Java Programming

U Hou Lok

Department of Computer Science and Information Engineering,
National Taiwan University

Java 273
22 Aug.–2 Sep., 2016

```
1 class Lecture5 {
2
3                     "Arrays"
4
5 }
```

Arrays

An array stores a large collection of data which is of the same type.

```
1 ...
2         // assume the size variable exists above
3         T[] x = new T[size];
4         // this creates an array of T type referenced by x
5 ...
```

- **T** can be any data type.
- This statement comprises two parts:
  - Variable declaration
  - Creating an array

Variable Declaration

- In the left-hand side of the assignment operator, it is a declaration for an array variable, which does not allocate real space for the array.
- In reality, this variable occupies only a certain space for the reference to an array.[1]
- If a reference variable does not refer to an array, the value of the variable is null.[2]
- So you cannot assign elements to this array variable unless it has already been created.

[1] Recall the stack and the heap in the memory layout.

[2] Moreover, this holds for any reference variable. For example, the **Scanner** type.

Creating A Real Array

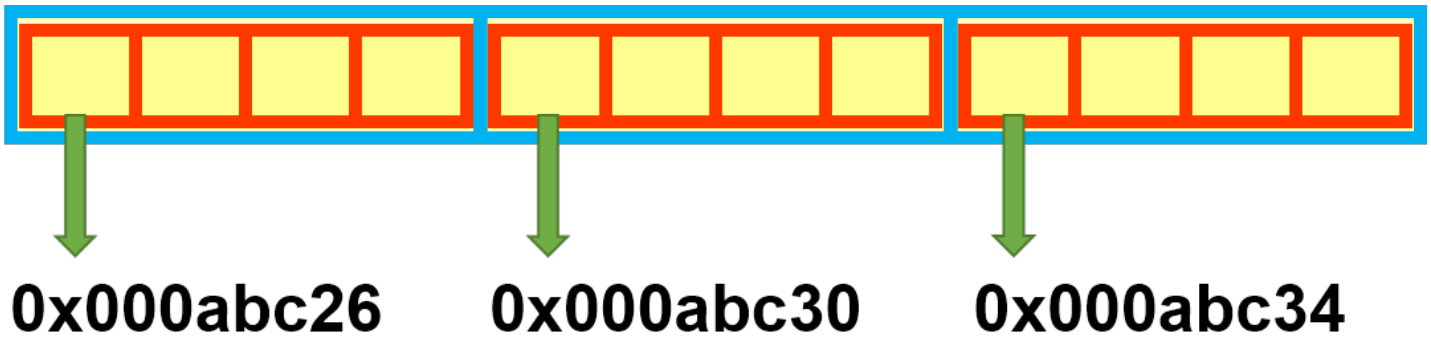
- All arrays of Java are objects.
- So the new operator returns the reference after creating an array object.
- The type of reference variables must be compatible to that of the array object.
- The variable *size* must be a positive integer for the number of elements.
- Note that the size of an array cannot be changed after the array is created.[3]

[3] You can try the **ArrayList** class. See any textbook for data structures.

Arrays and Memory

- Consider this array whose elements are all int type:

```
1 int[] x = new int[3];
```



- The array is allocated contiguously in the memory.
- Note that the arrays (in Java) are zero-based indexing. (Why?)
- So we have x[0], x[1], and x[2].

Array Initializer

Arrays can be initialized when they are declared.

- When an array is created, the elements are assigned the default value:
  - 0 for the numeric primitive data types
  - \u0000 for char type
  - false for boolean type
- An array also can be initialized by enumerating all the elements in a list.
- For example,

```
1 int[] x = {1, 2, 3};
```

- Note that there is no need to use new if enumeration is used.

Processing Arrays

When processing array elements, we often use a for loop.

- Since the size of the array is known, it is natural to use a for loop to manipulate the array.
- For all arrays, they have a field called **length** which records the size of this array.
  - For example, use x.length to get the size of x.

Examples

Initializing arrays with input values

```
1 ...
2         // let x be an integer array with a certain size
3         for (int i = 0; i < x.length; ++i) {
4             x[i] = input.nextInt();
5         }
6 ...
```

Initializing arrays with random values

```
1 ...
2         for (int i = 0; i < x.length; ++i) {
3             x[i] = (int) (Math.random() * 10);
4         }
5 ...
```

Displaying arrays

```
1 ...
2         for (int i = 0; i < x.length; ++i) {
3             System.out.printf("x[%d] = %d\n", i, x[i]);
4         }
5 ...
```

Summing all elements

```
1 ...
2         int sum = 0;
3         for (int i = 0; i < x.length; ++i) {
4             sum += x[i];
5         }
6 ...
```

Finding the extreme values

```
1 ...
2         int max = x[0];
3         int min = x[0];
4         for (int i = 1; i < x.length; ++i) {
5             if (max < x[i]) max = x[i];
6             if (min > x[i]) min = x[i];
7         }
8 ...
```

- How about the location of the extreme values?

Shuffling

```
1  ...
2          // Assume that x is an integer array.
3          for (int i = 0; i < x.length; ++i) {
4              int j = (int) (Math.random() * x.length);
5              // swap
6              int tmp = x[i];
7              x[i] = x[j];
8              x[j] = tmp;
9          }
10 ...
```

- How to swap values of two variables without tmp?
- However, this simple (or naive) algorithm is biased.[4]

[4] See https://blog.codinghorror.com/the-danger-of-naivete/.

Exercise[5]

Generate 4 distinct integers randomly ranging from 0 to 9.

- Consider this algorithm.
  - Generate the 1st random integer and the 2nd random integer.
  - Then check if the second one is identical to the first integer.
  - If so, redraw and check again.
  - If not, then generate the next random integer and repeat the previous steps until the 4 distinct integers are set.
- Argue the time complexity for this algorithm.

[5] Thanks to a lively discussion on January 24, 2016.

