301AA - Advanced Programming

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AP-09: *Frameworks and Inversion of Control*

Components: a recap

A **software component** can be defined as a ***modular***, ***reusable***, and ***encapsulated*** unit of software that provides a specific functionality or set of functionalities. It is designed to ***interact with other components*** via ***well-defined interfaces*** and can be ***independently developed***, ***deployed***, and ***maintained***.

- Examples: ***Java Beans, CLR Assemblies***
- *Well-defined interfaces*: events, methods and properties
- *Independently developed and deployed*: serializable, constructor with no argument
- *Composition model*: connection oriented programming (event source and listeners/delegates)

Software Frameworks

A **software framework** is a collection of *common code* providing *generic functionality* that can be *selectively overridden or specialized* by user code providing *specific functionality.*

Frameworks provide a standardized way to build and organize code, often offering pre-built functionality for tasks like user interface design, database interaction, and input/output management. The main benefits of using frameworks include:

- **Reusability**: Pre-written code for common tasks.
- **Efficiency**: Reduces development time and effort.
- **Structure**: Encourages best practices and organized code.
- **Extensibility**: Allows developers to customize and extend functionality while using core components.

General purpose Software Frameworks (1)

1. **Spring (Java)**
   - Use case: Enterprise-level Java applications, particularly web-based.
   - Features: Dependency injection, aspect-oriented programming (AOP), transaction management, and comprehensive web development support (via Spring MVC).
   - Notable projects: Large enterprise applications, microservices architecture (with Spring Boot).
2. **NET Framework (C# and .NET languages)**
   - Use case: Building Windows-based applications, web applications, and services.
   - Features: Comprehensive library for GUI, web apps, data access, and more; supports multiple languages (C#, VB.NET, etc.); provides ASP.NET for web development.
   - Notable projects: Enterprise-level web apps, desktop applications, cloud-based services.
3. **Django (Python)**
   - Use case: Web development using the Python language.
   - Features: Follows the "batteries-included" philosophy, meaning it comes with a lot of built-in features (ORM, admin panel, authentication, etc.); emphasizes rapid development and clean, pragmatic design.
   - Notable projects: Web applications, content management systems, and social networking sites.

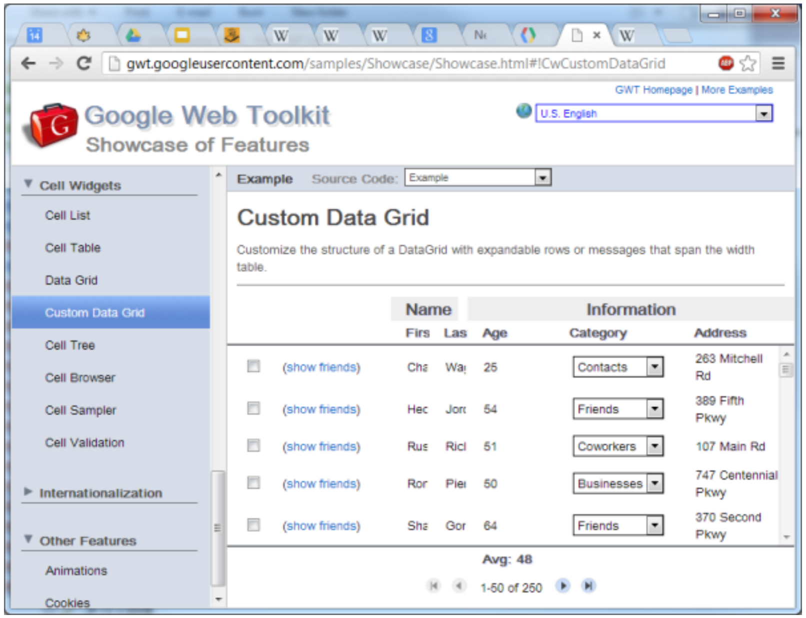
General purpose Software Frameworks (2)

4. **Ruby on Rails (Ruby)**
   - Use case: Web development with Ruby.
   - Features: Convention over configuration (fewer decisions to make), DRY (Don't Repeat Yourself) principle, built-in tools for database handling, scaffolding, and form handling.
   - Notable projects: Web applications like GitHub, Basecamp.
5. **React (JavaScript/TypeScript)**
   - Use case: Building user interfaces for web applications.
   - Features: Component-based architecture, virtual DOM for efficient UI updates, flexibility in integrating with other libraries or frameworks like Redux for state management.
   - Notable projects: Interactive user interfaces for single-page applications (SPAs), mobile apps (via React Native).
6. **Laravel (PHP)**
   - Use case: PHP-based web application development.
   - Features: Elegant syntax, built-in authentication, routing, ORM (Eloquent), task scheduling, and migrations.
   - Notable projects: Various types of web apps, from simple websites to complex enterprise applications.
7. **Qt (C++)**
   - Use case: Cross-platform desktop and embedded applications.
   - Features: GUI toolkit for desktop applications, support for cross-platform development (Windows, macOS, Linux), mobile, and embedded systems.
   - Notable projects: Applications in industries such as automotive, medical devices, and consumer electronics.

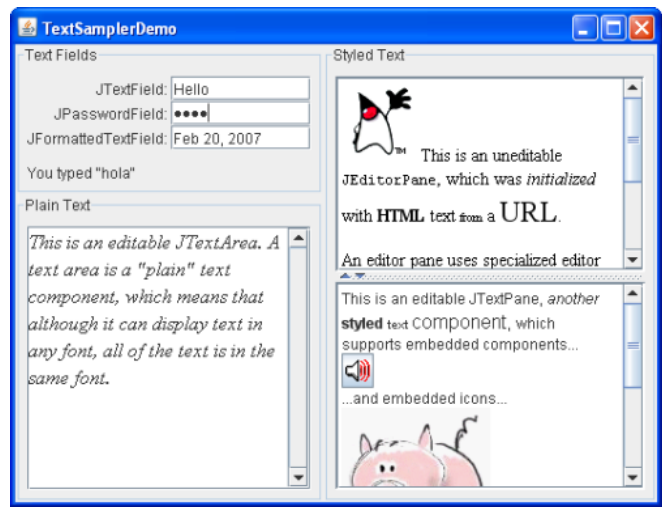
General purpose Software Frameworks (3)

8. **Electron (JavaScript)**
   - Use case: Building cross-platform desktop apps using web technologies (HTML, CSS, JS).
   - Features: Combines Node.js for backend functionality and Chromium for rendering web pages in desktop apps.
   - Notable projects: Desktop apps like Visual Studio Code, Slack, and Atom.
9. **Flask (Python)**
   - Use case: Lightweight web applications and APIs.
   - Features: Micro-framework with minimal built-in functionality, highly extensible, allows developers to pick and choose libraries as needed.
   - Notable projects: APIs and small-scale web apps, often paired with additional libraries for full-stack development.
10. **TensorFlow (Python, C++)**
    - Use case: Machine learning and AI applications.
    - Features: Provides tools for building deep learning models, including neural networks and natural language processing. Can be used for both research and production-level machine learning systems.
    - Notable projects: AI-driven applications, recommendation systems, image recognition software.

