

CSCI 132:

Basic Data Structures and Algorithms

Searching (Binary Search)

Reese Pearsall
Fall 2023

Announcements

Lab 12 due **tomorrow** @11:59 PM

Program 5 due Sunday December 10th

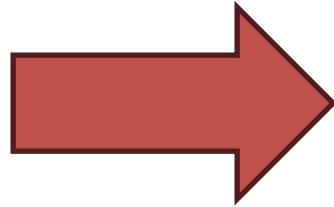
Gradebook



being called smart because you
can recite the complexities of
sorting algorithms but in reality
it's all surface level intelligence
and you don't feel like you're really
good at anything

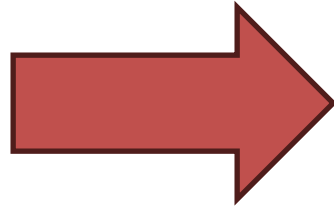


```
char[][] maze
[ [ #, #, #, #, #],
  [ #, ., ., ., #],
  [ ., ., #, ., #],
  [ #, #, #, ., #],
  [ #, ., ., ., .],
  ]
```



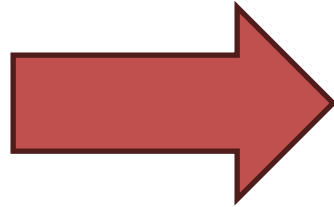

```
char[][] maze
[ [ #, #, #, #, # ],
  [ #, ., ., ., # ],
  [ ., ., #, ., # ],
  [ #, #, #, ., # ],
  [ #, ., ., ., . ],
  ]
```

```
maze[0]
```



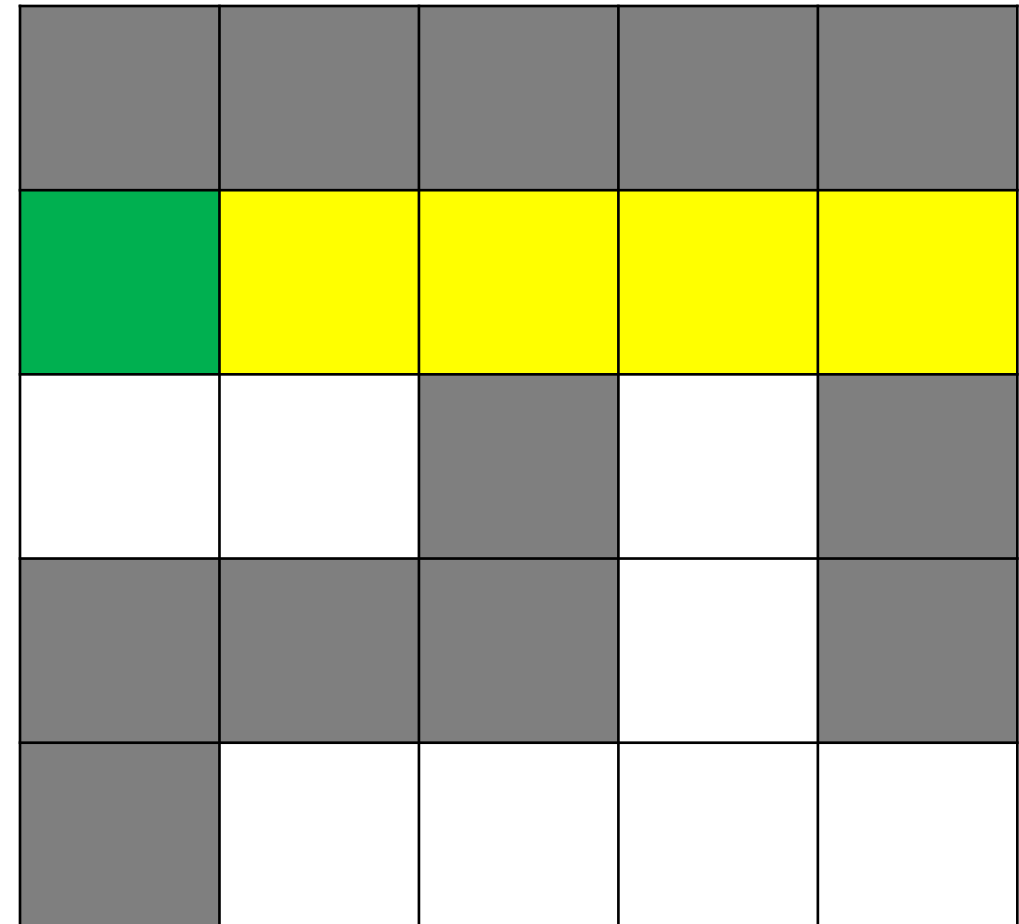
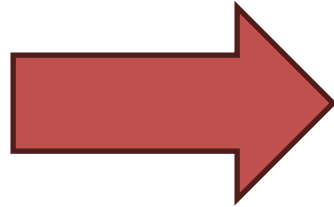

```
char[][] maze
[ [ #, #, #, #, #],
  [ #, ., ., ., #],
  [ ., ., #, ., #],
  [ #, #, #, ., #],
  [ #, ., ., ., .],
  ]
```

```
maze[1]
```



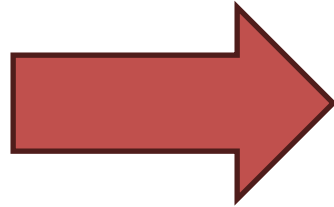

```
char[][] maze
[ [ #, #, #, #, #],
  [ #, ., ., ., #],
  [ ., ., #, ., #],
  [ #, #, #, ., #],
  [ #, ., ., ., .],
  ]
```

```
maze[1][0]
```



```
char[][] maze
[ [ #, #, #, #, #],
  [ #, ., ., ., #],
  [ ., ., #, ., #],
  [ #, #, #, ., #],
  [ #, ., ., ., .],
  ]
```

```
maze[1][2]
```



Gray	Gray	Gray	Gray	Gray
Yellow	Yellow	Green	Yellow	Yellow
White	White	Gray	White	Gray
Gray	Gray	Gray	White	Gray
Gray	White	White	White	White

```

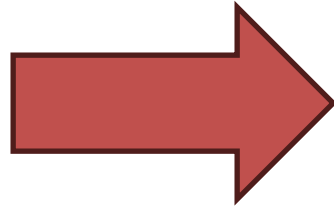
char[][] maze
[ [ #, #, #, #, #],
  [ #, ., ., ., #],
  [ ., ., #, ., #],
  [ #, #, #, ., #],
  [ #, ., ., ., .],
  ]

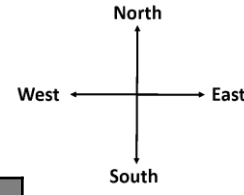
```

```

maze[y][x]

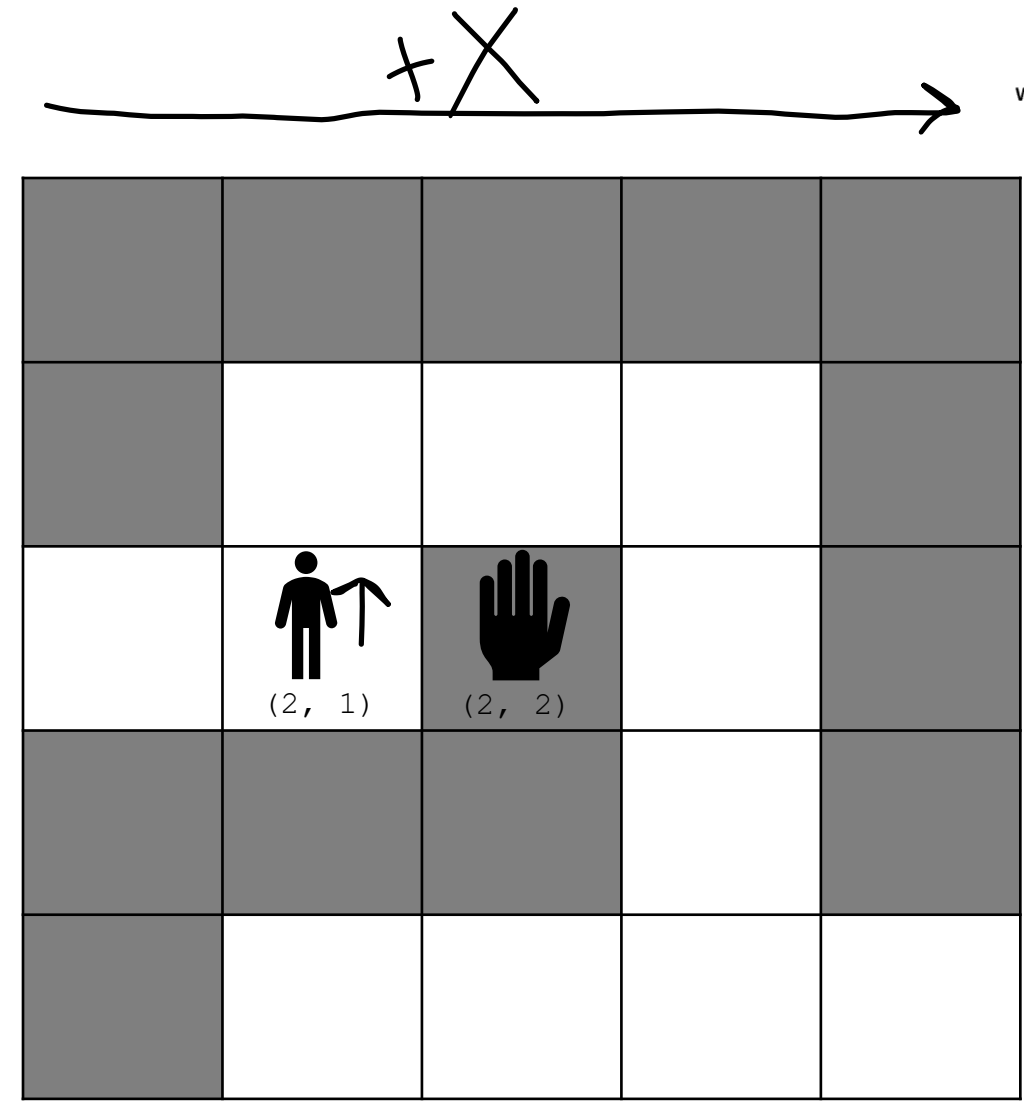
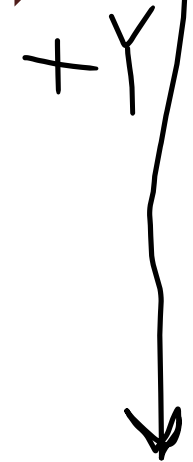
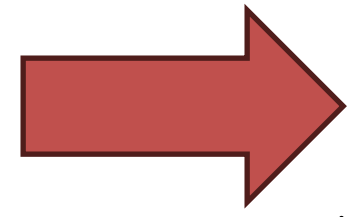
```





char[][] maze

```
[ [ #, #, #, #, # ],  
  [ #, ., ., ., # ],  
  [ ., ., #, ., # ],  
  [ #, #, #, ., # ],  
  [ #, ., ., ., . ],  
  ]
```

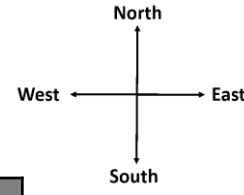


maze[y][x]

