

# Concepts of Object-Oriented Programming

**Peter Müller**

Programming Methodology Group

Autumn Semester 2024

**ETH** zürich

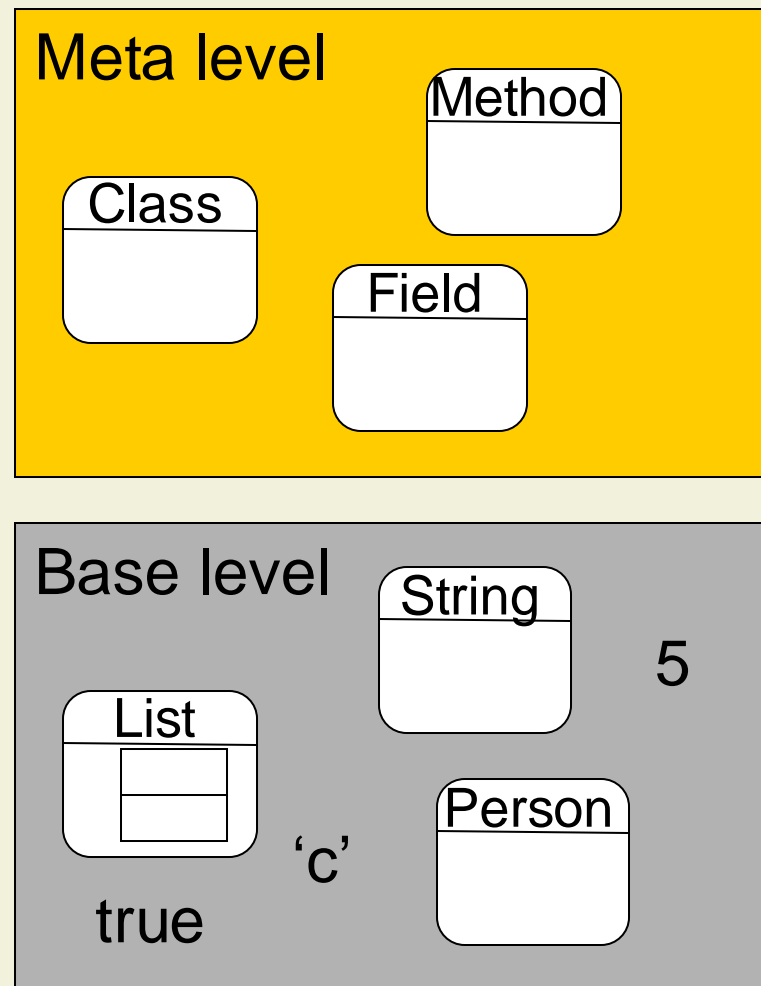
# Repetition: Dynamic Type Checking

- **instanceof** can be used to avoid run-time errors
- **instanceof** makes type information available to program executions

```
Object[ ] oa = new Object[ 10 ];  
String s = "A String";  
  
oa[ 0 ] = s;  
  
...  
if ( oa[ 0 ] instanceof String )  
    s = ( String ) oa[ 0 ];  
s = s.concat( "Another String" );
```

# Reflection

- A program can **observe and modify** its own **structure and behavior**
- Simplest form
  - Type information is available at run time
- Most elaborate
  - All compile-time information can be observed and modified



# 7. Reflection

## 7.1 Introspection

## 7.2 Reflective Code Generation

## 7.3 Dynamic Code Manipulation

# Class Objects

```
class Class<T> ... {  
    static Class<?>    forName( String name ) throws ...      {...}  
    Method[ ]  getMethods( )                                {...}  
    Method[ ]  getDeclaredMethods( )                        {...}  
    Method     getMethod( String name, Class<?>... parTypes ) {...}  
    Class<? super T> getSuperclass( )                       {...}  
    boolean     isAssignableFrom( Class<?> cls )           {...}  
    T           newInstance( ) throws ...                   {...}  
    ... }
```

