William McAllister

DATA STRUCTURES AND ALGORITHMS USING JAVA

Restricted Structures

Chapter 3

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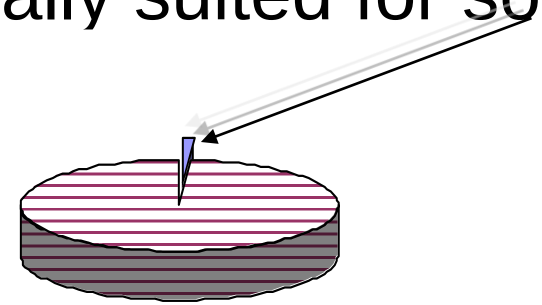
Overview Of Restricted Structures

- All restricted structures severely restrict the basic operations and access modes
- The two most commonly used restricted structures are Stack and Queue
  - Both can be implemented as array-based structures
  - Their restrictions are consistent with some applications, and the performance of Stack and Queue is excellent
- Coding generic data structures can be methodized. Our Stack implementation will be used as a case study
- A priority queue is a restricted structure used in scheduling applications
- Java's API Stack class is a generic stack structure

Restrictions on Restricted Structures

- Operation restrictions
  - Update is not supported
  - Insert is supported (not restricted)
  - Fetch and Delete are combined into one operation
- Access mode restrictions
  - Key field mode is not supported
  - Node number mode is severely restricted
- Still, they are ideally suited for some applications



Insert Operation

- A Restricted Structure after Nodes A, then B, the C and Finally D Have Been Inserted

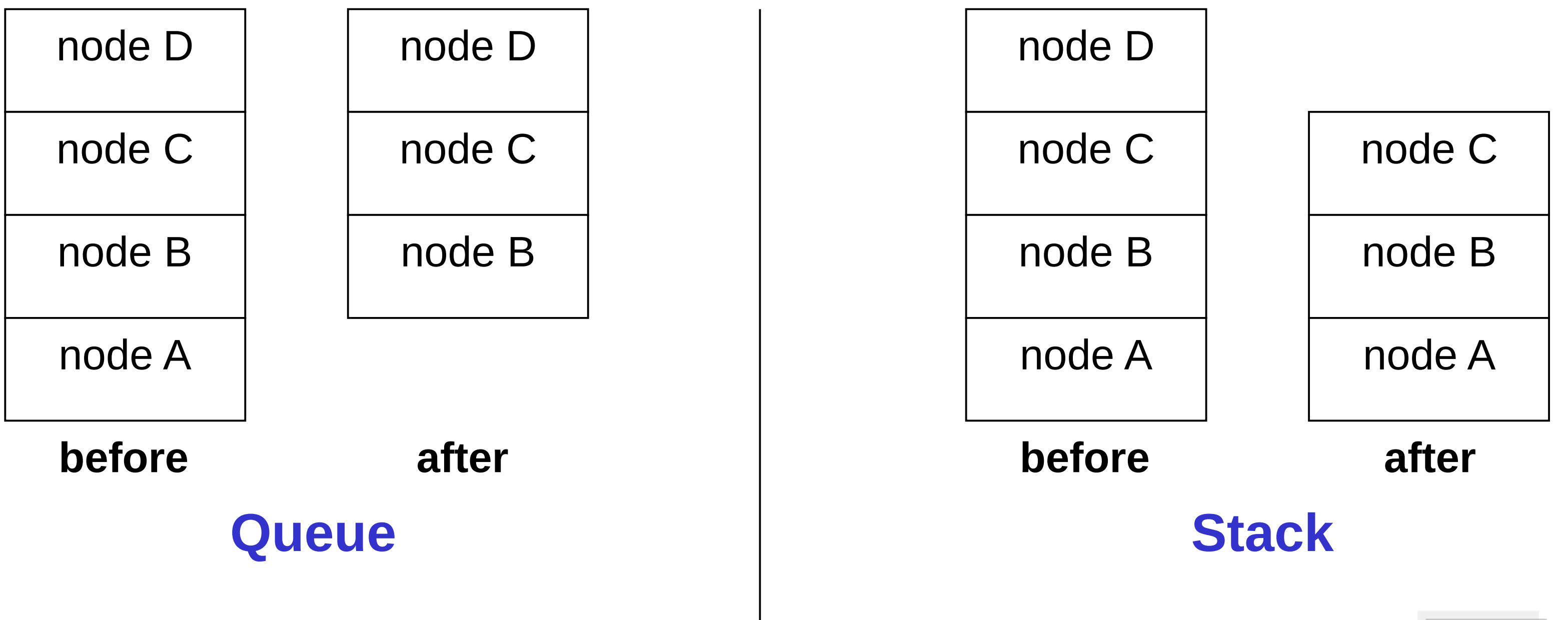
node D
node C
node B
node A

Restrictions on Node Number Access Mode

- Can't say "Fetch-and-Delete the 3rd node"
- Can only say "Fetch-and-Delete"
  - For a Queue: the node returned and deleted is the node in the structure the *longest* time
  - For a Stack: the node returned and deleted is the node in the structure the *shortest* time

Combined Fetch-and-Delete Operation (assumes Node A was inserted first, Node D last)

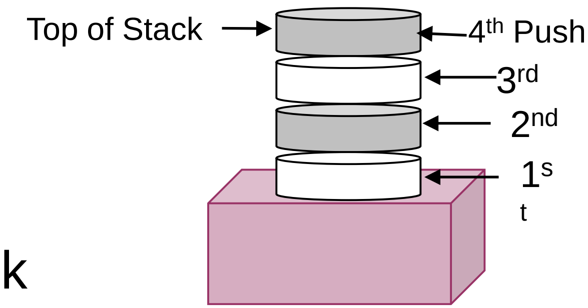
- A Queue and a Stack before and after a Fetch-and-Delete Operation is performed



Stack

- Stack has its own terminology
- When based on an array, its operation algorithms are simple and fast
- It is implemented as a separate class to promote software reusability and generic conversion
- Used in many applications
- Its two operations are sometime expanded and it can be made dynamic

Terminology of Stacks



- Operations
  - The Insert operation is called ***Push***
    - We say an item is pushed "onto" a stack
  - The Fetch-and-Delete operation is called ***Pop***
    - We say an item is popped "off of", or "from", a stack
- Errors
  - A Pop from an empty stack is an ***underflow*** error
  - A push onto a full stack is an ***overflow*** error
- The last item pushed onto the stack is said to be at the "***top***" of the stack
- Stack is a ***Last-In-First-Out*** structure, ***LIFO***

Stack Operations on a Three Member Stack

Operation	Result	The Stack After the Operation
push(nodeA)	nodeA is stored	nodeA
pop()	nodeA is returned	empty
pop()	**Underflow Error**	empty
push(nodeB)	nodeB is stored	nodeB
push(nodeC)	nodeC is stored	nodeC nodeB
push(nodeD)	nodeD is stored	nodeD nodeC nodeB
push(nodeE)	**Overflow Error**	nodeD nodeC nodeB

Continued

Stack Operations on a Three Member Stack (continued)

