

# Data structures

- A **data structure** is data type that is either simple or aggregate, built-in or user-defined, or an organized collection of these
- a particular way of organizing **data** in a computer memory so that it can be accessed **efficiently**

# Data type

- A **data type** is characterized by:
  - a set of *values*
  - a *data representation*, which is common to all these values, and
  - a set of *operations*, which can be applied uniformly to all these values

# Primitive data types in Java

- Java provides eight primitive types:
  - `boolean(1)`, `char(16)`
  - `byte(8)`, `short(16)`, `int(32)`, `long(64)`
  - `float(32)`, `double(64)`
- Each primitive type has
  - a set of values (int:  $-2^{31} \dots 2^{31}-1$ )
  - a data representation (32-bit)
  - a set of operations (+, -, \*, /, etc.)
- These are “**fixed**”—the programmer cannot change anything

# ADT = Abstract + Data Type

- To **Abstract** is to leave out information, keeping (hopefully) the more important parts

*What part of a Data Type does an ADT leave out?*

- An **Abstract Data Type** (ADT) has:
  - a set of *values*
  - a set of *operations*, which can be applied uniformly to all these values

It is **NOT** characterized by its data representation.

- Data representation is **private**, and **changeable**, with no effect on application code.

# Example ADT

- Simplest ADT is a **Bag**
  - no implied order to the items
  - duplicates allowed
  - items can be added, removed, accessed
- Another ADT is a **Set**
  - same as a bag, except duplicate elements not allowed
  - union, intersection, difference, subset

# Other types of ADT

- List
- Stack
- Queue
- Tree
- Binary Search Trees
- Heaps
- AVL and Red-Black Trees
- B Trees
- Hash Tables
- Maps
- Graphs

# ADTs

- many, many different ADTs
  - picking the right one for the job is an important step in design
- High level languages often provide built in ADTs,
  - the Java standard library