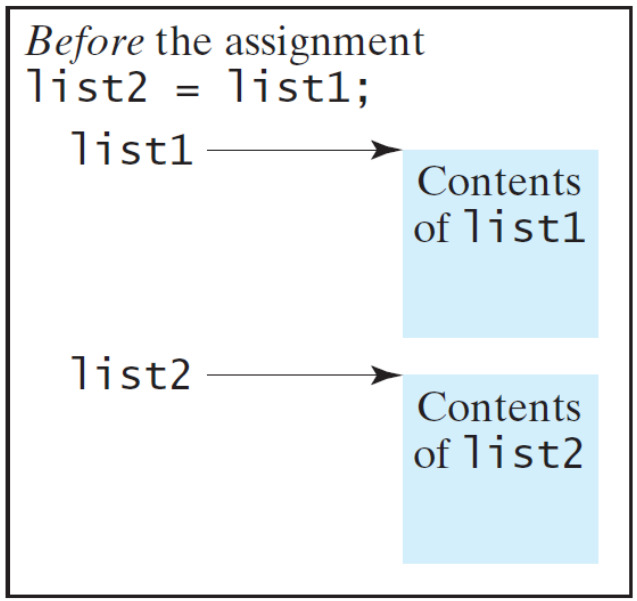
Cloning Arrays

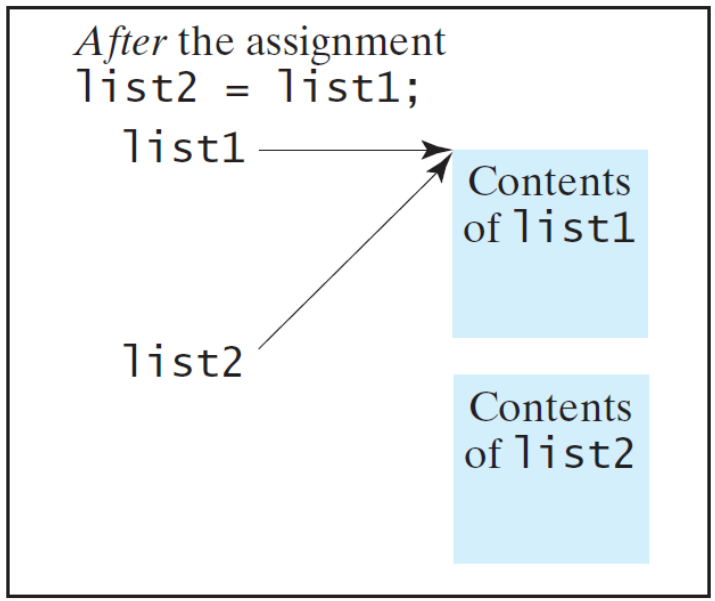
- In practice, one might duplicate an array for some reason.
- One could attempt to use the assignment statement (=), for example,

```
1  ...
2  T[] A = {...}; // some array
3  T[] B = A;
4  ...
```

- However, this is impossible to make two distinct arrays.
- Recall that arrays are objects and the array variables are simply references to these objects.
- So you actually copy the memory address to another reference variable!

- Moreover, all the reference variables share this property!
- For example,





- Use a loop to copy individual elements one by one.

```
1  ...
2  int[] A = {2, 1, 3, 5, 10};
3  int[] B = new int[A.length];
4  for (int i = 0; i < A.length; ++i) {
5  B[i] = A[i];
6  }
7  ...
```

- Use the static *arraycopy* method in the **System** class.

```
1  ...
2  int[] A = {2, 1, 3, 5, 10};
3  int[] B = new int[A.length];
4  System.arraycopy(A, 0, B, 0, A.length);
5  ...
```

for-each Loops[6]

- A for-each loop is designed to iterate over a collection of objects, such as an array, in strictly sequential fashion, from start to finish.
- For example,

```
1  ...
2  int[] A = {...}; // some T type array
3  for (T x: A) {
4  // body
5  }
6  ...
```

- Note that the type **T** should be compatible to the element type of *A*.

[6] Beginning with Java SE 5. Now we have Jave SE 8.

Example

```
1  ...
2  int[] A = {1, 2, 3};
3  int sum = 0;
4  for (int i = 0; i < A.length; ++i)
5  sum += A[i];
6  ...
```

- Not only is the syntax streamlined, but it also prevents boundary errors.

```
1  ...
2  int[] A = {1, 2, 3};
3  int x = 0;
4  for (int x: A)
5  sum += x;
6  ...
```

Exercise

Deck of Cards

Write a program which picks first 5 cards at random from a deck of 52 cards.

- 4 suits: Spade, Heart, Diamond, Club
- 13 ranks: $2, \ldots, 10$, J, Q, K, A
- Labeling 52 cards by $0, 1, \cdots, 51$ by a certain rule
- Shuffle the numbers
- Pick up the first 5 cards

Arrays Class

- The **Arrays** class contains useful methods for common array operations such as sorting and searching.
- For example,

```
1  import java.util.Arrays;
2
3  ...
4  int[] A = {5, 2, 8};
5  Arrays.sort(A); // sort the whole array
6
7  char[] B = {'A', 'r', 't', 'h', 'u', 'r'};
8  Arrays.sort(B, 1, 3); // sort the array partially
9  ...
```

Selection Sort

```
1   ...
2   // selection sort
3   for (int i = 0; i < A.length; i++) {
4   int k = i;
5   for (int j = i; j < A.length; j++) {
6   if (A[k] > A[j]) k = j;
7   }
8   int tmp = A[k];
9   A[k] = A[i];
10  A[i] = tmp;
11  }
12  ...
```

- Time complexity: $O(n^2)$
- You can find more sorting algorithms.[7]