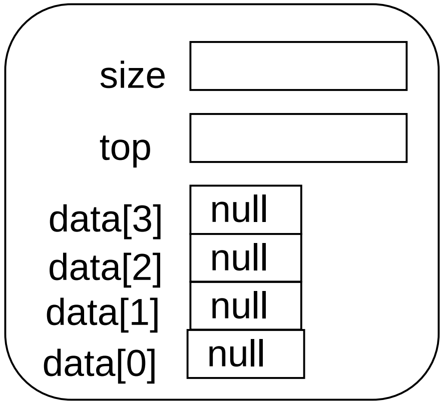
Initial Stack

nodeD
nodeC
nodeB

Operation	**Result**	**The Stack After the Operation**
pop()	nodeD is returned	nodeC nodeB
pop()	nodeC is returned	nodeB
pop()	nodeB is returned	empty
pop()	**UnderFlow Error**	empty

Stack Operation Algorithms For An Array Based Stack

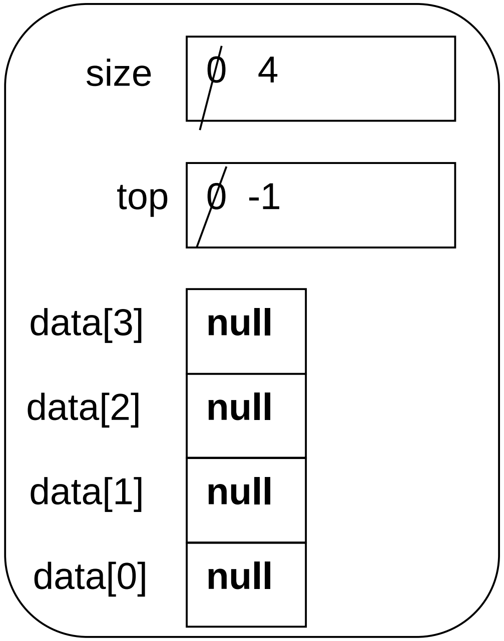
- Initialization, Push, and Pop algorithms assume
  - An array, **`data`**, stores references to the nodes
  - An integer variable **`top`** stores the index of the last node pushed
  - An integer variable **`size`** stores the size of the array



Stack Initialization Algorithm For a Stack of Size S

top = -1;

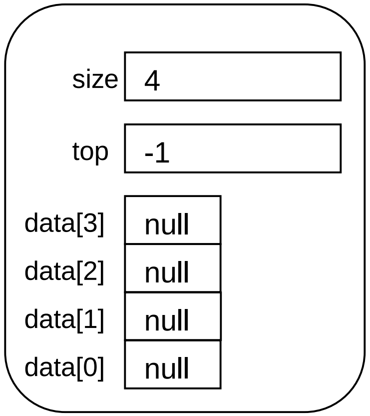
size = s;



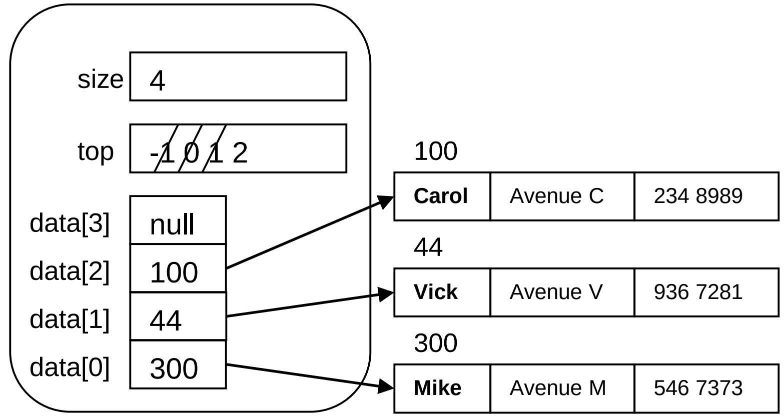
Push Algorithm
(assumes newNode is being pushed)

```
if(top == size - 1)
   return false;  // ** overflow error **
else
{ top = top + 1;
   data[top] = newNode.deepCopy();
   return true;  // push operation successful
}
```

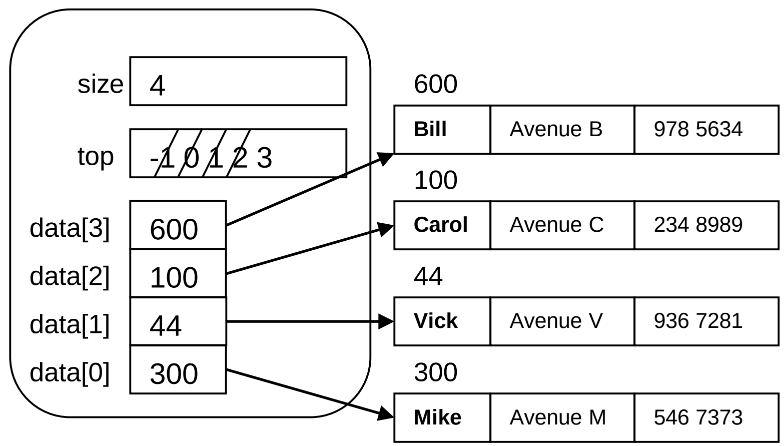
Memory Action of the Push Algorithm



Initialized State



After Mike, then Vick, then Carol have been Pushed

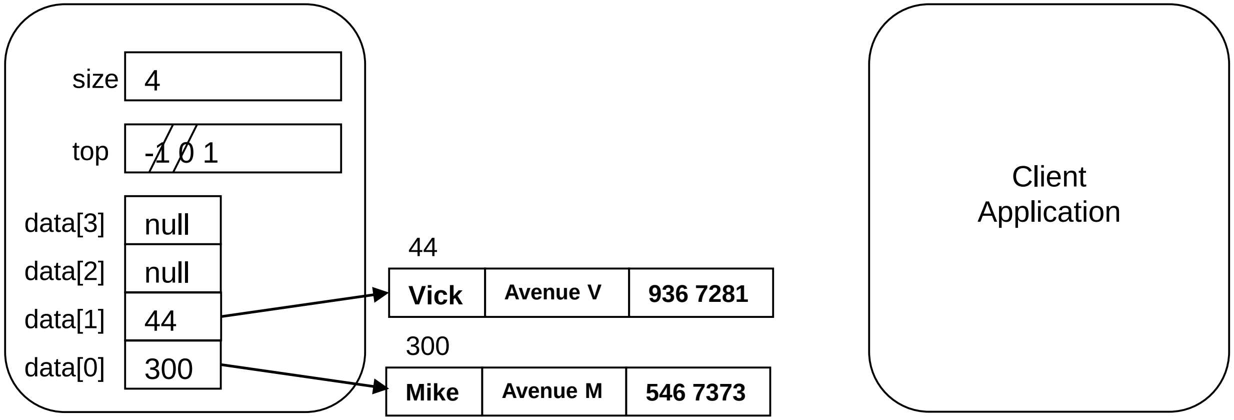


Full State: (the next Push generates an overflow error)

