CompSci 201, L14: Sorting

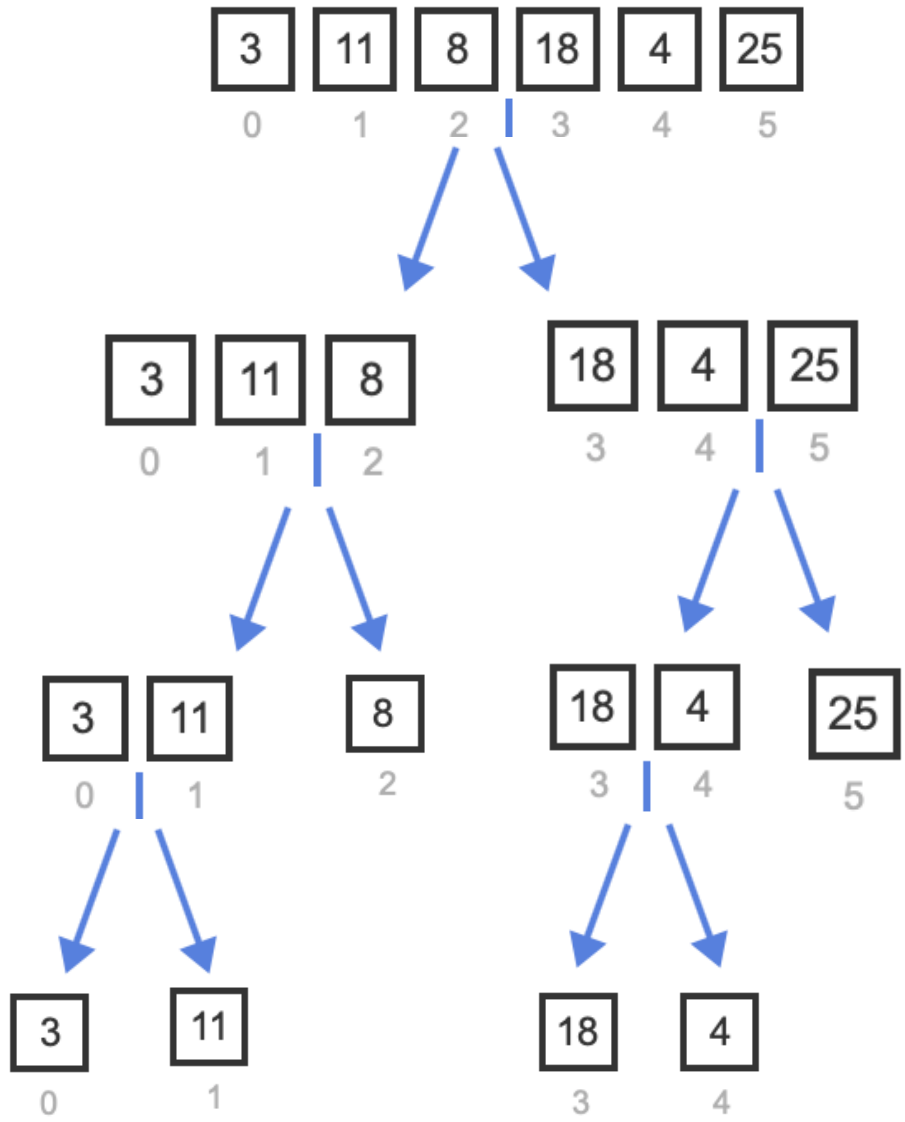
Logistics, Coming up

- Project 3: DNA due today 10/17
- Project 4: Autocomplete will release tomorrow, 10/18, will be due Monday after next 10/31.
- APT Quiz 1 due this Wednesday 10/19
  - Takes 2 hours, finish by 11:59
  - No regular APTs this week, just the quiz

Mergesort

High level idea:

- Base case: size 1
  - Return list
- Recursive case:
  - Mergesort(first half)
  - Mergesort(second half)
  - …



