```
channel: 41
session: cs2420
```

Generics & Comparators

cs2420 | Introduction to Algorithms and Data Structures | Fall 2016

administrivia…

-assignment 1 due today at midnight

-assignment 2 is out

-due next Wednesday at midnight

-another solo assignment

-next assignment is a pair — find a friend this week!

last time…

inheritance

```
public class Triangle{
  String color;
  double area;
}

public class Circle{
  String color;
  double area;
}
```

```
public class Rectangle{
  String color;
  double area;
}

public class Square{
  String color;
  double area;
}
```

```
public class Triangle{
  String color;
  double area;
}

public class Circle{
  String color;
  double area;
}
```

what if I want to redefine color as an integer array (R,G,B)?

```
public class Rectangle{
  String color;
  double area;
}

public class Square{
  String color;
  double area;
}
```

```
public class Triangle{
  String color;
  double area;
}

public class Circle{
  String color;
  double area;
}
```

what if I want to redefine color as an integer array (R,G,B)?

What if I want to give each shape an outline color?

```
public class Rectangle{
  String color;
  double area;
}

public class Square{
  String color;
  double area;
}
```

```
public class Triangle{
  String color;
  double area;
}

public class Circle{
  String color;
  double area;
}
```

```
public class Rectangle{
  String color;
  double area;
}

public class Square{
  String color;
  double area;
}
```

what if I want to redefine color as an integer array (R,G,B)?

What if I want to give each shape an outline color?

what can I do?

```
public class Triangle{
  String color;
  double area;
}

public class Circle{
  String color;
  double area;
}

public class Rectangle{
  String color;
  double area;
}

public class Square{
  String color;
  double area;
}
```

what if I want to redefine color as an integer array (R,G,B)?

What if I want to give each shape an outline color?

what can I do?

extends

```
public class Shape{
   String color;
   double area;
}
```

called a **base class** (or superclass)

```
public class Triangle extends Shape{
}

public class Circle extends Shape{
}

public class Rectangle extends Shape{
}

public class Square extends Rectangle{
}
```

inherit all public fields and methods of `Shape`

SIMONE VS SIMONE

```
public class Sport{
  public void compete();

  float world_record;
  …
}

public class Gymnastics extends Sport{
  // override
  public void compete(){
    //how to do a killer floor routine
  }
}

public class Swimming extends Sport{
  //override
  public void compete(){
    //how to swim freestyle really fast
  }
}
```

SIMONE VS SIMONE

without inheritance:

```
switch(athlete.sport_type)
{
   case GYMNASTICS:
      competeInFloorRoutine();
   break;
   case SWIMMING:
      competeInFreestyleRace();
   break;
   …
}
```

with inheritance:

```
athlete.sport.compete();
```

- **polymorphism** is a fancy word for automatically determining an object's type at runtime

- the most specific type possible is used

```
Shape s1 = new Circle();
Shape s2 = new Triangle();

s1.getArea();
s2.getArea();
```

- **polymorphism** is a fancy word for automatically determining an object's type at runtime

- the most specific type possible is used

```
Shape s1 = new Circle();
Shape s2 = new Triangle();

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what type is `s1` *treated as?*

- **polymorphism** is a fancy word for automatically determining an object's type at runtime

- the most specific type possible is used

```
Shape s1 = new Circle();
Shape s2 = new Triangle();

s1.getArea();
s2.getArea();
```

what type is `s1` *treated as?*

what type is `s2` *treated as?*

- **polymorphism** is a fancy word for automatically determining an object's type at runtime

- the most specific type possible is used

```
Shape s1 = new Circle();
Shape s2 = new Triangle();

s1.getArea();
s2.getArea();
```

what type is `s1` *treated as?*

what type is `s2` *treated as?*

- **suppose** `Triangle` **does not override** `toString()`

```
s2.toString();
```

what type is `s2` *treated as?*

-**a class with at least one** `abstract` **method is an** `abstract` **class**

-**derived classes MUST implement** `abstract` **methods**

-`abstract` **classes cannot be instantiated**

```
Shape s = new Shape();
Shape s = new Triangle();
```

which of these is illegal?

A) first line
B) second line

-`abstract` **classes are ONLY designated as base classes**

- **an interface is the ultimate abstract class**
  - every method is `abstract`
  - can contain only `public static final` fields
  - declared with the `interface` keyword instead of `class`
- **derived classes use keyword `implements` instead of `extends`**
- **subclasses can implement multiple interfaces, but can only extend one base class**

today…

-generic programming

-generic placeholder

-why generics

-primitive types and generics

-generic static methods

-function objects

-collections

-iterators

generic programming

-suppose we want a data structure that just contains "things"

-we want it to:

-automatically grow if it gets full

-be able to remove items from it

-be able to add items to it

-suppose we want a data structure that just contains "things"

-we want it to:

- -automatically grow if it gets full
- -be able to remove items from it
- -be able to add items to it

-will an array work?