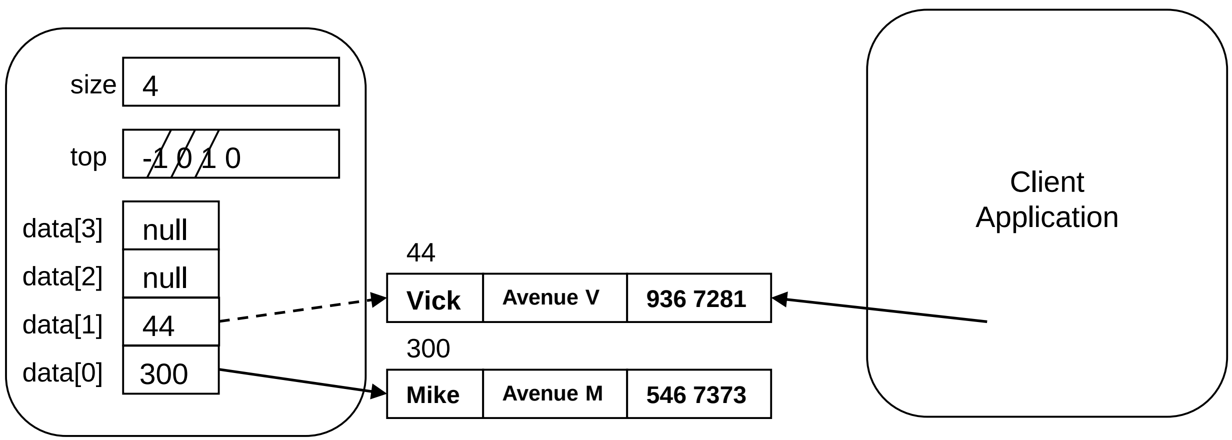
Pop Algorithm

```
if(top == -1)
   return null;  // ** underflow error **
else
{  topLocation = top;
   top = top - 1;
   return data[topLocation]; // returns a
}                            // shallow copy
```

Memory Action of the Pop Algorithm



The Initial Stack (Mike then Vick has been Pushed)



The Stack After Vick has been Popped

Stack Implementation

- Implemented as a class
- Private data members
  - **`data`**, **`next`**, and **`size`**
- Methods
  - A constructor to initializes **`data`** and **`next`** and allocates the array
  - **`push`** and **`pop`**
    - the Java equivalent of the pseudocode algorithms
  - **`showAll`** to output all nodes
    - invokes the node definition class' **`toString`** method
- The method **`pop`** returns a shallow copy

Stack Applications

- Any algorithm that requires a LIFO structure
  - Artificial intelligence algorithms e.g., backtracking
  - Tree traversals
  - Graph traversals
  - In compilers
    - For passing information to, and from, subprograms
    - Remembering return addresses
    - Evaluation of arithmetic expressions

Evaluation of Arithmetic Strings

- Programmers write in infixed notation
  - operators in between operands: 2 + 3 * 4
  - Ambiguity of operand order requires precedence rules (slow runtime evaluation)
- To improve speed, compilers
  - change infixed notation to postfixed 2 3 4 * + using a Stack and a Queue structure
  - Use a Stack to evaluate the expression at run time

Evaluating Postfixed Expressions

1- Begin at left side of the postfixed expression

2- Move to right

3- **if** an operand is found

Push it onto a stack

else when an operator is found

Pop two operands off the stack

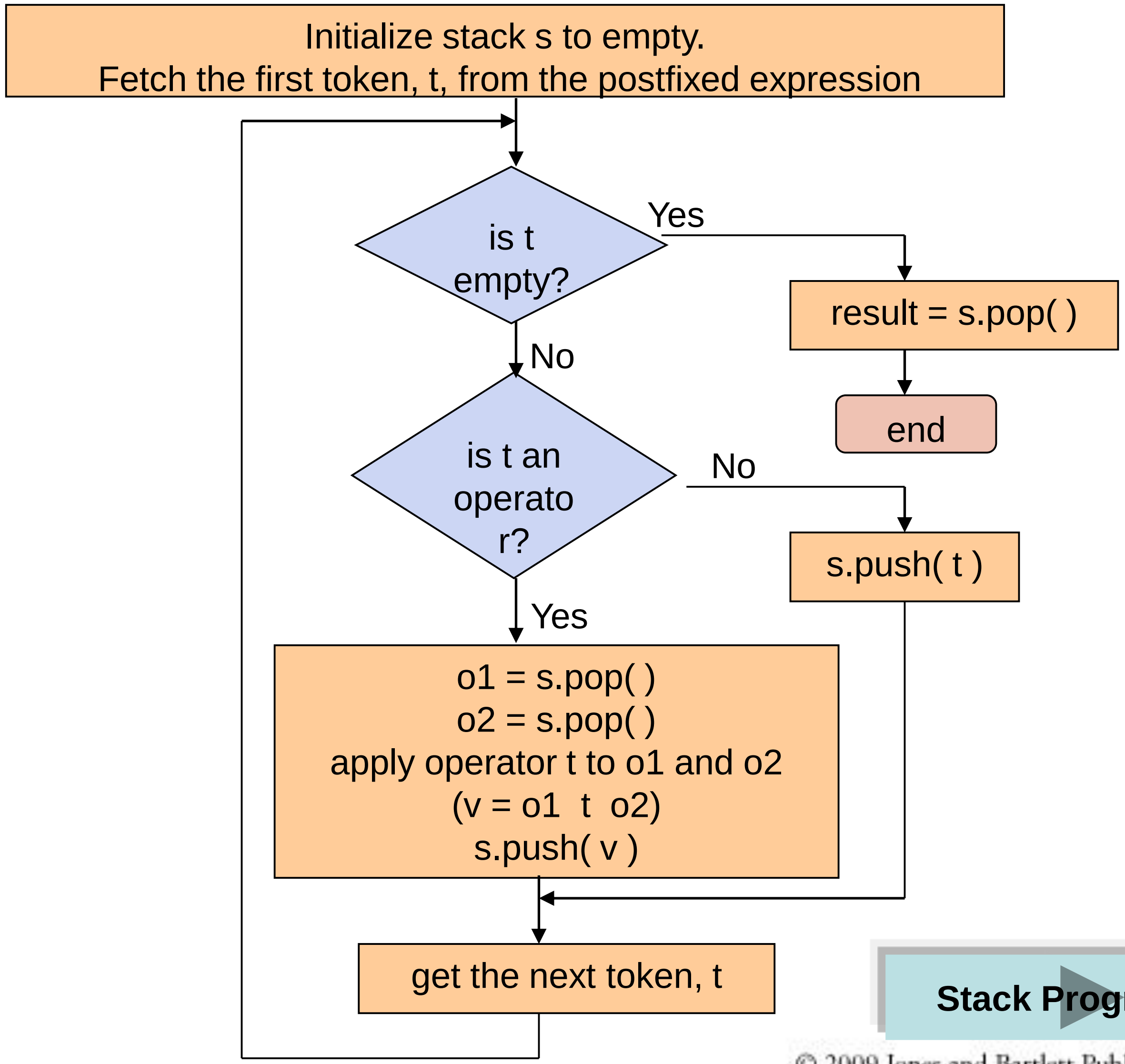
Apply the operator to these two operands

