Creational Patterns

- Patterns used to abstract the process of instantiating objects.
  - class-scoped patterns
    - uses inheritance to choose the class to be instantiated
      - Factory Method
  - object-scoped patterns
    - uses delegation
      - Abstract Factory
      - Builder
      - Prototype
      - Singleton

Importance

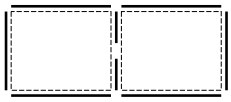
- Becomes important as emphasis moves towards dynamically composing smaller objects to achieve complex behaviours.
  - need more than just instantiating a class
  - need consistent ways of creating related objects.
  - helps manage compositions of objects implementing abstract interfaces. Which is an crucial tool for handling complexity.

Recurring Themes

- Hide the details about which concrete classes the system uses.
- Hide the details of how instances are created and associated.
- Gives flexibility in
  - what gets created
  - who creates it
  - how it gets created
  - when it get gets created

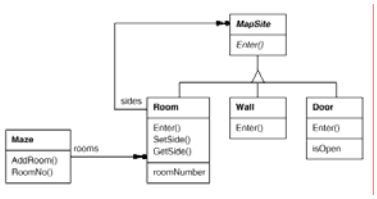
Running Example

- Building a maze for a computer game.



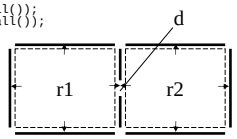
- A Maze is composed of many instances of the Room.
- A Room knows its neighbours.
  - another room
  - a wall
  - a door

Maze Example



Creating Mazes

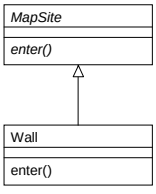
```
public class MazeGame
{
    public static void main(String args[]) {
        Maze m = new MazeGame().createMaze();
    }

    public Maze createMaze() {
        Room r1 = new Room(1);
        Room r2 = new Room(2);
        Door d  = new Door(r1,r2);

        r1.setSide(Direction.North, new Wall());
        r1.setSide(Direction.East, d);
        r1.setSide(Direction.West, new Wall());
        r1.setSide(Direction.South, new Wall());

        r2.setSide(Direction.North, new Wall());
        r2.setSide(Direction.West, d);
        r2.setSide(Direction.East, new Wall());
        r2.setSide(Direction.South, new Wall());

        Maze m  = new Maze();
        m.addRoom(r1);
        m.addRoom(r2);
        return m;
    }
}
```



Maze Classes

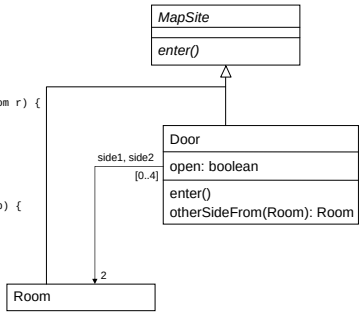
```
public abstract class MapSite
{
    public abstract void enter();
}
```

```
public class Wall extends MapSite
{
    public void enter() {
    }
}
```



Maze Classes

```
public class Door extends MapSite
{
    Door(Room s1, Room s2) {
        side1 = s1;
        side2 = s2;
    }

    public void enter() {
    }

    public Room otherSideFrom(Room r) {
        if( r == side1 )
            return side2;
        else if( r == side2 )
            return side1;
        else
            return null;
    }

    public void setOpen(boolean b) {
        open = b;
    }

    public boolean getOpen() {
        return open;
    }

    private Room side1;
    private Room side2;
    boolean open;
}
```

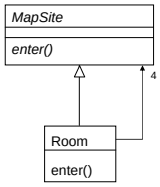


Maze Classes

```
public class Direction
{
    public final static int First = 0;
    public final static int North = First;
    public final static int South = North+1;
    public final static int East = South+1;
    public final static int West = East+1;
    public final static int Last = West;
    public final static int Num = Last-First+1;
}
```

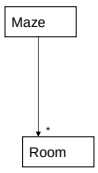

Maze Classes

```
public class Room extends MapSite
{
    public Room(int r) {
        room_no = r;
    }

    public void enter() {
    }

    public void setSide(int direction, MapSite ms) {
        side[direction] = ms;
    }

    public MapSite getSide(int direction) {
        return side[direction];
    }

    public void setRoom_no(int r) {
        room_no = r;
    }

    public int getRoom_no() {
        return room_no;
    }

    private int room_no;
    private MapSite[] side = new MapSite[Direction.Num];
}
```