Application Frameworks



Web Application Frameworks



GUI Toolkits

Frameworks for Applications with GUI

- Qt (C++) - Autodesk Maya, VLC Media Player
- Electron (JavaScript) - Visual Studio Code, Slack, Discord
- JavaFX (Java) - Enterprise and educational tools, data visualization apps
- GTK (C) [default for Linux GNOME] - GIMP, Inkscape
- WPF (Windows Presentation Foundation, C#/.NET) - Visual Studio, Windows internal tools
- Swing (Java) - Enterprise apps, educational and simulation tools
- Tkinter (Python) - Basic desktop utilities, educational apps
- wxWidgets (C++) - Offers native-looking applications on Windows, macOS, and Linux
- Avalonia (C#/.NET) - open-source framework for building cross-platform .NET applications.

Frameworks for concurrency

- **Apache Hadoop** - software framework for applications which process big amounts of data in-parallel using the Map/Reduce programming model on large clusters (thousands of nodes) in a fault-tolerant manner.
    - **Map:** Takes input data and converts it into a set of tuples (key/value pairs).
    - **Reduce:** Takes the output from Map and combines the data tuples into a smaller set of tuples.

Features of Frameworks

- A framework embodies some abstract design, with more behavior built in.
- In order to use it you need to insert your behavior into various places in the framework either by subclassing or by plugging in your own classes.
- The framework's code then calls your code at these points.
- A very general concept, emphasizing ***inversion of control***: as opposed to libraries, is the code of the framework that calls the programmer's code

Component Frameworks

- Frameworks that support development, deployment, composition and execution of components designed according to a given **Component Model**
- Support the **development of individual components**, enforcing the design of precise interfaces
- Support the **composition/connection of components** according to the mechanisms provided by the Component Model
- Allow instances of these components to be “plugged” into the component framework itself
- Provide **prebuilt functionalities**, such as useful components or automated assembly functions that automatically instantiate and compose components to perform common tasks.
- The component framework establishes **environmental conditions** for the component instances and regulates the **interaction** between component instances.

Frameworks vs Integrated Development Environments (IDEs)

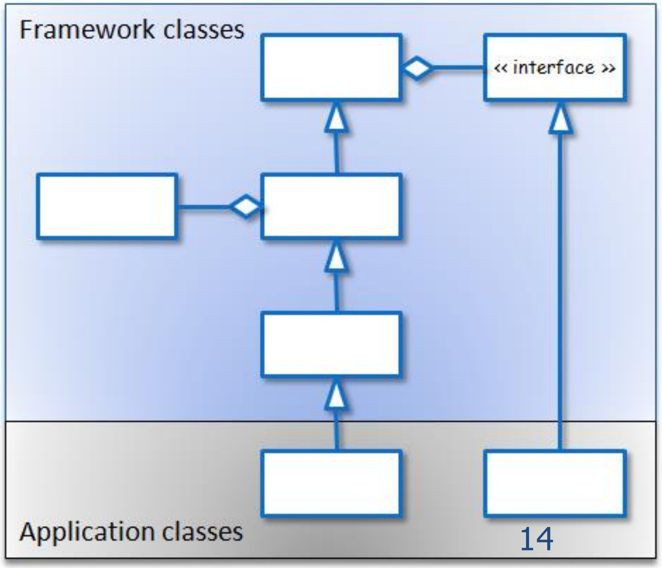
- Orthogonal concepts
- A framework can be supported by several IDEs
  - Eg: Spring supported by Spring Tool Suite (based on Eclipse), NetBeans, IntelliJ IDEA, Eclipse, …
- An IDE can support several frameworks
  - Eg: NetBeans supports JavaBeans, Spring, J2EE, Maven, Hibernate, JavaServer Faces, Struts, Qt,…

Frameworks Features

- Consist of **parts** that are found in many apps of that type
  - **Libraries** with APIs (classes with methods etc.)
  - Ready-made extensible programs ("**engines**")
  - Sometimes also **tools** (e.g. for development, configuration, content)
- Frameworks, like software libraries, provide ***reusable abstractions*** of code wrapped in a well-defined API
- But: **Inversion of control**
  - unlike in libraries, the overall program's flow of control is not dictated by the caller, but by the framework
- Helps solving recurring design problems
  - Providing a default behavior
  - Dictating how to fill-in-the-blanks
- Non-modifiable framework code
  - Extensibility: usually by selective overriding

Extensibility

- All frameworks can be extended to cater for app-specific functionality.
  - A framework is intended to be extended to meet the needs of a particular application
- Common ways to extend a framework:
  - Extension within the framework language:
    - Subclassing & overriding methods
    - Implementing interfaces
    - Registering event handlers
  - Plug-ins: framework can load certain extra code in a specific format



Two selected topics

We give a closer look to two general topics related to frameworks:

- Inversion of control
- Mastering dependencies among components

Inversion of Control (IoC) in GUIs

```
#ruby
puts 'What is your name?'
name = gets
process_name(name)
puts 'What is your quest?'
quest = gets
process_quest(quest)
```

TEXT

```
require 'tk'
root = TkRoot.new()
name_label = TkLabel.new() {text "What is Your Name?"}
name_label.pack
name = TkEntry.new(root).pack
name.bind("FocusOut") {process_name(name)}
quest_label = TkLabel.new() {text "What is Your Quest?"}
quest_label.pack
quest = TkEntry.new(root).pack
quest.bind("FocusOut") {process_quest(quest)}
Tk.mainloop()
```