Push the result onto the stack

4- Repeat steps 2 and 3 until the end of the expression is reached. Then pop the value of the expression off the stack

Flowchart

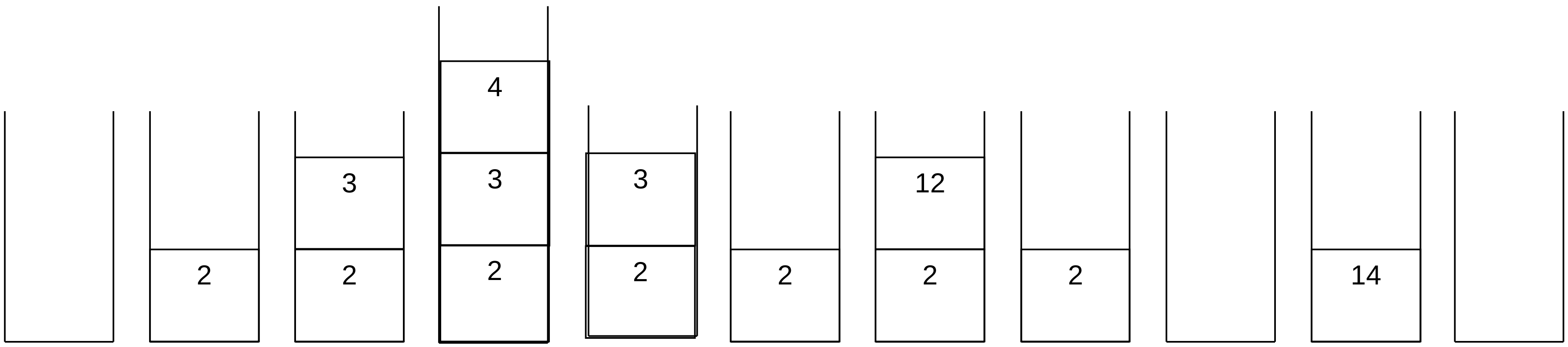
Postfixed Expression Evaluation Algorithm



Stack Progression

Stack Progression During The Evaluation Of 2 3 4 * +

Progression → → →



Expanded Stack Operations

- Reinitialize the stack to empty, **`init`**

  top = -1;

- Test for an empty stack (underflow condition), **`isEmpty`**

  if (top == -1) // stack empty

- Test for a full stack (overflow condition), **`isFull`**

  if (top == size - 1) // stack full

Continued

Expanded Stack Operations (continued)

- Pop a node from the stack *without* deleting it from the structure, **`peek`**
  - Same as Pop algorithm, but **`top`** is not decremented

- Expand the stack at run time within the limits of system memory (inside of the Push algorithm)
  - Use Java's **`arraycopy`** and set **`size`** to the expanded size

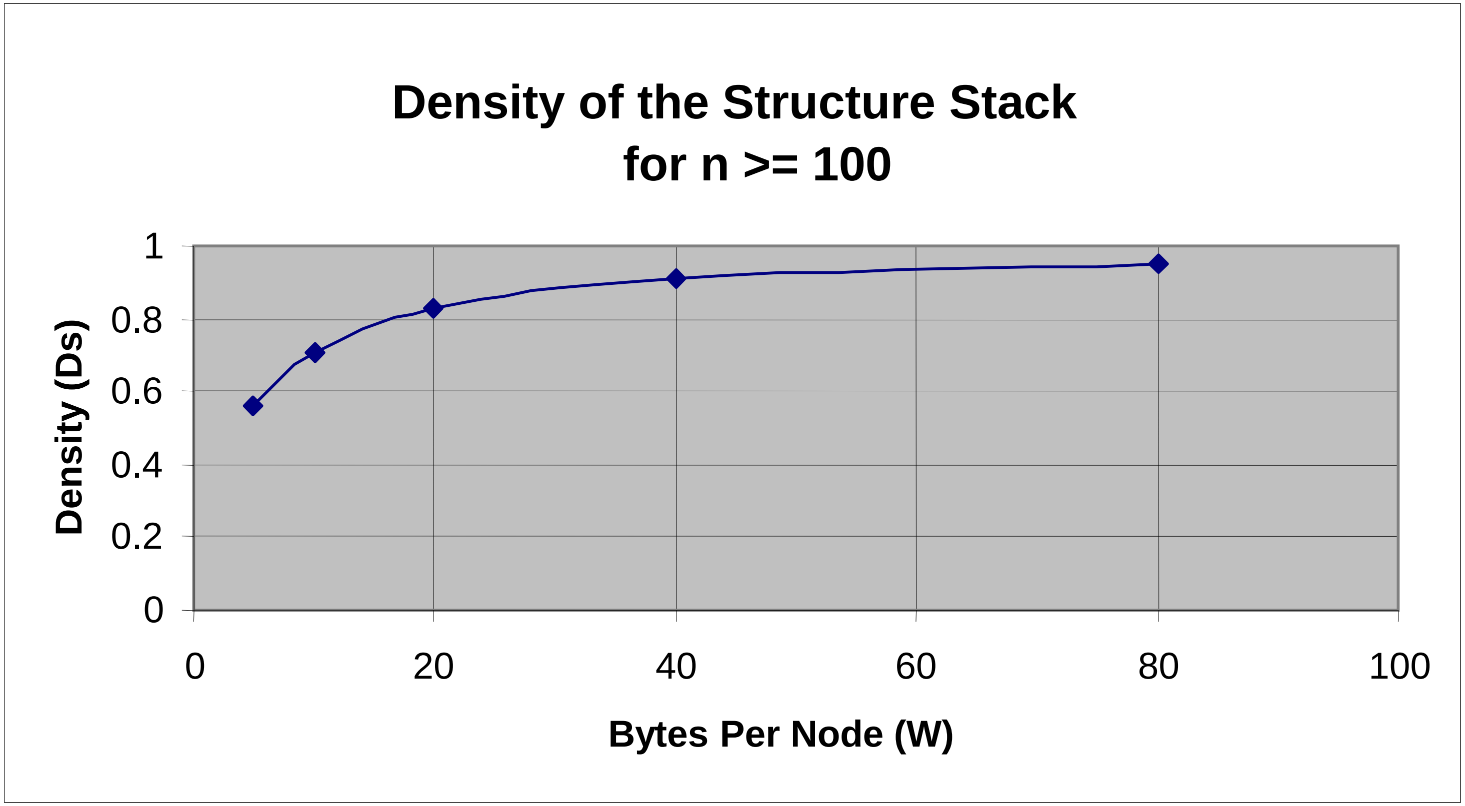
Performance of the Stack Structure

- Speed
  - Push performs 4 memory access to: fetch `top` and `size`, rewrite `top`, and write the node location into `data[top]`, O(1)
  - Pop performs 3 memory accesses to: fetch top, rewrite `top`, and to fetch the contents of `data[topLocation]`, O(1)
- Density > 0.8 for node widths >= 16 bytes
- Outperforms the Unsorted-Optimized structure

