Lecture 13: Queues, Deques, and Priority Queues

CS 0445: Data Structures

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http://db.cs.pitt.edu/courses/cs0445/current.term/

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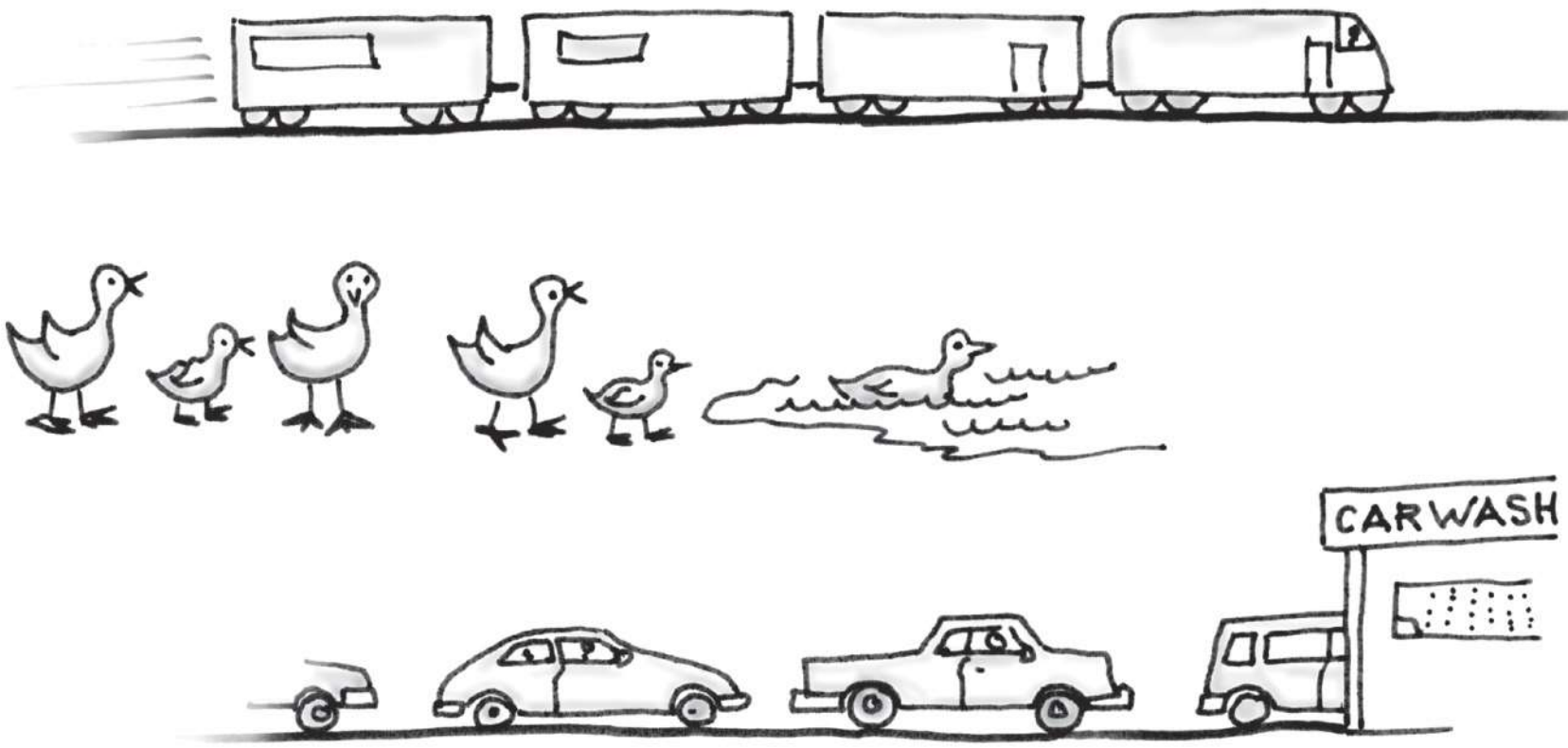
The ADT Queue

- A queue is another name for a waiting line
- Used within operating systems and to simulate real-world events
  - Come into play whenever processes or events must wait
- Entries organized first-in, first-out

The ADT Queue



The ADT Queue

- Terminology
  - Item added first, or earliest, is at the front of the queue
  - Item added most recently is at the back of the queue
- Additions to a software queue must occur at its back
- Client can look at or remove only the entry at the front of the queue

The ADT Queue

- Data
  - A collection of objects in chronological order and having the same data type

enqueue(newEntry)	+enqueue(newEntry: integer): void	Task: Adds a new entry to the back of the queue. Input: newEntry is the new entry. Output: None.
dequeue()	+dequeue(): T	Task: Removes and returns the entry at the front of the queue. Input: None. Output: Returns the queue's front entry. Throws an exception if the queue is empty before the operation.
getFront()	+getFront(): T	Task: Retrieves the queue's front entry without changing the queue in any way. Input: None. Output: Returns the queue's front entry. Throws an exception if the queue is empty.
isEmpty()	+isEmpty(): boolean	Task: Detects whether the queue is empty. Input: None. Output: Returns true if the queue is empty.
clear()	+clear(): void	Task: Removes all entries from the queue. Input: None. Output: None.