GUI

- In text-based interaction, the order of interactions and of invocations is decided by the the code.
- In the GUI-based interaction, the GUI loop decides when to invoke the methods (listeners), based on the order of events

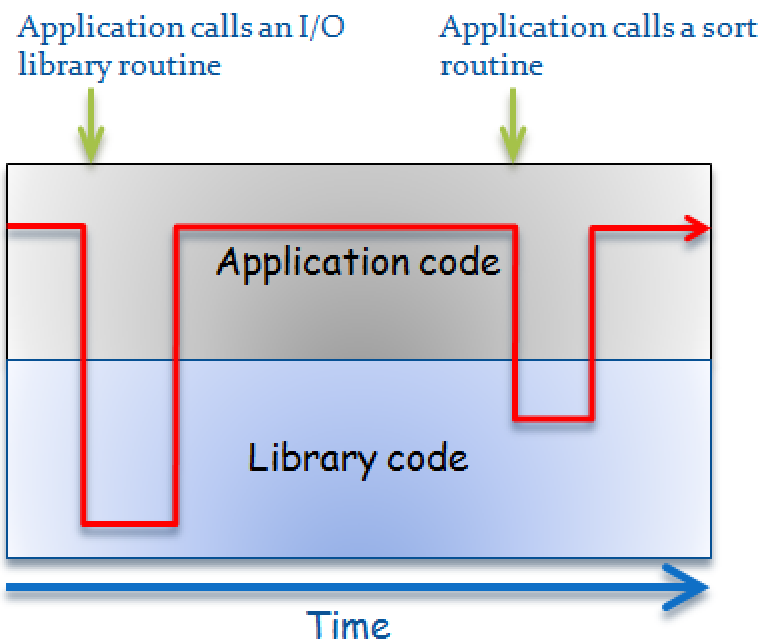
https://martinfowler.com/bliki/InversionOfControl.html

Inversion of Control in Frameworks

- With Frameworks the **Inversion of Control** becomes dominant
- The application architecture is often fixed, even if customizable, and determined by the Framework
  - When using a framework, one usually just implements a few callback functions or specializes a few classes, and then invokes a single method.
  - The framework does the rest of the work for you, invoking any necessary client callbacks or methods at the appropriate time and place.
  - In essence, IoC in frameworks lets developers focus more on business logic while the framework manages lower-level operations like object creation and lifecycle management.
- Example: Java's Swing and AWT classes, NetBeans projects
  - They have a huge amount of code to manage the user interface, and there is inversion of control because you start the GUI framework and then wait for it to call your listeners

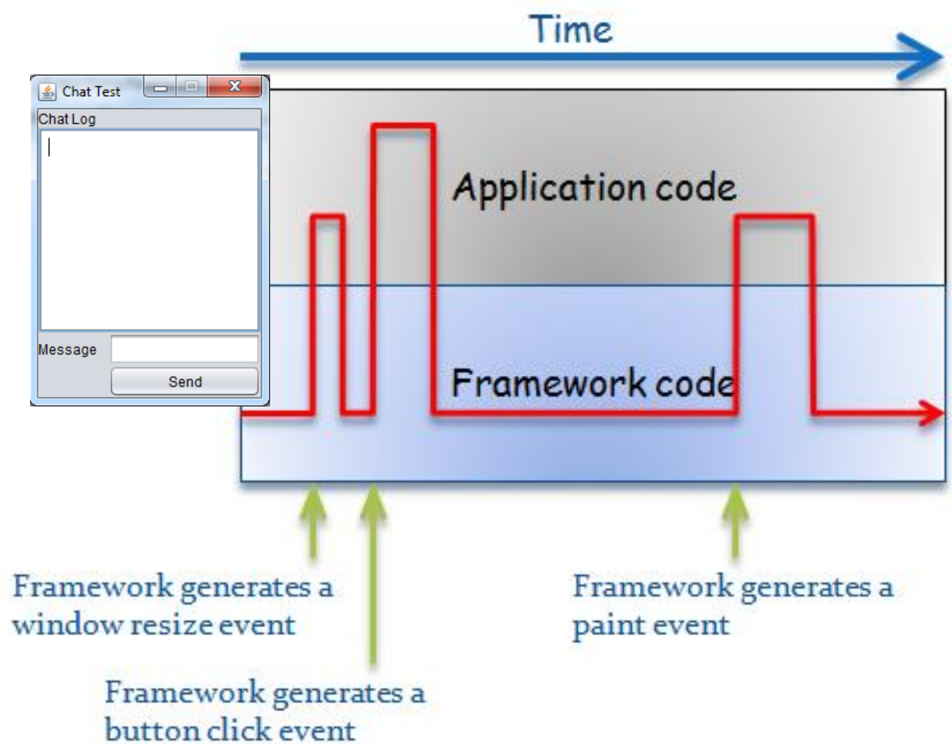
Inversion of Control

Traditional Program Execution



The app has control over the execution flow, calling library code when it needs to.

Inversion of Control

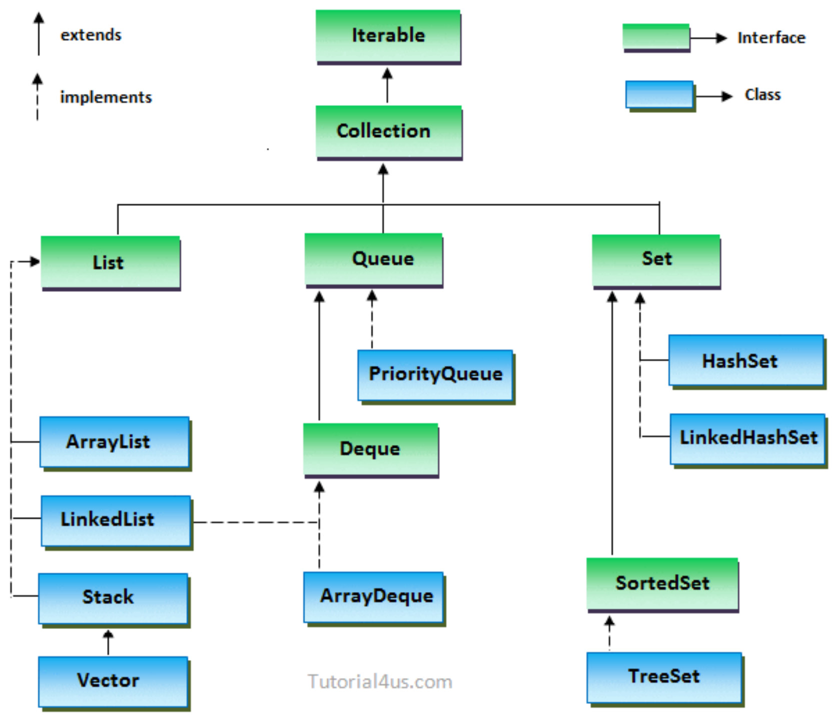


The framework has control over the execution flow, calling app code for app-specific behavior.

