Recreation

What is the sum of the coefficients of

$$(1-3x+3x^2)^{743}(1+3x-3x^2)^{744}$$

after expanding and collecting terms?

CS61B Lecture #5: Arrays

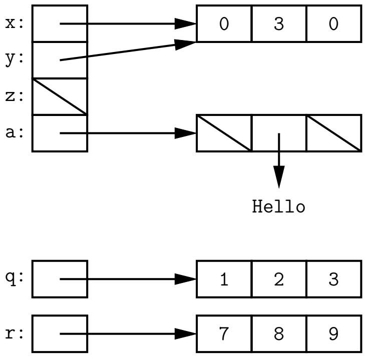
- An array is a structured container whose components are
  - **length**, a fixed integer.
  - a sequence of **length** simple containers of the same type, numbered from 0.
  - (.length field usually implicit in diagrams.)
- Arrays are anonymous, like other structured containers.
- Always referred to with pointers.
- For array pointed to by `A`,
  - Length is `A.length`
  - Numbered component i is `A[`i`]` (i is the *index*)
  - Important feature: index can be *any integer expression*.

A Few Samples

Java

```
int[] x, y, z;
String[] a;
x = new int[3];
y = x;
a = new String[3];
x[1] = 2;
y[1] = 3;
a[1] = "Hello";

int[] q;
q = new int[] { 1, 2, 3 };
// Short form for declarations:
int[] r = { 7, 8, 9 };
```

Results



x: 0 3 0

y:

z:

a:

Hello

q: 1 2 3

r: 7 8 9

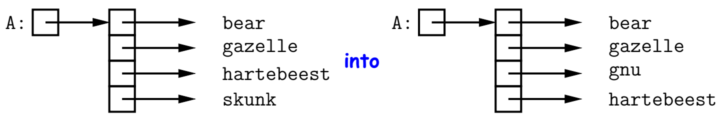
Example: Accumulate Values

Problem: Sum up the elements of array A.

```
static int sum(int[] A) {
  int N;
  N = 0;                                    // New (1.5) syntax
  for (int i = 0; i < A.length; i += 1)     for (int x : A)
    N += A[i];                                N += x;
  return N;
}


// For the hard-core: could have written

int N, i;
for (i=0, N=0; i<A.length; N += A[i], i += 1)
  { }   // or just ;

// But please don't: it's obscure.
```

Example: Insert into an Array

Problem: Want a call like `insert(A, 2, "gnu")` to convert (destructively)



A: bear gazelle hartebeest skunk

into

A: bear gazelle gnu hartebeest

```
/** Insert X at location K in ARR, moving items K, K+1, ... to locations
 *  K+1, K+2, ....  The last item in ARR is lost. */
static void insert (String[] arr, int k, String x) {
  for (int i = arr.length-1; i > k; i -= 1) // Why backwards?
    arr[i] = arr[i-1];
  /* Alternative to this loop:
       System.arraycopy(arr, k,  arr, k+1,  arr.length-k-1);*/
                        from      to        # to copy
  arr[k] = x;
}
```

(Aside) Java Shortcut

- **Useful tip:** Can write just '`arraycopy`' by including at the top of the source file:

  `import static java.lang.System.arraycopy;`

- This means "define the simple name `arraycopy` to be the equivalent of `java.lang.System.arraycopy` in the current source file."
- Can do the same for `out` so that you can write

  `out.println(...);`

  in place of

  `System.out.println(...);`

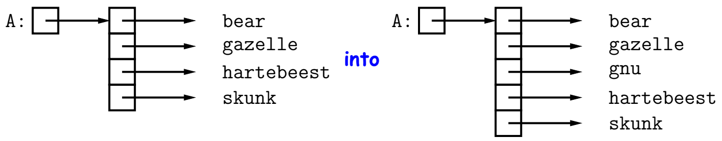
- Finally, a declaration like

  `import static java.lang.Math.*;`

  means "take all the (public) static definitions in `java.lang.Math` and make them available in this source file by their simple names (the name after the last dot)."
- Useful for functions like `sin`, `sqrt`, etc.