Java

- The Class-object for a class can be obtained by the pre-defined class-field

```
Class StringClass = String.class;
```

# Example: Simple Introspection

```
import java.lang.reflect.*;

public class FieldInspector {
    public static void main( String[ ] ss ) {
        Class cl = Class.forName( ss[ 0 ] );
        Field[ ] fields = cl.getFields( );

        for( int i = 0; i < fields.length; i++ ) {
            Field f = fields[ i ];
            Class type = f.getType( );
            String name = f.getName( );
            System.out.println( type.getName( ) + " " + name + "; " );
        }
    }
}
```

Java

Error  
handling  
omitted

# Example: Universal toString-Method

```
public static String getString( Object o ) {  
    if ( o == null ) return "null";  
    Class toExamine = o.getClass( );  
    String state = "[";  
    Field[ ] fields = toExamine.getDeclaredFields( );  
    for ( int fi = 0; fi < fields.length; fi++ ) {  
        Field f = fields[ fi ];  
        if ( !Modifier.isStatic( f.getModifiers( ) ) )  
            state += f.getName( ) + "=" + f.get( o ) + ", ";  
    }  
    return state + "]";  
}
```

Obtain  
Class-object

Ignore static  
fields

Include  
field name

Include  
field value

Java

Compile-time error:  
uncaught exception

# Field.get

```
public Object get( Object obj ) throws  
    IllegalArgumentException,  
    IllegalAccessException
```

Java

- **Safety checks** have to be done **at run time**
  - Type checking: does obj have that field?
  - Accessibility: is the client allowed to access that field?

# Universal toString-Method (cont'd)

```
public static String getString( Object o ) {  
    if ( o == null ) return "null";  
    Class toExamine = o.getClass( );  
    String state = "[";  
    Field[ ] fields = toExamine.getDeclaredFields( );  
    for ( int fi = 0; fi < fields.length; fi++ )  
        try {  
            Field f = fields[ fi ];  
            if ( !Modifier.isStatic( f.getModifiers( ) ) )  
                state += f.getName() + "=" + f.get( o ) + ", ";  
        } catch ( Exception e ) { return "Exception"; }  
    return state + "];"  
}
```

Java

```
class Cell {  
    private int value = 5;  
    ...  
}
```

```
Cell c = new Cell( );  
String s = getString( c );  
System.out.println( s );
```

Exception

# Universal toString-Method (cont'd)

```
public static String getString( Object o ) {  
    if ( o == null ) return "null";  
    Class toExamine = o.getClass( );  
    String state = "[";  
    Field[ ] fields = toExamine.getDeclaredFields( );  
    for ( int fi = 0; fi < fields.length; fi++ )  
        try {  
            Field f = fields[ fi ];  
            f.setAccessible( true );  
            if ( !Modifier.isStatic( f.getModifiers( ) ) )  
                state += f.getName() + "=" + f.get( o ) + ", ";  
        } catch ( Exception e ) { return "Exception"; }  
    return state + "];"  
}
```

Suppress Java's  
access checking

Java

```
class Cell {  
    private int value = 5;  
    ...  
}
```

```
Cell c = new Cell( );  
String s = getString( c );  
System.out.println( s );
```

[value=5, ]

# Example: Unit Testing

```
class Cell {  
    int value;  
  
    Cell( int v ) { value = v; }  
  
    int get( ) { return value; }  
  
    void set( int v ) { value = v; }  
  
    void swap( Cell c ) {  
        int tmp = value;  
        value = c.value;  
        c.value = tmp;  
    }  
}
```

```
class TestCell {  
    void testSet( ) { ... }  
  
    void testSwap( ) {  
        Cell c1 = new Cell( 5 );  
        Cell c2 = new Cell( 7 );  
        c1.swap( c2 );  
        assert c1.get( ) == 7;  
        assert c2.get( ) == 5;  
    }  
}
```