```
Shape[] shape_array = new Shape[5];
```

- **what if we implement an `ArrayList`?**
  - here's what the code might look like:

```
public class ArrayList {
  Shape storage[];
  int capacity, numItems;

  public void addItem(Shape item)
  { /*some code*/ }

  public void autoGrow()
  { /*some code*/ }
}
```

- **what if we implement an `ArrayList`?**
  - here's what the code might look like:

```
public class ArrayList {
  Shape storage[];
  int capacity, numItems;

  public void addItem(Shape item)
  { /*some code*/ }

  public void autoGrow()
  { /*some code*/ }
}
```

what's the problem with this?

- **this is why we always see <> associated with `ArrayList`**

```
ArrayList<Shape> list = new ArrayList<Shape>();
```

- **`ArrayList` is a generic class — we can create any version of it that we want**

- **generic programming: algorithms are written in terms of types to-be-specified-later**
  - algorithms instantiated when needed for specific types defined by parameters

-here's what the code actually looks like:

```
public class ArrayList<T> {
  T storage[];
  int capacity, numItems;

  public void add(T item)
    {  ...  }
}
```

-the placeholder `T` is replaced with the real type when you instantiate an `ArrayList` with `<>`

-`T` can be used as a type anywhere in `ArrayList` class

generic placeholder

generic placeholder <>

what is the dynamic type of `T`*?*

`ArrayList<Shape>`

generic placeholder <>

what is the dynamic type of `T`*?*

```
ArrayList<Shape>
ArrayList<ClassThatArrayListDoesntKnowAbout>
```

generic placeholder <>

what is the dynamic type of `T`*?*

`ArrayList<Shape>`

`ArrayList<ClassThatArrayListDoesntKnowAbout>`

-the generic placeholder type is VERY specific

- `ArrayList<Triangle>` is not an `ArrayList<Shape>`, even though `Triangle` is a `Shape`!

-`ArrayList<type>` is only EXACTLY an `ArrayList<type>`, regardless of `type`'s heritage

inheritance and generics

-**example:**

```
public void doStuff(ArrayList<Shape>) {…}

ArrayList<Triangle> tri_list;
ArrayList<Shape> shape_list;

doStuff(tri_list);    // ILLEGAL
doStuff(shape_list); // OK
```

-**we can still add `Triangles` to `shape_list`**

-**restriction applies only to the generic object itself**

- Java has a way around the restriction: the wildcard placeholder ?

- `<? extends Shape>` refers to `Shape` or anything that extends `Shape`
  - `Shape, Triangle, Circle, …`

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bounded wildcard

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  -Shape, Triangle, Circle, …

what types can be used here?

<? super Circle>

A) Circle
B) Triangle
C) Shape
D) Object
E) A & B
F) A & C
G) A & C & D

-Java has a way around the restriction: the wildcard placeholder ?

bounded wildcard

-**<? extends Shape>** refers to **Shape** or anything that extends **Shape**

  -Shape, Triangle, Circle, …

A) Object

B) everything

what types can be used here?

<? super Circle>

<?>

-Java has a way around the restriction: the wildcard placeholder ?

bounded wildcard

-**<? extends Shape>** refers to **Shape** or anything that extends **Shape**

  -Shape, Triangle, Circle, …

A) Object

B) everything

what types can be used here?

<? super Circle>

<?>

is this a good idea?

```
public void addRectangle(ArrayList<? extends Shape> shapes)
{
   shapes.add( new Rectangle() ); // compile error!
}
```

```
public void addRectangle(ArrayList<? extends Shape> shapes)
{
   shapes.add( new Rectangle() ); // compile error!
}
```

you don't get something for nothing: it is now illegal to modify `shapes` *in this method.*

why generics?

- **everything in Java is an `Object`**
  - so, why not just make all data structures hold `Objects`?

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- **generics allow for type-checking at compile time instead of run-time**

- **everything in Java is an `Object`**
  - so, why not just make all data structures hold `Objects`?

- **generics allow for type-checking at compile time instead of run-time**

- **can detect type mismatch BEFORE your code runs**

before generics:

```
ArrayList l;
l.add(new String(“hi”));
Shape i = (Shape)l.get(0); // crash
```

before generics:

```
ArrayList l;
l.add(new String(“hi”));
Shape i = (Shape)l.get(0); // crash
```

alternative:

```
ArrayList<String> l;
l.add(new String(“hi”));
Shape i = (Shape)l.get(0); // compile error
```

before generics:

```
ArrayList l;
l.add(new String(“hi”));
Shape i = (Shape)l.get(0); // crash
```

alternative:

```
ArrayList<String> l;
l.add(new String(“hi”));
Shape i = (Shape)l.get(0); // compile error
```

compile-time errors are always better than run-time!

primitive types and generics

- **generics only work with reference types**
  - no `int, char, float, double, …`
- **what if we need an `ArrayList` of `ints`?**
- **Java has "wrapper" classes**
  - `Integer, Float, Double`
  - these are reference types containing a single primitive…
  - …and methods to access it
    - `intValue(), doubleValue()`

- **Java will automatically insert the appropriate code to convert between primitive/reference**