# Implementation of ADTs

ADTs are implemented

in Java using classes, and

in C++ using classes and structures

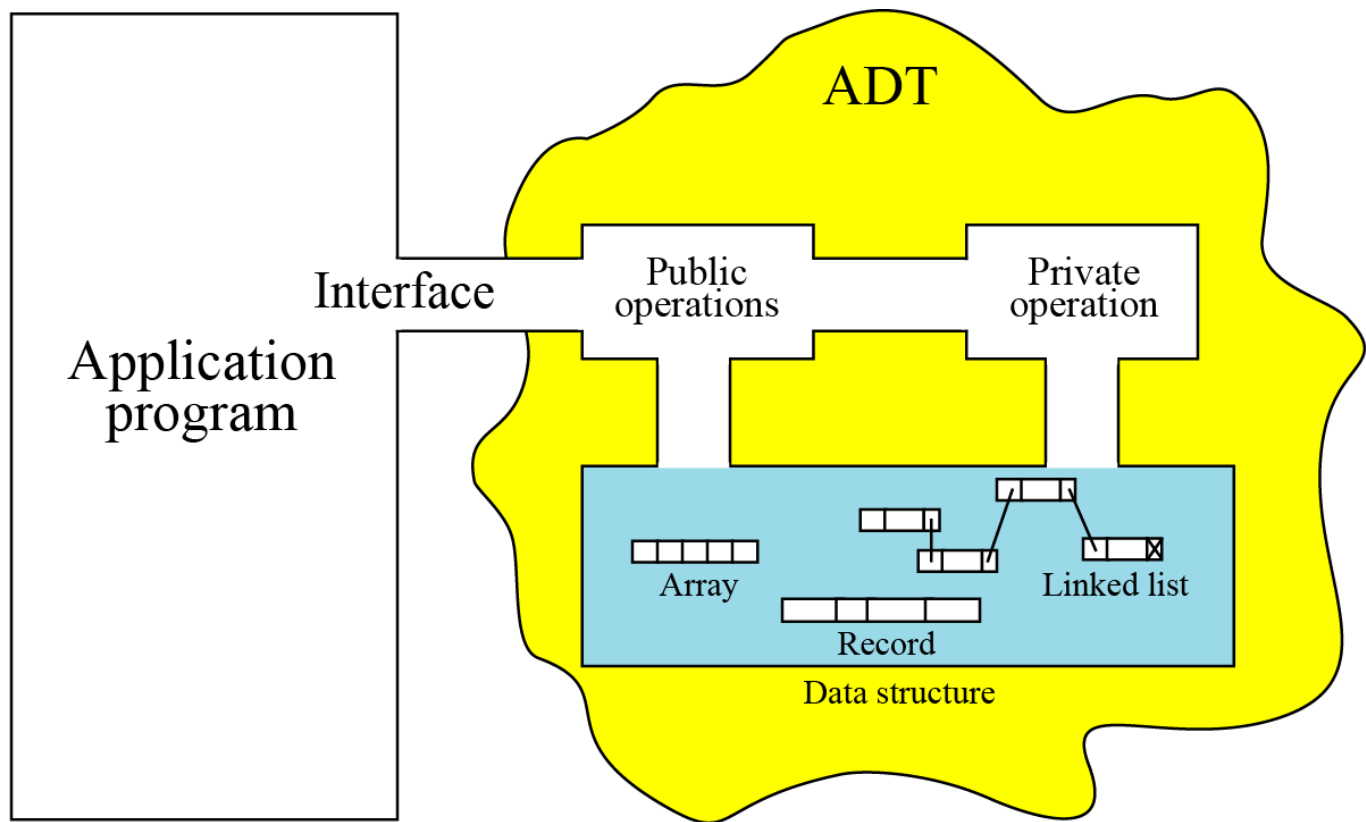


## Model for an abstract data type

The ADT model is shown in Figure below

There are two different parts of the model:

data structure and operations (public and private).



**Figure:** The model for an ADT

# Lists ADT

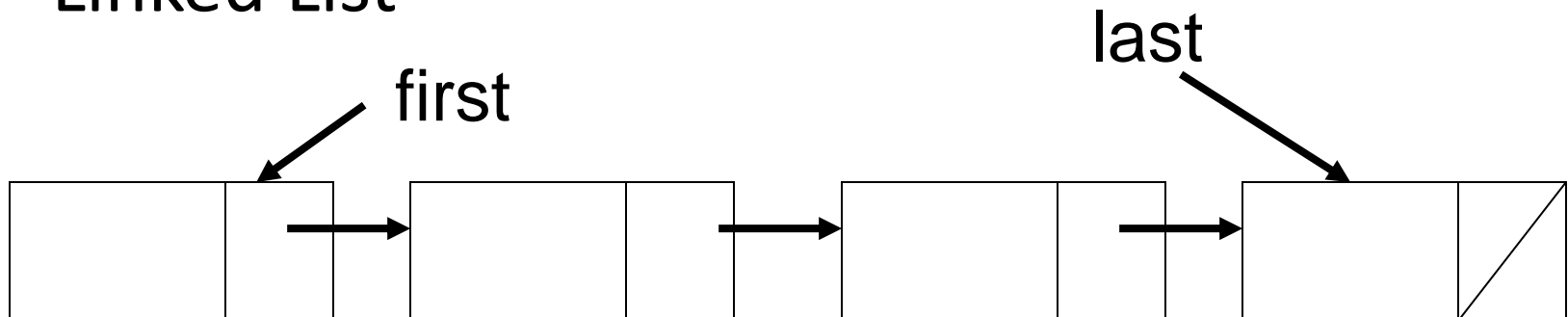
- Linear collection of items (or elements, data)
- Operations: add, delete,...

