

Loops

When to Use Loops

Iterating with Numbers

Many computations involve iterating over numbers:

- Checking each item in an array
- Computing sums or products from 0 to n

Iterating with Numbers

Many computations involve iterating over numbers:

- Checking each item in an array
- Computing sums or products from 0 to n

One way to write such loops:

Step 1. Set i to the starting number

Step 2. If i is too big, stop

Otherwise, do something with i

Step 3. Change i to the next value and go to **Step 2**

For Loops

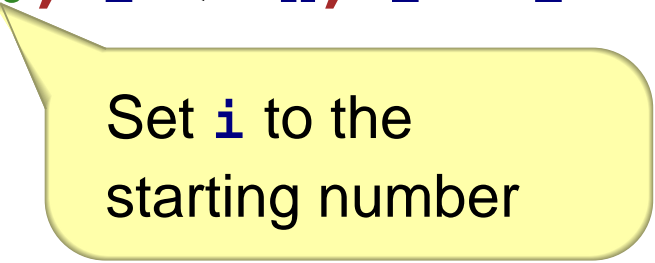
Java supports this pattern with `for`

```
int sum(int n) {  
    int res = 0;  
    for (int i = 0; i <= n; i = i + 1) {  
        res = res + i;  
    }  
    return res;  
}
```

For Loops

Java supports this pattern with `for`

```
int sum(int n) {  
    int res = 0;  
    for (int i = 0; i <= n; i = i + 1) {  
        res = res +  
    }  
    return res;  
}
```

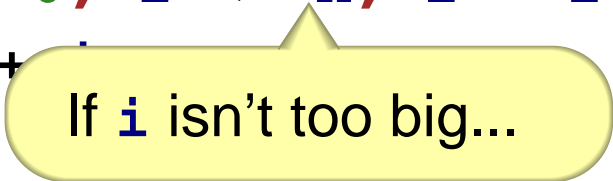


Set `i` to the starting number

For Loops

Java supports this pattern with `for`

```
int sum(int n) {  
    int res = 0;  
    for (int i = 0; i <= n; i = i + 1) {  
        res = res + i;  
    }  
    return res;  
}
```

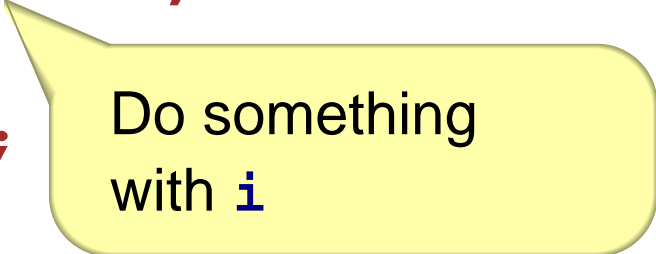


If `i` isn't too big...

For Loops

Java supports this pattern with `for`

```
int sum(int n) {  
    int res = 0;  
    for (int i = 0; i <= n; i = i + 1) {  
        res = res + i;  
    }  
    return res;  
}
```



Do something
with `i`

For Loops

Java supports this pattern with `for`

```
int sum(int n) {  
    int res = 0;  
    for (int i = 0; i <= n; i = i + 1) {  
        res = res + i;  
    }  
    return res;  
}
```

Change `i` to the next value

Another Example

```
int sumElements(int[] a) {  
    int res = 0;  
    for (int i = 0; i < a.length(); i = i + 1) {  
        res = res + a[i];  
    }  
    return res;  
}
```

Another Example

```
int maxElement(int[] a) {  
    int res = a[0];  
    for (int i = 1; i < a.length(); i = i + 1) {  
        if (res < a[i])  
            res = a[i];  
    }  
    return res;  
}
```

Another Example

```
int isArrayMember(Object o, Object[] a) {  
    for (int i = 0; i < a.length(); i = i + 1) {  
        if (o.equals(a[i]))  
            return true;  
    }  
    return false;  
}
```

