# CSE 12: PA3

1-21-21

Focus: PA3, BFS & DFS Maze Search

# Tips on PAs overall

- If you know you can’t finish, at least get the Gradescope Questions done.
  - Can get points back from Autograded portion, but not from the questions
- Look at the starter code! It is there to help and guide you
- Start early! The sooner we can help you the better you will do

# PA 3

# PA3 Breakdown

- Solving a 2D `Maze` represented by a 2D `Square` array (`Square[][]`)
- To maintain your search data and results as you progress through the maze, you will be implementing the `SearchWorklist` interface *twice*
  - Once using a queue to perform **BFS** in the `QueueWorklist` class
  - Once using a stack to perform **DFS** in the `StackWorklist` class
- To solve it, you will be implementing the `solve` method in the `MazeSolver` class
  - This will work by traversing the `previous` fields of squares from `finish` to `start`
- To see the solution path, you will implement the method `storePath()` in Maze.java
- You will also be making JUnit tests to test your `solve` method and two worklist classes

# Some recommendations for PA3

- You can use java built-in tools like the `Stack` class and `LinkedList` interface
- Check out the provided tests in `TestSolvers.java` (provided with this discussion) to see how to create tests that will compare an expected maze solution against what your `solve` method returns
- Create dummy methods (that do nothing meaningful) for the `StackWorklist` class, `QueueWorklist` class, and `solve` method of the `MazeSolver` class
  - `TestSolvers.java` will not compile until the above items are implemented with the bare minimum components
  - We recommend creating dummy methods so you can compile and run `TestSolvers.java` and work incrementally on each of the methods you're to implement
  - example dummy methods are provided with this discussion to demonstrate what we mean as well as 2 additional tests on BFS and DFS solutions for the maze during discussion today with some extra comments to clarify parts of `TestSolvers.java`. You can find them on the course Github in the discussion directory.

# DFS and BFS with a Maze

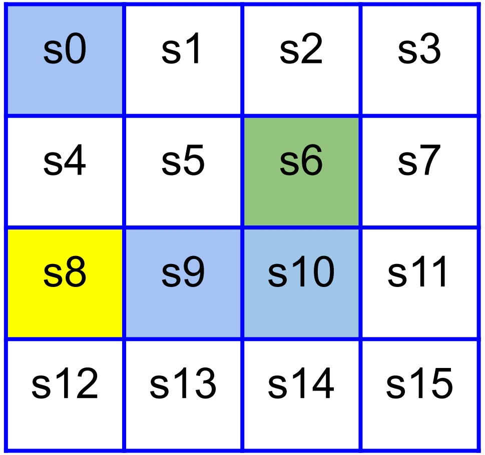
To mirror the tasks for PA3, we will be going through the two following searches step-by-step to find solution paths for a maze:

- **DFS** using a stack
- **BFS** using a queue

The following step-by-step processes should be relevant to your task of implementing the `solve` method in the `MazeSolver` class

# An example starting Maze and key

| | |
|---|---|
| 🟨 | Start square |
| 🟩 | Finish square (goal) |
| □ | Empty, unvisited space |
| 🟦 | Wall |
| ▨ | Visited |



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

**Remember:** Order matters when adding neighbors of a square to a worklist. For PA3, that order is: **NORTH, SOUTH, EAST, WEST**

# DFS (Depth First Search)

Stepping through an example

# Algorithm Pseudocode

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

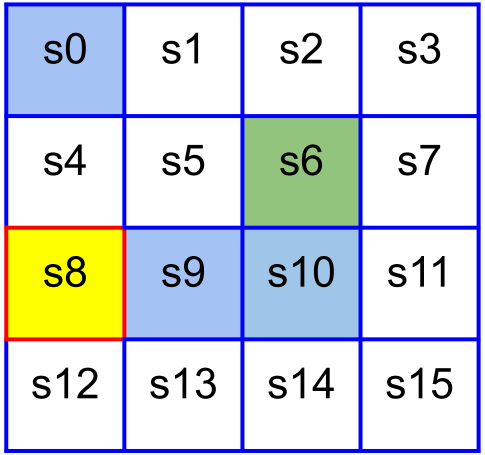
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | | |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | | |
| s13 | | |
| s14 | | |
| s15 | | |

- Create a new stack
- Push s8 onto the stack
- Mark s8 as visited

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s8 | | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | | |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | | |
| s13 | | |
| s14 | | |
| s15 | | |

- Pop the top element off of the stack (s8)

**TOP** **BOTTOM**

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | | |
| s14 | | |
| s15 | | |

