ECE2800J

Programming and Elementary Data Structures

Queue

Learning Objectives:

Understand what is a queue

Know how to implement it

Discover some applications of queue

Understand what is a deque

Outline

- Queue
  - Implementation
  - Applications
  - Relative: Deque

Queues

- A "line" of items in which the **first** item inserted into the queue is the **first** one out.
  - Restricted form of a linear list: insert at **one end** and remove from **the other**.
  - FIFO access: first in, first out.

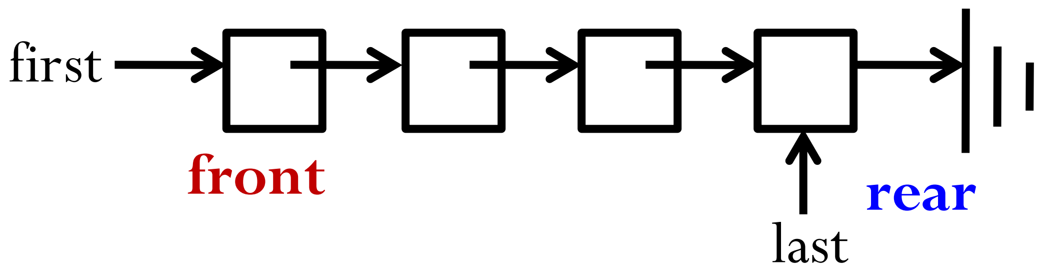
Methods of Queue

- `size()` : number of elements in the queue.
- `isEmpty()` : check if queue has no elements.
- `enqueue(Object o)` : add object `o` to the **rear** of the queue.
- `dequeue()` : remove the **front** object of the queue if not empty; otherwise, throw `queueEmpty`.
- `Object &front()` : return a reference to the front element of the queue.
- `Object &rear()` : return a reference to the rear element of the queue.

Queues Using Linked Lists

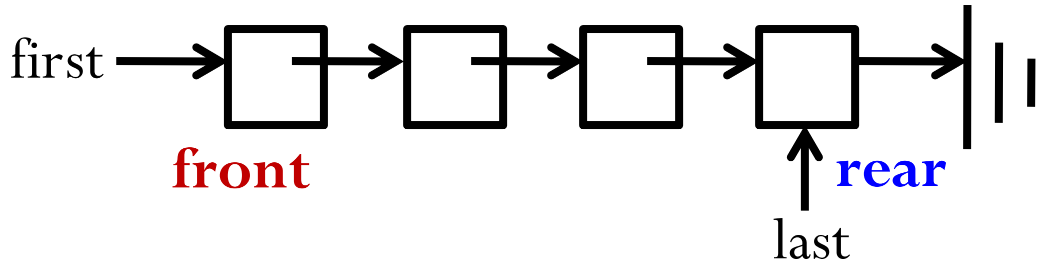
- Which type of linked list should we choose?
  - We need fast **`enqueue`** and **`dequeue`** operations.

- Double-ended singly-linked list is sufficient!



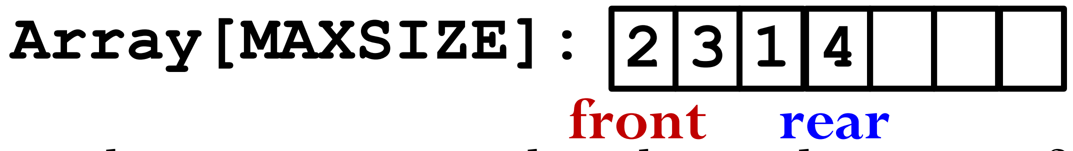
- **`enqueue(Object o):`** append object at the end
  `LinkedList::insertLast(Object o);`
- **`dequeue():`** remove the first node
  `LinkedList::removeFirst();`

Queues Using Linked Lists



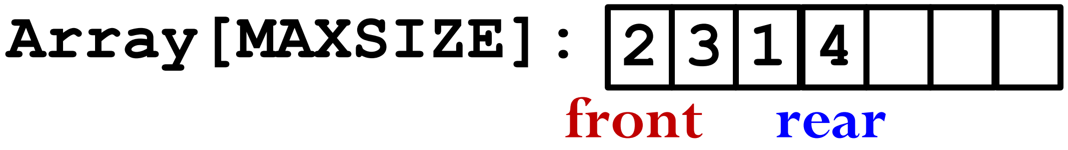
- `size()`: `LinkedList::size();`
- `isEmpty()`: `LinkedList::isEmpty();`
- `Object &front()`: return a reference to the object stored in the first node.
- `Object &rear()`: return a reference to the object stored in the last node.

Queues Using Arrays



- If we stick to the requirement that the n elements of a queue are the **beginning** n elements of the array, select all the correct statements:
  - **A.** The runtime for **enqueue** is independent of n
  - **B.** The runtime for **enqueue** is proportional to n
  - **C.** The runtime for **dequeue** is independent of n
  - **D.** The runtime for **dequeue** is proportional to n

Queues Using Arrays

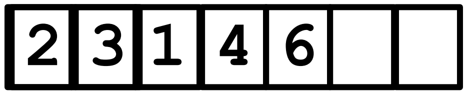


- A better way is to let the elements "**drift**" within the array.

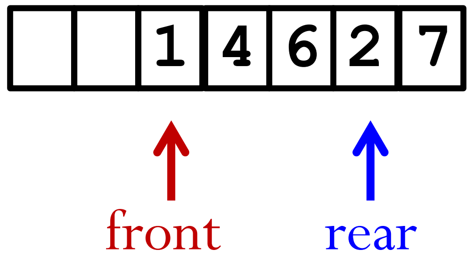
  enqueue(6);

  dequeue();

  dequeue();