- Goal: Write generic test driver that executes tests

# Unit Testing: Test Driver

```
public static void testDriver( String testClass ) {  
    Class c = Class.forName( testClass );  
    Object tc = c.newInstance( );  
    Method[ ] methods = c.getDeclaredMethods( );  
    for( int i = 0; i < methods.length; i++ ) {  
        if( methods[ i ].getName( ).startsWith( "test" ) &&  
            methods[ i ].getParameterTypes( ).length == 0 )  
            methods[ i ].invoke( tc );  
    }  
}
```

Find all parameter-less methods whose name starts with "test"

Invoke the method

Error handling omitted

Java

- Basic mechanism behind JUnit
  - Newer versions use annotation `@Test` instead of prefix

# Unit Testing: Error Handling

```
public static void testDriver( String testClass ) {  
    try {  
        Class c = Class.forName( testClass );  
        Object tc = c.newInstance( );  
        Method[ ] methods = c.getDeclaredMethods( );  
  
        for( int i = 0; i < methods.length; i++ ) {  
            if( methods[ i ].getName( ).startsWith( "test" ) &&  
                methods[ i ].getParameterTypes( ).length == 0 )  
                methods[ i ].invoke( tc );  
        }  
    } catch( Exception e ) { ... }  
}
```

Java

# Class.newInstance

```
public T newInstance( ) throws  
    InstantiationException,  
    IllegalAccessException
```

Java

- **Safety checks** have to be done **at run time**
  - Type checking:  
Does the Class-object represent a concrete class?  
Does the class have a parameter-less constructor?
  - Accessibility:  
Are the class and the parameter-less constructor accessible?

# Reminder: Double Invocation

```
class Shape {  
  Shape intersect( Shape s )  
  { return s.intersectShape( this ); }  
  
  Shape intersectShape( Shape s )  
  { // general code for all shapes }  
  
  Shape intersectRectangle( Rectangle r )  
  { return intersectShape( r ); }  
}
```

- Additional dynamically-bound call for specialization based on dynamic type of explicit argument

```
class Rectangle extends Shape {  
  Shape intersect( Shape s )  
  { return s.intersectRectangle( this ); }  
  
  Shape intersectRectangle( Rectangle r )  
  { // efficient code for two rectangles }  
}
```

# Visitor Pattern

```
interface Visitor {  
    void visitExpr( Expr e );  
    void visitLiteral( Literal l );  
    void visitVariable( Variable v );  
}
```

```
class PrintVisitor implements Visitor {  
    void visitExpr( Expr e ) { ... }  
    void visitLiteral( Literal l ) { ... }  
    void visitVariable( Variable v ) { ... }  
}
```

```
class EvalVisitor implements Visitor {  
    ...  
}
```

```
class Expr {  
    void accept( Visitor v )  
    { v.visitExpr( this ); }  
}
```

```
class Literal extends Expr {  
    void accept( Visitor v )  
    { v.visitLiteral( this ); }  
}
```

```
class Variable extends Expr {  
    void accept( Visitor v )  
    { v.visitVariable( this ); }  
}
```

# Reflective Visitor

```
abstract class Visitor {  
  void visit( Expr e ) {  
    String name = "visit" + e.getClass( ).getName( );  
    Method m = this.getClass( ).getMethod( name, e.getClass( ) );  
    m.invoke( this, e );  
  }  
}
```

Construct  
method name,  
e.g., visitLiteral

Invoke the  
method

Find method  
visitX( X )  
in dynamic type  
of **this**

Java

```
class PrintVisitor extends Visitor {  
  void visitExpr( Expr e ) { ... }  
  void visitLiteral( Literal l ) { ... }  
  void visitVariable( Variable v ) { ... }  
}
```

Error handling omitted

# Reflective Visitor: Discussion

## Pros

- Much simpler code
  - Second dynamic dispatch implemented via reflection
  - No accept-methods in visited structure
- Flexible look-up mechanism
  - E.g., visit could look for most specific method

## Cons

- Not statically safe
  - Missing method detected at run time
- Slower
  - Many run-time checks involved