[7] See http://www.sorting-algorithms.com/

Example: Linear Search

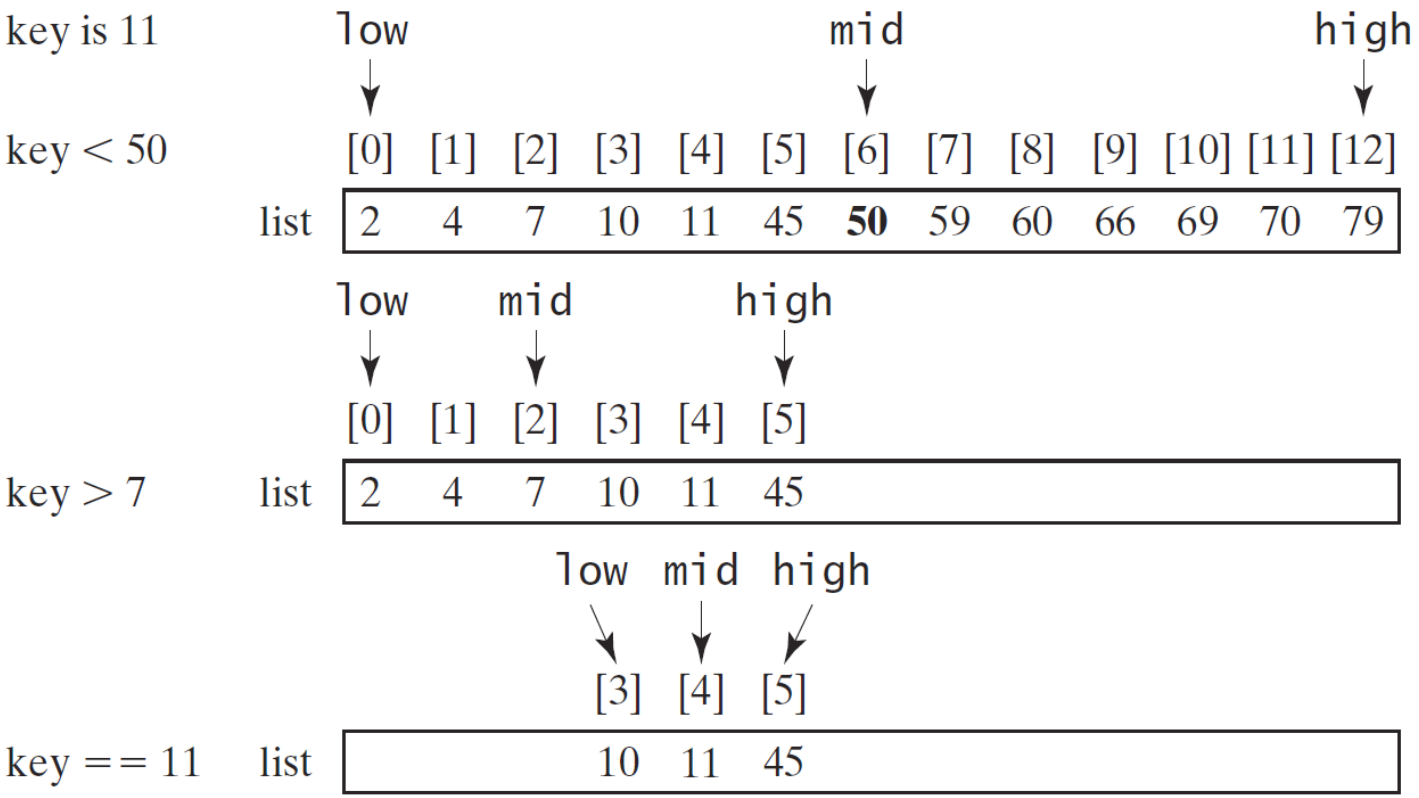
Write a program which searches for the index associated with the key value.

- The linear search approach compares the key with each element in the array sequentially.

```
1   ...
2   public static void main (String[] args) {
3   int[] A = new int[10];
4   for (int i = 0; i < A.length; i++) {
5   A[i] = (int) (Math.random() * 10);
6   System.out.printf("[%2d]: %d\n", i, A[i]);
7   }
8
9   Scanner in = new Scanner(System.in);
10  System.out.println("Enter a key number? ");
11  int key = in.nextInt();
12  in.close();
13
14  int index = -1;
15  for (int i = 0; i < A.length; i++) {
16  if (A[i] == key) {
17  System.out.printf("%2d", i);
18  }
19  }
20  }
21  ...
```

- Time complexity: $O(n)$

Alternative: Binary Search



- Time complexity: $O(\log n)$
- Overall time complexity (sorting + searching): still $O(\log n)$?

```
1    ...
2    int index = -1;
3
4    int high = A.length - 1, low = 0, mid;
5    while (high > low) {
6    mid = (high + low) / 2;
7    if (A[mid] == keyValue) {
8    index = mid;
9    break;
10   } else if (A[mid] > keyValue)
11   high = mid - 1;
12   else
13   low = mid + 1;
14   }
15
16   if (index > -1)
17   System.out.printf("%d: %d\n", keyValue, index);
18   else
19   System.out.printf("%d: does not exist\n", keyValue);
20   ...
```

Data Structures In A Nutshell

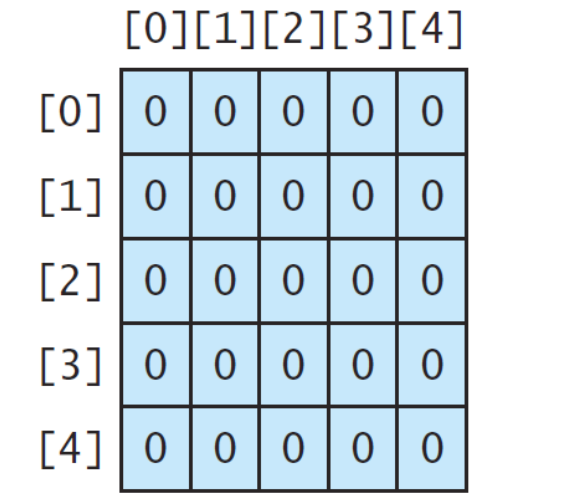
- A data structure is a particular way of organizing data in a program so that it can be used efficiently.
- Data structures can implement one or more particular abstract data types (ADT), which specify the operations that can be performed on a data structure and the computational complexity of those operations.
- In comparison, a data structure is a concrete implementation of the specification provided by some ADT.
- Different kinds of data structures are suited to different kinds of applications, and some are highly specialized to specific tasks.[8]

[8] See `http://bigocheatsheet.com/`.