Queues Using Arrays

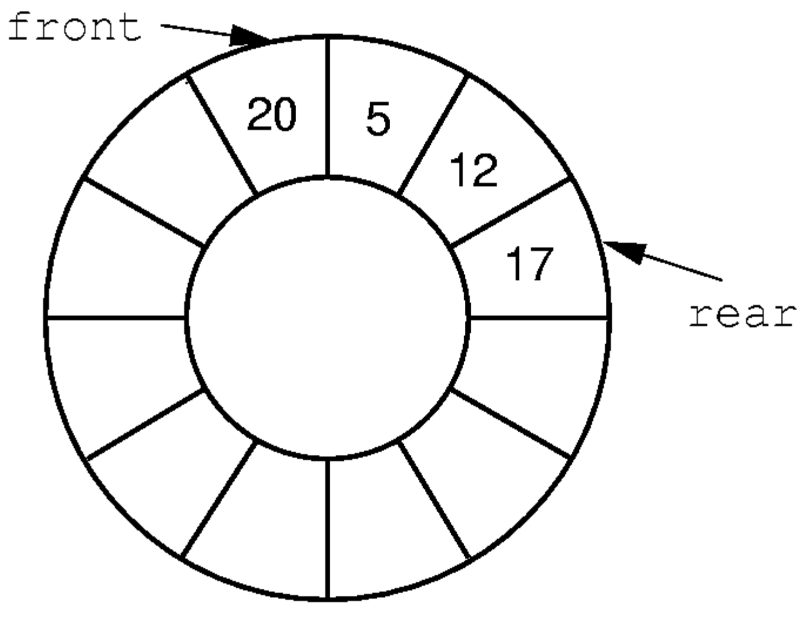


- We maintain two integers to indicate the front and the rear of the queue.

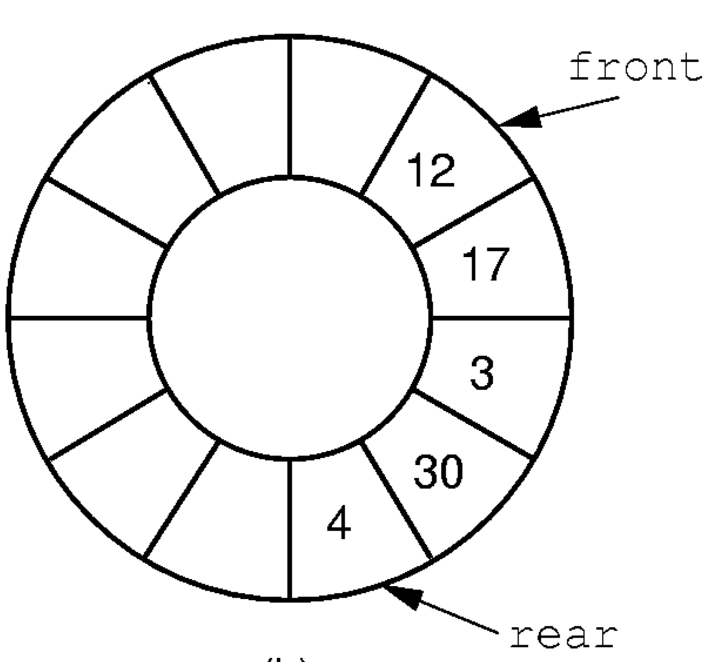
- However, as items are added and removed, the queue “drifts” toward the end.
  - Eventually, there will be no space to the right of the queue, even though there is space in the array.

Queues Using Arrays

- To solve the problem of memory waste, we use a **circular array**.



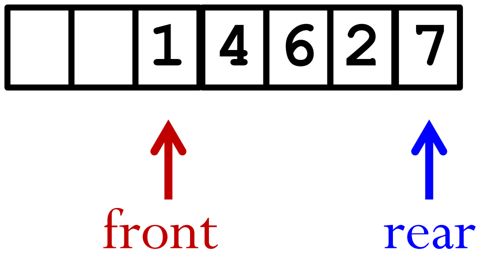
(a)



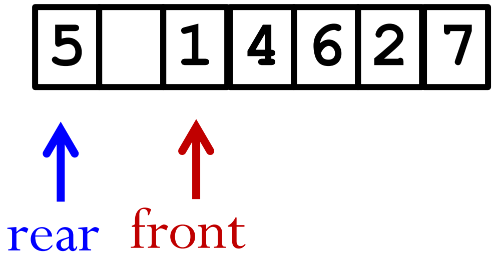
(b)

Circular Arrays

- We can implement a circular array using a plain linear array:
  - When front/rear equals the **last** index (i.e., MAXSIZE-1), increment of front/rear gives the **first** index (i.e., 0).



`enqueue(5)`



Circular Arrays

- To realize the “circular” increment, we can use modulo operation:

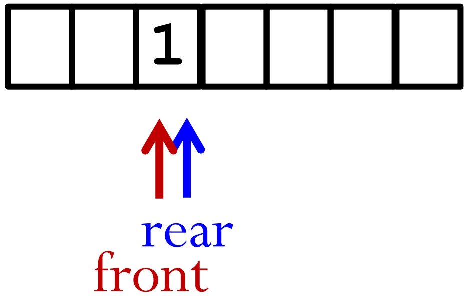
```
front = (front+1) % MAXSIZE;

rear = (rear+1) % MAXSIZE;
```

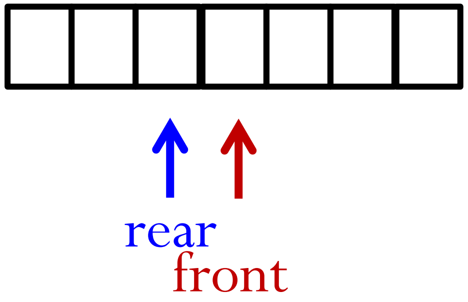
If **`front(or rear) == MAXSIZE-1`**, the statement sets **`front(or rear)`** to 0.

Boundary Conditions

- Suppose that `front` points to the **first** element in the queue and that `rear` points to the **last** element in the queue.
- What will a queue with one element look like?

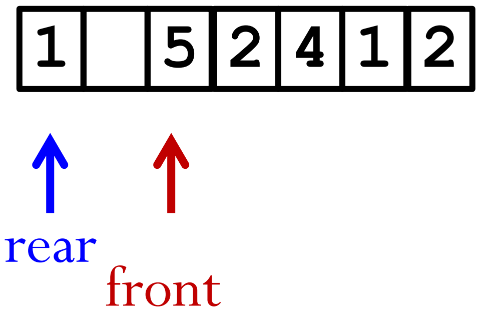


- What will an empty queue look like?