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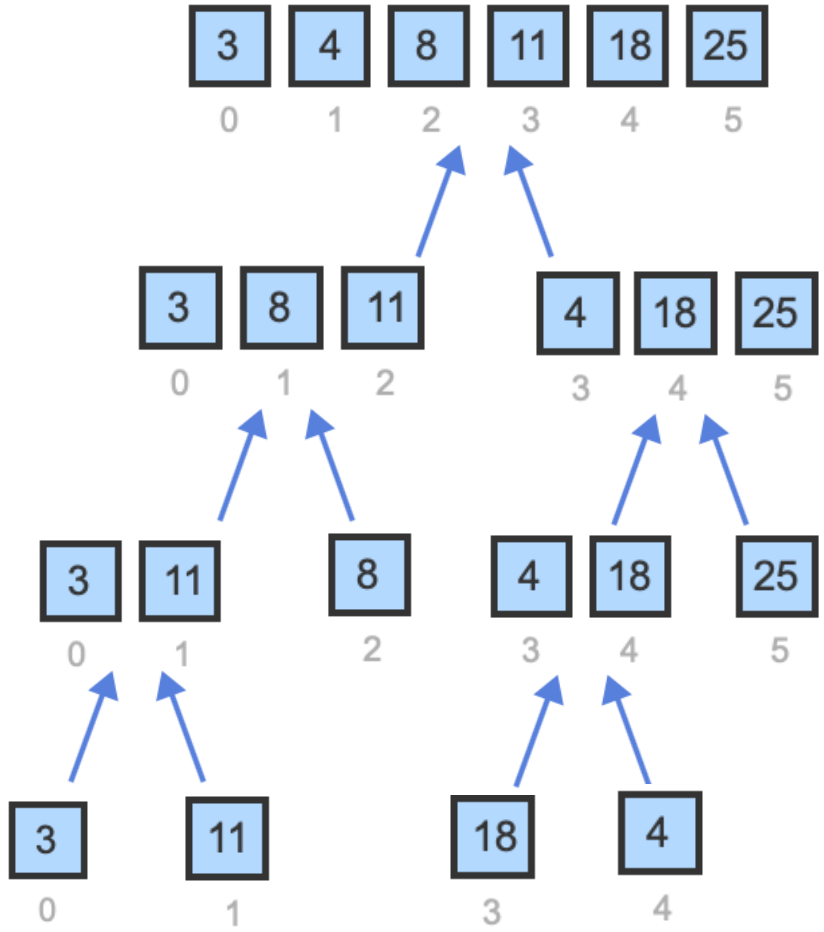
Mergesort

High level idea:

- Base case: size 1
  - Return list
- Recursive case:
  - Mergesort(first half)
  - Mergesort(second half)
  - Merge the sorted halves
  - Return sorted

