Introduction to Java (cs2514)

Lecture 10: The Joys of Enums

M. R. C. van Dongen

February 17, 2017

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Multiway Branching
Int Enums
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Outline

- Many applications require groups of named constants.
- For example:
  - A suit of cards: `HEARTS`, `SPADES`, `CLUBS`, and `DIAMONDS`;
  - Predefined colours: `BLACK`, `WHITE`, `RED`, `BLUE`, ...;
  - And so on.
- In `Java` named constants are called `enum`s.
- They are the topic of this lecture.
  - We start with the `switch` statement.
    - This is a multi-way branching construct.
    - (Not really for `enum`s but needed for examples.)
  - We study a common, flawed pattern called *`int enums`*.
  - `Java` `enum`s overcome most of the flaws of `int` `enum`s.
  - `Java` `enum`s are just objects.
    - They may have state and common and specific behaviour.
- This lecture is partially based on [Bloch 2008, Item 30].
- Some of this lecture is based on the `Java` API documentation.

Multiway Branching

Java

```java
if (var == 0) {
    // First stuff
} else if (var == 1 || var == 3) {
    // Second stuff
} else if (var == 2 || var == 4) {
    // Third stuff
} ...
} else {
    // Final stuff
}
```

Java

```java
switch (var) {
case 0: // First stuff
case 1:
case 3: // Second stuff
case 2:
case 4: // Third stuff
...
default: // Final stuff
}
```


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The `switch` Statement: Single Guards

Statements may end with `break`

Java

```
switch (⟨expr⟩) {
case ⟨constant #1⟩: ⟨statements #1⟩
case ⟨constant #2⟩: ⟨statements #2⟩
...
case ⟨constant #n⟩: ⟨statements #n⟩
}
```


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Multiple Guards

First Guards have Empty Statements

Java

```
switch (⟨expr⟩) {
case ⟨constant #1⟩:
case ⟨constant #2⟩:
...
case ⟨constant #m⟩: ⟨statements⟩
...
}
```


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The switch Statement

Java

```
switch (⟨expr⟩) {
    case ⟨constant #1⟩: ⟨statements #1⟩
    case ⟨constant #2⟩: ⟨statements #2⟩
    ...
    case ⟨constant #n⟩: ⟨statements #n⟩
    default: ⟨default statements⟩
}
```

Example

Java

```
switch (character) {
    case 'A':
    case 'B':
    case 'C':
        System.out.println( "Range: A--C." );
        break;
    case 'e':
        System.out.println( "It's an 'e'" );
        break;
    default:
        System.out.println( "It's not in {A,B,C,e}" );
}
```


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The `int`-`enum` Anti-Pattern

- An *enumerated type* represent a related set of constants.
  - The seasons of the year;
  - The suits in a deck of cards;
  - The graduation levles (pass, 2H2, 2H1, 1H);
  - ....
- Common, but flawed, implementation that uses `int` constants.

Don't Try This at Home

```
public static final int APPLE_FUJI     = 0;
public static final int APPLE_PIPPIN   = 1;

public static final int ORANGE_NAVEL   = 0;
public static final int ORANGE_TEMPLE  = 1;
public static final int ORANGE_BLOOD   = 2;
```

- This technique is called the *`int enum` pattern*.

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The `int-enum` Anti-Pattern

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public static final int ORANGE_NAVEL   = 0;
public static final int ORANGE_TEMPLE  = 1;
public static final int ORANGE_BLOOD   = 2;
```

- This technique is called the *`int enum` pattern*.
- Never, ever, ever, use it.

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Int Enums are Flawed

Type safety: Int enums don't provide type safety.

Don't Try This at Home

```
if (APPLE_FUJI == ORANGE_BLOOD) {  }
int apple = ORANGE_BLOOD;
```

Maintainability: Programs with int enums are brittle.
- Int enums are compile-time constants.
- They are compiled into clients that use them.
- Client will break if enum constant changes.

Ease of use: Int enums are difficult to use.
- It is difficult to translate them to `Strings`.
- No reliable iteration over all allowed values.

Namespace: Int enum types have no private name space.

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Int Enums are Flawed

Comparing Apples and Oranges??

Type safety: Int enums don't provide type safety.

Don't Try This at Home