The ADT Queue

```
/** An interface for the ADT queue.  */
public interface QueueInterface<T>
{
 /** Adds a new entry to the back of this queue.
    @param newEntry  An object to be added. */
 public void enqueue(T newEntry);

 /** Removes and returns the entry at the front of this queue.
    @return  The object at the front of the queue.
    @throws  EmptyQueueException if the queue is empty before the operation. */
 public T dequeue();

 /**  Retrieves the entry at the front of this queue.
    @return  The object at the front of the queue.
    @throws  EmptyQueueException if the queue is empty. */
 public T getFront();

 /** Detects whether this queue is empty.
    @return  True if the queue is empty, or false otherwise. */
 public boolean isEmpty();

 /** Removes all entries from this queue. */
 public void clear();
} // end QueueInterface
```

A queue of strings

(a) enqueue adds *Jada*

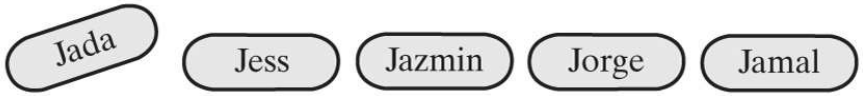
(b) enqueue adds *Jess*

(c) enqueue adds *Jazmin*

(d) enqueue adds *Jorge*

(e) enqueue adds *Jamal*

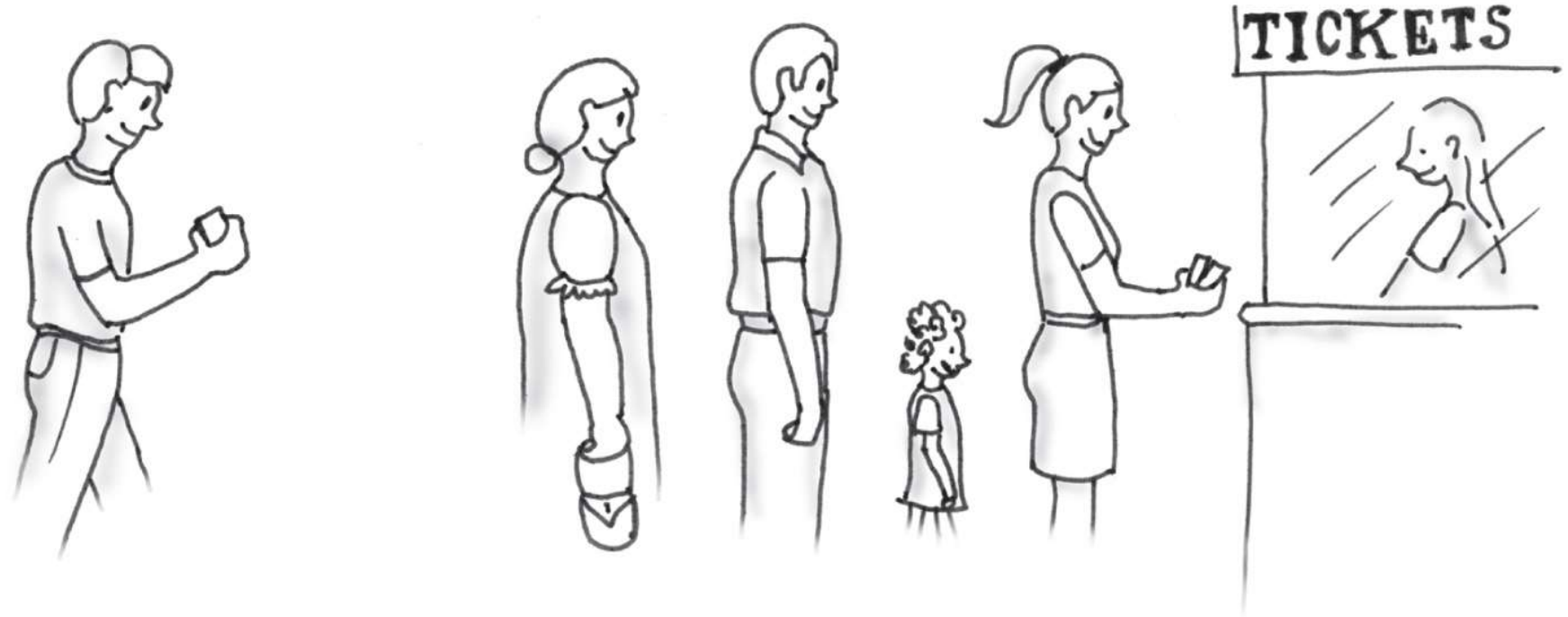
(f) dequeue retrieves and removes *Jada*



