Breaking things down

- In functional (and procedural) programming, break programs down into functions that perform some operation
- In object-oriented programming, break programs down into classes that give behavior to some kind of data

This lecture:
- These two forms of decomposition are so exactly opposite that they are two ways of looking at the same "matrix"
- Which form is "better" is somewhat personal taste, but also depends on how you expect to change/extend software
- For some operations over two (multiple) arguments, functions and pattern-matching are straightforward, but with OOP we can do it with double dispatch (multiple dispatch)

The expression example

Well-known and compelling example of a common pattern:
- Expressions for a small language
- Different variants of expressions: ints, additions, negations, ...
- Different operations to perform: eval, toString, hasZero, ...

Leads to a matrix (2D-grid) of variants and operations
- Implementation will involve deciding what "should happen" for each entry in the grid regardless of the PL

<table>
<thead>
<tr>
<th>eval</th>
<th>toString</th>
<th>hasZero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Int</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard approach in ML

- Define a datatype, with one constructor for each variant
  - (No need to indicate datatypes if dynamically typed)
- "Fill out the grid" via one function per column
  - Each function has one branch for each column entry
  - Can combine cases (e.g., with wildcard patterns) if multiple entries in column are the same

Standard approach in OOP

- Define a class, with one abstract method for each operation
  - (No need to indicate abstract methods if dynamically typed)
- Define a subclass for each variant
- So "fill out the grid" via one class per row with one method implementation for each grid position
  - Can use a method in the superclass if there is a default for multiple entries in a column

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A big course punchline

- FP and OOP often doing the same thing in exact opposite way
  - Organize the program "by rows" or "by columns"
- Which is "most natural" may depend on what you are doing (e.g., an interpreter vs. a GUI) or personal taste
- Code layout is important, but there is no perfect way since software has many dimensions of structure
  - Tools, IDEs can help with multiple "views" (e.g., rows / columns)
Extensibility

For implementing our grid so far, SML / Racket style usually by column and Ruby / Java style usually by row

But beyond just style, this decision affects what (unexpected?) software extensions need not change old code

Functions [see ML code]:
- Easy to add a new operation, e.g., noNegConstants
- Adding a new variant, e.g., Mult requires modifying old functions, but ML type-checker gives a to-do list if original code avoided wildcard patterns

Objects [see Ruby code]:
- Easy to add a new variant, e.g., Mult
- Adding a new operation, e.g., noNegConstants requires modifying old classes, but Java type-checker gives a to-do list if original code avoided default methods

The other way is possible

Functions allow new operations and objects allow new variants without modifying existing code even if they didn’t plan for it
- Natural result of the decomposition

Optional:
- Functions can support new variants somewhat awkwardly “if they plan ahead”
  - Not explained here: Can use type constructors to make datatypes extensible and have operations take function arguments to give results for the extensions
- Objects can support new operations somewhat awkwardly “if they plan ahead”
  - Not explained here: The popular Visitor Pattern uses the double-dispatch pattern to allow new operations "on the side"

Thoughts on Extensibility

Making software extensible is valuable and hard
- If you know you want new operations, use FP
- If you know you want new variants, use OOP
- If both? Languages like Scala try; it’s a hard problem
- Reality: The future is often hard to predict!

Extensibility is a double-edged sword
- Code more reusable without being changed later
- But makes original code more difficult to reason about locally or change later (could break extensions)
- Often language mechanisms to make code less extensible (ML modules hide datatypes; Java’s final prevents subclassing/overriding)

Binary operations

- Situation is more complicated if an operation is defined over multiple arguments that can have different variants
- Can arise in original program or after extension
- Function decomposition deals with this much more simply...

Example

To show the issue:
- Include variants String and Rational
- (Re)define Add to work on any pair of Int, String, Rational
  - Concatenation if either argument a String, else math

Now just defining the addition operation is a different 2D grid:
ML Approach

Addition is different for most Int, String, Rational combinations
- Run-time error for non-value expressions
Natural approach: pattern-match on the pair of values
- For commutative possibilities, can re-call with (v2,v1)

```plaintext
fun add_values(v1,v2) =
  case (v1,v2) of
    (Int i, Int j) => Int (i+j)
  | (Int i, String s) => String (Int.toString i ^ s)
  | (Int i, Rational(j,k)) => Rational (i*k+j,k)
  | (Rational _, Int _) => add_values (v2,v1)
  | ... (* 5 more cases (3*3 total): see the code *)

fun eval e =
  case e of
          ...
    | Add(e1,e2) => add_values (eval e1, eval e2)
```

Example

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- Include variants String and Rational
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    - Concatenation if either argument a String, else math

Now just defining the addition operation is a different 2D grid:

```
+---+---+---+
|   | Int| String| Rational |
+---+---+---+
| Int|   |     |         |
+---+---+---+
| String|   |     |         |
+---+---+---+
| Rational|   |     |         |
+---+---+---+
```

Worked just fine with functional decomposition — what about OOP...