## Implementation of List ADT

- Array List



- Linked List



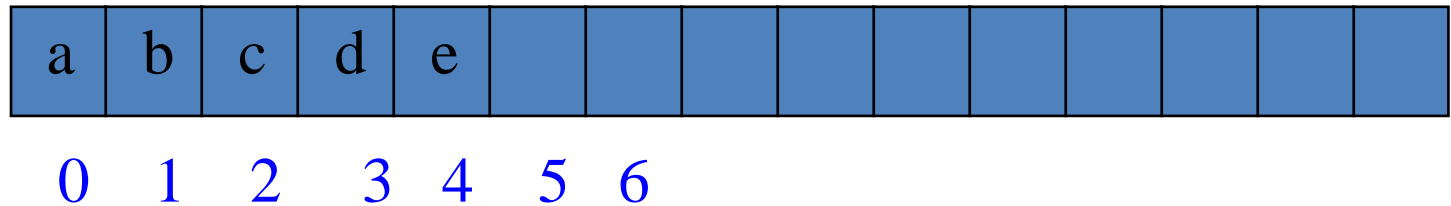
# Data representation methods

array

linked

# Array List Representation

use a one-dimensional array `element[]`



$L = (a, b, c, d, e)$

Store element  $i$  of list in `element[i]`.

# Right to left mapping



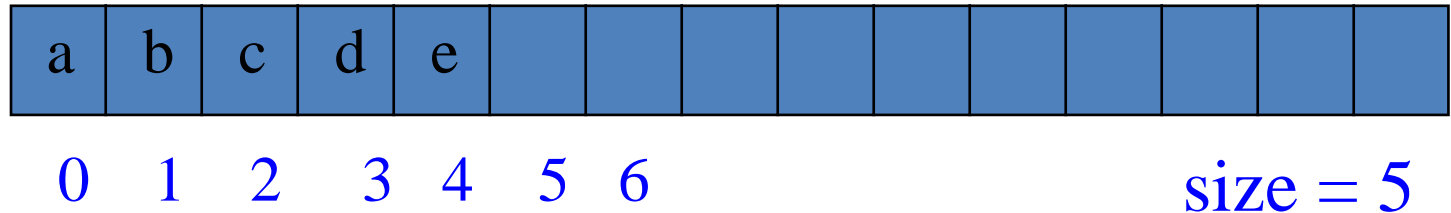
# Mapping that skips every other position



# Wrap around mapping



# Representation used



put element *i* of list in `element[i]`

use a variable `size` to record current number of elements





# Data type of array element[]

Data type of list elements is **unknown**.

Define **element[]** to be of data type **Object**.

data types (**int**, **float**, **double**, **char**, etc.)

<b>Primitive Type</b>	<b>Wrapper Type</b>
int	Integer
double	Double
char	Character
boolean	Boolean

# Two questions

- Difference between `int` and `Integer`?  
(Similarly, `double` and `Double`)
- Can we implement a generic list class?
- Can we create a dynamic size array?

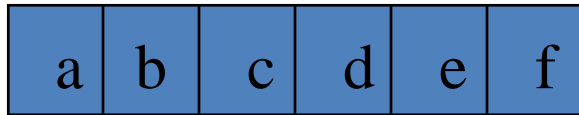
# Length of array element[]

Don't know how many elements will be in your list.

Must pick an initial length and dynamically increase as needed.

# Increasing array length

Length of array `element[]` is 6.



First create a new and larger array

```
newArray = new Object[15];
```



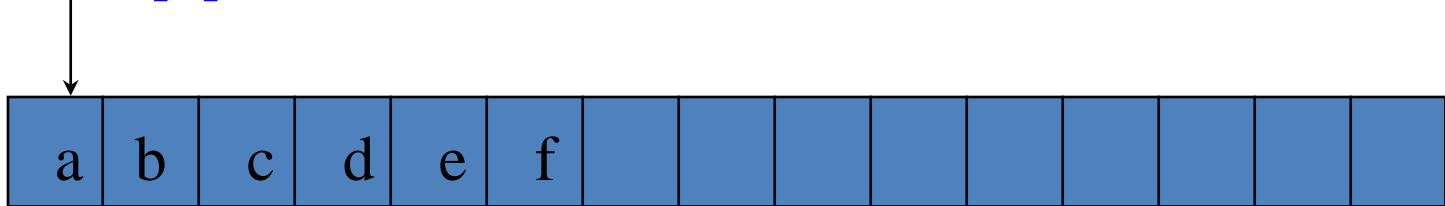


# Increasing array length

Finally, rename new array.

```
element = newArray;
```

element[0]



```
element.length = 15
```

# Altogether now

// create a new array of proper length and data type

```
Object [] newArray = new Object [newLength];
```