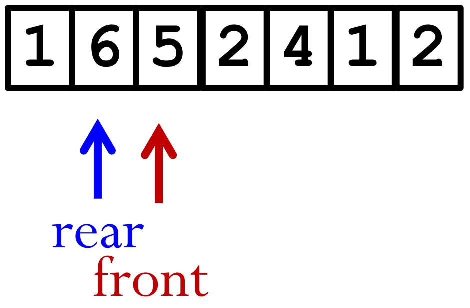


Boundary Conditions

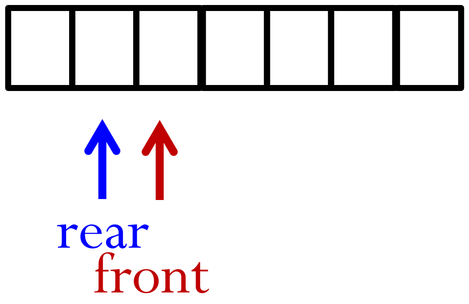
- What will a queue with one empty slot look like?



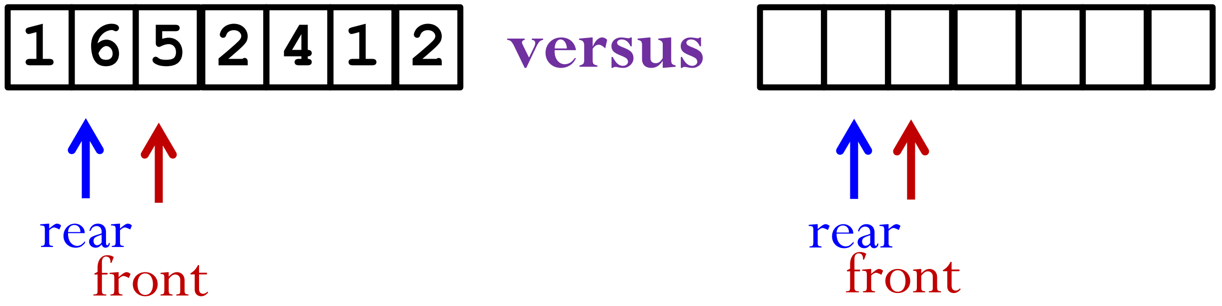
- What will a full queue look like?



versus an empty queue



Boundary Conditions



- To distinguish between the full array and the empty array, we need a flag indicating **`empty`** or **`full`**, or a **`count`** on the number of elements in the queue.

Queues Using Arrays

- **`enqueue(Object o)`**: if full, reallocate array. Increment **`rear`**, wrapping to the beginning of the array if the end of the array is reached. Insert **`o`** at the position of **`rear`**
- **`dequeue()`**: if empty, throw **`queueEmpty`**; otherwise, increment **`front`**, wrapping to the beginning of the array if the end of the array is reached;.
- **`isEmpty(): return (count == 0);`**
- **`size(): return count;`**

Outline

- Queue
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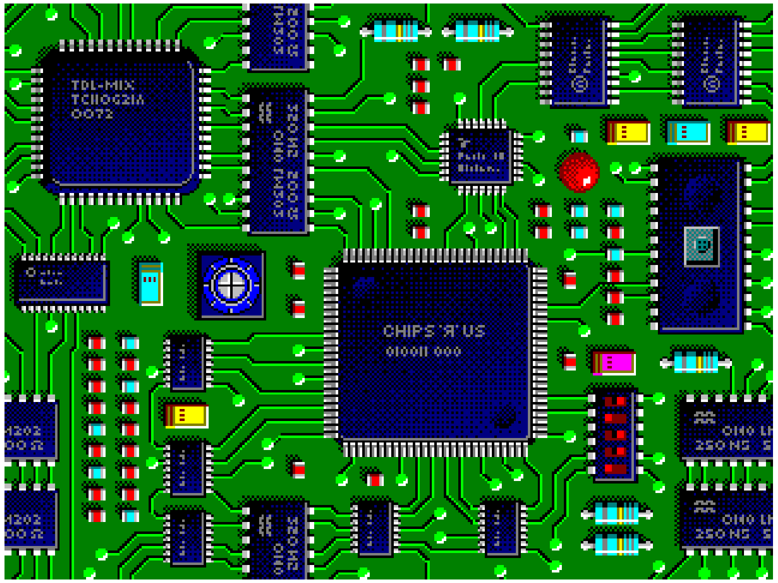
  - Applications
  - Relative: Deque

Application of Queues

- Request queue of a web server
  - Each user can send a request.
  - The arriving requests are stored in a **queue** and processed by the computer in a **first-come-first-serve** way.

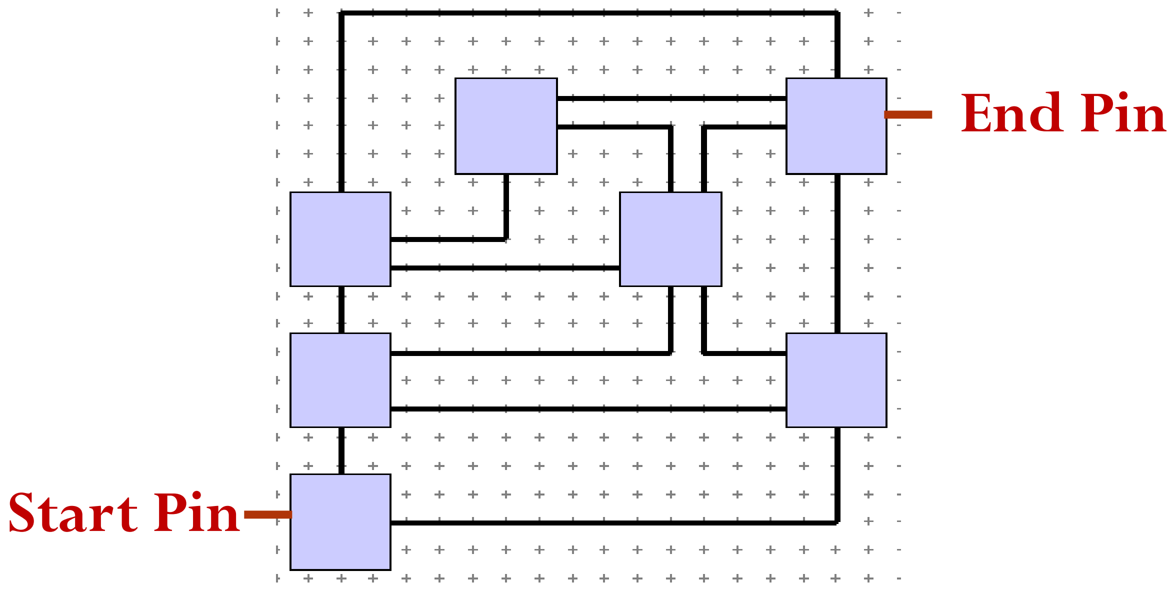
Application of Queue: Wire Routing

- Select paths to connect all pairs of pins that need to be connected together.
- An important problem in **electronic design automation**.