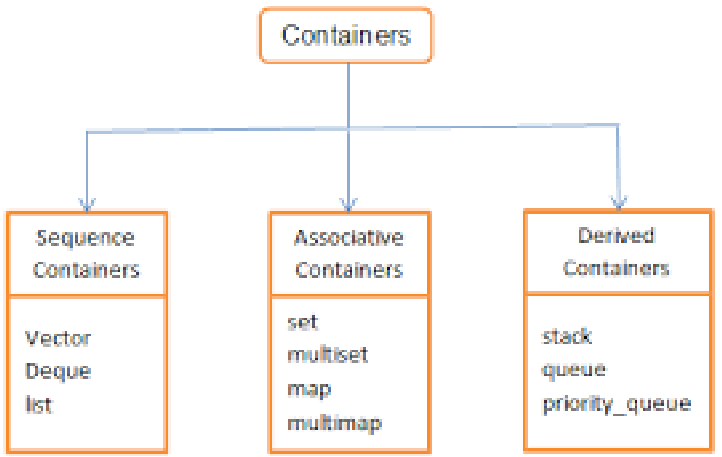
Frameworks vs Libraries

- Frameworks consist of large sets of classes /interfaces, suitably packaged
- Not much different from libraries
- (Possible) Key feature: wide use of Inversion of Control
- “Framework” sometimes intended as “well-designed library”
- **Java Collection Framework** vs C++ **Standard Template Library**: are them *frameworks* or *libraries*?

JCF vs STL



Java Collection Framework



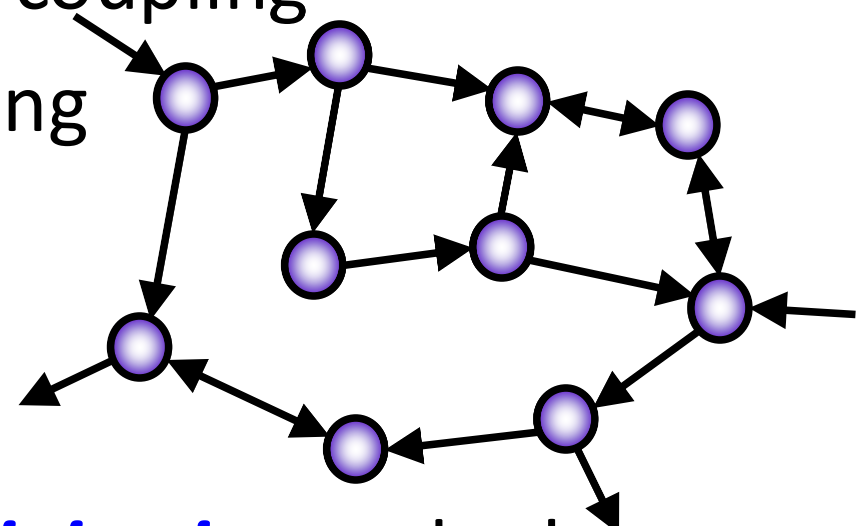
Standard Template Library

Components, Containers and IoC

- Often Frameworks provide ***containers*** for deploying components
- A container may provide at runtime functionalities needed by the components to execute
- Example: ***EJB containers*** are responsible of the persistent storage of data and of the availability of EJB's for all authorized clients
- Using IoC, EJB containers can invoke on session beans methods like *ejbRemove*, *ejbPassivate* (store to secondary storage), and *ejbActivate* (restore from passive state).
- **Spring's IoC containers**: a related concept…

Loosely coupled systems: advantages and techniques

- Good OO Systems should be organised as network of interacting objects
- Goal: High cohesion, low coupling
- Advantages of low coupling
  - Extensibility
  - Testability
  - Reusability



- We discuss ***Dependency injection*** and other techniques to achieve it

Nick Hines - *Dependency Injection and Inversion of Control* - ThoughtWorks, 2006

More on Inversion of Control

- **Control**: not only *control flow,* but also control over *dependencies, coupling, configuration*
- **Inversion**: component gives up control to a framework and agrees to play by some rules
- Framework calls component in well-defined ways (setters, template methods, interface)

Dependency injection

- IoC with respect to dependencies
- something outside a component handles:
  - configuration (properties)
  - wiring / dependencies (components)
- component-oriented
- removes coupling
  - coupling of configuration and dependencies to the point of use
  - coupling of component to concrete dependent components
- somewhat contrary to encapsulation