// copy all elements from old array into new one

```
System.arraycopy(element, 0, newArray, 0,  
    element.length);
```

// rename array

```
element = newArray;
```



```
public static Object [] changeLength(Object [] a,  
                                     int newLength)  
{  
    Object [] newArray = new Object [newLength];  
    System.arraycopy(...);  
    return newArray;  
}
```

.....

```
element = changeLength(element, 100);
```

# How big should the new array be?

At least **1** more than current array length.

Cost of increasing array length is

$O(\text{new length})$

Cost of **n** add operations done on an initially empty linear list increases by

$O(n^2)$

When array length is increased by 1 each time we need to resize the array element[], the cost of n add operations goes up by  $O(n^2)$ .

# Space complexity

element[6]

a	b	c	d	e	f
---	---	---	---	---	---

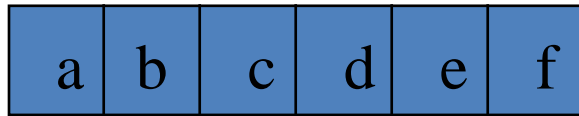
newArray = new char[7];

--	--	--	--	--	--	--

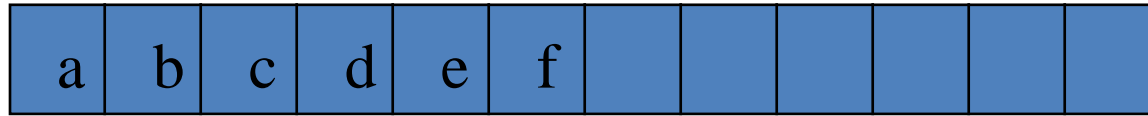
space needed =  $2 * \text{newLength} - 1$

# Array doubling

Double the array length.



```
newArray = new char[12];
```



Time for  $n$  adds goes up by  $O(n)$ .

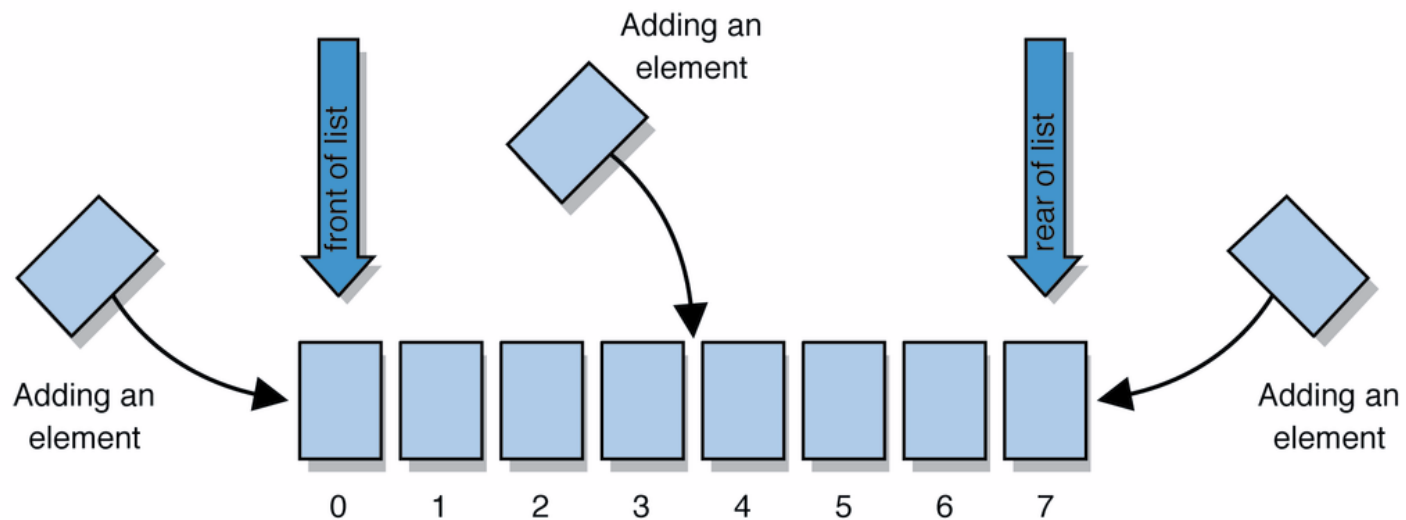
Space needed =  $1.5 * \text{newLength}$ .

