Search

- A note on arrays
- JDB, revisited - setting breakpoints
- Assignment 4, example
- Linear search
- Binary search

Arrays

- **Declaring**
  - **C style(Java Gently): <type> <id> [ ] ;**
  - **Java style: <type> [ ] <id>;**
- **Allocating a new array**
  - **C style:**

<type> <id> [ ] = new <type> [<limit>]

  - **Java style:**

<type> [ ] <id> = new <type> [<limit>]

- **It’s optional which style you use**

jdb, Revisited

- **Breakpoints work**
  - **Stop in <classname>.<method_name>**
    - **Causes execution to stop each time an invocation of that method occurs**
  - **Stop at <method_name>:<line_no>**
    - **Causes exeuction to stop at that line_no in that method**
  - **cont causes execution to resume until next breakpoint**
- **Type ? in JDB to see help on commands**

jdb, Revisited

- Execution with breakpoints
  - step causes execution of next statement (can step by step through entire program)
  - step up continues execution until return to caller of current method
  - clear <classname>.<method_name>

  clear <method_name>:<line_no>

  both clear an already set breakpoint
- Breakpoint commands can be intermingled with other commands (e.g., list, locals, print)

Example

```
27 remus!assignment3-s98> jdb myTest
Initializing jdb...
0xee32b370:class(myTest)
> stop in Segment.pointOnSegment
Breakpoint set in Segment.pointOnSegment
> stop in Polygon.getPerimeter
Breakpoint set in Polygon.getPerimeter
> run
run myTest
running ...
main[1]
Breakpoint hit: Segment.pointOnSegment (Segment:230)
```

Example

```
main[1] list
226
227
228       public boolean pointOnSegment(Point p){
229       //first get endpoints of Segment
230    => double x1 = (this.getFirstPoint()).getX(),
231            y1 = (this.getFirstPoint()).getY(),
232            x2 = (this.getSecondPoint()).getX(),
233            y2 = (this.getSecondPoint()).getY(),
234            x3 = p.getX(),
main[1] cont
main[1] (150.0 , 150.0) is on [ (100.0 , 100.0), (200.0 , 200.0) ]//1st call of
   pointOnSegment in myTest.main
Breakpoint hit: Segment.pointOnSegment (Segment:230)

main[1] cont
main[1] (300.0 , 300.0) is not on [ (100.0 , 100.0), (200.0 , 200.0) ]//2nd call
Breakpoint hit: Segment.pointOnSegment (Segment:230)
```

...we continue to do list and watch execution of pointOnSegment...

...we could clear this breakpoint with **clear Segment:230** ***or use*** **step up**

Example

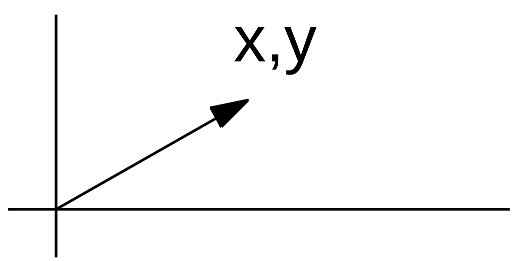
```
main[1] step up //continues execution until reaches caller of this method
main[1]             //myTest.main; next breakpoint found is in getPerimeter

Breakpoint hit: Polygon.getPerimeter (Polygon:130)
main[1] list
126        //method to use an enumerator to calculate
127        //the perimeter of a Polygon object
128        //needs to use getLength() from Segment class
129             public double getPerimeter(){
130     =>        double perimeter = 0.0;
131             Enumeration edgeEnum = this.getEdges();
132             while (edgeEnum.hasMoreElements()){
133                     Segment seg = (Segment)edgeEnum.nextElement();
134                     System.out.println(seg.toString() + "length= "
main[1] step //executes one statement at a time
main[1]
Breakpoint hit: Polygon.getPerimeter (Polygon:131)
```

Example

```
main[1] list
127       //the perimeter of a Polygon object
128       //needs to use getLength() from Segment class
129           public double getPerimeter(){
130           double perimeter = 0.0;
131     =>      Enumeration edgeEnum = this.getEdges();
132           while (edgeEnum.hasMoreElements()){
133                 Segment seg = (Segment)edgeEnum.nextElement();
134                 System.out.println(seg.toString() + "length= "
135                       + seg.getLength());
main[1] step
main[1]
Breakpoint hit: Polygon.getEdges (Polygon:62)
main[1] cont
main[1] [ (100.0 , 100.0), (200.0 , 200.0) ]length= 141.4213562373095
etc. //program terminates normally
```