Helper method



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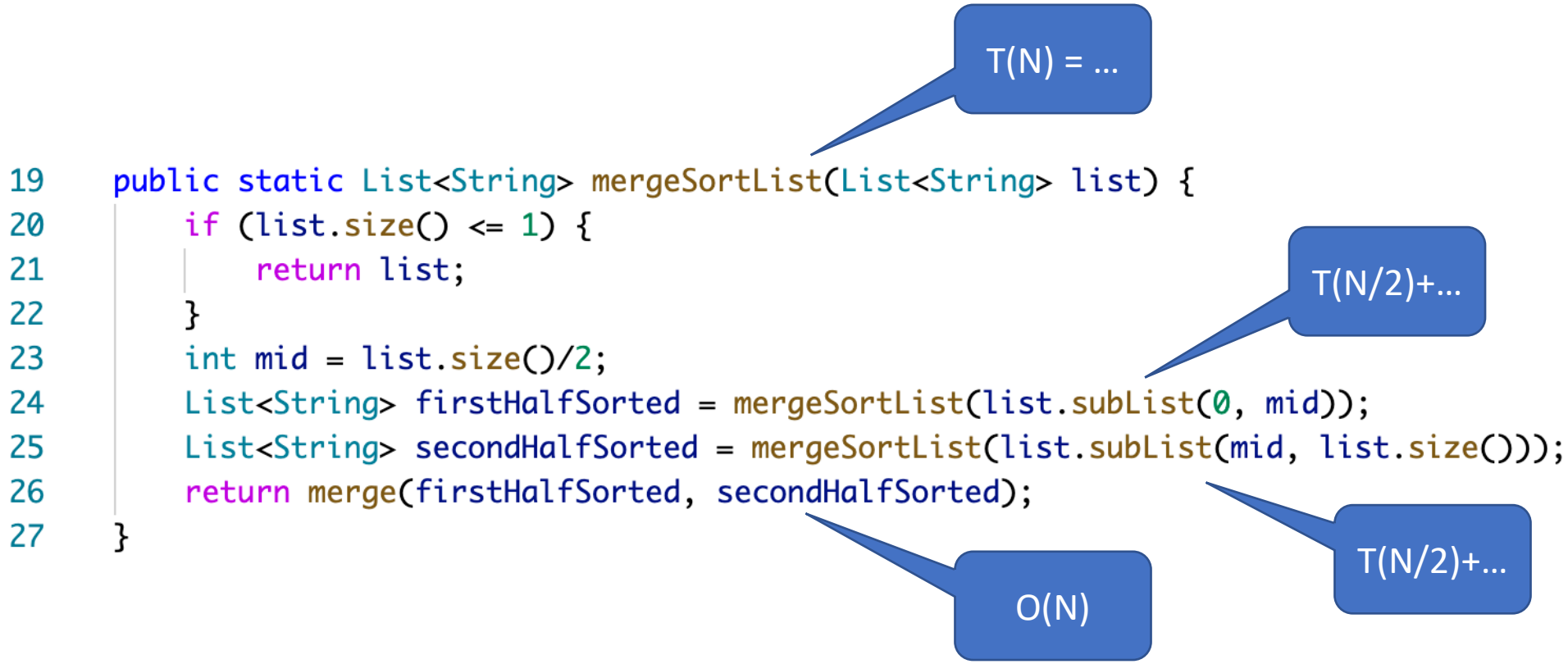
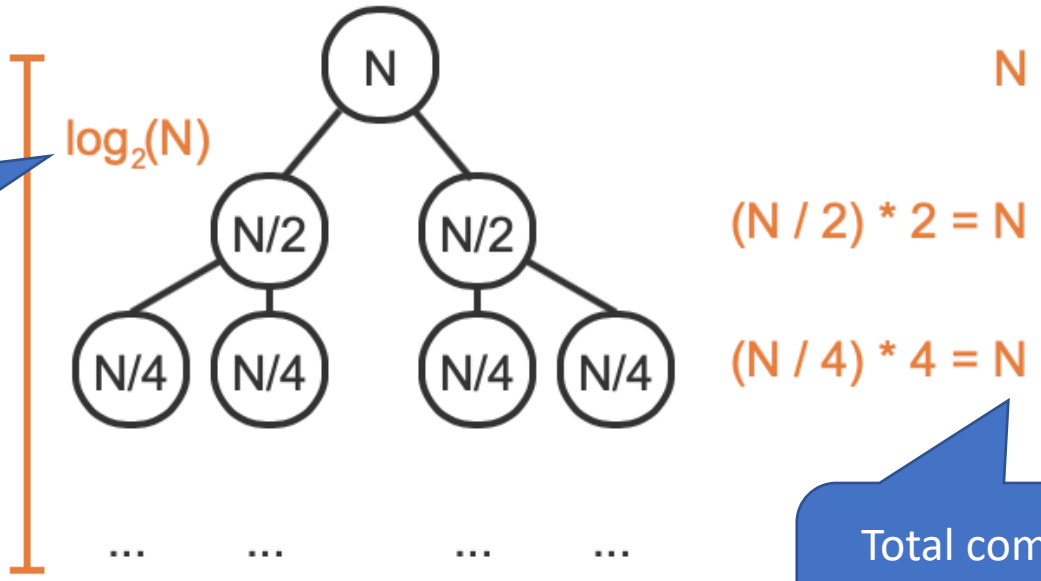
Runtime complexity of mergesort?



Recursion tree

$$T(N) = N + T(N / 2) + T(N / 2)$$

Depth of the recursion tree: Number of recursive calls before base case.



Total complexity of each level across all of the recursive calls.

$$T(N) = O(N \log N)$$

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Sorting in Java: Comparable, Comparator

Java API Sort Algorithms

- `Collections.sort` (for a List)
- `Arrays.sort` (for an Array)

- Both implement *Timsort* a variant of Mergesort.
  - O(N log(N)), *nearly* linear runtime complexity.
  - Sorts in-place, mutates the input rather than return a new List/Array.
    - `Collections.sort(myList);` causes `myList` to be sorted.
  - Stable, does not reorder elements if not needed (e.g., if two elements are equal).