Looping with Values Other than Numbers

With suitable methods and helpers, the same pattern can work for list-shaped data:

```
int isListMember(Object o, List lst) {
    for (Enumerator e = lst.elements();
         e.hasMoreElements();
         ) {
        Object elem = e.nextElement();
        if (o.equals(elem))
            return true;
    }
    return false;
}
```

While Loops

```
while (test) { ... }
```

is a shorthand for

```
for (; test; ) { ... }
```

```
int isListMember(Object o, List lst) {  
    Enumerator e = lst.elements();  
    while (e.hasMoreElements()) {  
        Object elem = e.nextElement();  
        if (o.equals(elem))  
            return true;  
    }  
    return false;  
}
```

Do/While Loops

```
do { ... } while (test);
```

is a shorthand for

```
for (boolean ok=true; ok; ) { ... ok = test; }
```

```
int tryUntil(List lst, Tester t) {  
    Enumerator e = lst.elements();  
    do {  
        Object elem = e.nextElement();  
    } while (!t.tryIt(elem));  
}
```

➤ **Loops**

➤ **When to Use Loops**

... and why Java needs a special form for loops

When to Use Loops

Use `for`, `while` and `do` like you would use `filter` or `map`

- In other words, it's a question of reusing a pattern

When to Use Loops

Use `for`, `while` and `do` like you would use `filter` or `map`

- In other words, it's a question of reusing a pattern

Using `map` in Scheme is always optional, but sometimes you really *must* use `for` in Java

This is a design flaw in Java that you'll have to live with

When to Use Loops

Use `for`, `while` and `do` like you would use `filter` or `map`

- In other words, it's a question of reusing a pattern

Using `map` in Scheme is always optional, but sometimes you really *must* use `for` in Java

This is a design flaw in Java that you'll have to live with

As someone who knows how to design programs, you should understand

- why `for` is necessary
- how to convert recursive programs to use `for`

Cost of Computation, Revisited

```
; sum : num -> num  
; Sums the numbers from 0 to n  
(define (sum n)  
  (cond  
    [(zero? n) 0]  
    [else (+ n (sum (- n 1)))]))
```

How long does `(sum n)` take?

Cost of Computation, Revisited

```
; sum : num -> num
; Sums the numbers from 0 to n
(define (sum n)
  (cond
    [(zero? n) 0]
    [else (+ n (sum (- n 1)))]))
```

How long does `(sum n)` take?

$$\begin{aligned}T(0) &= k_1 \\ T(n) &= k_2 + T(n-1)\end{aligned}$$

So it takes $k_1 + k_2n$, i.e., proportional to n

Cost of Computation, Revisited

```
; sum : num -> num
; Sums the numbers from 0 to n
(define (sum n)
  (cond
    [(zero? n) 0]
    [else (+ n (sum (- n 1)))])))
```

How much *space* does `(sum n)` take?

Cost of Computation, Revisited

```
; sum : num -> num
; Sums the numbers from 0 to n
(define (sum n)
  (cond
    [(zero? n) 0]
    [else (+ n (sum (- n 1)))]))
```

How much *space* does `(sum n)` take?

```
(sum n)
→ → (+ n (sum n-1))
→ → (+ n (+ n-1 (sum n-2)))
→ → → (+ n (+ n-1 (+ n-2 ... 0)))
```

Cost of Computation, Revisited

```
; sum : num -> num
; Sums the numbers from 0 to n
(define (sum n)
  (cond
    [(zero? n) 0]
    [else (+ n (sum (- n 1)))]))
```

How much *space* does `(sum n)` take?

```
(sum n)
→ → (+ n (sum n-1))
→ → (+ n (+ n-1 (sum n-2)))
→ → → (+ n (+ n-1 (+ n-2 ... 0)))
```

So it takes space proportional to n

Cost of Computation with an Accumulator

```
; asum : num num -> num  
; Sums the numbers from 0 to n, added to res  
(define (asum n res)  
  (cond  
    [(zero? n) res]  
    [else (asum (- n 1) (+ res n))]))
```

How long does `(asum n 0)` take?