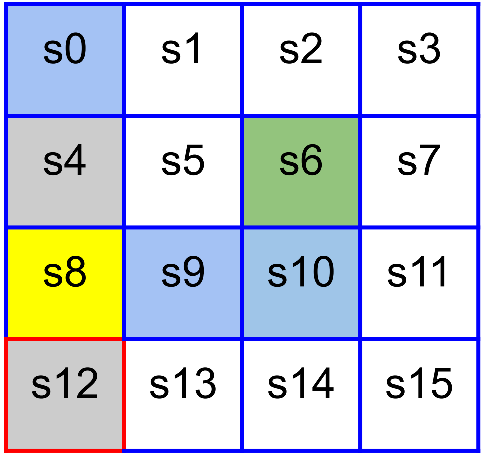
- s8 neighbors: s4, s12, s9
- Neighbors to push: s4, s12 (s9 is a wall)
- For s4, s12: Mark as visited, Set previous to s8
- Push s4, s12

Remember: For PA3 order matters (NORTH, SOUTH, EAST, WEST)

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s12 | s4 | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

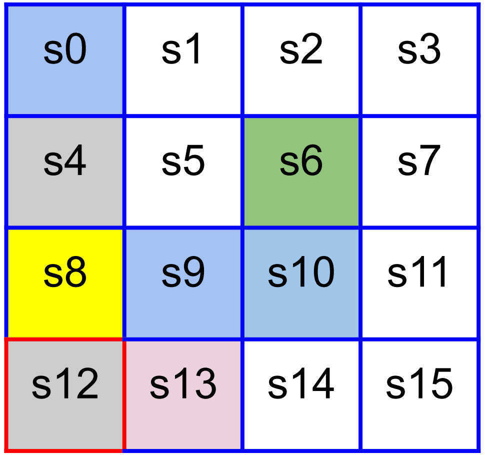
| **square** | **visited** | **prev** |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | | |
| s14 | | |
| s15 | | |

- Pop the top element off of the stack (s12)

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s4 | | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

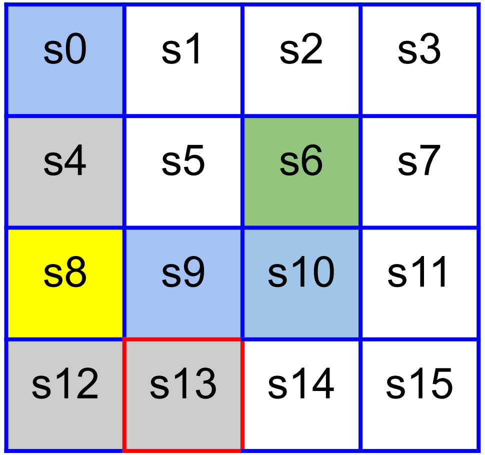
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | | |
| s15 | | |

- s12 neighbors: s8, s13
- Neighbors to push: s13
- For s13: Mark as visited, set prev to s12
- Push s13

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s13 | s4 | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

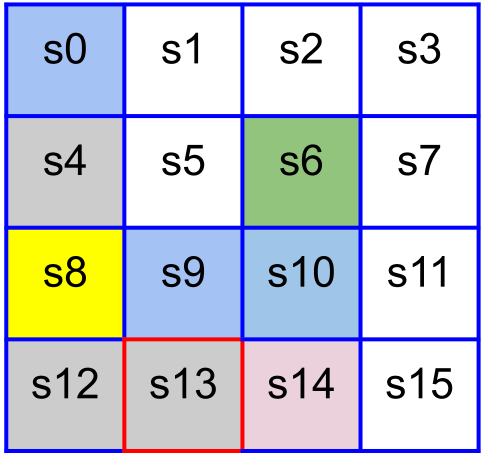
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | | |
| s15 | | |

- Pop the top element off of the stack (s13)

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s4 | | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

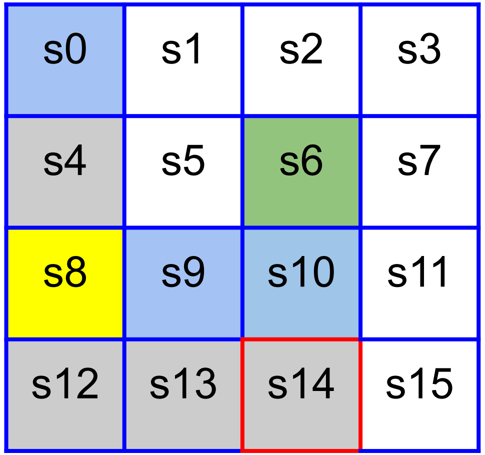
- s13 neighbors: s9, s14, s12
- Neighbors to push: s14
- For s14: Mark as visited, set prev to s13
- Push s14

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s14 | s4 | | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | | |

- Pop the top element off of the stack (s14)

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s4 | | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