(g) enqueue adds *Jerry*

(h) dequeue retrieves and removes *Jess*

Simulating a Waiting Line



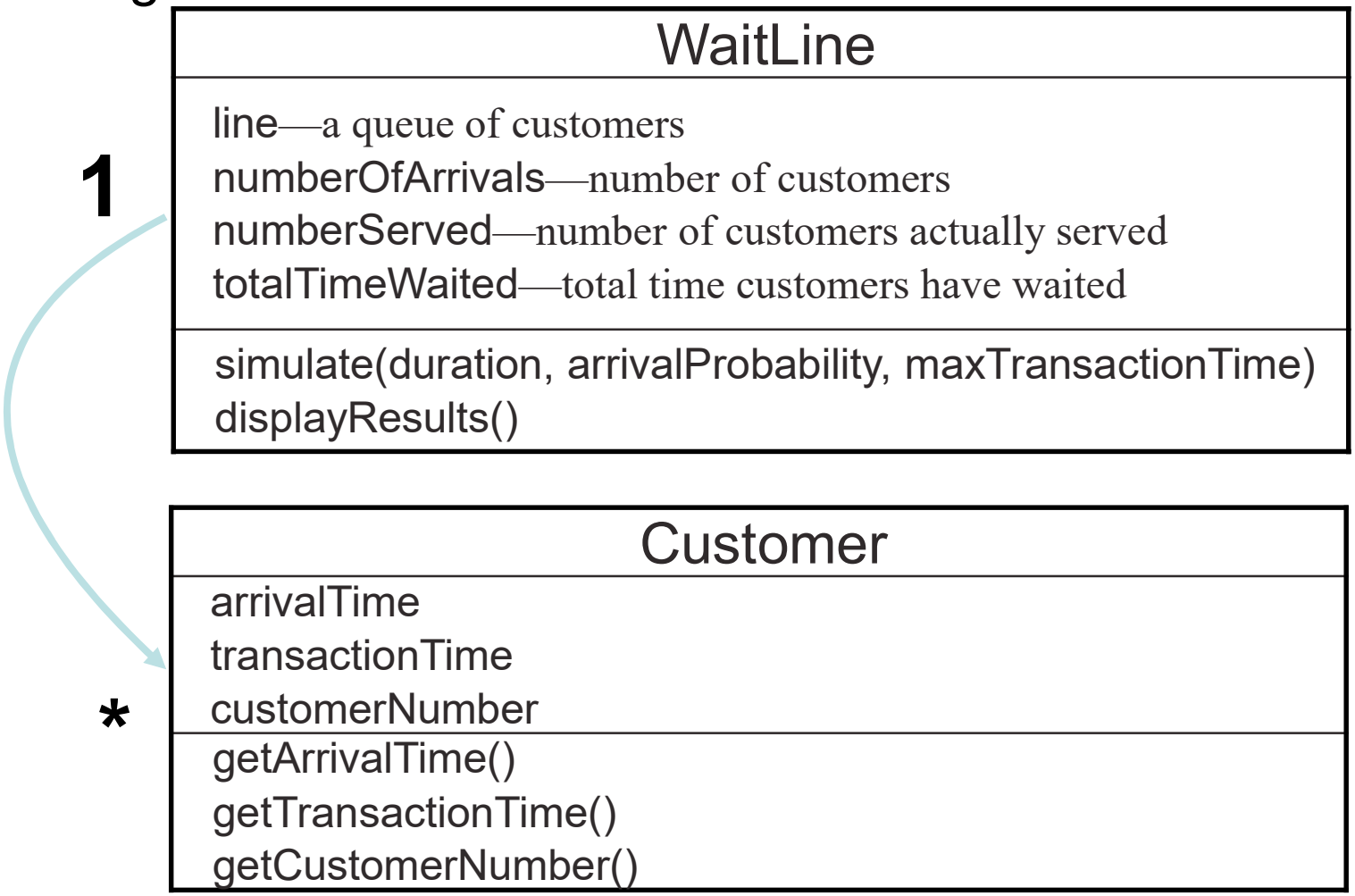
Simulating a Waiting Line

A CRC card for the class WaitLine

WaitLine
Responsibilities
Simulate customers entering and leaving a waiting line
Display number served, total wait time, average wait time, and number left in line
Collaborations
Customer

Simulating a Waiting Line

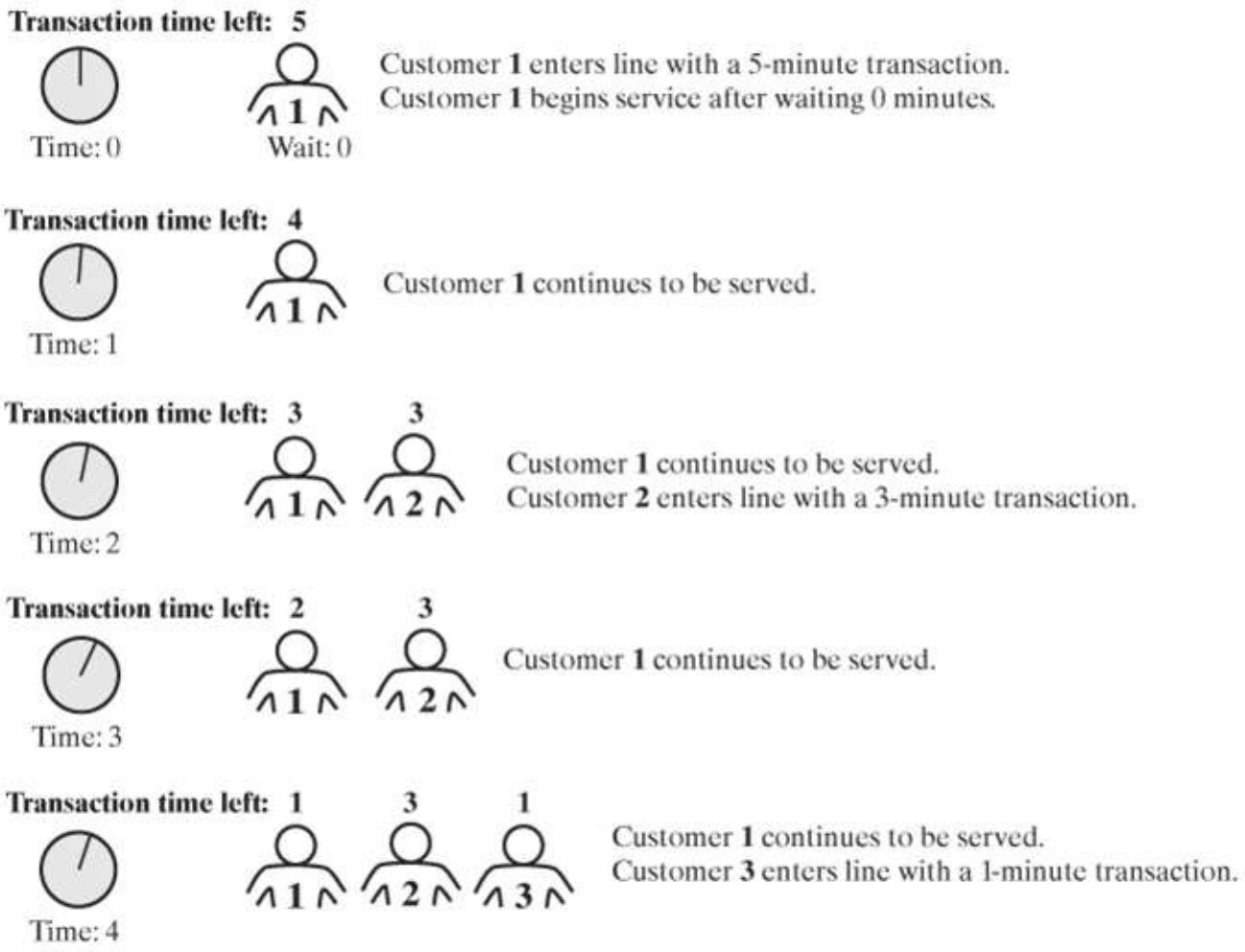
A diagram of the classes WaitLine and Customer