```
if (APPLE_FUJI == ORANGE_BLOOD) { /* ?? */ }
int apple = ORANGE_BLOOD;
```

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Int Enums are Flawed

Value Out of Range!

Type safety: Int enums don't provide type safety.

Don't Try This at Home

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if (APPLE_FUJI == ORANGE_BLOOD) {  }
int apple = ORANGE_BLOOD;         // ??
```

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Implementing It Yourself

Java

```
public abstract class Beef {
    public static final Beef SHANK = new Beef( ) {
        @Override public double price( ) { return 1.0; }
    };
    public static final Beef SIRLOIN = new Beef( ) {
        @Override public double price( ) { return 2.0; }
    };
    public abstract double price( );

    private Beef( ) { }

    public static void main( String[] args ) {
        final Beef shank = Beef.SHANK;
        final Beef sirloin = Beef.SIRLOIN;
        ...
    }
}
```

Implementing It Yourself

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    private Beef( ) { }

    public static void main( String[] args ) {
        final Beef shank = Beef.SHANK;
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        ...
    }
}
```

Implementing It Yourself

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    };
    public abstract double price( );

    private Beef( ) { }

    public static void main( String[] args ) {
        final Beef shank = Beef.SHANK;
        final Beef sirloin = Beef.SIRLOIN;
        ...
    }
}
```


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    public static void main( String[] args ) {
        final Beef shank = Beef.SHANK;
        final Beef sirloin = Beef.SIRLOIN;
        ...
    }
}
```

A Serious Problem

Java

```java
public class MrEd extends Beef, implements Horse {
    @Override public double price( ) { return 0.2; }

    @Override public void talk( ) { ... }
}
```


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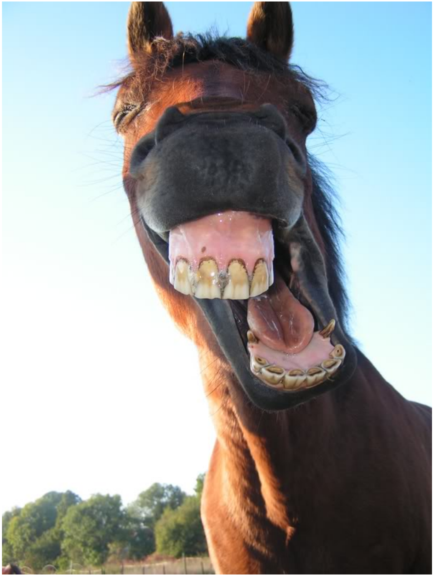
A Serious Problem

Of Course



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Java enums to the Rescue

- As of Release 1.5 Java provides the enum *type*.
- It overcomes most, if not all, shortcomings of int enums.

Java

```
public enum Apple  { FUJI, PIPPIN }
public enum Orange { NAVEL, TEMPLE, BLOOD }
```

- Each '`public enum` ⟨`class`⟩ { ⟨constants⟩ }' is a *class*.
- Each constant in ⟨constants⟩ is an instance of the class: an *object*.
- For each constant in any `enum` class, Java automatically defines one `public final` class attribute.
- Name of ⟨`constant`⟩ in ⟨`class`⟩ is ⟨`class`⟩.⟨`constant`⟩.
- All Java `enum` constructors are (implicitly) `private`.
- All instance methods are `final`, except for `toString( )`.

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Why enums are Good

Type safety: Java enums are type safe.

Don't Try This at Home

```
if (Apple.FUJI == Orange.BLOOD) {  }
Apple apple = Orange.BLOOD;
```

Maintainability:
- enums aren't compiled as constants into clients.
- Rearranging values doesn't break clients.

Ease of use:
- Translating to Strings is easy: toString().
- Iterating over all enums is easy: values().

Namespace: Enum classes have a private name space.

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Comparing Apples and Oranges??

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Methods in `enum` Classes

`compareTo( that )`: Compares `this` `enum` with `that` for order.

`equals( that )`: Returns `true` if `this` `enum` equals `that`.

`hashCode( )`: Returns a hash code for `this` `enum`.

`toString( )`: Returns the name of this `enum` constant.

`name( )`: Returns the original name of this `enum`.

`ordinal( )`: Returns the *ordinal* of `this` `enum`.

Java Enums are Objects

- `int` enums only have a value.
- `Java` enums are objects.
  - They have state.
  - They have behaviour.
- Makes `Java` enums much more flexible.

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State and Behaviour

- Consider the eight planets of the solar system.
- Each planet has a mass and a radius.
- Using the mass and radius we compute the surface gravity.

Implementing the `Planet` Class

Java