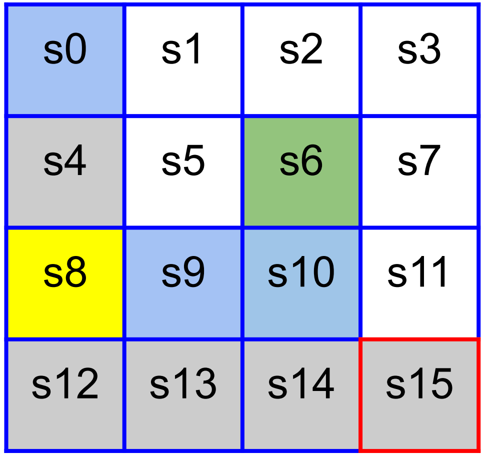
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

- s14 neighbors: s10, s15, s13
- Neighbors to push: s15
- For s15: Mark as visited, Set previous to s14
- Push s15

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s15 | s4 | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

- Pop the top element off of the stack (s15)

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s4 | | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

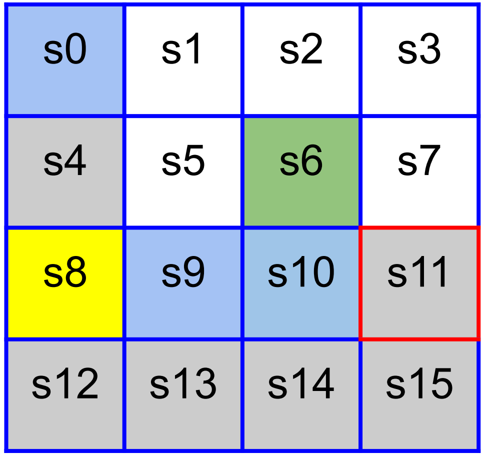
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

- s15 neighbors: s11, s14
- Neighbors to push: s11
- For s11: Mark as visited, Set previous to s15
- Push s11

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s11 | s4 | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

- Pop the top element off of the stack (s11)

**TOP** **BOTTOM**

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s4 |  |  |  |  |  |  |  |  |  |

| square | visited | prev |
|---|---|---|
| s1 |  |  |
| s2 |  |  |
| s3 |  |  |
| s4 | true | s8 |
| s5 |  |  |
| s6 |  |  |
| s7 |  |  |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

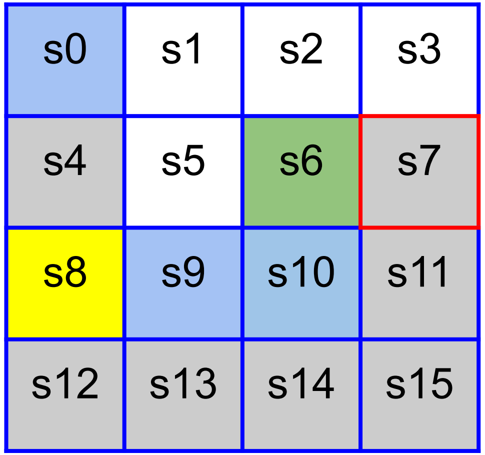
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | true | s11 |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

- s11 neighbors: s7, s10, s15
- Neighbors to push: s7
- For s7: Mark as visited, Set previous to s11
- Push s7

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s7 | s4 | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

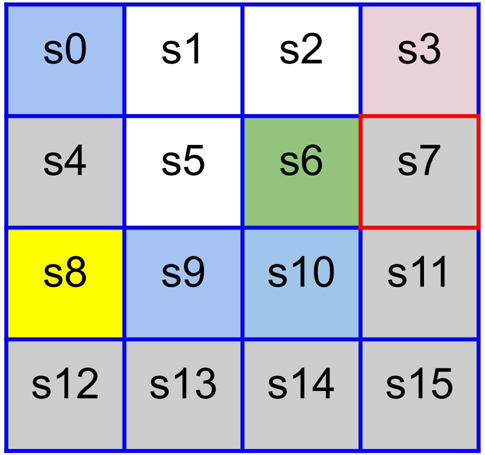
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | true | s11 |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

- Pop the top element off of the stack (s7)

**TOP** **BOTTOM**

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s4 | | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

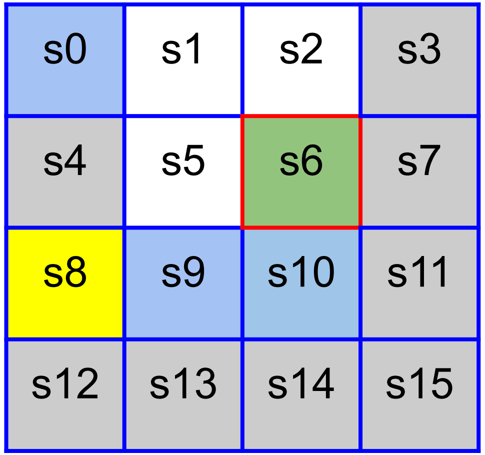
- s7 neighbors: s3, s11, s6
- Neighbors to push: s3, s6
- For s3, s6: Mark as visited, Set previous to s7
- Push s3, s6

