
    r2.setSide(MazeGame.South, new Wall());
    r2.setSide(MazeGame.West, door);
    return maze;
  }

}
```

Factory Method Example 2 (Continued)

- The problem with this createMaze() method is its *inflexibility*.
- What if we wanted to have enchanted mazes with EnchantedRooms and EnchantedDoors? Or a secret agent maze with DoorWithLock and WallWithHiddenDoor?
- What would we have to do with the createMaze() method? As it stands now, we would have to make significant changes to it because of the explicit instantiations using the *new* operator of the objects that make up the maze. How can we redesign things to make it easier for createMaze() to be able to create mazes with new types of objects?

Factory Method Example 2 (Continued)

- Let's add factory methods to the MazeGame class:

```
/**
 * MazeGame with a factory methods.
*/
public class MazeGame {

   public Maze makeMaze() {return new Maze();}

   public Room makeRoom(int n) {return new Room(n);}

   public Wall makeWall() {return new Wall();}

   public Door makeDoor(Room r1, Room r2)
     {return new Door(r1, r2);}
```

Factory Method Example 2 (Continued)

```
  public Maze createMaze() {
    Maze maze = makeMaze();
    Room r1 = makeRoom(1);
    Room r2 = makeRoom(2);
    Door door = makeDoor(r1, r2);
    maze.addRoom(r1);
    maze.addRoom(r2);
    r1.setSide(MazeGame.North, makeWall());
    r1.setSide(MazeGame.East, door);
    r1.setSide(MazeGame.South, makeWall());
    r1.setSide(MazeGame.West, makeWall());
    r2.setSide(MazeGame.North, makeWall());
    r2.setSide(MazeGame.East, makeWall());
    r2.setSide(MazeGame.South, makeWall());
    r2.setSide(MazeGame.West, door);
    return maze;
  }
}
```


Factory Method Example 2 (Continued)

- We made createMaze() just slightly more complex, but a lot more flexible!
- Consider this EnchantedMazeGame class:

```
public class EnchantedMazeGame extends MazeGame {
  public Room makeRoom(int n) {return new EnchantedRoom(n);}
  public Wall makeWall() {return new EnchantedWall();}
  public Door makeDoor(Room r1, Room r2)
    {return new EnchantedDoor(r1, r2);}
}
```

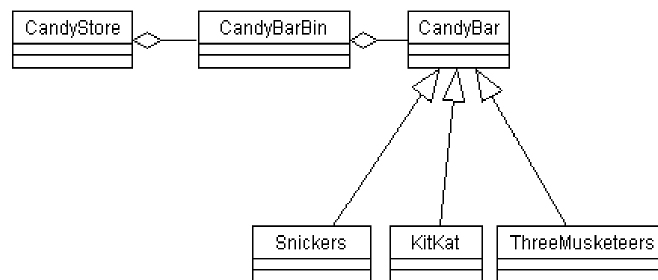
- The createMaze() method of MazeGame is inherited by EnchantedMazeGame and can be used to create regular mazes or enchanted mazes *without modification*!

Factory Method Example 2 (Continued)

- The reason this works is that the createMaze() method of MazeGame defers the creation of maze objects to its subclasses. That's the Factory Method pattern at work!
- In this example, the correlations are:
  - ⇨ Creator => MazeGame
  - ⇨ ConcreteCreator => EnchantedMazeGame (MazeGame is also a ConcreteCreator)
  - ⇨ Product => MapSite
  - ⇨ ConcreteProduct => Wall, Room, Door, EnchantedWall, EnchantedRoom, EnchantedDoor

Factory Method Example 3

- Consider the following class hierarchy:



Factory Method Example 3 (Continued)

- Each CandyBarBin can hold zero or more candy bars, but all the candy bars in one bin are of the same type. (In this case, we say that each bin is a *homogeneous container*.) We want to write a restock() method for a CandyBarBin, such that when the number of candy bars drops below a certain level, the restock method will add one candy bar of the proper type to the bin.
- (Yes, it's silly to add just one candy bar during a restock operation, but it's easy to add a simple loop in the code to restock by a fixed amount.)

Factory Method Example 3 (Continued)

- We could have a String attribute of CandyBarBin telling us what type of candy bar the bin holds:

```
// CandyBarBin.
public class CandyBarBin {
  private String cbType; // CandyBar Type

  public CandyBarBin(String cbType) {this.cbType = cbType;}

  public void restock() {
    if (getAmountInStock() < LowStockLevel) {
      if (cbType.equals("Snickers")) add(new Snickers());
      else if (cbType.equals("KitKat")) add(new KitKat());
      else if (cbType.equals("ThreeMusketeers"))
                 add(new ThreeMusketeers());
    }
  }
```

Factory Method Example 3 (Continued)

```
  public void add(CandyBar cb) {
     // Code to add a candy bar to the bin.
     // Homogeneity insured here.
  }
  ...
}
```

- I trust you are shuddering with revulsion right now just looking at the above code! Does this restock() method satisfy the Open-Closed Principle? Nope! If we want to sell a new type of candy bar, we have to modify the restock() method.
- Whenever we have an if-else statement of this sort, deciding what to do based on alternatives represented by the state of an object, it's a sure sign that polymorphism can come to the rescue!

Factory Method Example 3 (Continued)

- First, let's have CandyBar provide a factory method for creation of candy bars:

```
public class CandyBar {
  // Factory Method.
  public CandyBar createCandyBar() {return new CandyBar();}
  ...
}
```

- Now each CandyBar subclass can provide the correct implementation of the createCandyBar() method. For example, here is the KitKat class:

```
public class KitKat extends CandyBar {
  // Factory Method.
  public Candybar createCandyBar() {return new KitKat();}
  ...
}
```

Factory Method Example 3 (Continued)

- Now CandyBarBin can look like this:

```
public class CandyBarBin {
  private CandyBar cb;
  public CandyBarBin(CandyBar cb) {this.cb = cb;}

  public void restock() {
    if (getAmountInStock() < LowStockLevel) {
      add(cb.createCandyBar());
    }
  }

  public void add(CandyBar cb) {
    // Code to add a candy bar to the bin.
    // Homogeneity already guaranteed by the CandyBar subclass.
  }
}
```


Factory Method Example 3 (Continued)

- Actually, in Java, we have both an Object class and a Class class with some neat methods that allow us to write the restock() method without a factory method:

```
public void restock() {
  if (getAmountInStock() < LowStockLevel) {
    add( (Candybar) cb.getClass().newInstance());
  }
}
```

- And if our String candy bar type attribute is an actual Java type (such as Store.Candy.KitKat), we could do this:

```
public void restock() {
  if (getAmountInStock() < LowStockLevel) {
    add( (Candybar) Class.forName(cbType).newInstance());
  }
}
```

The Factory Method Pattern

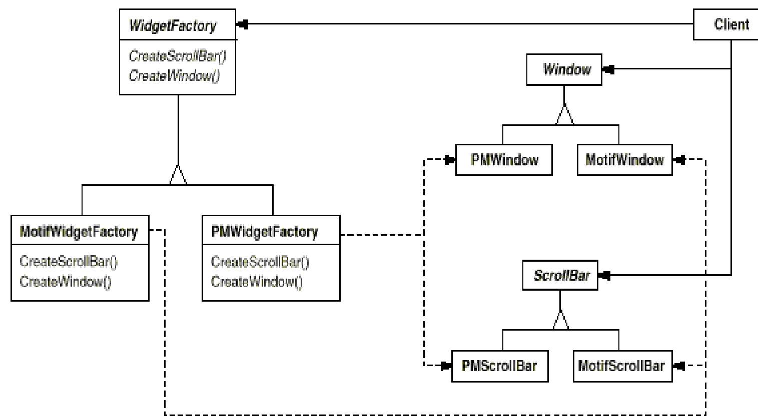
- Consequences
  - ⇨ Benefits
    - Code is made more flexible and reusable by the elimination of instantiation of application-specific classes
    - Code deals only with the interface of the Product class and can work with any ConcreteProduct class that supports this interface
  - ⇨ Liabilities
    - Clients might have to subclass the Creator class just to instantiate a particular ConcreteProduct
- Implementation Issues
  - ⇨ Creator can be abstract or concrete
  - ⇨ Should the factory method be able to create multiple kinds of products? If so, then the factory method has a parameter (possibly used in an if-else!) to decide what object to create. We could override this factory method in a subclass to try to avoid OCP problems.

The Abstract Factory Pattern

- Intent
  - ⇨ Provide an interface for creating families of related or dependent objects without specifying their concrete classes.
  - ⇨ The Abstract Factory pattern is very similar to the Factory Method pattern. The main difference between the two is that with the Abstract Factory pattern, a class delegates the responsibility of object instantiation to another object via composition whereas the Factory Method pattern uses inheritance and relies on a subclass to handle the desired object instantiation.
  - ⇨ Actually, the delegated object frequently uses factory methods to perform the instantiation!

The Abstract Factory Pattern

- Motivation
  - ⇨ A GUI toolkit that supports multiple look-and-feels:



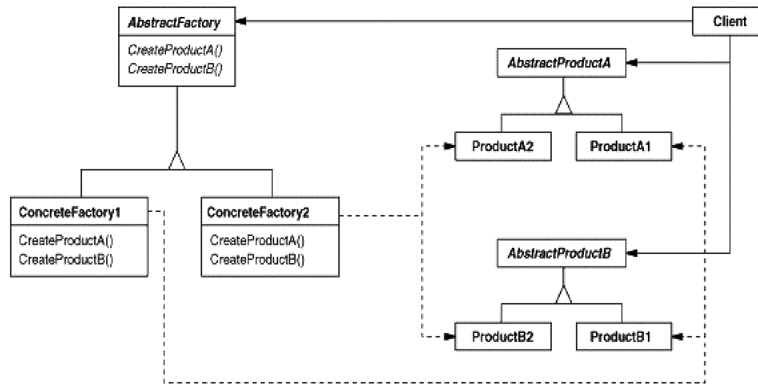
The Abstract Factory Pattern

- Applicability

  Use the Abstract Factory pattern in any of the following situations:
  - ⇨ A system should be independent of how its products are created, composed, and represented
  - ⇨ A class can't anticipate the class of objects it must create
  - ⇨ A system must use just one of a set of families of products
  - ⇨ A family of related product objects is designed to be used together, and you need to enforce this constraint

The Abstract Factory Pattern

- Structure



The Abstract Factory Pattern

- Participants
  - AbstractFactory
    - Declares an interface for operations that create abstract product objects
  - ConcreteFactory
    - Implements the operations to create concrete product objects
  - AbstractProduct
    - Declares an interface for a type of product object
  - ConcreteProduct
    - 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

The Abstract Factory Pattern

- Collaborations
  - ⇨ Normally a single instance of a ConcreteFactory class is created at run-time. (This is an example of the Singleton Pattern.) This concrete factory creates product objects having a particular implementation. To create different product objects, clients should use a different concrete factory.
  - ⇨ AbstractFactory defers creation of product objects to its ConcreteFactory
- Common Terminology Usage
  - ⇨ Anytime we delegate object creation to a contained object we our using the Abstract Factory pattern
  - ⇨ But we tend to just say that "we are using a factory."

Abstract Factory Example 1

- Let's see how an Abstract Factory can be applied to the MazeGame
- First, we'll write a MazeFactory class as follows:

```
// MazeFactory.
public class MazeFactory {
  public Maze makeMaze() {return new Maze();}
  public Room makeRoom(int n) {return new Room(n);}
  public Wall makeWall() {return new Wall();}
  public Door makeDoor(Room r1, Room r2) {return new Door(r1, r2);}
}
```

- Note that the MazeFactory class is just a collection of factory methods!
- Also, note that MazeFactory acts as both an AbstractFactory and a ConcreteFactory.

Abstract Factory Example 1 (Continued)

- Now the createMaze() method of the MazeGame class takes a MazeFactory reference as a parameter:

```
public class MazeGame {

  public Maze createMaze(MazeFactory factory) {
    Maze maze = factory.makeMaze();
    Room r1 = factory.makeRoom(1);
    Room r2 = factory.makeRoom(2);
    Door door = factory.makeDoor(r1, r2);
    maze.addRoom(r1);
    maze.addRoom(r2);
    r1.setSide(MazeGame.North, factory.makeWall());
    r1.setSide(MazeGame.East, door);
```


Abstract Factory Example 1 (Continued)

```
    r1.setSide(MazeGame.South, factory.makeWall());
    r1.setSide(MazeGame.West, factory.makeWall());
    r2.setSide(MazeGame.North, factory.makeWall());
    r2.setSide(MazeGame.East, factory.makeWall());
    r2.setSide(MazeGame.South, factory.makeWall());
    r2.setSide(MazeGame.West, door);
    return maze;
  }

}
```

- Note how createMaze() delegates the responsibility for creating maze objects to the MazeFactory object

Abstract Factory Example 1 (Continued)

- We can easily extend MazeFactory to create other factories:

```
public class EnchantedMazeFactory extends MazeFactory {
  public Room makeRoom(int n) {return new EnchantedRoom(n);}
  public Wall makeWall() {return new EnchantedWall();}
  public Door makeDoor(Room r1, Room r2)
    {return new EnchantedDoor(r1, r2);}
}
```

- In this example, the correlations are:
  - AbstractFactory => MazeFactory
  - ConcreteFactory => EnchantedMazeFactory (MazeFactory is also a ConcreteFactory)
  - AbstractProduct => MapSite
  - ConcreteProduct => Wall, Room, Door, EnchantedWall, EnchantedRoom, EnchantedDoor
  - Client => MazeGame

Abstract Factory Example 2

- The Java 1.1 Abstract Window Toolkit is designed to provide a GUI interface in a heterogeneous environment
- The AWT uses an Abstract Factory to generate all of the required peer components for the specific platform being used
- For example, here's part of the List class:

```
public class List extends Component implements ItemSelectable {
...
  peer = getToolkit().createList(this);
...
}
```

- The getToolkit() method is inherited from Component and returns a reference to the factory object used to create all AWT widgets

Abstract Factory Example 2 (Continued)

- Here's the getToolkit() method in Component:

```
public Toolkit getToolkit() {
   // If we already have a peer, return its Toolkit.
   ComponentPeer peer = this.peer;
   if ((peer != null) && ! (peer instanceof
      java.awt.peer.LightweightPeer)){
       return peer.getToolkit();
   }
   // If we are already in a container, return its Toolkit.
   Container parent = this.parent;
   if (parent != null) {
     return parent.getToolkit();
   }
   // Else return the default Toolkit.
   return Toolkit.getDefaultToolkit();
}
```


Abstract Factory Example 2 (Continued)

- And here's the getDefaultToolkit() method in Toolkit:

```
public static synchronized Toolkit getDefaultToolkit() {
  if (toolkit == null)
    String nm = System.getProperty("awt.toolkit",
                         "sun.awt.motif.MToolkit");
    toolkit = (Toolkit)Class.forName(nm).newInstance();
  }
  return toolkit;
}
```

Abstract Factory Example 3

- Let's revisit our Candy Store. At one point we had:

```
public class CandyBarBin {
  private CandyBar cb;
  public CandyBarBin(CandyBar cb) {this.cb = cb;}
  public void restock() {
    if (getAmountInStock() < LowStockLevel) {
      add(cb.createCandyBar());
    }
  }
}
```

- We are delegating the creation of CandyBar objects to our contained CandyBar member, cb, which acts as a concrete factory of CandyBar objects. And the createCandyBar method is a Factory Method of CandyBar, whose proper implementation is provided by the subclass of CandyBar we are actually using!

Abstract Factory Example 4

- Sockets are a very useful abstraction for communication over a network
- The socket abstraction was originally developed at UC Berkeley and is now in widespread use
- Java provides some very nice implementations of Berkeley sockets in the Socket and ServerSocket classes in the java.net package
- The Socket class actually delegates all the real socket functionality to a contained SocketImpl object
- And the SocketImpl object is created by a SocketImplFactory object contained in the Socket class
- Sounds like Abstract Factory!

Abstract Factory Example 4 (Continued)

- Here's some code from the Socket class:

```
/**
 * A socket is an endpoint for communication between two machines.
 * The actual work of the socket is performed by an instance of the
 * SocketImpl class. An application, by changing
 * the socket factory that creates the socket implementation,
 * can configure itself to create sockets appropriate to the local
 * firewall.
 */
public class Socket {

  // The implementation of this Socket.
  SocketImpl impl;

  // The factory for all client sockets.
  private static SocketImplFactory factory;
```


Abstract Factory Example 4 (Continued)

```
    /**
     * Sets the client socket implementation factory for the
     * application. The factory can be specified only once.
     * When an application creates a new client socket, the socket
     * implementation factory's createSocketImpl method is
     * called to create the actual socket implementation.
    */
    public static synchronized void
      setSocketImplFactory(SocketImplFactory fac)
      throws IOException {
      if (factory != null) {
        throw new SocketException("factory already defined");
      }
      factory = fac;
    }
```

Abstract Factory Example 4 (Continued)