A Simplified Problem

- Condition: We have all blocks laid on the chip. We also have some of the wires routed.
- Problem: We want to connect the next pair of pins.
- Constraint: we can only draw wires horizontally or vertically.



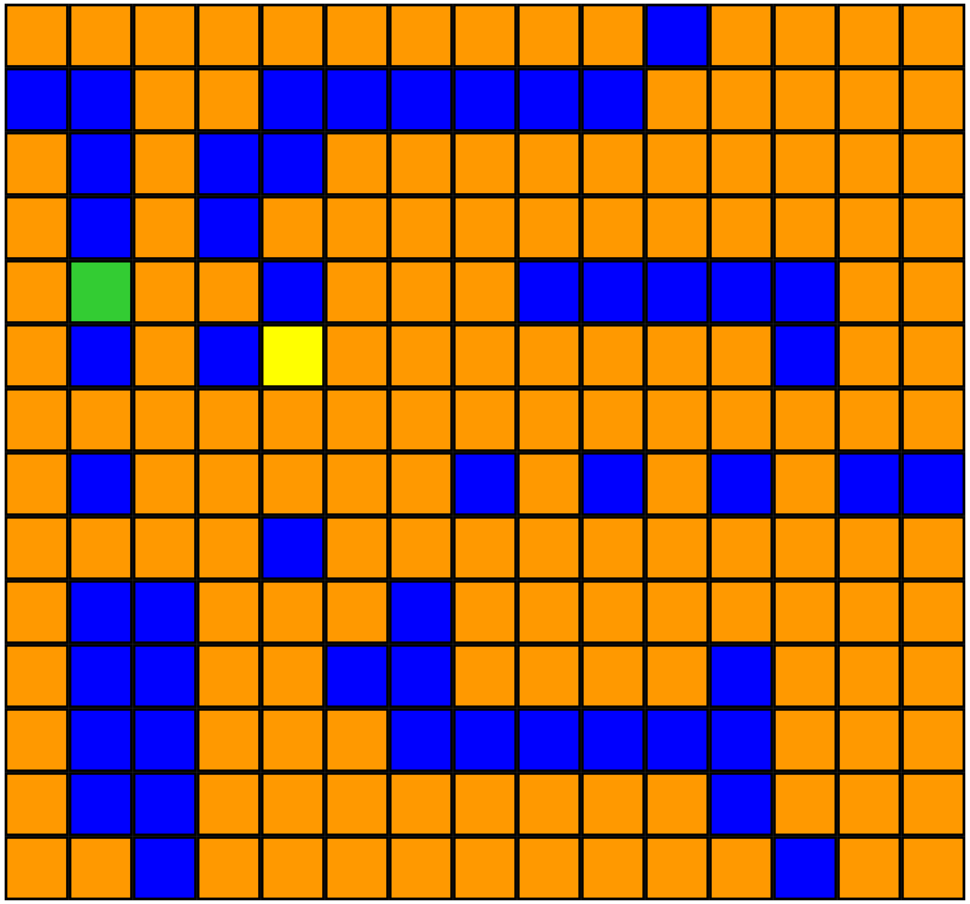
Modeling as a Grid

🟩 Start Pin

🟨 End Pin

- Blue squares are **blocked** squares.
- Orange squares are **available** to route a wire.

How to find a path from the start pin to the end pin?



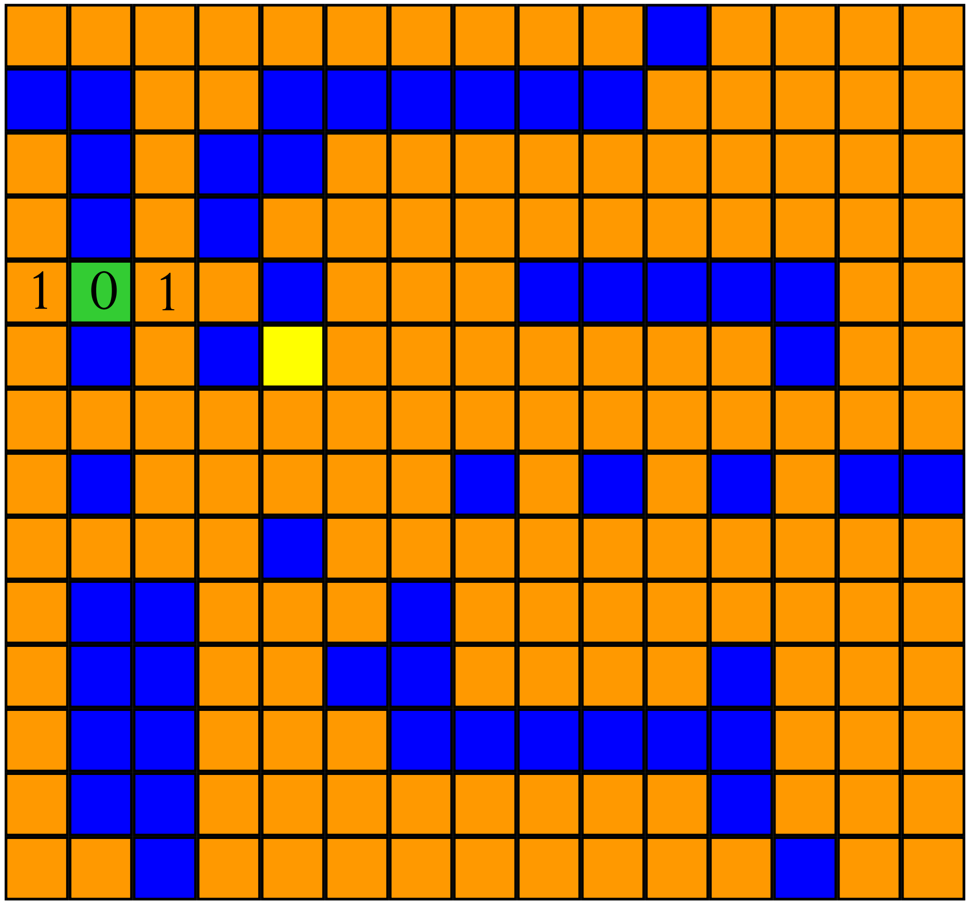
Wire Routing: Lee's Algorithm

- A **queue** of reachable squares from the start pin is used.
- The cell of the start pin is set with a distance value of 0.
- It is enqueued into an initial empty queue.
- **While** the queue is not empty.
  - A cell is **dequeued** from the queue and made the **examine cell**.
  - For each **unreached unblocked** square adjacent to the **examine cell**
    - Mark its distance as "1 + the distance value of the **examine cell**"
    - Is this cell the target? If yes, path found and return.
    - Otherwise, **enqueue** the cell into the queue.
- When queue becomes empty but not reach end pin yet, means no path found.