# The Class `ArrayList`

- General purpose implementation of linear lists.

# Lists

- a collection storing a sequence of elements
  - each element is accessible by a 0-based **index**
  - a list has a **size** (# of elements present)
  - element can be added to the front, back, or elsewhere
  - in Java, a list can be represented as an **ArrayList** object



# Linear List

## Method Summary

void [addToFront](#)(Object element)

Adds the given element to the front of the current list

void [addToRear](#)(Object element)

Adds the given element to the rear of the current list

boolean [isEmpty](#)()

Predicate returns true if the list is empty and false otherwise

Object [removeFront](#)()

Removes the first element in the list and returns a reference to it.

Object [removeRear](#)()

Removes the last element in the list and returns a reference to it.

int [size](#)()

Returns the number of nodes in the list

String [toString](#)()

Returns a string representation of the list.

# Create an empty List

```
ArrayLinearList a = new ArrayLinearList(100);
```

```
b = new ArrayLinearList()
```



# The class ArrayLinearList

```
/** array implementation of LinearList */  
import java.util.*; // has Iterator interface  
import utilities.*; // has array resizing class  
  
public class ArrayLinearList // implements LinearList  
{  
    // data members  
    protected Object [] element; // array of elements  
    protected int size; // number of elements in array  
    // constructors and other methods come here  
}
```

# A Constructor

```
/** create a list with initial capacity initialCapacity
 * @throws IllegalArgumentException when
 * initialCapacity < 1 */
public ArrayLinearList(int initialCapacity)
{
    if (initialCapacity < 1)
        throw new IllegalArgumentException
            ("initialCapacity must be >= 1");
    element = new Object [initialCapacity];
    size = 0;
}
```

## Another Constructor

```
/** create a list with initial capacity 10 */
```

```
public ArrayList()  
{// use default capacity of 10  
    this(10);  
}
```

## The Method isEmpty

```
/** @return true iff list is empty  
*/  
public boolean isEmpty()  
{return size == 0;}
```

## The Method size()

```
/** @return current number of elements in list */  
public int size()  
    {return size;}
```

# The Method checkIndex

```
/** @throws IndexOutOfBoundsException when  
    * index is not between 0 and size - 1 */  
void checkIndex(int index)  
{  
    if (index < 0 || index >= size)  
        throw new IndexOutOfBoundsException  
            ("index = " + index + " size = " + size);  
}
```

# The Method get

```
/** @return element with specified index  
 * @throws IndexOutOfBoundsException when  
 * index is not between 0 and size - 1 */  
public Object get(int index)  
{  
    checkIndex(index);  
    return element[index];  
}
```

## The Method indexOf

```
/** @return index of first occurrence of theElement,  
    * return -1 if theElement not in list */  
public int indexOf(Object theElement)  
{  
    // search element[] for theElement  
    for (int i = 0; i < size; i++)  
        if (element[i].equals(theElement))  
            return i;  
  
    // theElement not found  
    return -1;  
}
```



# The Method remove

```
public Object remove(int index)
{
    checkIndex(index);

    // valid index, shift elements with higher index
    Object removedElement = element[index];
    for (int i = index + 1; i < size; i++)
        element[i-1] = element[i];

    element[--size] = null; // enable garbage collection
    return removedElement;
}
```

# The Method add

[illegible]

# The Method add

```
// shift elements right one position
```

```
for (int i = size - 1; i >= index; i--)
```

```
    element[i + 1] = element[i];
```

```
element[index] = theElement;
```

```
size++;
```

```
}
```