```
ArrayList<Integer> l;


l.add(5);
```

equivalent to

```
l.add(new Integer(5));
```

```
int i = l.get(n);
```

equivalent to

```
int i = l.get(n).intValue();
```

questions...

questions...

what types are included in `<? super Triangle>`

A. `Shape`

B. `Triangle, Circle, Rectangle, Square`

C. `Triangle, Shape, Object`

questions...

what types are included in `<? super Triangle>`

A. `Shape`
B. `Triangle, Circle, Rectangle, Square`
C. `Triangle, Shape, Object`

what types are included in `<Shape>`

A. `Shape`
B. `Triangle, Circle, Rectangle, Square`
C. both 1 and 2

generic static methods

- **`static` methods can have their own generic types**

- **declare the generic type before the return type:**

```
public static <T> boolean doWork(…){…}
```

- **we can refer to `T` as a type within that method only!**

- **`static` methods can have their own generic types**

- **declare the generic type before the return type:**

```
public static <T> boolean doWork(…){…}
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- **example:**

- **`static` methods can have their own generic types**

- **declare the generic type before the return type:**

```
public static <T> boolean doWork(…){…}
```

- **we can refer to `T` as a type within that method only!**

- **example:**

```
public static <T> boolean contains(T[] array, T item)
{
  for(int i=0; i < array.length; i++)
    if(array[i].equals(item))
      return true;

  return false;
}
```

function objects

-suppose we want a generic sorting function

-and we want it to be able to sort ANY type…

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-what can we do?

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-what can we do?

-what do we need to be able to do?

-suppose we want a generic sorting function

-and we want it to be able to sort ANY type…

-what can we do?

-what do we need to be able to do?

decide which item is larger

`Comparable` interface

```
public interface Comparable<T> {
  public int compareTo(T item);
}
```

-defines a natural ordering (*in fact, it is contractually obligated to!*)

- `String, Integer,...` all implement `Comparable`

-what if we want a different ordering? or to order `Shapes`? or to order `Strings` based on length?

function objects

-a function object is an object that defines a single method

-example:

-a `Comparator` has a single method: `compare`

-takes two arguments

-decides which one is greater

-we write a sorting function that takes a `Comparator`

`Comparator` interface

```
public interface Comparator<T> {
  int compare(T left, T right);
}
```

-returns a number `<0` if `left < right`

-returns a `0` if they are equal

-returns a number `>0` if `left > right`

`Collection` interface

-a `Collection` is a data structure that holds items

  -very unspecific as to how the items are held

    -ie. the data structure

-supports various operations:

  -`add`, `remove`, `contains`, ...

-examples:

  -`ArrayList`

  -`PriorityQueue`

  -`LinkedList`

  -`TreeSet`

-you'll be working with `Collections` for assignment 3

  -backed by an array for storage that you will implement yourselves

  -items will be sorted as they are inserted

  -no duplicates allowed

-what are some of the issues with using an array?

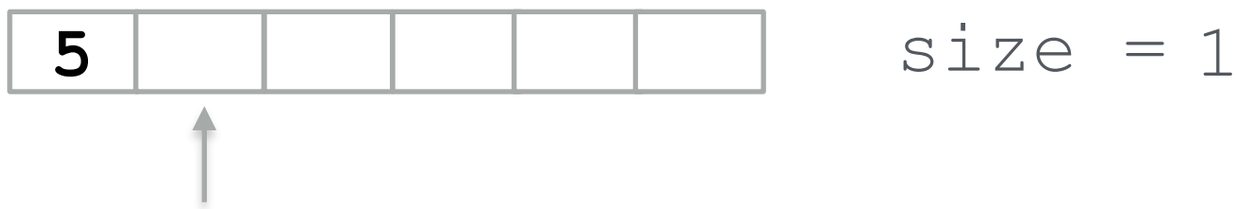
add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
```

size = 0

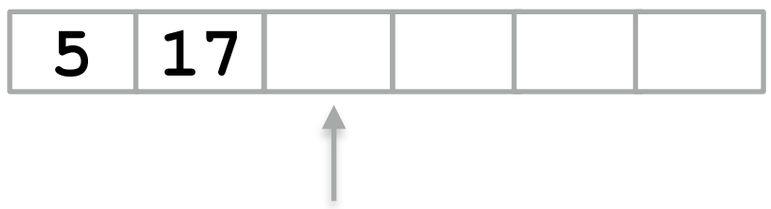
add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
```



add

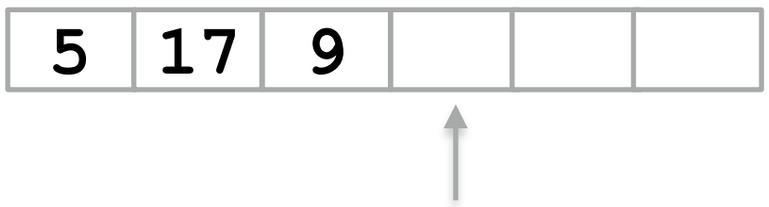
```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
```