Growing an Array

Problem: Suppose that we want to change the description above, so that `A = insert2 (A, 2, "gnu")` does *not* shove "skunk" off the end, but instead "grows" the array.



A:
bear
gazelle
hartebeest
skunk

into

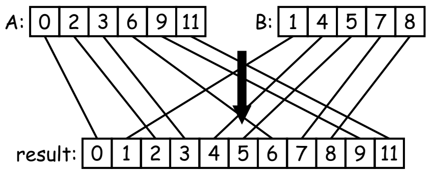
A:
bear
gazelle
gnu
hartebeest
skunk

```
/** Return array, r, where r.length = ARR.length+1; r[0..K-1]
 *  the same as ARR[0..K-1], r[k] = x, r[K+1..] same as ARR[K..]. */
static String[] insert2(String[] arr, int k, String x) {
  String[] result = new String[arr.length + 1];
  arraycopy(arr, 0, result, 0, k);
  arraycopy(arr, k, result, k+1, arr.length-k);
  result[k] = x;
  return result;
}
```

Why do we need a different return type from `insert2`??

Example: Merging

Problem: Given two sorted arrays of ints, A and B, produce their *merge*: a sorted array containing all items from A and B.



A: 0 2 3 6 9 11

B: 1 4 5 7 8

result: 0 1 2 3 4 5 6 7 8 9 11

Example: Merging Program

Problem: Given two sorted arrays of ints, A and B, produce their *merge*: a sorted array containing all from A and B.
Remark: In order to solve this recursively, it is useful to *generalize* the original function to allow merging *portions* of the arrays.

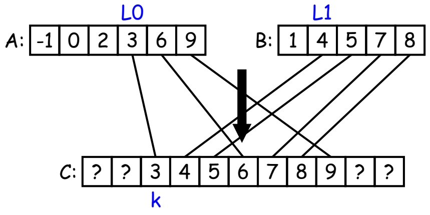
```
/** Assuming A and B are sorted, returns their merge. */
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0);
}

/** The merge of A[L0..] and B[L1..] assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1) {
   int N = A.length - L0 + B.length - L1; int[] C = new int[N];
   if (L0 >= A.length) arraycopy(B, L1, C, 0, N);
   else if (L1 >= B.length) arraycopy(A, L0, C, 0, N);
   else if (A[L0] <= B[L1]) {
      C[0] = A[L0]; arraycopy(mergeTo(A, L0+1, B, L1), 0, C, 1, N-1);
   } else {
      C[0] = B[L1]; arraycopy(mergeTo(A, L0, B, L1+1), 0, C, 1, N-1);
   }
   return C;
}
```

What is wrong with this implementation?

A Tail-Recursive Strategy

```
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0, new int[A.length+B.length], 0);
}

/** Merge A[L0..] and B[L1..] into C[K..], assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1, int[] C, int k){
   ...
}
```

This last method merges *part* of `A` with part of `B` into part of `C`. For example, consider a possible call `mergeTo(A, 3, B, 1, C, 2)`



L0

L1

A: -1 0 2 3 6 9

B: 1 4 5 7 8

C: ? ? 3 4 5 6 7 8 9 ? ?

k

A Tail-Recursive Solution

```
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0, new int[A.length+B.length], 0);
}

/** Merge A[L0..] and B[L1..] into C[K..], assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1, int[] C, int k){
   if (??) {
      return C;
   } else if (??) {
      C[k] = A[L0];
      return mergeTo(A, ??, B, ??, C, ??)
   } else {
      C[k] = B[L1];
      return mergeTo(A, ??, B, ??, C, ??)
   }
}
```

A Tail-Recursive Solution

```
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0, new int[A.length+B.length], 0);
}

/** Merge A[L0..] and B[L1..] into C[K..], assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1, int[] C, int k){
   if (L0 >= A.length && L1 >= B.length) {
      return C;
   } else if (??) {
      C[k] = A[L0];
      return mergeTo(A, ??, B, ??, C, ??)
   } else {
      C[k] = B[L1];
      return mergeTo(A, ??, B, ??, C, ??)
   }
}
```