Density of a Stack

- Density = information bytes / total bytes
  - Information bytes = n * w
    - n is the number of nodes, w is the bytes per node
  - Overhead = 4n + 8
    - 4 bytes per array element + 8 bytes for `next` and `size`
- Density = n * w / (n * w + 4n + 8)
  - As n gets large n * w/ (n * w + 4n + 8) → 1/(1 + 4/w)

Variation in the Density of a Stack With Node Width



Comparison of the Stack and Unsorted-Optimized Structures

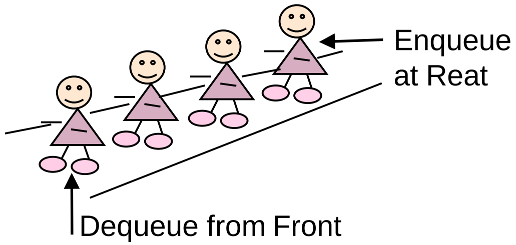
Data Structure	Operation Speed (in memory accesses)							Condition for Density >0.8
	Insert	Delete	Fetch	Update = Delete + Insert	Average[1]	Big-O Average	Average for $n = 10^7$	
Unsorted - Optimized array	3	$\leq n$	$\leq n$	$\leq n + 3$	(3n+6)/4	O(n)	0.75x107 + 1.5	wi > 16
Stack	4 push	combined with Fetch	3 (pop)	not supported	7/2 = 3.5	O(1)	3.5	$w_i > 16$

[1] Assumes all operations are equally probable and is therefore calculated as an arithmetic average of the four operation times.

Queue

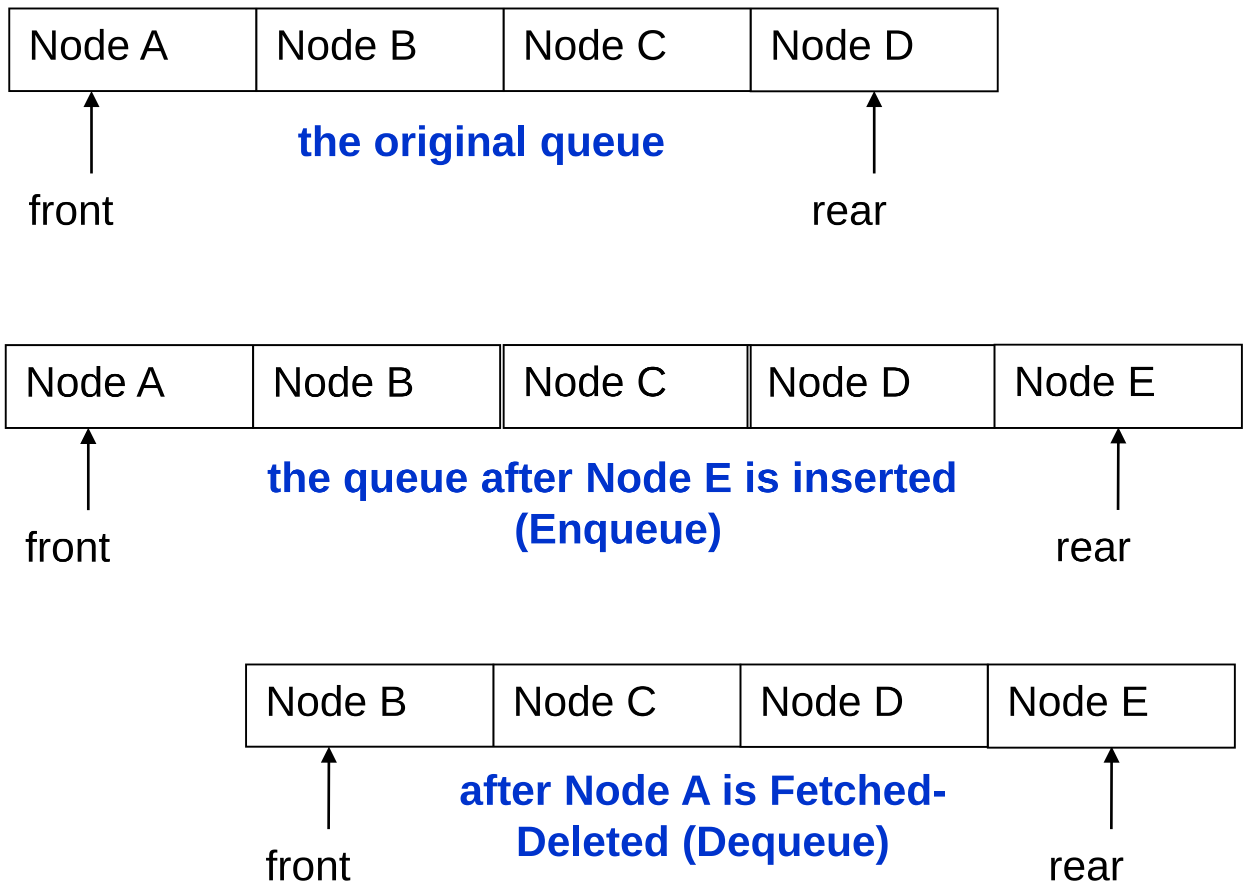
- Like Stack,
  - Queue has its own terminology
  - When based on an array, its operation algorithms are simplistic and demonstrate good performance
  - It is implemented as a separate class to promote software reusability and generic conversion
  - It is used in many applications
  - Its two operations are sometime expanded, and it can be made dynamic

Terminology of Queues



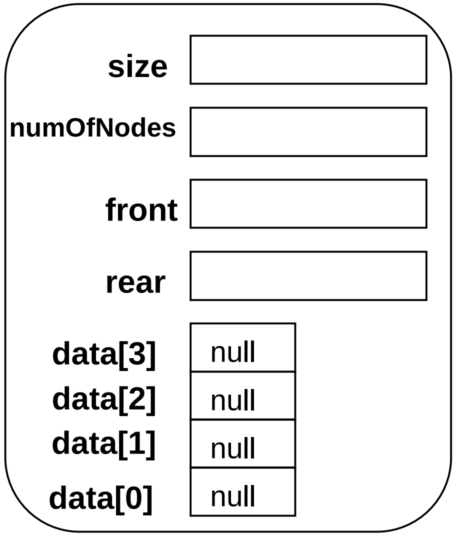
- Operations
  - The Insert operation is called *Enqueue*
    - We say an item is "entered into" a queue
  - The Fetch-and-Delete operation is called *Dequeue*
    - We say an item is "removed from", a queue
- Errors
  - A Dequeue from an empty queue is an *underflow* error
  - An enqueue into a full queue is an *overflow* error
- The first and last items entered into a queue is said to be at the "front" and "rear" of the queue
- Queue is a First-In-First-Out structure, *FIFO*