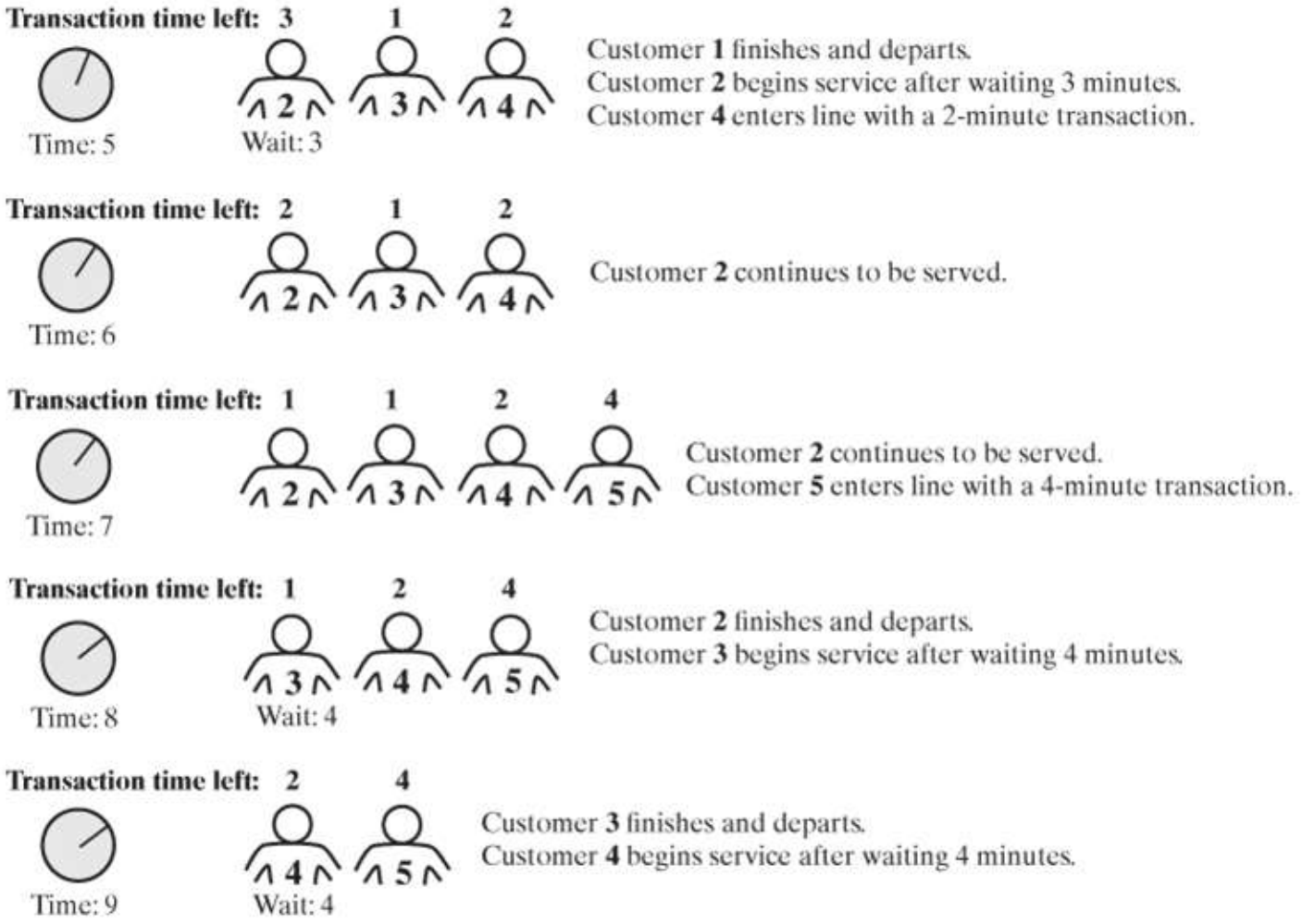
Simulating a Waiting Line

```
Algorithm simulate(duration, arrivalProbability, maxTransactionTime)
transactionTimeLeft = 0
for (clock = 0; clock < duration; clock++)
{
        if (a new customer arrives)
        {
                numberOfArrivals++
                transactionTime = a random time that does not exceed maxTransactionTime
                nextArrival = a new customer containing clock, transactionTime, and
                                a customer number that is numberOfArrivals
                line.enqueue(nextArrival)
        }
        if (transactionTimeLeft > 0) // If present customer is still being served
                transactionTimeLeft--
        else if (!line.isEmpty())
        {
                nextCustomer = line.dequeue()
                transactionTimeLeft = nextCustomer.getTransactionTime() − 1
                timeWaited = clock − nextCustomer.getArrivalTime()
                 totalTimeWaited = totalTimeWaited  +  timeWaited numberServed++
        }
}
```