Goal: Move forward one spot

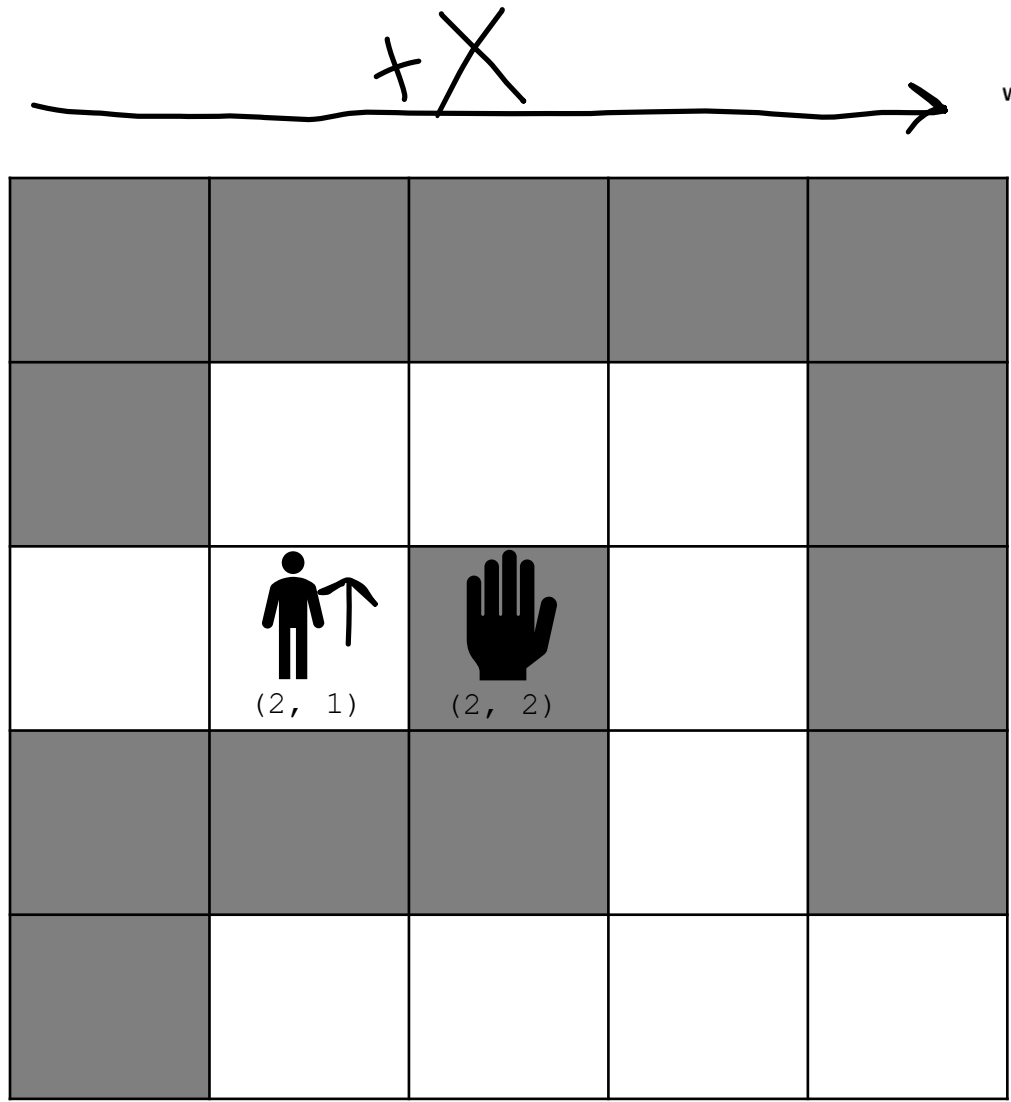
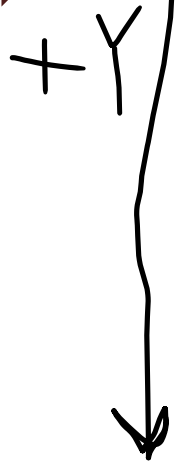
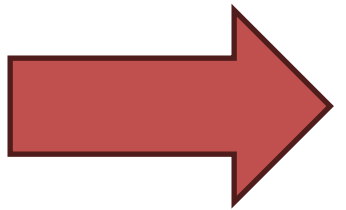
We need to know which direction we are facing first!

How do we know direction we are facing?



char[][] maze

```
[ [ #, #, #, #, # ],  
  [ #, ., ., ., # ],  
  [ ., ., #, ., # ],  
  [ #, #, #, ., # ],  
  [ #, ., ., ., . ],  
  ]
```



(2, 1)

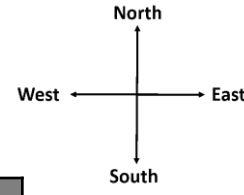
(2, 2)

maze[y][x]

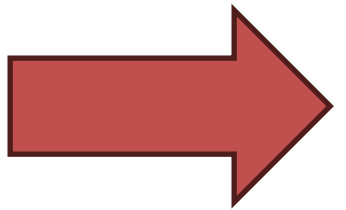
Goal: Move forward one spot

We need to know which direction we are facing first!

Our character Y value and our hand's Y value is the same,
And our character's X value is *less than* our hands' X value

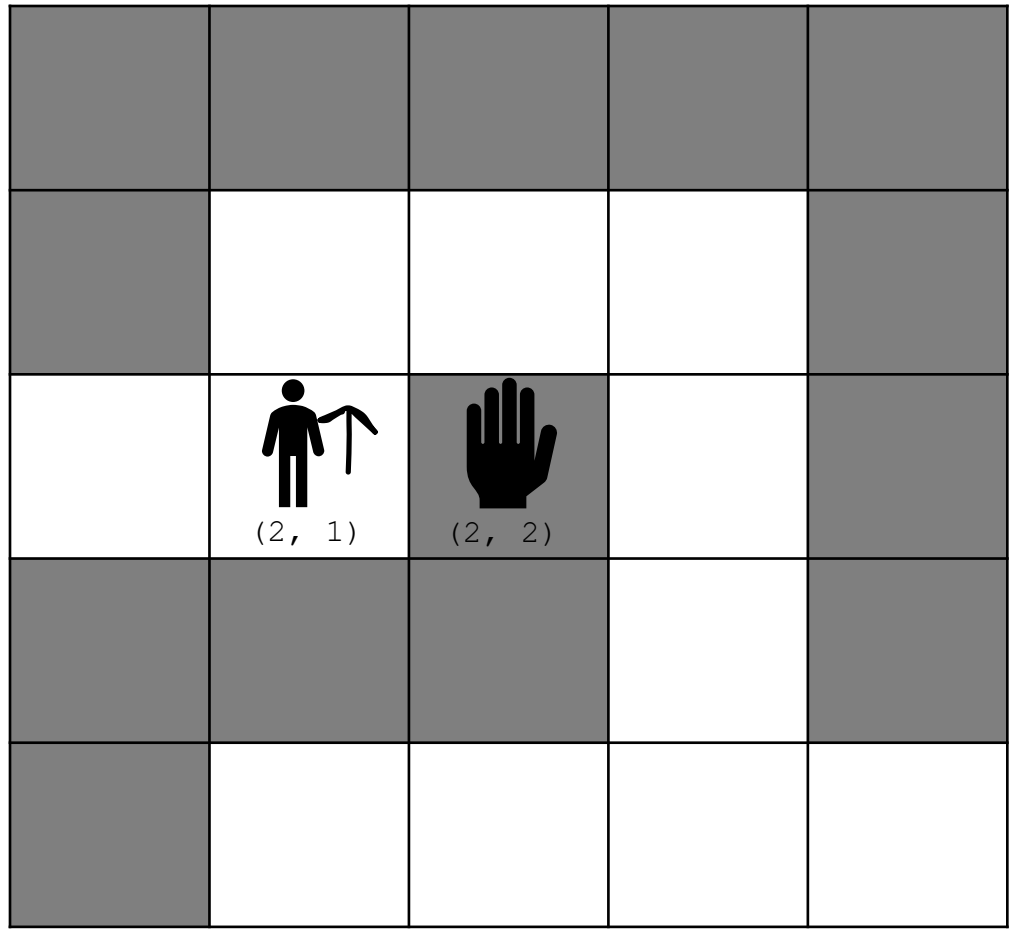


```
char[][] maze
[ [ #, #, #, #, #],
  [ #, ., ., ., #],
  [ ., ., #, ., #],
  [ #, #, #, ., #],
  [ #, ., ., ., .],
  ]
if(y == hand_y && hand_x > x)
    direction = "North";
}
```



+ Y

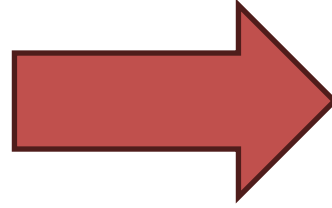
+ X



maze[y][x]

```
char[][] maze
```

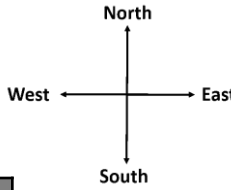
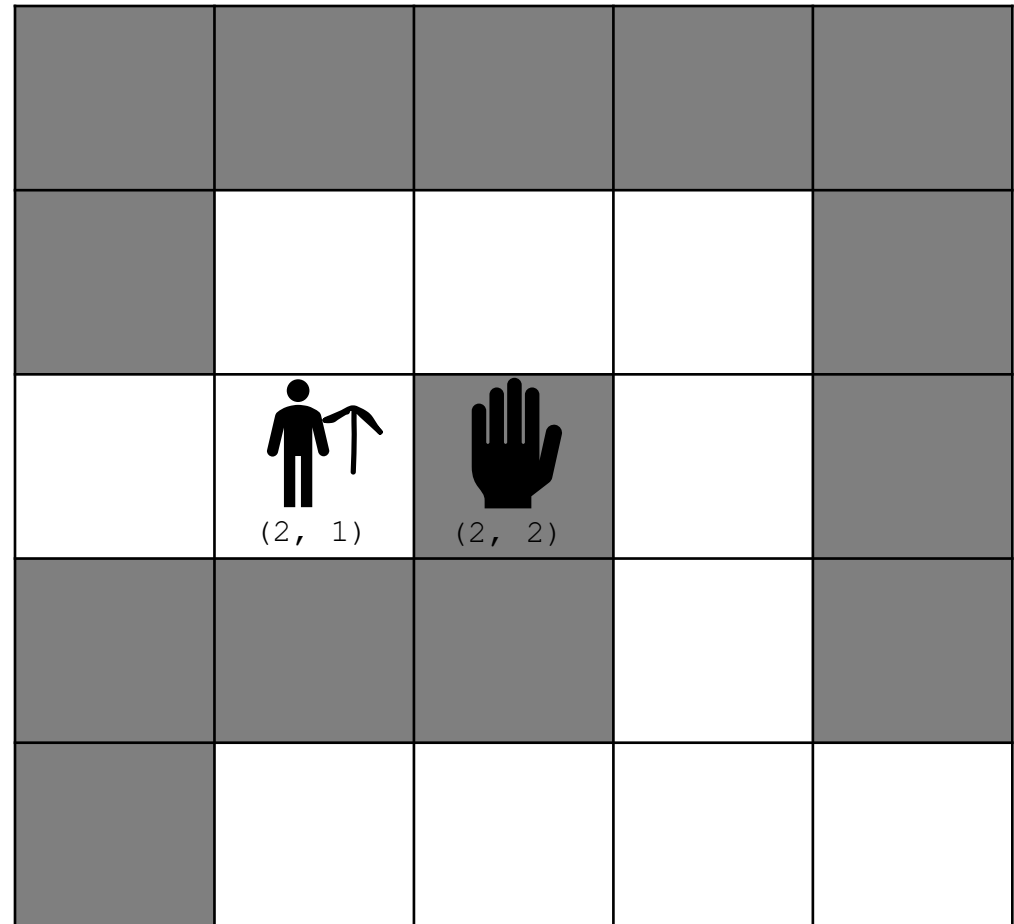
```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...
```

How do we detect if we can move forward?

