301AA - Advanced Programming

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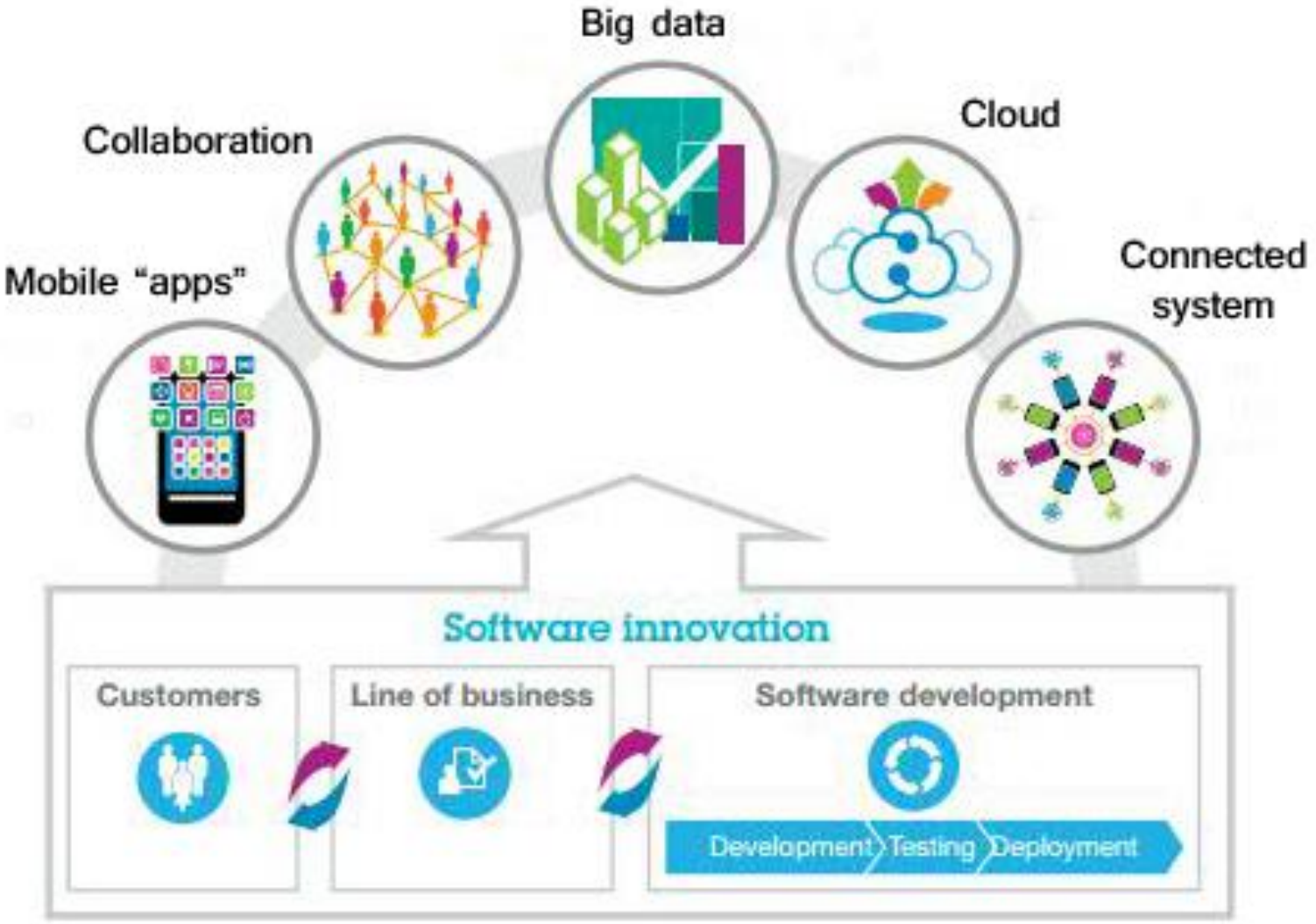
***AP-02**: Motivations and Introduction*

Software is Everywhere



Programming in the 21 century

- Software as complex as ever
- Command line interface not enough
- Data comes from multiple sources: structured (DB) and unstructured
- Single computer not enough
- Software development is a group activity
- Deployment on Web or mobile devices

Complexity Prompts for Innovation

- Object-Oriented Programming allows ever larger applications to be built
- But limited support for reuse
- OS + libraries not enough
- Reusable components are needed
- Multi-tier applications development increases the choices on how to build applications

Key Ingredients for Complex Software

- **Advanced features** extending programming languages
- **Component models** to ensure reusability
- **Frameworks** to support efficient development of (component based) applications
- **Execution environments** providing runtime support for ever dynamic software systems