# Java Generics

- Due to Java's erasure semantics, generic type information is not represented at run time

```
try {  
    LinkedList<String> list = new LinkedList<String>( );  
    Class c = list.getClass( );  
    Method add = c.getMethod( "add", String.class );  
} catch( Exception e ) {  
    System.out.println( "Method not found" );  
}
```

Java

Method not found

# Java Generics

- Due to Java's erasure semantics, generic type information is not represented at run time

```
try {  
    LinkedList<String> list = new LinkedList<String>( );  
    Class c = list.getClass( );  
    Method add = c.getMethod( "add", Object.class );  
} catch( Exception e ) {  
    System.out.println( "Method not found" );  
}
```

Java

```
// no exception
```

# 7. Reflection

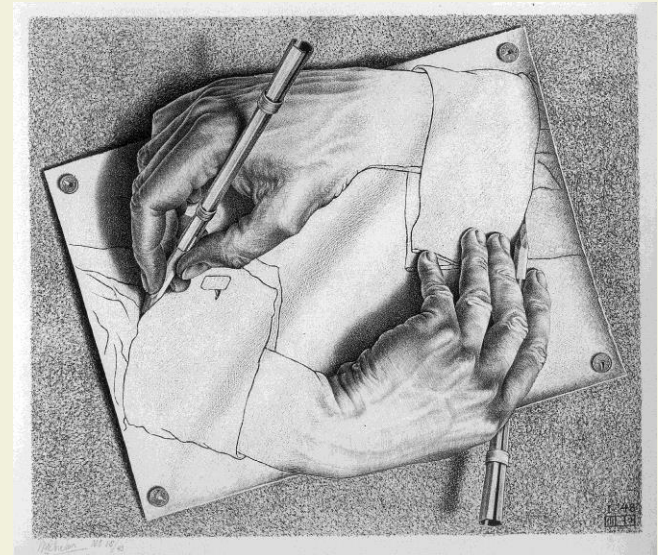
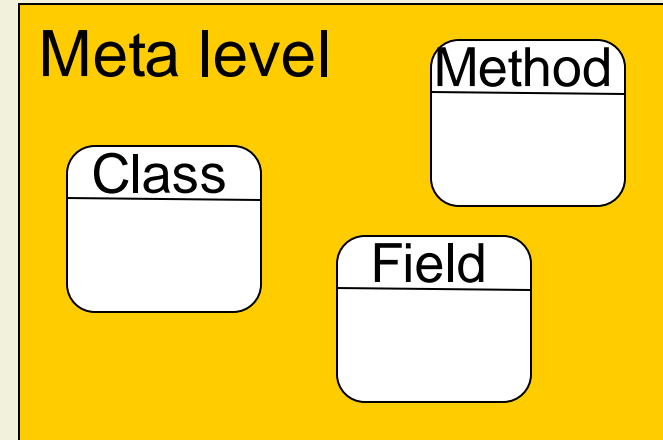
7.1 Introspection

7.2 Reflective Code Generation

7.3 Dynamic Code Manipulation

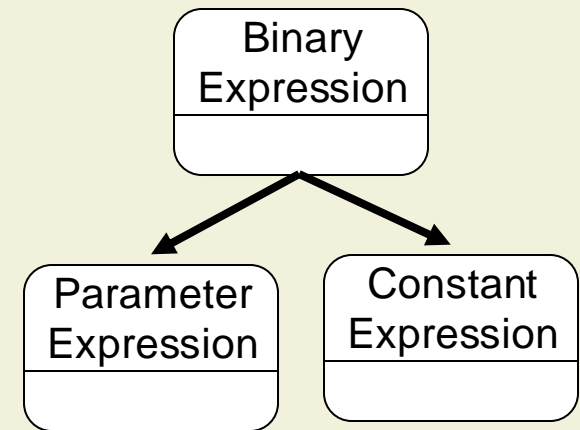
# Motivation

- If code is represented as data, we can as well allow programs to **create code from data**
- Generate code dynamically according to user input and execution environment
- Examples
  - Class loading in Java
  - Expression trees in C#