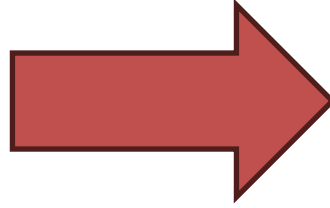
+ Y



maze[y][x]

```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";
```

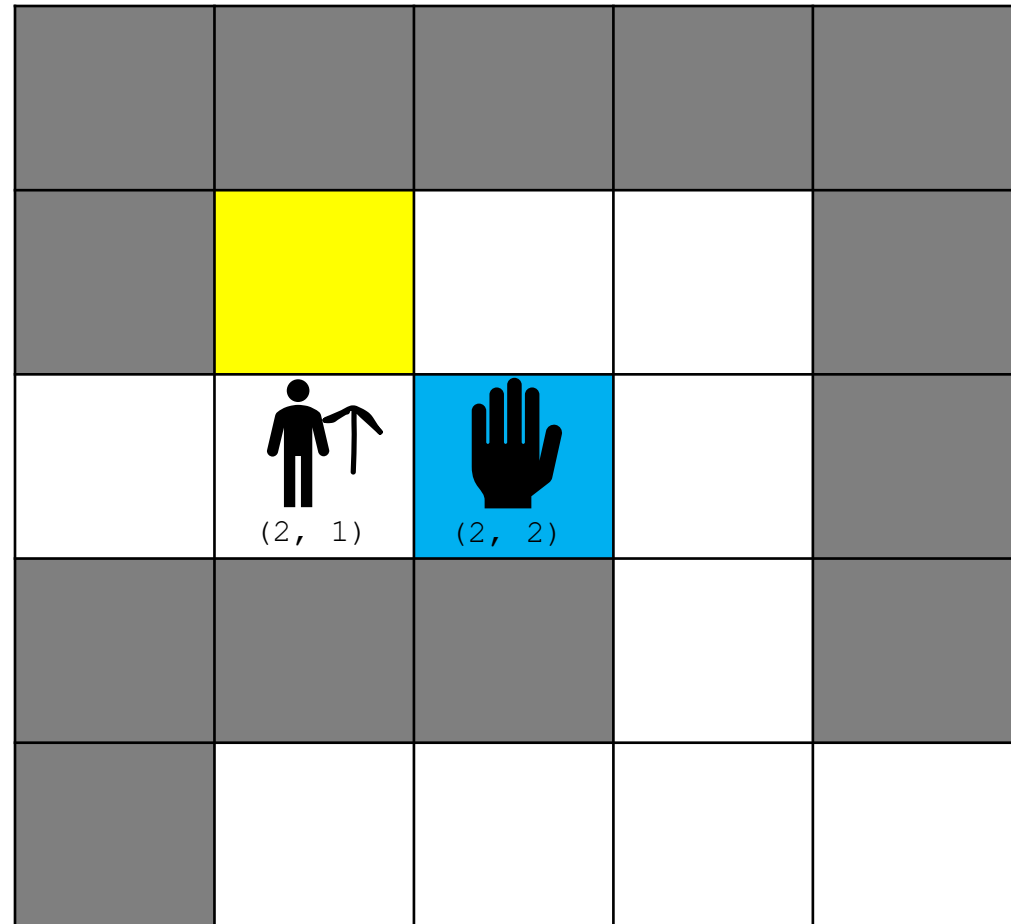
```
}
```

```
...
```

```
if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){
```

```
}
```

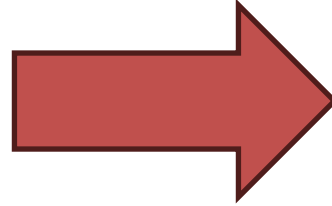
+ Y



maze[y][x]

```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";
```

```
}
```

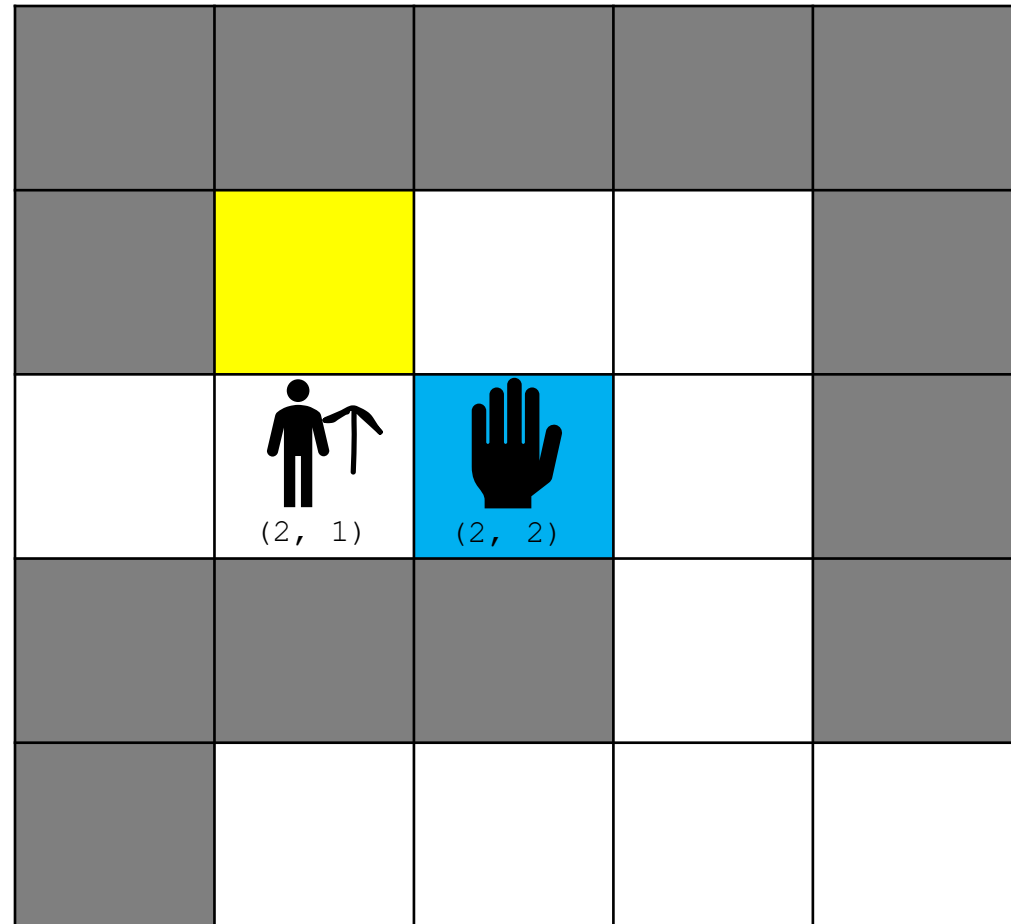
```
...
```

```
if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){
```

Make one move by recursively calling
the method with the new values

```
}
```

+ Y

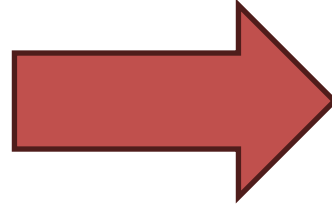


maze[y][x]

```
makeMove(x, y, hand_x, hand_y)
```

```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";
```

```
}
```

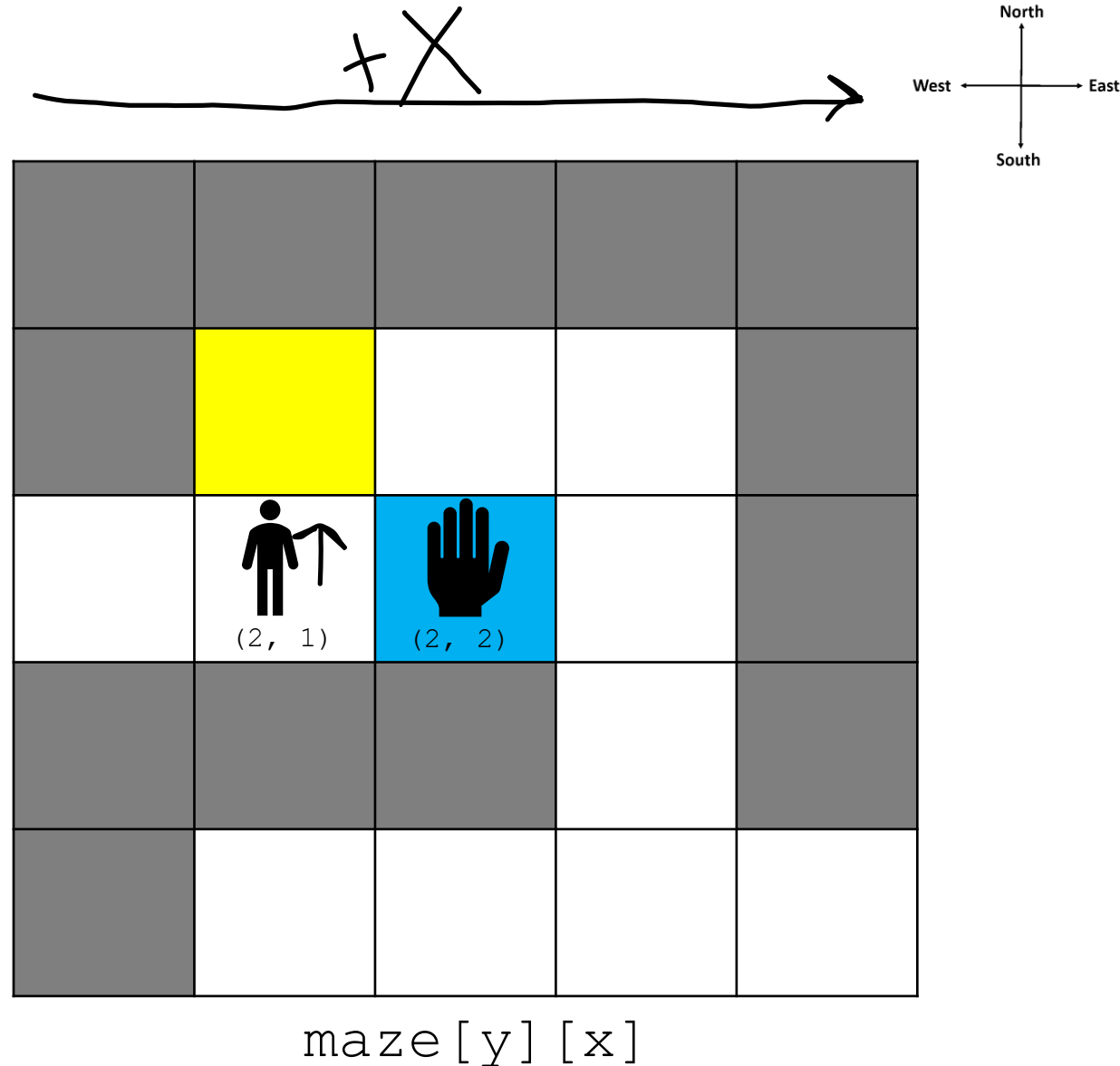
```
...
```

```
if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){
```

Make one move by recursively calling
the method with the new values

```
}
```

+ Y

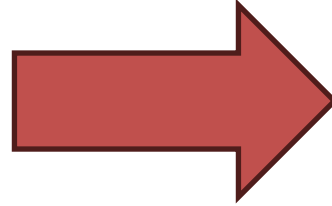


maze[y][x]