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s6 | s3 | s4 | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | true | s7 |
| s4 | true | s8 |
| s5 | | |
| s6 | true | s7 |
| s7 | true | s11 |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

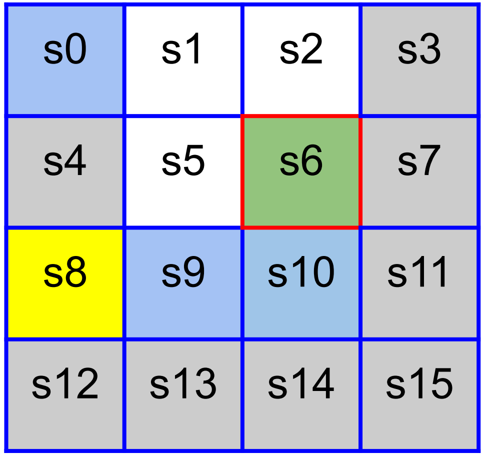
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | true | s7 |
| s4 | true | s8 |
| s5 | | |
| s6 | true | s7 |
| s7 | true | s11 |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

- Pop the top element off of the stack (s6)

**TOP** **BOTTOM**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s3 | s4 | | | | | | | | |

```
initialize wl to be a new empty Stack
push the start square to the Stack
mark the start as visited
while wl is not empty:
  let current = pop the first element from Stack
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      push the neighbor to the Stack
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

- Return s6
- 
- WE ARE DONE!!!! YAY!

**TOP** **BOTTOM**

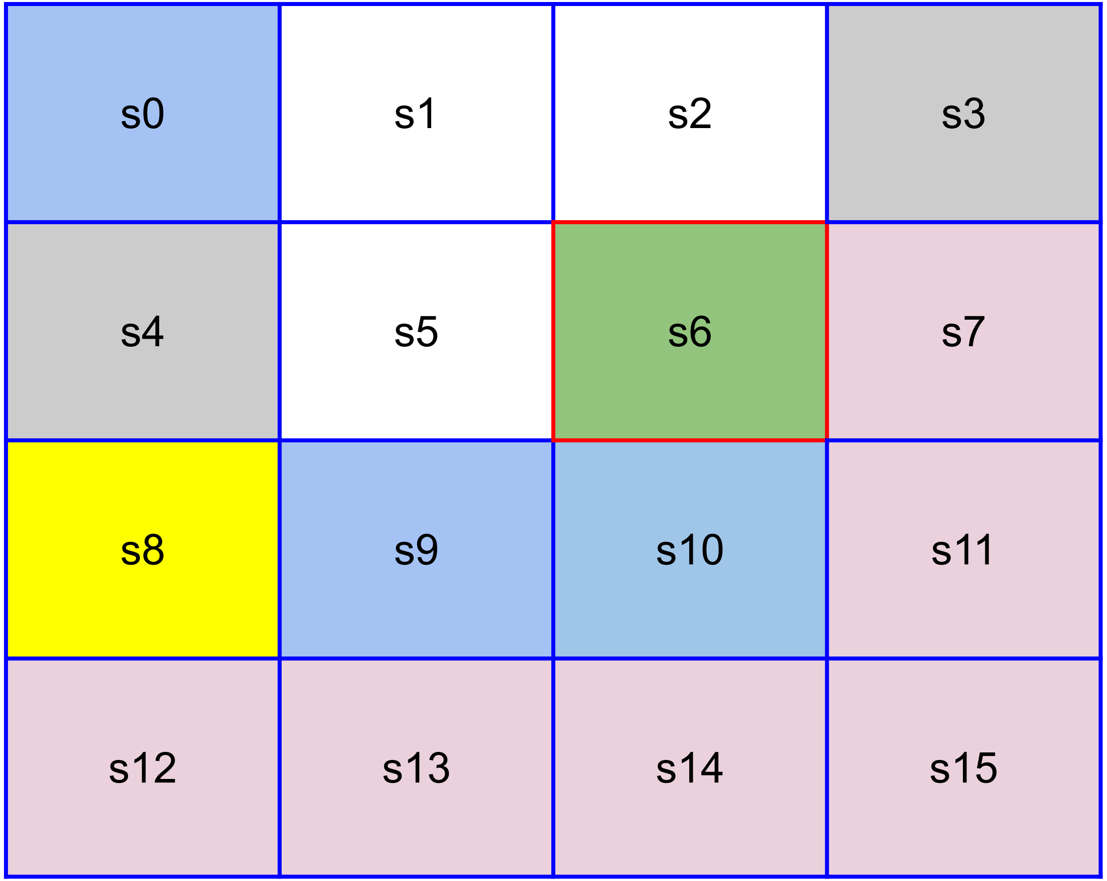
|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s3 | s4 |  |  |  |  |  |  |  |  |

| square | visited | prev |
|---|---|---|
| s1 |  |  |
| s2 |  |  |
| s3 | true | s7 |
| s4 | true | s8 |
| s5 |  |  |
| s6 | true | s7 |
| s7 | true | s11 |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

# How do we get the solution path with just the finish square (s6) returned?

Work backwards from finish to start!

- Check the finish square's previous square
- Check that square's previous square, then the next, and so forth until you hit the start square
- This gives you the solution path in reverse!



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

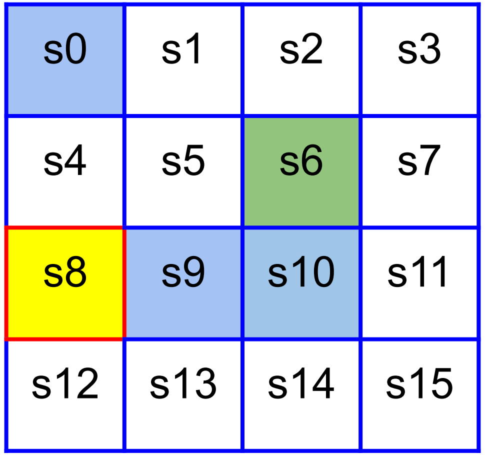
**Path solution:** s8, s12, s13, s14, s15, s11, s7, s6

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | true | s7 |
| s4 | true | s8 |
| s5 | | |
| s6 | true | s7 |
| s7 | true | s11 |
| s8 | true | --- |