# C# Expression Trees

- Expression trees represent the abstract syntax tree of C# expressions
  - Can be created like any other data structure
- Class Expression provides a Compile-method, which, compiles expression tree to executable code
  - Compilation happens at run time
- Main application: generation of SQL queries



# Expression Trees: Example

```
Expression<Func<int, bool>> Build( string op, int c ) {  
    ParameterExpression lhs = Expression.Parameter( typeof( int ), "x" );  
    ConstantExpression ce = Expression.Constant( c, typeof( int ) );  
    BinaryExpression be = null;  
  
    switch ( op ) {  
        case "<": be = Expression.LessThan( lhs, ce ); break;  
        case ">": be = Expression.GreaterThan( lhs, ce ); break;  
        ...  
    }  
  
    return Expression.Lambda<Func<int, bool>>  
        ( be, new ParameterExpression[ ] { lhs } );  
}
```

C#

AST for lambda-expression  
 $x \Rightarrow x \text{ op } c$

# Expression Trees: Example (cont'd)

```
class Filter {  
    void Demo( string condition, int[ ] data ) {  
        string op; int c;  
        Parse( condition, out op, out c );  
        Func<int, bool> filter = Build( op, c ).Compile();  
        foreach ( int i in data ) {  
            if ( filter( i ) ) Console.WriteLine( i );  
        }  
    }  
    ...  
}
```

Parse condition to  
determine operator  
and constant

Compile  
expression  
tree

Invoke compiled  
lambda-expression

C#

# 7. Reflection

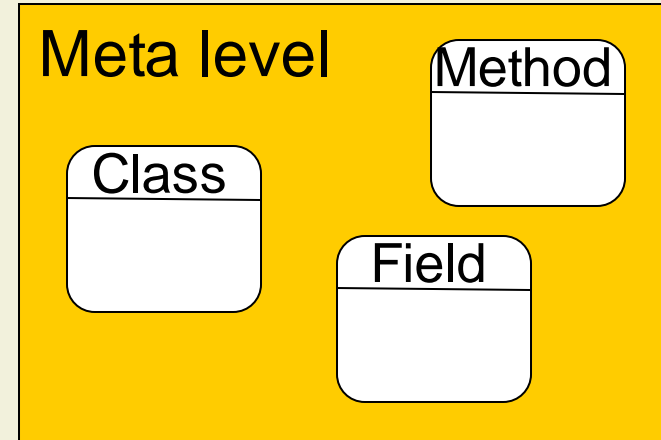
7.1 Introspection

7.2 Reflective Code Generation

7.3 Dynamic Code Manipulation

# Motivation

- If code is represented as data, we can as well allow programs to **modify the code**
- Adapt program dynamically according to user input and execution environment
- Apply systematic changes to programs
  - Code instrumentation



# Code Manipulation in Python

- Example: create a case-insensitive string class

```
class iStr( str ):
    def __init__( self, *args ):
        self._lowered = str.lower( self )

    def _makeCI( name ):
        theMethod = getattr( str, name )
        def newCImethod( self, other, *args ):
            other = other.lower( )
            return theMethod( self._lowered, other, *args )
        setattr( iStr, name, newCImethod )
```