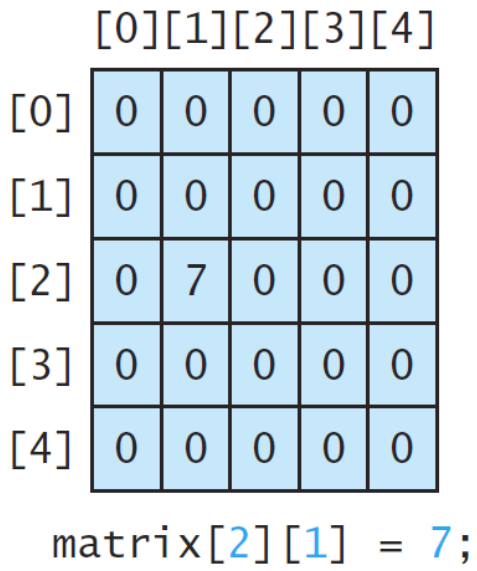
Beyond 1-Dimensional Arrays

- 2D or high-dimensional arrays are common, say a photo which is represented by 2D arrays.
- For example, we can have a 2D **T** array with 4 rows and 3 columns:

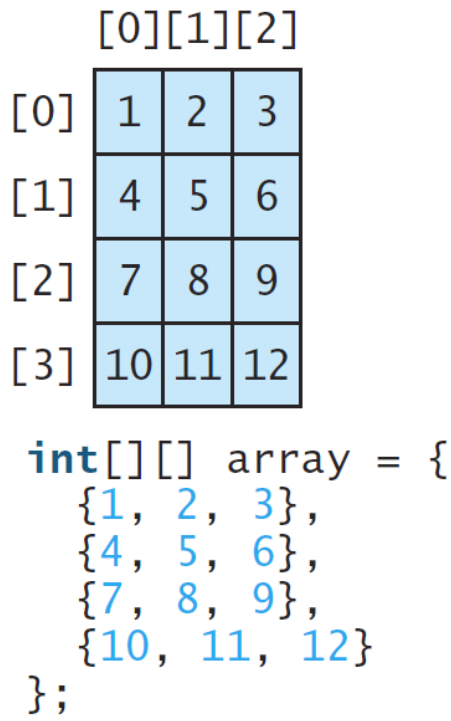
```
1    ...
2    int rowSize = 4; // row size
3    int colSize = 3; // column size
4    T[][] x = new T[rowSize][colSize];
5    ...
```



(a)



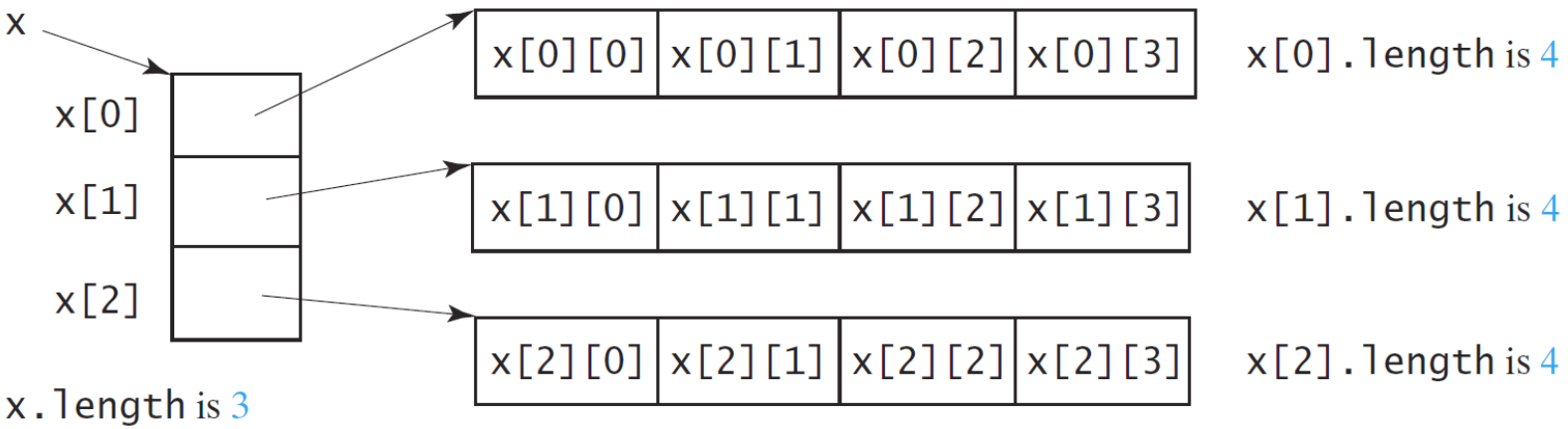
(b)



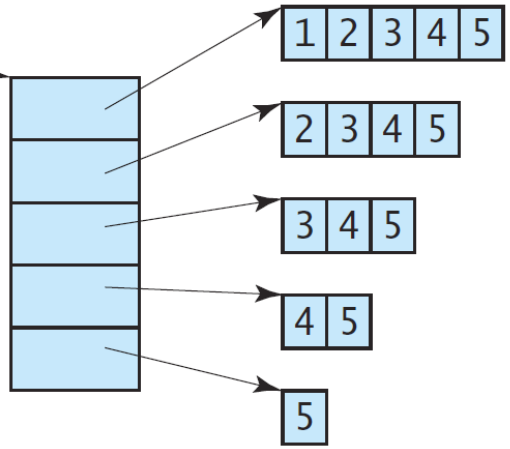
(c)

- Case (c) shows that we can create a 2D array by enumeration.