```java
public enum Planet {
    MERCURY( 3.303e+23, 2.439e6 ),
    VENUS  ( 4.869e+24, 6.052e6 ),
    EARTH  ( 5.975e+24, 6.378e6 ),
    MARS   ( 6.419e+23, 3.393e6 ),
    JUPITER( 1.899e+27, 7.149e7 ),
    SATURN ( 5.685e+26, 6.027e7 ),
    URANUS ( 8.683e+25, 2.556e7 ),
    NEPTUNE( 1.024e+26, 2.477e7 );

    // Universal gravitational constant in m^3/kg s^2.
    private static final double G = 6.67300E-11;
    private final double mass;
    private final double radius;
    private final double gravity;

    Planet( double mass, double radius ) {
        this.mass = mass;
        this.radius = radius;
        gravity = G * mass / (radius * radius);
    }

    public double getMass( ) { return mass; }
    public double getRadius( ) { return radius; }
    public double getGravity( ) { return gravity; }
}
```


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Implementing the Planet Class

State

Java

```
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    VENUS  ( 4.869e+24, 6.052e6 ),
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    private final double gravity;

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        this.radius = radius;
        gravity = G * mass / (radius * radius);
    }

    public double getMass( ) { return mass; }
    public double getRadius( ) { return radius; }
    public double getGravity( ) { return gravity; }
}
```

Implementing the Planet Class

Behaviour

Java

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Let's Rock

Java

```
public class WeightTable {
    public static void main( String[] args ) {
        for (Planet planet : Planet.values( )) {
            double weight = surfaceWeight( planet, 1.0 );
            System.out.println( "1kg on " + planet
                              + " has a surface weight of "
                              + weight + "." );
        }
    }

    private static double surfaceWeight( final Planet planet, final double mass ) {
        return mass * planet.getGravity( );
    }
}
```


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Running the Application

Unix Session

```
$
```


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Running the Application

Unix Session

```
$ java WeightTable
```

Running the Application

Unix Session

```
$ java WeightTable
1kg on MERCURY has a surface weight of 3.7051525865812165.
1kg on VENUS has a surface weight of 8.870805573987766.
1kg on EARTH has a surface weight of 9.80144268461249.
1kg on MARS has a surface weight of 3.720666819023476.
1kg on JUPITER has a surface weight of 24.794508028173404.
1kg on SATURN has a surface weight of 10.443575504720215.
1kg on URANUS has a surface weight of 8.868889152162147.
1kg on NEPTUNE has a surface weight of 11.137021762915634.
$
```


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Specific Behaviour

- Our `Planet` application is very well behaved.
- All method results depend on input and attributes *only*.
- This is not always the case.
- For example, consider a calculator application.
  - There are four operations `PLUS`, `MINUS`, `TIMES`, and `DIVIDE`.
  - We'd like to apply operations to `double`s and get the result:
    - `double apply( double first, double second ).`
  - `assertTrue( 1.00 == PLUS.apply( 0.0, 1.0 ) ) &&` `assertTrue( -1.00 == MINUS.apply( 0.0, 1.0 ) ),` ....

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Specific Behaviour

- Our `Planet` application is very well behaved.
- All method results depend on input and attributes *only*.
- This is not always the case.
- For example, consider a calculator application.
  - There are four operations `PLUS`, `MINUS`, `TIMES`, and `DIVIDE`.
  - We'd like to apply operations to `double`s and get the result:
    - `double apply( double first, double second )`.
  - `assertTrue( 1.00 == PLUS.apply( 0.0, 1.0 ) ) &&` `assertTrue( -1.00 == MINUS.apply( 0.0, 1.0 ) )`, ...
  - The result *also* depends on the `enum` constant.

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How do we Implement This?

Don't Try This at Home

```
public enum Operation {
    PLUS, MINUS, TIMES, DIVIDE;

    public double apply( double first, double second ) {
        double result;
        switch(this) {
        case PLUS:   result = first + second; break;
        case MINUS:  result = first - second; break;
        case TIMES:  result = first * second; break;
        case DIVIDE: result = first / second; break;
        default: String error = "Unknown Operation: " + this;
                 throw new AssertionError( error );
        }
        return result;
    }
}
```


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How do we Implement This?

No!

Don't Try This at Home

