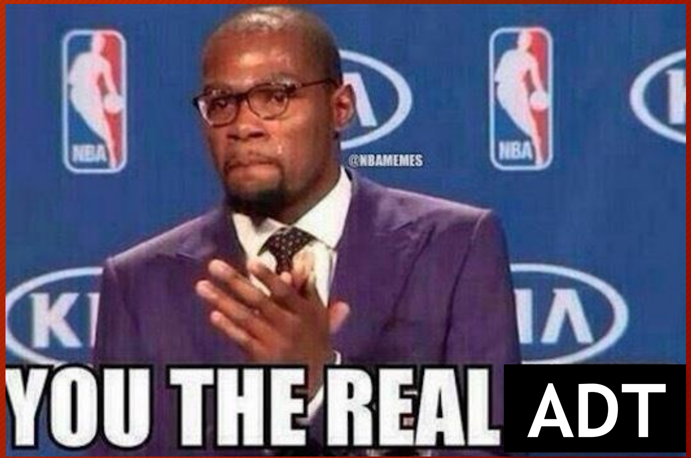
YEAH A2

Fun with Collections!



Agenda

- Logistics
- Part 1: Maze
- Part 2: Index

Logistics

- Due: Friday, October 2nd (11:59PM PDT)
- Grace period: Sunday October 4th (11:59PM PDT)
- Must be completed individually!

Questions about logistics?

Agenda

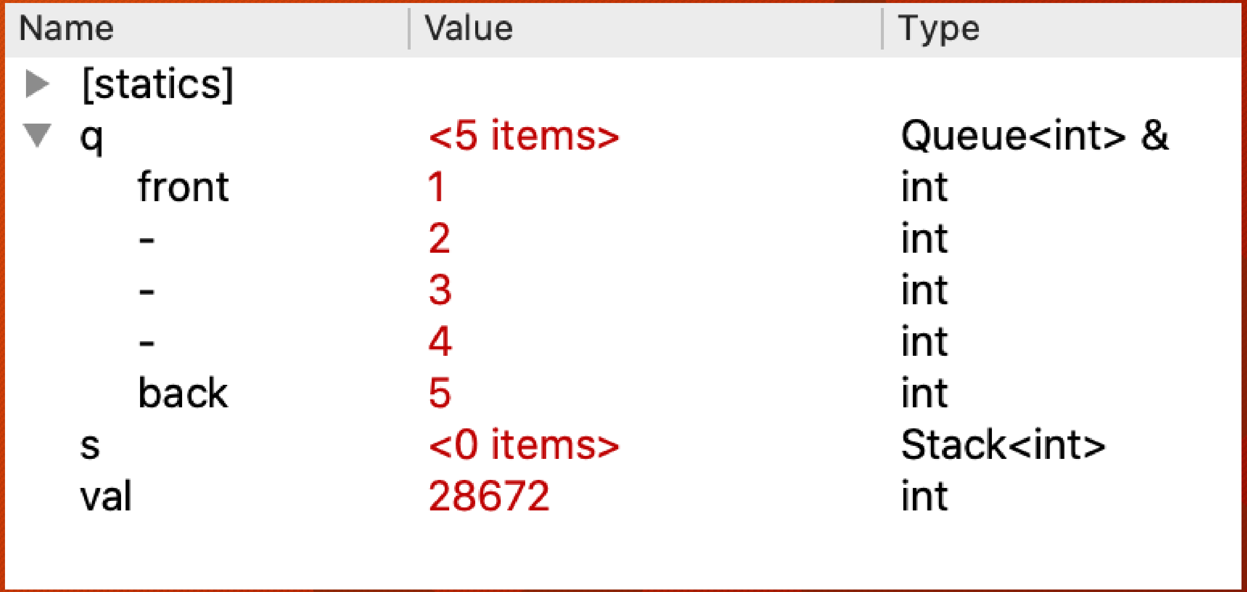
- ~~Logistics~~
- Part 1: Maze
- Part 2: Index

Warmups

- The warmups were designed to be fairly straightforward problems that equip you with the tools needed to complete the rest of the assignment!
- Please do the warmups **before** you attempt the assignment.
  - I promise they'll make your life easier ☺
- Your only deliverables for this part will be in **shortanswer.txt.**

Warmup 0: Patch the Debugger!

- This first part is simply a test to verify that you're able to visualize ADT's in the debugger!
- You should be able to run the warmup program in the debugger and see a view in the top right like this when looking at ADT's. If not, check out the website for details on how to patch this!
- Thanks to SL Jeremy Barenholtz for the fix!



Name	Value	Type
▶ [statics]		
▼ q	<5 items>	Queue<int> &
front	1	int
-	2	int
-	3	int
-	4	int
back	5	int
s	<0 items>	Stack<int>
val	28672	int

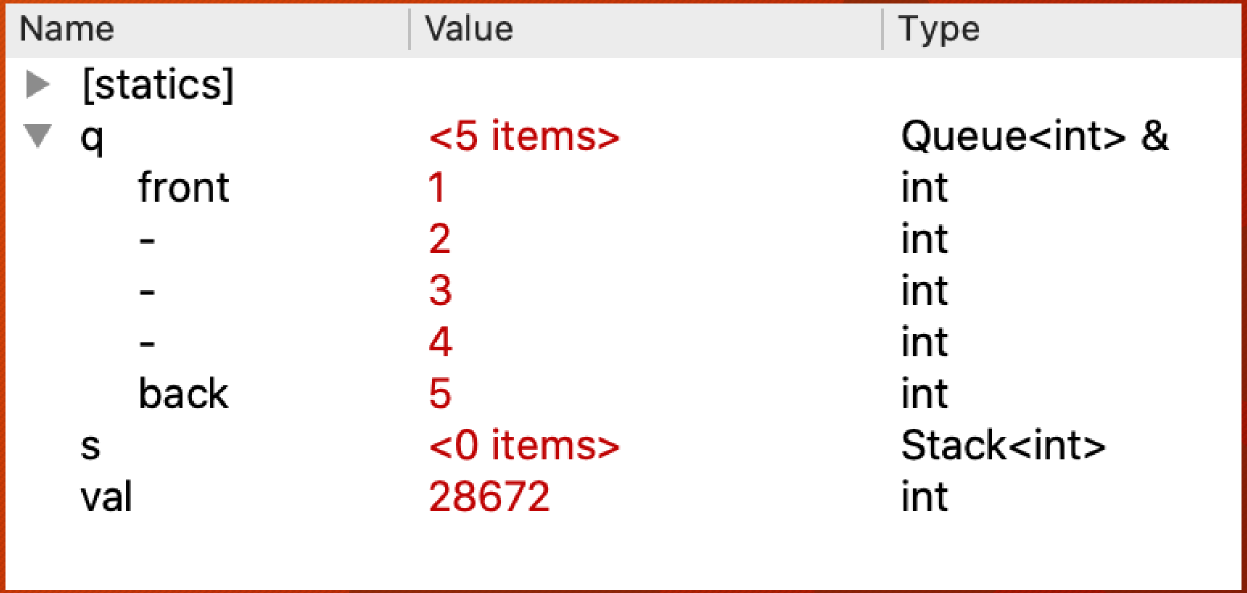
Warmup 1: Observing ADT's in the Debugger

- For the first part, you'll examine the following function:
- This function is already implemented for you, and you'll be using the **debugger** to step through it!
- To view the internals, put a **breakpoint** on the first line of the function and **run** the program in the debugger!

```
void reverse(Queue<int>& q) {
    Stack<int> s;
    while (!q.isEmpty()) {
        int val = q.dequeue();
        s.push(val);
    }
    while (!s.isEmpty()) {
        int val = s.pop();
        q.enqueue(val);
    }
}
```

Warmup 1: Observing ADT's in the Debugger

- In the top right corner of QT, you'll see the names of the variables in your function! You can expand them via the arrows on the left!
- As you can see, you can peek into the queue at runtime! As you step thru the debugger, you can watch these values change in real time!



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s	<0 items>	Stack<int>
val	28672	int

Warmup 2: Debugging an ADT question

- For this next part, you're going to use your new debugging skills to debug this function:
- Step through the function for a few iterations and determine where things go wrong!

```
void duplicateNegatives(Queue<int>& q) {
    for (int i = 0; i < q.size(); i++) {
        int cur = q.dequeue();
        q.enqueue(cur);
        if (cur < 0) {
            q.enqueue(cur);    // double up on negative numbers
        }
    }
}
```

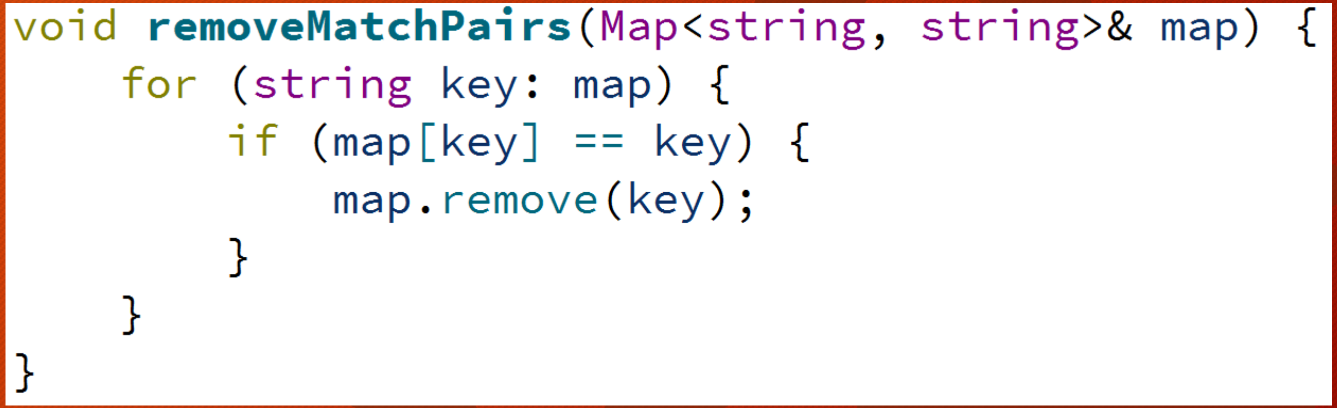
Warmup 3: Debugging an Error

- For the final warmup, you’ll be debugging the following function:
  - This function **raises an error**, meaning during runtime, it encounters a problem and terminates!
- The problem is, you’re not allowed to modify a data structure while you loop thru it with a **for each loop**.

```
void removeMatchPairs(Map<string, string>& map) {
    for (string key: map) {
        if (map[key] == key) {
            map.remove(key);
        }
    }
}
```

Warmup 3: Debugging an Error

- You’ll need to step thru this function in the debugger to determine **exactly where** it throws the error!
- Pro tip: remember this error for later – if you’re looping thru some data, **don’t modify it.** If the code doesn’t crash, it’ll usually give you strange and incorrect behavior.

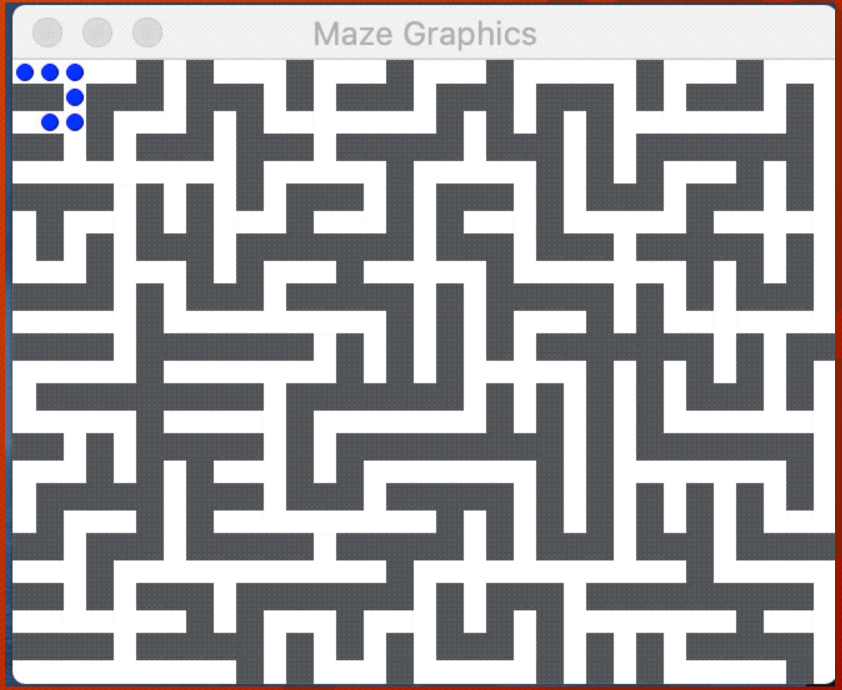


```
void removeMatchPairs(Map<string, string>& map) {
    for (string key: map) {
        if (map[key] == key) {
            map.remove(key);
        }
    }
}
```

Questions about the warmups?

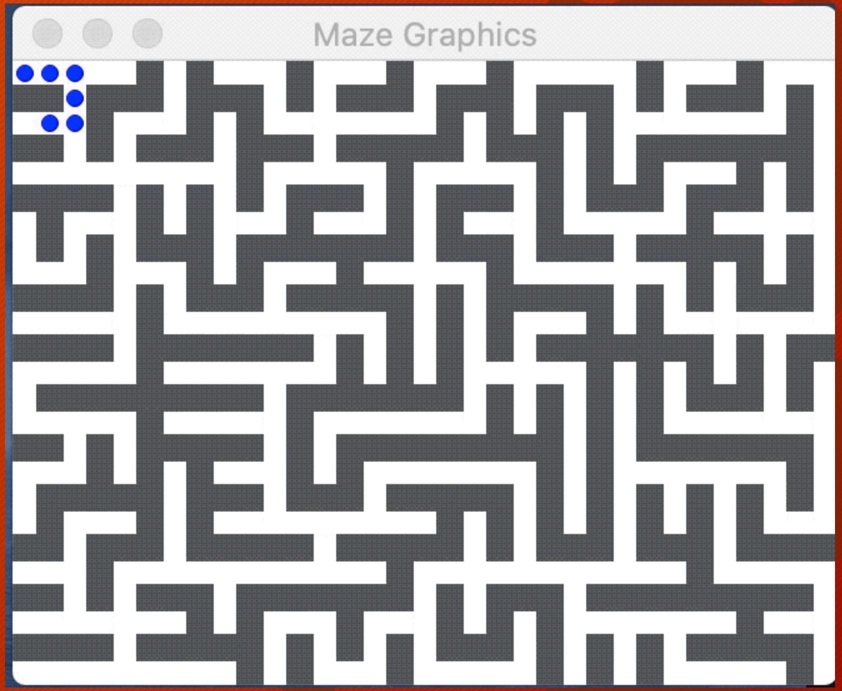
Part I: Maze

- Welcome to the first coding part of the assignment!
- You’ll be working with a **mazes** like the one to your right – these mazes will start in the top left and have exits in the bottom right.



Part I: Maze

- Let's talk a little more about these mazes:
  - The maze itself is actually represented as a Grid<bool> in your program, where a cell marked **true** is an open corridor and a cell marked **false** is a wall.
  - mazeGrid[row][col] returns a Boolean that indicates whether {row, col} are the coordinates of a wall or a corridor!

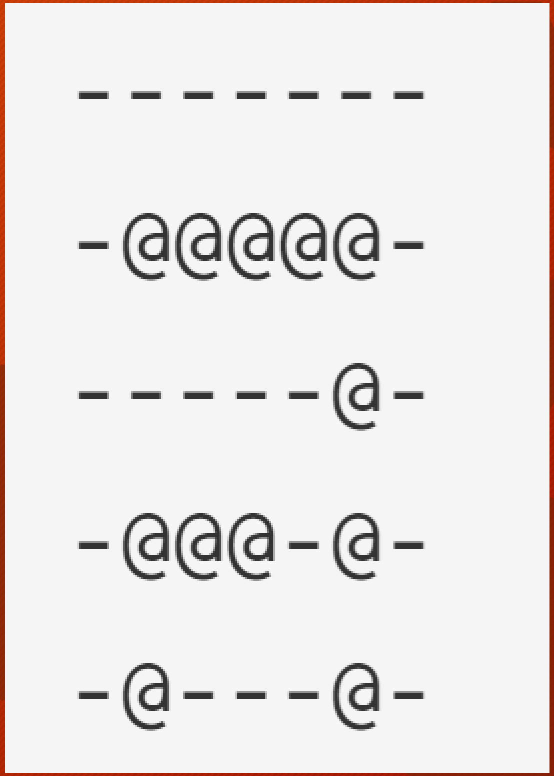


Part I: Maze

- Where do these Grid<bool> come from?
  - Great question, rhetorical viewer. Mazes are provided to you in the starter code as **text files.**
  - We've provided you the function

```
void readMazeFile(string filename, Grid<bool>& maze) {
```

that reads in a text file like the one on the right and converts it into a Grid<bool>. We use '@' to represent walls and '-' to represent corridors.



```
-------
-@@@@@-
-----@-
-@@@-@-
-@---@-
```

Part I: Maze GridLocations

- There’s a new abstraction you’ll need to become comfortable with using!
- A GridLocation represents a **pair of coordinates.** You can think of it like

  { row, col }

```
// You can create a GridLocation by separately setting its row and col fields
GridLocation chosen;
chosen.row = 3;       // separate assignment to row
chosen.col = 4;       // then col

// Or you can create a GridLocation by setting its row and col during initialization
GridLocation exit = { maze.numRows()-1, maze.numCols()-1 }; // last row, last col

// You can use GridLocations to index into a Grid (maze is a Grid)
if (maze[chosen]) // equivalent to maze[3][4]
...

// You can directly compare two GridLocations
if (chosen == exit)
...

// You can also access and use a GridLocation's row,col separately
if (chosen.row == 0 && chosen.col == 0)
...
```

Questions about the Grid<bool> or GridLocations?

```
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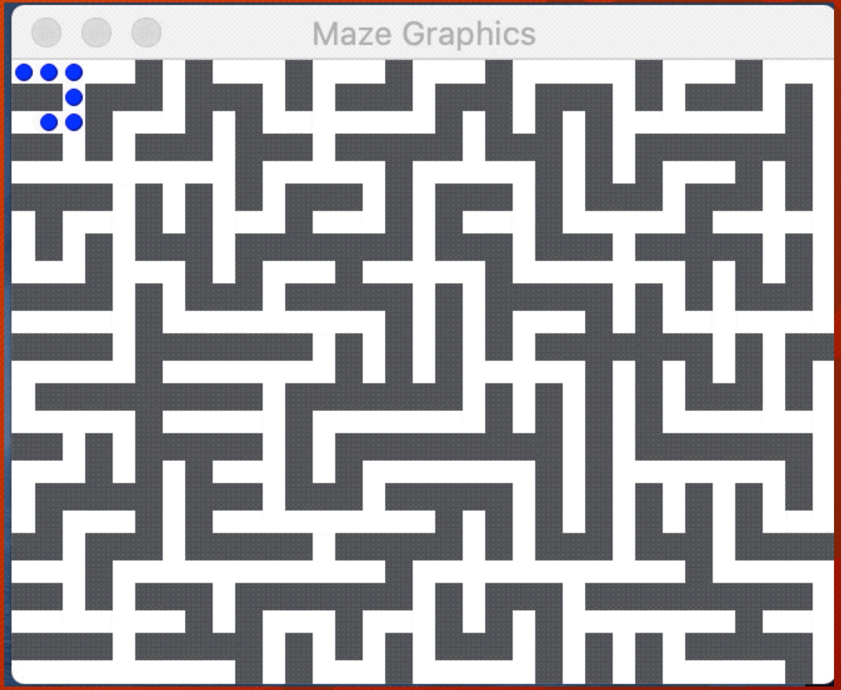
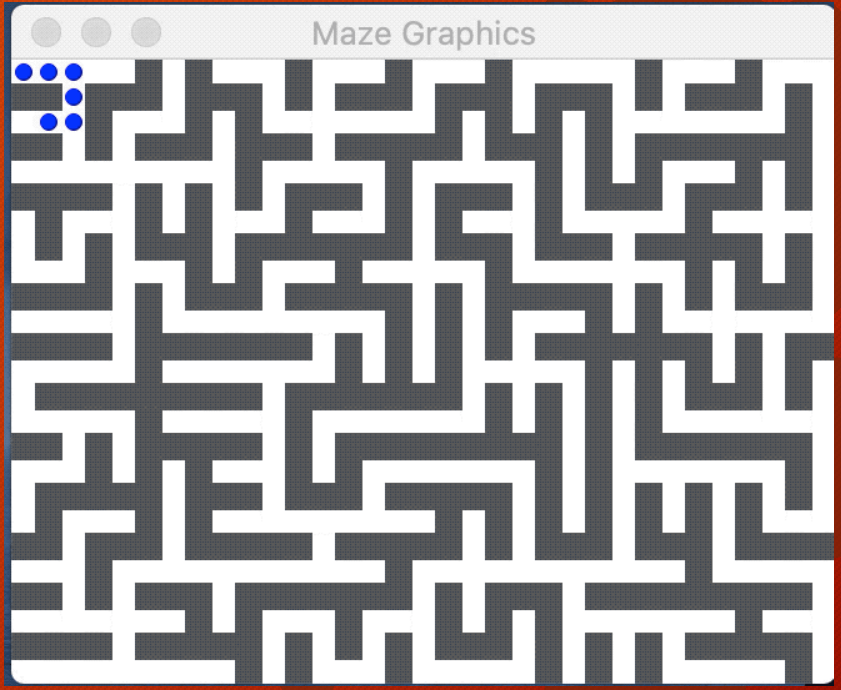
Part I: Maze

- How can we store a **path** in our maze?



Part I: Maze

- How can we store a **path** in our maze?
- We can use a Stack<GridLocation>
    - In this case, the **top** of the stack would represent the **last visited location** (the exit in a complete path!)
    - The bottom would be the **start** of the path, (typically the top left corner).



Part I: Maze

- For some of the mazes we provide for you, we **also** give you the maze **solutions** stored in a text file!
- Take a second to verify that the locations below represent a valid path out of the maze!
    - The path reads left(start) to right(end)

```
-------

-@@@@@-

-----@-

-@@@-@-

-@---@-
```

```
{r0c0, r0c1, r0c2, r0c3, r0c4, r0c5, r0c6, r1c6, r2c6, r3c6, r4c6}
```

Part I: Maze

- We've **also** written a function for you that turns a solution .txt file into a Stack<GridLocation> called

```
void readSolutionFile(string filename, Stack<GridLocation>& soln) {
```

```
-------
-@@@@@-
-----@-
-@@@-@-
-@---@-
```

```
{r0c0, r0c1, r0c2, r0c3, r0c4, r0c5, r0c6, r1c6, r2c6, r3c6, r4c6}
```

Questions about mazes, text files or data structures?

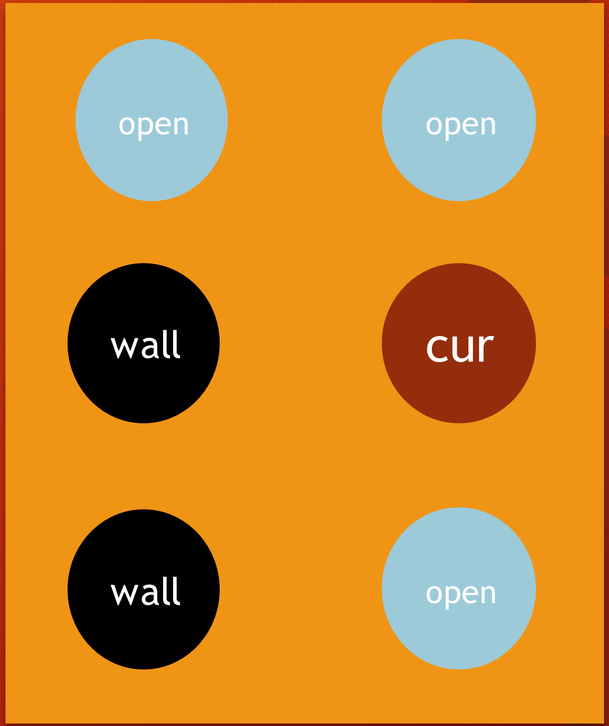
```
-------
-@@@@@-
-----@-
-@@@-@-
-@---@-
```

```
{r0c0, r0c1, r0c2, r0c3, r0c4, r0c5, r0c6, r1c6, r2c6, r3c6, r4c6}
```

Part I: Maze generateValidMoves()

- To begin, you're going to implement the following function:
- This function takes in a maze as well as a current location in that maze.
- You are tasked with returning a set of **valid neighbors**
  - These are locations one step away in the (NSEW) directions that are non-walls and in bounds!

```
Set<GridLocation> generateValidMoves(Grid<bool>& maze, GridLocation cur)
```



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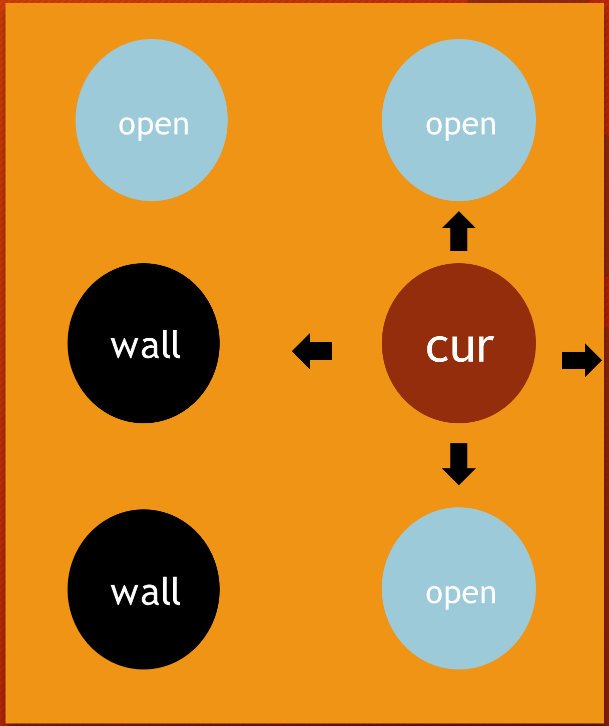

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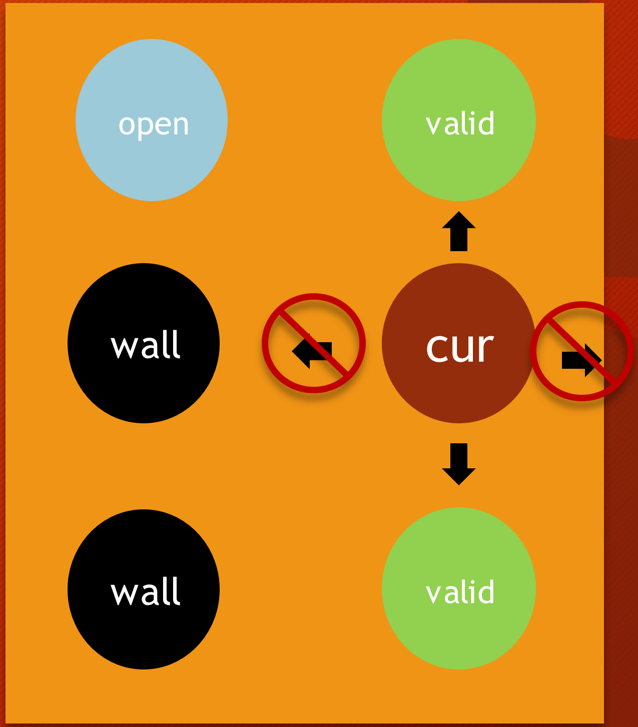
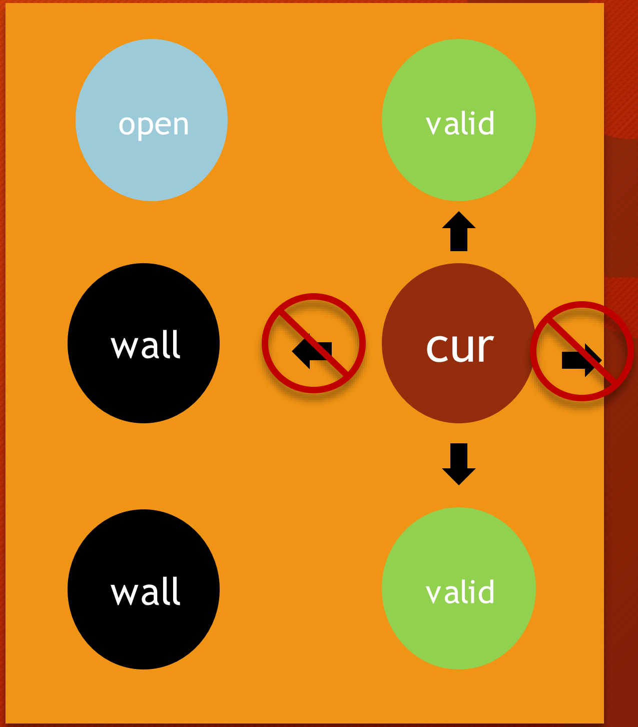


Part I: Maze generateValidMoves()

- In this case, you'd return a Set<GridLocation> that contained 2 things: the coordinates of the above location and the coordinates of the below location.