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin



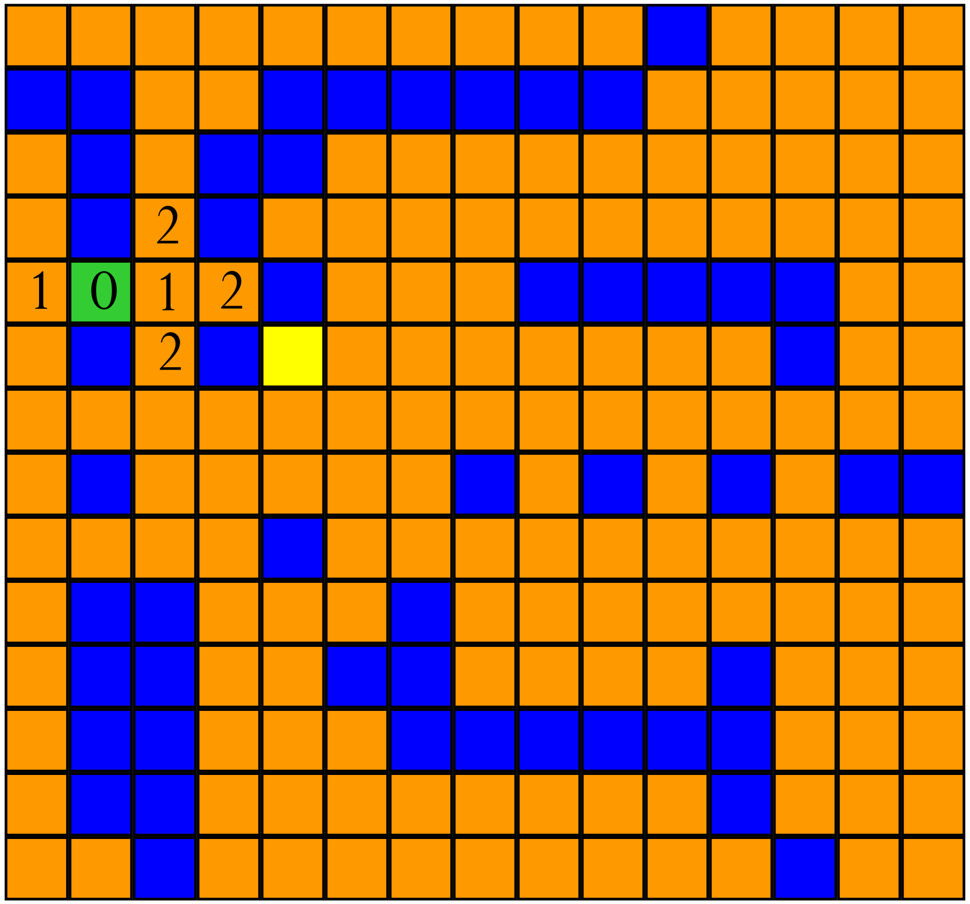
Expand "0"

queue: 0

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin



Expand right "1"

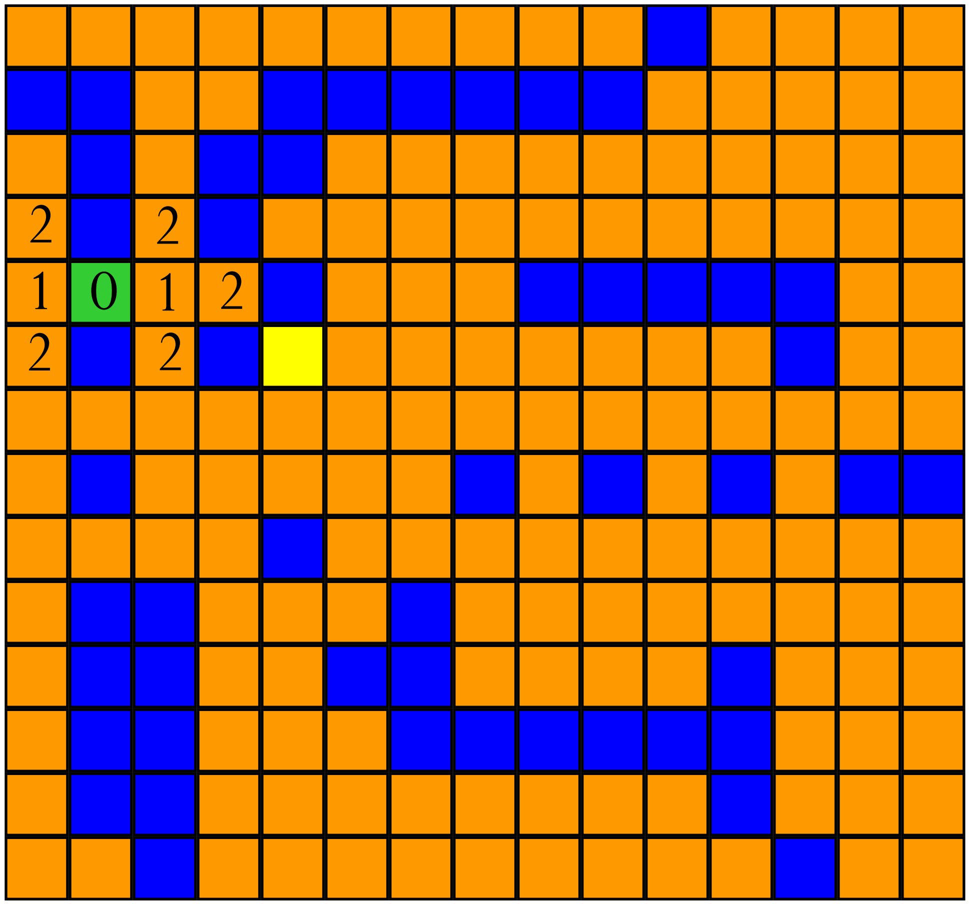
queue: 1, 1

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin

Expand left "1"