```
public enum Operation {
    PLUS, MINUS, TIMES, DIVIDE, RECIPROCAL;

    public double apply( double first, double second ) {
        double result;
        switch(this) {
        case PLUS:   result = first + second; break;
        case MINUS:  result = first - second; break;
        case TIMES:  result = first * second; break;
        case DIVIDE: result = first / second; break;
        default: String error = "Unknown Operation: " + this;
                 throw new AssertionError( error );
        }
        return result;
    }
}
```

Constant-Specific Methods

Java

```
public enum Operation {
    PLUS   { @Override
             public double apply( double x, double y ) { return x + y; } },
    MINUS  { @Override
             public double apply( double x, double y ) { return x - y; } },
    TIMES  { @Override
             public double apply( double x, double y ) { return x * y; } },
    DIVIDE { @Override
             public double apply( double x, double y ) { return x / y; } };

    public abstract double apply( double first, double second );
}
```


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Adding More Intuitive Printing

Java

```
public enum Operation {
    PLUS   { @Override
             public String toString( ) { return "+"; }
             @Override
             public double apply( double x, double y ) { return x + y; }},
  ⟨rest of class omitted⟩
```


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Using the Operation Class

Java

```
public class Calculator {
    public static void main( String[] args ) {
        final double first  = 6;
        final double second = 2;
        for (Operation op : Operation.values( )) {
            double result = op.apply( first, second );
            System.out.println( first + " " + op + " " + second
                                + " = " + result );
        }
    }
}
```

Unix Session

```
$
```


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Using the `Operation` Class

Java

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public class Calculator {
    public static void main( String[] args ) {
        final double first  = 6;
        final double second = 2;
        for (Operation op : Operation.values( )) {
            double result = op.apply( first, second );
            System.out.println( first + " " + op + " " + second
                                + " = " + result );
        }
    }
}
```

Unix Session

```
$ java Calculator
```


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Using the Operation Class

Java

```
public class Calculator {
    public static void main( String[] args ) {
        final double first  = 6;
        final double second = 2;
        for (Operation op : Operation.values( )) {
            double result = op.apply( first, second );
            System.out.println( first + " " + op + " " + second
                                + " = " + result );
        }
    }
}
```

Unix Session

```
$ java Calculator
6.0 + 2.0 = 8.0
6.0 - 2.0 = 4.0
6.0 * 2.0 = 12.0
6.0 / 2.0 = 3.0
$
```


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Getting Really Fancy Now??

Java

```
public enum Operation {
    PLUS {
        @Override
        public String toString( ) { return "+"; }
        @Override
        public double apply( double x, double y ) { return x + y; }
    }, MINUS {
        @Override
        public String toString( ) { return "-"; }
        @Override
        public double apply( double x, double y ) { return x - y; }
    }, TIMES {
        @Override
        public String toString( ) { return "*"; }
        @Override
        public double apply( double x, double y ) { return x * y; }
    }, DIVIDE {
        @Override
        public String toString( ) { return "/"; }
        @Override
        public double apply( double x, double y ) { return x / y; }
    };

    public abstract double apply( double first, double second );
}
```


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Factoring out Identical Behaviour

Java

```java
public enum Operation {
    PLUS( "+" ) {
        @Override
        public double apply( double x, double y ) { return x + y; }
    }, MINUS( "-" ) {
        @Override
        public double apply( double x, double y ) { return x - y; }
    }, TIMES( "*" ) {
        @Override
        public double apply( double x, double y ) { return x * y; }
    }, DIVIDE( "/" ) {
        @Override
        public double apply( double x, double y ) { return x / y; }
    };
    public abstract double apply( double first, double second );
    private final String symbol;

    Operation( String symbol ) {
        this.symbol = symbol;
    }

    @Override public String toString( ) { return symbol; }
}
```

Payroll Application

- Employees have a pay rate that depends on their grade.
- Our application gets the pay rate as its input.
- An employee's pay for a given day of the week is given by

$$\text{pay} = \text{base pay} + \text{overtime pay for that day}\,.$$

- The base pay is given by pay rate $\times$ hours worked.
- The overtime pay is given by

$$\text{overtime pay} = \text{pay rate} \times \text{overtime hours}/2\,.$$

Weekdays: Hours worked in excess of hours per shift (8).
Weekend: Hours worked on that day.