What can be compared and sorted in Java?

- Class objects that implement the `Comparable` interface. Has a `naturalOrder`.
- Requires implementing a `.compareTo()` method

Should return an int:

- < 0 if `this` comes before the parameter.
- 0 if `this` and the parameter are equal.
- > 0 if `this` comes after the parameter.

```
private static class Person implements Comparable<Person> {
    String first;
    String last;
    public Person(String s) {...}
    public String getLast() { return last; }
    public String getFirst() { return first; }
    public String toString() { return first + " " + last; }
    @Override
    public int compareTo(Person p){
        int diff = last.compareTo(p.last);
        if (diff != 0) return diff;
        return first.compareTo(p.first);
    }
}
```

Strings are Comparable

- What is the equivalent of < for Strings?
- Use the `compareTo` method for the natural lexicographic (dictionary/sorted) ordering.

```
jshell> "a".compareTo("b");
$30 ==> -1
```

Negative for “less than”

```
jshell> "b".compareTo("b");
$31 ==> 0
```

Zero for “equal”

```
jshell> "b".compareTo("a");
$32 ==> 1
```

Positive for “less than”

```
jshell> "az".compareTo("cb");
$37 ==> -2
```

Lexicographic, check first character, second if equal, third if still equal, …

Comparable for other classes?

- Can implement `Comparable` interface and `compareTo` method when defining your own class.
  - Defines a natural ordering, can sort
  - Collections.sort, Arrays.sort

- What if it's someone else's class and they didn't implement Comparable?
- Or what if you want to sort by something *other* than the "natural order" defined by Comparable?

`Comparable` vs. `Comparator`

- `a.compareTo(b)`
  - What is method signature? One parameter
  - Method in class of which object `a` is an instance
  - `a` is `this`, `b` is a parameter

- Create a `Comparator c`, use `c.compare(a,b)`
  - Method has two parameters
  - Part of `Comparator` (Java API link)
  - Returns an int:
    - < 0 (means a comes before b)
    - == 0 (means a equals b)
    - > 0 (means a comes after b)

java.util.Comparator Examples

- `Comparator.naturalOrder`

```
jshell> Comparator<String> c = Comparator.naturalOrder()
c ==> INSTANCE

jshell> c.compare("a","b")
$12 ==> -1

jshell> c.reversed().compare("a","b")
$13 ==> 1
```

Must be Comparable

- `Comparator.comparing`

```
jshell> Comparator<String> c = Comparator.comparing(String::length)
c ==> java.util.Comparator$$Lambda$27/0x0000000800b97c4[illegible]2b71fc7e

jshell> c.compare("this", "is")
$15 ==> 1

jshell> c.compare("is", "it")
$16 ==> 0
```

Syntax is: <Type>::<method name> to sort something of the Type by the result of some getter method that returns something Comparable.

Sorting `Comparable` objects by `naturalOrder`

`[sloth, house, owl, ant, mice, kelp]`

`[ant, house, kelp, mice, owl, sloth]`

- naturalOrder for Strings is lexicographic (alphabetical or dictionary order)

```
String[] a = {"sloth", "house", "owl", "ant", "mice", "kelp"};
System.out.println(Arrays.toString(a));

String[] copy = Arrays.copyOf(a, a.length);
Arrays.sort(copy);
System.out.println(Arrays.toString(copy));
```