```
Set<GridLocation> generateValidMoves(Grid<bool>& maze, GridLocation cur)
```



Part I: Maze generateValidMoves()

- Tips about generateValidMoves();
  - You can use the Grid's inbounds() function to tell whether a coordinate pair is within the bounds of a grid.
  - Be sure to add good tests for this part – we specifically leave edge cases out of the tests we provide you.
  - **You need to generalize your routine for validating a neighbor.** It is **poor** style to repeat the process of validation 4 times – once for each valid direction.
    - Think about how you might use a loop to fix this!

```
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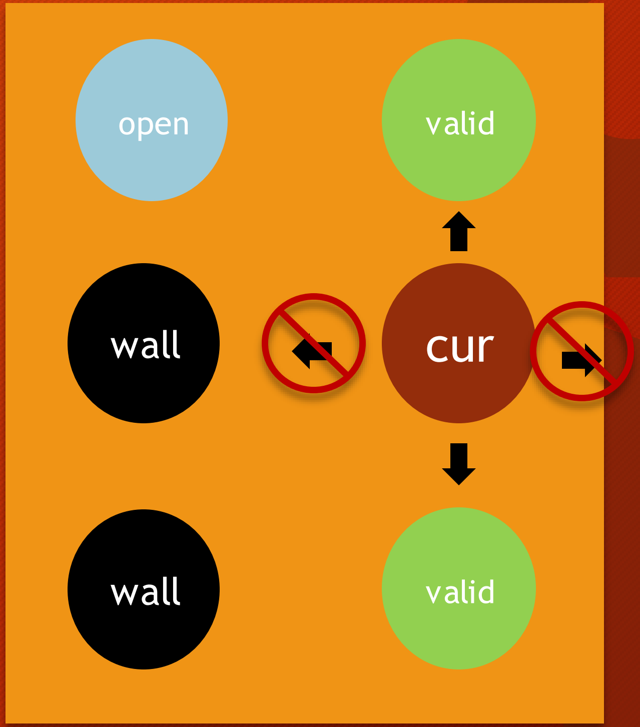
```



Questions about generateValidMoves()?

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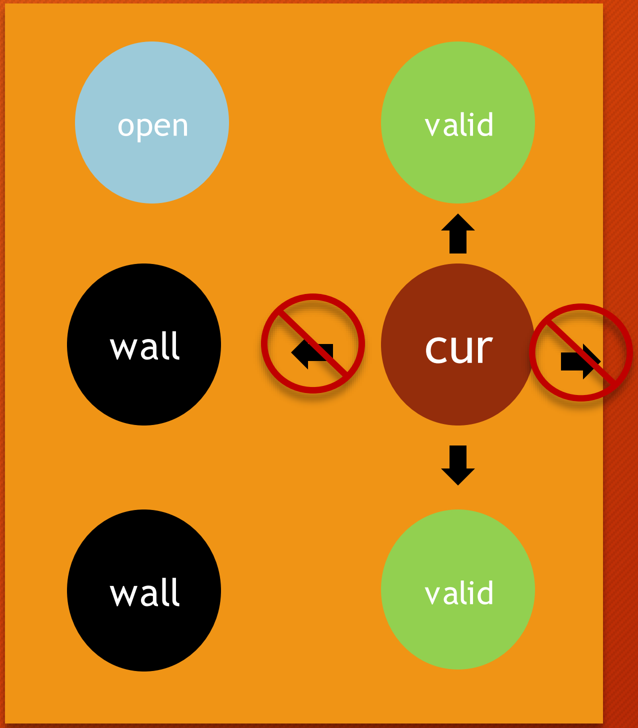


Part I: Maze checkSolution()

- Let’s say now that you generated a Grid<bool> and a Stack<GridLocation> representing a maze and a solution, respectively, and you wanted to verify that it actually **was** the solution to a maze.

```
-------

-@@@@@-

-----@-

-@@@-@-

-@---@-
```

```
{r0c0, r0c1, r0c2, r0c3, r0c4, r0c5, r0c6, r1c6, r2c6, r3c6, r4c6}
```

- How would you do it?

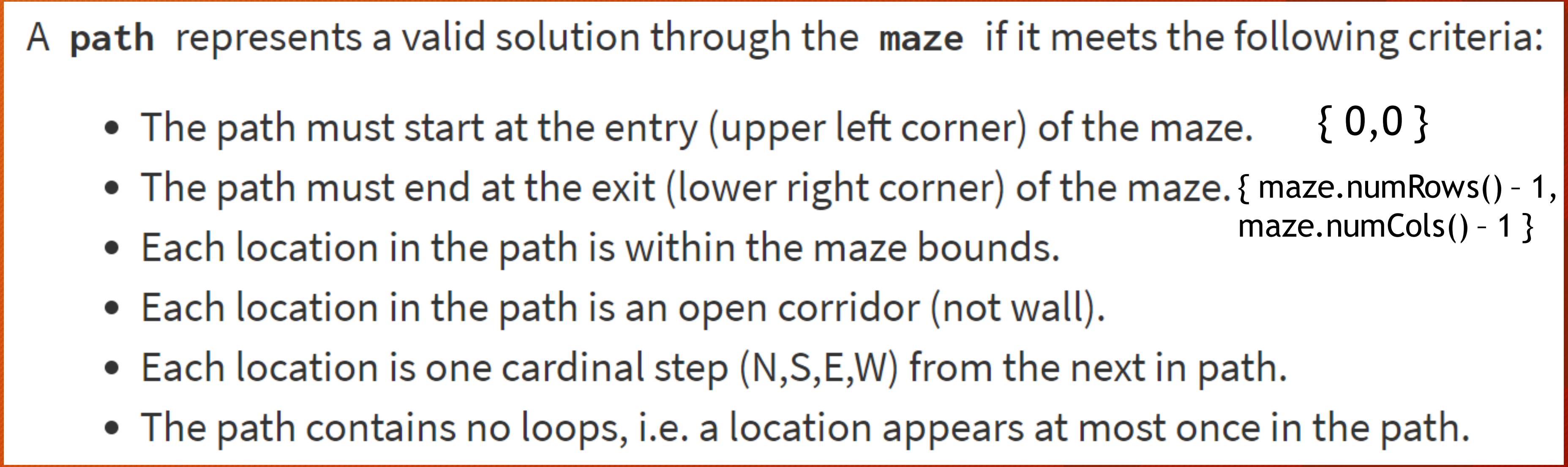
Part I: Maze checkSolution()

- Let’s say now that you generated a Grid<bool> and a Stack<GridLocation> representing a maze and a solution, respectively, and you wanted to verify that it actually **was** the solution to a maze.

- How would you do it?

Part I: Maze checkSolution()

- Here's the criteria for a valid solution:



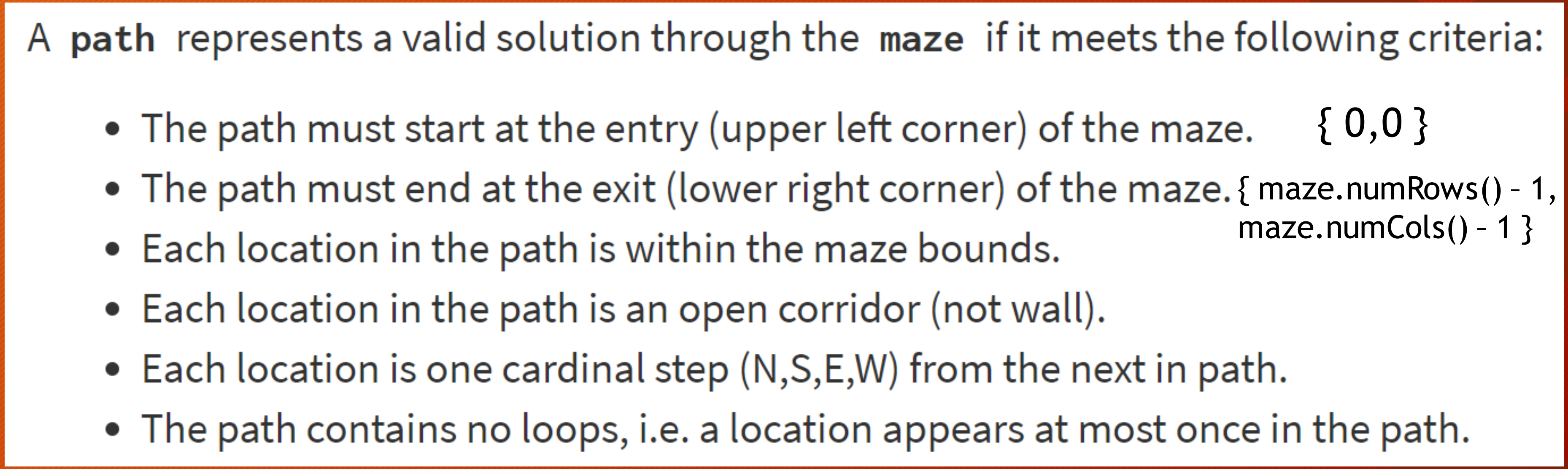
A **path** represents a valid solution through the **maze** if it meets the following criteria:

- The path must start at the entry (upper left corner) of the maze. { 0,0 }
- The path must end at the exit (lower right corner) of the maze. { maze.numRows() – 1, maze.numCols() – 1 }
- Each location in the path is within the maze bounds.
- Each location in the path is an open corridor (not wall).
- Each location is one cardinal step (N,S,E,W) from the next in path.
- The path contains no loops, i.e. a location appears at most once in the path.

Part I: Maze checkSolution()

If you identify that any of these things is **incorrect**, you can raise an error like this:

```
error("Here is my message about what has gone wrong");
```



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Part I: Maze checkSolution()

- You'll be implementing the following function:

```
void checkSolution(Grid<bool>& maze, Stack<GridLocation> path)
```

that verifies that PATH is contains the correct sequence of locations that navigate through MAZE without doing anything fishy.

- The function raises an ERROR if PATH is invalid, and it does nothing if the path is valid.
- You can test this functionality with the EXPECT_ERROR() and EXPECT_NO_ERROR() functions in the simple test framework!

Part I: Maze checkSolution()

```
void checkSolution(Grid<bool>& maze, Stack<GridLocation> path)
```

- A few more points about checkSolution:
  - One of the things you're going to have to do is examine the elements in PATH - but you can't use a for loop or a for-each loop to examine the internals of a Stack: what can you do instead?
  - Be sure that you test A LOT for this function – because there are so many cases, there's a lot of functionality and edge cases that you're responsible for here!
  - To verify that each location is a caridnal step away from the next, think about how you can reuse your generateValidMoves() function to help.
  - If you need to keep track of "visited" items, Sets are great!

Questions about checkSolution()?

"Hey can I copy your homework?"

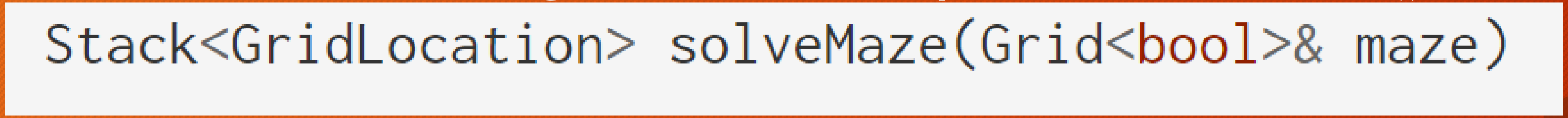
"Yeah just make sure to change it a little"

"Alright"

If you can't checkSolution(), you might run into this problem! (please abide by the honor code!)

Part I: Maze solveMaze()

- Now it’s time for the big code in this part: solveMaze()!



```
Stack<GridLocation> solveMaze(Grid<bool>& maze)
```

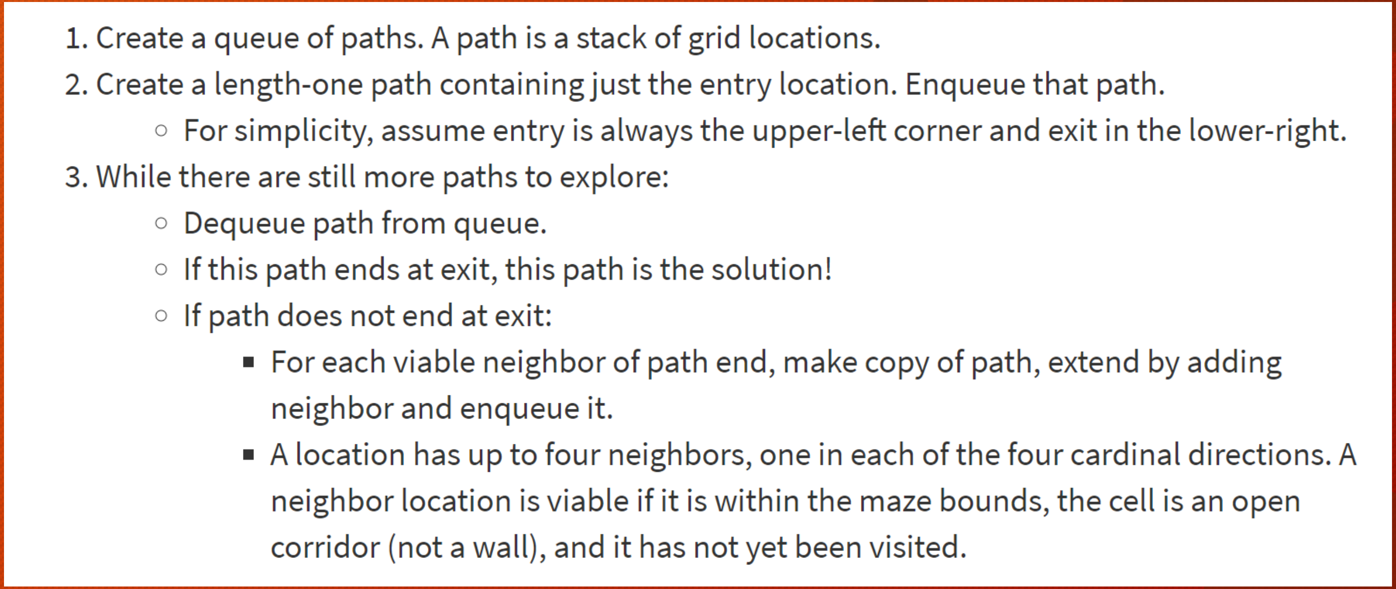
- Up to this point, you’ve been validating pre-generated maze solutions from text files. It’s now time to generate your own solutions to a given maze!

- Given a Grid<bool> MAZE, it’s your job to return a Stack<GridLocation> that contains the valid steps to escape it!

Part I: Maze solveMaze()