Cost of Computation with an Accumulator

```
; asum : num num -> num
; Sums the numbers from 0 to n, added to res
(define (asum n res)
  (cond
    [(zero? n) res]
    [else (asum (- n 1) (+ res n))]))
```

How long does `(asum n 0)` take?

Still proportional to *n*

Cost of Computation with an Accumulator

```
; asum : num num -> num
; Sums the numbers from 0 to n, added to res
(define (asum n res)
  (cond
    [(zero? n) res]
    [else (asum (- n 1) (+ res n))]))
```

How much *space* does `(asum n 0)` take?

Cost of Computation with an Accumulator

```
; asum : num num -> num
; Sums the numbers from 0 to n, added to res
(define (asum n res)
  (cond
    [(zero? n) res]
    [else (asum (- n 1) (+ res n))]))
```

How much *space* does `(asum n 0)` take?

```
(asum n 0)
→ → (asum n-1 n)
→ → (asum n-2 2n-1)
→ → → (asum 0  $n^2/2+n/2$ )
```

Cost of Computation with an Accumulator

```
; asum : num num -> num
; Sums the numbers from 0 to n, added to res
(define (asum n res)
  (cond
    [(zero? n) res]
    [else (asum (- n 1) (+ res n))]))
```

How much *space* does `(asum n 0)` take?

```
(asum n 0)
→ → (asum n-1 n)
→ → (asum n-2 2n-1)
→ → → (asum 0  $n^2/2+n/2$ )
```

So it takes constant space, independent of n

Time and Space

- Weeks ago, we saw how an accumulator can save lots of time
- Less frequently, an accumulator can save space (sometimes even when it saves no time)

Accumulators save space when the result of a recursive call is the result for the current call:

```
(define (asum n res)
  (cond
    [(zero? n) res]
    [else (asum (- n 1) (+ res n))]))
```

Time and Space

- Weeks ago, we saw how an accumulator can save lots of time
- Less frequently, an accumulator can save space (sometimes even when it saves no time)

Accumulators save space when the result of a recursive call is the result for the current call:

```
(define (asum n res)
  (cond
    [(zero? n) res]
    [else (asum (- n 1) (+ res n))]))
```

As it turns out, recursive-call space in Java tends to be more scarce than other space, so this kind of saving is often important

Cost of Computation in Java

```
class Summer {  
    int sum(int n) {  
        if (n == 0)  
            return 0;  
        else  
            return n+this.sum(n-1);  
        }  
    }
```

How long does `new Summer().sum(n)` take?

Cost of Computation in Java

```
class Summer {  
    int sum(int n) {  
        if (n == 0)  
            return 0;  
        else  
            return n+this.sum(n-1);  
        }  
    }
```

How long does `new Summer().sum(n)` take?

Still proportional to *n*

Cost of Computation in Java

```
class Summer {  
    int sum(int n) {  
        if (n == 0)  
            return 0;  
        else  
            return n+this.sum(n-1);  
    }  
}
```

How much *space* does `new Summer().sum(n)` take?

Cost of Computation in Java

```
class Summer {  
    int sum(int n) {  
        if (n == 0)  
            return 0;  
        else  
            return n+this.sum(n-1);  
    }  
}
```

How much *space* does `new Summer().sum(n)` take?

`s.sum(n)`

→ → `return n+s.sum(n-1)`

→ → `return n+(return n-1+s.sum(n-2))`

→ → → `return n+(return n-1+(return n-2+...0))`

Cost of Computation in Java

```
class Summer {  
    int sum(int n) {  
        if (n == 0)  
            return 0;  
        else  
            return n+this.sum(n-1);  
    }  
}
```

How much *space* does `new Summer.sum(n)` take?

`s.sum(n)`

→ → `return n+s.sum(n-1)`

→ → `return n+(return n-1+s.sum(n-2))`

→ → → `return n+(return n-1+(return n-2+...0))`

Again, space proportional to n

Cost of Computation in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

How long does `new Summer().asum(n, 0)` take?

Cost of Computation in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

How long does `new Summer().asum(n, 0)` take?

Still proportional to n

Cost of Computation in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

How much *space* does `new Summer().asum(n, 0)` take?