| s11 | true | s15 |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | true | s14 |

# BFS (Breadth First Search)

Stepping through an example

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

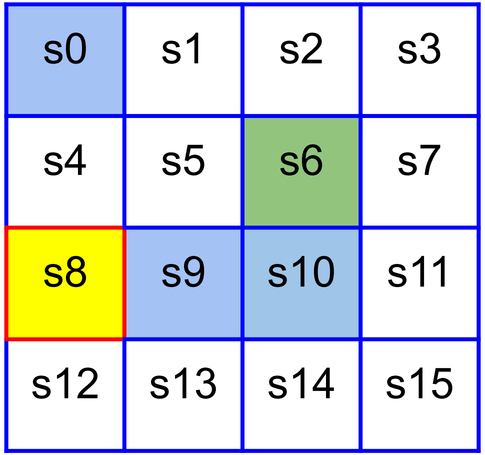
- Create a new queue
- enqueue s8 onto the queue
- Mark s8 as visited

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s8 | | | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | | |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | | |
| s13 | | |
| s14 | | |
| s15 | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

- Dequeue the first element of the queue (s8)

FRONT BACK

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | | |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | | |
| s13 | | |
| s14 | | |
| s15 | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

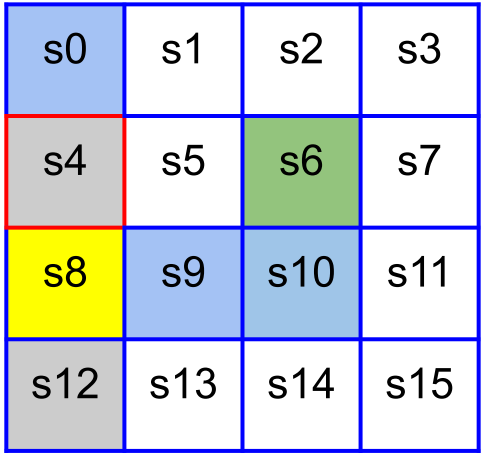
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | | |
| s14 | | |
| s15 | | |

- s8 neighbors: s4, s12, s9
- Neighbors to enqueue: s4, s12
- For s4, s12: mark as visited & set prev to s8
- enqueue s4, s12

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s4 | s12 | | | | | | | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

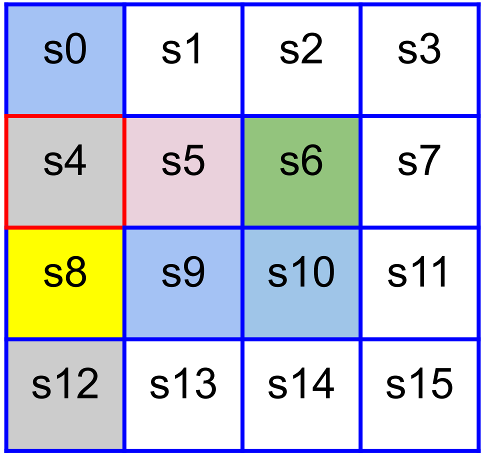
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | | |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | | |
| s14 | | |
| s15 | | |

- Dequeue the first element of the queue (s4)

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s12 | | | | | | | | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

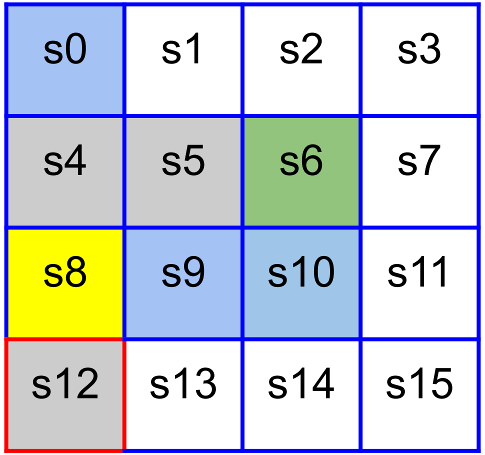
- s4 neighbors: s0, s8, s5
- Neighbors to enqueue: s5 (s8 visited, s0 wall)
- For s5: mark as visited & set prev to s4
- enqueue s5

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s12 | s5 | | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | | |
| s14 | | |
| s15 | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

| square | visited | prev |
|---|---|---|
| s1 |  |  |