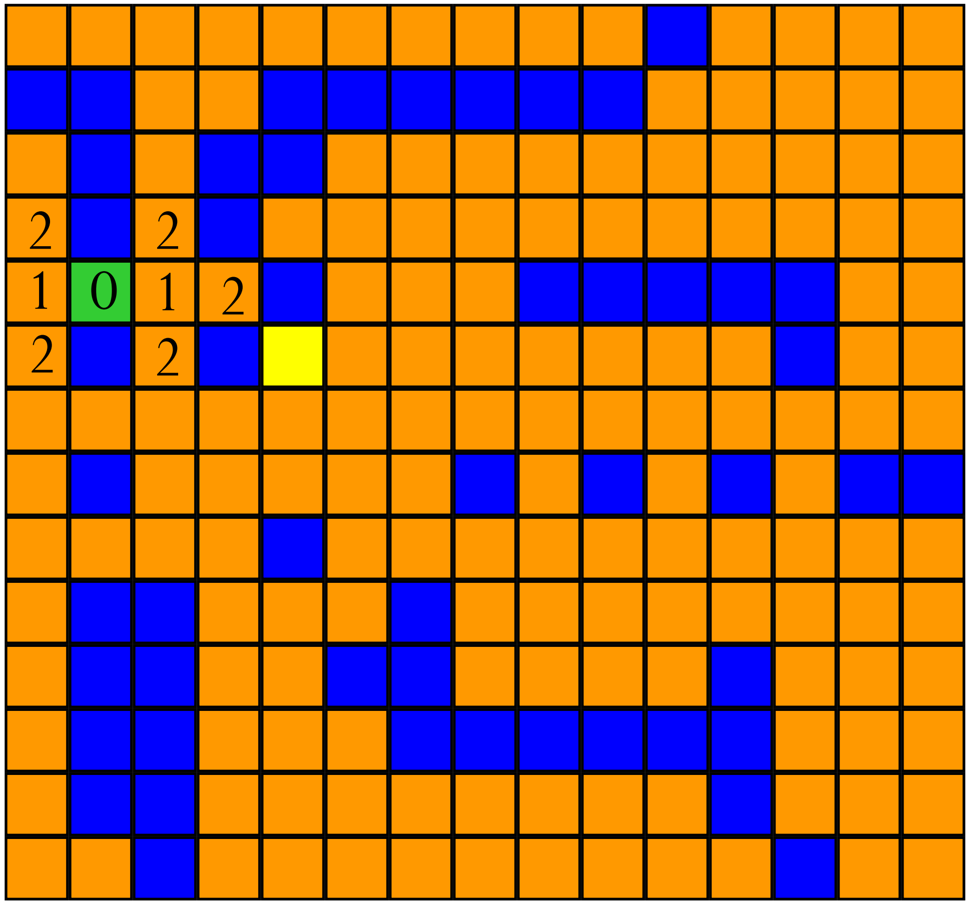


queue: 1,2,2,2

Illustration of Lee’s Algorithm

🟩 start pin

🟨 end pin

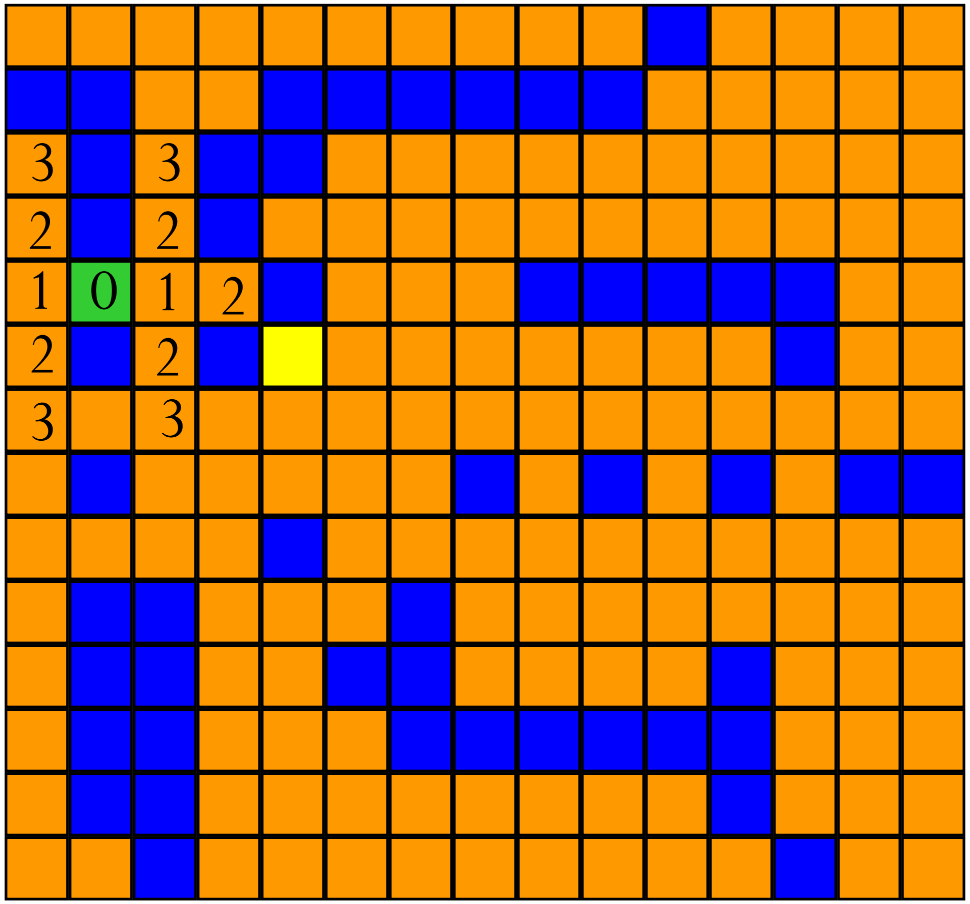


Expand and reach all squares 3 units from start.