```
  /**
   * Creates an unconnected socket, with the
   * system-default type of SocketImpl.
   */
  protected Socket() {
    impl = (factory != null) ? factory.createSocketImpl() :
      new PlainSocketImpl();
  }

  /**
   * Returns the address to which the socket is connected.
   */
  public InetAddress getInetAddress() {
    return impl.getInetAddress();
  }
  // Other sockets methods are delegated to the SocketImpl object!
}
```


Abstract Factory Example 4 (Continued)

- SocketImplFactory is just an interface:

```
public interface SocketImplFactory {
  SocketImpl createSocketImpl();
}
```

- SocketImpl is an abstract class:

```
/**
 * The abstract class SocketImpl is a common superclass
 * of all classes that actually implement sockets.
 * A "plain" socket implements these methods exactly as
 * described, without attempting to go through a firewall or proxy.
 */
public abstract class SocketImpl implements SocketOptions {
  // Details omitted.
}
```

The Abstract Factory Pattern

- Consequences
  - Benefits
    - Isolates clients from concrete implementation classes
    - Makes exchanging product families easy, since a particular concrete factory can support a complete family of products
    - Enforces the use of products only from one family
  - Liabilities
    - Supporting new kinds of products requires changing the AbstractFactory interface
- Implementation Issues
  - How many instances of a particular concrete factory should there be?
    - An application typically only needs a single instance of a particular concrete factory
    - Use the Singleton pattern for this purpose

The Abstract Factory Pattern

- Implementation Issues
  - How can the factories create the products?
    - Factory Methods
    - Factories
  - How can new products be added to the AbstractFactory interface?
    - AbstractFactory defines a different method for the creation of each product it can produce
    - We could change the interface to support only a make(String kindOfProduct) method

How Do Factories Create Products?

- Method 1: Use Factory Methods

```
/**
  * WidgetFactory.
  * This WidgetFactory is an abstract class.
  * Concrete Products are created using the factory methods
  *   implemented by sublcasses.
*/
public abstract class WidgetFactory {
  public abstract Window createWindow();
  public abstract Menu createScrollBar();
  public abstract Button createButton();
}
```


How Do Factories Create Products? (Continued)

```
/**
  * MotifWidgetFactory.
  * Implements the factory methods of its abstract superclass.
*/
public class MotifWidgetFactory
  extends WidgetFactory {

  public Window createWindow() {return new MotifWidow();}
  public ScrollBar createScrollBar() {return new MotifScrollBar();}
  public Button createButton() {return new MotifButton();}

}
```

How Do Factories Create Products? (Continued)

- Method 2: Use Factories

```
/**
  * WidgetFactory.
  * This WidgetFactory contains references to factories used
  *   to create the  Concrete Products.
*/
public class WidgetFactory {
  private WindowFactory windowFactory;
  private ScrollBarFactory scrollBarFactory;
  private ButtonFactory buttonFactory;

  public Window createWindow() {return
    windowFactory.createWindow();}
  public ScrollBar createScrollBar() {return
    scrollBarFactory.createScrollBar();}
  public Button createButton() {return
    buttonFactory.createButton();}
}
```


How Do Factories Create Products? (Continued)

```
/**
  * MotifWidgetFactory.
  * Instantiates the factories used by its superclass.
*/
public class MotifWidgetFactory
  extends WidgetFactory {
  public MotifWidgetFactory() {
    windowFactory = new MotifWindowFactory();
    scrollBarFactory = new MotifScrollBarFactory();
    buttonFactory = new MotifButtonFactory();
  }
}
```

How Do Factories Create Products? (Continued)

- Method 3: Use Factories With No Required Subclasses (Pure Composition)

```
/**
  * WidgetFactory.
  * This WidgetFactory contains reference to factories used
  *   to create Concrete Products.  It also has a constructor
  *   and does not need to be subclassed.
*/
public class WidgetFactory {

  private Window windowFactory;
  private ScrollBar scrollBarFactory;
  private Button buttonFactory;
```


How Do Factories Create Products? (Continued)

```
  public WidgetFactory(windowFactory wf,
                       scrollBarFactory sbf,
                       buttonFactory bf) {
    windowFactory = wf;
    scrollBarFactooy = sbf;
    buttonFactory = bf;
  }

  public Window createWindow() {return
    windowFactory.createWindow();}
  public ScrollBar createScrollBar() {return
    scrollBarFactory.createScrollBar();}
  public Button createButton() {return
    buttonFactory.createButton();}
}
```