Simulating a Waiting Line (Part 1)



Simulating a Waiting Line (Part 2)



Simulating a Waiting Line

```
/** Simulates a waiting line.  */
public class WaitLine
{ private QueueInterface<Customer> line;
  private int numberOfArrivals;
  private int numberServed;
  private int totalTimeWaited;

  public WaitLine()
  {
    line = new LinkedQueue<>();
    reset();
  } // end default constructor

  /** Initializes the simulation. */
  public final void reset()
  {
    line.clear();
    numberOfArrivals = 0;
    numberServed = 0;
    totalTimeWaited = 0;
  } // end reset

  public void simulate(int duration, double arrivalProbability,
                       int maxTransactionTime)
  {  < implementation on next slide > }

  public void displayResults()
  {  < implementation on next slide >  }
} // end WaitLine
```

Simulating a Waiting Line

```
public void simulate(int duration, double arrivalProbability, int maxTransactionTime)
{ int transactionTimeLeft = 0;

  for (int clock = 0; clock < duration; clock++)
  {
    if (Math.random() < arrivalProbability)
    {
      numberOfArrivals++;
      int transactionTime = (int)(Math.random() * maxTransactionTime + 1);
      Customer nextArrival = new Customer(clock, transactionTime,
                                numberOfArrivals);
      line.enqueue(nextArrival);
      System.out.println("Customer " + numberOfArrivals +
                  " enters line at time " + clock +
                  ". Transaction time is " + transactionTime);
    } // end if

    if (transactionTimeLeft > 0)
      transactionTimeLeft--;
    else if (!line.isEmpty())
    {
      Customer nextCustomer = line.dequeue();
      transactionTimeLeft = nextCustomer.getTransactionTime() - 1;
      int timeWaited = clock - nextCustomer.getArrivalTime();
      totalTimeWaited = totalTimeWaited + timeWaited;
      numberServed++;
      System.out.println("Customer " + nextCustomer.getCustomerNumber() +
                  " begins service at time " + clock +
                  ". Time waited is " + timeWaited);
    } // end if
  } // end for
} // end simulate
```

Simulating a Waiting Line

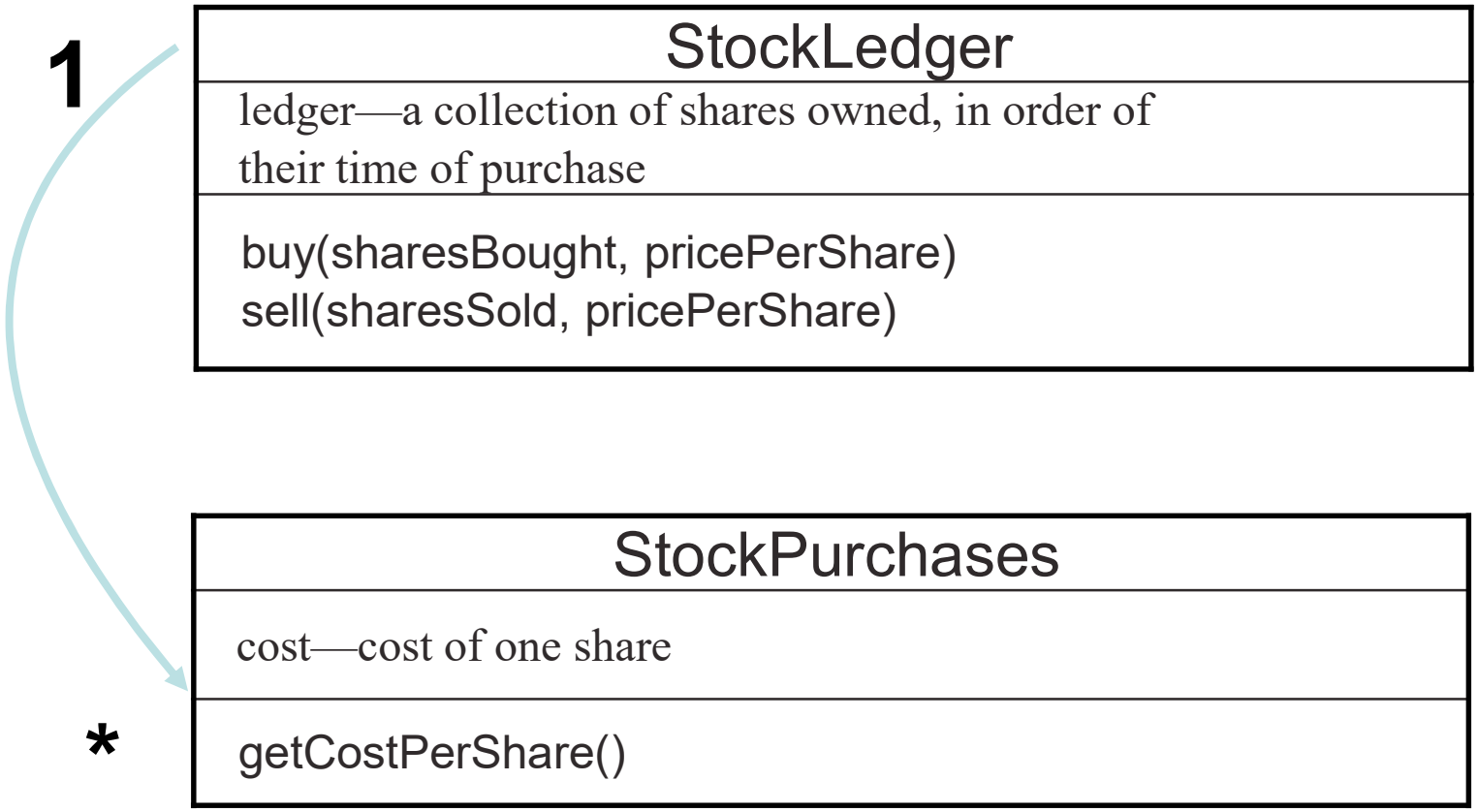
```
/** Displays summary results of the simulation. */
 public void displayResults()
{
   System.out.println();
   System.out.println("Number served = " + numberServed);
   System.out.println("Total time waited = " + totalTimeWaited);
   double averageTimeWaited = ((double)totalTimeWaited) / numberServed;
   System.out.println("Average time waited = " + averageTimeWaited);
   int leftInLine = numberOfArrivals - numberServed;
   System.out.println("Number left in line = " + leftInLine);
 } // end displayResults
```