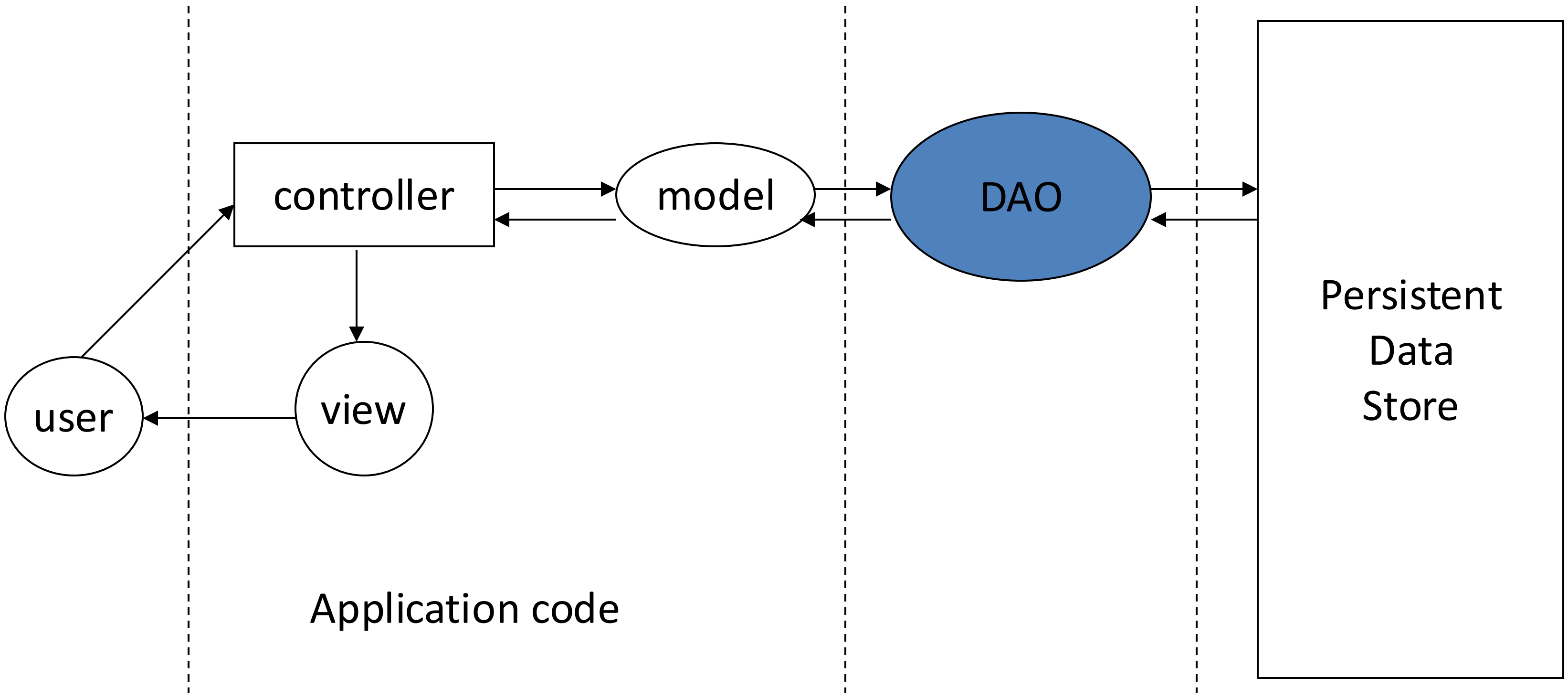
A Concrete Example – A Trade Monitor

- *A trader wants that the system rejects trades when the exposure reaches a certain limit*
- Thus the component **TradeMonitor** (a class…) provides a method **TryTrade** which checks the condition
- The current exposure and the exposure limit are stored in some persistent storage, and are accessed by TryTrade using another component, a **DAO** (Data Access Object)
- We discuss various solutions to limit dependencies among the two components

```
public class TradeMonitor
{
     // other stuff
     public bool TryTrade(string symbol, int amount){
          int limit = limitDao.GetLimit(symbol);
          int exposure = limitDao.GetExposure(symbol);
          return (exposure + amount > limit) ? false : true;
        }
 }
```

Data Access Object (DAO)

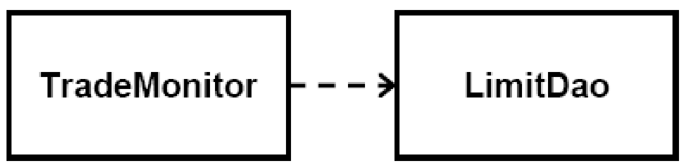
- A Java EE design pattern



Trade Monitor – The first design

```
public class TradeMonitor
{
   private LimitDao limitDao;

   public TradeMonitor()
   {
      limitDao = new LimitDao();
   }

   public bool TryTrade(string symbol, int amount)
   {
      int limit = limitDao.GetLimit(symbol);
      int exposure = limitDao.GetExposure(symbol);
 return (exposure + amount > limit)? false : true;
   }
}
```

```
public class LimitDao
{
    public int GetExposure(string symbol)
    {
        // Do something with the database
    }

    public int GetLimit(string symbol)
    {
       // Do something with the database
    }
}
```

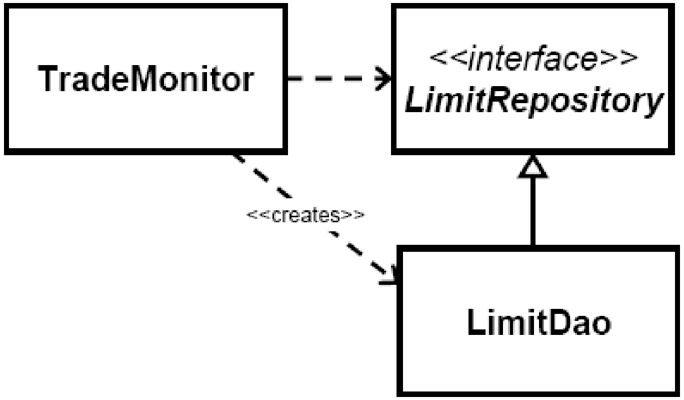


- TradeMonitor is tightly coupled to LimitDao
  - ***Extensibility*** – what if we replace the database with a distributed cache?
  - ***Testability*** – where do the limits for test come from?

Trade Monitor – The Design Refactored (1)

- Introduce **interface/implementation** separation
  - Logic does not depend on DAO anymore.
  - Does this really solve the problem?
- The constructor still has a static dependency on DAO

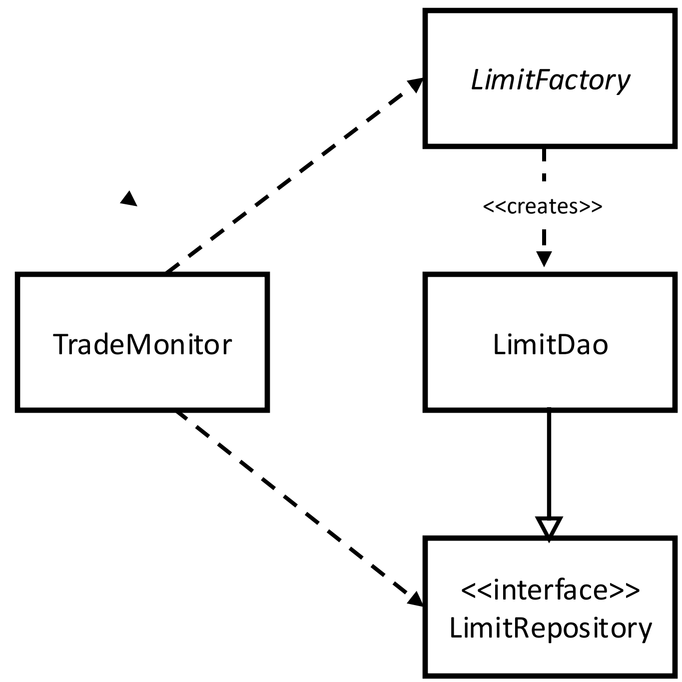
```
public interface LimitRepository
{
        int GetExposure(string symbol);
        int GetLimit(string symbol);
}
public class LimitDao extends LimitRepository
{
        public int GetExposure(string symbol){…}

        public int GetLimit(string symbol){…}
}
public class TradeMonitor
{
        private LimitRepository limitRepository;

        public TradeMonitor()
        {
            limitRepository = new LimitDao();
        }

        public bool TryTrade(string symbol, int amount)
        {
      . . .
        }
}
```