size = 2

add

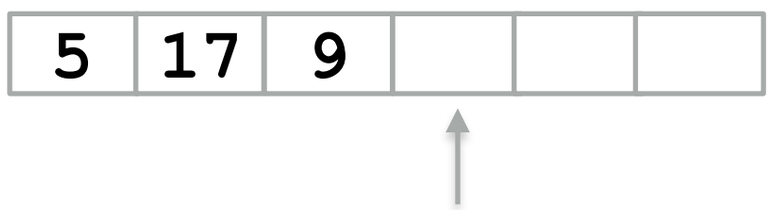
```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
```



add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
```

don't forget `size++`

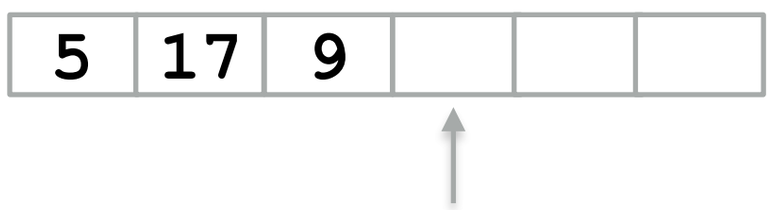


size = 3

add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
data.add(12);
data.add(1);
data.add(33);
```

don't forget `size++`

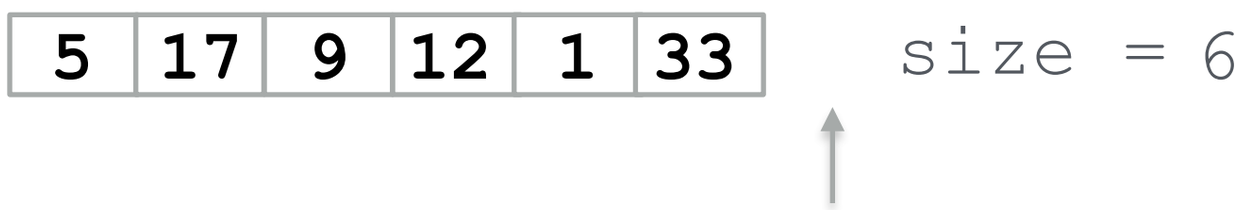


size = 3

add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
data.add(12);
data.add(1);
data.add(33);
```

don't forget `size++`



add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
data.add(12);
data.add(1);
data.add(33);
```

don't forget `size++`

5	17	9	12	1	33

size = 6

```
data.add(22);
```

add

```
int[] data = new int[6];
data.add(5);
data.add(17);
data.add(9);
data.add(12);
data.add(1);
data.add(33);
```

don't forget `size++`

5	17	9	12	1	33

size = 6

```
data.add(22);
```

now what???

-we need to grow our array!

-avoid allocating slightly larger arrays

  -you will most likely need to grow again soon

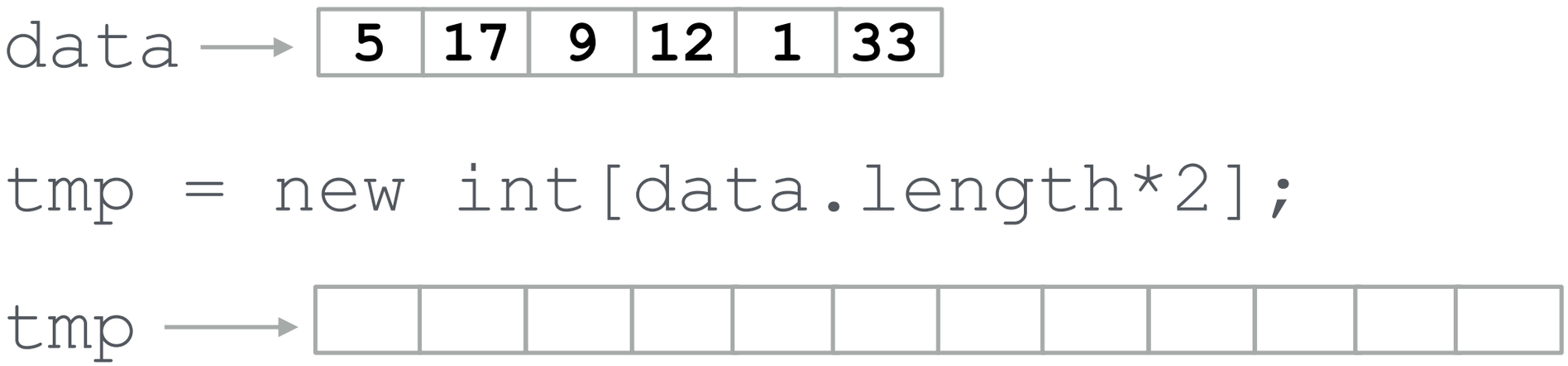
-good rule of thumb is to double the size