Maze Classes

```
import java.util.Vector;

public class Maze
{
    public void addRoom(Room r) {
        rooms.addElement(r);
    }

    public Room getRoom(int r) {
        return (Room)rooms.elementAt(r);
    }

    public int numRooms() {
        return rooms.size();
    }

    private Vector rooms = new Vector();
}
```



Maze Creation

```
    public Maze createMaze() {
        Room r1 = new Room(1);
        Room r2 = new Room(2);
        Door d  = new Door(r1,r2);

        r1.setSide(Direction.North, new Wall());
        r1.setSide(Direction.East, d);
        r1.setSide(Direction.West, new Wall());
        r1.setSide(Direction.South, new Wall());

        r2.setSide(Direction.North, new Wall());
        r2.setSide(Direction.East, d);
        r2.setSide(Direction.West, new Wall());
        r2.setSide(Direction.South, new Wall());

        Maze m  = new Maze();
        m.addRoom(r1);
        m.addRoom(r2);
        return m;
    }
```

Maze Creation

- Fairly complex method (just) to create a maze with two rooms.
- Knows a lot of details (everything?) about Rooms, Doors, Walls.
- Obvious simplification:
  - Room() could initialize sides with 4 new instances of Wall
  - That just moves the code elsewhere.
- Problem lies elsewhere: *inflexibility*
  - Hard-codes the maze creation
  - Changing the layout can only be done by re-writing, or overriding and re-writing.
- Promotes code copying which is a Bad Thing.

Creational Patterns Benefits

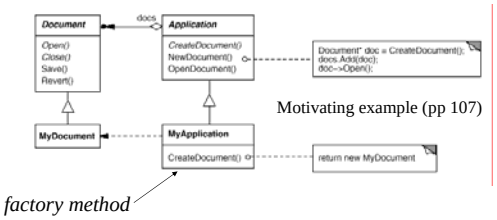
- Will make the maze more flexible.
  - easy to change the components of a maze
  - e.g., DoorNeedingSpell, EnchantedRoom
    - How can you change createMaze() so that it creates mazes with these different kind of classes?
    - Biggest obstacle is hard-coding of class names mixed in with code that composes a Room from the bits and pieces.

Creational Patterns

- If createMaze() calls virtuals to construct components
  - Factory Method
- If createMaze() is uses a factory object to create rooms, walls, …
  - Abstract Factory
- If createMaze() is passed a object to create and connect-up mazes
  - Builder
- If createMaze is parameterized with various exemplars, or prototypes, of rooms, doors, walls, … which it clones and then adds to the maze
  - Prototype
- Need to ensure there is only one maze per game, and everybody can access it, and can extend or replace the maze without touching other code.
  - Singleton

Factory Method

- Define an interface for creating an object, but let subclasses decide which class to instantiate.
- a.k.a. Virtual Constructor
- e.g., app framework

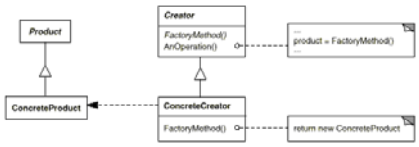


Motivating example (pp 107)

Applicability

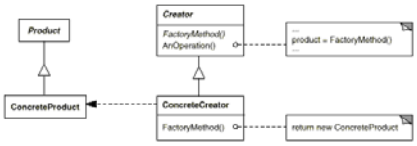
- Use when:
  - A class can't anticipate the kind of objects to create.
  - Hide the secret of which helper subclass is the current delegate.