Queue Operations



Queue Operation Algorithms For An Array Based Stack

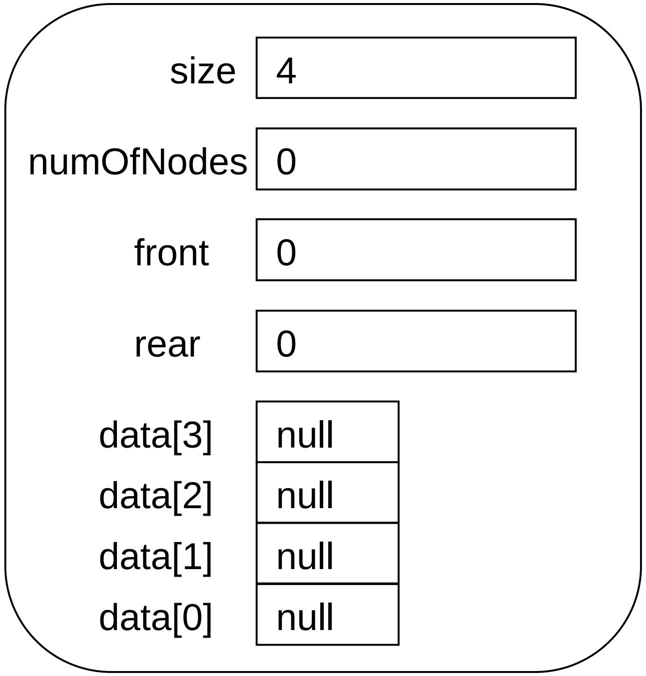
- Initialization, Enqueue, and Dequeue algorithms assume
  - An array, `data`, stores references to the nodes
  - An integer variable `size` stores the size of the array
  - Integer variables `front` and `rear` keep track of the front and rear of the queue
  - An integer variable `numOfNodes` stores the number of nodes in the queue



Queue Initialization Algorithm for a Queue of Size s

size = s;   numberOfNodes = 0;

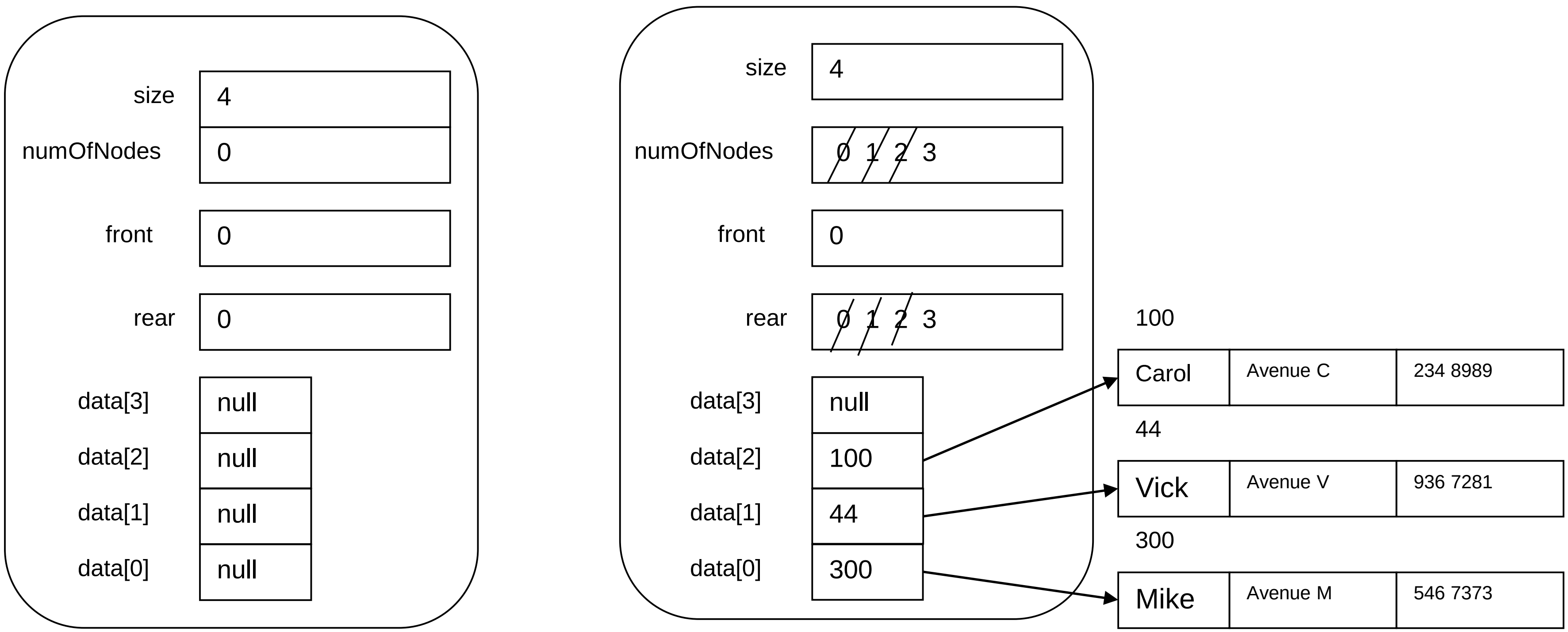
front = 0;   rear = 0;



Enqueue Algorithm
(assumes newNode is being inserted)

```
if(numOfNodes == size)
   return false;  // ** overflow error **
else
{ numOfNodes = numOfNodes + 1;
   data[rear] = newNode.deepCopy();
   rear = (rear + 1) % size; // % keeps rear in bounds
   return true;  // Enqueue operation successful
}
```