  -***con:*** wastes up to 2x space

  -***pro:*** growth will be rare

grow

grow



grow


```
tmp = new int[data.length*2];
```

copy all from `data` to `tmp`

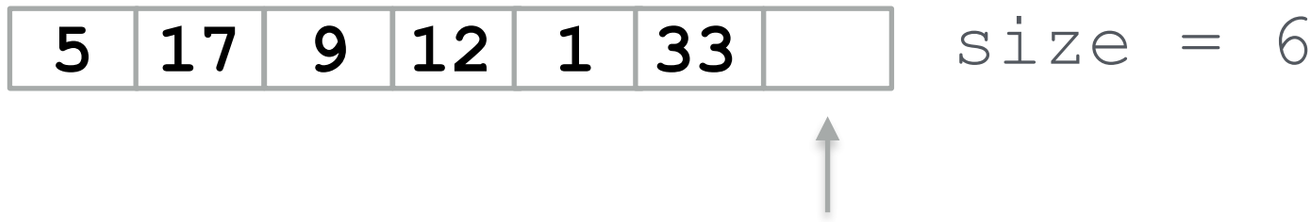
grow


```
tmp = new int[data.length*2];
```

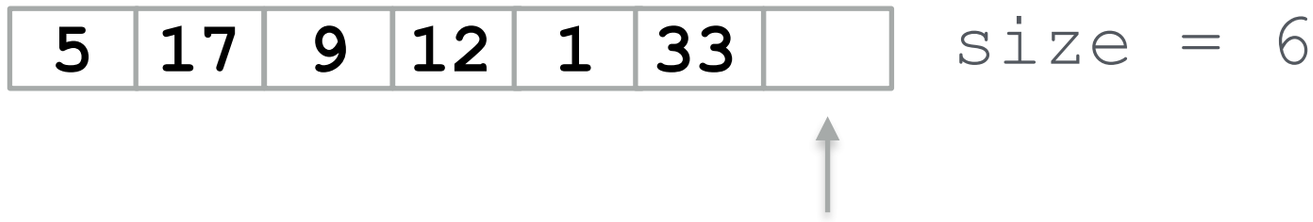
copy all from `data` to `tmp`


```
data = tmp;
```