Structure



- Product
  - defines the interface of objects the factory method creates
- ConcreteProduct
  - implements the Product interface

Structure



- Creator
  - declares the factory method which return a Product type.
  - [define a default implementation]
  - [call the factory method itself]
- ConcreteCreator
  - overrides the factory method to return an instance of a ConcreteProduct

Sample Code

```
public class MazeGame {
    public static void main(String args[]) {
        Maze m = new MazeGame().createMaze();
    }

    private Maze makeMaze() { return new Maze(); }
    private Wall makeWall() { return new Wall(); }
    private Room makeRoom(int r) { return new Room(r); }
    private Door makeDoor(Room r1, Room r2) { return new Door(r1,r2); }

    public Maze createMaze() {
        …
    }
}
```

Sample Code

```
public Maze createMaze() {
   Room r1 = makeRoom(1);
   Room r2 = makeRoom(2);
   Door d  = makeDoor(r1,r2);

   r1.setSide(Direction.North, makeWall());
   r1.setSide(Direction.East, d);
   r1.setSide(Direction.West, makeWall());
   r1.setSide(Direction.South, makeWall());

   r2.setSide(Direction.North, makeWall());
   r2.setSide(Direction.East, d);
   r2.setSide(Direction.West, makeWall());
   r2.setSide(Direction.South, makeWall());

   Maze m  = makeMaze();
   m.addRoom(r1);
   m.addRoom(r2);
   return m;
}
```

Recall: these were constructors in "orange arrow" slide.

Sample Code

```
public class BombedMazeGame extends MazeGame
{
    private Wall makeWall() { return new BombedWall(); }
    private Room makeRoom(int r) { return new RoomWithABomb(r); }
}
```

```
public class EnchantedMazeGame extends MazeGame
{
    private Room makeRoom(int r)
        { return new EnchantedRoom(r, castSpell()); }
    private Door makeDoor(Room r1, Room r2)
        { return new DoorNeedingSpell(r1,r2); }
    private Spell castSpell()
        { return new Spell(); }
}
```

createMaze will create mazes with same structure but different components

Sample Code

```
public static void main(String args[]) {
    Maze m = new EnchantedMazeGame().createMaze();
}
```

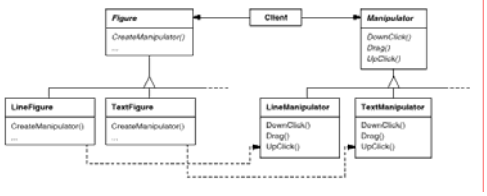
```
public static void main(String args[]) {
    Maze m = new BombedMazeGame().createMaze();
}
```


Consequences

- Advantage:
  - Eliminates the need to bind to specific implementation classes.
    - Can work with any user-defined ConcreteProduct classes.
- Disadvantage:
  - Uses an inheritance dimension
  - Must subclass to define new ConcreteProduct objects
    - interface consistency required

Consequences

- Provides hooks for subclasses
  - always more flexible than direct object creation
- Connects parallel class hierarchies
  - hides the secret of which classes belong together
  - consistent types of object created by consistent factory methods



Implementation

- Two major varieties
  - creator class is abstract
    - *requires* subclass to implement
  - creator class is concrete, and provides a default implementation
    - *optionally allows* subclass to re-implement
- Parameterized factory methods
  - takes a class id as a parameter to a generic make() method.
  - (more on this later)
- Naming conventions
  - use 'makeXXX()' type conventions (e.g., MacApp – DoMakeClass())
- Can use templates instead of inheritance
- Return class of object to be created
  - or, store as member variable

Question

- What gets printed?

```
public class Main {
    public static void main(String args[])
        { new DerivedMain(); }
    public String myClass()
        { return "Main"; }
}

class DerivedMain extends Main {
    public DerivedMain()
        { System.out.println(myClass()); }
    public String myClass()
        { return "DerivedMain"; }
}
```


What is printed?

```
public class Main {
   public Main(){ System.out.println(myClass()); }

  public static void main(String args[]) {
      new DerivedMain();
      }
    public String myClass() { return "Main"; }
}

class DerivedMain extends Main {
    public DerivedMain(){}
    public String myClass() {return "DerivedMain"; }
}
```

What is printed by C++?

```
using namespace std;

class Main {
public:
   Main(){cout << myClass() << "\n";}
    virtual char * myClass()  {    return "Main";  }
};

class DerivedMain: public Main {
public:
   DerivedMain():Main(){  }

 virtual char * myClass(){   return "DerivedMain"; }
};

int _tmain(int argc, _TCHAR* argv[]){
   new DerivedMain();
   return 0;
}
```