Trade Monitor – The Design Refactored (2)

- Introduce a ***Factory***. It has the responsibility to create the required instance.
- TradeMonitor decoupled from LimitDao
- LimitDao still tightly-coupled, this time to Factory

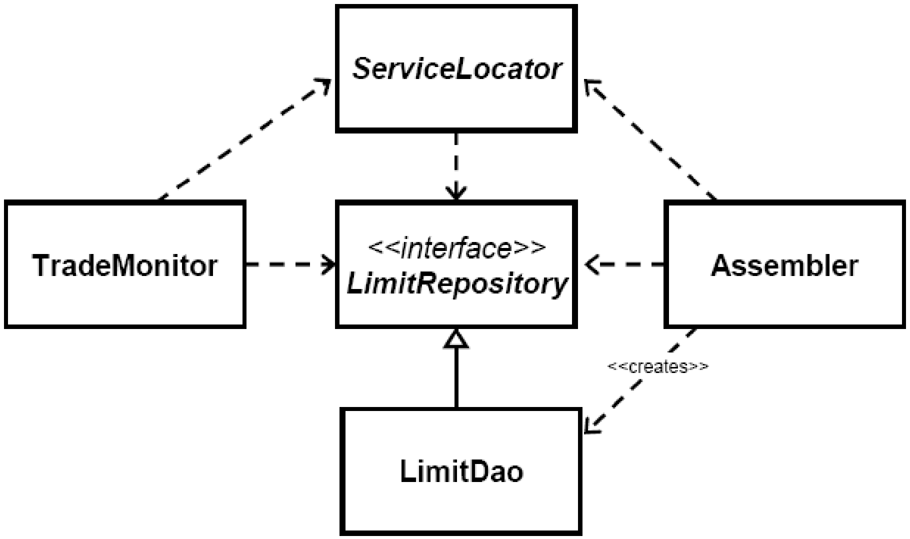
```
public class LimitFactory
{
        public static LimitRepository GetLimitRepository()
        {
            return new LimitDao();
        }
}

public class TradeMonitor
{
        private LimitRepository limitRepository;

        public TradeMonitor()
        {
        limitRepository = LimitFactory.GetLimitRepository();
        }

        public bool TryTrade(string symbol, int amount)
        {
            . . .
        }
}
```



Trade Monitor – The Design Refactored (3)

- Introduce a ***ServiceLocator***. This object acts as a (static) registry for the LimitDao you need.
- This gives us extensibility, testability, reusability
- Note that an external Assembler sets up the registry

```
public class ServiceLocator{

    public static void RegisterService(Type t, object o)
            {. . .}
    public static object GetService(Type t)
            {. . .}
}

public class TradeMonitor{
     private LimitRepository limitRepository;

     public TradeMonitor(){
         object o =
      ServiceLocator.GetService(typeof(LimitRepository));
         limitRepository = (LimitRepository) o;
     }

     public bool TryTrade(string symbol, int amount){
         . . .
     }
}
```



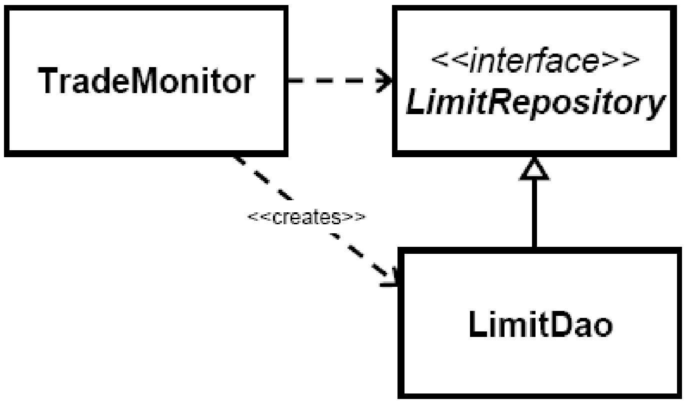
ServiceLocator – Pros and cons

- The Service Locator pattern succeeds in decoupling the **TradeMonitor** from the **LimitDao**
- Allows new components to be dynamically created and used by other components later
- It can be generalized in several ways, eg. to cover dynamic lookup

Cons:

- Every component that needs a dependency must have a reference to the service locator
- All components need to be registered with the service locator
- If bound by name:
  - Services can't be type-checked
  - Component has a dependency to the dependent component names
  - if many components share an instance but later you want to specify different instance for some, this becomes difficult
- If bound by type:
  - Can only bind one instance of a type in a container
- Code needs to handle lookup problems

