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

|     | eval | toString | hasZero | ...
|-----|------|----------|---------|-----
| Int |      |          |         |     
| Add |      |          |         |     
| Negate |  |          |         |     
| ...  |      |          |         |     |
Standard approach in ML

<table>
<thead>
<tr>
<th></th>
<th>eval</th>
<th>toString</th>
<th>hasZero</th>
<th>...</th>
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</thead>
<tbody>
<tr>
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<td>...</td>
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- 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

[See the ML code]
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

[See the Ruby and Java code]
A big course punchline

|          | eval | toString | hasZero | ...
|----------|------|----------|---------|------
| Int      |      |          |         |      |
| Add      |      |          |         |      |
| Negate   |      |          |         |      |
| ...      |      |          |         |      |

- 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 are easy and/or do 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
Extensibility

<table>
<thead>
<tr>
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<th>hasZero</th>
<th>noNegConstants</th>
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<td><strong>Mult</strong></td>
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- 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* are easy and/or do not change old code

- **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**

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- 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:

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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 \((v2,v1)\)

```haskell
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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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

```ruby
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”

```ruby
class Int
    ...
    def add_values v
        ...
        # what goes here?
    end
end
```
First try

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

```ruby
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
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”
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” \( \text{self} \) is
  – We know that!
  – “Tell” \( v \) by calling different methods on \( v \), passing \( \text{self} \)

• 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(Strng other);
    abstract Value addRational(Rational other);
}

class Int extends Value { ... }
class Strng 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