remove

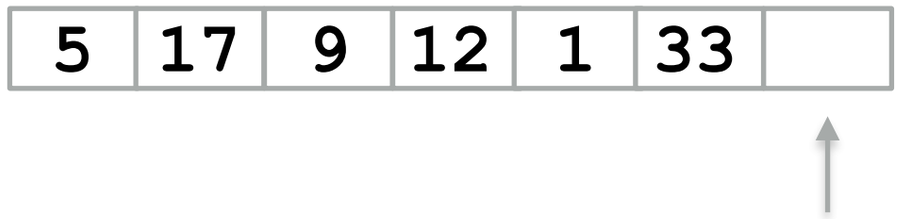


remove

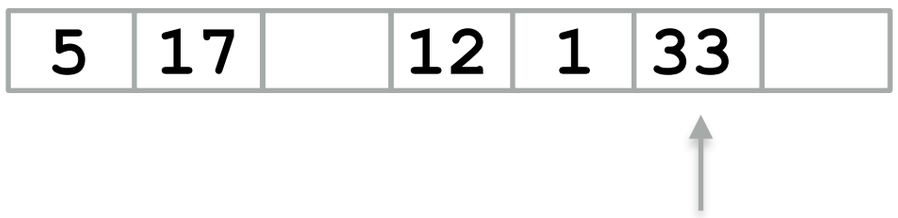



```
data.remove(9);
```

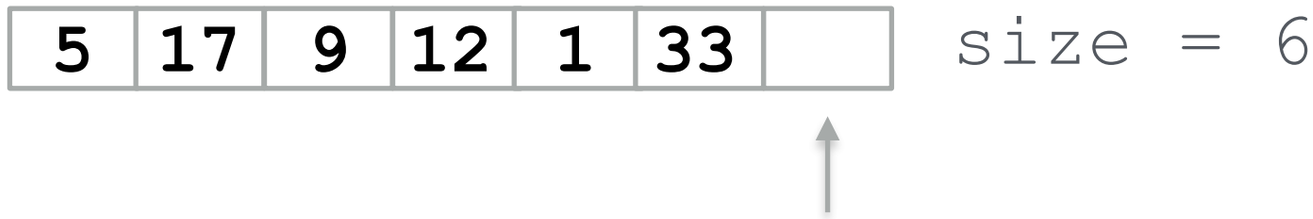
remove



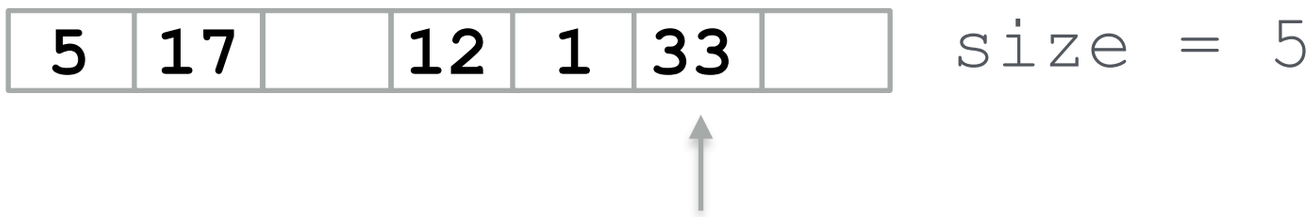

```
data.remove(9);
```



remove



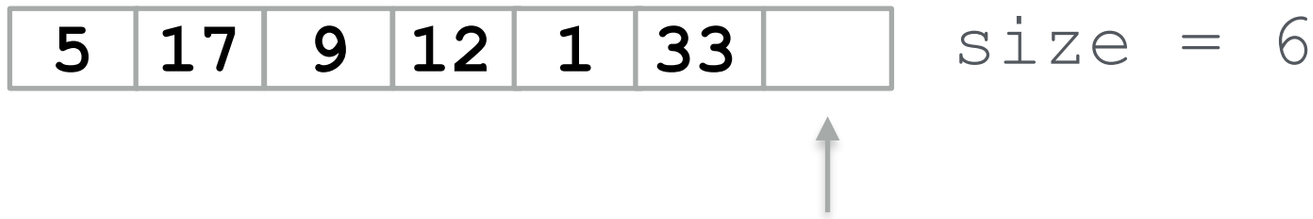

```
data.remove(9);
```



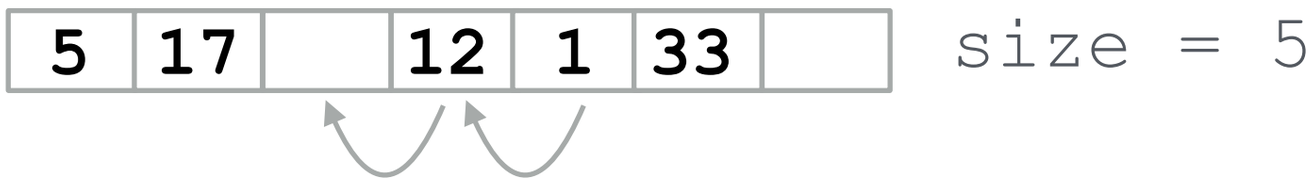
is this correct?

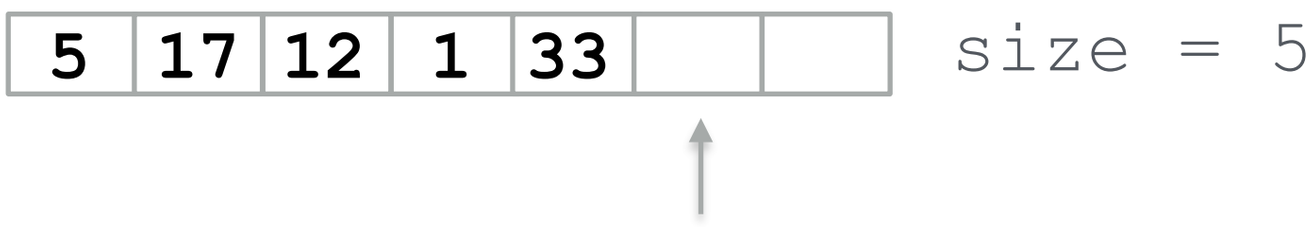
A) yes
B) no

remove




```
data.remove(9);
```





wait, what were we talking about?

Collection

-a `Collection` is an object that groups multiple elements into a single unit

-used to store, retrieve, manipulate, and communicate stored data

-is like an array except their size can change dynamically, and have more advanced behaviors

-the Java Collections API provides a set of classes and interfaces for storing data in different types of data structures

-you will be implementing many of these on your own in assignments!

iterators

- not all data structures are guaranteed to use an array
  - thus, we can't just do:

```
for(i=0; i<size; i++)
   data[i]…
```

- the `Iterator` interface provides generic retrieval of items from a data structure

- the `Collection` interface ***requires*** an `Iterator`
  - for example, `ArrayCollection` has `iterator()` method that returns an `Iterator`

`Iterator`

-an `Iterator` is specific to a data structure, and knows how to traverse the structure