Towards Dependency Injection



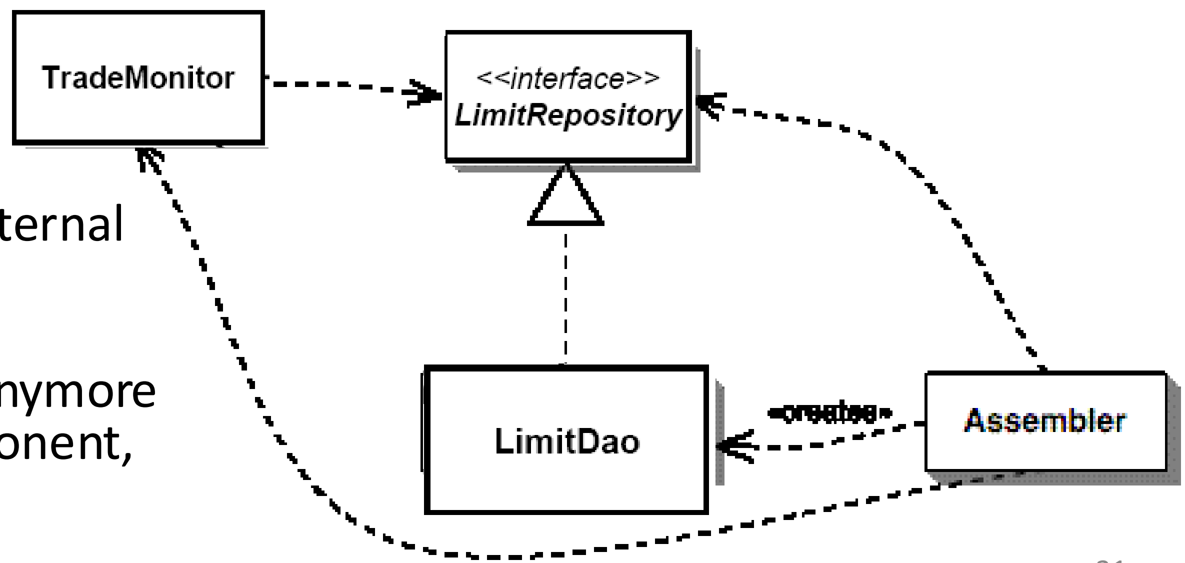
- In the original situation, we aim at relaxing the coupling using solutions based on ***Inversion of Control***

Q: Which “control” is inverted?

A: The dependency of TradeMonitor from the LimitDao

The plugin is created by an external ***Assembler*** and it is passed to TradeMonitor in some way.

Thus the dependency is not anymore in the code of the main component, but it is ***injected*** into it



Dependency Injection

- **Dependency injection** allows avoiding hard-coded dependencies (strong coupling) and changing them
- Allows selection among multiple implementations of a given dependency interface at run time
- Examples:
  - load plugins dynamically
  - replace ***mock objects*** in test environments vs. real objects in production environments
- Three forms:
  - Setter injection
  - Constructor injection
  - *(Interface injection)*

Dependency injection based on **setter methods**

- Idea: add a **setter,** leaving creation and resolution to others

```
public class TradeMonitor
 {
        private LimitRepository limitRepository;

        public TradeMonitor()
        {
        }

        public LimitRepository Limits
        {
            set { limitRepository = value;}
        }
        public bool TryTrade(string symbol, int amount){
                . . .
        }
}
```

This is ***Setter Injection***

- Widely used in ***Spring***

- Pros:
  - Leverages existing JavaBean reflective patterns
  - Simple, often already available
- Cons:
  - Possible to create partially constructed objects
  - Advertises that dependency can be changed at runtime (as opposed to constructor)

Dependency Injection based on **Constructors**

- Why not just use the constructor?

```
public class TradeMonitor
{
    private LimitRepository limitRepository;

    public TradeMonitor(LimitRepository
                           limitRepository)
    {
        this.limitRepository = limitRepository;
    }
    public bool TryTrade(string symbol, int amount){
                 . . .
     }
}
```

This is ***Constructor Injection***

- Widely used in ***PicoContainer***

Pros:

- Object can't be partially constructed
- Simple, often already available

Cons:

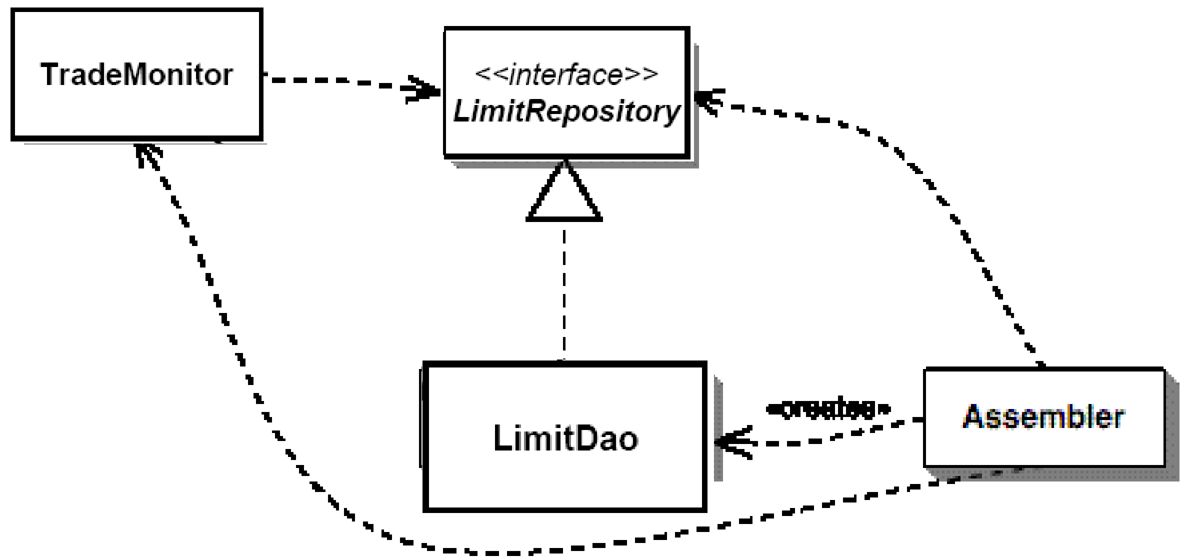
- Bidirectional dependencies between objects can be tricky
- Constructors can easily get big and parameters confusing
- If lots of optional dependencies, may have lots of constructors
- Can make class evolution more complicated (an added dependency affects all users of the class) wrt setter injection