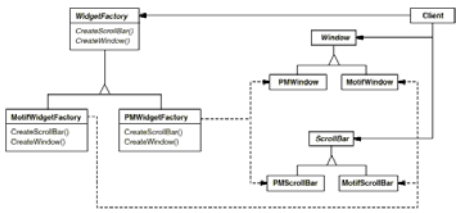

Implementation

- Lazy initialization
  - In C++, subclass vtable pointers aren't installed until after parent class initialization is complete.
    - DON'T CREATE DURING CONSTRUCTION!
    - can use lazy instatiation:

```
Product getProduct() {
    if( product == null ) {
        product = makeProduct();
    }
    return product;
}
```


Abstract Factory

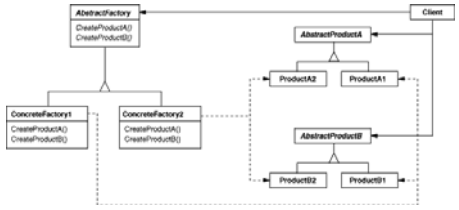
- Provide an interface for creating families of related or dependent objects without specifying their concrete classes.
- e.g., look-and-feel portability
  - independence
  - enforced consistency



Applicability

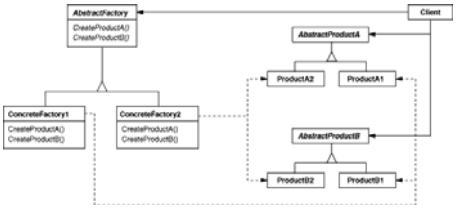
- Use when:
  - a system should be independent of how its products are created, composed, and represented
  - a system should be configured with one of multiple families of products.
  - a family of related product objects is designed to be used together, and you need to enforce this constraint.
  - you want to provide a class library of products, and you want to reveal just their interfaces, not their implementations.
  - you want to hide and reuse awkward or complex details of construction
  - For instance, GUI applications that compile under X windows and win32.
    - At cost of abstracting some (probably) lowest common denominator of widgets.

Structure



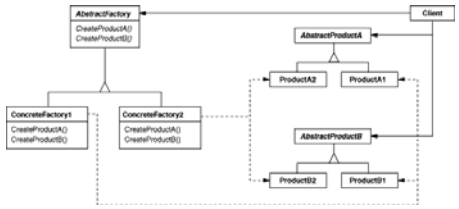
- AbstractFactory
  - declares an interface for operations that create product objects.
- ConcreteFactory
  - implements the operations to create concrete product objects.

Structure



- AbstractProduct
  - declares an interface for a type of product object.
- Product
  - defines a product to be created by the corresponding concrete factory.
  - implements the AbstractProduct interface.

Structure



- Client
  - uses only interfaces declared by AbstractFactory and AbstractProduct classes.
  - This is significant. These interfaces had better be useful abstractions.

Sample Code

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

Maze Creation (old way)

```
public Maze createMaze() {
    Room r1 = new Room(1);
    Room r2 = new Room(2);
    Door d  = new Door(r1,r2);

    r1.setSide(Direction.North, new Wall());
    r1.setSide(Direction.East, d);
    r1.setSide(Direction.West, new Wall());
    r1.setSide(Direction.South, new Wall());

    r2.setSide(Direction.North, new Wall());
    r2.setSide(Direction.East, d);
    r2.setSide(Direction.West, new Wall());
    r2.setSide(Direction.South, new Wall());

    Maze m  = new Maze();
    m.addRoom(r1);
    m.addRoom(r2);
    return m;
}
```

Recall: these were constructors in "orange arrow" slide.