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First Stab at Implementation

Don’t Try This at Home

```
public enum SimplePayrollDay {
    SUNDAY, MONDAY, TUESDAY, WEDNESDAY, THURSDAY, FRIDAY, SATURDAY;

    private static final int HOURS_PER_SHIFT = 8;

    public double pay( double hoursWorked, double payRate ) {
        double basePay = hoursWorked * payRate;
        double overtimePay = overtimePay( hoursWorked, payRate );

        return basePay + overtimePay;
    }

    public double overtimePay( double hoursWorked, double payRate ) {
        double overtime;

        switch (this) {
        case SATURDAY:
        case SUNDAY: // Weekend
            overtime = hoursWorked;
            break;
        default:     // Weekday
            double difference = hoursWorked - HOURS_PER_SHIFT;
            overtime  = (difference < 0 ? 0 : difference);
        }
        return overtime * payRate / 2;
    }
}
```

What's Wrong?

- What if we add an extra type of day?
- For example, a Bank Holiday (special kind of Monday).
- We'd have to modify `overtimePay( )`.
- The application will break if we forget to make the change.

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How to Fix It?

- We need different *strategies* for paying overtime.
- Strategy for `toString( )` in our computation is 100% shared.
- With the payrole application *some* strategies are shared, not all.
- Currently we have two strategies.
  - Each is *determined* by the kind of day: week days/weekend days.
  - The kind of day is a *property* of the day.
  - A property can be implemented as an *attribute*.
  - The attribute now *determines* the kind of day:
    - We can *compute* the kind of day from the attribute.
    - The kind of day *determines* the strategy.
    - Therefore, the attribute *determines* the strategy.
- We could implement our attribute as a `boolean`: `isWeekday`.
  - This would work now, but the requirements may change:
    - Double overtime rate for Christmas days?
- Probably better to have a *strategy* `enum` type.
  - The new strategy determines overtime pay computation.
- (Of course we implement it as an inner (`enum`) class.)

A Better Implementation

Java

```
public enum PayrollDay {
    SUNDAY(    PayType.WEEKEND ),
    MONDAY(    PayType.WEEKDAY ),
    TUESDAY(   PayType.WEEKDAY ),
    WEDNESDAY( PayType.WEEKDAY ),
    THURSDAY(  PayType.WEEKDAY ),
    FRIDAY(    PayType.WEEKDAY ),
    SATURDAY(  PayType.WEEKEND );

    private static final int HOURS_PER_SHIFT = 8;
    private final PayType type;

    PayrollDay( PayType type ) { this.type = type; }

    public double pay( double hoursWorked, double payRate ) {
        double basePay = hoursWorked * payRate;
        double overtimePay = type.overtimePay( hoursWorked, payRate );

        return basePay + overtimePay;
    }

    private enum PayType {
        WEEKEND { /* omitted. */ }, WEEKDAY { /* omitted. */ };
        public abstract
        double overtimePay( double hoursWorked, double payRate );
    }
}
```


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The Details

Java

```
private enum PayType {
    WEEKEND {
        @Override
        public double overtimePay( double hoursWorked, double payRate ) {
            return hoursWorked * payRate / 2;
        }
    }, WEEKDAY {
        @Override
        public double overtimePay( double hoursWorked, double payRate ) {
            double difference = hoursWorked - HOURS_PER_SHIFT;
            double overtime   = (difference < 0 ? 0 : difference);
            return overtime * payRate / 2;
        }
    };
    public abstract
    double overtimePay( double hoursWorked, double payRate );
}
```


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Why Strategy enums are Good for You

- The overtime pay computation is *what varies*.
- The strategy enum *isolates* what varies.
- *Localises* the code for overtime pay computation.
- *Global* change in rules translates to *local* change in code:
  - Easy to remove days and strategies.
  - Easy to change strategies.
  - Easy to add new days for existing strategies.
  - Easy to add new days and new strategies.