Memory Action OF The Enqueue Algorithm



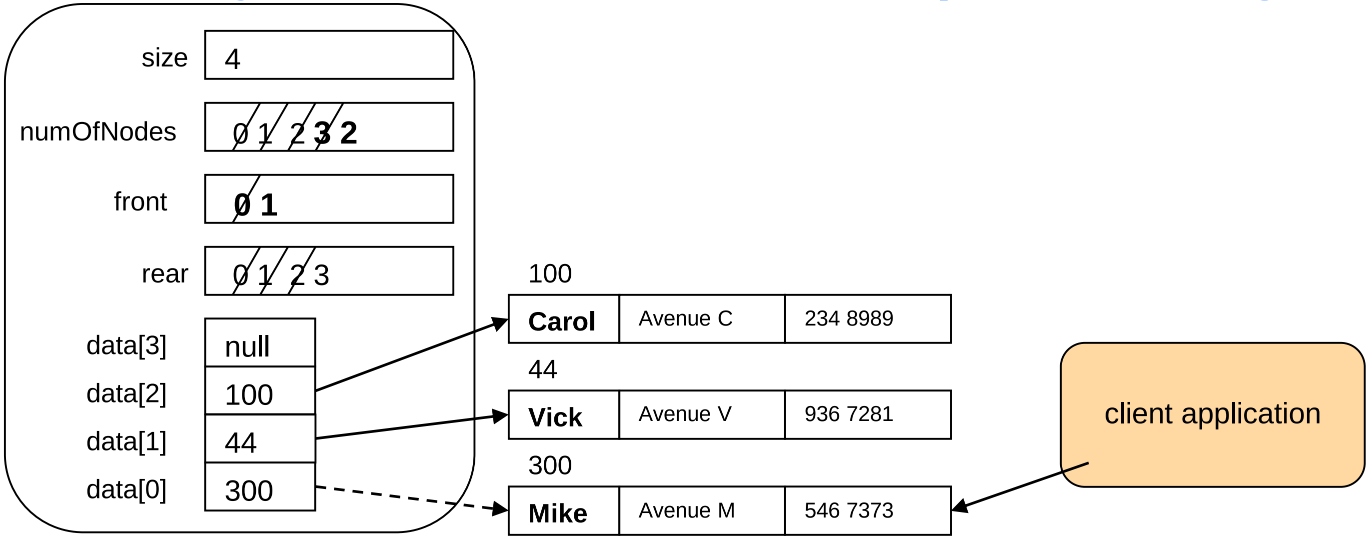
Initialized State

After Mike, then Vick, then Carol have been Inserted

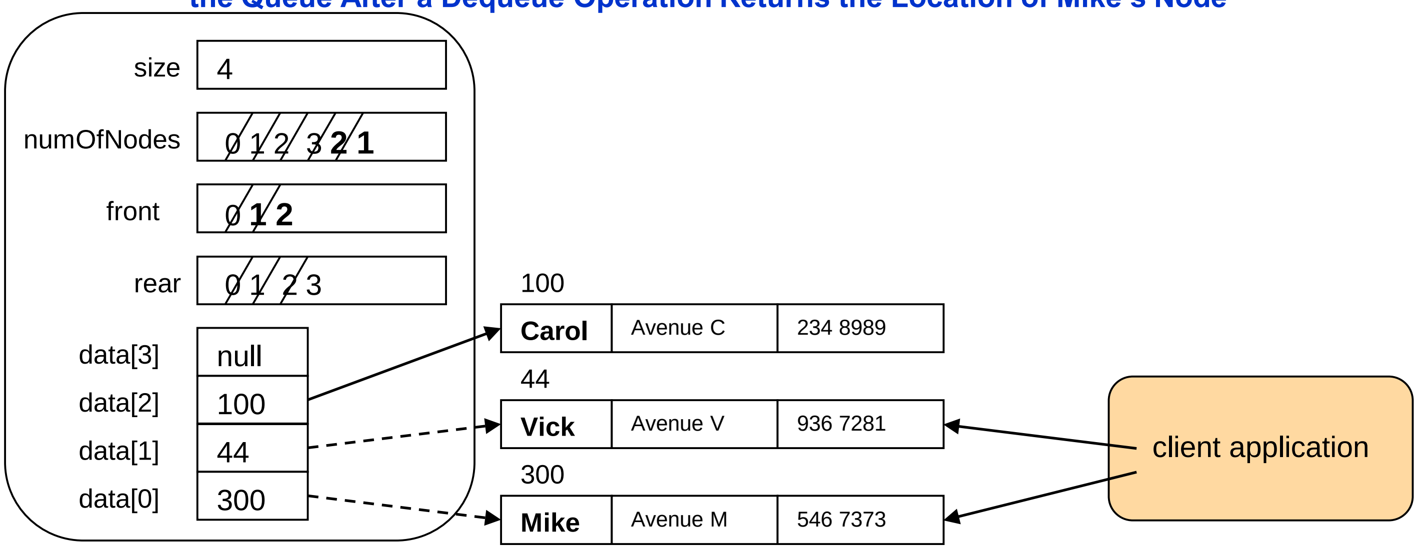
Dequeue Algorithm

```
if(numOfNodes == 0)
    return null;  // ** underflow error **
else
{  frontLocation = front;
   front = (front + 1) % size; // % keeps front in
                               // bounds
   numOfNodes = numOfNodes - 1;
   return data[frontLocation];
}
```