```
Stack<GridLocation> solveMaze(Grid<bool>& maze)
```

- To programmatically generate a solution to a given maze, you'll need to use a Breadth-First Search (BFS) algorithm.
- This is the first complex algorithm you'll need to write up in this class! Luckily, it's not too bad, and we'll go over it together.
  - Here's the algorithm:



1. Create a queue of paths. A path is a stack of grid locations.
2. Create a length-one path containing just the entry location. Enqueue that path.
   - For simplicity, assume entry is always the upper-left corner and exit in the lower-right.
3. While there are still more paths to explore:
   - Dequeue path from queue.
   - If this path ends at exit, this path is the solution!
   - If path does not end at exit:
     - For each viable neighbor of path end, make copy of path, extend by adding neighbor and enqueue it.
     - A location has up to four neighbors, one in each of the four cardinal directions. A neighbor location is viable if it is within the maze bounds, the cell is an open corridor (not a wall), and it has not yet been visited.

Part I: Maze solveMaze()

- Let’s walk thru a very small example:

Part I: Maze solveMaze()

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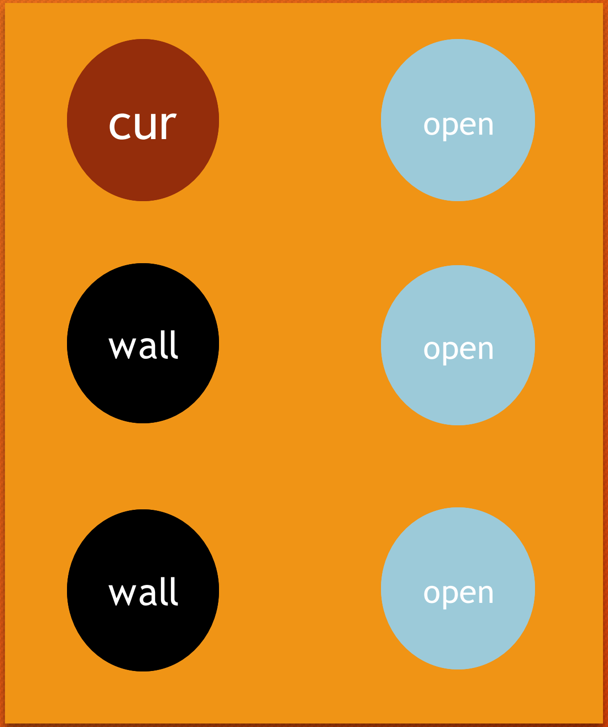

MAZE

Part I: Maze solveMaze()

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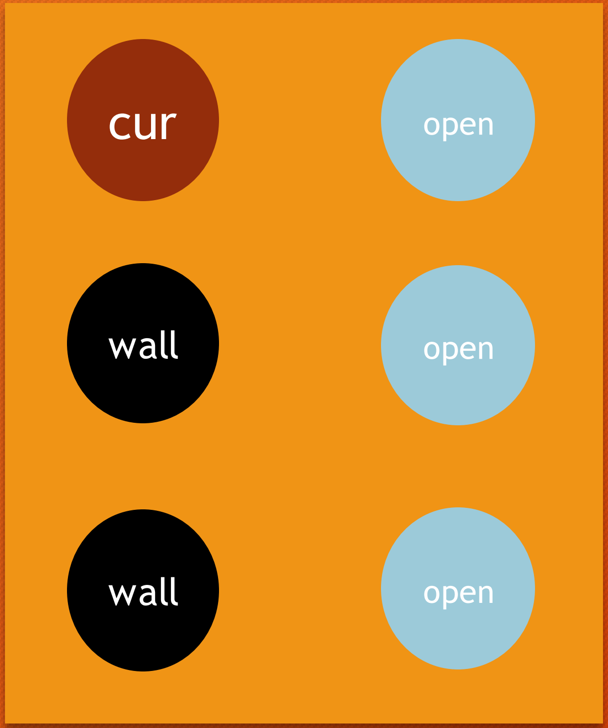

MAZE

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Part I: Maze solveMaze()

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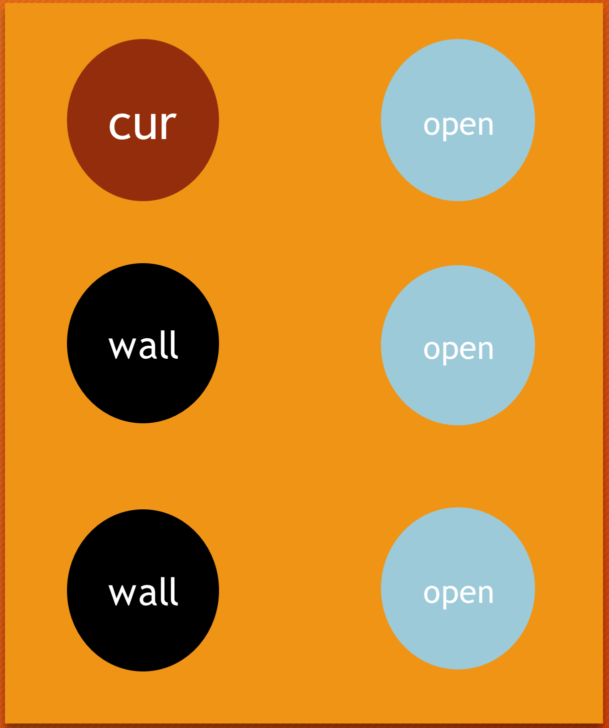
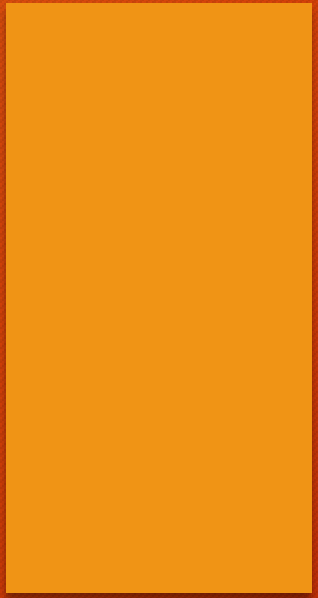


MAZE



PATHS

Part I: Maze solveMaze()

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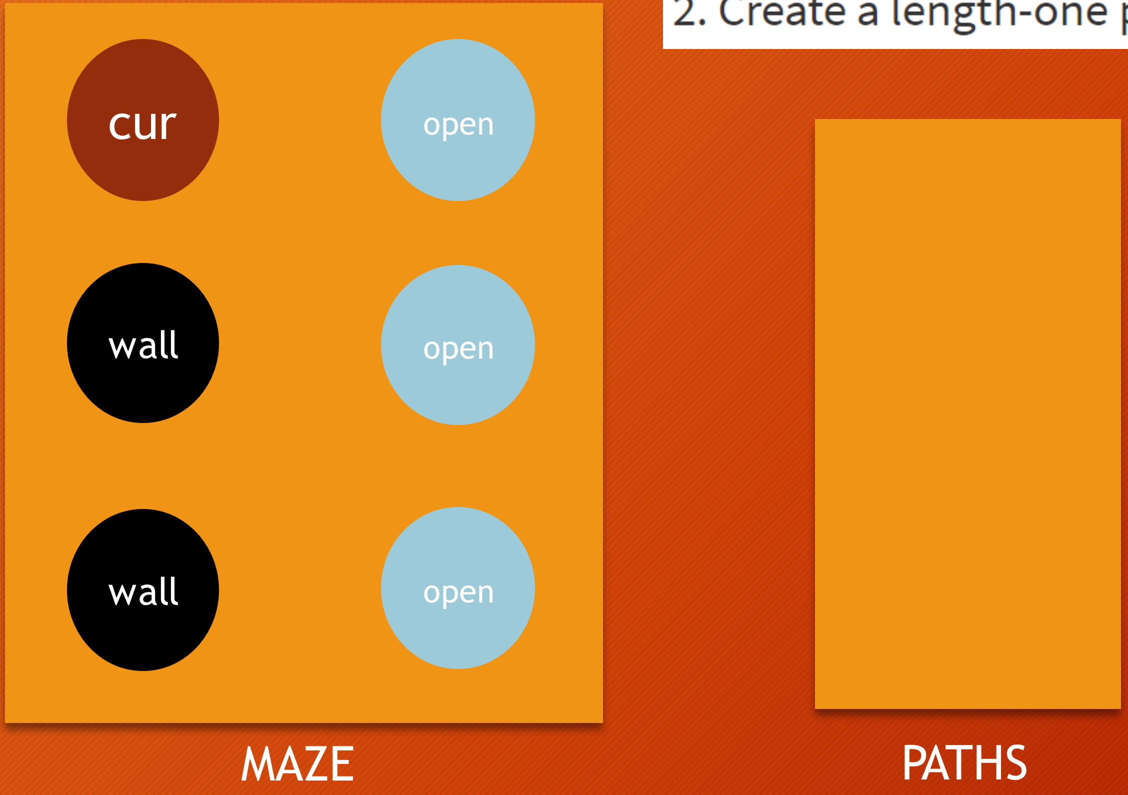

Part I: Maze solveMaze()

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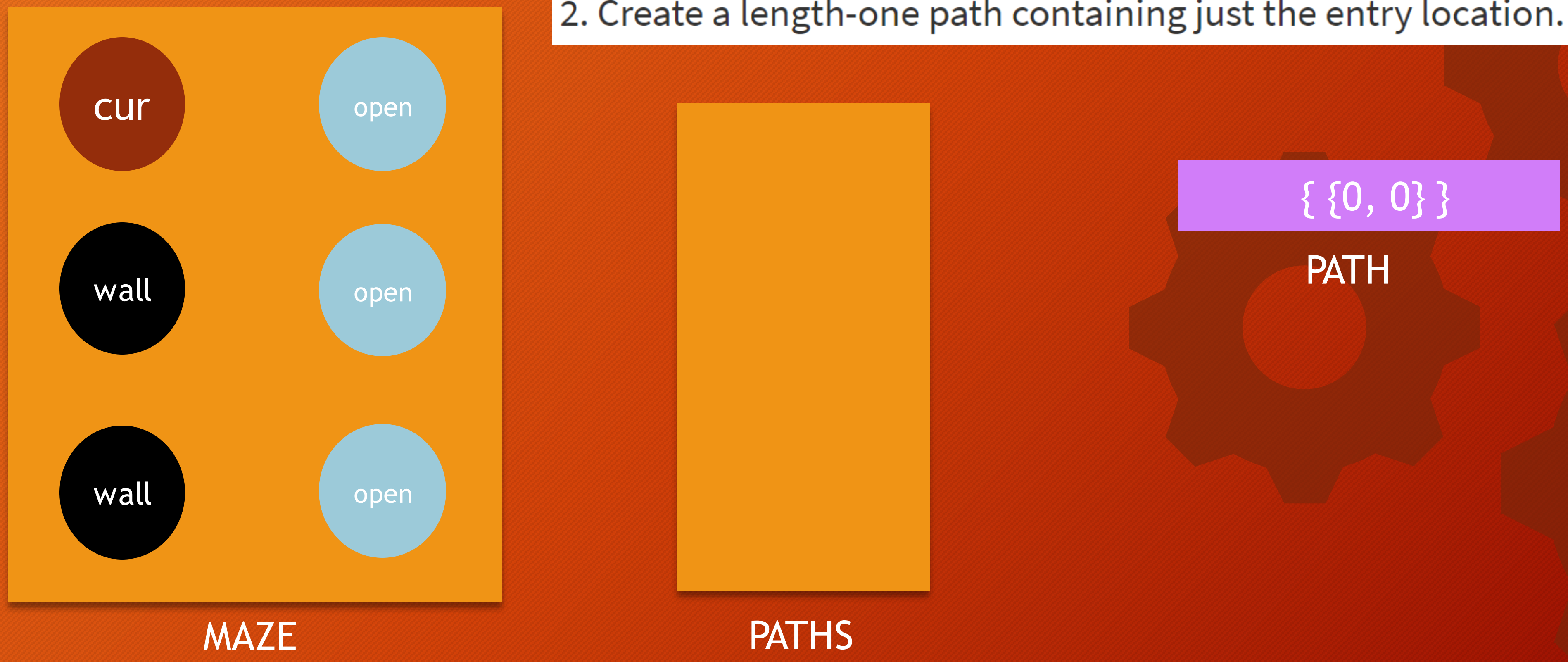

Part I: Maze solveMaze()

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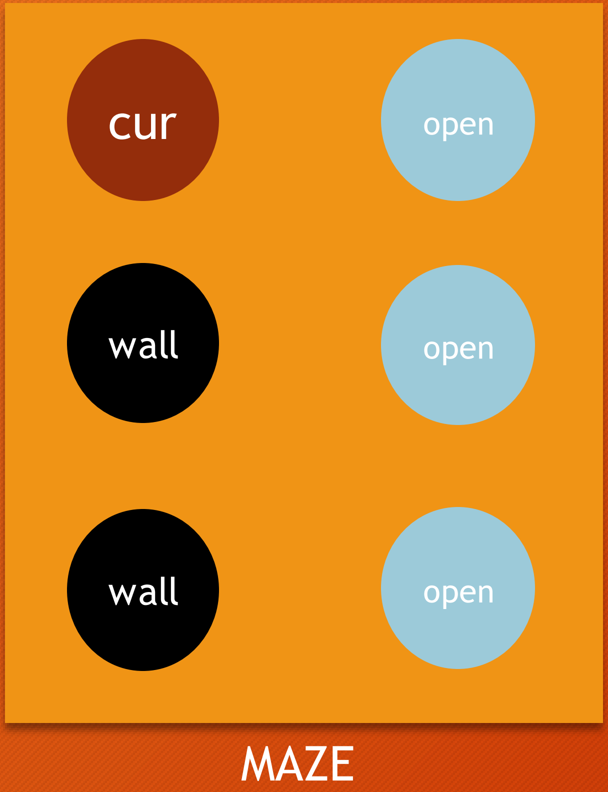

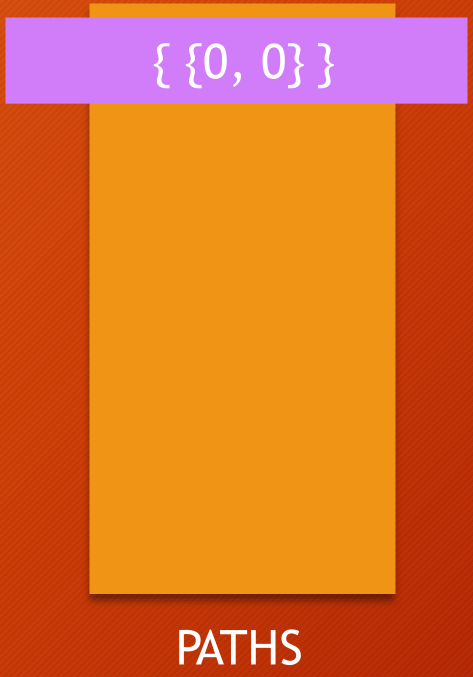

Part I: Maze solveMaze()

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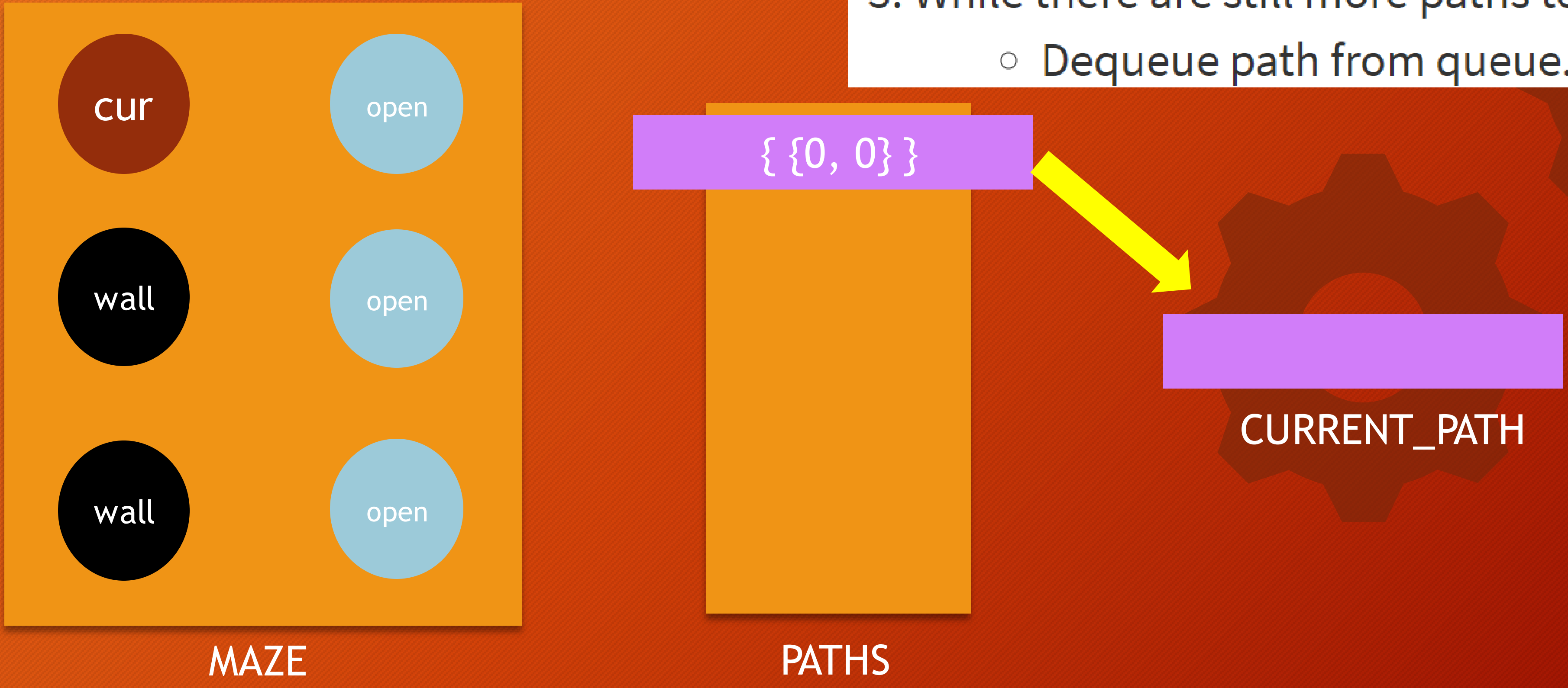

Part I: Maze solveMaze()

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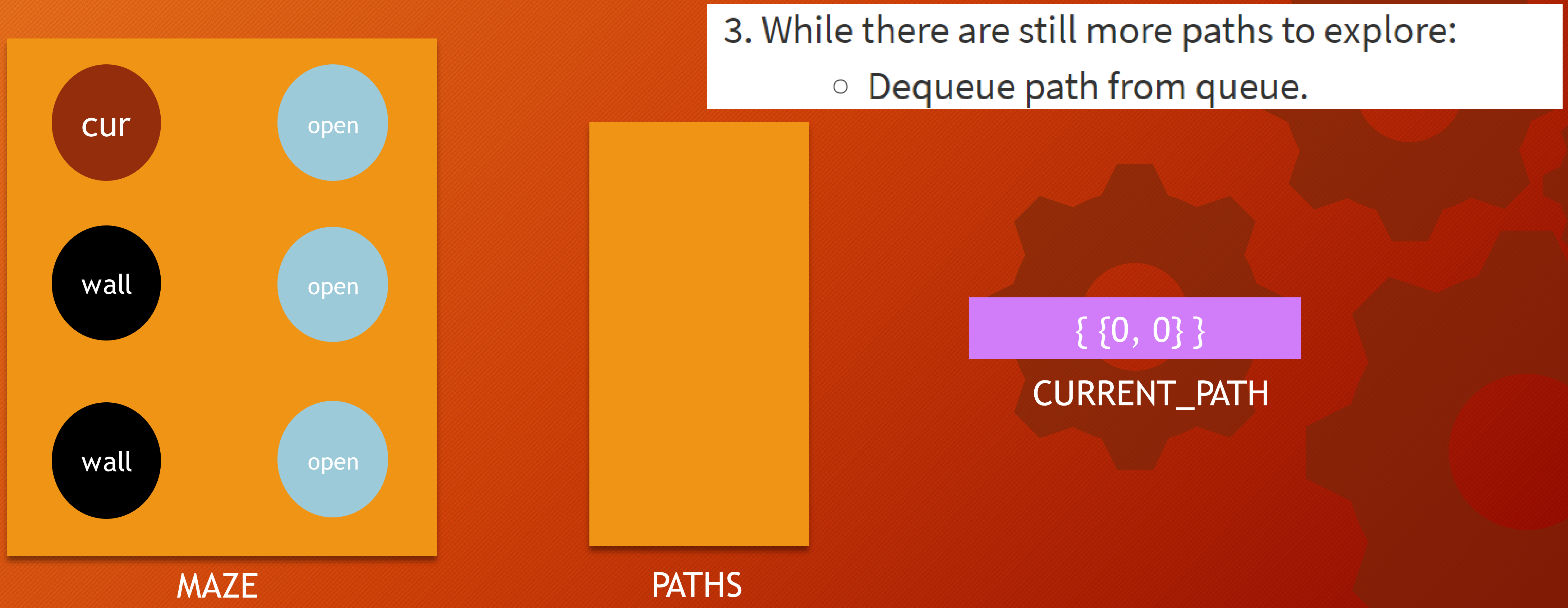

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Part I: Maze solveMaze()

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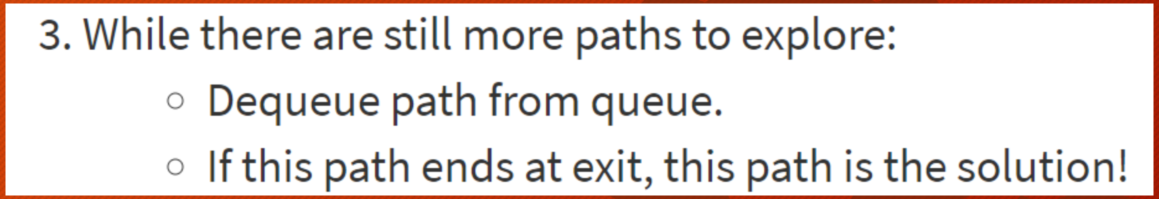

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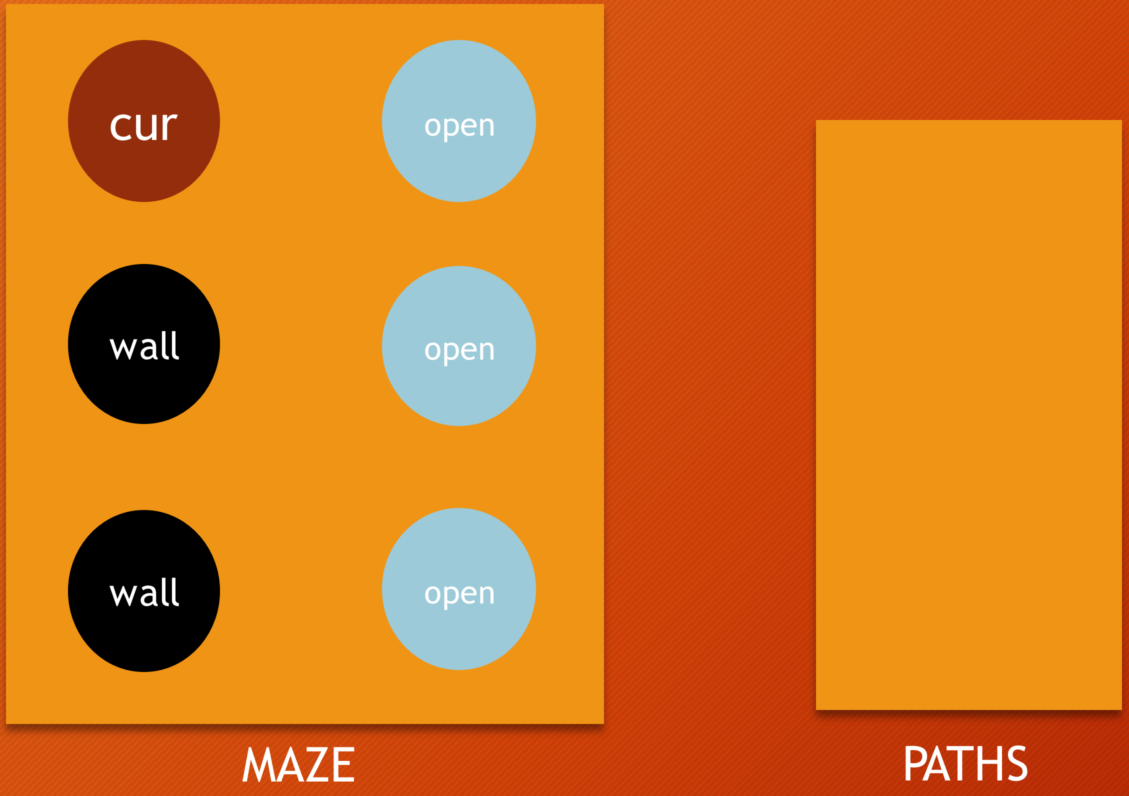
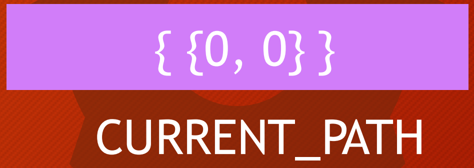
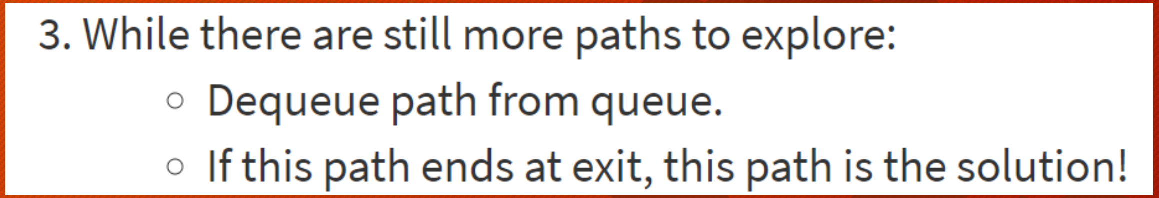


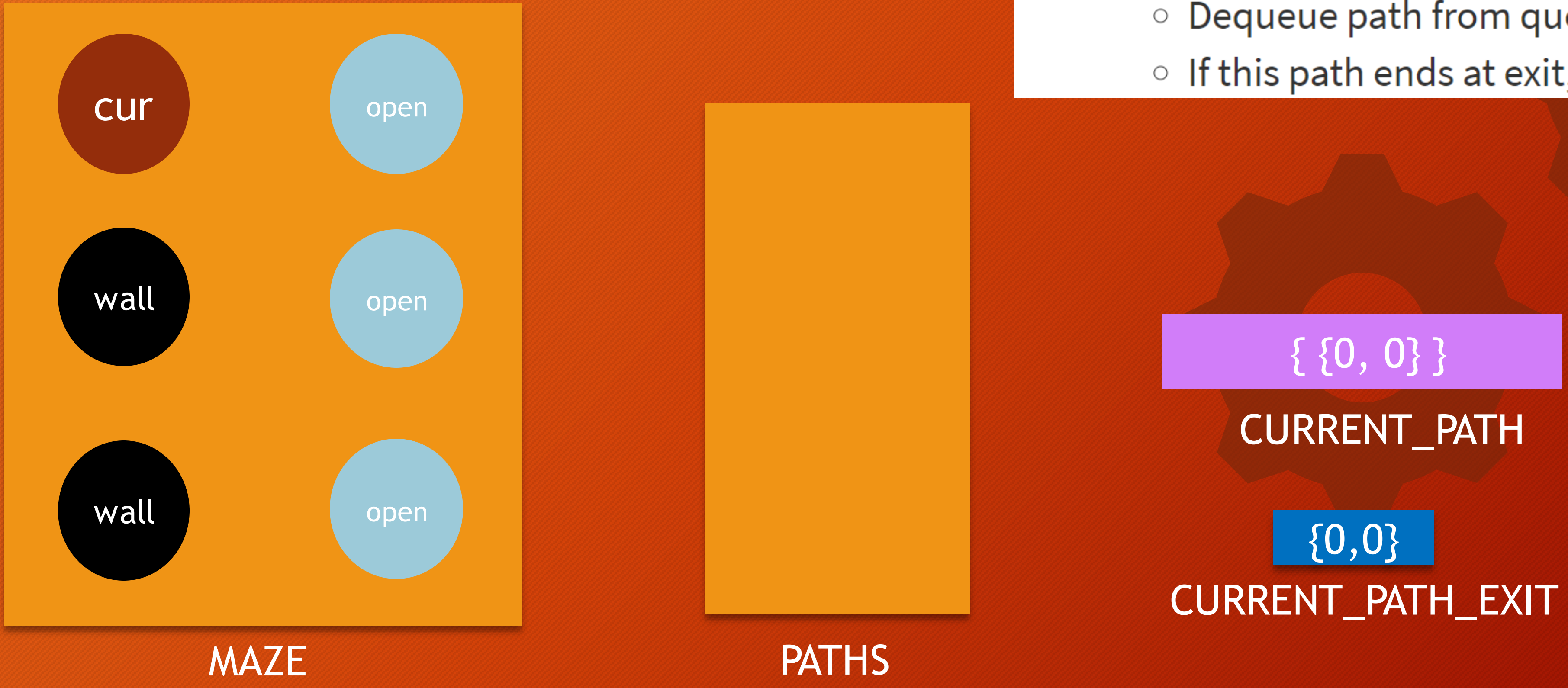


Part I: Maze solveMaze()

- Let's walk thru a very small example:



3. While there are still more paths to explore:
    - Dequeue path from queue.
    - If this path ends at exit, this path is the solution!



Part I: Maze solveMaze()

- Let’s walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.
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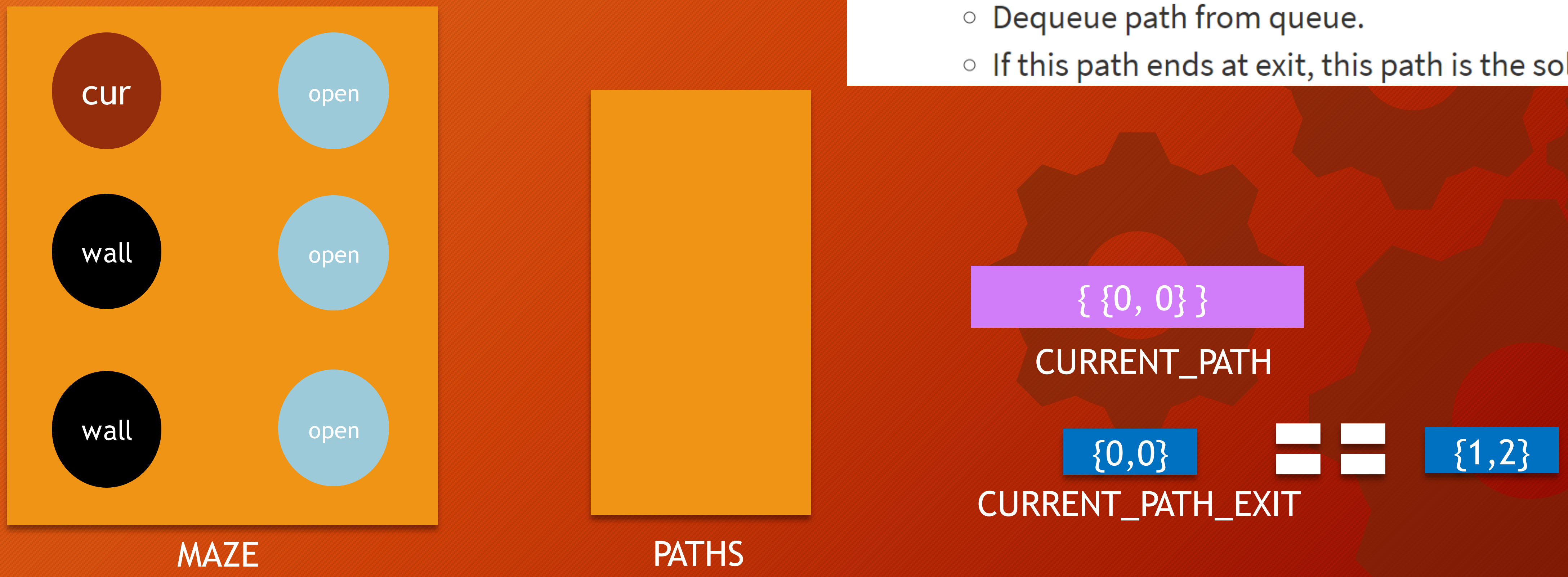

Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.
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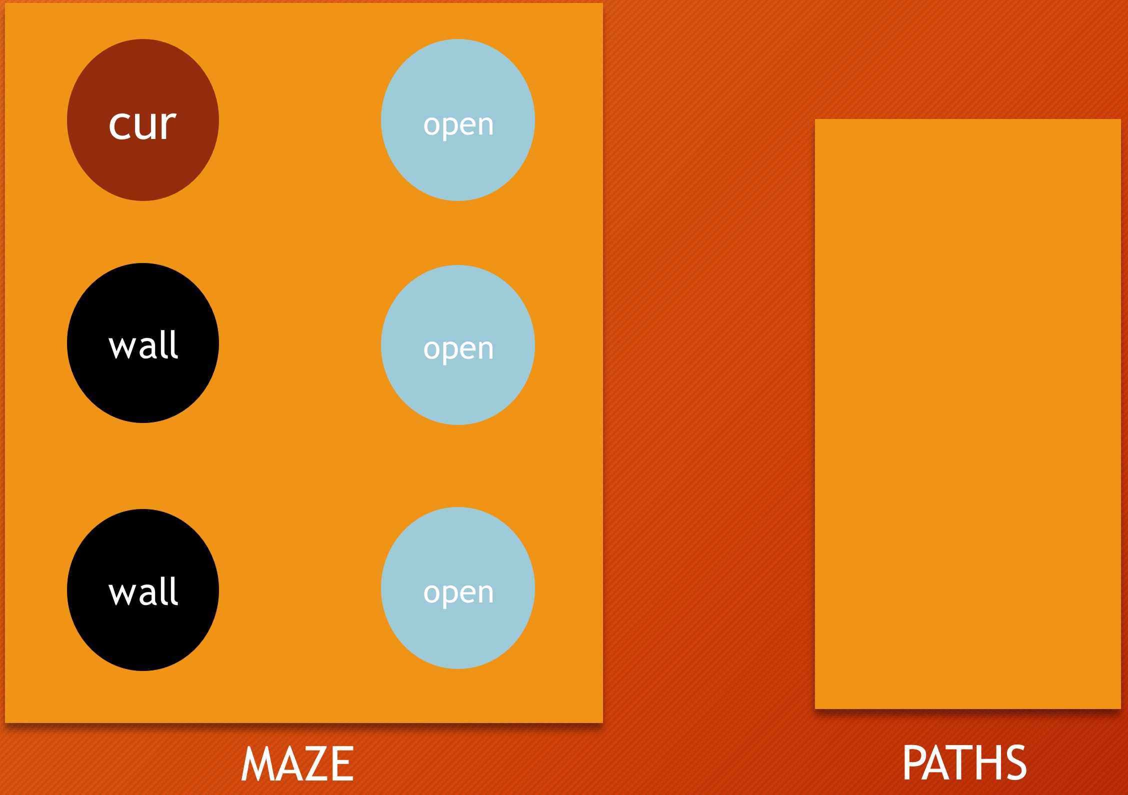
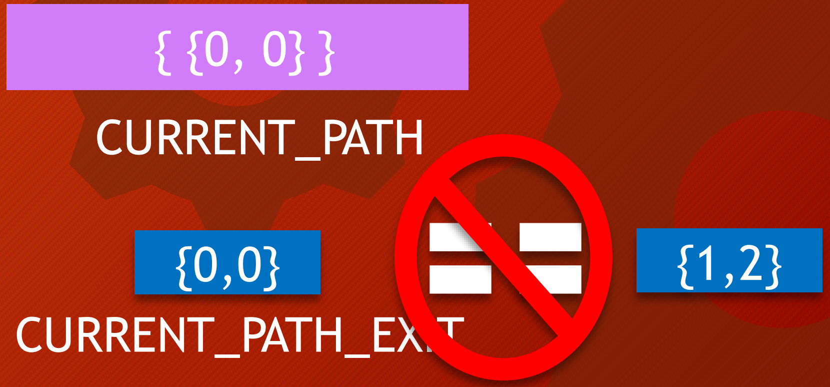
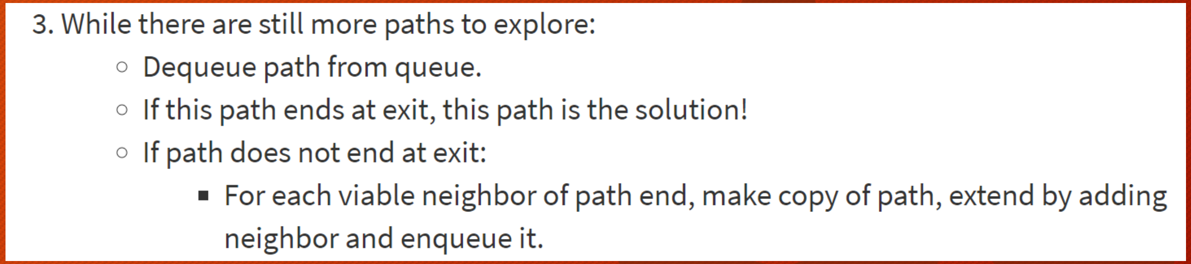




Part I: Maze solveMaze()

- Let's walk thru a very small example:



```
3. While there are still more paths to explore:
     ○ Dequeue path from queue.
     ○ If this path ends at exit, this path is the solution!
     ○ If path does not end at exit:
          ▪ For each viable neighbor of path end, make copy of path, extend by adding
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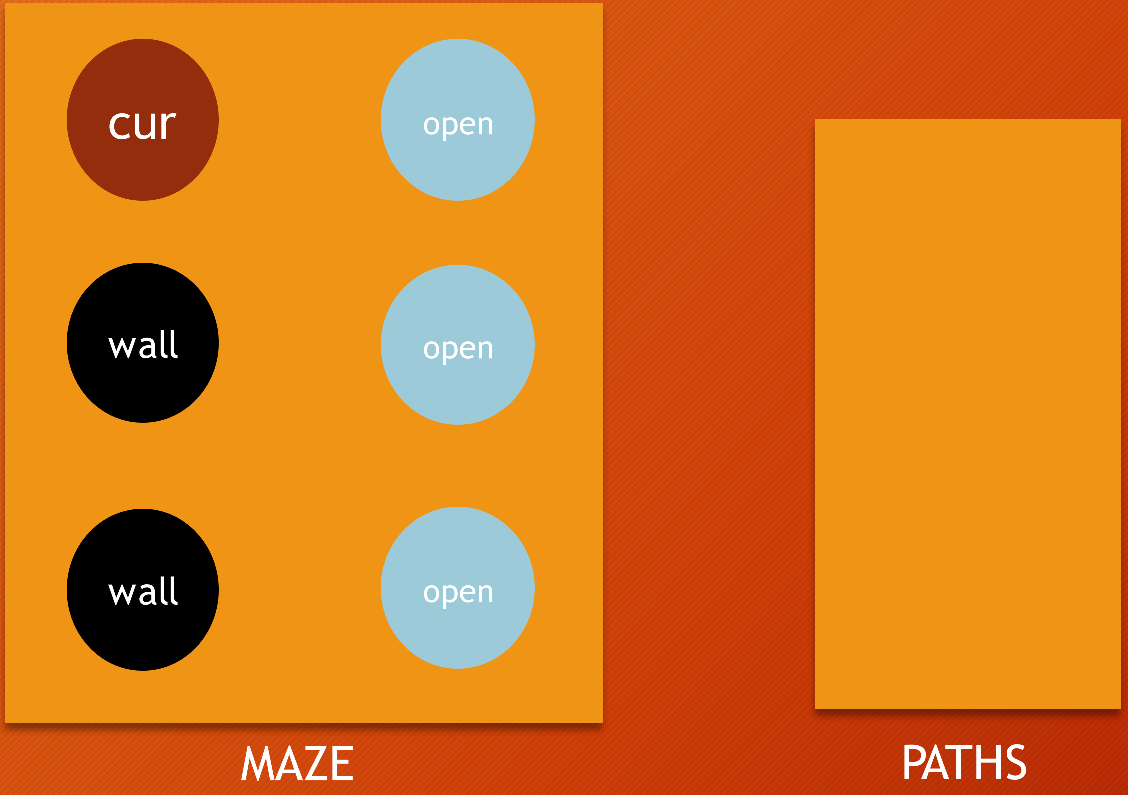
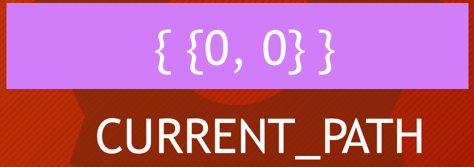
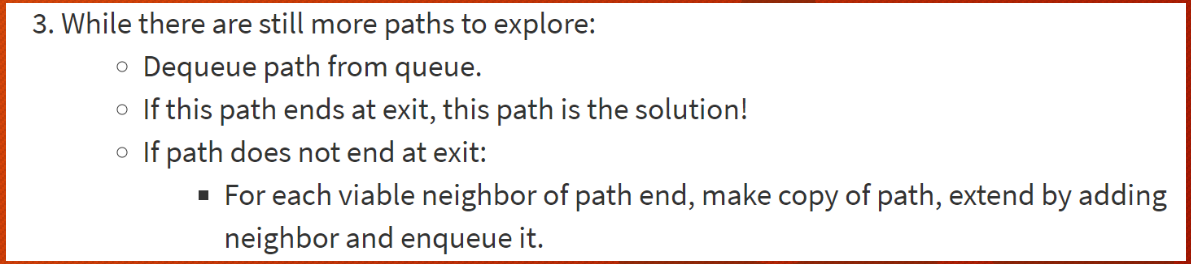
```





Part I: Maze solveMaze()

- Let's walk thru a very small example:



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3. While there are still more paths to explore:
    ○ Dequeue path from queue.
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    ○ If path does not end at exit:
        ▪ For each viable neighbor of path end, make copy of path, extend by adding
          neighbor and enqueue it.
```
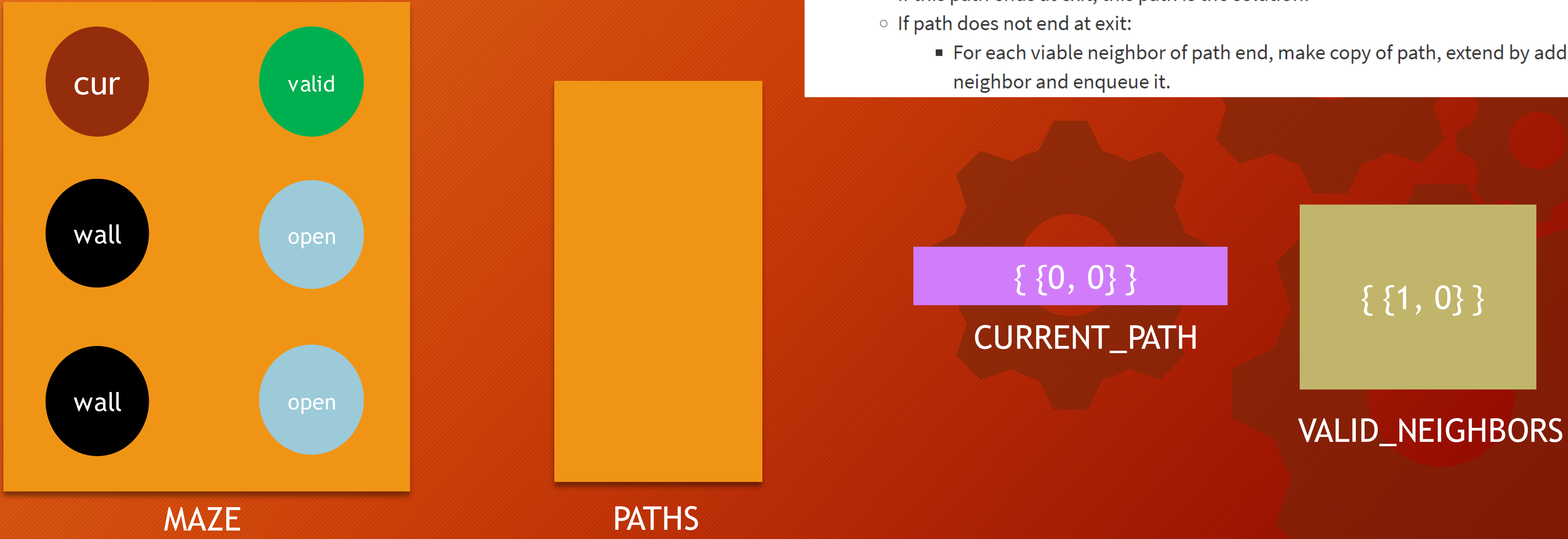
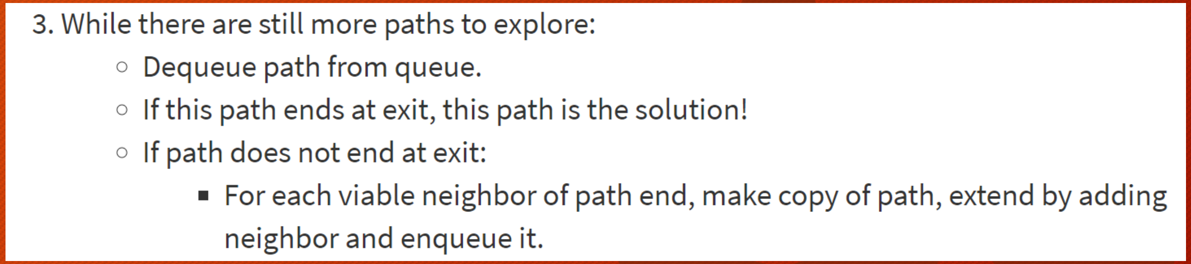



Part I: Maze solveMaze()

- Let's walk thru a very small example:



3. While there are still more paths to explore:
    - Dequeue path from queue.
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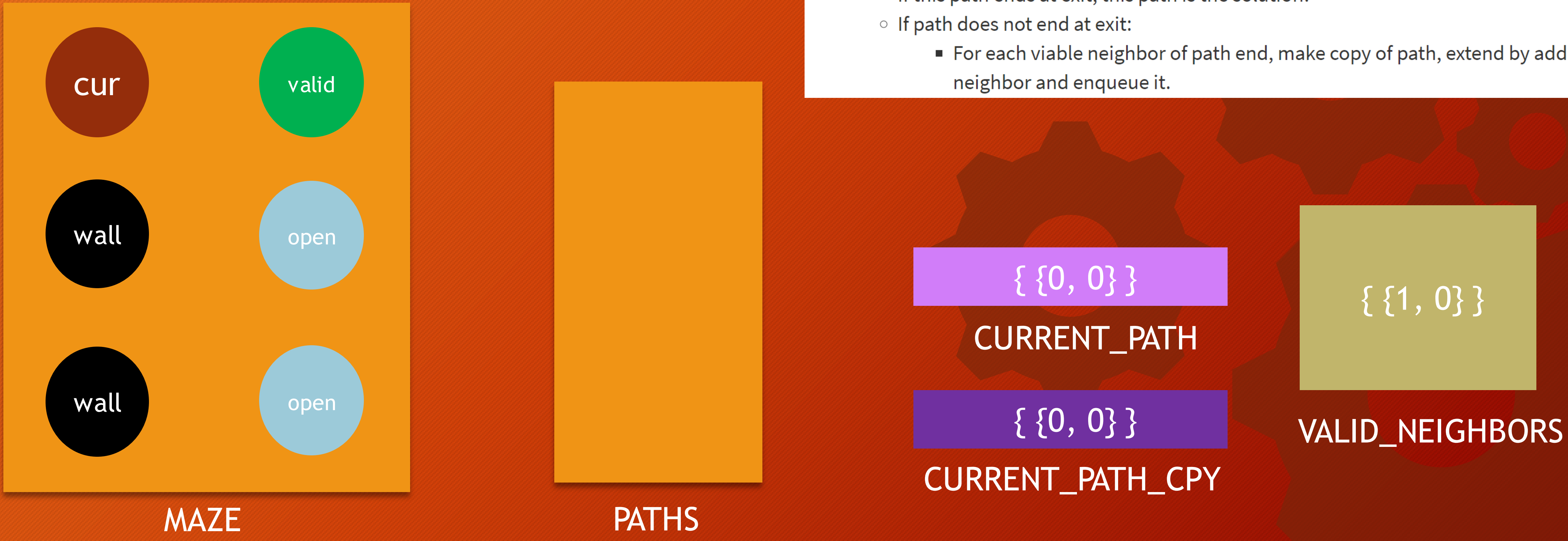
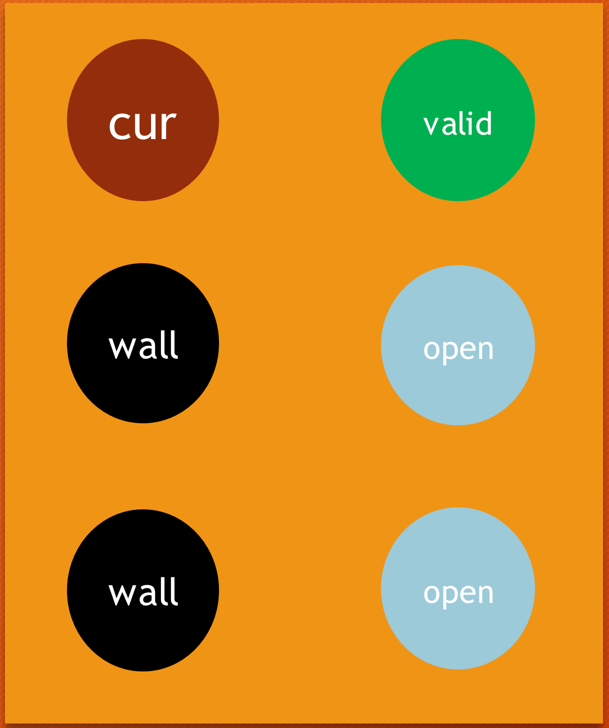