Computing the Capital Gain in a Sale of Stock

- CRC card for the class `StockLedger`

StockLedger
Responsibilities
Record the shares of a stock purchased,
in chronological order
Remove the shares of a stock sold,
beginning with the ones held the longest
Compute the capital gain (loss) on shares of a
stock sold
Collaborations
Share of stock

Computing the Capital Gain in a Sale of Stock



Computing the Capital Gain in a Sale of Stock (Part 1)

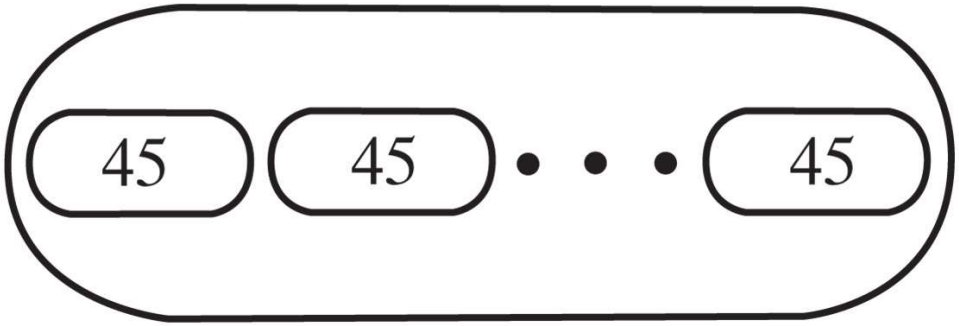
```
public class StockLedger
{
 private QueueInterface<StockPurchase> ledger;

 public StockLedger()
 {
   ledger = new LinkedQueue<>();
 } // end default constructor

 /** Records a stock purchase in this ledger.
    @param sharesBought   The number of shares purchased.
    @param pricePerShare  The price per share. */
 public void buy(int sharesBought, double pricePerShare)
 {
  while (sharesBought > 0)
  {
    StockPurchase purchase = new StockPurchase(pricePerShare);
    ledger.enqueue(purchase);
    sharesBought--;
  } // end while
 } // end buy
```

Computing the Capital Gain in a Sale of Stock (Part 2)

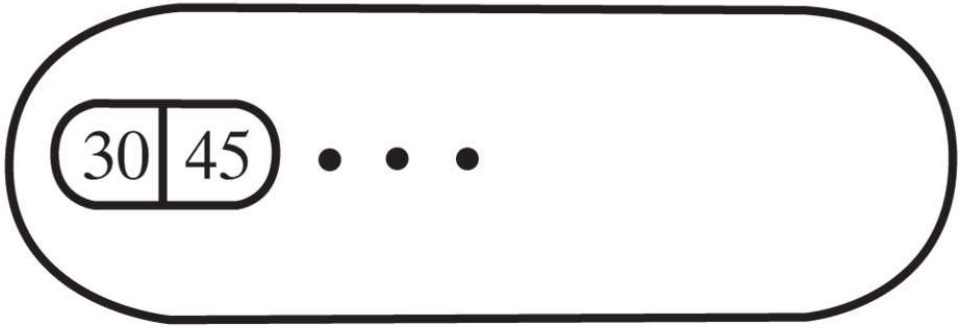
```
/** Removes from this ledger any shares that were sold
    and computes the capital gain or loss.
    @param sharesSold     The number of shares sold.
    @param pricePerShare  The price per share.
    @return  The capital gain (loss). */
 public double sell(int sharesSold, double pricePerShare)
 {
   double saleAmount = sharesSold * pricePerShare;
   double totalCost = 0;

   while (sharesSold > 0)
   {
     StockPurchase share = ledger.dequeue();
     double shareCost = share.getCostPerShare();
     totalCost = totalCost + shareCost;
     sharesSold--;
   } // end while

   return saleAmount - totalCost; // Gain or loss
 } // end sell
} // end StockLedger
```