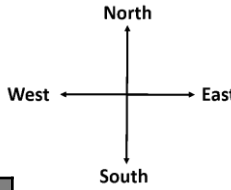
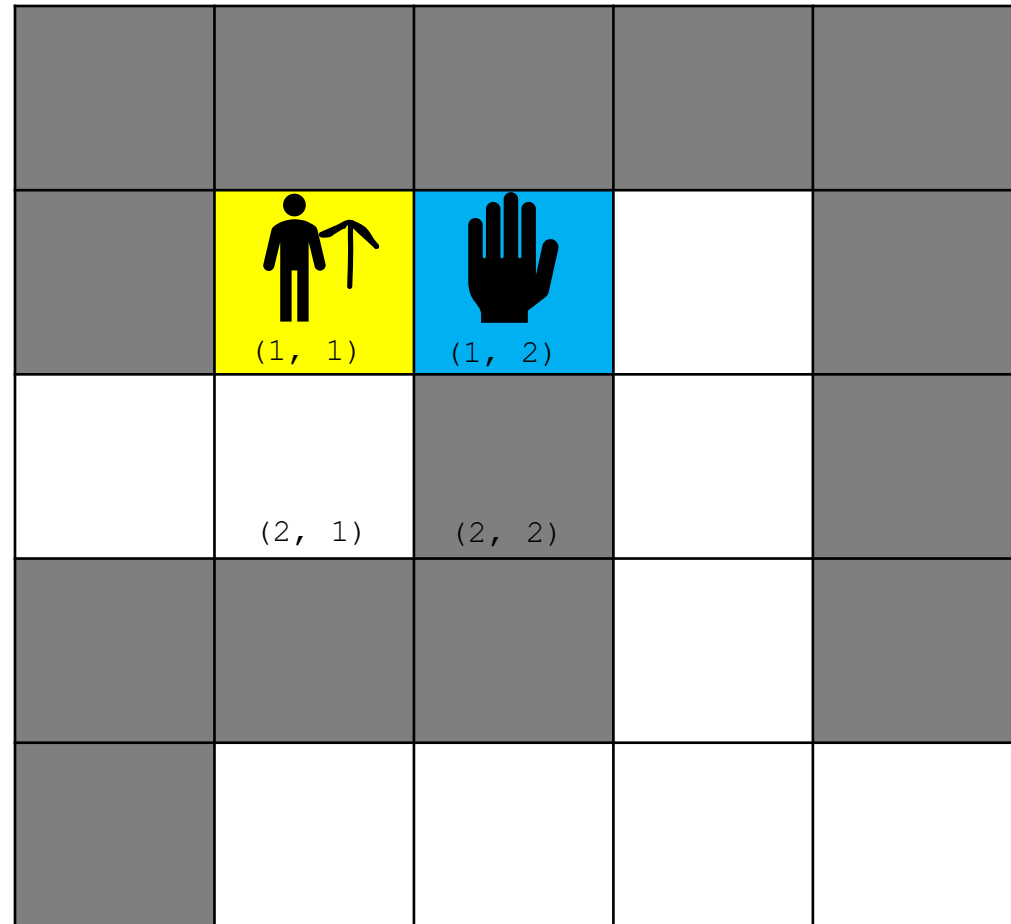
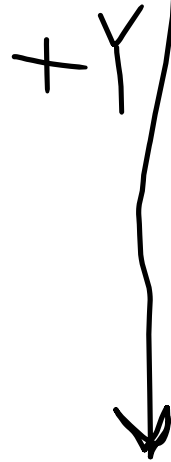
```
makeMove(x, y, hand_x, hand_y)
```

```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
    makeMove(x, y-1, hand_x, hand_y-1);  
}
```



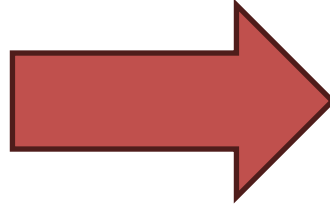
maze[y][x]

```
makeMove(x, y, hand_x, hand_y)
```



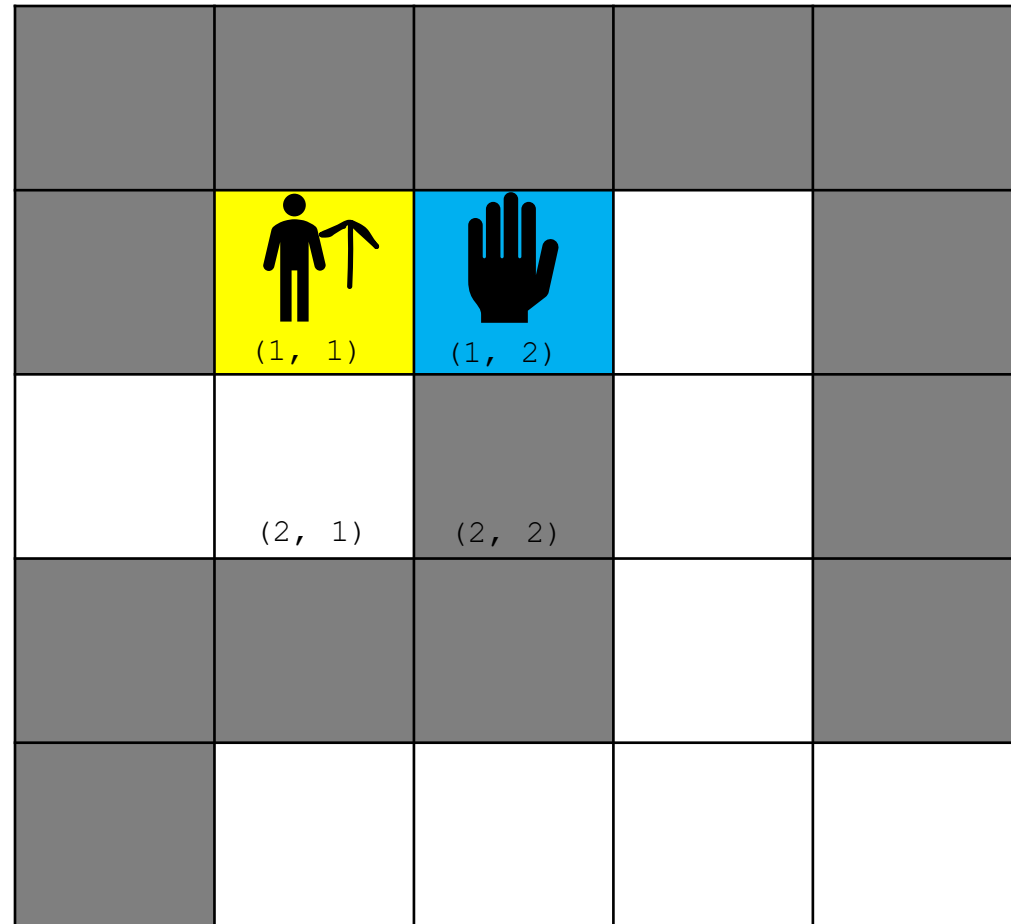
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
}
```

+ Y

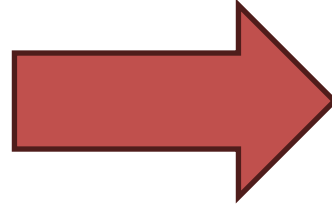


maze[y][x]

```
makeMove(x, y, hand_x, hand_y)
```

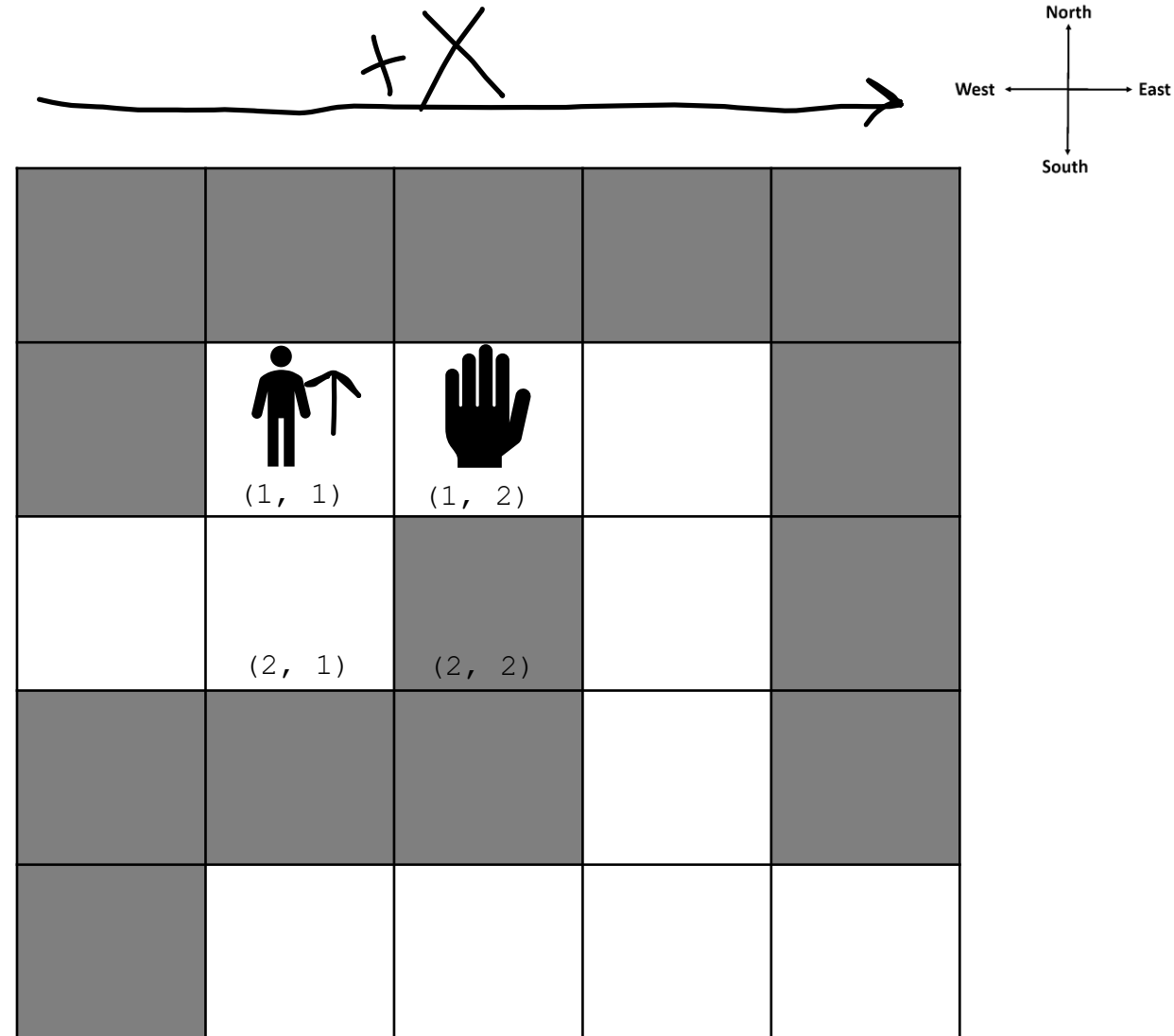
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
}
```

Turn right and move forward one spot?