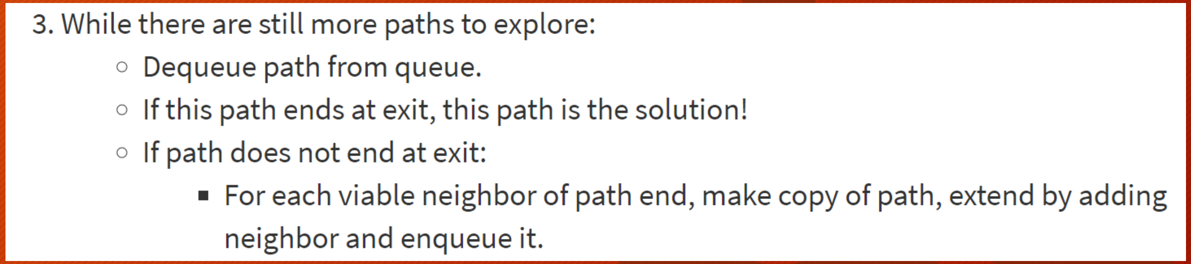
Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS



```
3. While there are still more paths to explore:
     ○ Dequeue path from queue.
     ○ If this path ends at exit, this path is the solution!
     ○ If path does not end at exit:
          ■ For each viable neighbor of path end, make copy of path, extend by adding
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```
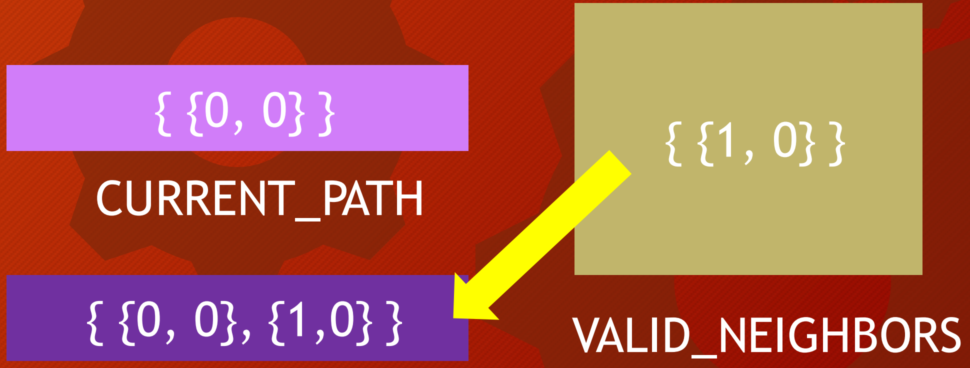
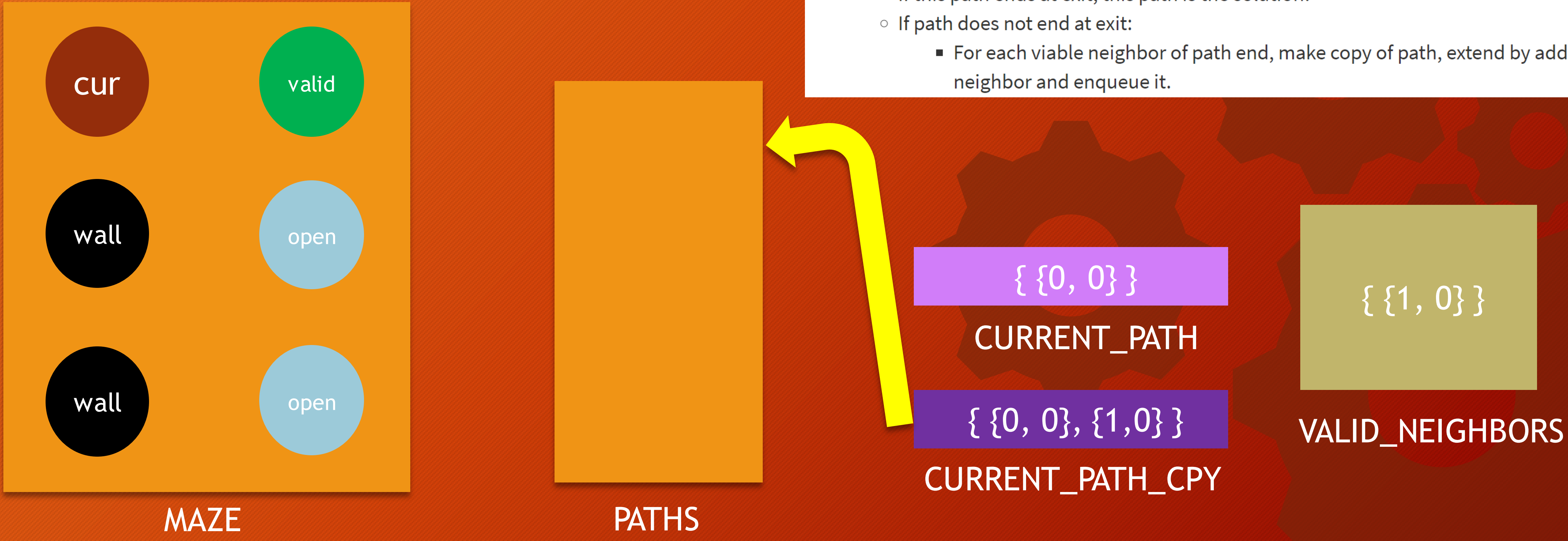



CURRENT_PATH_CPY

Part I: Maze solveMaze()

- Let's walk thru a very small example:

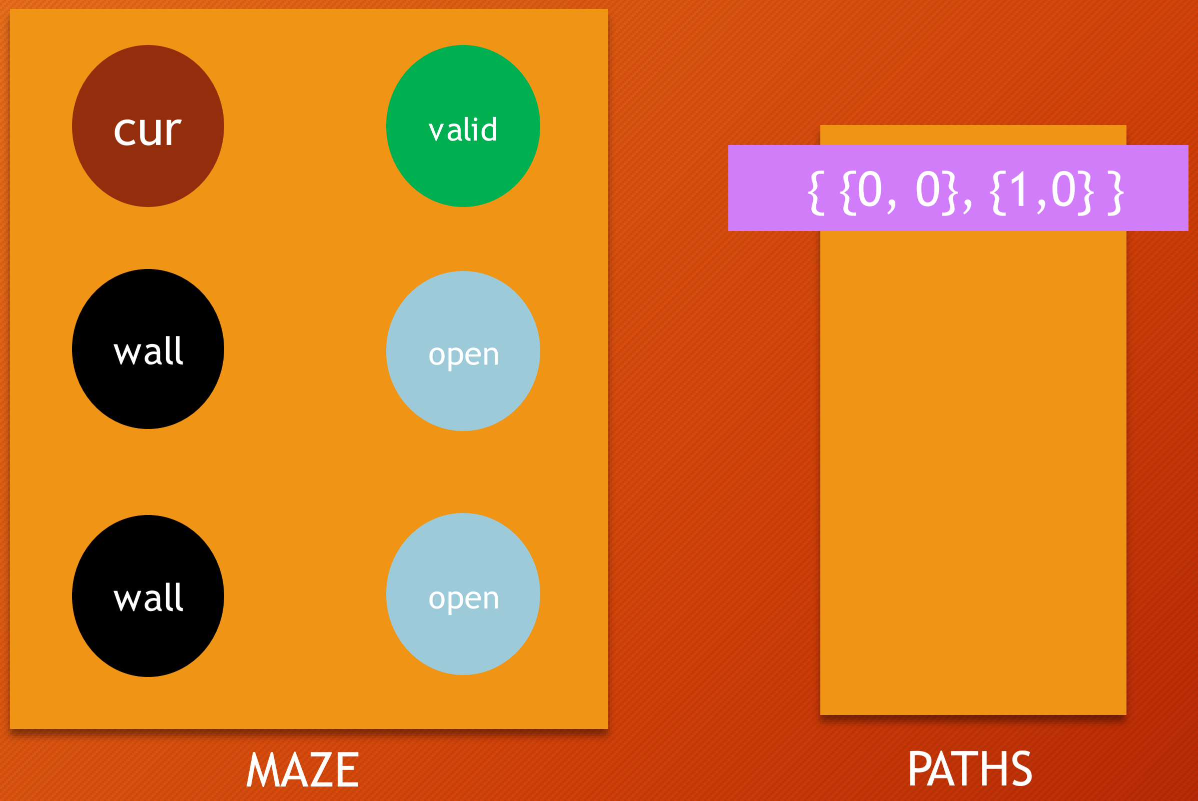
3. While there are still more paths to explore:
    - Dequeue path from queue.
    - If this path ends at exit, this path is the solution!
    - If path does not end at exit:
        - For each viable neighbor of path end, make copy of path, extend by adding neighbor and enqueue it.

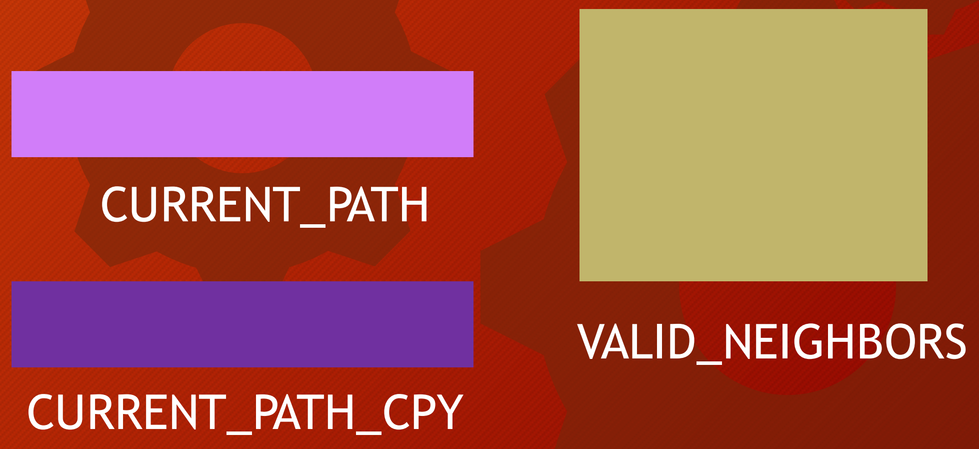


Part I: Maze solveMaze()

- Let's walk thru a very small example:

Repeat!

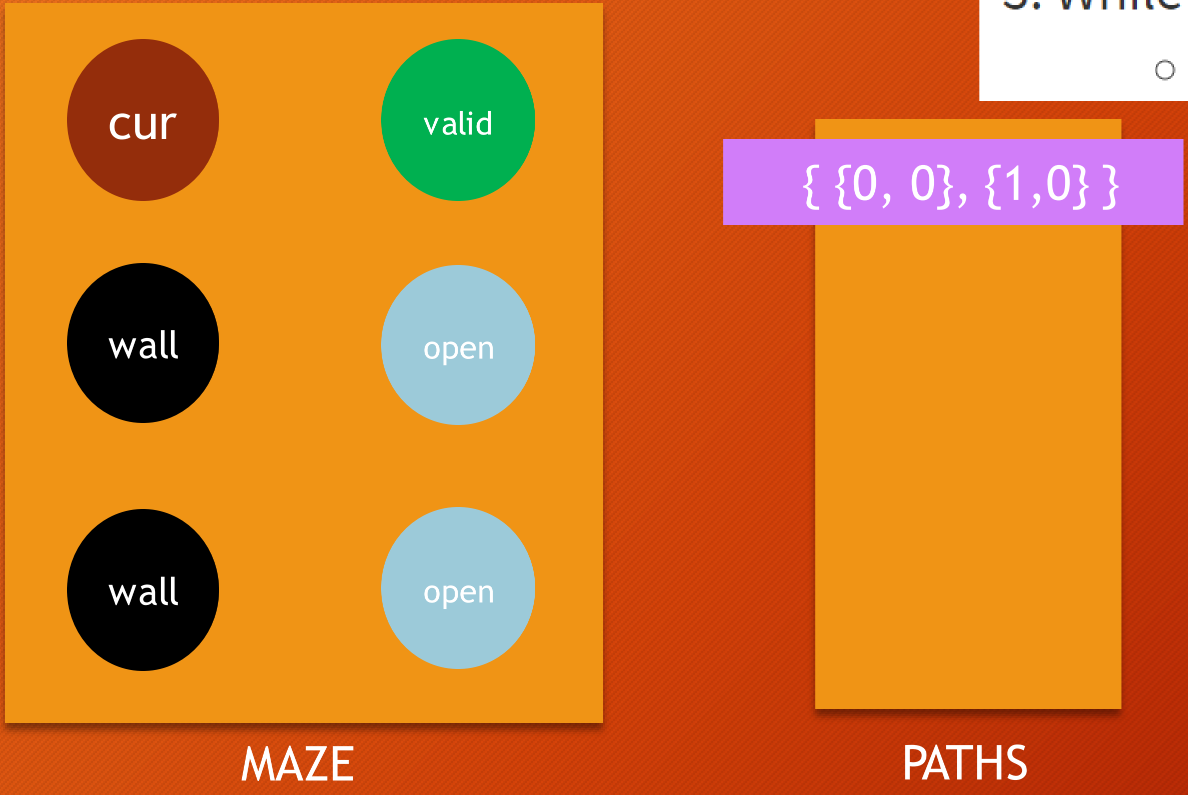




Part I: Maze solveMaze()

- Let's walk thru a very small example:

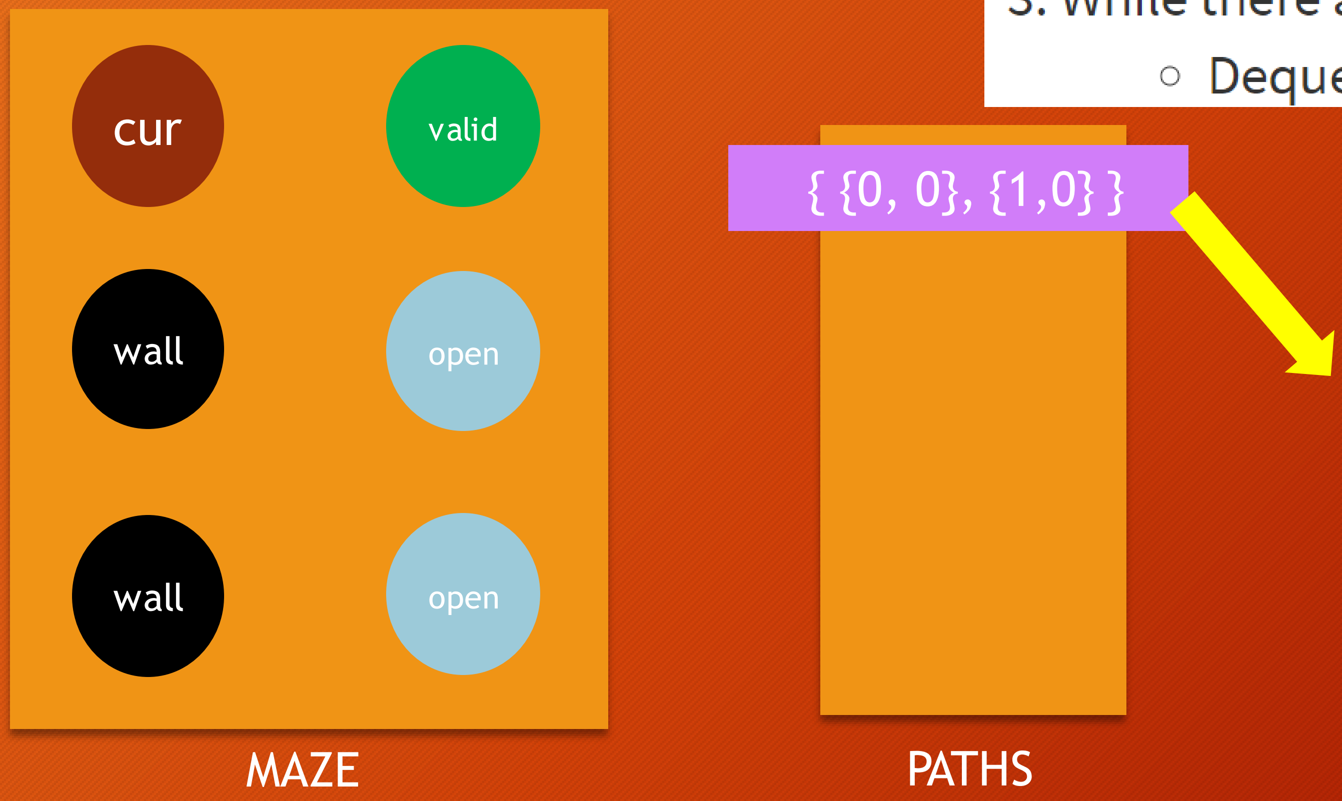
3. While there are still more paths to explore:
    - Dequeue path from queue.



Part I: Maze solveMaze()

- Let's walk thru a very small example:

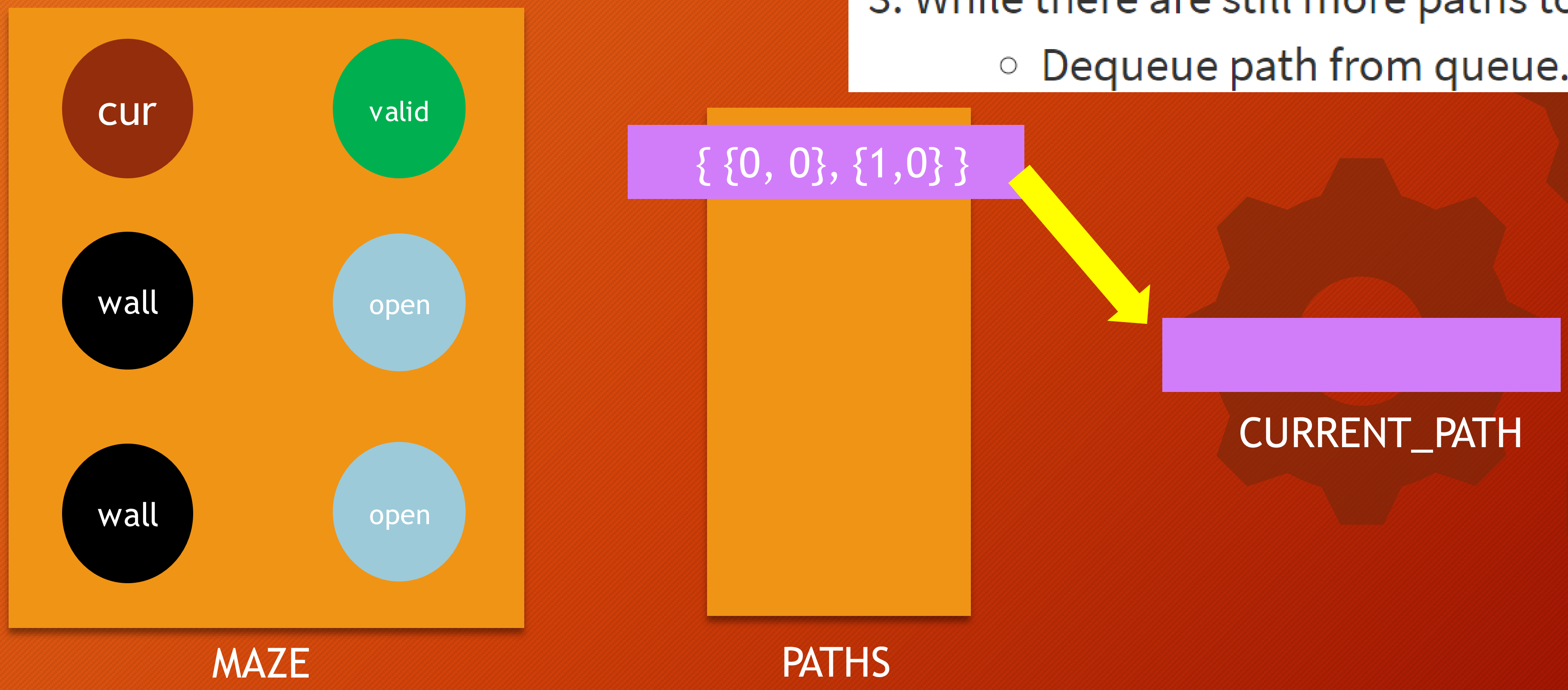
3. While there are still more paths to explore:
    - Dequeue path from queue.



Part I: Maze solveMaze()

- Let's walk thru a very small example:

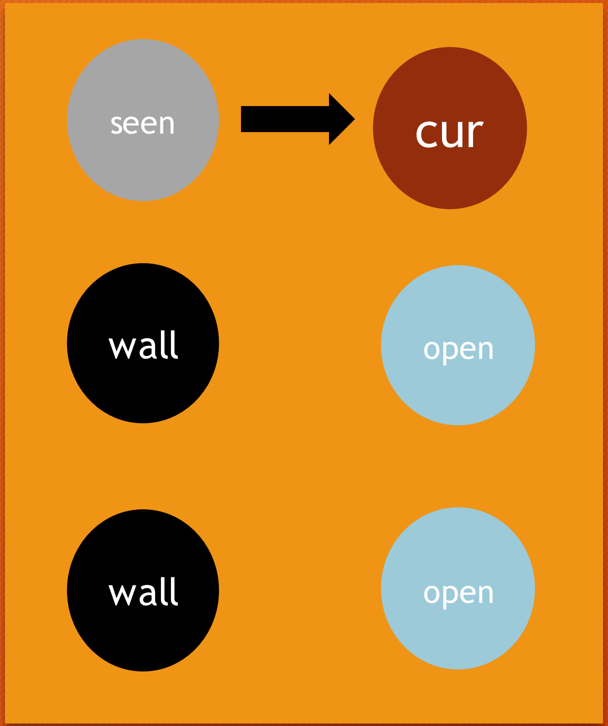
3. While there are still more paths to explore:
    - Dequeue path from queue.



Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
   - Dequeue path from queue.



MAZE

PATHS

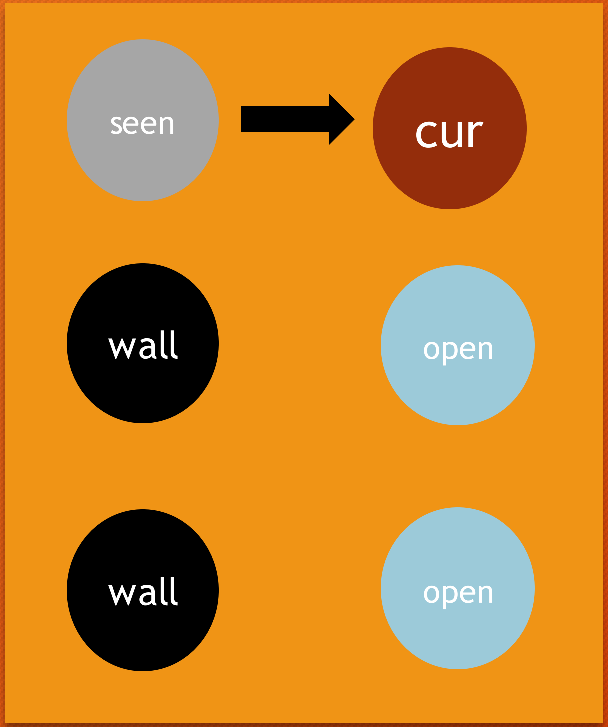
{ {0, 0}, {1,0} }

CURRENT_PATH

Part I: Maze solveMaze()

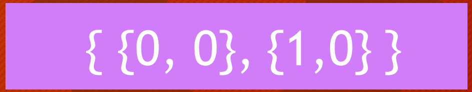
- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.
    - If this path ends at exit, this path is the solution!



MAZE

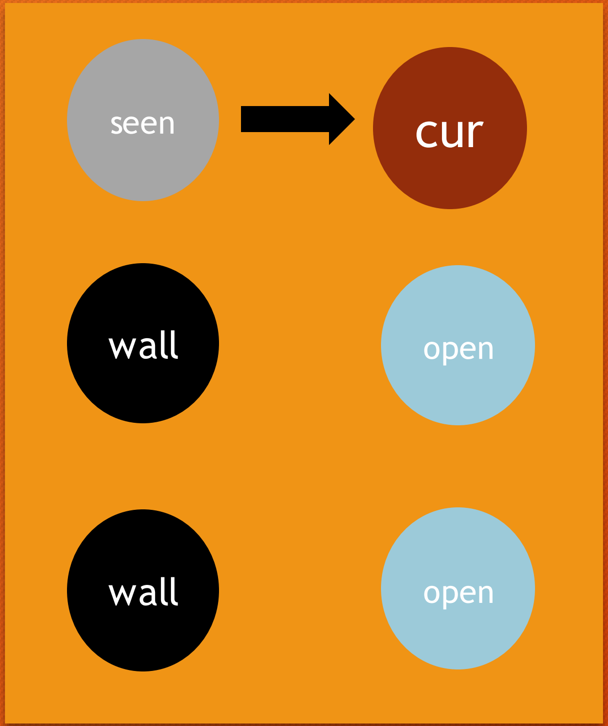
PATHS



CURRENT_PATH

Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS

3. While there are still more paths to explore:
   - Dequeue path from queue.
   - If this path ends at exit, this path is the solution!

{1,0} == {1,2}

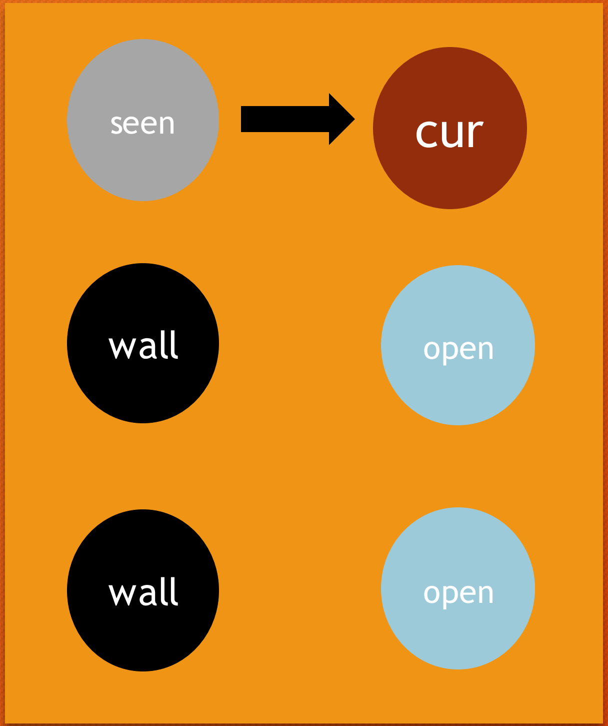
CURRENT_PATH_EXIT

{ {0, 0}, {1,0} }

CURRENT_PATH

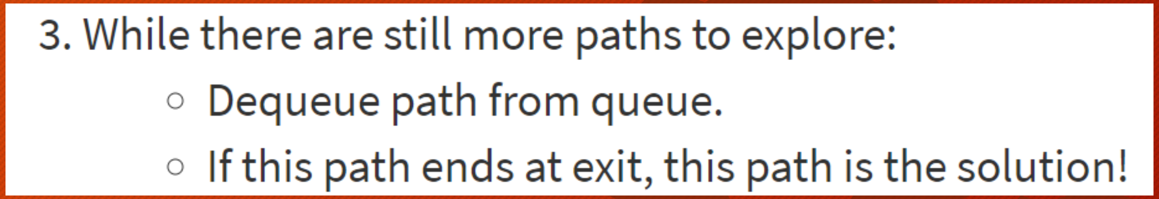
Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS



3. While there are still more paths to explore:
    - Dequeue path from queue.
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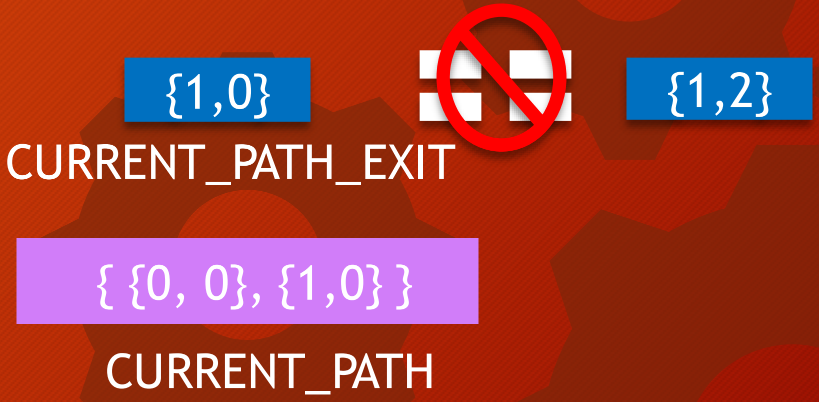
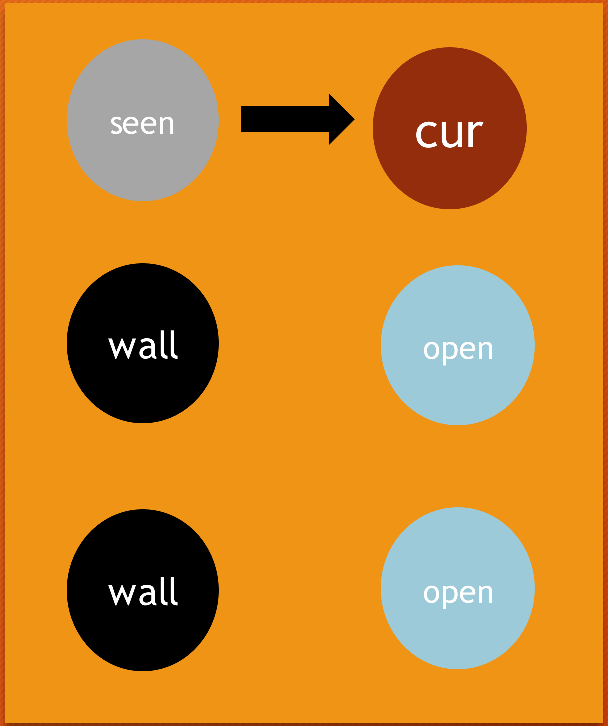


Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS

3. While there are still more paths to explore:
    - Dequeue path from queue.
    - If this path ends at exit, this path is the solution!

{ {0, 0}, {1,0} }

CURRENT_PATH

Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.
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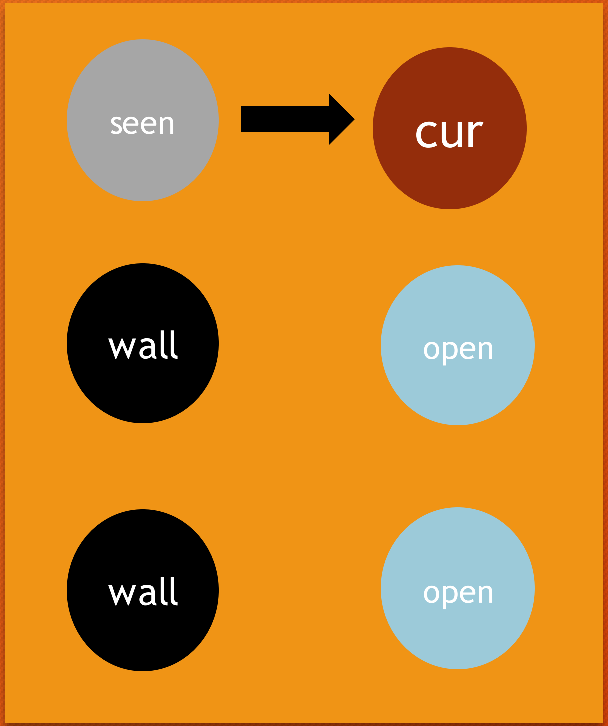


MAZE

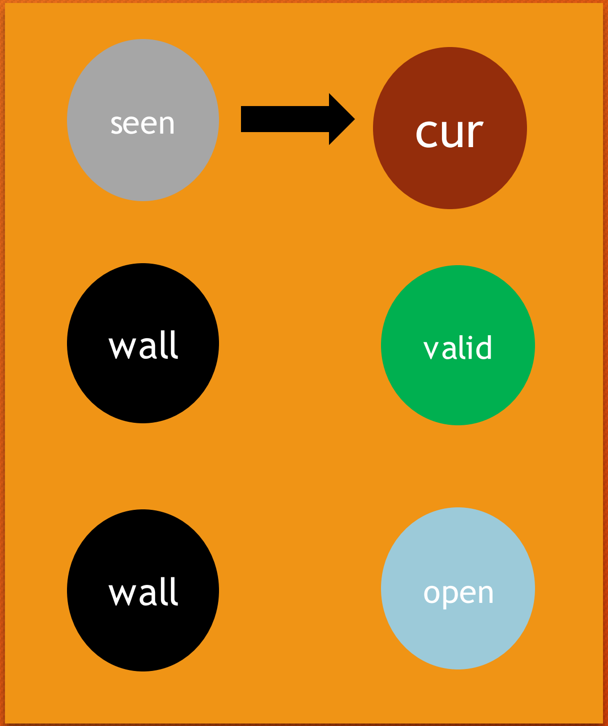
PATHS

{ {0, 0}, {1,0} }

CURRENT_PATH

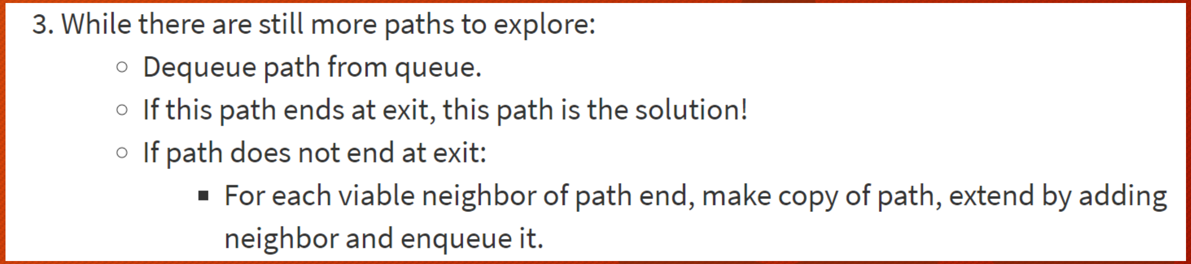
Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS



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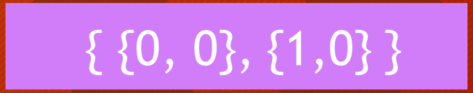
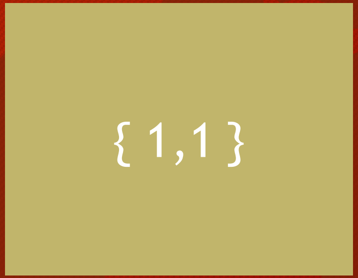


{ {0, 0}, {1,0} }

CURRENT_PATH

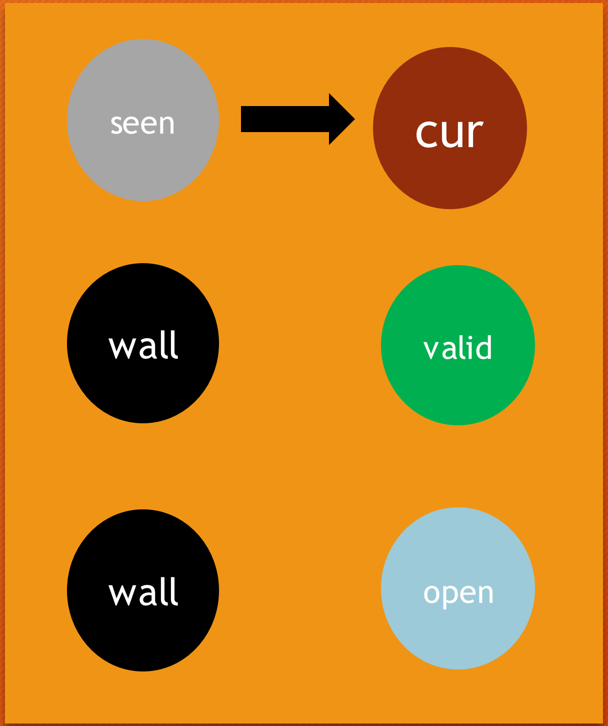


{ 1,1 }

VALID_NEIGHBORS

Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS

3. While there are still more paths to explore:
    - Dequeue path from queue.
    - If this path ends at exit, this path is the solution!
    - If path does not end at exit:
        - For each viable neighbor of path end, make copy of path, extend by adding neighbor and enqueue it.

{ {0, 0}, {1,0} }

CURRENT_PATH

{ {0, 0}, {1,0} }

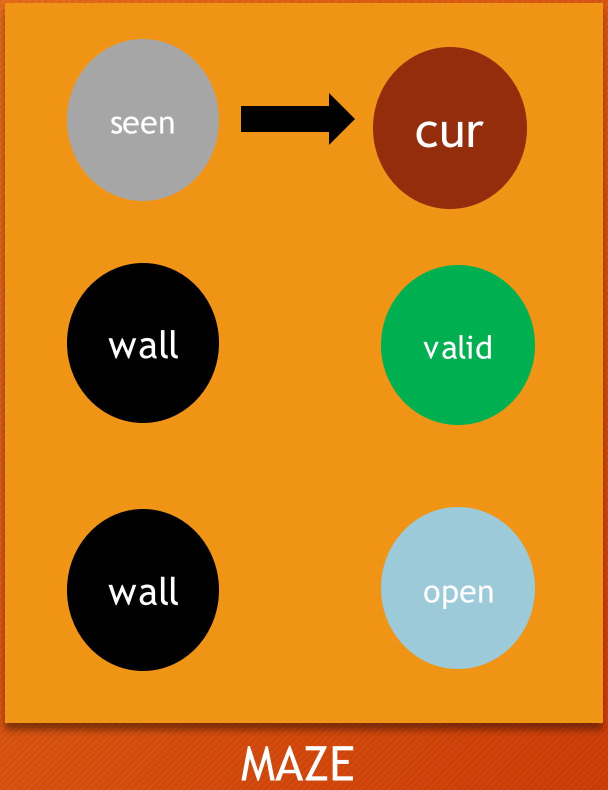
CURRENT_PATH_CPY

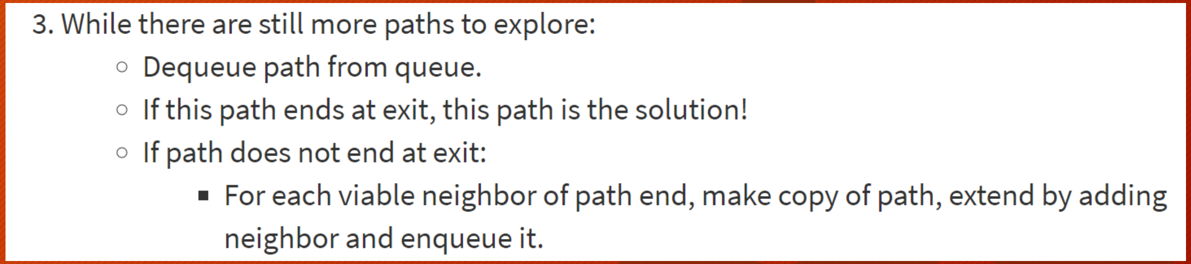
{ 1,1 }

VALID_NEIGHBORS

Part I: Maze solveMaze()

- Let's walk thru a very small example:





```
3. While there are still more paths to explore:
    ○ Dequeue path from queue.
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        ▪ For each viable neighbor of path end, make copy of path, extend by adding
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```