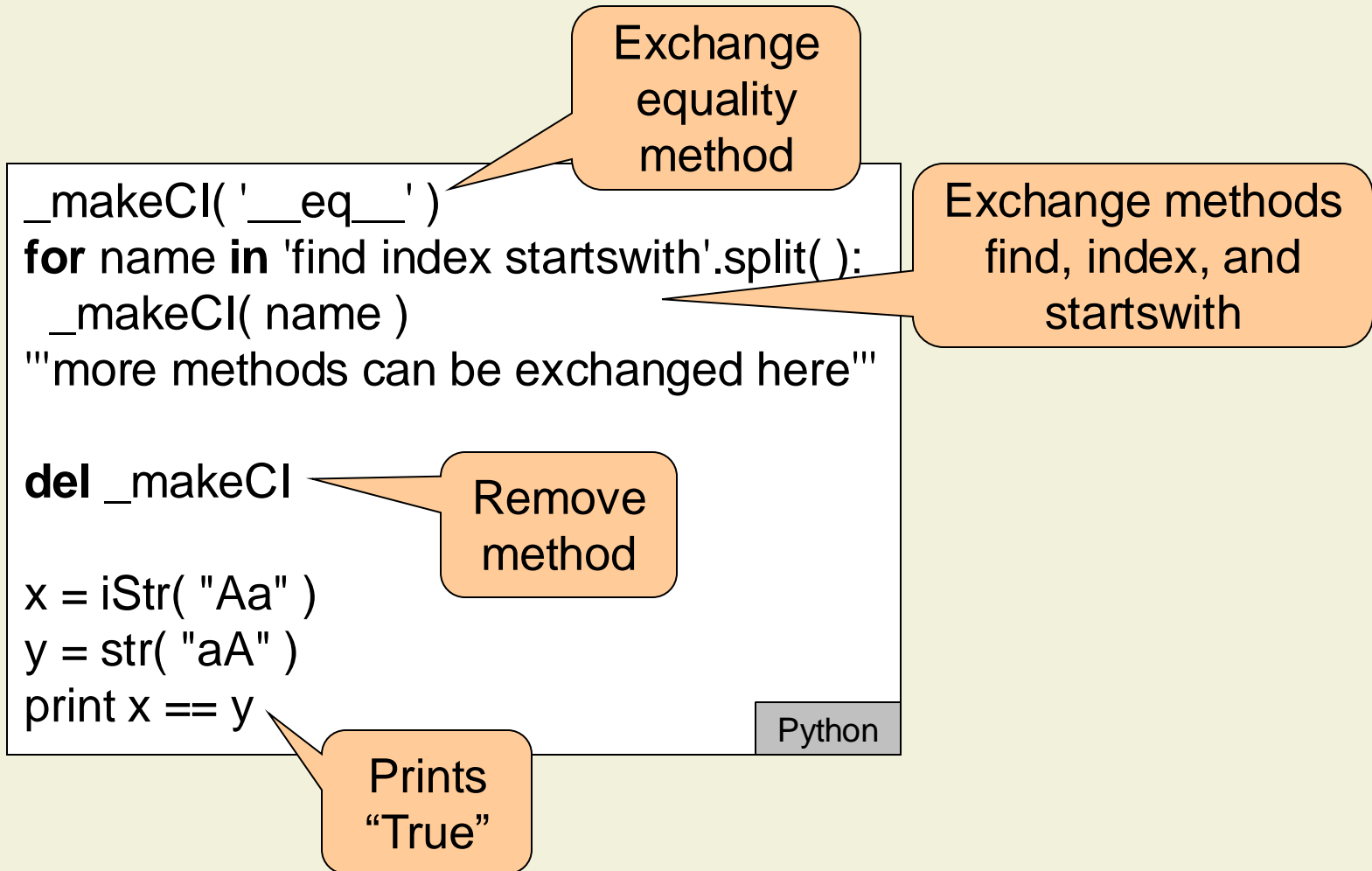
Create a new string class that inherits from str

Method that wraps theMethod

Exchange method implementation in class iStr

Python

# Code Manipulation in Python (cont'd)



# Reflection and Type Checking

Degree of Reflection	Type Checking
Introspection	Code can be type checked once, during compilation
Reflective code generation	Code can be type checked once, when it is created
Dynamic code manipulation	Typically requires dynamic type checking

# Reflection: Summary

## Applications

- Flexible architectures (plug-ins)
- Object serialization
- Persistence
- Design patterns
- Dynamic code generation

## Drawbacks

- Not statically safe
- May compromise information hiding
- Code is difficult to understand and debug
- Performance