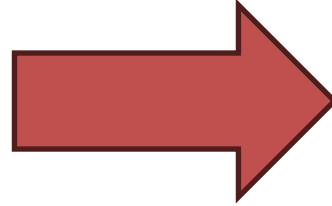


maze[y][x]

```
makeMove(x, y, hand_x, hand_y)
```

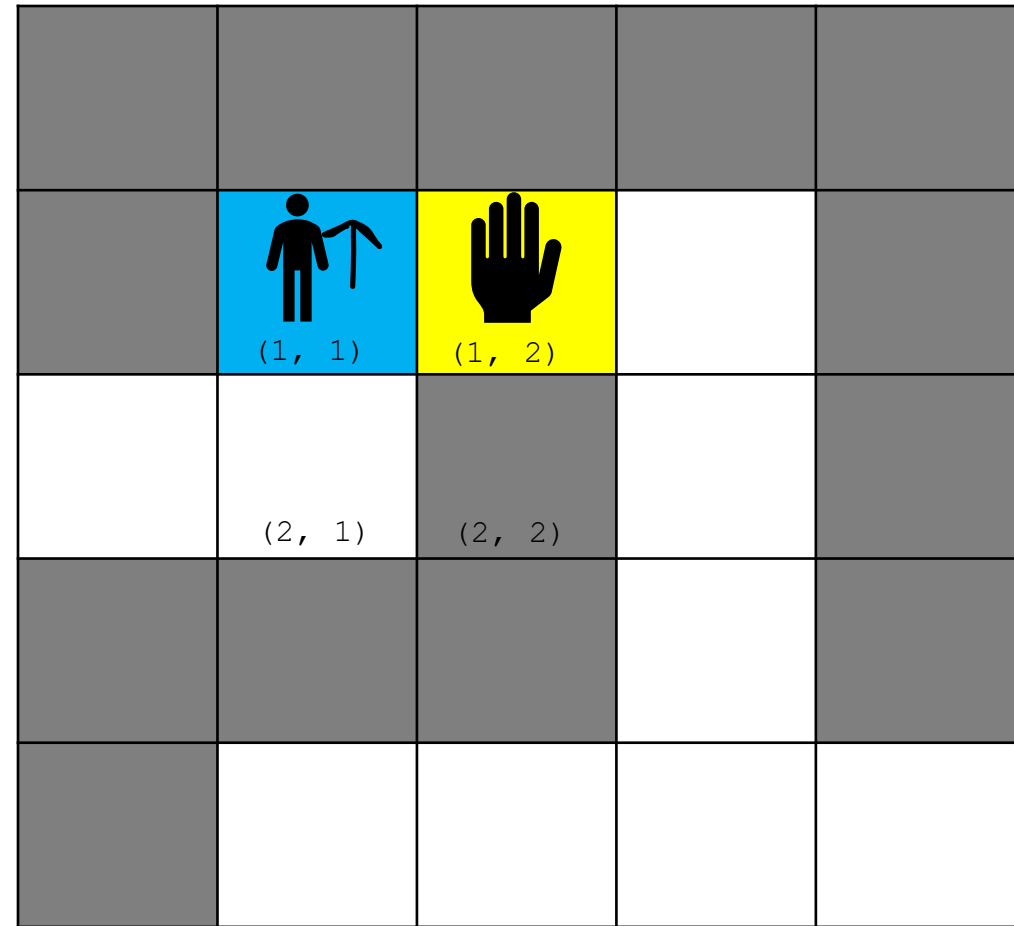
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x, y, hand_x, hand_y)  
    }  
}
```

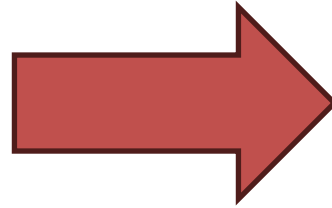
+ Y



maze[y][x]

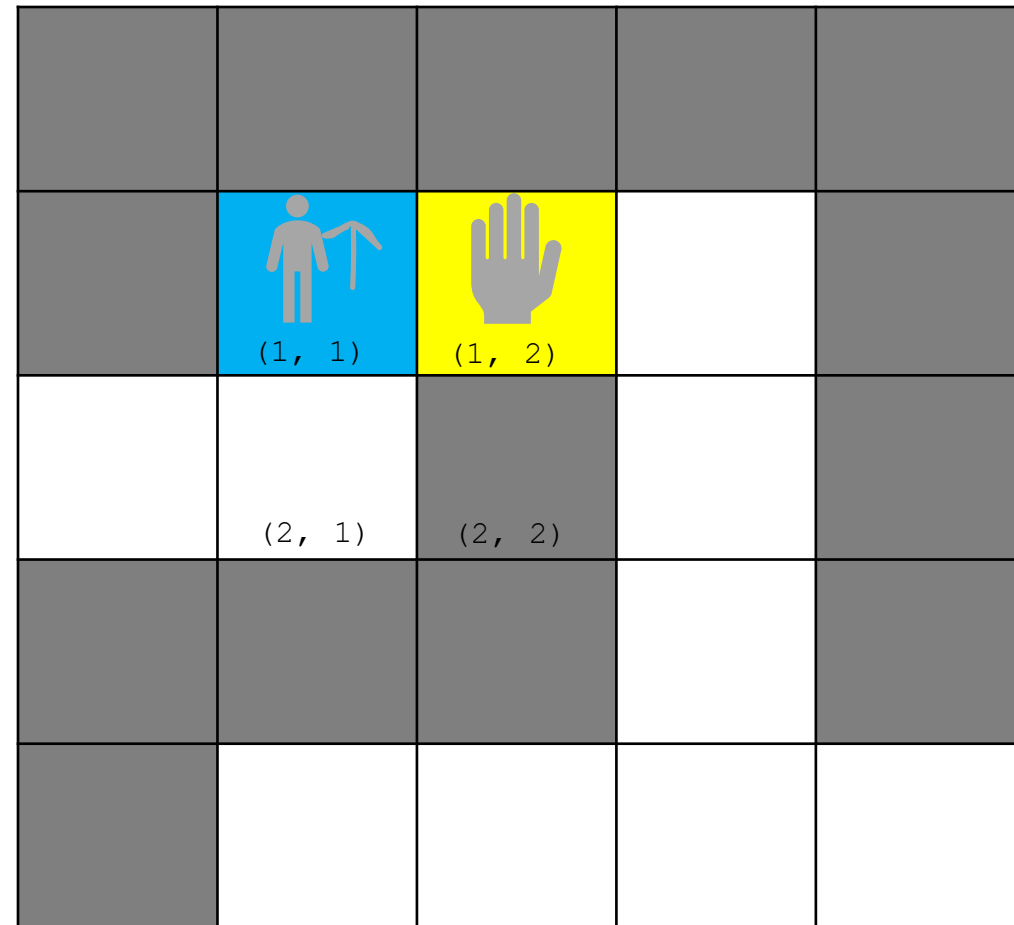
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(??, ??, ??, ??);  
    }  
}
```

+ Y

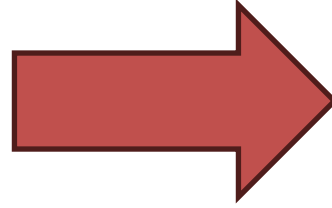


maze[y][x]

```
makeMove(x, y, hand_x, hand_y)
```

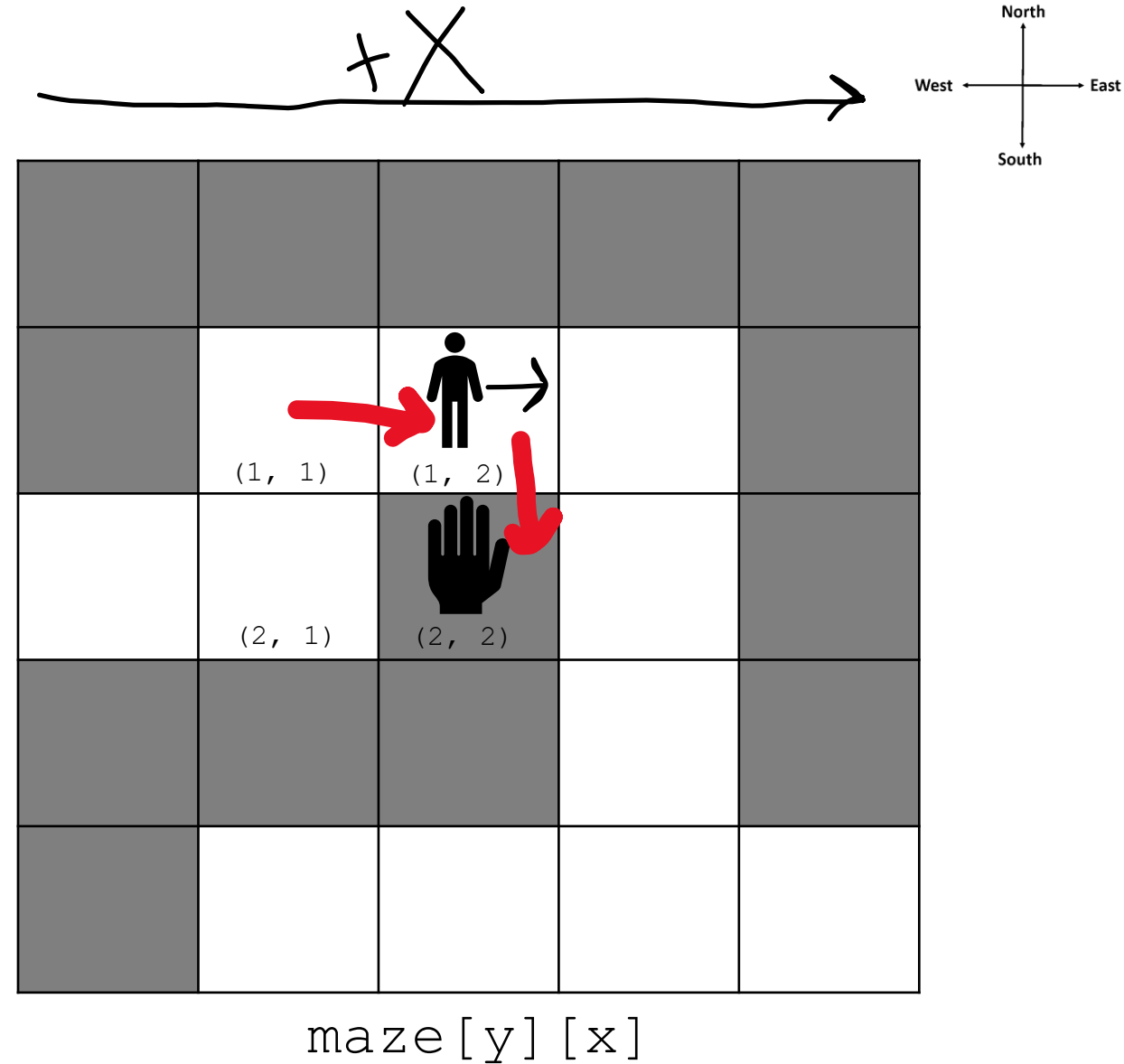
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



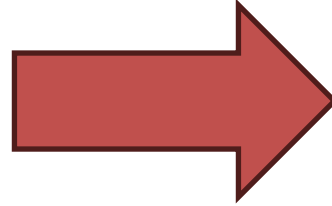
```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x+1, y, hand_x, hand_y+1);  
    }  
}
```

```
makeMove(x, y, hand_x, hand_y)
```