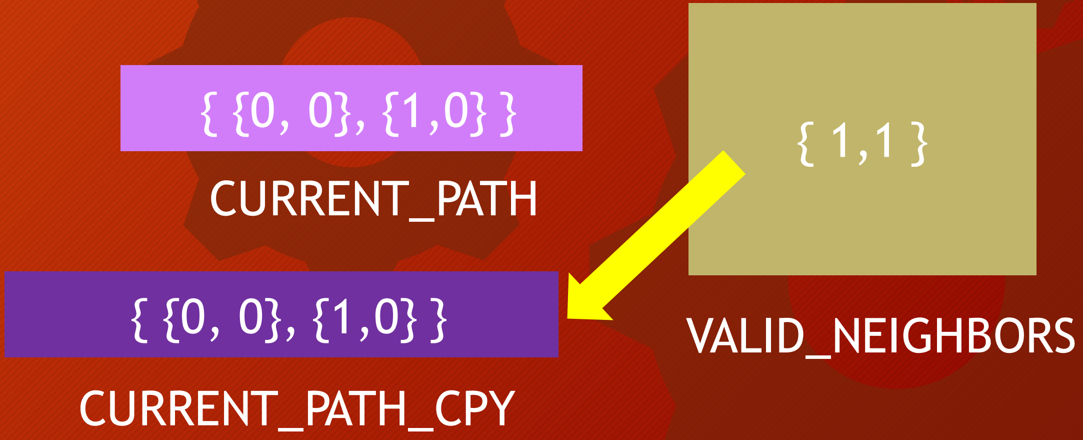

Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.
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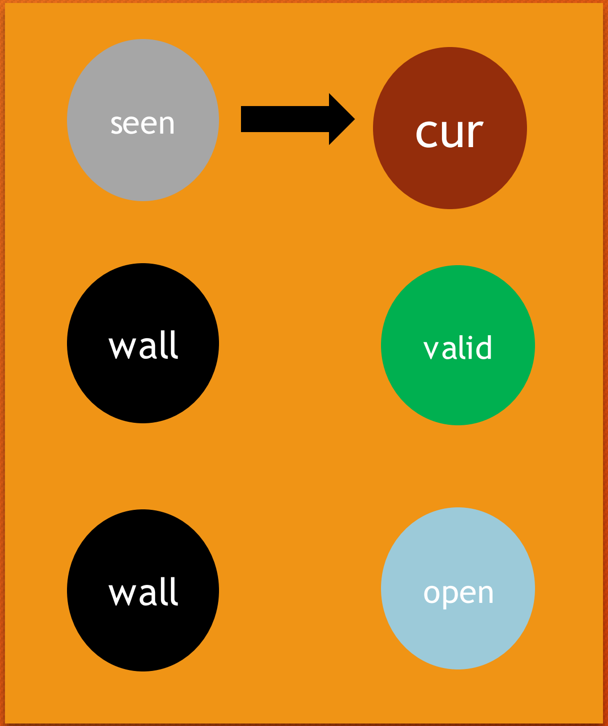
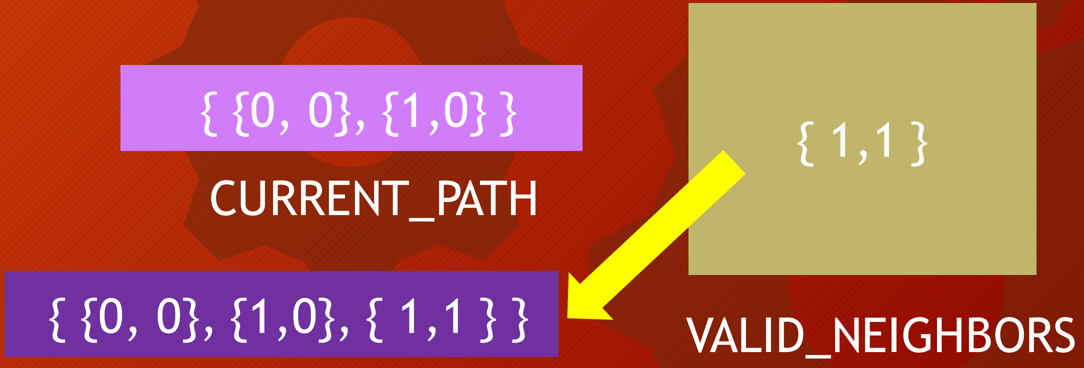


MAZE

PATHS



CURRENT_PATH_CPY

Part I: Maze solveMaze()

- Let's walk thru a very small example:

```
3. While there are still more paths to explore:
    ○ Dequeue path from queue.
    ○ If this path ends at exit, this path is the solution!
    ○ If path does not end at exit:
        ▪ For each viable neighbor of path end, make copy of path, extend by adding
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```
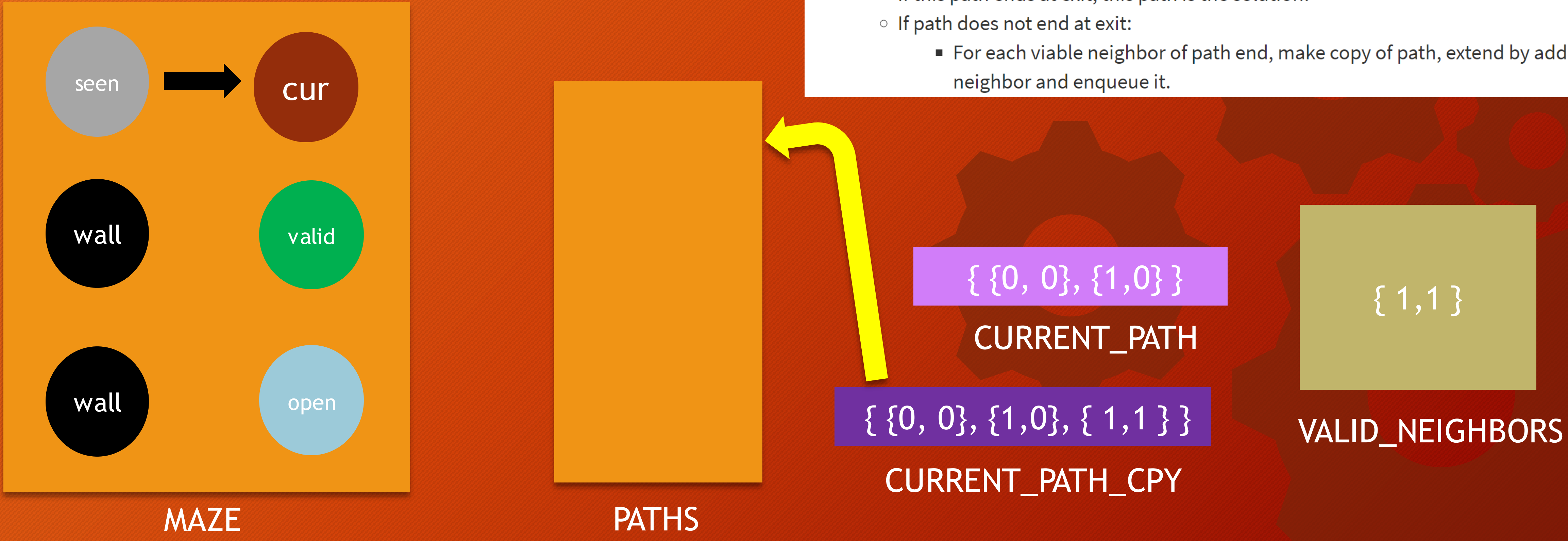
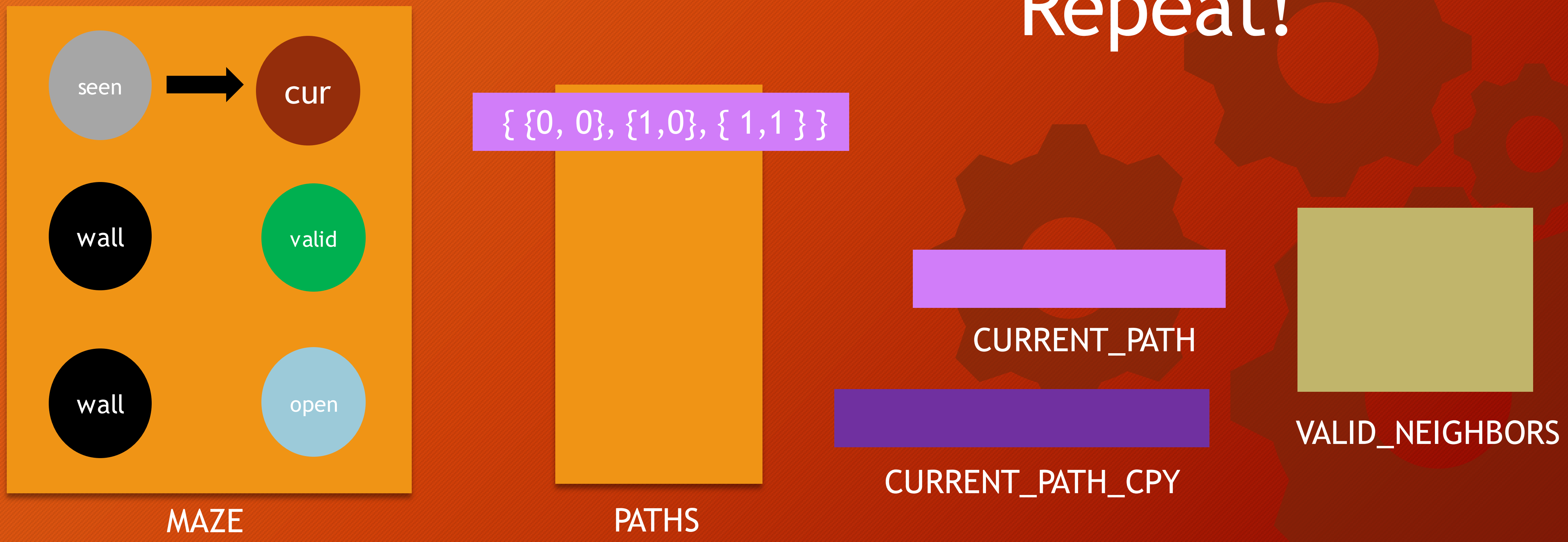



Part I: Maze solveMaze()

- Let's walk thru a very small example:

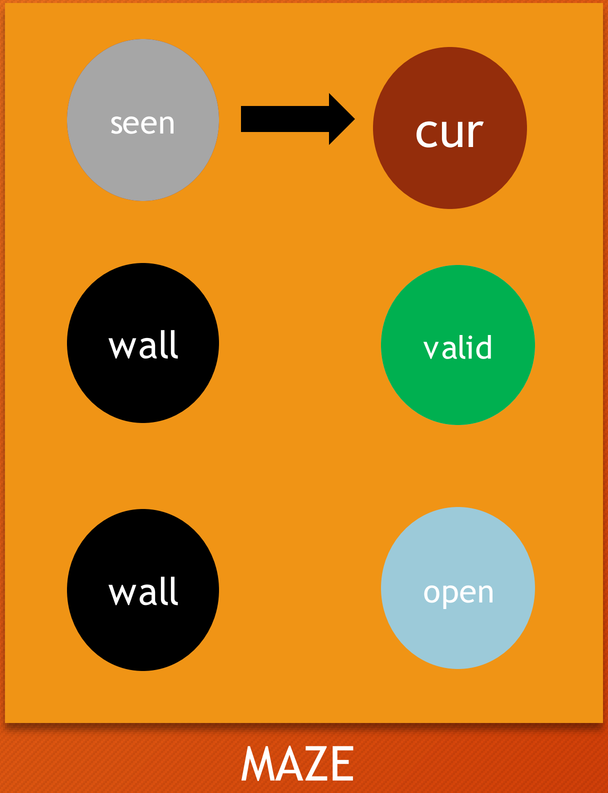
Repeat!

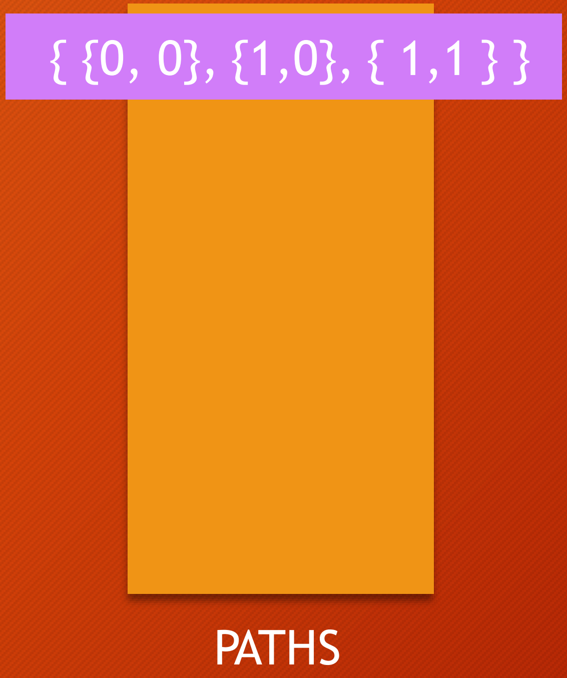


Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.

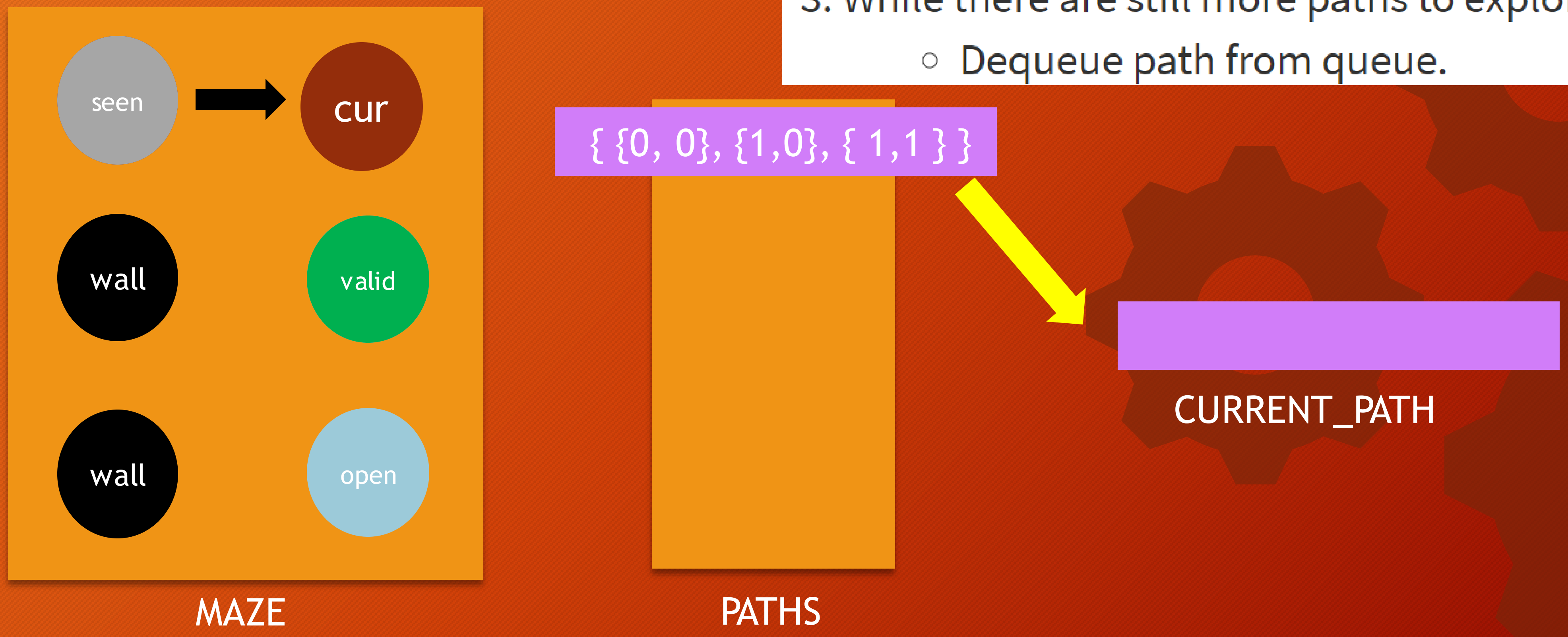




Part I: Maze solveMaze()

- Let's walk thru a very small example:

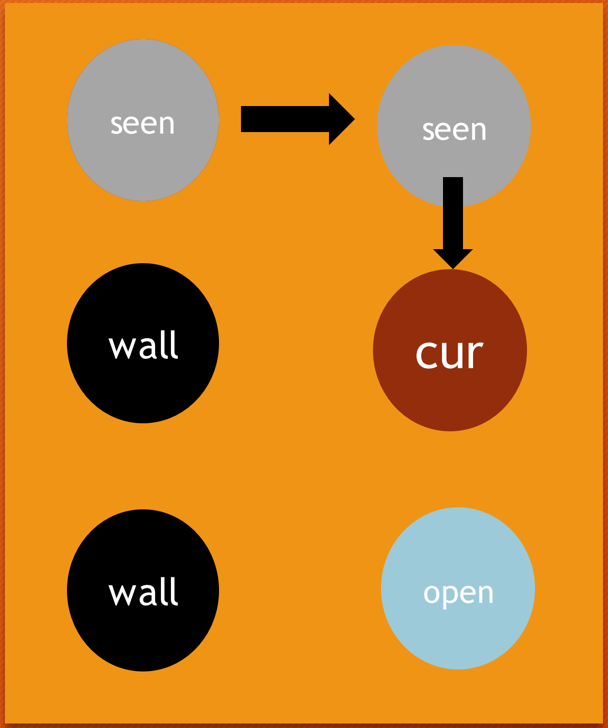
3. While there are still more paths to explore:
    - Dequeue path from queue.



Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.



MAZE

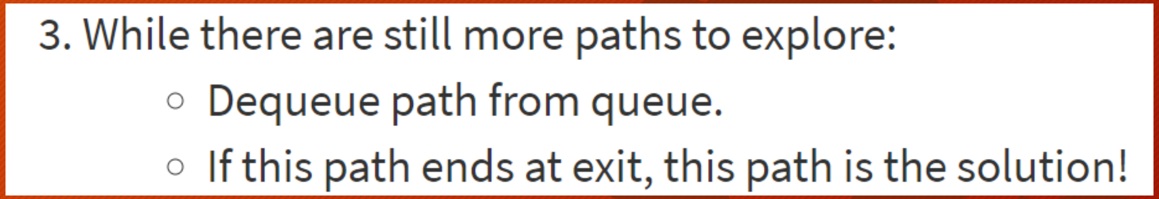
PATHS

{ {0, 0}, {1,0}, { 1,1 } }

CURRENT_PATH

Part I: Maze solveMaze()

- Let's walk thru a very small example:



3. While there are still more paths to explore:
   - Dequeue path from queue.
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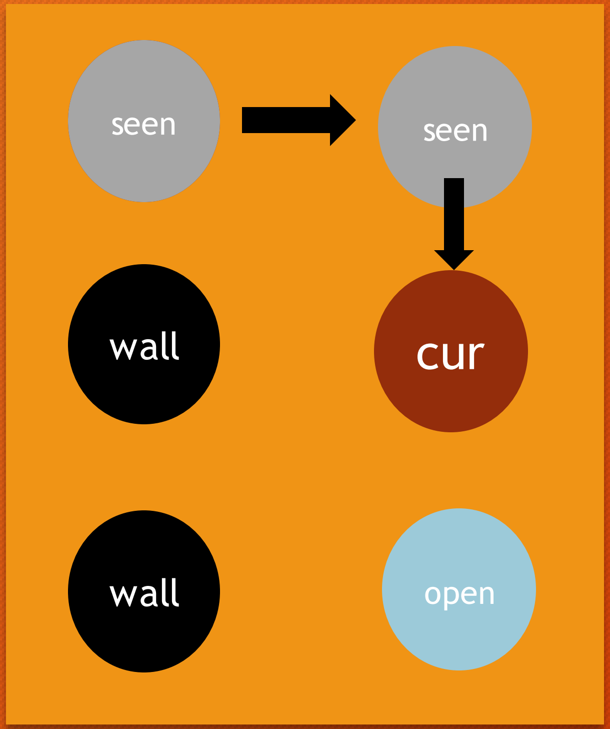
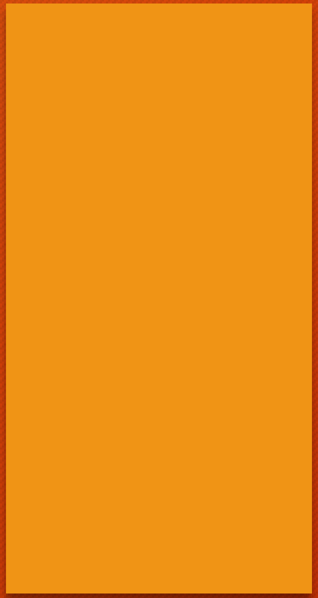


MAZE



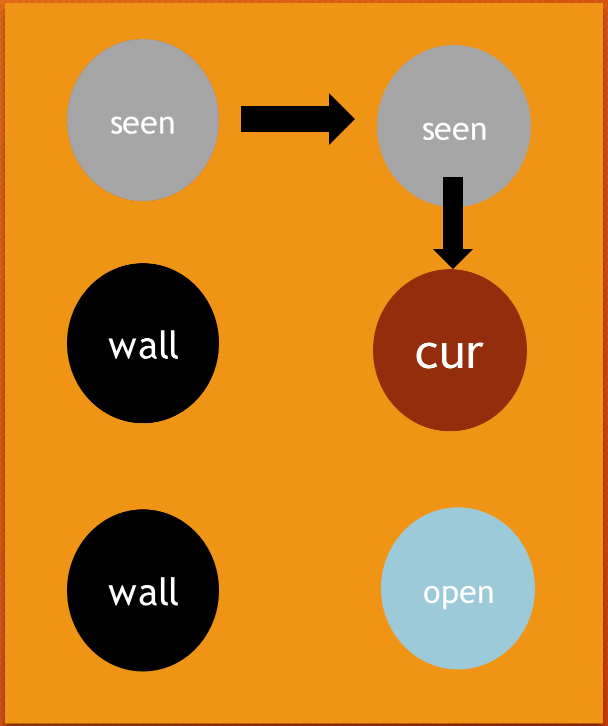
PATHS

{ {0, 0}, {1,0}, { 1,1 } }

CURRENT_PATH

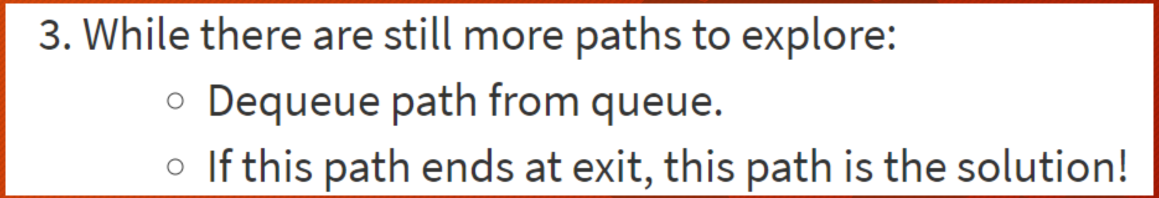
Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS



3. While there are still more paths to explore:
   - Dequeue path from queue.
   - If this path ends at exit, this path is the solution!

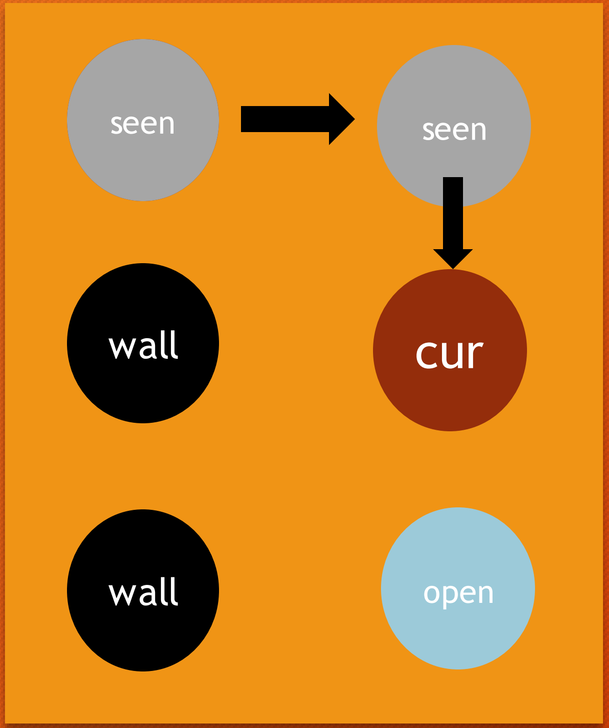
{ {0, 0}, {1,0}, { 1,1 } }

CURRENT_PATH

{1,1} != {1,2}, QED

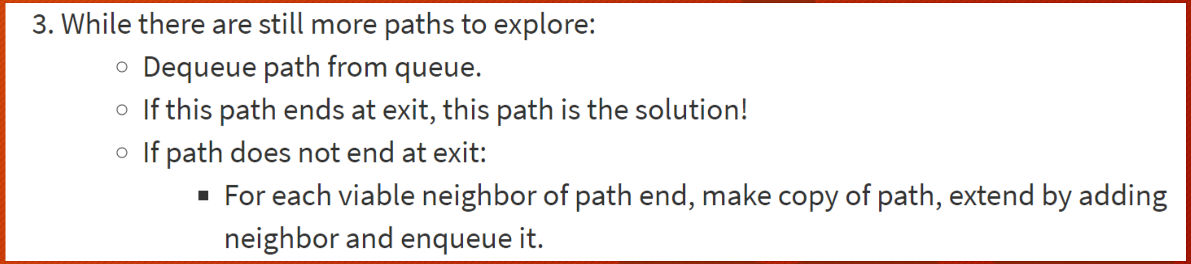
Part I: Maze solveMaze()

- Let’s walk thru a very small example:



MAZE

PATHS



3. While there are still more paths to explore:
   - Dequeue path from queue.
   - If this path ends at exit, this path is the solution!
   - If path does not end at exit:
     - For each viable neighbor of path end, make copy of path, extend by adding neighbor and enqueue it.

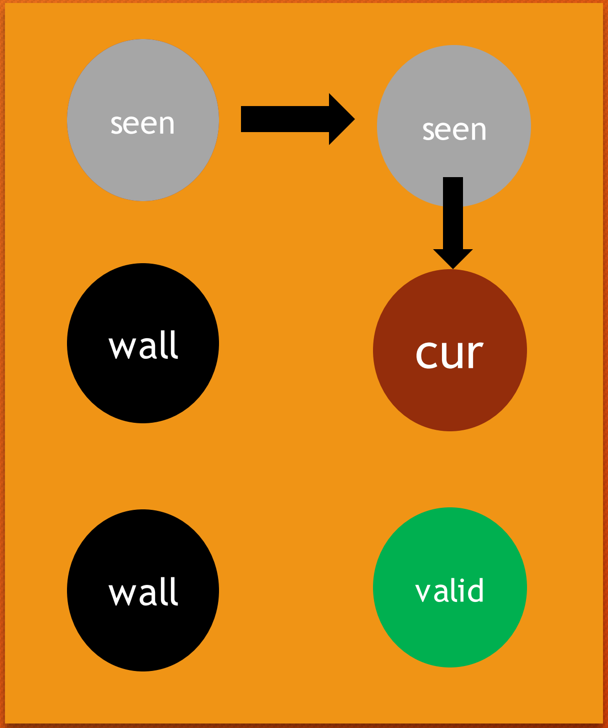
{ {0, 0}, {1,0}, { 1,1 } }

CURRENT_PATH

Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
   - Dequeue path from queue.
   - If this path ends at exit, this path is the solution!
   - If path does not end at exit:
     - For each viable neighbor of path end, make copy of path, extend by adding neighbor and enqueue it.



MAZE

PATHS

{ {0, 0}, {1,0}, { 1,1 } }

CURRENT_PATH

{ 1,2 }

VALID_NEIGHBORS

Part I: Maze solveMaze()

- Let's walk thru a very small example:

3. While there are still more paths to explore:
    - Dequeue path from queue.
    - If this path ends at exit, this path is the solution!
    - If path does not end at exit:
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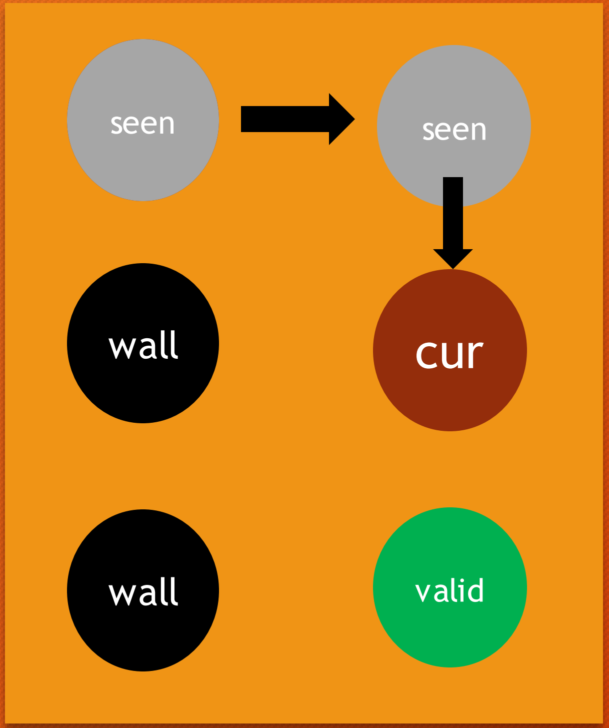


MAZE

PATHS

{ {0, 0}, {1,0}, { 1,1 } }

CURRENT_PATH

{ 1,2 }

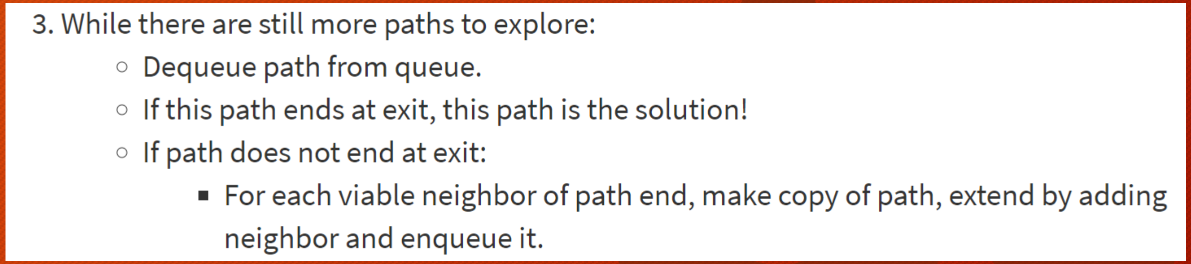
VALID_NEIGHBORS

{ {0, 0}, {1,0}, {1,1} }

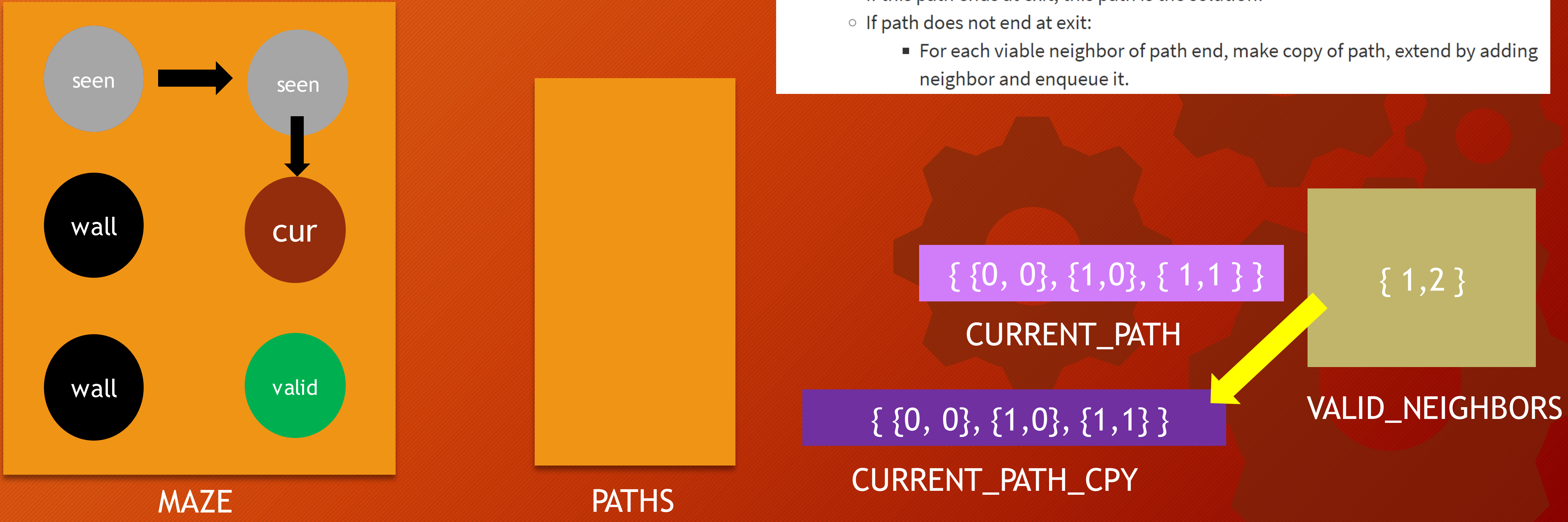
CURRENT_PATH_CPY

Part I: Maze solveMaze()

- Let's walk thru a very small example:

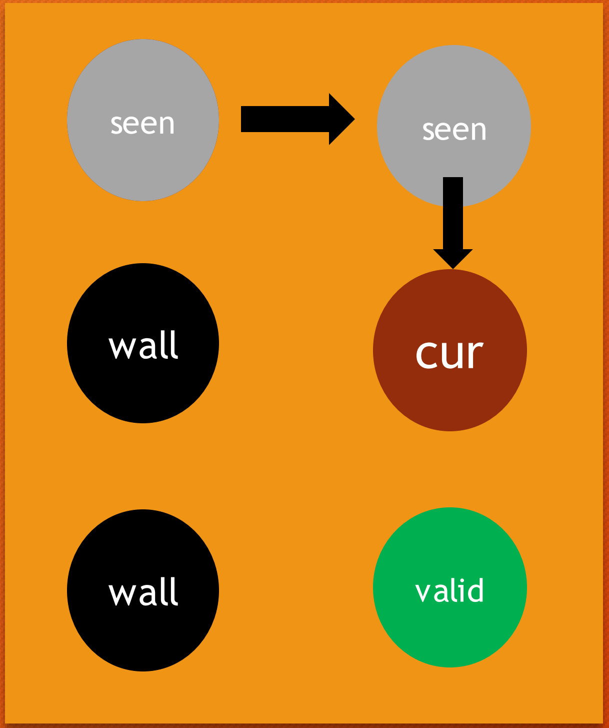