Cost of Computation in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

How much *space* does `new Summer().asum(n, 0)` take?

`s.asum(n, 0)`

→ → `return s.asum(n-1, n)`

→ → `return return s.asum(n-2, 2n-1)`

→ → → `return return ... return $n^2/2+n/2$`

Cost of Computation in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

How much *space* does `new Summer().asum(n, 0)` take?

```
s.asum(n, 0)  
→ → return s.asum(n-1, n)  
→ → return return s.asum(n-2, 2n-1))  
→ → → return return ... return  $n^2/2+n/2$ 
```

Still space proportional to n , due to all the `returns`

Tail Calls in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

The `return` explanation reflects the actual semantics of Java: redundant `returns` do not get dropped

Tail Calls in Java

```
class Summer {  
    int asum(int n, int res) {  
        if (n == 0)  
            return res;  
        else  
            return this.asum(n-1, res+n);  
    }  
}
```

The `return` explanation reflects the actual semantics of Java: redundant `returns` do not get dropped

- To allow constant-space loops, languages like Java provide a special form
- The special form only works for loops with no arguments

Getting Rid of Arguments

```
(define (sum n)
  (local [(define (asum i res)
            (cond
              [(zero? i) res]
              [else (asum (- i 1) (+ res i))]))])
    (asum n 0)))
```

Getting Rid of Arguments

```
(define (sum n)
  (local [(define (asum i res)
            (cond
              [(zero? i) res]
              [else (asum (- i 1) (+ res i))])]))]
    (asum n 0)))
```

Equivalent Scheme code (in extremely poor style):

```
(define (sum n)
  (local [(define res 0)
          (define i n)
          (define (asum)
            (cond
              [(zero? i) (void)]
              [else (set! res (+ res i))
                    (set! i (- i 1))
                    (asum)])]))]
    (asum)
    res))
```

Loops in Java

```
(define (sum n)
  (local
    [(define res 0)
     (define i n)
     (define (asum)
       (cond
         [(zero? i) (void)]
         [else (set! res (+ res i))
              (set! i (- i 1))
              (asum)]))])
  (asum)
  res))
```

```
class Summer {
  int sum(int n) {
    int res = 0;
    int i = n;
    while (true) {
      if (i == 0)
        break;
      else {
        res = res + i;
        i = i - 1;
      }
    }
    return res;
  }
}
```

The `while` form is like a recursive function that always either returns void or calls itself with no arguments

Loops in Java, Slightly Better Style

```
while (true) { if (test) break; else ... }  
⇒ while (test) { ... }
```

```
class Summer {  
    int sum(int n) {  
        int res = 0;  
        int i = n;  
        while (true) {  
            if (i == 0)  
                break;  
            else {  
                res = res + i;  
                i = i - 1;  
            }  
        }  
        return res;  
    }  
}
```

```
class Summer {  
    int sum(int n) {  
        int res = 0;  
        int i = n;  
        while (i >= 0) {  
            res = res + i;  
            i = i - 1;  
        }  
        return res;  
    }  
}
```

Loops in Java, Good Style

init; while (*test*) { ... *incr*; }
⇒ for (*init*; *test*; *incr*) { ... }

```
class Summer {  
    int sum(int n) {  
        int res = 0;  
        int i = n;  
        while (true) {  
            if (i == 0)  
                break;  
            else {  
                res = res + i;  
                i = i - 1;  
            }  
        }  
        return res;  
    }  
}
```

```
class Summer {  
    int sum(int n) {  
        int res = 0;  
        for (int i = n;  
            i != 0;  
            i = i - 1) {  
            res = res + i;  
        }  
    }  
}
```

When Loops Don't Work

Converting tree recursion into a loop usually won't work, because there are multiple recursive calls for each call

Some algorithms, such as **merge-sort**, also involve multiple recursive calls

Technically, any program can be converted by manually creating ***continuations***, but that's a topic for CS 3520

Loops in Java

Conclusion:

- Use **for** and **while** to make your code look and run better
- When in doubt, write the recursive version first