Memory Action of the Dequeue Algorithm



the Queue After a Dequeue Operation Returns the Location of Mike's Node



the Queue After a Dequeue Operation Returns the Location of Vick's Node

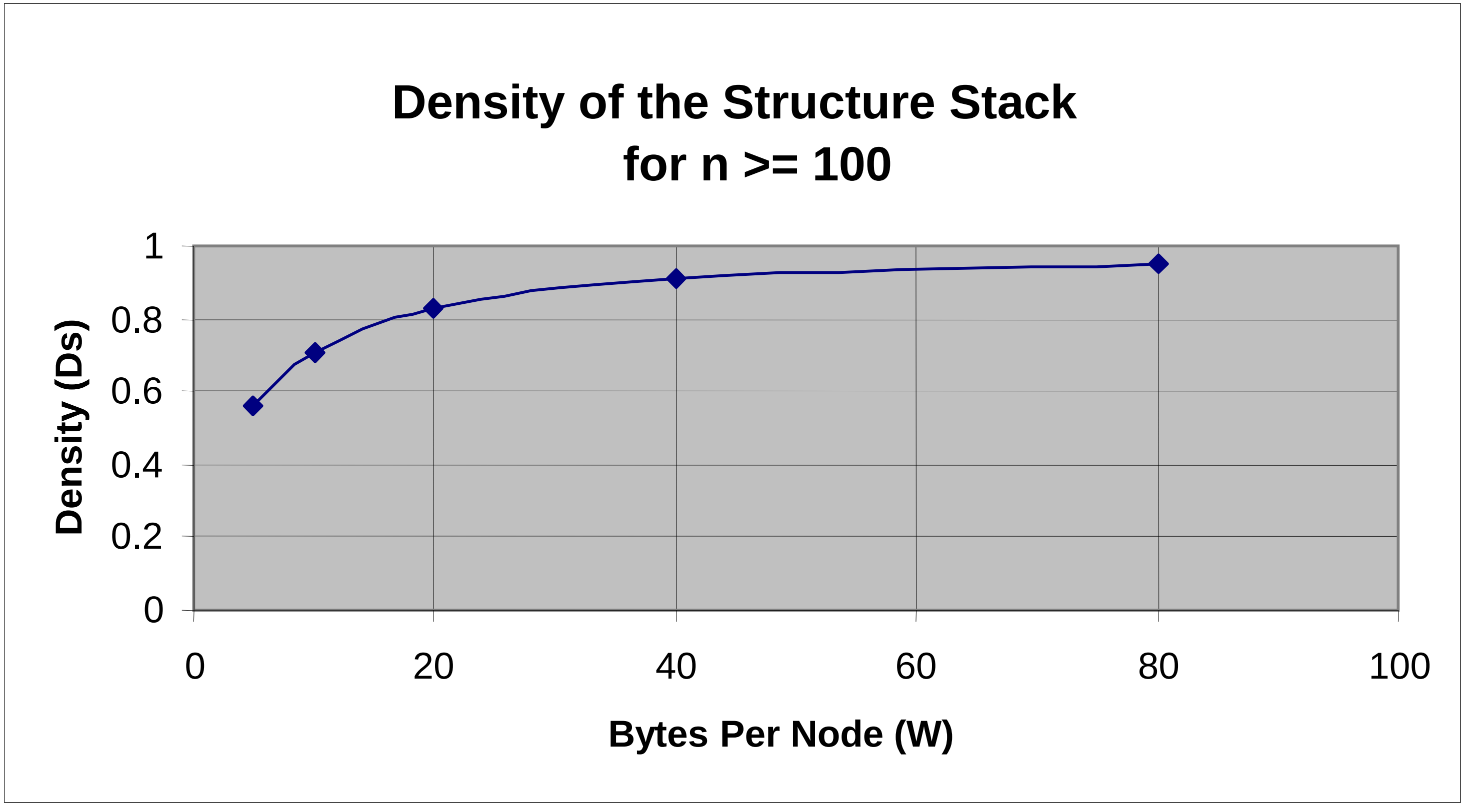
Performance of a Queue

- Speed
  - Enque performs 6 memory access to: fetch `numOfNodes`,`size`, and `rear;` rewrite `top` and numOfNodes, and write the node location into `data[rear]`, O(1)
  - Dequeue performs 6 memory accesses to: fetch `numOfNodes`, `front`,and `size;` rewrite `front` and `numOfNodes`, and to fetch the contents of `data[front]`, O(1)
- Density > 0.8 for node widths >= 16 bytes
- Outperforms the Unsorted-Optimized structure

Density Of A Queue

- Density = information bytes / total bytes
  - Information bytes = n * w
    - n is the number of nodes, w is the bytes per node
  - Overhead = 4n + 16
    - 4 bytes per array element + 16 bytes for `front`, `rear`, `size`, and `numOfNodes`
- Density = n * w / (n * w + 4n + 16)
  - As n gets large n * w/ (n * w + 4n + 16) → 1/(1 + 4/w)
- Density → 1/(1 + 4/w) is the same as that of a Stack

Variation in the Density of a Stack With Node Width



Comparison of Stack's Performance With Previously Developed Structures

Data Structure	Operation Speed (in memory accesses)							Condition For Density >0.8
	Insert	Delete	Fetch	Update = Delete + Insert	Average[1]	Big-O Average	Average for $n = 10^7$	
Unsorted - Optimized array	3	$\leq n$	$\leq n$	$\leq n + 3$	$(3n+6)/4$	O(n)	$0.75 \times 10^7 + 1.5$	w > 16
Stack	4 (push)	combined with fetch	3 (pop)	not supported	7/2 = 3.5	O(1)	3.5	w > 16
Queue	6 enqueue	combined with fetch	6 dequeue	not supported	12/2 = 6	12/2 = 6	6	w > 16

[1] Assumes all operations are equally probable and is therefore calculated as an arithmetic average of the four operation times.

Implementation Of A Queue

- Implemented as a class
- Private data members
  - `data`, `numberOfNodes`, `front`, `rear`, and `size`
- Methods
  - A constructor initialize the data members and allocate the array
  - `enqueue` and `dequeue`
    - the Java equivalent of the pseudocode algorithms
  - `showAll` to output all nodes
    - invokes the node definition class' `toString` method
- The method `dequeue` returns a shallow copy

Queue Applications

- Any algorithm that process data in the order it is received, FIFO
  - Print spoolers (several tasks sharing a printer)
  - Queuing theory algorithms in Operations Research
  - Artificial intelligence algorithms
  - Sorting algorithms
  - Graph traversals
  - Conversion of infixed expressions to postfixed

Methodized Generic Coding Process

- Code a node definition class and a non-generic data structure class that complies to a set of coding guidelines (e.g., our Stack and Listing classes)
- Test and debug the two classes
- Use a four-step methodology to convert the data structure class to a generic implementation

Generic Coding Guidelines

- The **node definition and** the **data structure** are coded as two **separate classes**
- The **data structure cannot mention** the names of the **data fields** that make up a node
- If the structure is going to be **encapsulated**, a method to perform a **deep copy** of a node must be coded **in** the **node definition** class
- **If** the structure is going to be **accessed in** the **key field mode**, a **method to determine** if a **given key** is **equal to** the **key of a node** must be coded **in** the **node definition class**
- The **data structure** class **cannot mention** the **key field's type**

Four-Step Methodology To Convert a Data Structure Class To A Generic Structure

- Step 1
  - Add a generic placeholder at the end of the class' heading e.g., `<T>`

    public class GenericStack **<T>**
- Step 2
  - Replace all occurrences of the name of the node definition class with the generic placeholder `T`

    e.g., **public boolean** push(**T** newNode)
- Step 3
  - Wherever the operator **`new`** operates on the placeholder `T`, substitute `Object` for `T`, include coercion

    e.g., data = **(T[ ]) new Object**[100]

Continued

Four-Step Generic Conversion Methodology (continued)

- Step 4
  - Wherever a method operates on an instance of type T (e.g., **`newNode`**)
    - The method's signature is added to an interface (named, e.g., **`GenericNode`**), which must be implemented by the node definition class
    - An instance of the interface is declared and assigned the instance's address

      Generic node = (GenericNode) newNode;
    - The method invocation is changed to operate on the instance of the generic type

      e.g., data[top] = node.deepCopy();

Priority Queue

- The Insert operation is called Add
  - Nodes are assigned a priority when inserted
- The Fetch-and-Delete operation is called Poll
  - The node with the highest, or lowest, priority is returned (depending on the Priority Queue structure)
  - Various strategies are employed in the event of a priority tie
    - One strategy is the node in the structure the longest is returned, FIFO
- Priority Queues are often implemented using a Heap (discussed in Chapter 8)
- Operating systems use Priority Queues in their task scheduling algorithms

Java's API Stack Class

- A generic data structure
  - Access is restricted to the node at the top of the stack
  - Supports *five* Operations
  - *Not* encapsulated
  - Stores *objects*, but primitive types are wrapped automatically in Wrapper objects
  - Expandable
- Client codes

Stack <Car> garage = new Stack<Car> ( )

to create an empty homogeneous stack named `garage` that can store only Car objects

Five Basic Operations in the Class Stack

Table assumes the heterogeneous structure `boston` was declared as:
Stack boston = new Stack( );
And the code is executed in the order shown

Basic Operation	**`Stack` method name**	**Coding example**	**Comments**
Test for empty	empty	**if**(boston.empty( )) System.out.println("boston is empty);	Returns **true** if empty, otherwise **false**

Push	push	boston.push(tom); // adds tom to boston
		boston.push(mary); // adds mary to boston
		boston.push(21); // adds 21 to boston
			boston expands dynamically.
			the 21 gets wrapped

Find a node's position on the stack	search	if(boston.search(tom) != 1) System.out.println(Tom's node is not " + at the top of the stack");	returns a node's position on the stack

Pop	pop	int i = (Integer) boston.pop( ) // fetch 21
		temp = (Node) boston.pop( ) // fetch mary
		temp = (Node) boston.pop( ) // fetch tom
			Coercion not necessary for homogeneous uses.
			Next pop throws an exception.

Peek	peek	boston.push(tom); temp = boston.peek( ); // tom fetched	tom is not deleted.

The End

Return to, Overview, Restrictions, Stack, Queue, Methodized Generic Conversion Process, Priority Queue, or Java's Stack class

End Presentation