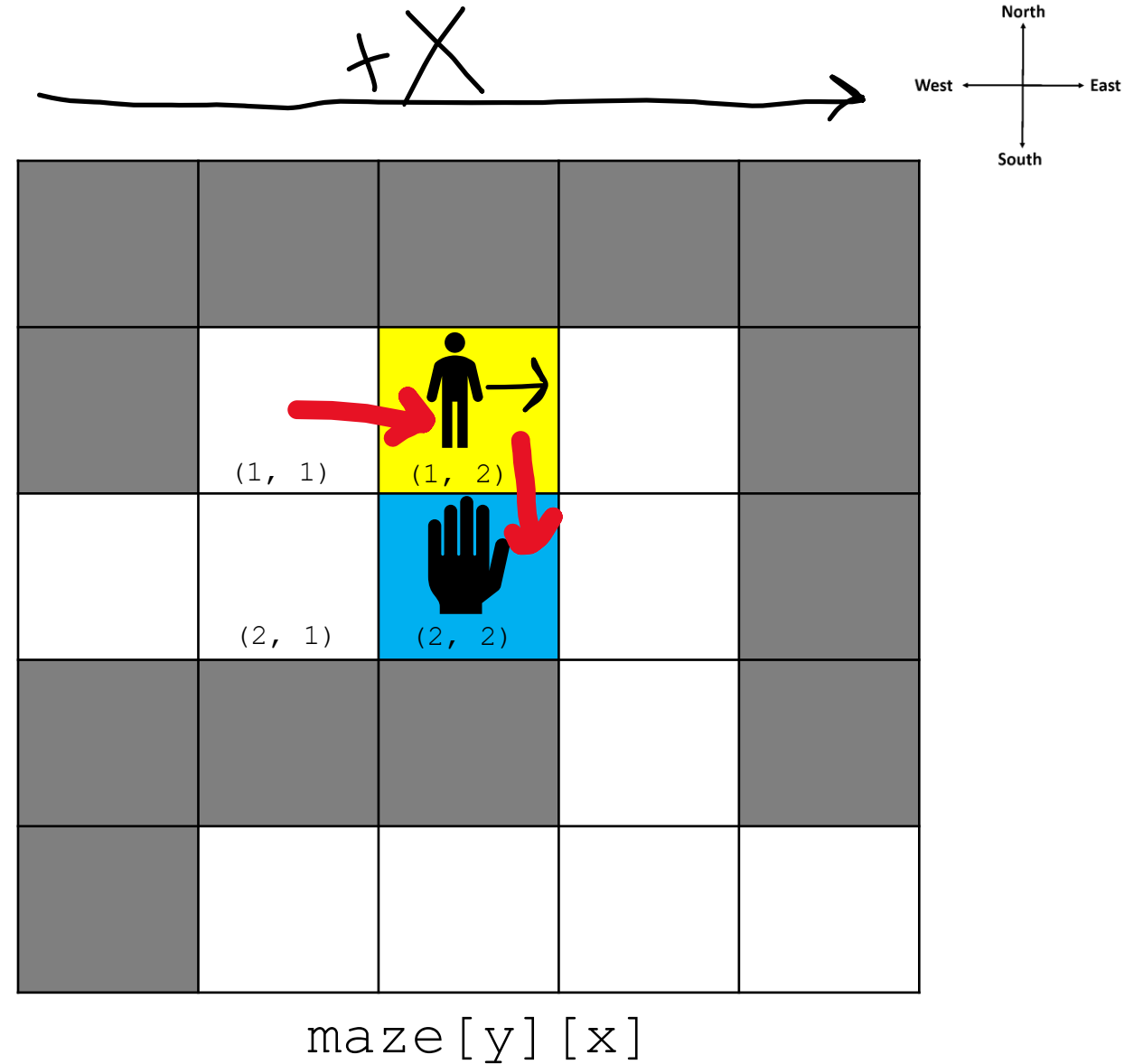
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



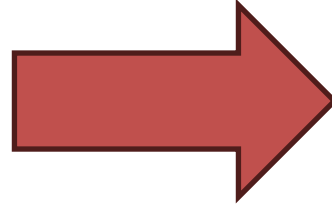
```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x+1, y, hand_x, hand_y+1);  
    }  
}
```

```
makeMove(x, y, hand_x, hand_y)
```



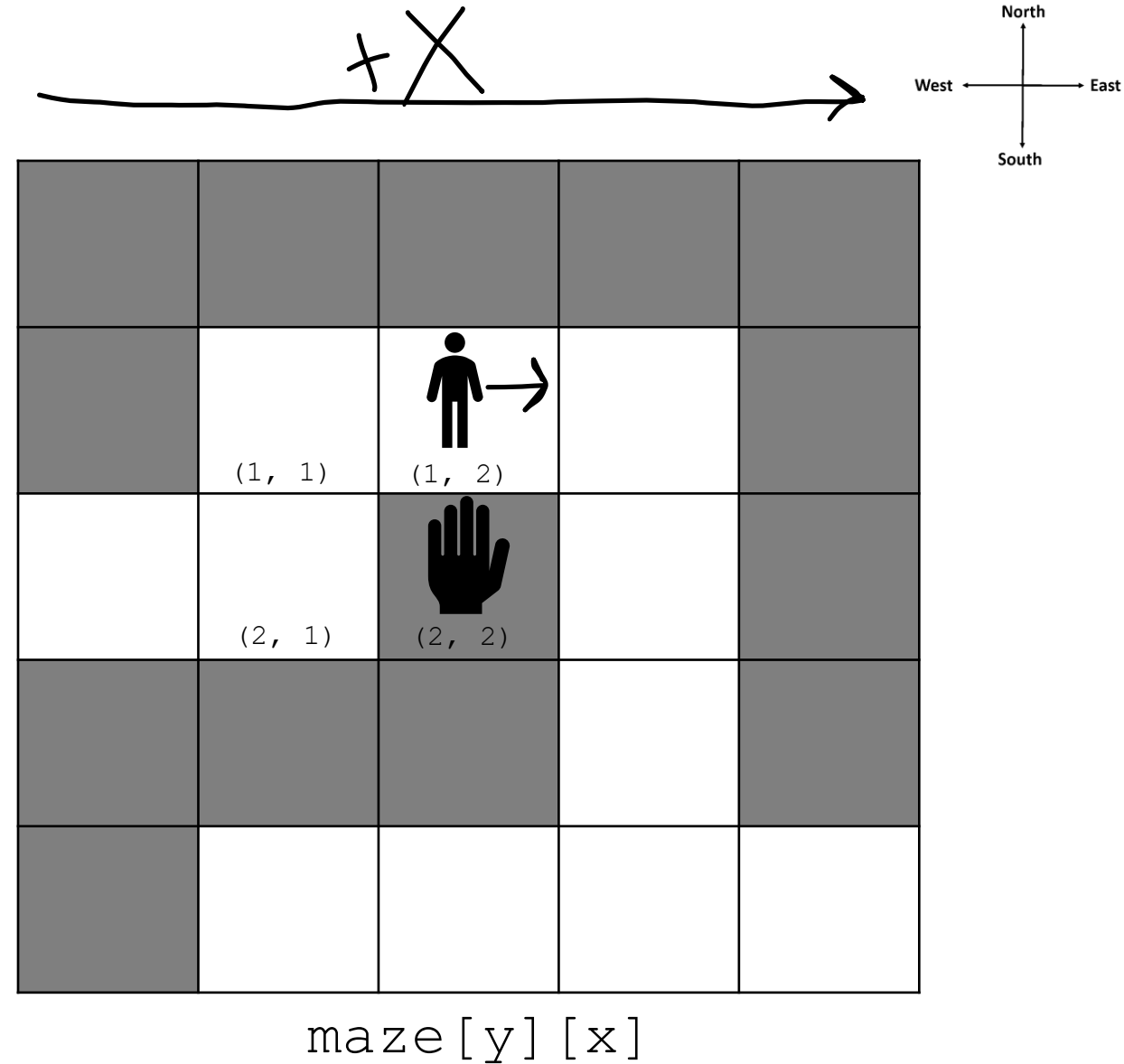
```
char[][] maze
```

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



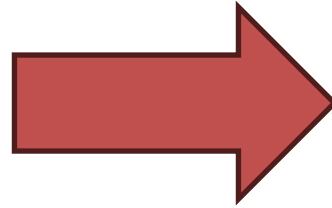
```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x+1, y, hand_x, hand_y+1);  
    }  
}
```

```
makeMove(x, y, hand_x, hand_y)
```

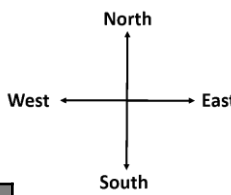
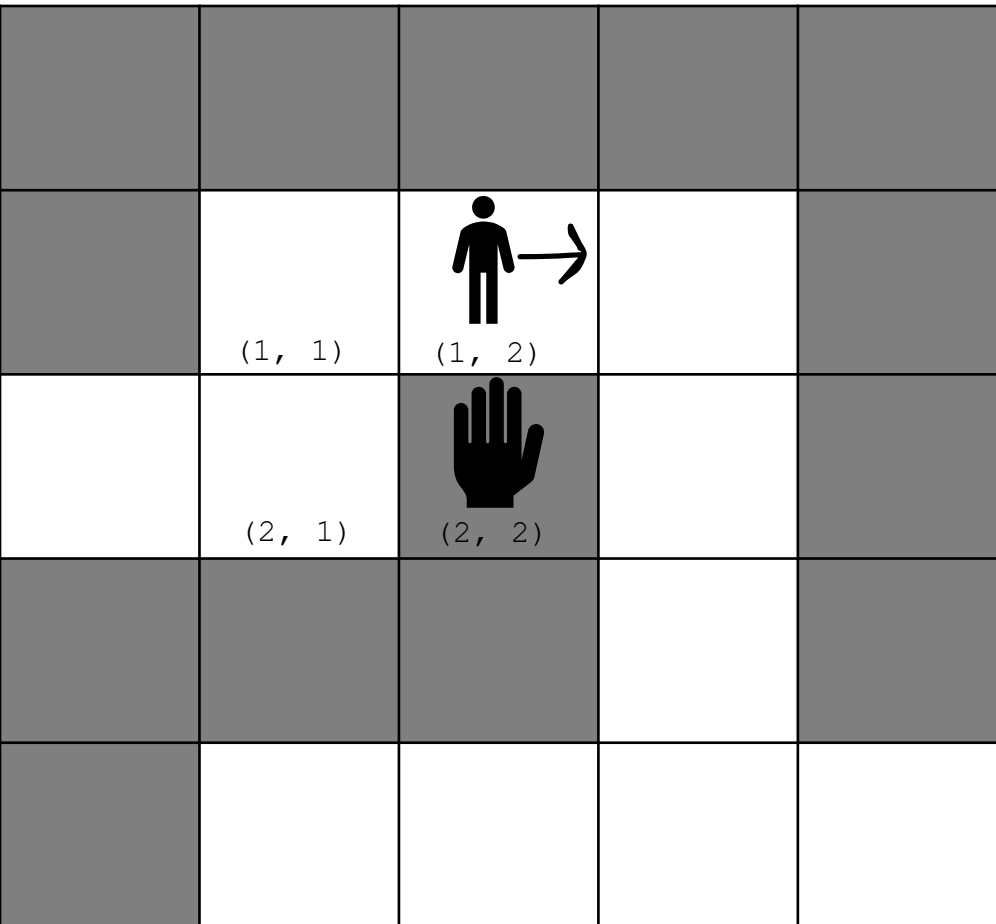


char[][] maze

```
[ [ #, #, #, #, #],  
  [ #, ., ., ., #],  
  [ ., ., #, ., #],  
  [ #, #, #, ., #],  
  [ #, ., ., ., .],  
  ]
```



maze[y][x]



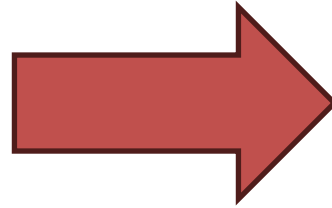
```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}  
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);  
    }  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x+1, y, hand_x, hand_y+1);  
    }  
}
```

makeMove(x, y, hand_x, hand_y)