| s2 |  |  |
| s3 |  |  |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 |  |  |
| s7 |  |  |
| s8 | true | --- |
| s11 |  |  |
| s12 | true | s8 |
| s13 |  |  |
| s14 |  |  |
| s15 |  |  |

- Dequeue the first element of the queue (s12)

**FRONT** **BACK**

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s5 |  |  |  |  |  |  |  |  |  |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```

| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

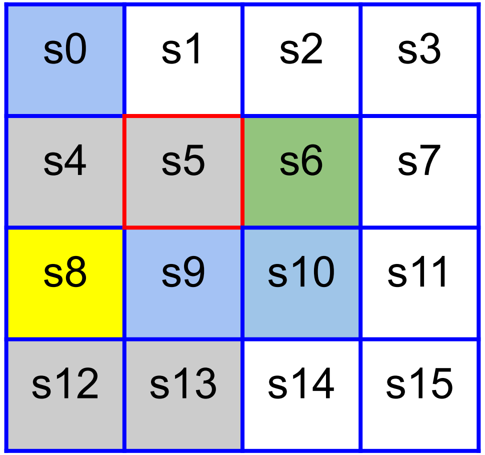
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | | |
| s15 | | |

- s12 neighbors: s8, s13
- Neighbors to enqueue: s13 (s8 visited)
- For s13: mark as visited & set prev to s12
- enqueue s13

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s5 | s13 | | | | | | | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

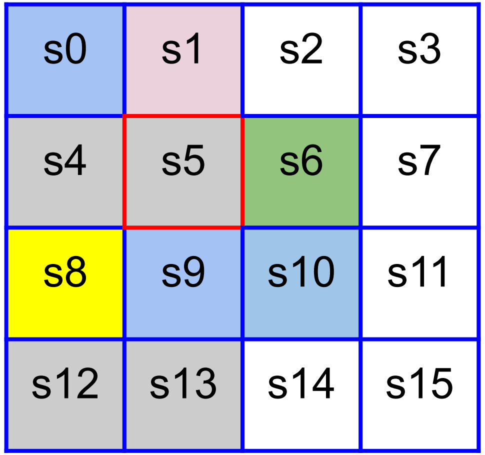
| square | visited | prev |
|---|---|---|
| s1 | | |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | | |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | | |
| s15 | | |

- Dequeue the first element of the queue (s5)

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s13 | | | | | | | | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

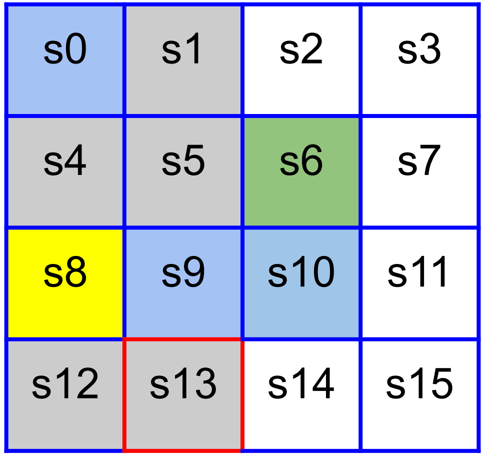
| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | | |
| s15 | | |

- s5 neighbors: s1, s9, s6, s4
- Neighbors to enqueue: s1, s6 (s4 visited, s9 wall)
- For s1, s6: mark as visited & set prev to s5
- enqueue s1, s6

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s13 | s1 | s6 | | | | | | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

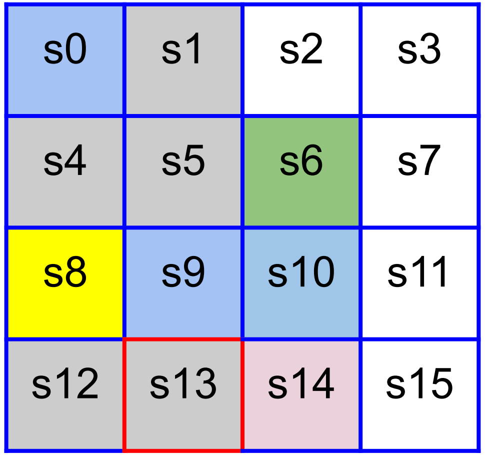
| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 | | |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | | |
| s15 | | |

- Dequeue the first element of the queue (s13)

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s1 | s6 | | | | | | | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