What about OOP?

Starts promising:
- Use OOP to call method `add_values` to one value with other value as result

```plaintext
class Add
...
  def eval
  e1.eval.add_values e2.eval
  end
end
```

Classes Int, MyString, MyRational then all implement
- Each handling 3 of the 9 cases: "add self to argument"

```plaintext
class Int
...
  def add_values v
  ... # what goes here?
  end
end
```

- A "hybrid" style where we used dynamic dispatch on 1 argument
  and then switched to Racket-style type tests for other argument
  - Definitely not "full OOP"

First try

- This approach is common, but is "not as OOP"
  - So do not do it on your homework

```plaintext
class Int
  def add_values v
  if v.is_a? Int
  Int.new(v.i + i)
  elsif v.is_a? MyRational
  MyRational.new(v.i+v.j*i,v.j)
  else
  MyString.new(v.s + i.to_s)
  end
end
```

Another way...

- `add_values` method in Int needs "what kind of thing" `v` has
  - Same problem in MyRational and MyString
- In OOP, "always" solve this by calling a method on `v` instead!
- But now we need to "tell" `v` "what kind of thing" `self` is
  - We know that!
  - "Tell" `v` by calling different methods on `v`, passing `self`
- Use a "programming trick" (?) called double-dispatch...

Double-dispatch “trick”

- Int, MyString, and MyRational each define all of addInt, addString, and addRational
  - For example, String’s addInt is for concatenating an integer argument to the string in self
  - 9 total methods, one for each case of addition
- Add's eval method calls e1.eval.add_values e2.eval, which dispatches to add_values in Int, String, or Rational
  - Int's add_values: v.addInt self
  - MyString's add_values: v.addString self
  - MyRational's add_values: v.addRational self
  - So add_values performs "2nd dispatch" to the correct case of 9!

[Definitely see the code]
**Why showing you this**

- Honestly, partly to belittle full commitment to OOP
- To understand dynamic dispatch via a sophisticated idiom
- Because required for the homework
- To contrast with *multimethods* (optional)

**Works in Java too**

- In a statically typed language, double-dispatch works fine
  - Just need all the dispatch methods in the type

```java
abstract class Value extends Exp {
    abstract Value add_values(Value other);
    abstract Value addInt(Int other);
    abstract Value addString(String other);
    abstract Value addRational(Rational other);
}
class Int extends Value { … }
class String extends Value { … }
class Rational extends Value { … }
```

[See Java code]

**Being Fair**

Belittling OOP style for requiring the manual trick of double dispatch is somewhat unfair…

What would work better:

- Int, MyString, and MyRational each define three methods all named add_values
  - One add_values takes an Int, one a MyString, one a MyRational
  - So 9 total methods named add_values
  - e1.eval.add_values e2.eval picks the right one of the 9 at run-time using the classes of the two arguments
- Such a semantics is called *multimethods* or *multiple dispatch*

**Multimethods**

General idea:

- Allow multiple methods with same name
- Indicate which ones take instances of which classes
- Use dynamic dispatch on arguments in addition to receiver to pick which method is called

If dynamic dispatch is essence of OOP, this is more OOP

- No need for awkward manual multiple-dispatch

Downside: Interaction with subclassing can produce situations where there is "no clear winner" for which method to call

**Ruby: Why not?**

Multimethods a bad fit (?) for Ruby because:

- Ruby places no restrictions on what is passed to a method
- Ruby never allows methods with the same name
  - Same name means overriding/replacing

**Java/C#/C++: Why not?**

- Yes, Java/C#/C++ allow multiple methods with the same name
- No, these language do not have multimethods
  - They have *static overloading*
  - Uses static types of arguments to choose the method
    - But of course run-time class of receiver [odd hybrid?]?
  - No help in our example, so still code up double-dispatch manually
- Actually, C# 4.0 has a way to get effect of multimethods
- Many other language have multimethods (e.g., Clojure)
  - They are not a new idea