Two representations of stock shares in a queue

(a) Individual shares of stock in a queue



(b) Grouped shares of stock as objects in a queue



Java Class Library: The Interface `Queue`

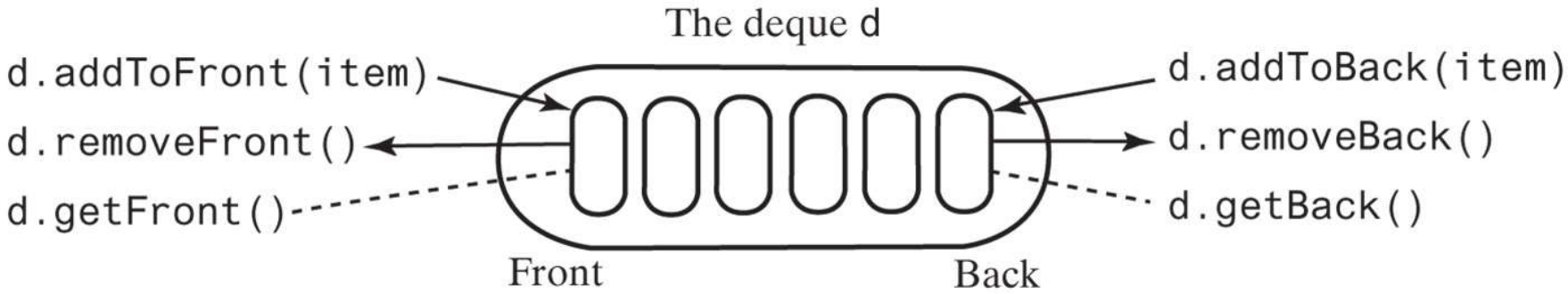
- Methods provided
  - `add`
  - `offer`
  - `remove`
  - `poll`
  - `element`
  - `peek`
  - `isEmpty`
  - `size`

The ADT `Deque`

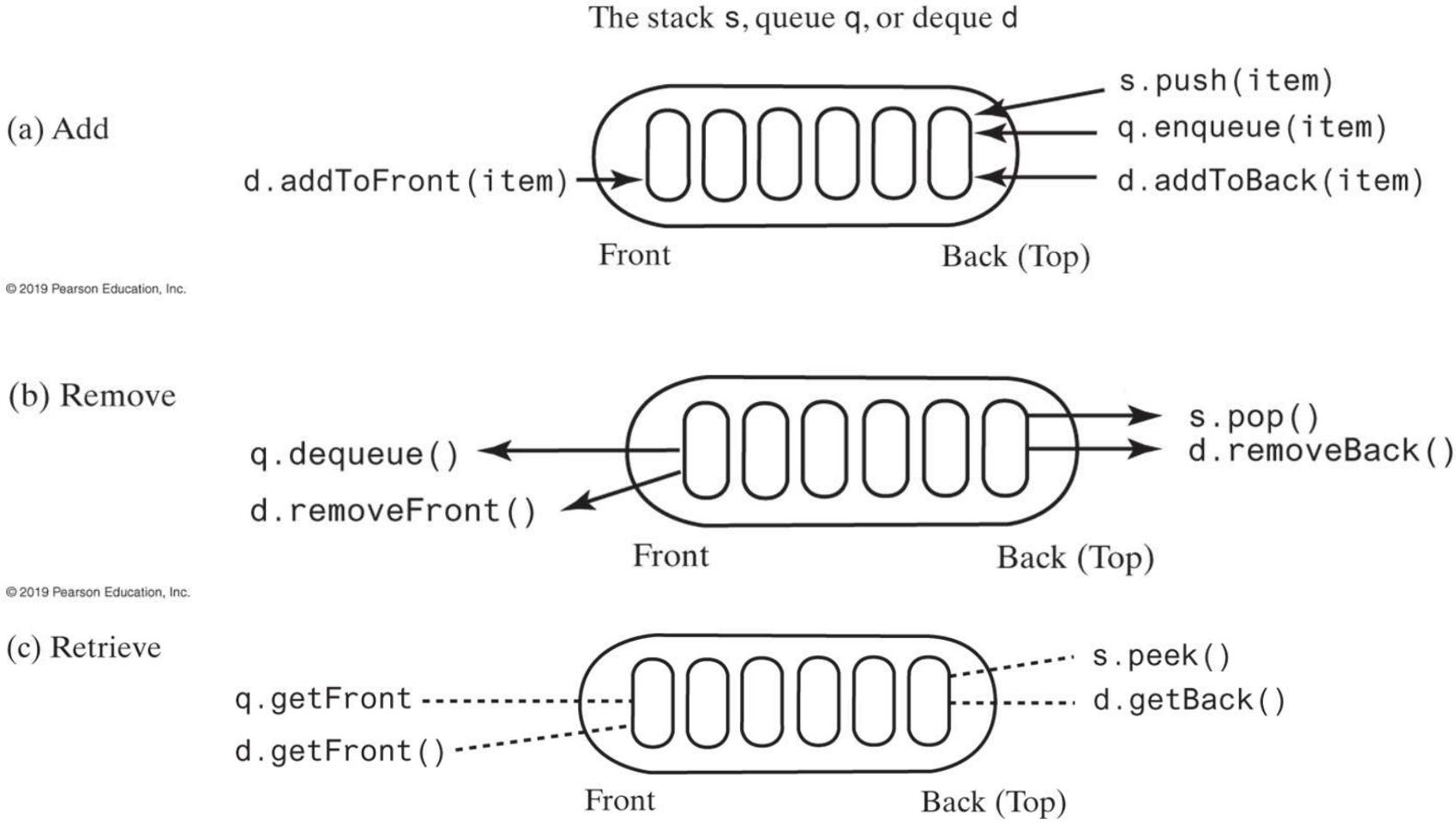
- A double ended queue
- `Deque` pronounced “deck”
- Has both queue-like operations and stack-like operations