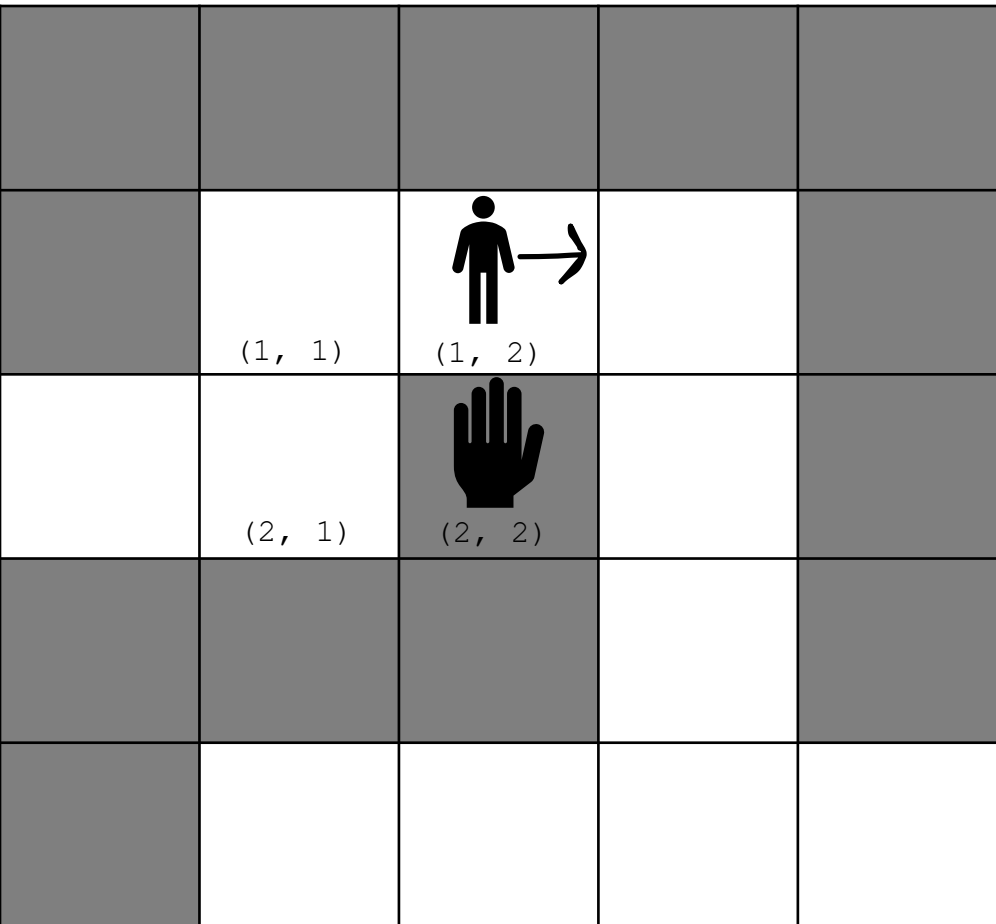
1. Turn right
2. Go forward
3. Turn left

char[][] maze

```
[ [ #, #, #, #, # ],  
  [ #, ., ., ., # ],  
  [ ., ., #, ., # ],  
  [ #, #, #, ., # ],  
  [ #, ., ., ., . ],  
  ]
```

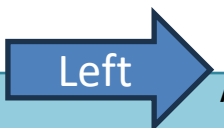


maze[y][x]



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}
```

```
...  
if(direction.equals("North")) {  
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x+1, y, hand_x, hand_y+1);  
    }  
}
```



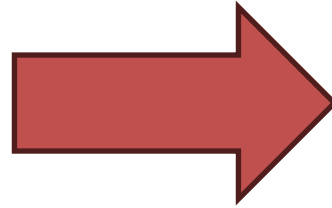
```
if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
    makeMove(x, y-1, hand_x, hand_y-1);  
}
```

// Turn left

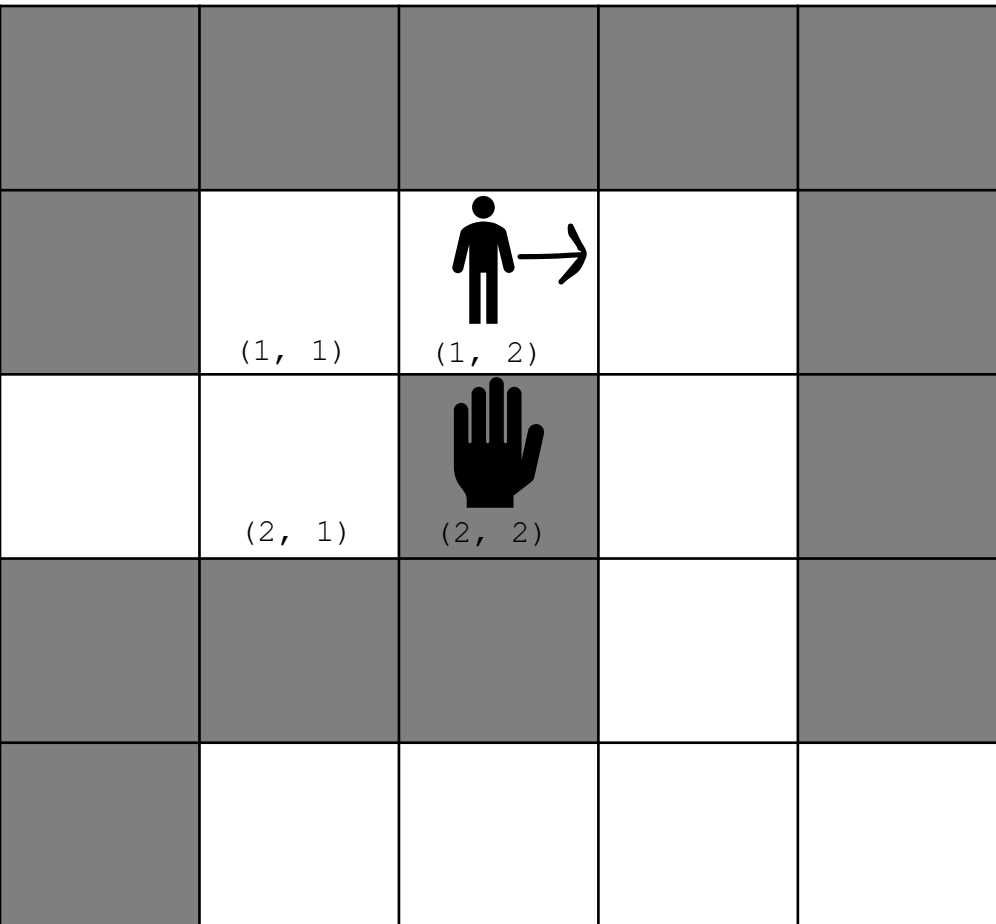
1. Turn right
2. Go forward
3. Turn left

char[][] maze

```
[ [ #, #, #, #, # ],  
  [ #, ., ., ., # ],  
  [ ., ., #, ., # ],  
  [ #, #, #, ., # ],  
  [ #, ., ., ., . ],  
  ]
```



maze[y][x]



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}
```

```
...  
if(direction.equals("North")) {
```

```
    if(maze[hand_y][hand_x] == '.' && maze[y-1][x] == '#'){  
        makeMove(x+1, y, hand_x, hand_y+1);  
    }
```

Right

```
    if(maze[hand_y][hand_x] == '#' && maze[y-1][x] == '.'){  
        makeMove(x, y-1, hand_x, hand_y-1);
```

You will have need if statements for North, East, South, and West

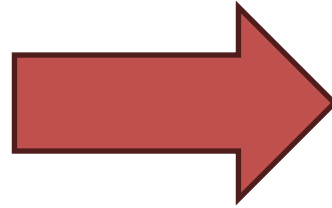
Left

// Turn left

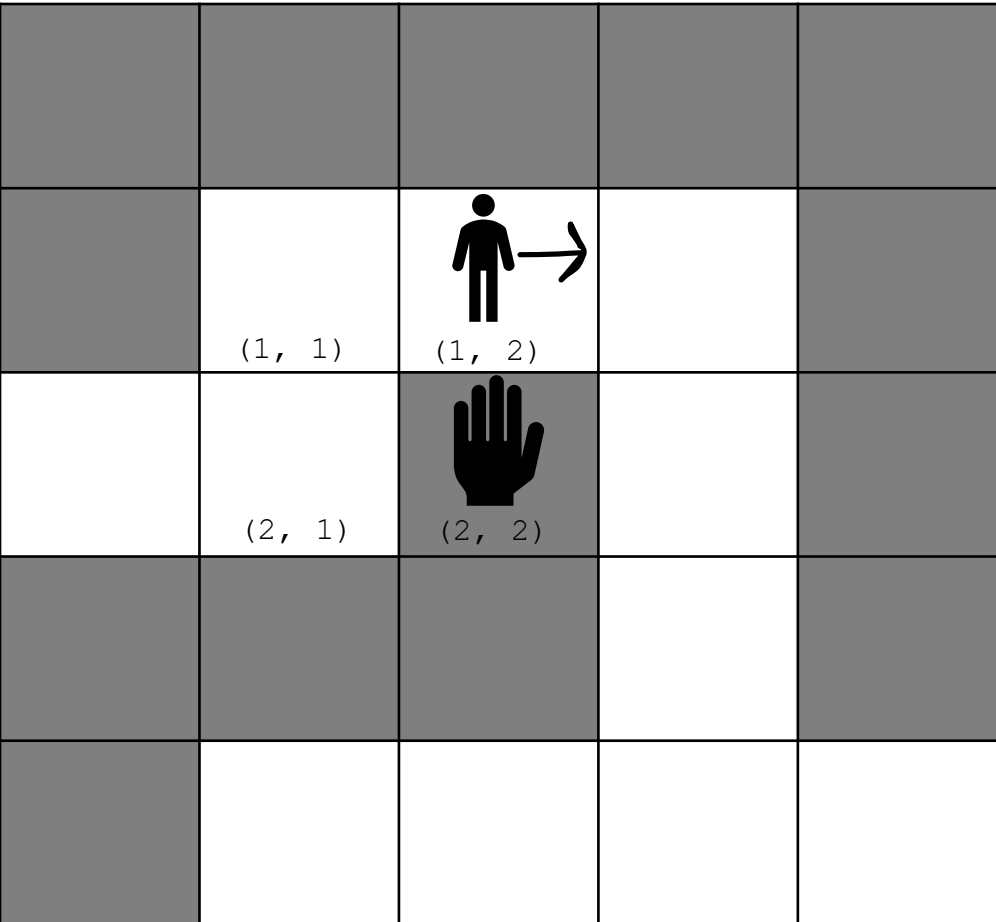
Lots of if statements ☺

char[][] maze

```
[ [ #, #, #, #, # ],  
  [ #, ., ., ., # ],  
  [ ., ., #, ., # ],  
  [ #, #, #, ., # ],  
  [ #, ., ., ., . ],  
  ]
```



maze[y][x]



```
if(y == hand_y && hand_x > x)  
    direction = "North";  
}
```

```
...  
if(direction.equals("North")) {
```

```
    if(maze[hand_y][x] == '#' && maze[y-1][x] == '#') {  
        makeMove(y-1, x);  
    }
```

```
    if(maze[hand_y][x] == '.' && maze[y+1][x] == '#') {  
        makeMove(y+1, x);  
    }
```