```
3. While there are still more paths to explore:
    ○ Dequeue path from queue.
    ○ If this path ends at exit, this path is the solution!
    ○ If path does not end at exit:
        ▪ For each viable neighbor of path end, make copy of path, extend by adding
          neighbor and enqueue it.
```



Part I: Maze solveMaze()

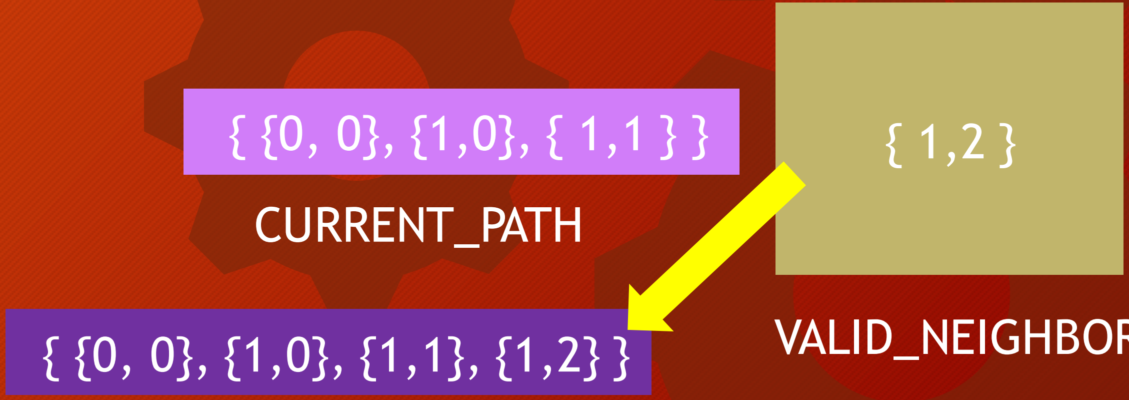
- Let's walk thru a very small example:



MAZE

PATHS

```
3. While there are still more paths to explore:
      ○ Dequeue path from queue.
      ○ If this path ends at exit, this path is the solution!
      ○ If path does not end at exit:
            ▪ For each viable neighbor of path end, make copy of path, extend by adding
              neighbor and enqueue it.
```

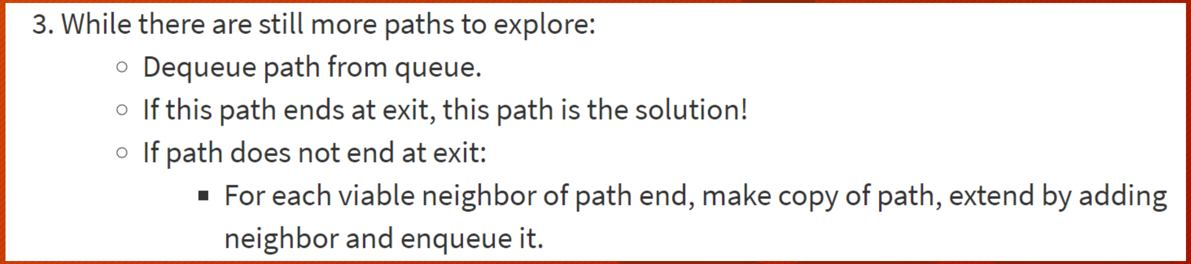


VALID_NEIGHBORS

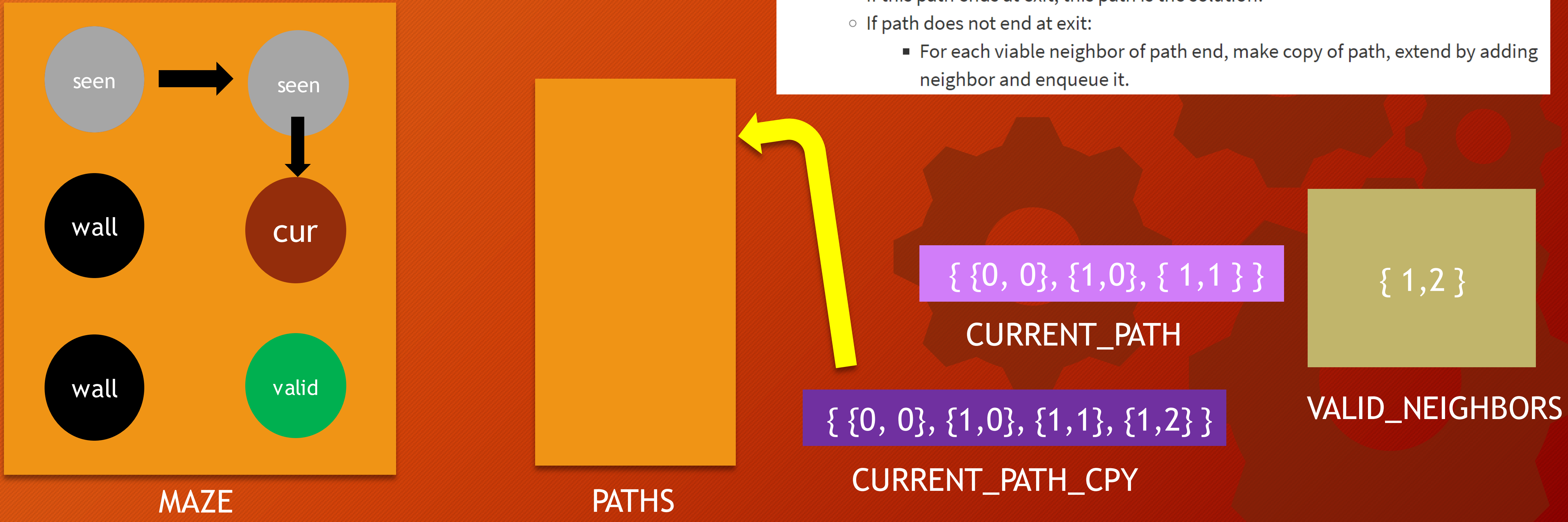
CURRENT_PATH_CPY

Part I: Maze solveMaze()

- Let's walk thru a very small example:



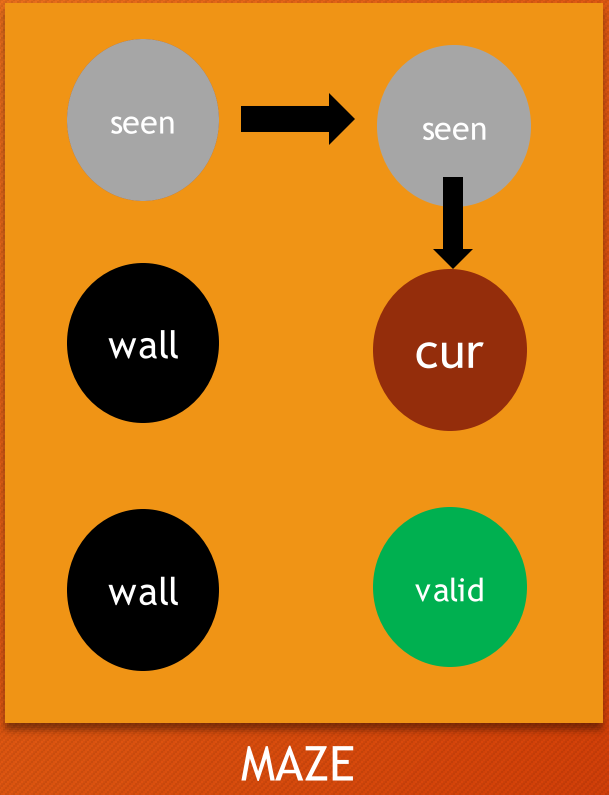
```
3. While there are still more paths to explore:
    ○ Dequeue path from queue.
    ○ If this path ends at exit, this path is the solution!
    ○ If path does not end at exit:
        ▪ For each viable neighbor of path end, make copy of path, extend by adding
          neighbor and enqueue it.
```

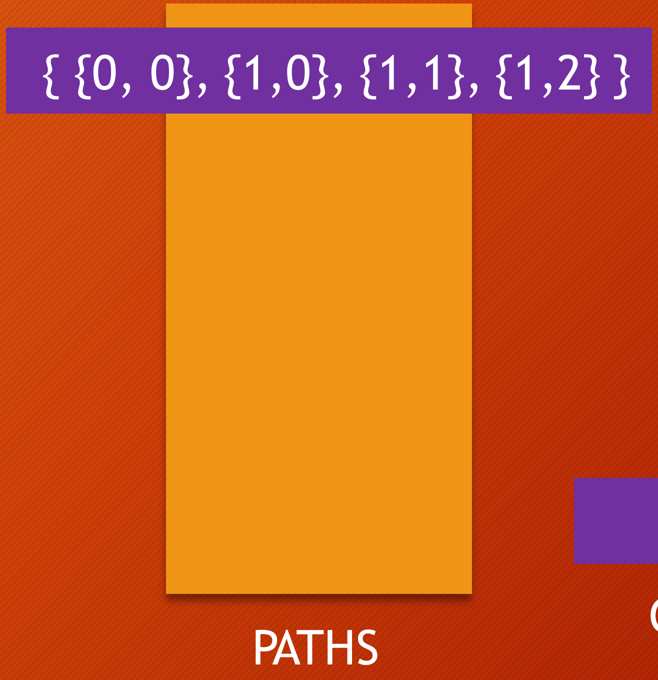


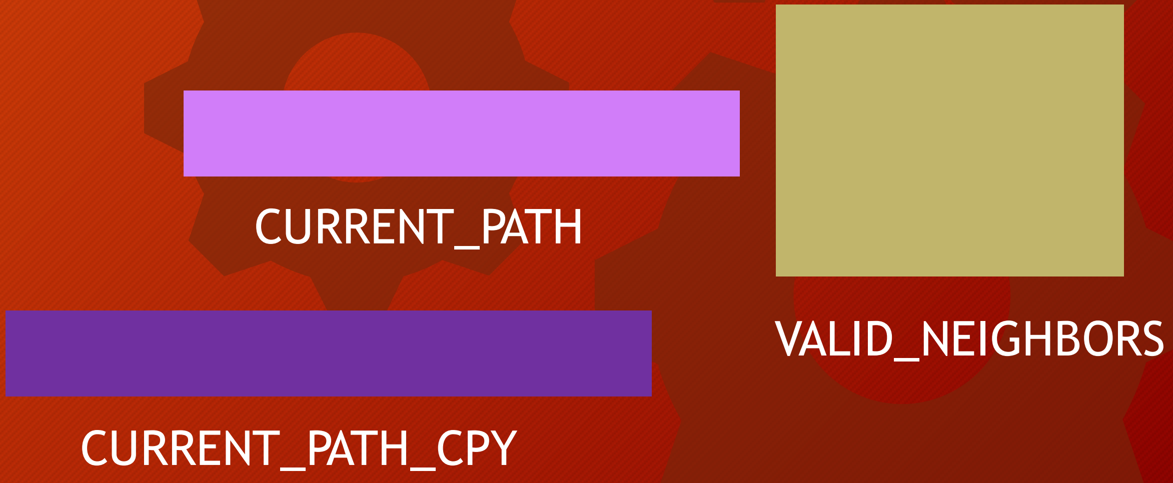
Part I: Maze solveMaze()

- Let's walk thru a very small example:

Repeat!

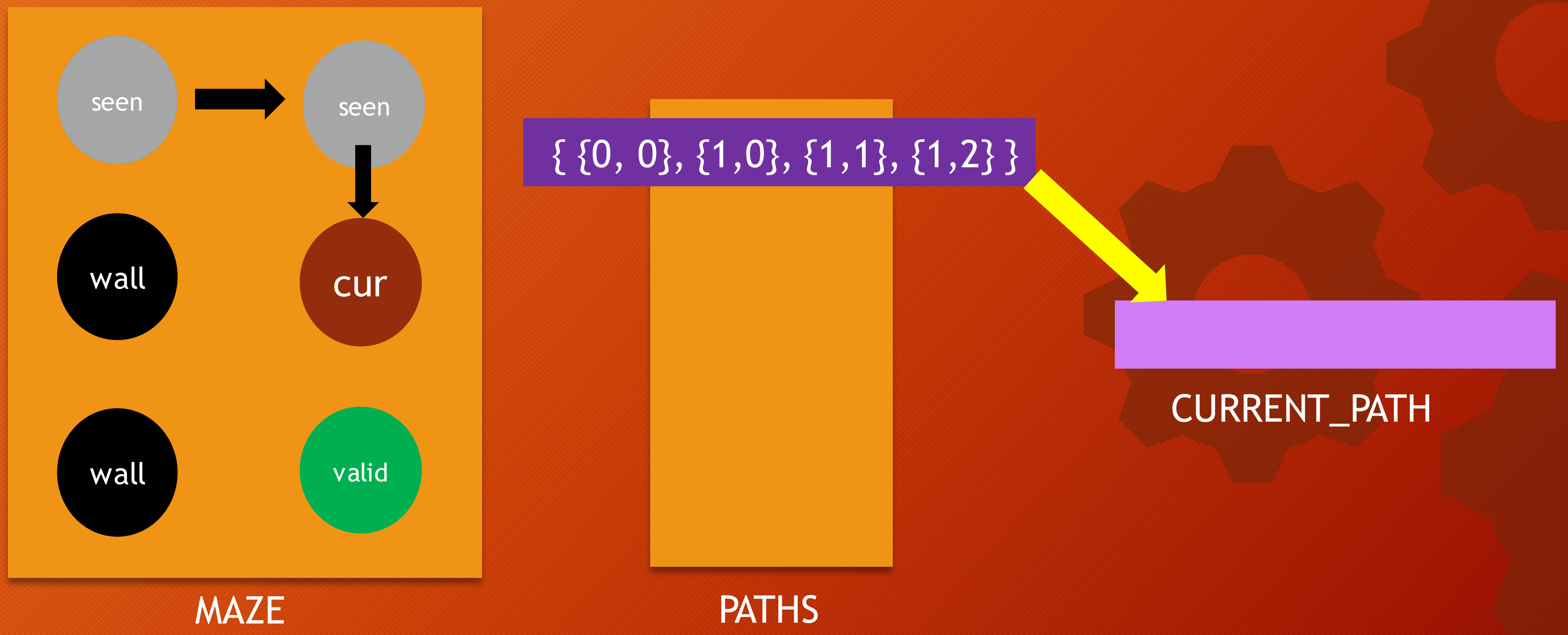






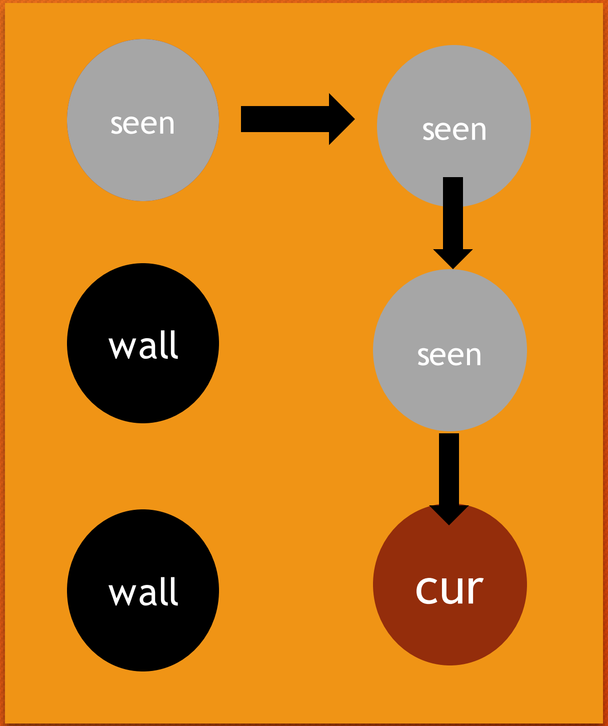
Part I: Maze solveMaze()

- Let's walk thru a very small example:



Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

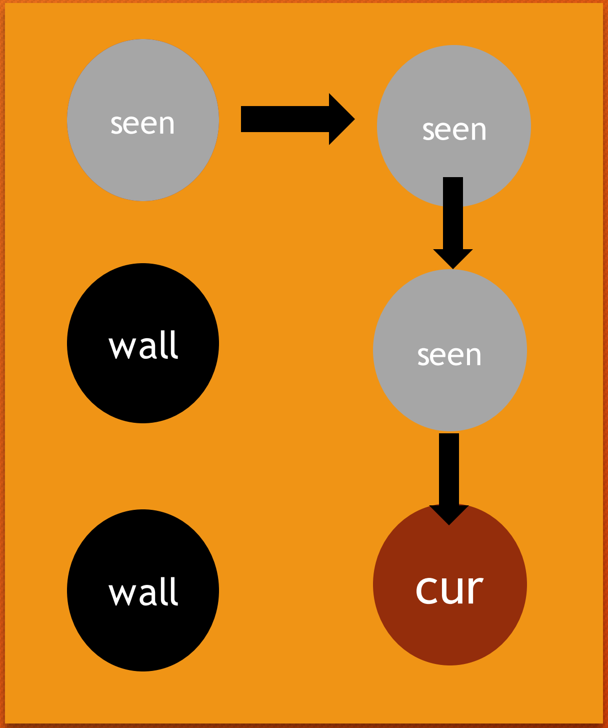
PATHS

{ {0, 0}, {1,0}, {1,1}, {1,2} }

CURRENT_PATH

Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS

{1,2} == {1,2}

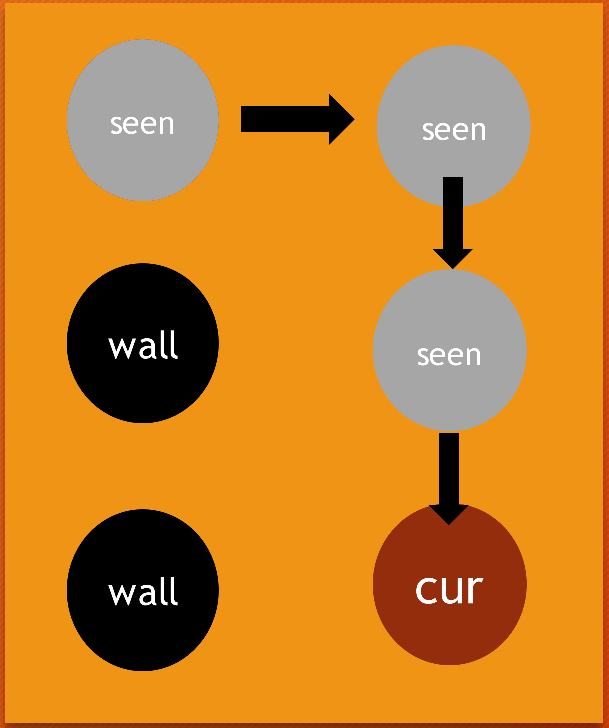
CURRENT_PATH_EXIT

{ {0, 0}, {1,0}, {1,1}, {1,2} }

CURRENT_PATH

Part I: Maze solveMaze()

- Let's walk thru a very small example:



MAZE

PATHS

Done!
Return
CURRENT_PATH

{1,2} == {1,2}

CURRENT_PATH_EXIT

{ {0, 0}, {1,0}, {1,1}, {1,2} }

CURRENT_PATH

Part I: Maze solveMaze()

- A few notes about this problem:
  - Once again, use your validMoves() helper you wrote earlier to get valid neighbors!
  - You can return an empty stack {} if you exhaust the maze and can’t find a solution.
  - You need to keep track of **visited** locations and ensure that you don’t revisit them! Else you’ll enter a loop :/
  - Follow the provided algorithm closely!
  - Read the handout for more deets about BFS!

Part I: Maze solveMaze()

- Once you get a working solution, you'll need to **add graphics** to the maze.
- We give you access to the MazeGraphics class to do this – all you need to do is call the function

```
MazeGraphics::highlightPath(Stack<GridLocation> path, string color)
```

- to highlight the current path that you're considering.
    - For more details about this documentation, look at MazeGraphics.h in your starter project!

Part I: Maze

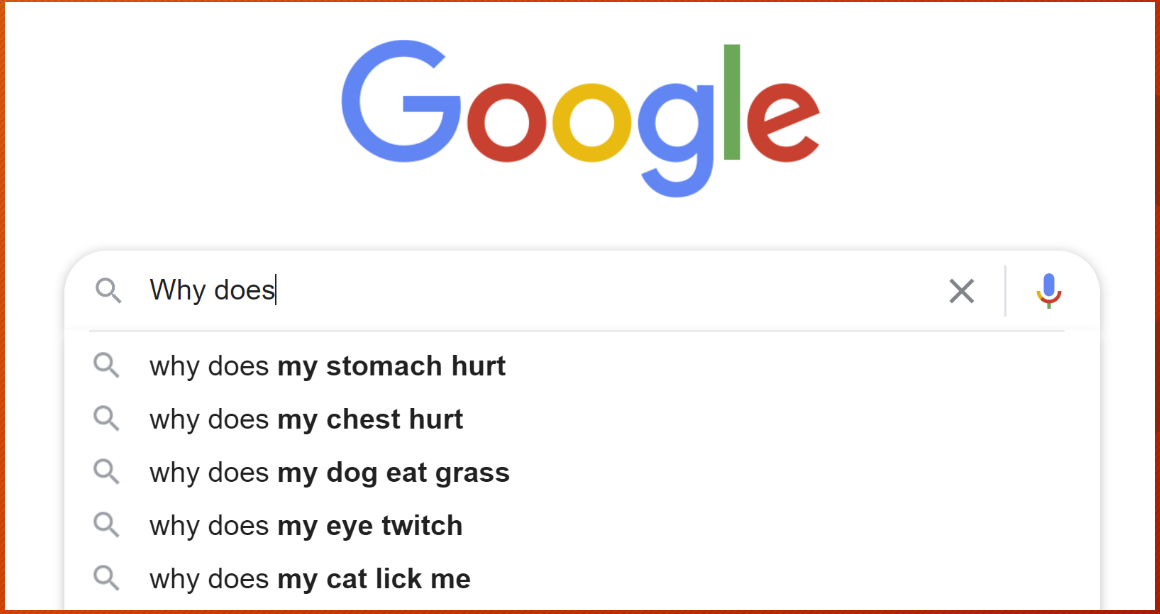
- Any questions about part 1? That’s it!

Agenda

- ~~Logistics~~
- ~~Part 1: Maze~~
- Part 2: Index

Part II: Search engine

- In this final part, you'll be putting your ADT skills to the test by creating a data structure that can power a **search engine.**
  - This is not an easy feat, so we'll go step by step!


Why does
why does **my stomach hurt**
why does **my chest hurt**
why does **my dog eat grass**
why does **my eye twitch**
why does **my cat lick me**

Shows you something about the human condition, no?

An old A6 in CS106b was "MiniBrowser," where you implement page history, autocorrect and auto scrolling! It was a toughie :p

Part II: Search engine

- The first thing you'll need to do is implement the helper function

```
string cleanToken(string token)
```

that formats the provided TOKEN and returns the formatted verson.

- Here are the steps to formatting a token:
    1. If TOKEN does not contain any letters at all, return empty string (“”);
    2. **Trim all** leading and trailing punctuation from TOKEN.
        - **,,,.EG'GS!; becomes EG'GS**
    3. Convert TOKEN to lowercase.
        - **EGGS becomes eggs**
- You might find the char functions isaplha() and ispunct() helpful here!

Part II: Search engine

- Next, you’ll need to implement the following function:

```
Set<string> gatherTokens(string bodytext)
```

- Where BODYTEXT is a string consisting of all tokens found in a webpage.
  - You must first tokenize the bodyText string into individual tokens separated by spaces. Look at stringSplit() for help there!
  - Next, clean each token with your shiny new cleanToken() function, and store them in a Set<string> you'll return!

Part II: Search engine

- Any questions about gatherTokens()?

Part II: Search engine buildIndex()

- It’s now time for you to build an **inverted index!**
  - This function takes in the name of a database file that you will parse, and a map that you will populate, pairing keywords with sets of urls that contain the keywords.