Reality




```
int[][] triangleArray = {
  {1, 2, 3, 4, 5},
  {2, 3, 4, 5},
  {3, 4, 5},
  {4, 5},
  {5}
};
```



Example[9]

```
1   ...
2   int[][] x = {{1, 2, 3}, {4, 5}, {6}};
3
4   for (int i = 0; i < x.length; i++) {
5   for (int j = 0; j < x[i].length; j++) {
6   System.out.printf("%2d", x[i][j]);
7   }
8   System.out.println();
9   }
10
11  // alternative: for-each loop
12  for (int[] y: x) {
13  for (int z: y) {
14  System.out.printf("%2d", z);
15  }
16  System.out.println();
17  }
18  ...
```

[9] Thanks to a lively discussion on January 31, 2016.

Exercise: Matrix Multiplication

Write a program which determines $C = A \times B$ for the input matrices $A_{m \times n}$ and $B_{n \times q}$ for $m, n, q \in \mathbb{N}$.

- You may use the formula

$$c_{ij} = \sum_{k=1}^{n} a_{ik} b_{kj}$$

  where a_{ik}, $i = 1, 2, \ldots, m$ is a shorthand for A and b_{kj}, $j = 1, 2, \ldots, q$ for B.
- Time complexity: $O(n^3)$ (Why?)

Data Structures In A Nutshell

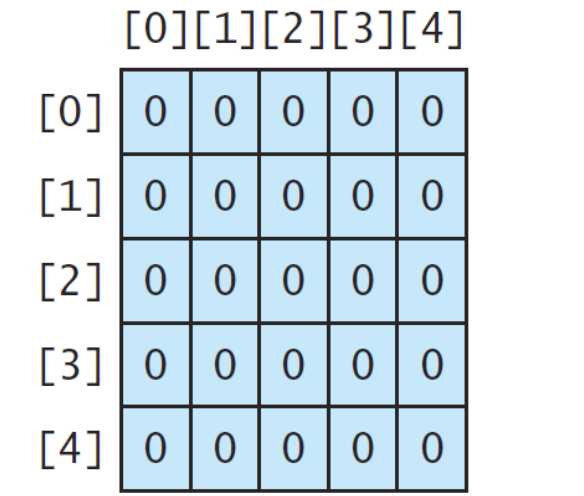
- A data structure is a particular way of organizing data in a program so that it can be used efficiently.
- Data structures can implement one or more particular abstract data types (ADT), which specify the operations that can be performed on a data structure and the computational complexity of those operations.
- In comparison, a data structure is a concrete implementation of the specification provided by some ADT.
- Different kinds of data structures are suited to different kinds of applications, and some are highly specialized to specific tasks.[10]

[10] See `http://bigocheatsheet.com/`.

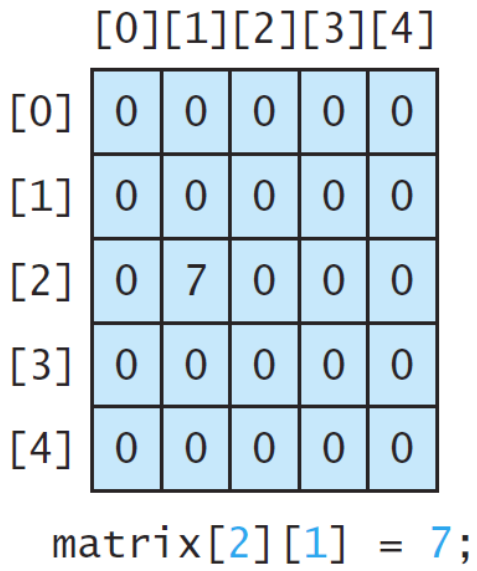
Beyond 1-Dimensional Arrays

- 2D or high-dimensional arrays are common, say a photo which is represented by 2D arrays.
- For example, we can have a 2D **T** array with 4 rows and 3 columns:

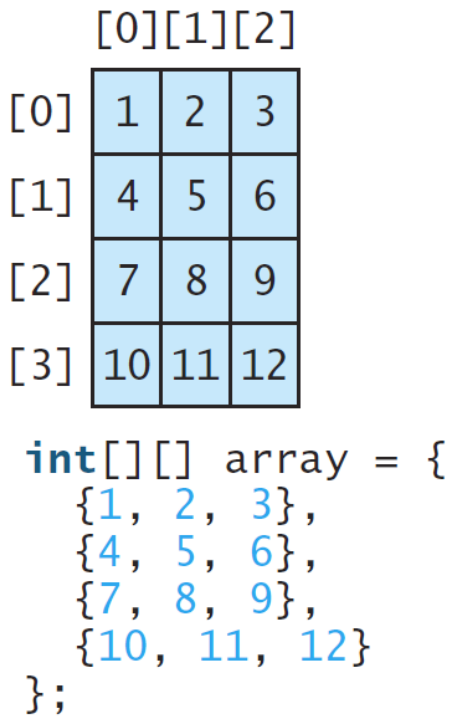
```
1    ...
2    int rowSize = 4; // row size
3    int colSize = 3; // column size
4    T[][] x = new T[rowSize][colSize];
5    ...
```



(a)



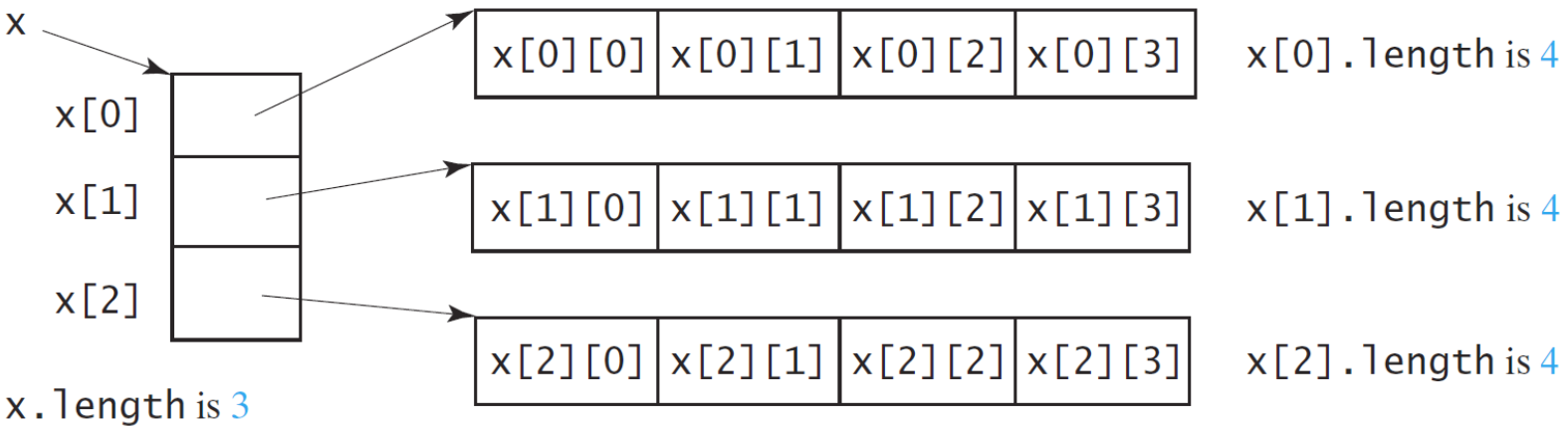
(b)