The Software Architect

- A new role is needed: **Software Architect**
- to create, define or choose an **application framework**
- to create the component design according to a **component model**
- to structure a complex application into pieces
- to understand the interactions and dependencies among components
- to select the **execution environment / platform** based on cost/performance criteria
- to organize and supervise the development process

Course Objectives

- Understand programming language technology:
  - Execution Models
  - Run-time systems
- Analyze programming metaphors:
  - Objects
  - Components
  - Patterns
- Learn advanced programming techniques
- Present state-of-the-art frameworks incorporating these techniques
- Practice with all these concepts through small projects

Course Syllabus

- Programming Language Pragmatics
- Run Time Support and Execution Environments: the Java Virtual Machine
- Components based programming and Frameworks
- Polymorphism: a classification and examples in several languages
- Functional languages: Haskell and advanced concepts
- Stream API and lambda-expressions in Java
- Ownership and Borrowing in Rust
- Scripting Languages and Python

Programming language pragmatics

- Syntax, Semantics and Pragmatics of PLs
- Programming languages and Abstract Machines
- Interpretation vs. Compilation vs. Mixed
- Examples of Virtual Machines
- Examples of Compilation Schemes

Run-Time Systems and the JVM

- RTSs provide a Virtual Execution Environment interfacing a program in execution with the OS.
- They support, among others:
  - Memory Management, Thread Management
  - Exception Handling and Security
  - AOT and JIT Compilation
  - Dynamic Link/Load
  - Debugging Support and Reflection
  - Verification
- A concrete example: the Java Virtual Machine

Component-based Programming

- Component models and frameworks, an Introduction
- Examples of component-based frameworks:
  - JavaBeans and NetBeans
  - Spring and Spring Beans
  - COM
  - CLR and .NET
  - OSGi and Eclipse
  - Hadoop Map/Reduce

Software Frameworks and Inversion of Control

Software Framework: A collection of *common code* providing *generic functionality* that can be *selectively overridden or specialized* by user code providing *specific functionality*

Inversion of control: unlike in libraries, the overall program's flow of control is not dictated by the caller, but by the framework

Framework Design is a challenging task. It requires mastering of design patterns, OO methods, polymorphism…

Polymorphism and Generic Programming

- A classification of Polymorphism
- Polymorphism in C++: inclusion polymorphism and templates
- Java Generics
- The Standard Template Library: an overview
- Generics and inheritance: invariance, covariance and contravariance

Functional programming and Haskell

- Introduction to Functional Programming
- Evaluation strategies (lambda-calculus)
- Haskell: main features
- Type Classes and overloading
- Monads
- Functional programming in Java
  - Lambdas and Stream API

Scripting Languages and Python

- Overview of scripting languages
- Main features of Python
- Imperative, functional and OO programming in Python
- Higher-order functions and Decorators
- On the implementation of Python: the Global Interpreter Lock

Selected Advanced Concepts in Programming Languages

- Closures vs Delegates in CLI
- The RUST programming language
  - Avoiding Aliases + Mutable: Ownership and borrowing
  - Traits, generics and inheritance
- …

Design Patterns

Design Patterns in a few slides

- A fundamental concept in Software Engineering & Programming, useful whenever one is designing a solution to a problem
- We shall meet several Design Patterns along the course (e.g., *Observer* or *Publish-Subscribe, Visitor, Template Method,*…)
- Just a brief introduction…

Design Patterns: From Architecture to Software Development

- Invented in the 1970's by architect Christopher Alexander:

"Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice"

Christopher Alexander, A Pattern Language, 1977

- The book includes 253 patterns for architectural design
- Common definition of a pattern:

"A solution to a problem in a context."

- Patterns can be applied to many different areas of human endehavour, including software development (where they are more successful!)

(Software) Design Patterns

- A **(software) design pattern** is a general, reusable solution to a commonly occurring problem within a given context in software design.
- Different abstraction levels:
  - Complex design for an entire application or subsystem
  - Solution to a general design problem in a particular context
  - Simple reusable design class such as ***linked list***, ***hash table***, etc.

Patterns solve **software structural problems** like:

- Abstraction
- Encapsulation
- Information hiding
- Separation of concerns
- Coupling and cohesion
- Separation of interface and implementation
- Single point of reference
- Divide and conquer

Patterns also solve **non-functional problems** like:

- Changeability
- Interoperability
- Efficiency
- Reliability
- Testability
- Reusability