`Comparator` to sorting strings by length

`[sloth, house, owl, ant, mice, kelp]`

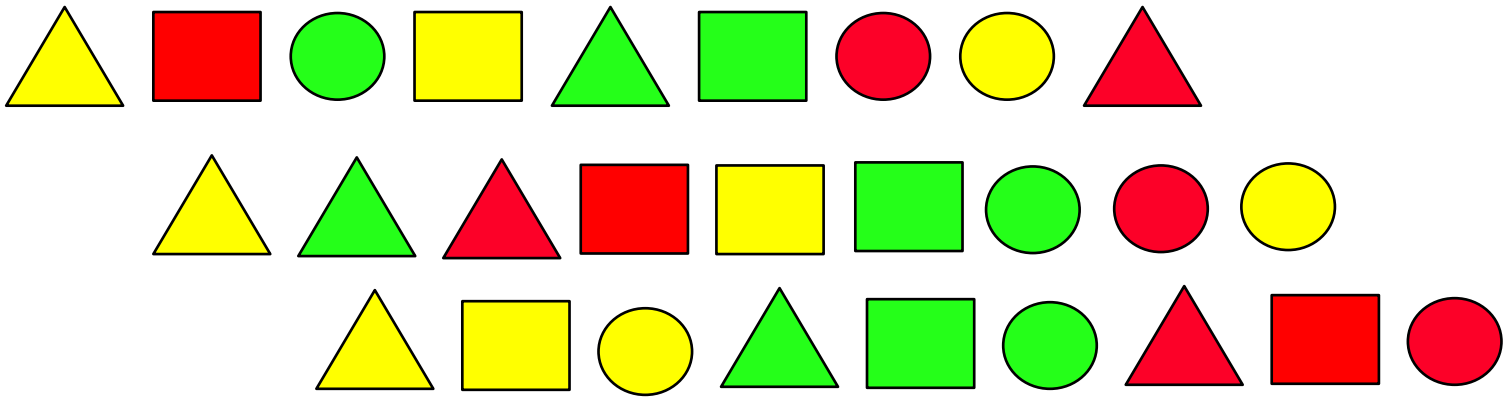
`[owl, ant, mice, kelp, sloth, house]`

- Why does "owl" come before "ant"?
  - Stable sort respects order of equal keys

```
copy = Arrays.copyOf(a, a.length);
Arrays.sort(copy, Comparator.comparing(String::length));
System.out.println(Arrays.toString(copy));
```

Stable, Stability

- Respect order of equal keys when sorting
  - First sort by shape, then by color: Stable!
    - Triangle < Square < Circle; Yellow < Green < Red



Sorting by length and then naturally

[sloth, house, owl, ant, mice, kelp]

[ant, owl, kelp, mice, house, sloth]

- Could put this on one line, easier to read?
  - First sort by length, if same? naturally

```
Arrays.sort(copy, Comparator.
                    comparing(String::length).
                      thenComparing(Comparator.naturalOrder()));
```

Comparator with “lambdas”

- What if you want to sort by something that doesn’t have a getter method?
- Or you just want to do something different than sort by a getter method?
- Can also define a comparator with a “lambda” expression.
- Example: Sort an Array of Arrays

```
int[] ar1 = {2, 0, 1};    int[] ar2 = {1, 0, 2, 3};

int[][] bothAr = {ar1, ar2};
```

Comparator with lambda to sort Array of Arrays by first elements

```
int[] ar1 = {2, 0, 1};    int[] ar2 = {1, 0, 2, 3};

int[][] bothAr = {ar1, ar2};

     { int[3] { 2, 0, 1 }, int[4] { 1, 0, 2, 3 } }

 Comparator<int[]> comp =
                          (a, b) -> (a[0] - b[0]);
```

Type we want to compare

Given an a and a b of that type…

comp.compare(a,b) should return this expression

Comparator with lambda to sort Array of Arrays by first elements

```
int[] ar1 = {2, 0, 1};    int[] ar2 = {1, 0, 2, 3};

int[][] bothAr = {ar1, ar2};

     { int[3] { 2, 0, 1 }, int[4] { 1, 0, 2, 3 } }

 Comparator<int[]> comp =
                        (a, b) -> (a[0] - b[0]);
```

`comp.compare(ar1, ar2)` returns (2-1) = 1.
`comp.compare(ar1, ar1)` returns (2-2)=0
`comp.compare(ar2, ar1)` returns (1-2)=-1

Comparator with lambda to sort Array of Arrays by first elements

```
int[] ar1 = {2, 0, 1};    int[] ar2 = {1, 0, 2, 3};

int[][] bothAr = {ar1, ar2};

     { int[3] { 2, 0, 1 }, int[4] { 1, 0, 2, 3 } }

 Comparator<int[]> comp =
                          (a, b) -> (a[0] - b[0]);

 Arrays.sort(bothAr, comp);
 { int[4] { 1, 0, 2, 3 }, int[3] { 2, 0, 1 } }
```

WOTO

Go to duke.is/pra6v

Not graded for correctness, just participation.