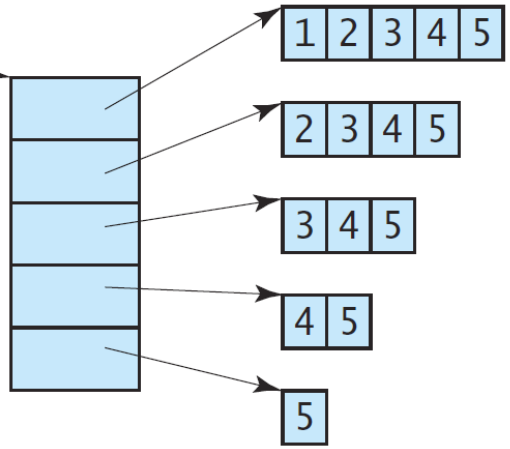
(c)

- Case (c) shows that we can create a 2D array by enumeration.

Reality




```
int[][] triangleArray = {
  {1, 2, 3, 4, 5},
  {2, 3, 4, 5},
  {3, 4, 5},
  {4, 5},
  {5}
};
```



Example[11]

```
1   ...
2   int[][] x = {{1, 2, 3}, {4, 5}, {6}};
3
4   for (int i = 0; i < x.length; i++) {
5   for (int j = 0; j < x[i].length; j++) {
6   System.out.printf("%2d", x[i][j]);
7   }
8   System.out.println();
9   }
10
11  // alternative: for-each loop
12  for (int[] y: x) {
13  for (int z: y) {
14  System.out.printf("%2d", z);
15  }
16  System.out.println();
17  }
18  ...
```

[11] Thanks to a lively discussion on January 31, 2016.

Exercise: Matrix Multiplication

Write a program which determines $C = A \times B$ for the input matrices $A_{m \times n}$ and $B_{n \times q}$ for $m, n, q \in \mathbb{N}$.

- You may use the formula

$$c_{ij} = \sum_{k=1}^{n} a_{ik} b_{kj}$$

  where a_{ik}, $i = 1, 2, \ldots, m$ is a shorthand for A and b_{kj}, $j = 1, 2, \ldots, q$ for B.
- Time complexity: $O(n^3)$ (Why?)

```
1    class Lecture6 {
2
3    "Methods"
4
5    }
6
7    // keywords:
8    return
```

Methods[13]

- Methods can be used to define reusable code, and organize and simplify code.
- The idea of function originates from math, that is,

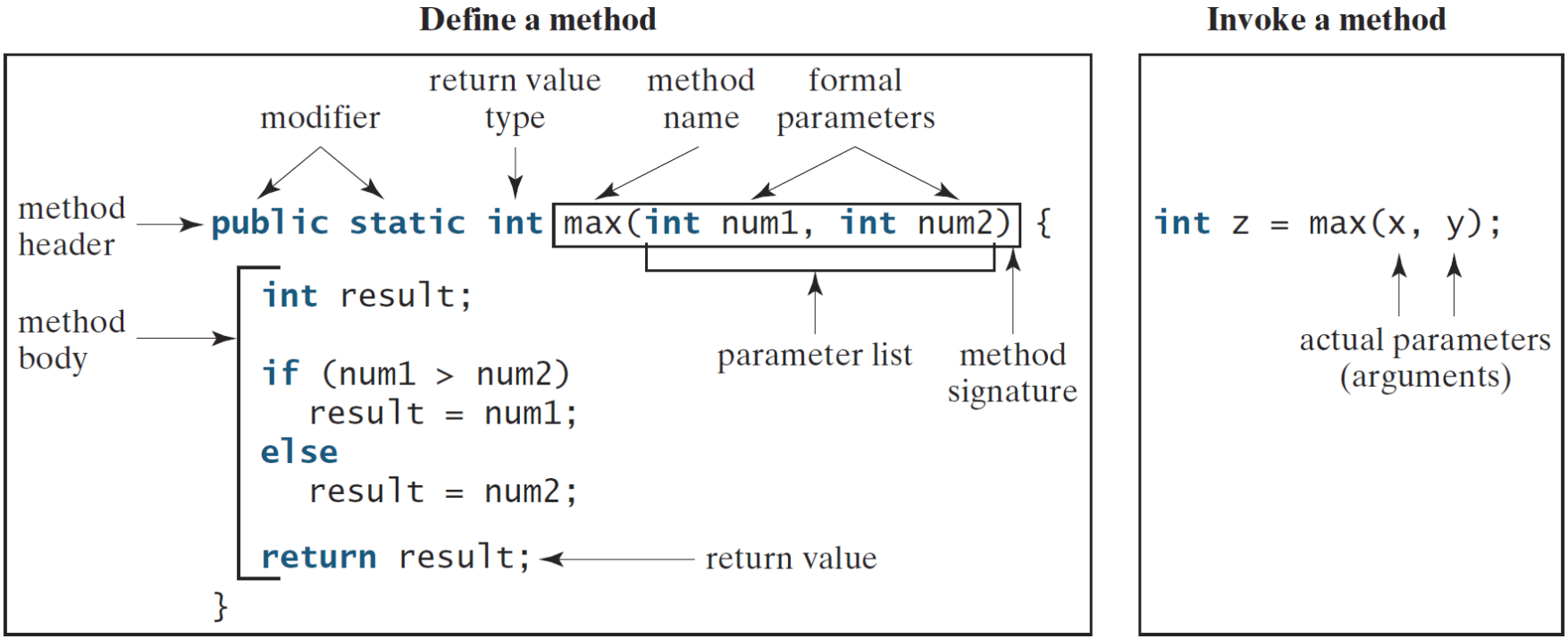
$$y = f(x),$$

  where x is the input parameter[12] and y is the function value.
- In computer science, each input parameter should be declared with a specific type, and a function should be assigned with a return type.