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin

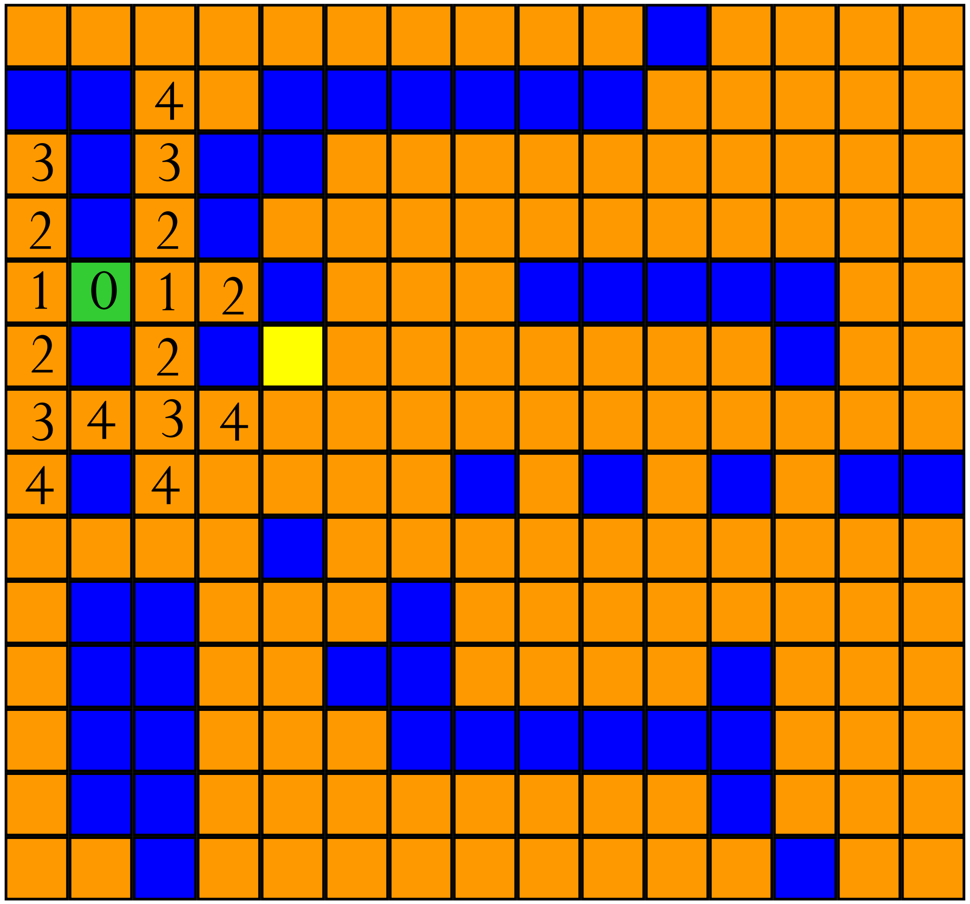


Expand and reach all squares 4 units from start.

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin

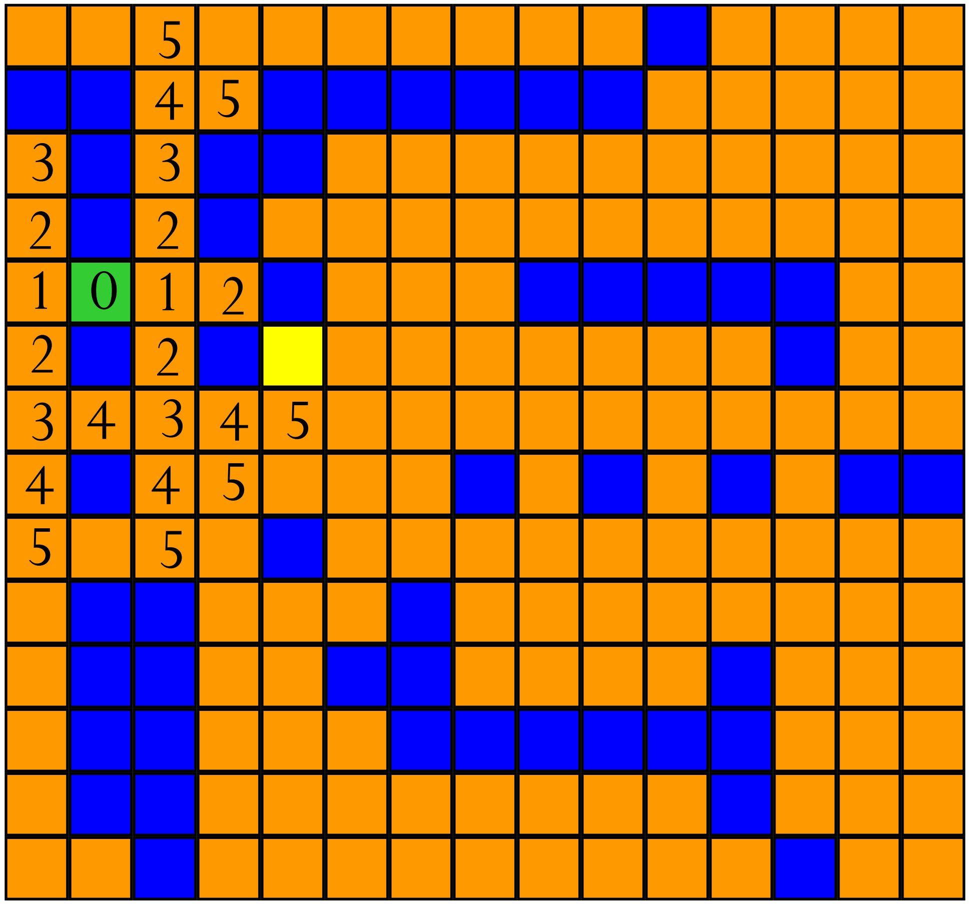


Expand and reach all squares 5 units from start.