  -`hasNext:` determines if iteration is complete

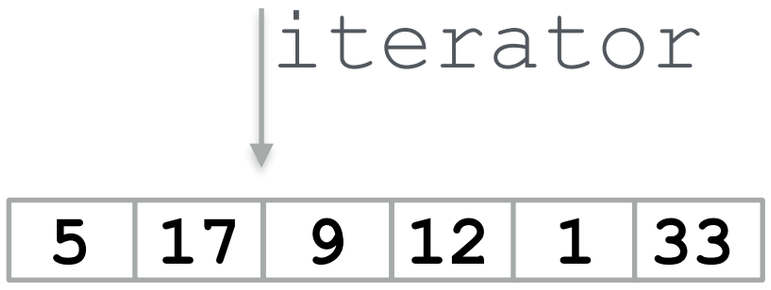
  -`next:` gets the next item

  -`remove:` removes the last seen item

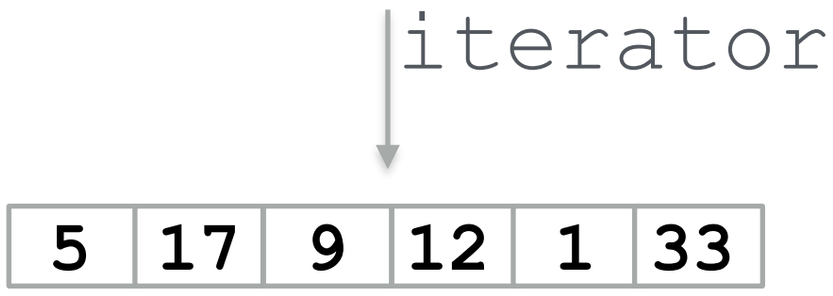
-internally, keeps track of where the next item is (as well as other state)

-actually points to ***between*** items

next

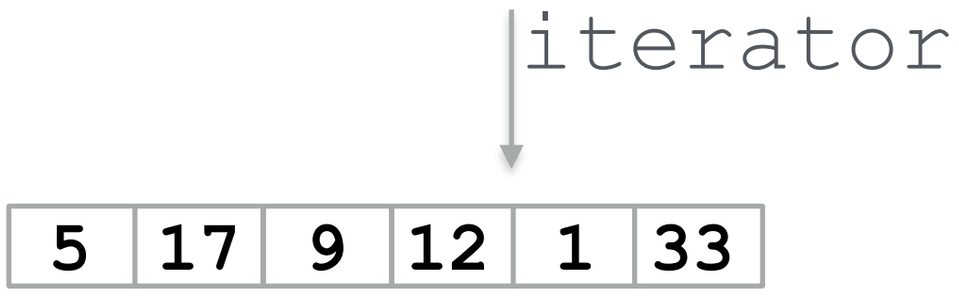


next



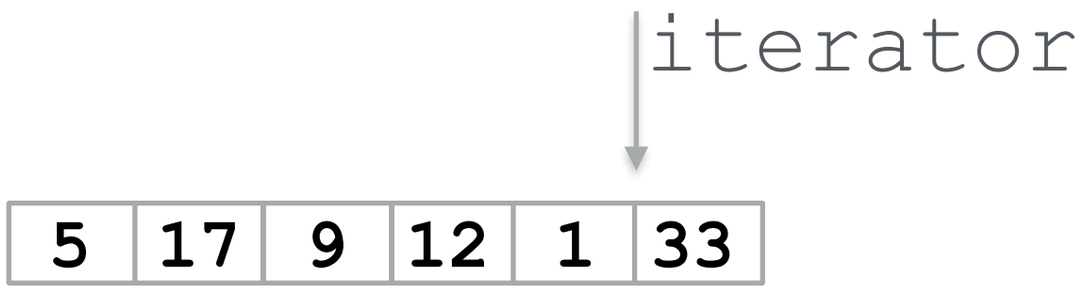

```
iterator.next(); // returns 9
```

next



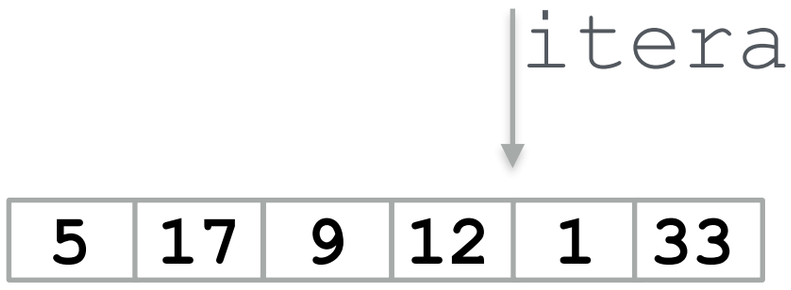

```
iterator.next(); // returns 9
iterator.next(); // returns 12
```

next

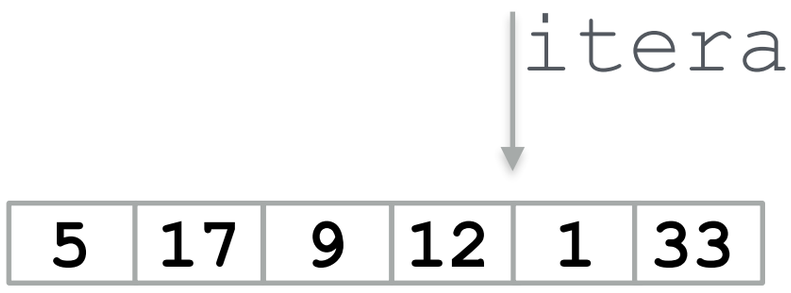



```
iterator.next(); // returns 9
iterator.next(); // returns 12
iterator.next(); // returns 1
```