[12] Recall the multivariate functions. The input can be a vector, say the position vector (x, y, z).

[13] Aka procedures and functions.

Example: max


Define a method
Invoke a method
modifier
return value type
method name
formal parameters
method header
method body
public static int max(int num1, int num2) {
int result;
if (num1 > num2)
result = num1;
else
result = num2;
return result;
}
parameter list
method signature
return value
int z = max(x, y);
actual parameters (arguments)

```
1    ...
2    modifier returnType methodName(listOfParameters) {
3    // method body
4    }
5    ...
```

- So far, the *modifier* could be static and public.
- The *returnType* could be primitive types, reference types[14], and void.[15]
- The *listOfParameters* is the input of the method, separated by commas if there are multiple items.
- Note that a method can have no input.[16]
- The method name and the parameter list together constitute the method signature.[17]

[14] A method can return an object.
[15] Recall that a void method does not return a value.
[16] For example, **Math.random**().
[17] It is the key to the method overloading. We will see it soon.

More Observations

- There are alternatives to the method max():

```
1  ...
2  public static int max(int x, int y) {
3  if (x > y) {
4  return x;
5  } else {
6  return y;
7  }
8  }
9  ...
```

```
1  ...
2  public static int max(int x, int y) {
3  return x > y ? x : y;
4  }
5  ...
```

"All roads lead to Rome."
– Anonymous

""

–

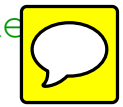
The return Statements

- The return statement is the end point of the method.
- A callee is a method invoked by a caller.
- The callee returns to the caller if the callee
  - completes all the statements (w/o a return statement, say main());
  - reaches a return statement;
  - throws an exception (introduced later).
- Note that the return statement is not necessarily at the bottom of the method.[18]
- Once one defines the return type (except void), the method should return a value or an object of that type.

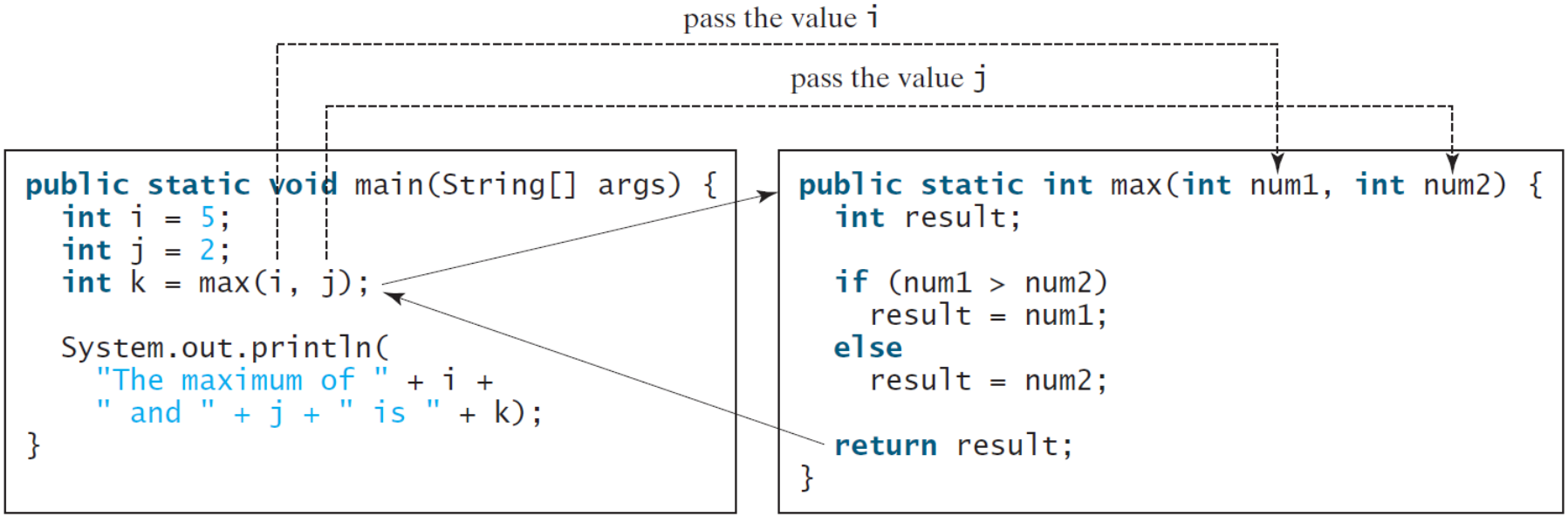
[18] Thanks to a lively discussion on November 22, 2015.