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin

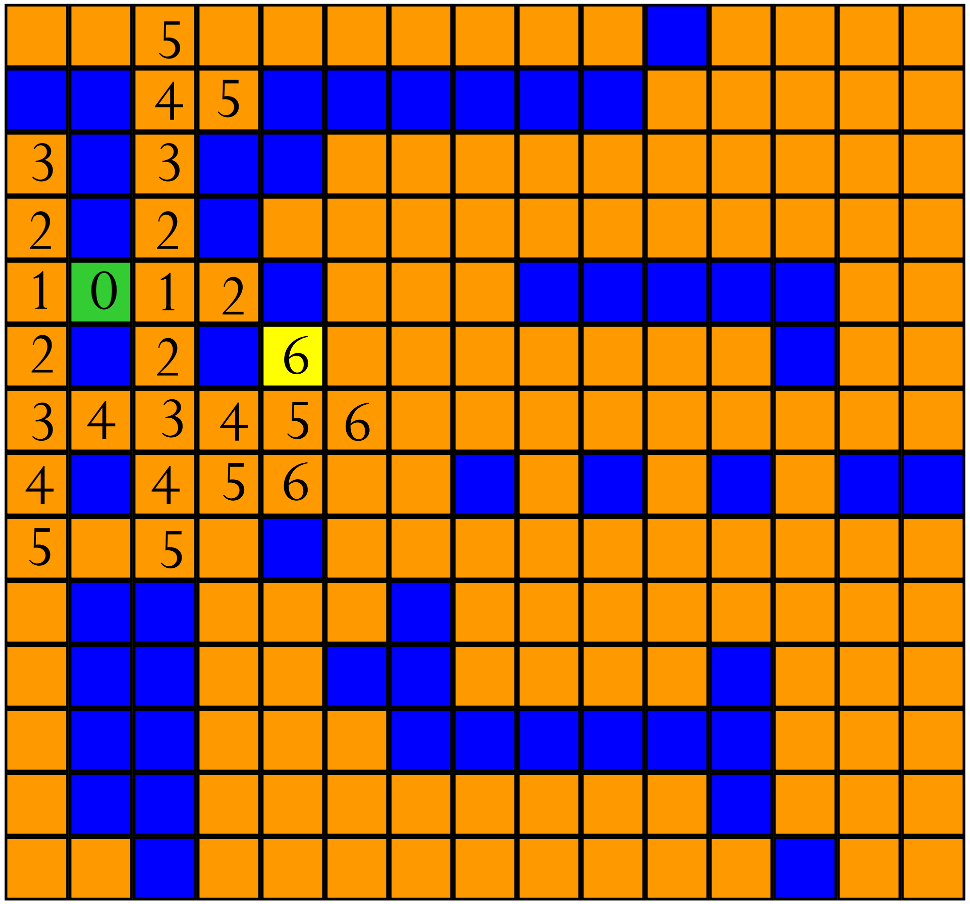


Expand and reach all squares 6 units from start.

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin

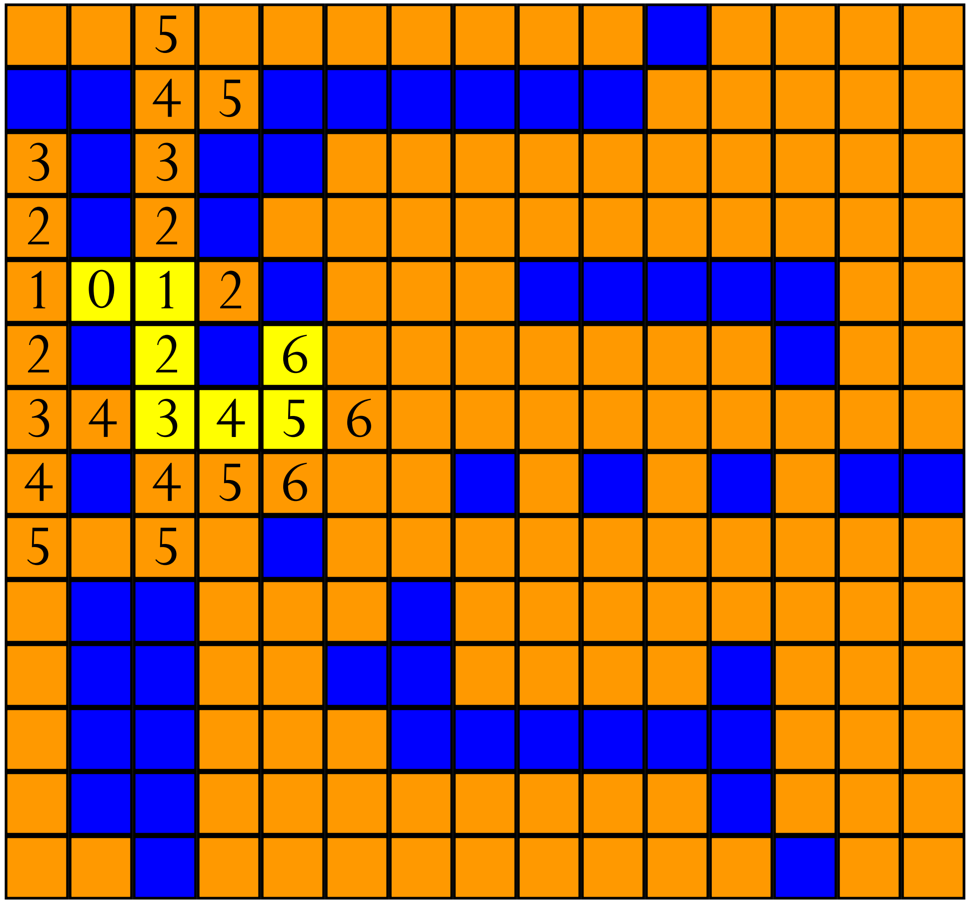


End pin reached. Trace back.

Illustration of Lee's Algorithm

🟩 start pin

🟨 end pin



A queue can be used:

Select all the correct answers.

- **A.** to handle printing jobs on a printer
- **B.** to reverse a string
- **C.** to implement a waiting list
- **D.** to share a CPU among different processes

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Deque

- Not a proper English word, pronounced as "deck".
  - Means <u>d</u>ouble-<u>e</u>nded <u>que</u>ue
- A combination of stack and queue.
  - Items can be inserted and removed from **both ends** of the list.

- Methods supported:
  - **`push_front(Object o)`**
  - **`push_back(Object o)`**
  - **`pop_front()`**
  - **`pop_back()`**

Deque Implementation

- Linked list
  - Which type of linked list will you choose to support fast insertion and removal?
  - Double-ended doubly-linked list

- Circular array
  - front and rear not only need to be incremented (**`push_back, pop_front`**), but also need to be decremented (**`push_front, pop_back`**).

Reference

- **Problem Solving with C++ (8th Edition)**, by *Walter Savitch*, Addison Wesley Publishing (2011)
  - Chapter 13.2 Queue