A Tail-Recursive Solution

```
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0, new int[A.length+B.length], 0);
}

/** Merge A[L0..] and B[L1..] into C[K..], assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1, int[] C, int k){
   if (L0 >= A.length && L1 >= B.length) {
      return C;
   } else if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
      C[k] = A[L0];
      return mergeTo(A, ??, B, ??, C, ??)
   } else {
      C[k] = B[L1];
      return mergeTo(A, ??, B, ??, C, ??)
   }
}
```

A Tail-Recursive Solution

```
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0, new int[A.length+B.length], 0);
}

/** Merge A[L0..] and B[L1..] into C[K..], assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1, int[] C, int k){
   if (L0 >= A.length && L1 >= B.length) {
      return C;
   } else if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
      C[k] = A[L0];
      return mergeTo(A, L0 + 1, B, L1, C, k + 1);
   } else {
      C[k] = B[L1];
      return mergeTo(A, ??, B, ??, C, ??)
   }
}
```

A Tail-Recursive Solution

```
public static int[] merge(int[] A, int[] B) {
   return mergeTo(A, 0, B, 0, new int[A.length+B.length], 0);
}

/** Merge A[L0..] and B[L1..] into C[K..], assuming A and B sorted. */
static int[] mergeTo(int[] A, int L0, int[] B, int L1, int[] C, int k){
   if (L0 >= A.length && L1 >= B.length) {
      return C;
   } else if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
      C[k] = A[L0];
      return mergeTo(A, L0 + 1, B, L1, C, k + 1);
   } else {
      C[k] = B[L1];
      return mergeTo(A, L0, B, L1 + 1, C, k + 1);
   }
}
```

Iterative Solution

In general, we don't use either of the previous approaches in languages like C and Java. Array manipulation is most often iterative:

```
public static int[] merge(int[] A, int[] B) {
   int[] C = new int[A.length + B.length];
   // mergeTo(A, 0, B, 0, C, 0)
   int L0, L1, k;
   L0 = L1 = k = 0;

   while (??) {
       if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
           C[k] = A[L0];
           ??
       } else {
           C[k] = B[L1];
           ??
       }
   }
   return C;
}
```

Iterative Solution

In general, we don't use either of the previous approaches in languages like C and Java. Array manipulation is most often iterative:

```
public static int[] merge(int[] A, int[] B) {
   int[] C = new int[A.length + B.length];
   // mergeTo(A, 0, B, 0, C, 0)
   int L0, L1, k;
   L0 = L1 = k = 0;

   while (L0 < A.length || L1 < B.length) {
       if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
           C[k] = A[L0];
           ??
       } else {
           C[k] = B[L1];
           ??
       }
   }
   return C;
}
```

Iterative Solution

In general, we don't use either of the previous approaches in languages like C and Java. Array manipulation is most often iterative:

```
public static int[] merge(int[] A, int[] B) {
   int[] C = new int[A.length + B.length];
   // mergeTo(A, 0, B, 0, C, 0)
   int L0, L1, k;
   L0 = L1 = k = 0;

   while (L0 < A.length || L1 < B.length) {
       if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
           C[k] = A[L0];
           L0 += 1; k += 1;
       } else {
           C[k] = B[L1];
           L1 += 1; k += 1;
       }
   }
   return C;
}
```

Iterative Solution II

The same, with a **for** loop:

```
public static int[] merge(int[] A, int[] B) {
   int[] C = new int[A.length + B.length];
   int L0, L1;
   L0 = L1 = 0;
   for (int k = 0; k < C.length; k += 1) {
       if (L1 >= B.length || (L0 < A.length && A[L0] <= B[L1])) {
           C[k] = A[L0]; L0 += 1;
       } else {
           C[k] = B[L1]; L1 += 1;
       }
   }
   return C;
}
```

Invariant (true after `int k = 0`):

$0 \le L0 \le A.length \ \wedge\ 0 \le L1 \le B.length \wedge\ C.length = A.length + B.length \ \wedge\ k = L0 + L1$