```
int buildIndex(string dbfile, Map<string, Set<string>>& index)
```

Small sample inverted index:

```
{
“seach” : { “google.com, bing.com” }
“login” : { “webkinz.com” }
}
```

Part II: Search engine buildIndex()

- The database file that you’re parsing will look something like this:
  - Basically, each collection of **2 lines** is a **url-content** combo.
  - The first line of the pair will be a URL and the second will be the text content (all in one line) of the corresponding page.
- You will need to populate the map RESULT with pairs of content tokens to sets of URL's that contain the content tokens.

db file

Pairs!

```
www.shoppinglist.com
EGGS! milk, fish,      @  bread cheese
www.rainbow.org
red ~green~ orange yellow blue indigo violet
www.dr.seuss.net
One Fish Two Fish Red fish Blue fish !!!
www.bigbadwolf.com
I'm not trying to eat you
```

Part II: Search engine buildIndex()

- Here's the important thing:
  - You've already written a function gatherTokens() that turns a string into a set of cleaned tokens! You should probably use it here…

Pairs!

db file

```
www.shoppinglist.com
EGGS! milk, fish,      @  bread cheese
www.rainbow.org
red ~green~ orange yellow blue indigo violet
www.dr.seuss.net
One Fish Two Fish Red fish Blue fish !!!
www.bigbadwolf.com
I'm not trying to eat you
```

Part II: Search engine buildIndex()

- A few tips about creating this map:
  - You’re going to need to store an entry in the map **once** every **two lines** (it takes 2 lines to get a single key-value pair) – can you manipulate a loop to help you do this?
  - readEntireFile() in filelib.h is an easy way to read an entire file into a vector using just the file name!

db file

Pairs!

```
www.shoppinglist.com
EGGS! milk, fish,      @  bread cheese
www.rainbow.org
red ~green~ orange yellow blue indigo violet
www.dr.seuss.net
One Fish Two Fish Red fish Blue fish !!!
www.bigbadwolf.com
I'm not trying to eat you
```

Part II: Search engine buildIndex()

- Some final notes about the problem:
  - Because the value in RESULT is a Set<string>, you can treat RESULT[somekey] as a Set<string> and do things like:
    - RESULT[somekey] += “hello”

db file

```
www.shoppinglist.com
EGGS! milk, fish,      @  bread cheese
www.rainbow.org
red ~green~ orange yellow blue indigo violet
www.dr.seuss.net
One Fish Two Fish Red fish Blue fish !!!
www.bigbadwolf.com
I'm not trying to eat you
```

Questions about buildIndex()?

Part II: Search engine findQueryMatches()

- In this next part, you're actually going to be servicing a user query, meaning that you'll take in a search request and return a result!

```
Set<string> findQueryMatches(Map<string, Set<string>>& index, string query)
```

- Given a specific **query** string and an **inverted index**, mapping **unique words** to **sets of urls** in which they appear, you need to return a set of url's that satisfy the **query.**
- But what does a query look like?

Part II: Search engine findQueryMatches()

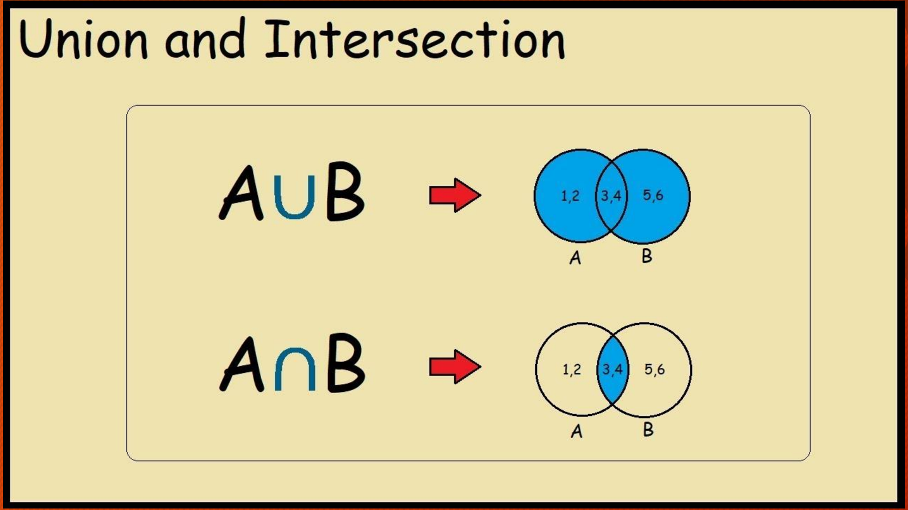
- Here’s an example query:
  - flake
- Handling this request is easy! You’d just return a list of urls in which the above word appears (in this case, www.Stanford.edu).
- Conveniently, the given paramenter INDEX does this for you – it maps a string to a set of urls in which that string appears!
  - Return index[query]
- Let’s try a more complex one…

Part II: Search engine findQueryMatches()

- Here’s an example query:
  - Fugu;   +fish
- Here we have TWO tokens! You can isolate them with stringSplit().
- Notice that the second string contains (+)! The (+) sign is a special operator in your query – it performs a set **intersection** between the left and right sets.
  - An **intersection** means the Set<string> returned should contain only the urls that contain both “fugu” AND ”fish”
- **VERY important note:** notice that the **same punctuation stripping and lowercase** rules apply to tokens in your query string
- You’ll need to keep an eye out for the (+) operator; it’ll be the first character of a query token – your string cleaning routine will attempt to remove it, so keep that in mind!

Part II: Search engine findQueryMatches()

- Here's another query:
  - Cat Dog
- Like the last example, you'll stringSplit() the line into two tokens. Because there's no operator here, you'll use set **union**, meaning the set you return should be a set of urls that **either** contain "Cat" **OR** "Dog".

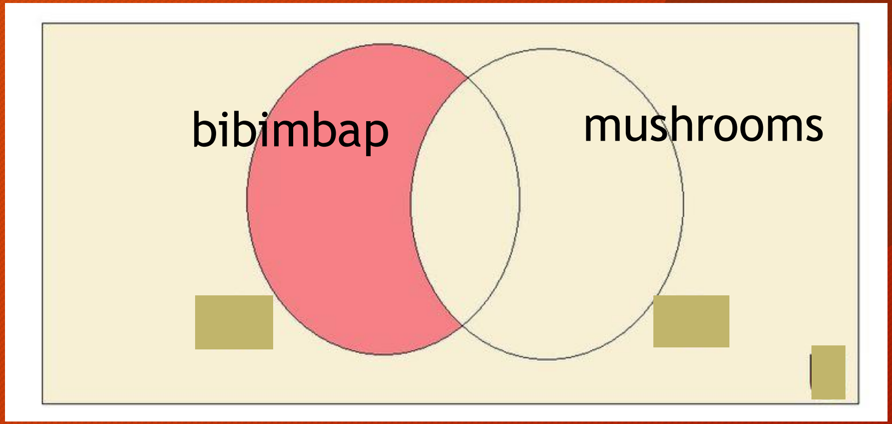


Union (no operator) – return all url's that contain at least 1 of the words!

Intersection (+ operator) – return all url's tht contain BOTH tokens (small subset!)

Part II: Search engine findQueryMatches()

- Here’s another example:
  - Bibimbap   -mushrooms
- Here we’ve introduced another example with the (-) operator. This operators performs set **subtraction**, meaning, the resulting set should contain all urls that contain “bibimbap” that DO NOT contain “mushrooms”



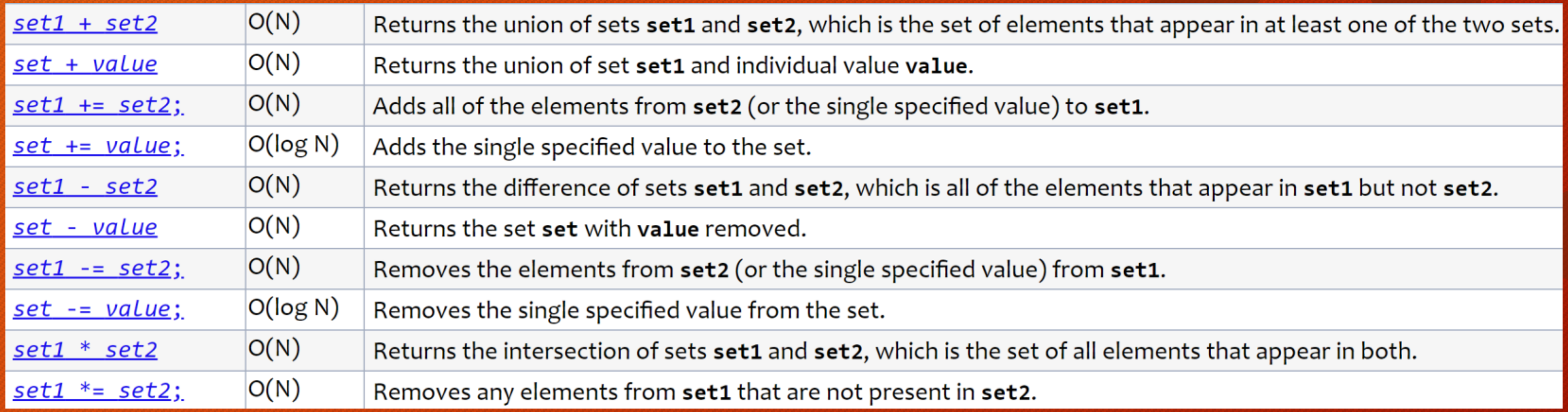
Part II: Search engine findQueryMatches()

- Here’s one last complex example:
  - CS +106B –RECURSION!!! fun
- Here we have multiple tokens in our query string. We’ll first need to split them and clean them to get
  - { “cs”, “106b”, “recursion”, “fun” }
  - You’ll of course need to remember the placement of the (+ and -) operators, but I just wanted to show you the string cleaning here.
- From there, you will process the query **from left to right.**
  - ((cs +106b) -recursion) fun

  or
  - ((“cs” intersection “106b”) subtracted from “recursion”) union “fun”

Part II: Search engine findQueryMatches()

- Some tips for findQuery Matches()
  - First and foremost, be sure to break this problem down into actionable pieces! **Please use helper functions** to solve this problem.
  - I would recommend reuising your cleanToken() helper function!
  - The tricky set operation stuff isn't actually as spooky as it might initially seem – check out this set documentation and bask in the operators we've provided you ☺ (you'll probably want +, *, and -)



`set1 + set2`	O(N)	Returns the union of sets **set1** and **set2**, which is the set of elements that appear in at least one of the two sets.
`set + value`	O(N)	Returns the union of set **set1** and individual value **value**.
`set1 += set2;`	O(N)	Adds all of the elements from **set2** (or the single specified value) to **set1**.
`set += value;`	O(log N)	Adds the single specified value to the set.
`set1 - set2`	O(N)	Returns the difference of sets **set1** and **set2**, which is all of the elements that appear in **set1** but not **set2**.
`set - value`	O(N)	Returns the set **set** with **value** removed.
`set1 -= set2;`	O(N)	Removes the elements from **set2** (or the single specified value) from **set1**.
`set -= value;`	O(log N)	Removes the single specified value from the set.
`set1 * set2`	O(N)	Returns the intersection of sets **set1** and **set2**, which is the set of all elements that appear in both.
`set1 *= set2;`	O(N)	Removes any elements from **set1** that are not present in **set2**.

Part II: Search engine findQueryMatches()

- Some more tips for findQuery Matches()
  - You can always assume that a (+ or -) operator, if extant, will appear as the first character of a query token. You **cannot** assume that the characters following are non-punctuation characters
    - Ex. { Apple +windows -!!linux }
  - Remember (because this causes much grief later) that your query needs to be **case insensitive**. “Apple” and “apple” should be looked up the same (“apple”)!

Questions about findQueryMatches?

- This part is pretty complex, remember to decompose!

GREETINGS, STRANGER.
WHATEVER QUEST DRIVES YOU, *ABANDON IT.*
YOU SHALL FIND NO ANSWERS IN THESE DESOLATE WASTES.
I KNEW I WOULDN'T.
I GUESS I ... JUST HAD TO SEE.
I HATE FEELING DESPERATE ENOUGH TO VISIT THE SECOND PAGE OF GOOGLE RESULTS.

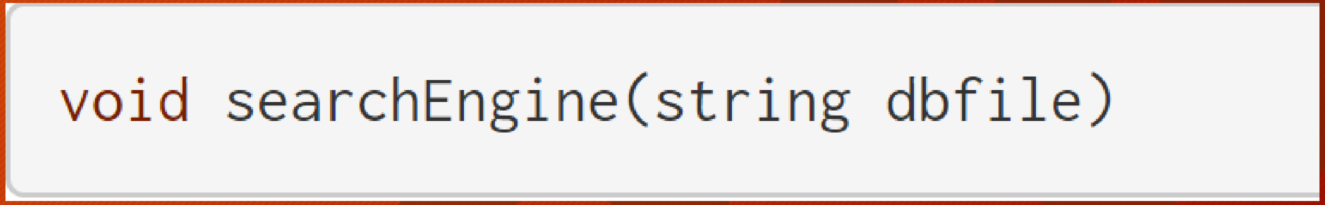
Part II: Search engine building searchEngine()

- It’s finally time for you to put your querying skills to the test - you’re going to write a function that serves as a search engine!
- You’ll be implementing the following function:

```
void searchEngine(string dbfile)
```

Part II: Search engine building searchEngine()

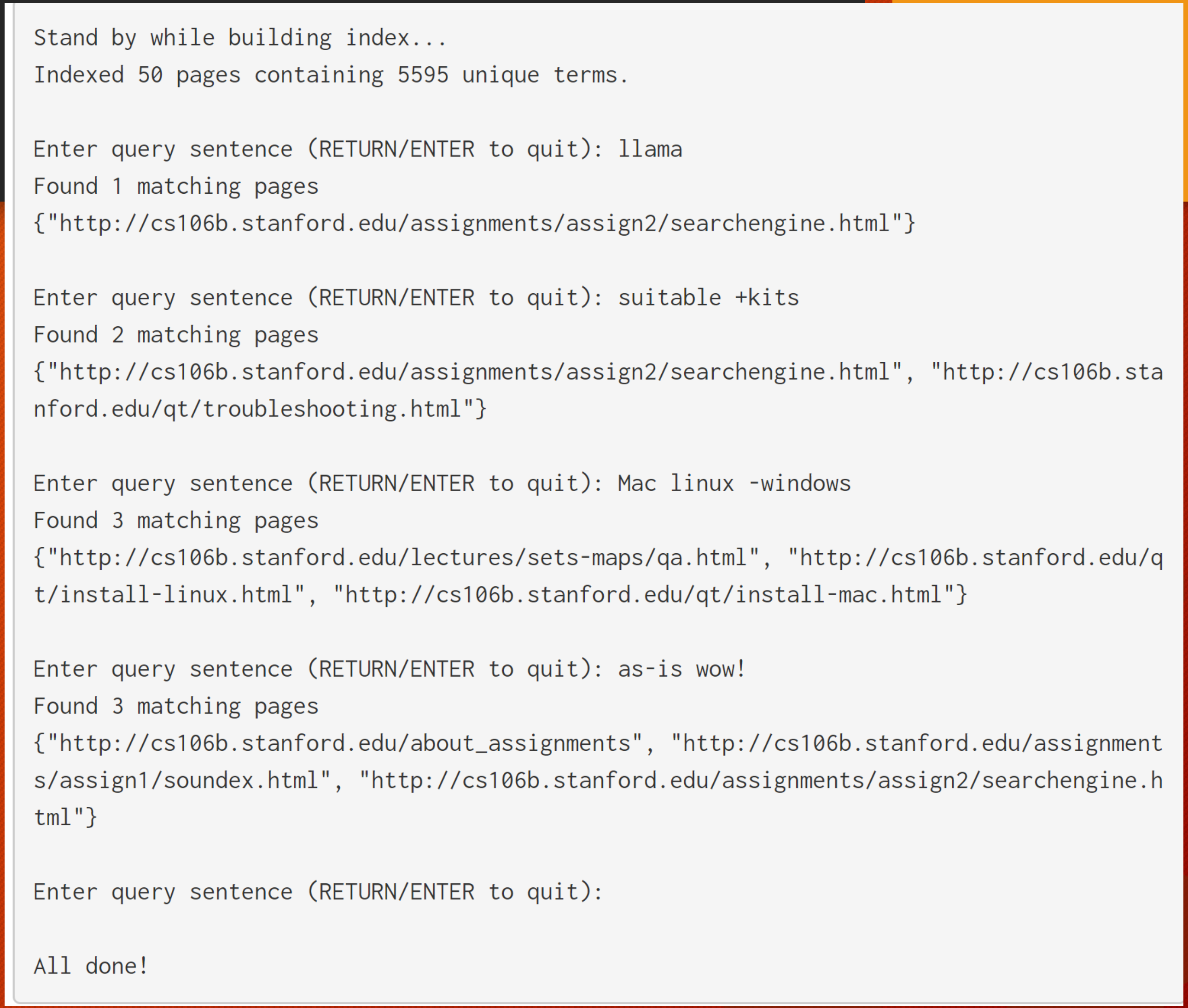
- You will need to read in the provided DBFILE and convert it into an inverted index.
  - You've already written the functions to do this ☺
- You'll then need to display to the user how many URL's were processed to build the index and how many distinct words were found in all of the files
  - Think about your data structures - is this data stored anywhere?



```
void searchEngine(string dbfile)
```

Part II: Search engine building searchEngine()

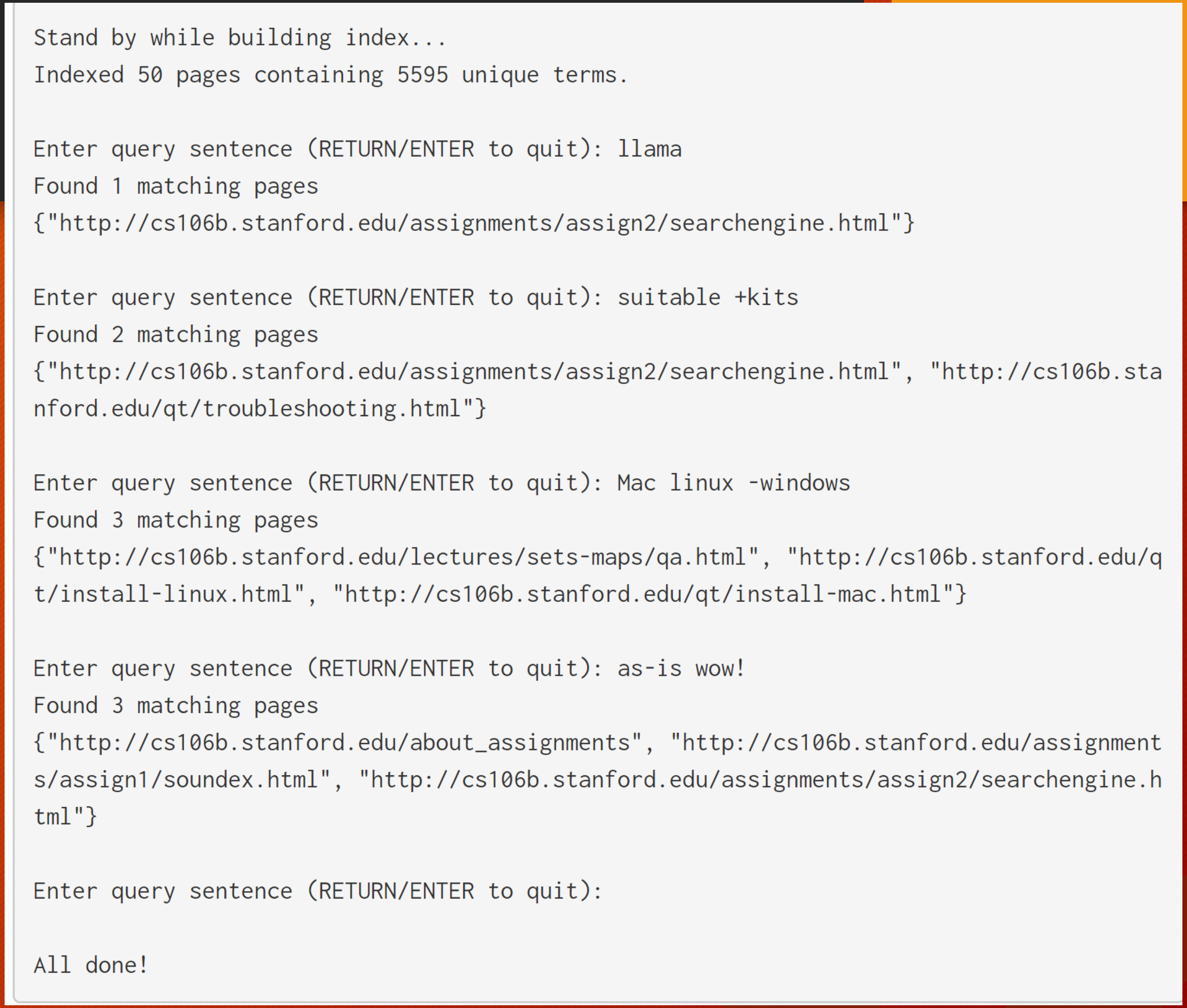
- You'll then need to repeatedly prompt the user for search queries like the ones discussed earlier.
    - You will find the appropriate Set<string> result for that query and print it.
- Repeat until the user enters "", and then exit the program.
- Your goal is to match this functionality exactly!



```
Stand by while building index...
Indexed 50 pages containing 5595 unique terms.

Enter query sentence (RETURN/ENTER to quit): llama
Found 1 matching pages
{"http://cs106b.stanford.edu/assignments/assign2/searchengine.html"}

Enter query sentence (RETURN/ENTER to quit): suitable +kits
Found 2 matching pages
{"http://cs106b.stanford.edu/assignments/assign2/searchengine.html", "http://cs106b.sta
nford.edu/qt/troubleshooting.html"}

Enter query sentence (RETURN/ENTER to quit): Mac linux -windows
Found 3 matching pages
{"http://cs106b.stanford.edu/lectures/sets-maps/qa.html", "http://cs106b.stanford.edu/q
t/install-linux.html", "http://cs106b.stanford.edu/qt/install-mac.html"}

Enter query sentence (RETURN/ENTER to quit): as-is wow!
Found 3 matching pages
{"http://cs106b.stanford.edu/about_assignments", "http://cs106b.stanford.edu/assignment
s/assign1/soundex.html", "http://cs106b.stanford.edu/assignments/assign2/searchengine.h
tml"}

Enter query sentence (RETURN/ENTER to quit):

All done!
```

Part II: Search engine building searchEngine()

- Some notes about searchEngine()
    - You shouldn't have to write a ton of new code here - virtually all of the lifting has already been done by the other functions in the program - you're just bringing them together now!
    - If you've written some great tests for your helper functions, this part should just work! If you encounter a bug, try to isolate it to a particular function by using the debugger!



```
Stand by while building index...
Indexed 50 pages containing 5595 unique terms.

Enter query sentence (RETURN/ENTER to quit): llama
Found 1 matching pages
{"http://cs106b.stanford.edu/assignments/assign2/searchengine.html"}

Enter query sentence (RETURN/ENTER to quit): suitable +kits
Found 2 matching pages
{"http://cs106b.stanford.edu/assignments/assign2/searchengine.html", "http://cs106b.sta
nford.edu/qt/troubleshooting.html"}

Enter query sentence (RETURN/ENTER to quit): Mac linux -windows
Found 3 matching pages
{"http://cs106b.stanford.edu/lectures/sets-maps/qa.html", "http://cs106b.stanford.edu/q
t/install-linux.html", "http://cs106b.stanford.edu/qt/install-mac.html"}

Enter query sentence (RETURN/ENTER to quit): as-is wow!
Found 3 matching pages
{"http://cs106b.stanford.edu/about_assignments", "http://cs106b.stanford.edu/assignment
s/assign1/soundex.html", "http://cs106b.stanford.edu/assignments/assign2/searchengine.h
tml"}

Enter query sentence (RETURN/ENTER to quit):

All done!
```

Any questions about Part II?

That’s it!

Congrats!

Nice job!

Great work!

You did it!

Stack Efron, 106B alum, congratulating you on a job well done!