Assignment 4

- Given a set of Polygons, find the one with the closest vertex to the origin (0,0).
- Need a nested enumeration, one through the Set of Polygons, and for each Polygon, through each of its sides to find the corresponding vertices.
- Use Euclidean distance to compare points



dist = x*x+y*y

```
Polygon p,psave = null; Point closest = null;
double Double.POSITIVE_INFINITY,dist1,dist2,p1X,p1Y,p2X,p2Y;
Enumeration polyenum = polys.elements();
while (polyenum.hasMoreElements()){// extract polygon
   p = (Polygon) polyenum.nextElement();
   Enumeration sidesenum = p.getEdges();
   while (sidesenum.hasMoreElements()){//extract side
        Segment ss = (Segment) sidesenum.nextElement();
         p1X = (ss.getFirstPoint()).getX();
         p1Y = (ss.getFirstPoint()).getY();
         p2X = (ss.getSecondPoint()).getX();
         p2Y = (ss.getSecondPoint()).getY();
         dist1 = p1X*p1X+p1Y*p1Y;
         dist2 = p2X*p2X+p2Y*p2Y;
        if (dist1 < d) {closest = ss.getFirstPoint();
                         d = dist1; psave = p;}
         if (dist2 < d) {closest = ss.getSecondPoint();
                         d = dist2; psave = p;}
    }
} //have found closest point on this polygon
   System.out.println("closest point to origin is " + closest +
                "on polygon " + psave);}
```

myTest2.java

Algorithm Complexity

- Constant number of operations in innermost loop
- Perform these once per side for each of k Polygons.
- Complexity of the nested loop over all will be proportional to

Sum (over all Polygons) #sides of each Polygon

so if all Polygons were triangles, it would be 3k.

- If sum all sides over all Polygons to obtain s sides, then work is proportional to **constant*s.**

Search

- Standard useful algorithm involves looking through a list of values for a particular value
- Can use arrays for this task
- Efficiency is important, especially for long lists

Linear Search I

- **Search an unordered list of values for 0**

  5 2 7 3 4 9 2 0 1 7 //stored in array

```
int desired = 0;
f1: for (int i= 0; i < a.length; i++)
{ if (a[i] == desired){
        System.out.println(desired +
        " found at position " + i);
        break f1};
}//may search entire array before know
//value not contained therein
```

Linear Search I

- **If desired value not in array may have to search entire array to find out.**
- **If desired value in array it may be at the end so may have to search entire array to find it. Worst case**
- **If desired value in array, you may find it in the first element! Best case**

Linear Search II

- **Search an ordered list of values for 3**
- **0 1 2 4 5 7 7 9 //stored in sorted array**

  0 1 2 4 5 7 7 9

  0 1 2 4 5 7 7 9

  0 1 2 4 5 7 7 9 NOT FOUND!
- **Proceed up from smallest value, comparing to desired value, until hit a value which is larger than the desired value.**
- **Don’t have to search entire array, unless desired value is bigger than all values in array or is largest value in array, Worst case**
- **In Best case, find value in first element.**

Linear Search II

- **Search an ordered list of values for 5**
- **0 1 2 4 5 7 7 9 //stored in sorted array**

  0 1 2 4 5 7 7 9

  0 1 2 4 5 7 7 9

  0 1 2 4 5 7 7 9

  0 1 2 4 5 7 7 9 FOUND!

Linear Search II: Code

```
int desired = 2;
f1: for (int i= 0; i < a.length; i++){
   if (desired < a[i]) break f1;
   else if (a[i] == desired){
        System.out.println(desired +
        "found at element" + i);
        break f1;}
  }//only search until find number larger
   //than desired
```

Worst Case Complexity

- **Linear search I: n checks if *desired* not in unordered array of n values**
  - **On average, *desired* value could be anywhere in the array**
- **Linear search II: 2n checks, if *desired* is larger than the largest element;**
  - **On average, will check n/2 elements**
- **Is there a better way?**

Twenty Questions

- The game allows you twenty questions to guess the number I'm thinking of between 1 and 1 million
- Suppose the chosen number is 445,362
  - [1:1,000,000]: 500,000 $\Rightarrow$ lower
  - [1:500,000]: 250,000 $\Rightarrow$ higher
  - [250,000:500,000]: 375,000 $\Rightarrow$ higher
  - [375,000:500,000]: 437,500 $\Rightarrow$ higher
  - [437,500:500,000]: 468,750 $\Rightarrow$ lower
  - [437,500:468,750]: 453,125 $\Rightarrow$ lower
  - [437,500:453,125]: 445,312 $\Rightarrow$ higher

Twenty Questions

- Know the number is between 445,312 and 453,125 having asked only 7 questions!
- Each question eliminates half the possible numbers left.
- How many questions will it take?
  – How many times can 1,000,000 be divided by 2?
  – 2^{20} = 1,048,576, so 20 questions suffice.
- Let's use this idea to search an ordered list of numbers

Binary Search

Find 2 in the array, if it is there.

0 1 2 3 5 6 8 9	**2 == 9? F; 2 == 0? F**
0 1 2 3 4 5 6 7	***indices in the array***
0 1 2 3 5 6 8 9	**2 == 3? F; 2 < 3? T**
0 1 2 3 4 5 6 7	
0 1 2 3 5 6 8 9	**2 ==1? F; 2<1? F**
0 1 2 3 4 5 6 7	
0 1 2 3 5 6 8 9	**2 ==2? T; found with index 2**
0 1 2 3 4 5 6 7	

Binary Search

Find index of 4, if it is there.

