

Recursion and Iteration

Summing by recursion

- Iteration vs. Recursion
 - What is the more natural way to sum a collection? iteration or recursion?
 - A discrete series is often defined recursively (e.g. Fibonacci sequence). I suggest that our tendency towards iteration is a consequence of the Turing/von Neumann architecture.
 - A more mathematical (and natural) way of defining the sum of a list `xs` of numbers would be:
 - $\text{sum}(xs) = xs.\text{head} + \text{sum}(xs.\text{tail})$

Sum by recursion

- Here, for example, is how to do it in Scala:

```
object Sum extends App {
```

```
  def sum(xs: Seq[Int]): Int = xs match {  
    case Nil => 0  
    case h :: t => h + sum(t)  
  }
```



Recursively call sum

```
  val xs = Stream.from(1) take 10  
  println(sum(xs.toList))  
}
```

- But haven't we always been taught not to use recursion in our programs if we can avoid it?
 - What's wrong with recursion?
 - Think about what would happen if instead of 10 numbers, we summed 10 *billion* numbers.

Stack Overflow

- We'd get a stack overflow!
 - That's really bad news. That's why we were taught not to use recursion!
- But we can actually avoid using the stack provided that the recursion is *tail* recursive.
 - Suppose that the *last* thing we do in our code is the recursive call itself (that's why it's called *tail* recursion)? We'd also say that the recursive call is in *tail position*. In that case, there'd be nothing we'd need to store on the stack, right?
 - So, we can “unroll” a tail-recursive call into a kind of iteration.

Sum by recursion (take 2)

- Let's take another look (again, this is Scala):

```
object Sum extends App {  
  def sum(xs: Seq[Int]): Int = xs match {  
    case Nil => 0  
    case h :: t => h + sum(t)  
  }  
  
  val xs = Stream.from(1) take 10  
  println(sum(xs.toList))  
}
```



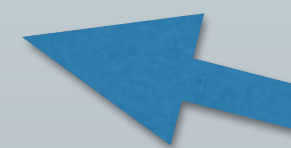
*Recursively call sum
but the last thing we do
is to add h to the result
of the recursive call—
“+” is in tail position.*

- How can we make this tail-recursive?
 - Actually, it's quite easy...

Sum by tail-recursion*

- We create an “inner” method which is tail-recursive
 - Its signature is based on two[†] things:
 - the current value of the result (and which will be yielded when the recursion terminates, in this case when *work* is *Nil*);
 - the work still to do.
- Here’s our new *sum* (note we use *BigInt* because we no longer have a restriction on the size of *xs*):

```
object Sum extends App {  
  def sum(xs: Seq[Int]): BigInt = {  
    def inner(result: BigInt, work: Seq[Int]): BigInt = work match {  
      case Nil => result  
      case h :: t => inner(result+h,t)  
    }  
    inner(0, xs)  
  }  
  
  val xs = Stream.from(1) take 10000000  
  println(sum(xs.toList))  
}
```



*Tail-recursively call inner
which is the last thing we do.*

* also known as tail call recursion

[†] three if you’re processing something 2-dimensional like a tree

Tail recursion in Java

- The problem is that the *Java* compiler doesn't take care of tail-recursion. You have to do it yourself.
- But it's quite easy (where *f* is called recursively):
$$f() = \text{if } E \text{ then } \{S; \text{return } f()\} \text{ else return } Q$$

where *E* and *Q* are expressions; and where *S* is a series of statements, is equivalent to:

$$\text{while } (E) \{ S \}; \text{return } Q$$

Example

- Tail-recursive Factorial function:

```
public long factorial(int n, long r) =  
    if (n>1) return factorial(n-1, r*n) else return r  
factorial(n, 1L);
```

- is equivalent to:

```
public long factorial(int n) = {  
    long r = 1;  
    while (n>1) {r = r*n; n = n-1}  
    return r;  
}  
factorial(n);
```


Multi-way recursion

- The examples we just looked at (sum and factorial) only involve one recursive call. What happens when you have more than one recursive call (e.g. in mergeSort or quickSort)?
- Well, you can never have tail recursion without resorting to an auxiliary (“inner”) method (because *both* recursive calls can’t be in tail position).
- But, as before, it is quite easy to “unroll” a multi-way recursion into an iteration as we did before.