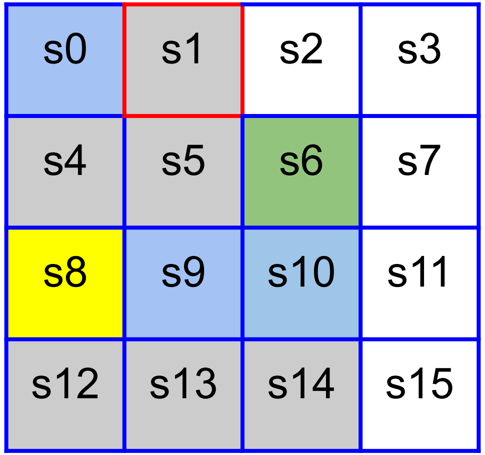
- s13 neighbors: s9, s14, s12
- Neighbors to enqueue: s14 (s12 visited, s9 wall)
- For s14: mark as visited & set prev to s13
- enqueue s14

**FRONT** **BACK**

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s1 | s6 | s14 |  |  |  |  |  |  |  |

| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 |  |  |
| s3 |  |  |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 |  |  |
| s8 | true | --- |
| s11 |  |  |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 |  |  |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

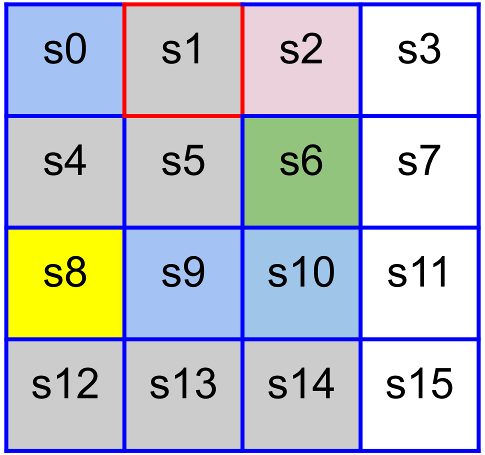
- Dequeue the first element of the queue (s1)

**FRONT** **BACK**

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s6 | s14 |  |  |  |  |  |  |  |  |

| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 |  |  |
| s3 |  |  |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 |  |  |
| s8 | true | --- |
| s11 |  |  |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 |  |  |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

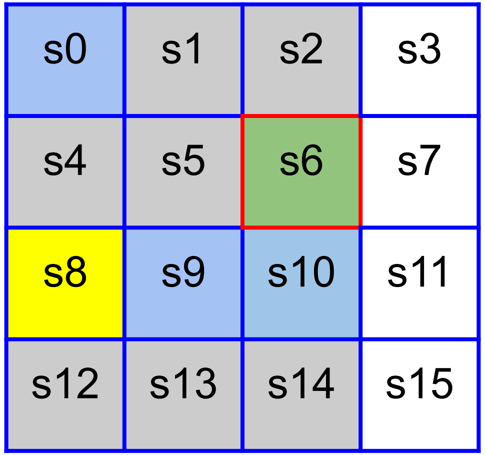
- s1 neighbors: s5, s2, s0
- Neighbors to enqueue: s2 (s5 visited, s0 wall)
- For s2: mark as visited & set prev to s1
- enqueue s2

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s6 | s14 | s2 | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 | true | s1 |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | | |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



|  |  |  |  |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

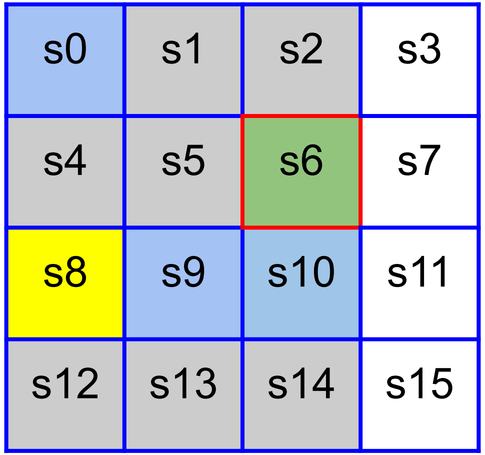
- Dequeue the first element of the queue (s6)

**FRONT** **BACK**

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| s14 | s2 |  |  |  |  |  |  |  |  |

| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 | true | s1 |
| s3 |  |  |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 |  |  |
| s8 | true | --- |
| s11 |  |  |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 |  |  |