Try to answer *without* looking back at slides and notes.

But do talk to your neighbors!

Summary: Sorting Blobs

```
1   public class Blob implements Comparable{
2       public String name;
3       public String shape;
4       public String color;
5
6       public Blob(String n, String c, String s) {
7           name = n;
8           shape = s;
9           color = c;
10      }
11
12      public String getShape() {
13          return shape;
14      }
15
16      @Override
17      public int compareTo(Object o) {
18          Blob other = (Blob) o;
19          return name.compareTo(other.name);
20      }
```

Getter method for shape, can use with Comparator

compareTo / natural order based on name

Sorting Blobs many ways

```
List<Blob> myBlobs = …
16    // Sorting by natural order (names)
17    Collections.sort(myBlobs);
18    System.out.println(myBlobs);
```

[(al, round, red), (bo, square, blue), (cj, triangle, green), (di, square, red)]

```
20    // Sorting by shape with Comparator using getShape method
21    Comparator<Blob> comp = Comparator.comparing(Blob::getShape);
22    Collections.sort(myBlobs, comp);
23    System.out.println(myBlobs);
```

[(al, round, red), (bo, square, blue), (di, square, red), (cj, triangle, green)]

Sorting Blobs even more ways

```
25   // Sorting by color with Comparator using lambda
26   Comparator<Blob> comp2 = (b1, b2) -> (b1.color.compareTo(b2.color));
27   Collections.sort(myBlobs, comp2);
28   System.out.println(myBlobs);
```

[(bo, square, blue), (cj, triangle, green),
(al, round, red), (di, square, red)]

```
30   // Sorting by with multiple comparators
31   Collections.sort(myBlobs, comp.thenComparing(comp2));
32   System.out.println(myBlobs);
```

[(al, round, red), (bo, square, blue),
(di, square, red), (cj, triangle, green)]

Algorithms using sorted-ness

Binary Search

- Given a **sorted** `list` of N elements and a `target`, in just O(log(N)) time, return:
  - Index `i` such that `list.get(i)` equals `target`, or
  - -1 if `target` not in `list`

- Example:
  - If we search for ‘h’, should return 4
  - If we search for ‘c’, should return -1

value	‘a’	‘b’	‘d’	‘g’	‘h’	‘j’	‘k’	‘m’	‘p’
index	0	1	2	3	4	5	6	7	8

Java API Binary Search

`Arrays.binarySearch` (for arrays) and `Collections.binarySearch` (for Lists).

```
String[] ar = {"ape", "bird", "cat", "dog", "elephant",
"ferret", "gecko", "hippo"};

int index = Arrays.binarySearch(ar, "cat");
```

Returns 2

Careful, does not check for you if list is sorted!

```
String[] ar = {"cat", "ape", "bird",…

int index = Arrays.binarySearch(ar, "cat");
```

Returns -4

Java API Binary Search with Comparator

Can pass a comparator `comp`, in which case:

1. Array/List should be sorted by that `comp`, and
2. Want an index `i` such `i`'th element e_i has `comp.compare(`e_i`, target)==0`.

Sorted by length

```
[ape, cat, dog, bird, gecko, hippo, ferret, elephant]
```

```
Comparator<String> comp =
    Comparator.comparing(String::length);

index = Arrays.binarySearch(ar, "dog", comp);
```

Returns 1. `comp.compare("cat", "dog")==0`

How is Binary Search O(log(N))?

- How to find something in a list of N elements without looping over the list?
- Let `low` (initially 0) and `high` (initially N-1) mark the limits of the active search space.
- Want to cut down the search space by half at each step:

N
N/2
N/4
N/8
…
1

log_2(N) steps!