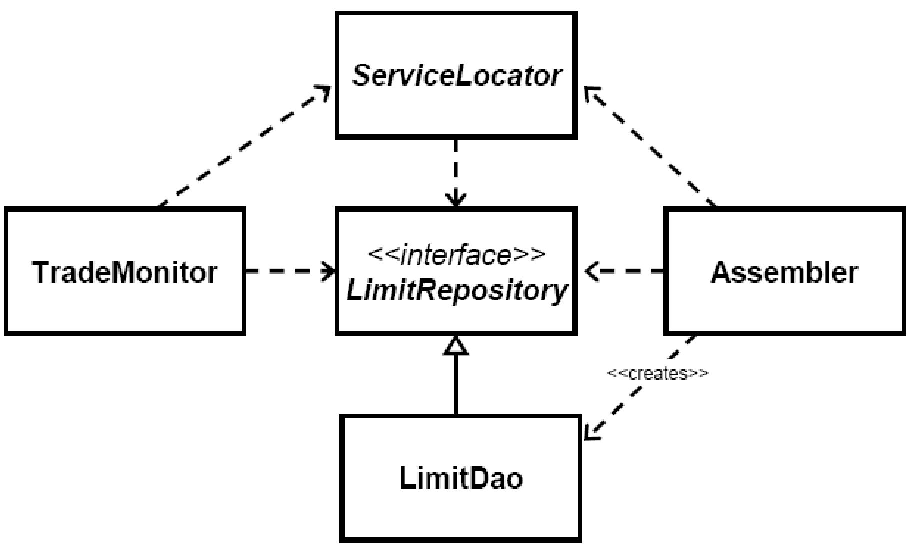
Exploiting Constructor Injection for Testing

```
public class TradeMonitor
{
    private LimitRepository repository;

    public TradeMonitor(LimitRepository repository) { this.repository =
repository; }

    public bool TryTrade(string symbol, int amount)
    {
        int limit = repository.GetLimit(symbol);
        int exposure = repository.GetExposure(symbol);
        return ((amount + exposure) <= limit);
    }
}
```

```
[TestFixture]
public class TradeMonitorTest
{
    [Test]
    public void MonitorBlocksTradesWhenLimitExceeded()
    {
        DynamicMock mockRepository = new DynamicMock(typeof(LimitRepository));
        mockRepository.SetupResult('GetLimit', 1000000, new Type[] { typeof(string) });
        mockRepository.SetupResult('GetExposure', 999999, new Type[] { typeof(string) });

        TradeMonitor monitor = new
    TradeMonitor((LimitRepository)mockRepository.MockInstance);
        Assert.IsFalse(monitor.TryTrade('MSFT', 1000), 'Monitor should block trade');
    }
}
```

Summary: decoupling using Service Locator vs Dependency Injection





Which solution to use?

- Both **Service Locator** and **Dependency Injection** provide the desired decoupling
- With service locator, the desired component is obtained after request by the **TradeMonitor** to the **Locator**: no IoC
- With dependency injection there is no explicit request: the component appears in the application class
- Inversion of control a bit harder to understand
- With Service Locator the application still depends on the locator
- It is easier to find dependencies of component if Dependency Injection is used
  - Check constructors and setters vs check all invocations to locator in the source code

Towards IoC Containers

- There are still some open questions
  - Who creates the dependencies? (who is the "Assembler"?)
  - What if we need some initialisation code that must be run after dependencies have been set?
  - What happens when we don't have all the components?
- **IoC Containers** solve these issues [eg: **Spring**]
  - Have configuration – often external
  - Create objects
  - Ensure all dependencies are satisfied
  - Provide lifecycle support

Other possible solutions

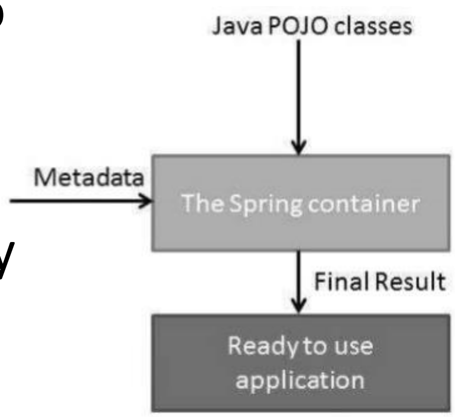
- **Reflection** can be used to determine dependencies, reducing the need for config files.
  - Make components known to container.
  - Container examines constructors and determines dependencies.
- Most IoC containers support **auto-wiring**: automatic wiring between properties of a bean and other beans based, eg, on name or type
- Auto-wiring provides other benefits:
  - Less typing.
  - Static type checking by IDE at edit time.
  - More intuitive for developer.

Dependency injection in Spring

- The objects that form the backbone of a Spring application are called **beans**
- A bean is an object that is instantiated, assembled, and otherwise managed by a **Spring IoC container**
- Bean definition contains the information called **configuration metadata**, which is needed for the container to know the following
  - How to create a bean
  - Bean's lifecycle details
  - Bean's dependencies
- The configuration metadata can be supplied to the container in three possible ways:
  - **XML based configuration file** (the standard)
  - **Annotation-based** configuration
  - **Java-based** configuration

Spring IoC containers

- The **Spring container** is at the core of the Spring Framework.
- The container will create the objects, wire them together, configure them, and manage their complete life cycle from creation till destruction.
- The Spring container uses **Dependency Injection** to manage the components that make up an application.
- The container gets its instructions on what objects to instantiate, configure, and assemble by reading the **configuration metadata** provided.
- The Spring IoC container makes use of Java POJO classes and configuration metadata to produce a fully configured and executable system or application.



```java
public class HelloWorld {
	private String message;
	public void setMessage(String message){
		this.message  = message;
	}
	public void getMessage(){
		System.out.println("Your Message : " + message);
	}
}
```

The bean: a POJO (Plain Old Java Object)

Setter Injection (performed by the IoC container)

```xml
<?xml version = "1.0" encoding = "UTF-8"?>
<beans xmlns = "http://www.springframework.org/schema/beans"
  xmlns:xsi = "http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation = "http://www.springframework.org/schema/beans
  http://www.springframework.org/schema/beans/spring-beans-3.0.xsd”>
  <bean id = "helloWorld" class = "com.tutorialspoint.HelloWorld">
    <property name = "message" value = "Hello World!"/>
  </bean>
</beans>
```

The Configuration Metafile (XML)

```java
// imports…
public class MainApp {
  public static void main(String[] args) {
    ApplicationContext context = new ClassPathXmlApplicationContext("Beans.xml");
    HelloWorld obj = (HelloWorld) context.getBean("helloWorld");
    obj.getMessage();   }}
```

The main class, loading an Application Context

Summary

- Recap: JavaBeans as Components
- Frameworks, Component Frameworks and their features
- Frameworks vs IDEs
- Inversion of Control and Containers
- Frameworks vs Libraries
- Decoupling Components
- Dependency Injection vs Service Locator
- IoC Containers in Spring