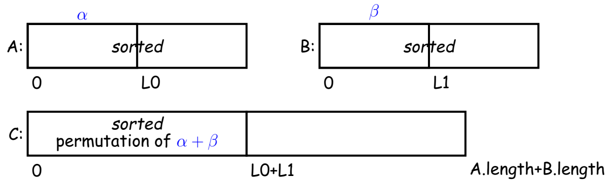
$\wedge\ C[0:k]$ is a permutation of A[0:L0] + B[0:L1]

$\wedge\ C[0:k], A, B$ are sorted.

Alternative Solution: Removing k

Using previous invariant that `k=L0+L1` simplifies things:

```
public static int[] merge(int[] A, int[] B) {
   int[] C = new int[A.length + B.length];
   int L0, L1;  L0 = L1 = 0;
   while (L0 + L1 < C.length) {
       if (L1 >= B.length || (L0 < A.length && A[L0] < B[L1])) {
           C[L0 + L1] = A[L0]; L0 += 1;
       } else {
           C[L0 + L1] = B[L1]; L1 += 1;
       }
   }
   return C;
}
```



Multidimensional Arrays

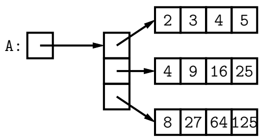
What about two- or higher-dimensional layouts, such as

$$A = \begin{array}{|r|r|r|r|}\hline 2 & 3 & 4 & 5 \\ \hline 4 & 9 & 16 & 25 \\ \hline 8 & 27 & 64 & 125 \\ \hline \end{array} \ \ ?$$

Multidimensional Arrays in Java

These are not primitive in Java, but we can build them as arrays of arrays:

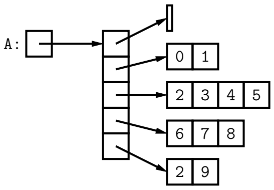
```
   int[][] A = new int[3][];
   A[0] = new int[] {2, 3, 4, 5};
   A[1] = new int[] {4, 9, 16, 25};
   A[2] = new int[] {8, 27, 64, 125};
// or
   int[][] A;
   A = new int[][] { {2, 3, 4, 5},
                     {4, 9, 16, 25},
                     { 8, 27, 64, 125} };
// or
   int[][] A = { {2, 3, 4, 5},
                 {4, 9, 16, 25},
                 {8, 27, 64, 125} };
// or
   int[][] A = new A[3][4];
   for (int i = 0; i < 3; i += 1)
       for (int j = 0; j < 4; j += 1)
           A[i][j] = (int) Math.pow(j + 2, i + 1);
```



Exotic Multidimensional Arrays

- Since every element of an array is independent, there is no single “width” in general:

```
int[][] A = new int[5][];
A[0] = new int[] {};
A[1] = new int[] {0, 1};
A[2] = new int[] {2, 3, 4, 5};
A[3] = new int[] {6, 7, 8};
A[4] = new int[] {9};
```



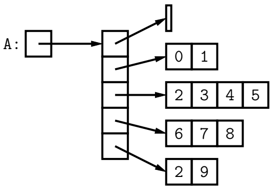
- What does this print?

```
int[][] ZERO = new int[3][];
ZERO[0] = ZERO[1] = ZERO[2] =
    new int[] {0, 0, 0};
ZERO[0][1] = 1;
System.out.println(ZERO[2][1]);
```

Exotic Multidimensional Arrays

- Since every element of an array is independent, there is no single “width” in general:

```
int[][] A = new int[5][];
A[0] = new int[] {};
A[1] = new int[] {0, 1};
A[2] = new int[] {2, 3, 4, 5};
A[3] = new int[] {6, 7, 8};
A[4] = new int[] {9};
```



- What does this print?

```
int[][] ZERO = new int[3][];
ZERO[0] = ZERO[1] = ZERO[2] =
    new int[] {0, 0, 0};
ZERO[0][1] = 1;
System.out.println(ZERO[2][1]);
```