0 1 2 3 5 6 8 9   **4 == 9? F; 4 == 0? F**
0 1 2 3 4 5 6 7   ***indices in the array***

0 1 2 3 5 6 8 9   **4 == 3? F; 4 < 3? F**
0 1 2 3 4 5 6 7

0 1 2 3 5 6 8 9   **4 == 6? F; 4 < 6 ? T**
0 1 2 3 4 5 6 7

0 1 2 3 5 6 8 9   **4 == 5? F; 4 < 5? T**
0 1 2 3 4 5 6 7   **4 isn't found**

Complexity: Binary Search

- **At each step divide number of numbers left to examine in half: j, j/2, j/4, j/8, j/16,...,1**
- **Do 2 comparisons each step (== and then <)**
- **Stop when reach k such that**
  - **$j/(2^k) == 1$ or $j == 2^k$ or**
  - **$\log_2 j = k$**
- **Will do in the worst case, $\log_2 j$ comparisons if number is not in the list of j numbers.**

Binary Search I- Code Exerpt

```
//assume have read in a[], desired
//have set hi=a.length-1,low=0,
//mid=(a.length-1)/2
System.out.println ("desired = "+ desired);
int hi=a.length-1,low=0,mid=(hi+low)/2;
System.out.println("low,mid,hi " + low + " "+
      mid + " " + hi);//debugging output
//first checks ends of the array
  if (desired == a[hi])
      {System.out.println(" found " +
            desired + " at " + hi);
      return;}
  else if (desired == a[low]) {System.out.println(
      " found "+ desired + " at " + low);
      return;}
```

newbinsearch.java

Binary Search I - Main Loop

```
else     w1:{
              w2: while (hi >= low) {
                      if (desired == a[mid]){
                           System.out.println(
                                 " found at a[" + mid + "]");
                           break w1;}
                     else if (desired < a[mid]) hi = mid-1;
                      else low = mid+1;
                      mid = (hi+low)/2;
                      System.out.println("low,mid,hi " +
                           low + " " + mid + " " + hi);
                      }
                 System.out.println(desired + " not found");
             };
```

Output

```
8 remus!111> !java
java BinarySearch
 Enter 8 numbers in nondecreasing order
Input an integer: 2 4 6 8 10 12 14 16
Input desired value 4
desired = 4
low,mid,hi0 3 7
low,mid,hi 0 1 2
 found at a[1]
10 remus!111> !java
java BinarySearch
 Enter 8 numbers in nondecreasing order
Input an integer: 2 4 6 8 10 12 14 16
Input desired value 17
desired = 17
low,mid,hi0 3 7
low,mid,hi 4 5 7
low,mid,hi 6 6 7
low,mid,hi 7 7 7
low,mid,hi 8 7 7
17 not found
11 remus!111>
```

Binary Search

- **What changes in the code if we use a nonincreasing array of numbers rather than a nondecreasing arrray?**

```
if (desired == mid) ....
else if (desired < a[mid]) hi = mid-1;
    else low = mid+1;
```

has to change to

```
if (desired == mid) ...
else if (desired < a[mid]) low = mid+1;
    else hi = mid-1;
```

Binary Search

- Problem decomposition
  - Finding desired in a[low]-a[hi] is reduced to finding it in a[low]-a[mid-1] or a[mid+1]-a[hi]
  - Problem size is halved at each step
- Do constant work at each step (2 compares) and no more than $\log_2 n$ steps for n values
- What if wanted to search for objects in an array
  - Need equals() and compareTo()

Binary Search II - Recursive

- Suggests we can solve this *recursively*, as in GCD example with Bert and Ernie

```
private static int binSearch(int low, int hi, int []
  a, int desired){
        int mid = (hi+low)/2;
        if (hi < low) {return -1;}
        if (desired == a[mid])  return mid;
        else if (desired < a[mid])
          return (binSearch(low,mid-1,a, desired));
        else return(binSearch(mid+1,hi,a,desired));
}
```

newbinsearchRec.java

How it works?

data:	**1**	**3**	**5**	**7**	**9**	**10**	**14**	**18**	**9**
index:	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***desired***

Initial interval is a[0] to a[7] ;

Ask Ernie to find 9 in a[0] to a[7]. Ernie checks a[3] == 9 , a[3] < 9?

Since answer is yes, Ernie asks Bert to find 9 in a[4] to a[7].

Bert checks a[5] == 9, a[5] < 9 ?

Since answer is no, Bert asks Elmo to find 9 in a[4] to a[4].

Elmo checks a[4] == 9 ? and finds it is! Elmo tells Bert the answer is index 4.

Bert tells Ernie the answer is 4.

Ernie tells the questioner the answer is 4.

3 pairs of comparisons!
$8 = 2^3$