Java

```
public enum PayrollDay {
    ...
    BANK_HOLIDAY( PayType.BANK_HOLIDAY ),
    ...
    private enum PayType {
        ...
        BANK_HOLIDAY {
            @Override
            public double overtimePay( double hoursWorked, double payRate ) {
                return hoursWorked * payRate;
            }
        ...
    }
}
```


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A Music Application

Don't Try This at Home

```
public enum Ensemble {
    SOLO,   DUET,   TRIO,  QUARTET, QUINTET,
    SEXTET, SEPTET, OCTET, NONET,   DECTET;

    public int size( ) { return 1 + ordinal( ); }
}
```

This class will break if:

- Constants are re-ordered.
- Constants are removed.
- Constants are added and there are "holes."
- Constants are added with the same size as existing ensembles.

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A Better Approach

Java

```
public enum Ensemble {
    SOLO( 1 ), DUET( 2 ), TRIO( 3 ), QUARTET( 4 ),
    QUINTET( 5 ), SEXTET( 6 ), SEPTET( 7 ), OCTET( 8 ),
    DOUBLE_QUARTET( 8 ), NONET( 9 ), DECTET( 10 );
    private final int size;

    private Ensemble( final int size ) {
        this.size = size;
    }

    public int size( ) {
        return size;
    }
}
```

- Order can be changed.
- Constants can be removed.
- Constants can be added.

A Better Approach

Java

```
public enum Ensemble {
    SOLO( 1 ), DUET( 2 ), TRIO( 3 ), QUARTET( 4 ),
    QUINTET( 5 ), SEXTET( 6 ), SEPTET( 7 ), OCTET( 8 ),
    DOUBLE_QUARTET( 8 ), NONET( 9 ), DECTET( 10 );
    private final int size;

    private Ensemble( final int size ) {
        this.size = size;
    }

    public int size( ) {
        return size;
    }
}
```

- Order can be changed.
- Constants can be removed.
- Constants can be added.

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Some Bitwise Operators

`lhs << rhs` Shift the `int lhs` to the left by `rhs` bits:[1]

- `(1 << 1) == 2;`
- `(2 << 2) == 8;`
- `(3 << 32) == 3;`

`~operand` Complement of `operand`:

- `(~0) == -1;`
- `(~1) == -2;`
- `(~-1) == 0;`

`lhs & rhs` Bitwise and of `lhs` and `rhs`:

- `(7 & 3) == 3;`
- `(16 & 15) == 0;`
- `(32 & 31) == 0;`

`lhs | rhs` Bitwise or of `lhs` and `rhs`:

- `(7 | 3) == 7;`
- `(4 | 3) == 7;`
- `(32 | 31) == 63;`

[1] Only the last 5 bits of `rhs` are used for the shift operation.

The *Bitwise Field Enumeration* Anti-Pattern

Java

```
public class TextStyle {
    public static final int STYLE_BOLD      = 1 << 0;
    public static final int STYLE_ITALIC    = 1 << 1;
    public static final int STYLE_UNDERLINE = 1 << 2;
    ...
    private int style = 0;

    public void computeUnion( int otherStyle ) {
        style |= otherStyle;
    }

    public void computeDifference( int otherStyle ) {
        style &= ~otherStyle;
    }

    public boolean containsStyle( int otherStyle ) {
        return otherStyle == (style & otherStyle);
    }
}
```

Disadvantages

- All disadvantages of bit-enum anti-pattern.
- Doesn't work if set has more than 32 members.

EnumSet to the Rescue

Java

```
import java.util.*;

public class TextStyle {
    public enum Style { BOLD, ITALIC, UNDERLINE }
    private EnumSet<Style> style
        = EnumSet.copyOf( new HashSet<Style>( ) );

    ...
}
```


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Java

```
public void computeUnion( EnumSet<Style> otherStyle ) {
    // addAll inherited from Set
    style.addAll( otherStyle );
}

public void computeDifference( EnumSet<Style> otherStyle ) {
    // removeAll inherited from AbstractSet
    style.removeAll( otherStyle );
}

public boolean containsStyle( EnumSet<Style> otherStyle ) {
    // containsAll inherited from AbstractCollction.
    return style.containsAll( otherStyle );
}
```

For Monday

- Study the presentation, and
- [Bloch 2008, Item 30] if you have the book.
- Do not use enumerated types for the assignment 2.

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Acknowledgements

- This lecture is partially based on [Bloch 2008, Item 30].
- This lecture is also based on the Java API documentation.

Question Time

Questions Anybody?

For Monday

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- This document was created with `pdflatex`.
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