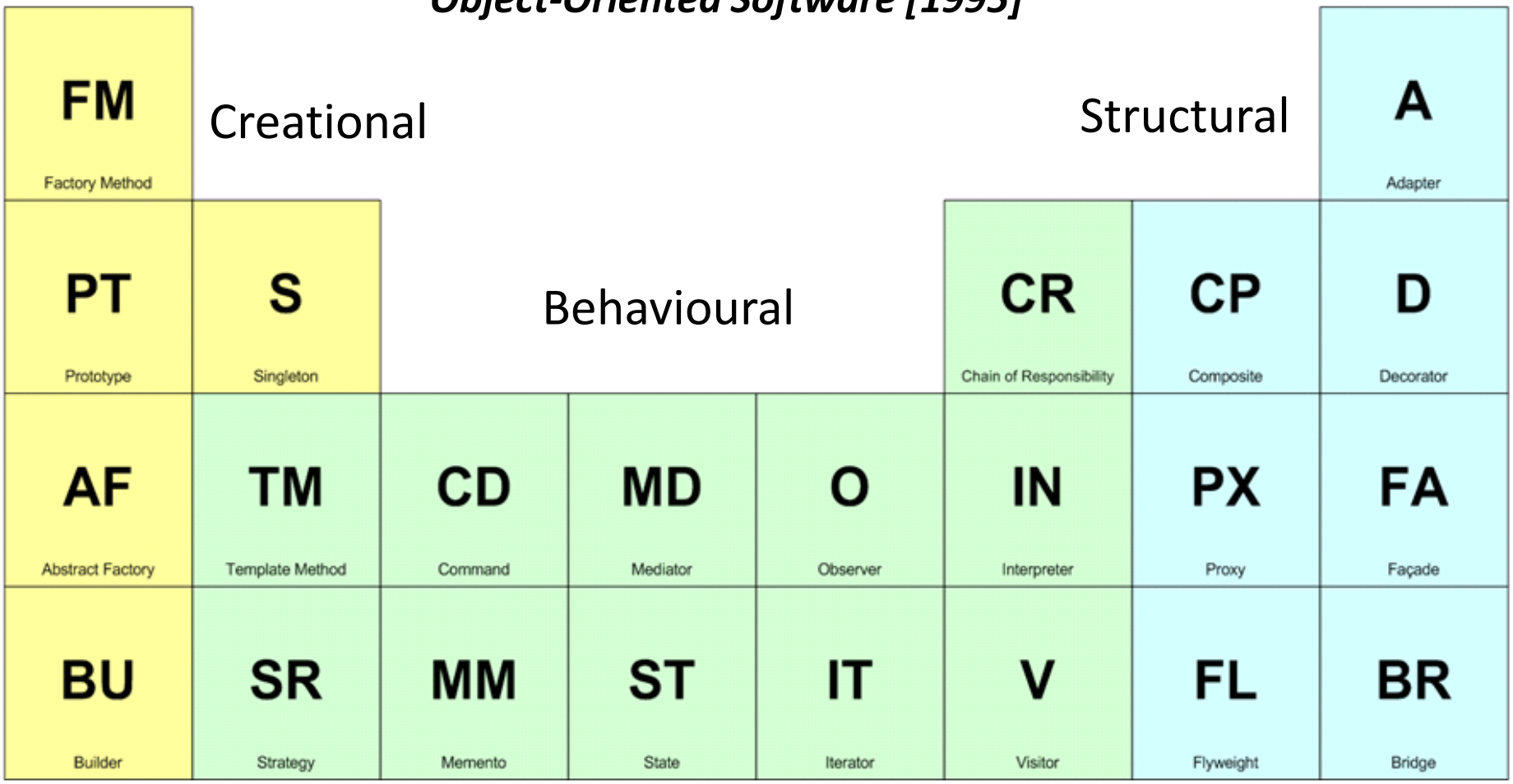
Main components of a Design Pattern

- **Name**: meaningful text that reflects the problem, e.g. Bridge, Mediator, Flyweight
- **Problem addressed**: intent of the pattern, objectives achieved within certain constraints
- **Context**: circumstances under which it can occur, used to determine applicability
- **Forces**: constraints or issues that solution must address, forces may conflict!
- **Solution**: the static and dynamic relationships among the pattern components. Structure, participants, collaboration. Solution must resolve all forces!

The 23 Design Patterns of the Gang of Four

Erich Gamma, Richard Helm, Ralph Johnson and John Vlissides

Design Patterns: Elements of Reusable Object-Oriented Software [1995]



5.5. Pattern: Singleton (Creational)

Name: Singleton

Problem:

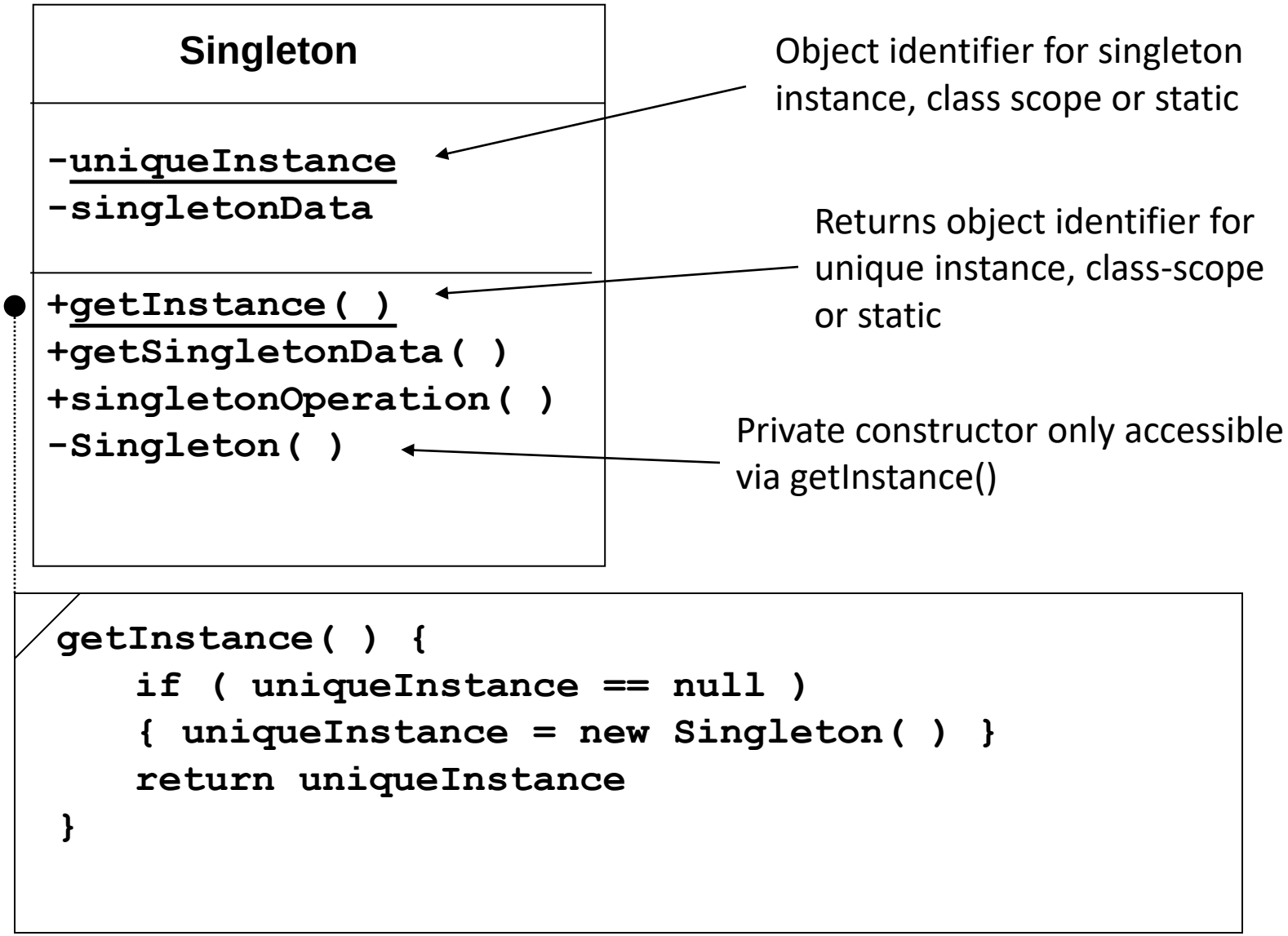
How can we guarantee that one and only one instance of a class can be created?

Context: In some applications it is important to have exactly one instance of a class, e.g. sales of one company.

Forces: Can make an object globally accessible as a global variable, but this violates encapsulation.
Could use class (static) operations and attributes, but polymorphic redefinition is not always possible.

Solution:
Create a class with a class operation **getInstance()**.
When class is first accessed, this creates relevant object instance and returns object identity to client.
On subsequent calls of **getInstance()**, no new instance is created, but identity of existing object is returned.

Singleton Structure




```
getInstance( ) {
    if ( uniqueInstance == null )
    { uniqueInstance = new Singleton( ) }
    return uniqueInstance
}
```

Example: Code

```
class Singleton {
   private static Singleton uniqueInstance = null;
   private Singleton( ) { .. } // private constructor
   public static Singleton getInstance( ) {
    if (uniqueInstance == null)
        uniqueInstance = new Singleton(); //call constructor
    return uniqueInstance;
   }
}
```

Comments

- To specify a class has only one instance, we make it inherit from **`Singleton`**.

+ controlled access to single object instance through **`Singleton`** encapsulation

+ Can tailor for any finite number of instances

+ namespace not extended by global variables

- access requires additional message passing

- Pattern limits flexibility, significant redesign if singleton class later gets many instances