Sample Code

```
public Maze createMaze(MazeFactory factory) {
    Room r1 = factory.makeRoom(1);
    Room r2 = factory.makeRoom(2);
    Door d  = factory.makeDoor(r1,r2);

    r1.setSide(Direction.North, factory.makeWall());
    r1.setSide(Direction.East, d);
    r1.setSide(Direction.West, factory.makeWall());
    r1.setSide(Direction.South, factory.makeWall());

    r2.setSide(Direction.North, factory.makeWall());
    r2.setSide(Direction.East, d);
    r2.setSide(Direction.West, factory.makeWall());
    r2.setSide(Direction.South, factory.makeWall());

    Maze m  = factory.makeMaze()
    m.addRoom(r1);
    m.addRoom(r2);
    return m;
}
```

Now call methods on factory object

Sample Code

```
public class EnchantedMazeFactory extends MazeFactory {
    public Room makeRoom(int r) {
        return new EnchantedRoom(r, castSpell());
    }

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

    private protected castSpell() {
        // randomly choose a spell to cast;
        …
    }
}
```


Sample Code

```
public class MazeGame
{
    public static void main(String args[]) {
        Maze m = new MazeGame().createMaze(new MazeFactory());
    }
}

public class MazeGame
{
    public static void main(String args[]) {
        Maze m = new MazeGame().createMaze(new EnchantedMazeFactory());
    }
}
```

Consequences

- It isolates concrete classes
  - Helps control the classes of objects that an application creates.
  - Isolates clients from implementation classes
  - Clients manipulate instances through abstract interfaces
  - Product class names are isolated in the implementation of the concrete factory
    - they do not appear in the client code
  - You had better be happy with those abstract interfaces!
    - Wouldn't even know what class to cast to!
    - Once upon a time this caused me Major Grief when I found I had to hack into "least common denominator" widget behind abstract interface.

Consequences

- It makes exchanging product families easy
  - The class of a concrete factory appears only once in the app.
    - where it's instantiated
  - Easy to change the concrete factory an app uses.
  - The whole product family changes at once

Consequences

- It promotes consistency among products
  - When products are designed to work together, it's important that an application use objects only from one family at a time.
  - AbstractFactory makes this easy to enforce.

Consequences

- Supporting new kinds of products is difficult.
  - Extending AbstractFactory to produce new product types isn't easy
    - extend factory interface
    - extend all concrete factories
    - add a new abstract product
    - + the usual (implement new class in each family)

Implementation

- Factories as Singletons
  - An app typically needs only one instance of a ConcreteFactory per product family.
  - Best implemented as a Singleton

Implementation

- Defining extensible factories
  - Hard to extend to new product types
  - Add parameter to operations that create products
    - need only `make()`
    - less safe
    - more flexible
    - easier in languages that have common subclass
      - e.g. java Object
    - easier in more dynamically-typed languages
      - e.g., Smalltalk
    - all products have same abstract interface
      - can downcast – not safe
      - classic tradeoff for a very flexible/extensible interface

Implementation

- Creating the products
  - AbstractFactory declares an interface for product creation
  - ConcreteFactory implements it. How?
    - Factory Method
      - virtual overrides for creation methods
      - simple
      - requires new concrete factories for each family, even if they only differ slightly
    - Prototype
      - concrete factory is initialized with a prototypical instance of each product in the family
      - creates new products by cloning
      - doesn't require a new concrete factory class for each product family
      - variant: can register class objects

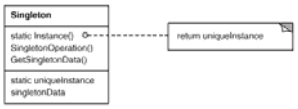
Singleton

- Ensure a class only has one instance, and provide a global point of access to it.
  - Many times need only one instance of an object
    - one file system
    - one print spooler
    - …
  - How do we ensure there is exactly one instance, and that the instance is easily accessible?
    - Global variable is accessible, but can still instantiate multiple instances.
    - make the class itself responsible

Applicability

- Use when:
  - there must be exactly one instance accessible from a well-known access point
  - the sole instance should be extensible via subclassing
    - clients should be able to use the extended instance without modifying their code

Structure



- Singleton
  - defines a class-scoped instance() operation that lets clients access its unique instance
  - may be responsible for creating its own unique instance

Sample Code

```
package penny.maze.factory;
public class MazeFactory {
    MazeFactory() { }

    private static MazeFactory theInstance = null;
    public static MazeFactory instance() {
        if( theInstance == null ) {
            String mazeKind =
                 AppConfig.getProperties().getProperty("maze.kind");
            if( mazeKind.equals("bombed") ) {
                theInstance = new BombedMazeFactory();
            } else if( mazeKind.equals("enchanted") ) {
                theInstance = new EnchantedMazeFactory();
            } else {
                theInstance = new MazeFactory();
            }
        }
        return theInstance;
    }
    …
}
```