- However, your method should make sure that the return statement is available for all conditions.
- For example,

```
1  ...
2  static int fun1() {
3  while (true);
4  return 0; //unreachable code
5  }
6
7  static int fun2(int x) {
8  if (x > 0) {
9  return x;
10 }
11 // what if x < 0?
12 }
13 ...
```

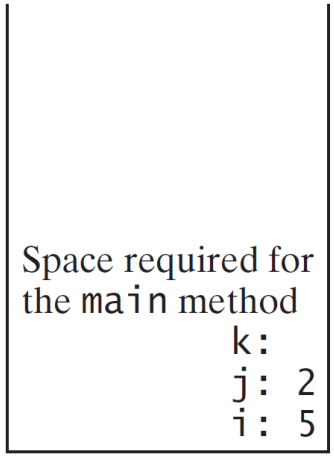


Method Invocation

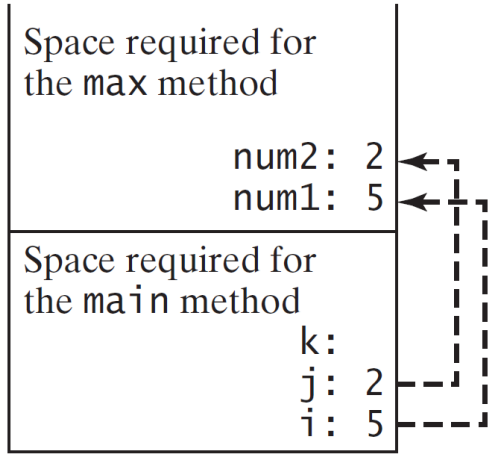


- Note that the input parameters are sort of variables declared within the method as placeholders.
- When calling the method, one needs to provide arguments, which must match the parameters in order, number, and compatible type, as defined in the method signature.

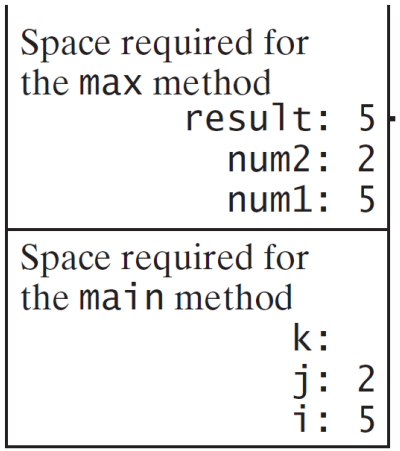
- In Java, method invocation uses pass-by-value.
- When the callee is invoked, the program control is transferred to the caller.
- For each invocation of methods, OS creates an frame which stores necessary information, and the frame is pushed in the call stack.
- The callee transfers the program control back to the caller once the callee finishes its job.



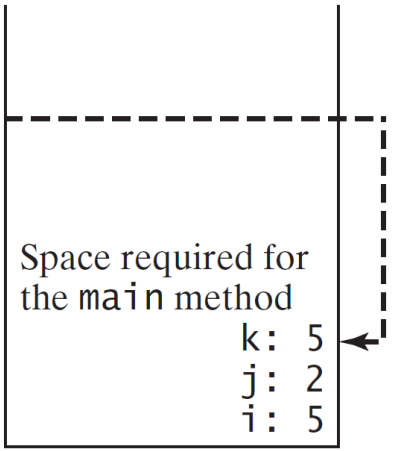
(a) The `main` method is invoked.



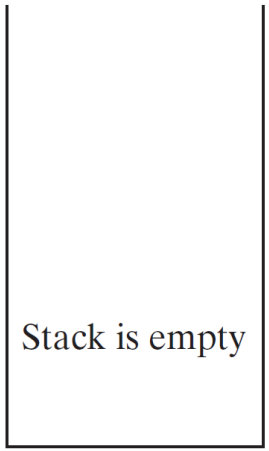
(b) The `max` method is invoked.



(c) The `max` method is being executed.



(d) The `max` method is finished and the return value is sent to `k`.



(e) The `main` method is finished.

Variable Scope

- The variable scope is the range where the variable can be referenced.
- Variables can be declared in class level, method level, and loop level.
- In general, a balanced curly brackets defines a particular scope.
- One can declare variables with the same name in different levels of scopes.
- Yet, one cannot declare the variables with the same name in the same scope.

Example

```
1   public class ScopeDemo {
2
3   static int i = 1; // class level
4
5   public static void main(String[] args) {
6   System.out.printf("%d\n", i); //output 1
7   int i = 2; // method level; local
8   i++;
9   System.out.printf("%d\n", i); // output 3
10  p();
11  System.out.printf("%d\n", i); // output ?
12  }
13
14  static void p() {
15  i = i + 1;
16  System.out.printf("%d\n", i); // output ?
17  }
18  }
```

Exercise

Write a program which allows the user to enter the math grades one by one (-1 to exit), and outputs a histogram.

```
Enter (-1 to exit): 40
Enter (-1 to exit): 90
Enter (-1 to exit): 86
Enter (-1 to exit): 56
Enter (-1 to exit): 78
Enter (-1 to exit): 64
Enter (-1 to exit): -1
End of Input...
Total: 6
 90 ~ 100: *
 80 ~  89: *
 70 ~  79: *
 60 ~  69: *
  0 ~  59: **
```

```
1     ...
2     int[] hist = new int[5];
3     // hist[0]: the counter for 90 ~ 100
4     // hist[1]: the counter for 80 ~ 89
5     // ...
6     // hist[4]: the counter for 0 ~ 59
7
8     Scanner in = new Scanner(System.in);
9     int inputValue;
10    do {
11    do {
12    System.out.println("Enter x? (-1 to exit)");
13    inputValue = in.nextInt();
14    } while (inputValue != -1 && (inputValue < 0 || inputValue > 100));
15    if (inputValue >= 90) ++hist[0];
16    else if (inputValue >= 80) ++hist[1];
17    else if (inputValue >= 70) ++hist[2];
18    else if (inputValue >= 60) ++hist[3];
19    else if (inputValue >= 0) ++hist[4];
20    else System.out.println("End of input.");
21    } while (inputValue != -1);
22    in.close();
23
24    int total = 0;
25    for (int i = 0; i < hist.length; i++) {
```

```
26      total += hist[i];
27      }
28      System.out.printf("Total: %d\n", total);
29
30      int[] tick = {0, 60, 70, 80, 90, 101};
31      for (int i = 0; i < 5; i++) {
32      System.out.printf("%3d ~ %3d: ", tick[i], tick[i + 1] - 1);
33      for (int j = 0; j < hist[i]; j++) {
34      System.out.printf("*");
35      }
36      System.out.printf("\n");
37      }
38      ...
```

- Shall we rearrange the codes in order to reduce the complexity of the main method?