`remove` removes the last item seen

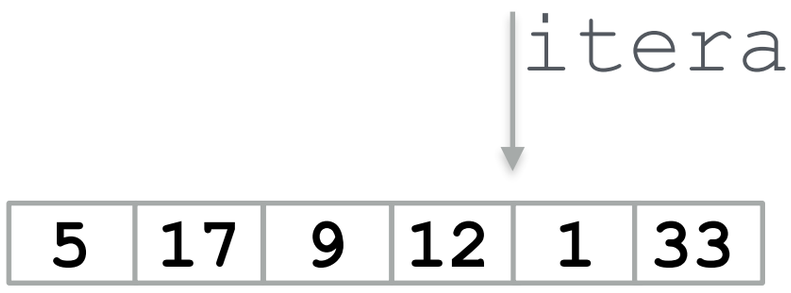


`remove` removes the last item seen

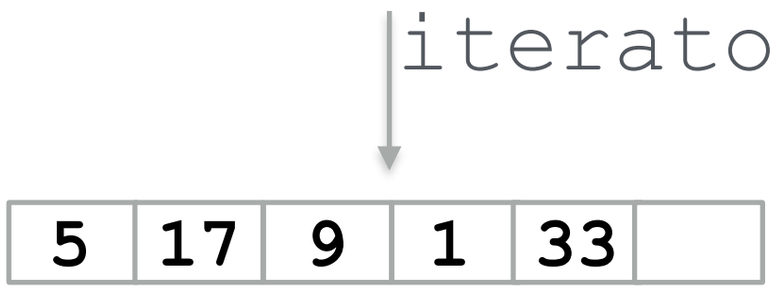



```
iterator.remove(); // removes 12
```

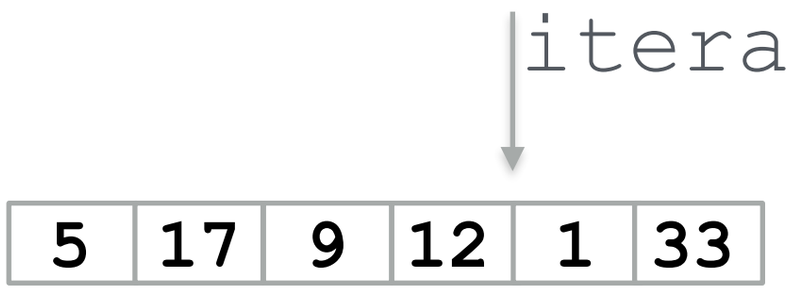
`remove` removes the last item seen



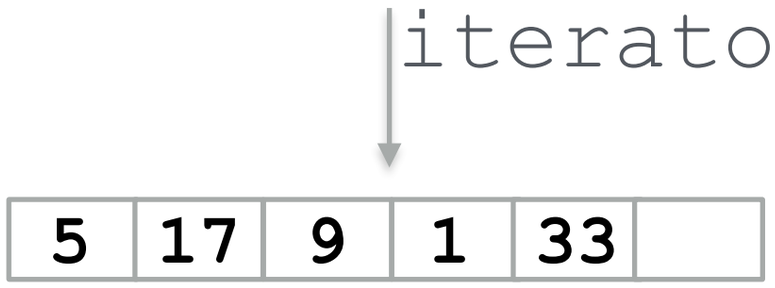

```
iterator.remove(); // removes 12
```



`remove` removes the last item seen




```
iterator.remove(); // removes 12
```



must be preceded by at least one call to **`next()`**

enhanced `for-loop`

-allows for simplification of code by representing a visit to each element of an array or `Collection` without explicitly expressing how you get from element to element

STANDARD WAY:

```
for(int i=0; i < things.length; i++)
  // do something with things[i]
```

ENHANCED LOOP:

```
for(Thing t : things)
  // do something with t
```

-uses an `Iterator` behind the scenes!

```
ArrayList<String> catNames = new ArrayList<String>();
catNames.add("Mooches");
catNames.add("Butterscotch");
catNames.add(“Mr.Pickles”);


useWhileLoop(catNames);
useForEnhancedForLoop(catNames);


void useWhileLoop(Collection<String> c)
{
   Iterator<String> iter = c.iterator();
    while (c.hasNext())
      System.out.println(iter.next());
}


void useEnhancedForLoop(Collection<String> c)
{
  for (String cn : c)
    System.out.println(cn);
}
```

next time…

-no class on Monday

-reading

-chapters 5 & 6

-homework

-assignment 1 due today at midnight

-assignment 2 due next Wednesday at midnight

-lab on Friday

-timing