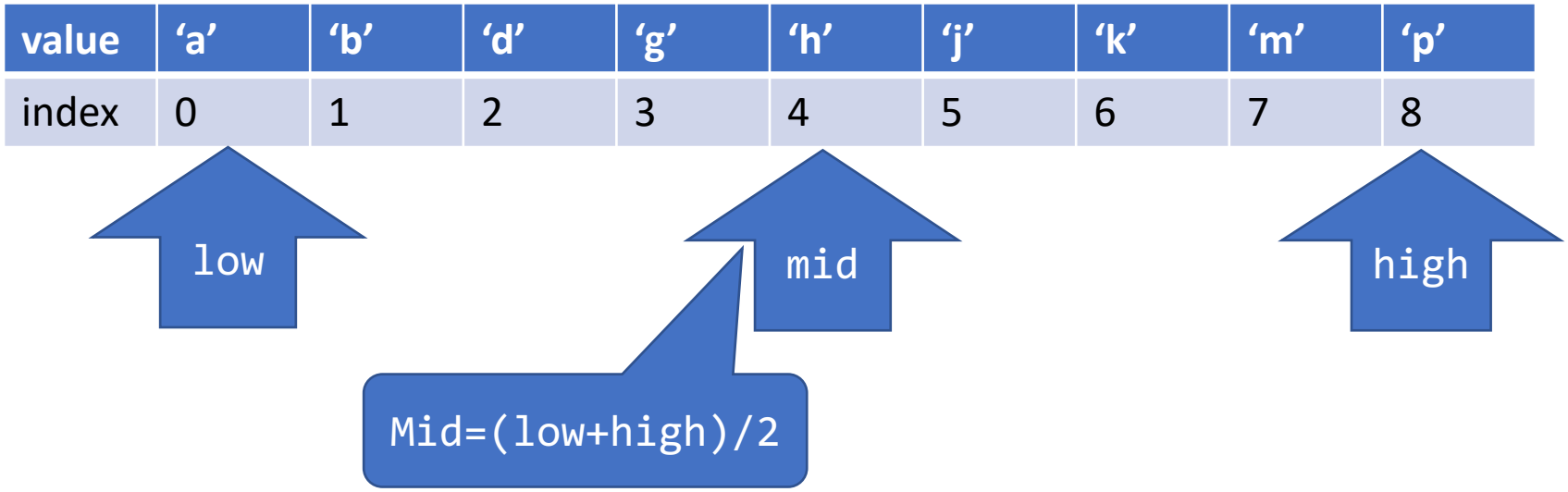
value	'a'	'b'	'd'	'g'	'h'	'j'	'k'	'm'	'p'
index	0	1	2	3	4	5	6	7	8

`low`

`high`

Binary Search in Pictures

- Searching for ‘d’ in

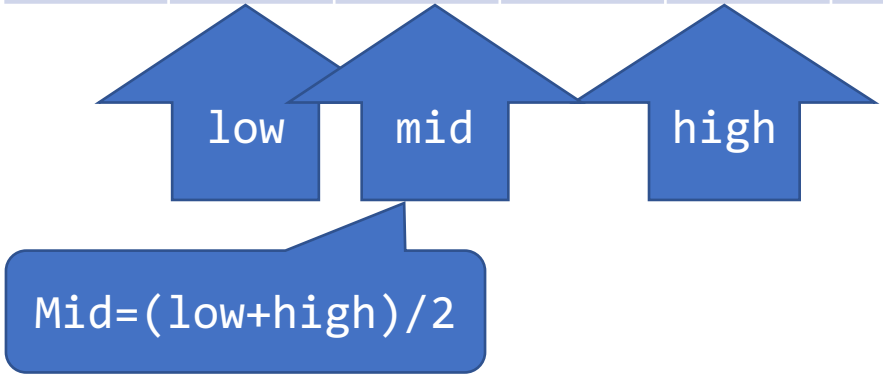


- ‘h’ > ‘d’, so need to keep searching in the *lower* half.
- Set `high = mid-1;`

Binary Search in Pictures

- Searching for ‘d’ in

value	‘a’	‘b’	‘d’	‘g’	‘h’	‘j’	‘k’	‘m’	‘p’
index	0	1	2	3	4	5	6	7	8



- ‘b’ < ‘d’, so need to keep searching in the *upper* half.
- Set `low = mid+1;`

Binary Search in Pictures

- Searching for ‘d’ in

value	‘a’	‘b’	‘d’	‘g’	‘h’	‘j’	‘k’	‘m’	‘p’
index	0	1	2	3	4	5	6	7	8

- ‘d’ equals ‘d’, return `mid (2)`