The ADT Deque

An instance d of a `deque`



A comparison of operations for a stack s, a queue q, and a deque d



The ADT Deque

```
/** An interface for the ADT deque. */
public interface DequeInterface<T>
{
  /** Adds a new entry to the front/back of this deque.
     @param newEntry  An object to be added. */
  public void addToFront(T newEntry);
  public void addToBack(T newEntry);

  /** Removes and returns the front/back entry of this deque.
     @return  The object at the front/back of the deque.
     @throws  EmptyQueueException if the deque is empty before the
           operation. */
  public T removeFront();
  public T removeBack();

  /** Retrieves the front/back entry of this deque.
     @return  The object at the front/back of the deque.
     @throws  EmptyQueueException if the deque is empty. */
  public T getFront();
  public T getBack();

  /** Detects whether this deque is empty.
     @return  True if the deque is empty, or false otherwise. */
  public boolean isEmpty();

  /*  Removes all entries from this deque. */
  public void clear();
} // end DequeInterface
```

The ADT Deque

- Pseudocode that uses a deque to read and display a line of keyboard input

```
// Read a line
d = a new empty deque
while (not end of line)
{
        character = next character read
        if (character == ←)
                d.removeBack()
        else
                d.addToBack(character)
}
// Display the corrected line
while (!d.isEmpty())
        System.out.print(d.removeFront())
System.out.println()
```

Computing the Capital Gain in a Sale of Stock

- Method buy creates an instance of `StockPurchase` and places it at the back of the deque

```
public double sell(int sharesSold, double pricePerShare)
{
  double saleAmount = sharesSold * pricePerShare;
  double totalCost = 0;

  while (sharesSold > 0)
  {
    StockPurchase transaction = ledger.removeFront();
    double shareCost = transaction.getCostPerShare();
    int numberOfShares = transaction.getNumberOfShares();

    if (numberOfShares > sharesSold)
    {
      totalCost = totalCost + sharesSold * shareCost;
      int numberToPutBack = numberOfShares - sharesSold;
      StockPurchase leftOver = new StockPurchase(numberToPutBack, shareCost);
      ledger.addToFront(leftOver); // Return leftover shares
      // Note: Loop will exit since sharesSold will be <= 0 later
    }
    else
      totalCost = totalCost + numberOfShares * shareCost;

    sharesSold = sharesSold - numberOfShares;
  } // end while

  return saleAmount - totalCost; // Gain or loss
} // end sell
```

Java Class Library: The Interface `Deque`

- Methods provided
  - `addFirst, offerFirst`
  - `addLast, offerLast`
  - `removeFirst, pollFirst`
  - `removeLast, pollLast`
  - `getFirst, peekFirst`
  - `getLast, peekLast`
  - `isEmpty, clear, size`
  - `push, pop`

Java Class Library: The Class `ArrayDeque`

- Implements the interface **`Deque`**
- Constructors provided
  - **`ArrayDeque()`**
  - **`ArrayDeque(int initialCapacity)`**

ADT Priority Queue

- Consider how a hospital assigns a priority to each patient that overrides time at which patient arrived.
- ADT priority queue organizes objects according to their priorities
- Definition of “priority” depends on nature of the items in the queue

ADT Priority Queue

```
/** An interface for the ADT priority queue. */
public interface PriorityQueueInterface<T extends Comparable<? super T>>
{
  /** Adds a new entry to this priority queue.
      @param newEntry  An object to be added. */
  public void add(T newEntry);

  /** Removes and returns the entry having the highest priority.
      @return  Either the object having the highest priority or, if the
               priority queue is empty before the operation, null. */
  public T remove();

  /** Retrieves the entry having the highest priority.
      @return  Either the object having the highest priority or, if the
               priority queue is empty, null. */
  public T peek();

  /** Detects whether this priority queue is empty.
      @return  True if the priority queue is empty, or false otherwise. */
  public boolean isEmpty();

  /** Gets the size of this priority queue.
      @return  The number of entries currently in the priority queue. */
  public int getSize();

  /** Removes all entries from this priority queue. */
  public void clear();
} // end PriorityQueueInterface
```

Tracking Your Assignments

- UML diagrams of the class `Assignment` and `AssignmentLog`

Assignment
course—the course code task—a description of the assignment date—the due date
getCourseCode() getTask() getDueDate() compareTo()

AssignmentLog
log—a priority queue of assignments
addProject(newAssignment) addProject(courseCode, task, dueDate) getNextProject() removeNextProject()

Tracking Your Assignments

```
public class AssignmentLog
{
  private PriorityQueueInterface<Assignment> log;

  public AssignmentLog()
  {
    log = new PriorityQueue<>();
  } // end constructor

  public void addProject(Assignment newAssignment)
  {
    log.add(newAssignment);
  } // end addProject

  public void addProject(String courseCode, String task, Date dueDate)
  {
    Assignment newAssignment = new Assignment(courseCode, task, dueDate);
    addProject(newAssignment);
  } // end addProject

  public Assignment getNextProject()
  {
    return log.peek();
  } // end getNextProject

  public Assignment removeNextProject()
  {
    return log.remove();
  } // end removeNextProject
} // end AssignmentLog
```

Java Class Library: The Class `PriorityQueue`

- Basic constructors and methods
- `PriorityQueue`
  - `add`
  - `offer`
  - `remove`
  - `poll`
  - `element`
  - `peek`
  - `isEmpty, clear, size`