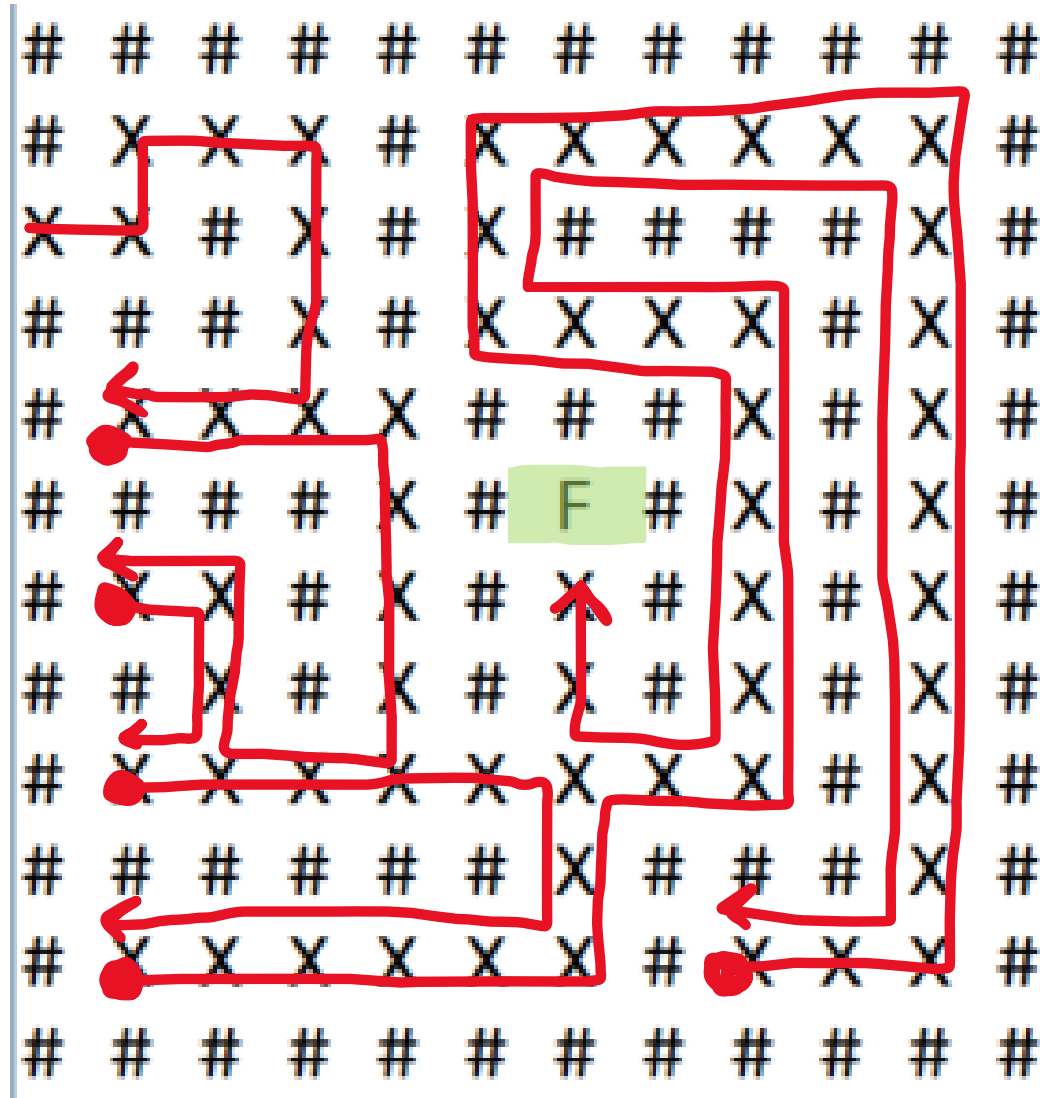
```
}
```

```
// Turn left
```

This code is technically not complete, you will need to add some more code here (backtracking)

You will have need if statements for North, East, South, and West

Lots of if statements ☺



● = Backtracking path



Searching

We store values in data structures, but we also need to retrieve/search for values!

Today, we will discuss techniques for how to search for a value in a data structure

(We will be using arrays, but these techniques could also be used on Linked Lists, queues, stacks, etc)



Searching

Option 1: Linear Search

Check every spot until one by one until we find what we are looking for

```
public int linear_search(int[] array, int s) {  
    for(int i = 0; i < array.length; i++) {  
        if(array[i] == s) {  
            return i;  
        }  
    }  
    return -1;  
}
```

Searching

Option 1: Linear Search

Check every spot until one by one until we find what we are looking for

Not efficient for large data structures. **$O(n)$** running time

```
public int linear_search(int[] array, int s) {  
    for(int i = 0; i < array.length; i++) {  
        if(array[i] == s) {  
            return i;  
        }  
    }  
    return -1;  
}
```


Searching

Option 1: Linear Search

Check every spot until we find it

Not efficient for large datasets

Can we do better?

```
public int  
for(int i = 0; i < arr.length; i++)
```

```
}
```

```
}
```

0												12
1	2	9	10	11	15	18	21	27	31	41	43	50

What if our array is sorted?

Target Value: 27

0												12
1	2	9	10	11	15	18	21	27	31	41	43	50

We can leverage the fact that this array is sorted to make searching more efficient

Target Value: 27

0						12						
1	2	9	10	11	15	18	21	27	31	41	43	50

- 1. Start at the middle of the array

Target Value: 27

0													12												
1	2	9	10	11	15	18	21	27	31	41	43	50													

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array
 - If the target value is less than the middle, discard the “right section” of the array

Target Value: 27

0												12
1	2	9	10	11	15	18	21	27	31	41	43	50
↑												↑
low												high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array
 - If the target value is less than the middle, discard the “right section” of the array

We will define two pointers, `low` and `high` that point to the possible bounds of the target value



Target Value: 27

0												12
1	2	9	10	11	15	18	21	27	31	41	43	50
↑												↑
low												high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
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 - If the target value is less than the middle, discard the “right section” of the array

We will define two pointers, `low` and `high` that point to the possible bounds of the target value

Target Value: 27



0												12
1	2	9	10	11	15	18	21	27	31	41	43	50
												
							low					high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)

Because we know the array is sorted, and the target value is greater than our mid point, then we know the target value must be located somewhere to the right.

We can eliminate half of the array!!!

Target Value: 27

0							7							12
1	2	9	10	11	15	18	21	27	31	41	43	50		
														
							low						high	

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

Target Value: 27

0							7					12
1	2	9	10	11	15	18	21	27	31	41	43	50
							↑					↑
							low					high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
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Target Value: 27

0							7					12
1	2	9	10	11	15	18	21	27	31	41	43	50
							↑					↑
							low					high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
							↑	↑				
							low	high				

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
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Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
							↑	↑				
							low	high				

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
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3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
							↑	↑				
							low	high				

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
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3. Recalculate the mid point, and repeat loop back to step 2 until target value is found



Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50

low high



1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
												
								low	high			

1. Start at the middle of the array
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 - If the value is the target value, return
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Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
												
								low	high			

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50

low high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

Target Value: 27

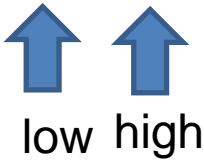

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50

low high

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

This algorithm is known as **Binary Search**

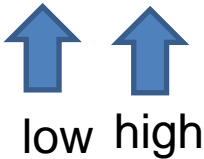
Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
												
												

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

How to calculate the mid point?

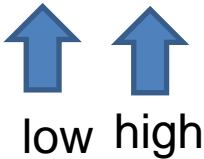
Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
												

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

How to calculate the mid point? $(low + high) / 2$

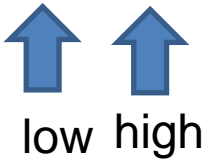
Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
												

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

How do we know when to stop looping?

Target Value: 27

0							7	8				12
1	2	9	10	11	15	18	21	27	31	41	43	50
												

1. Start at the middle of the array
2. Compare to target value:
 - If the value is the target value, return
 - If the target value is greater than the middle, discard the “left section” of the array (move the low pointer)
 - If the target value is less than the middle, discard the “right section” of the array (move the high pointer)
3. Recalculate the mid point, and repeat loop back to step 2 until target value is found

How do we know when to stop looping? If we find the target value, or if `low` and `high` cross each other (`low > high`)

Target Value: 27

0		7	8		12
1				43	50

LET'S CODE THIS

1. S

2. C

→ If

→ If

section

→ If

section

3. Rec

target value is found

How do we know when to stop looping? If we find the target value, or if `low` and `high` cross each other (`low > high`)


```
private static int binary_search(int[] array, int n) {  
    int low = 0;  
    int high = array.length - 1;  
    while(low <= high) {  
        int mid = (low + high) / 2;  
        if(n == array[mid]) {  
            return mid;  
        }  
        else if(n > array[mid]) {  
            low = mid + 1;  
        }  
        else {  
            high = mid - 1;  
        }  
    }  
    return -1;  
}
```

```
private static int binary_search(int[] array, int n) {  
    int low = 0;  
    int high = array.length - 1;  
    while(low <= high) {  
        int mid = (low + high) / 2;  
        if(n == array[mid]) {  
            return mid;  
        }  
        else if(n > array[mid]) {  
            low = mid + 1;  
        }  
        else {  
            high = mid - 1;  
        }  
    }  
    return -1;  
}
```

Running time?

```
private static int binary_search(int[] array, int n) {  
    int low = 0;  
    int high = array.length - 1;  
    while(low <= high) {  
        int mid = (low + high) / 2;  
        if(n == array[mid]) {  
            return mid;  
        }  
        else if(n > array[mid]) {  
            low = mid + 1;  
        }  
        else {  
            high = mid - 1;  
        }  
    }  
    return -1;  
}
```

Running time? Each time we loop, we eliminate **half** the array

Running time?

Initial length of array = n

Iteration 1 - Length of array = $n/2$

Running time?

Initial length of array = n

Iteration 1 - Length of array = $n/2$

Iteration 2 - Length of array = $(n/2)/2 = n/2^2$

Running time?

Initial length of array = n

Iteration 1 - Length of array = $n/2$

Iteration 2 - Length of array = $(n/2)/2 = n/2^2$

Iteration k - Length of array = $n/2^k$

Running time?

Initial length of array = n

Iteration 1 - Length of array = $n/2$

Iteration 2 - Length of array = $(n/2)/2 = n/2^2$

Iteration k - Length of array = $n/2^k$

After k iterations, eventually our array has been reduced to one element

Length of array = $n/2^k = 1$

$$n = 2^k$$

“Two to what power makes n ??”

Running time?

After k iterations, eventually our array has been reduced to one element

$$\text{Length of array} = n/2^k = 1$$

$$n = 2^k$$

“Two to what power makes n ??”

$$\log_2(n) = \log_2(2^k)$$

Running time?

After k iterations, eventually our array has been reduced to one element

$$\text{Length of array} = n/2^k = 1$$

$$n = 2^k$$

“Two to what power makes n ??”

$$\log_2(n) = \log_2(2^k)$$

$$\log_2(n) = k * \log_2 2 :$$

Running time?

After k iterations, eventually our array has been reduced to one element

$$\text{Length of array} = n/2^k = 1$$

$$n = 2^k$$

“Two to what power makes n??”

$$\log_2(n) = \log_2(2^k)$$

$$\log_2(n) = k * \cancel{\log_2 2}$$

$$\log_2(n) = k$$

After K iterations, we will have done log(n) divisions

```
private static int binary_search(int[] array, int n) {
    int low = 0;
    int high = array.length - 1;
    while(low <= high) {
        int mid = (low + high) / 2;
        if(n == array[mid]) {
            return mid;
        }
        else if(n > array[mid]) {
            low = mid + 1;
        }
        else {
            high = mid - 1;
        }
    }
    return -1;
}
```

Running time?

Generally speaking, whenever we eliminate half of the problem each iteration, that will give us **$O(\log n)$** running time

```

private static int binary_search(int[] array, int n) {
    int low = 0; O(1)
    int high = array.length - 1; O(1)
    while(low <= high) { O(log n)
        int mid = (low + high) / 2; O(1)
        if(n == array[mid]) { O(1)
            return mid; O(1)
        }
        else if(n > array[mid]) { O(1)
            low = mid + 1; O(1)
        }
        else {
            high = mid - 1; O(1)
        }
    }
    return -1; O(1)
}

```

Running time?

Generally speaking, whenever we eliminate half of the problem each iteration, that will give us **O(logn)** running time

```
private static int binary_search(int[] array, int n) {  
    int low = 0; O(1)  
    int high = array.length - 1; O(1)  
    while(low <= high) { O(log n)  
        int mid = (low + high) / 2; O(1)  
        if(n == array[mid]) { O(1)  
            return mid; O(1)  
        }  
        else if(n > array[mid]) { O(1)  
            low = mid + 1; O(1)  
        }  
        else {  
            high = mid - 1; O(1)  
        }  
    }  
    return -1; O(1)  
}
```

Running time? $O(\log n)$

```

private static int binary_search(int[] array, int n) {
    int low = 0;
    int high = array.length - 1;
    while(low <= high) {
        int mid = (low + high) / 2;

        int result = x.compareTo(array[mid])

        if(result == 0) {
            return mid;
        }
        else if(result > 0){
            low = mid + 1;
        }
        else {
            high = mid - 1;
        }
    }
    return -1;
}

```

We can do binary search on an array of Strings using the `compareTo()` method

```

private static int binary_search(???????????) {

    if(low <= high) {
        int mid = (low + high) / 2;
        if(n == array[mid]) {
            return mid;
        }
        else if(n > array[mid]) {
            return binary_search(??????????);
        }
        else {
            return binary_search(??????????);
        }
    }
    else {
        return -1;
    }
}

```

Binary Search can also be implemented using recursion