```
initialize wl to be a new empty Queue
enqueue the start square to the Queue
mark the start as visited
while wl is not empty:
  let current = dequeue the first element from Queue
  if current is the finish square
    return current
  else
    for each neighbor of current that isn't a wall and isn't visited
      mark the neighbor as visited
      set the previous of the neighbor to current
      enqueue the neighbor to the Queue
if the loop ended, return null (no path found)
```



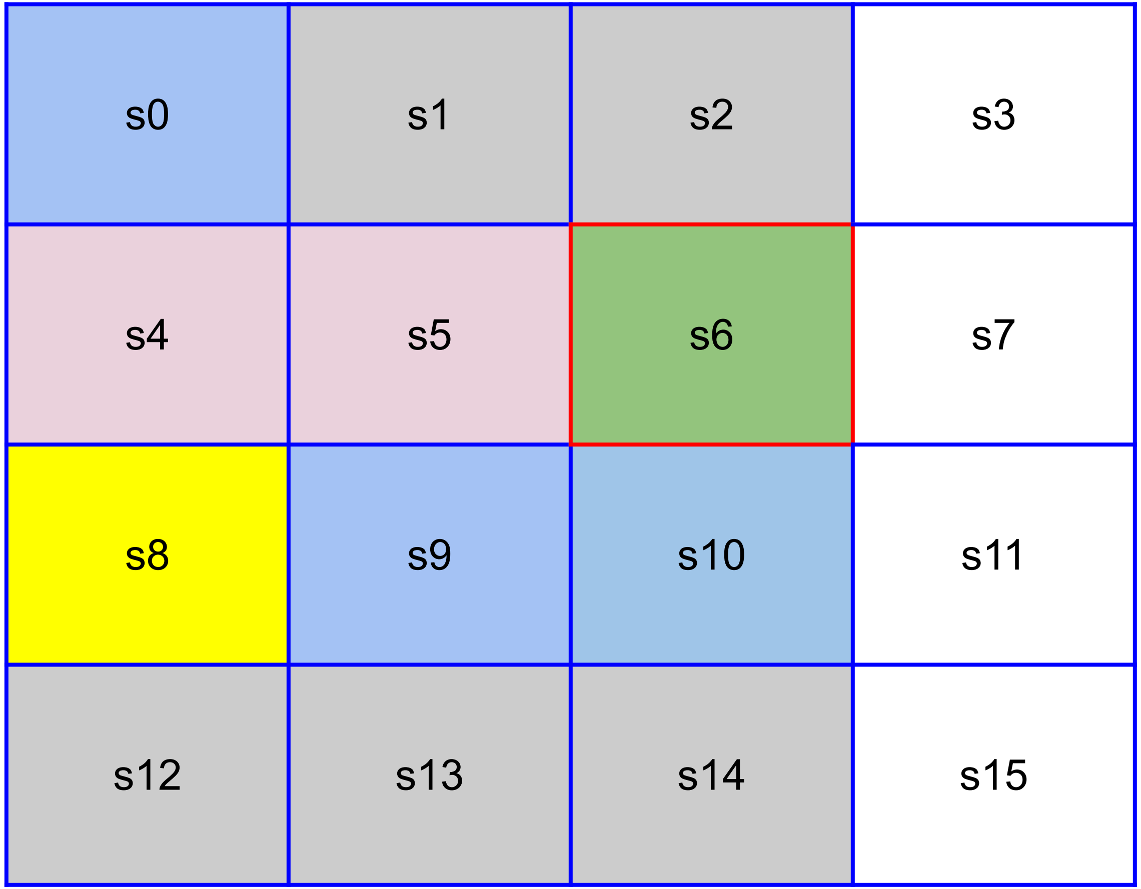
| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

- Return current (s6)
- WE ARE DONE!!!

**FRONT** **BACK**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| s14 | s2 | | | | | | | | |

| square | visited | prev |
|---|---|---|
| s1 | true | s5 |
| s2 | true | s1 |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | | |



| | | | |
|---|---|---|---|
| s0 | s1 | s2 | s3 |
| s4 | s5 | s6 | s7 |
| s8 | s9 | s10 | s11 |
| s12 | s13 | s14 | s15 |

| **square** | **visited** | **prev** |
|---|---|---|
| s1 | true | s5 |
| s2 | true | s1 |
| s3 | | |
| s4 | true | s8 |
| s5 | true | s4 |
| s6 | true | s5 |
| s7 | | |
| s8 | true | --- |
| s11 | | |
| s12 | true | s8 |
| s13 | true | s12 |
| s14 | true | s13 |
| s15 | | |

**Path solution:** s8, s4, s5, s6