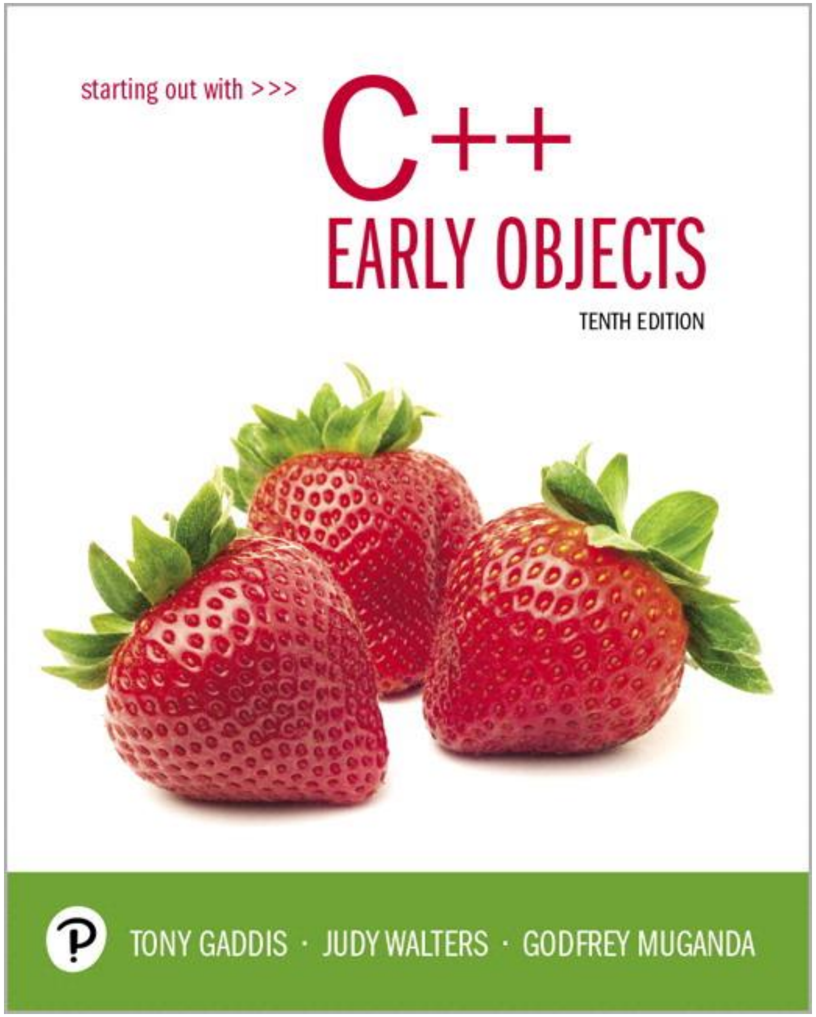
Starting Out with C++ Early Objects

Tenth Edition



Chapter 19

Stacks and Queues

Topics

19.1 Introduction to Stacks

19.2 Dynamic Stacks

19.3 The STL **`stack`** Container

19.4 Introduction to Queues

19.5 Dynamic Queues

19.6 The STL **`deque`** and **`queue`** Containers

19.7 Eliminating Recursion

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18.1 Introduction to Stacks

- Stack: a LIFO (last in, first out) data structure
- Examples:
  - plates in a cafeteria serving area
  - return addresses for function calls

Stack Basics

- Stack is usually implemented as a list, with additions and removals taking place at one end of the list
- The active end of the list implementing the stack is the top of the stack
- Stack types:
  - Static – fixed size, often implemented using an array
  - Dynamic – size varies as needed, often implemented using a linked list

Stack Operations and Functions

Operations:

- –push: add a value at the top of the stack
- –pop: remove a value from the top of the stack

Boolean function:

- –isEmpty: true if the stack currently contains no elements

Static Stack Implementation

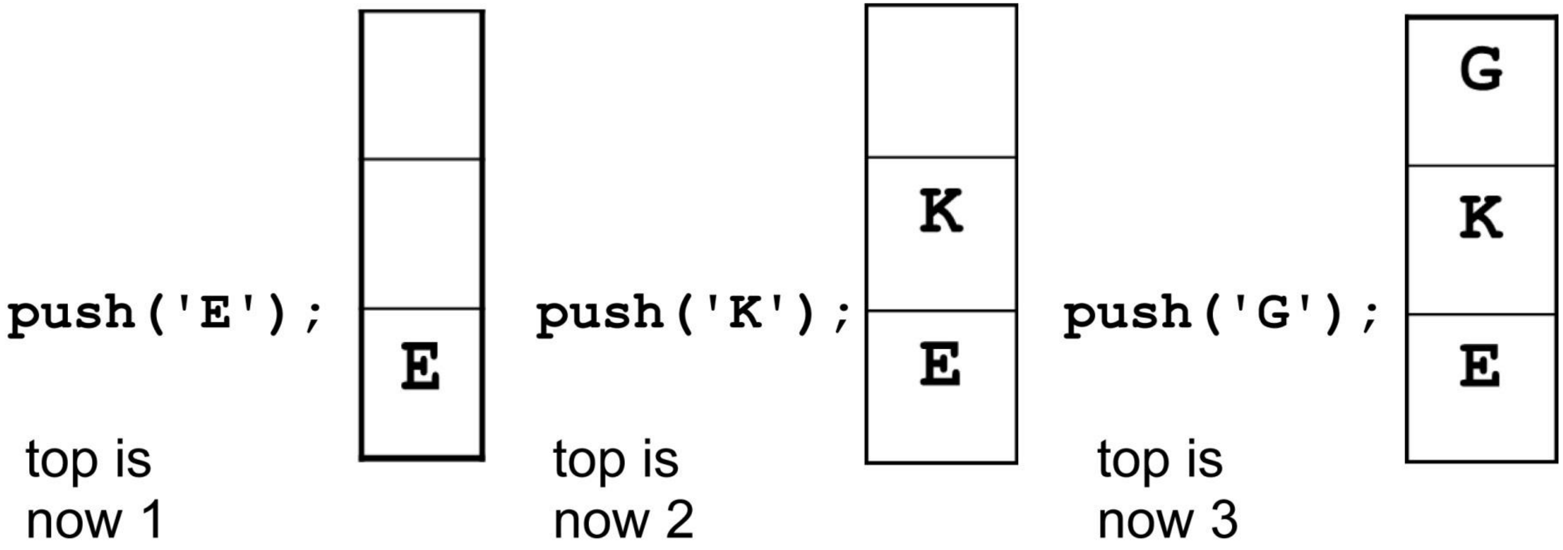
- Uses an array of a fixed size
- Bottom of stack is at index 0. A variable called top tracks the current top of the stack

```
const int STACK_SIZE = 3;
char s[STACK_SIZE];
int top = 0;
```

top is where the next item will be added

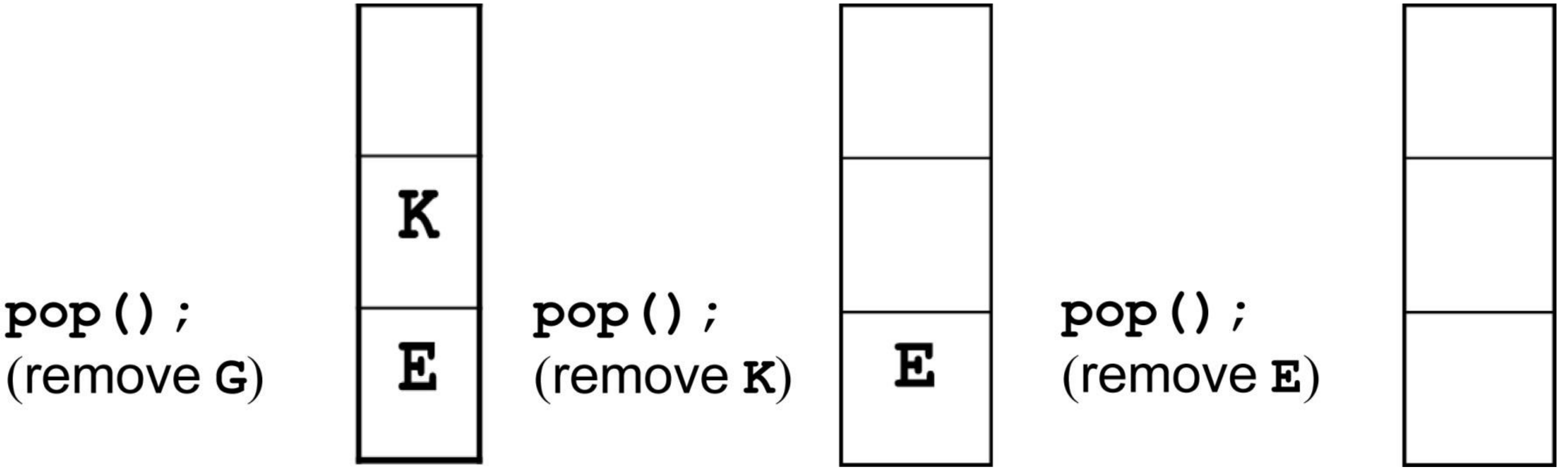
Array Implementation Example

This stack has max capacity 3, initially top = 0 and stack is empty.



Stack Operations Example

After three pops, **`top`** is **`0`** and the stack is empty



Class Implementation Using an Array 1 of 5

```
class STACK
{
 private:
      unique_ptr<char []> s;  // for the array
      int capacity, top;
   public:
      void push(char x);
      void pop(char &x);
      bool isEmpty();
      STACK(int capacity);
      ~STACK()
};
```

Class Implementation Using an Array 2 of 5

Use exception classes as members of the STACK class to signal that an underflow or overflow condition has occurred:

```
class Overflow {};
class Underflow {};
```

Class Implementation Using an Array 3 of 5

To check if the stack is empty:

```
bool STACK::isEmpty()
{

        return (top == 0);

}
```

Class Implementation Using an Array 4 of 5

To add an item to the stack

```
void STACK::push(char x)
{
  if (top==capacity)
     throw STACK::Overflow();
  s[top] = x;
  top++;
}
```

Class Implementation Using an Array 5 of 5

To remove an item from the stack

```
void STACK::pop(char &x)
{
 if (isEmpty())
     throw STACK::Underflow();
 top--;
 x = s[top];
}
```

Exceptions from Stack Operations

- The preceding example uses exception classes to handle cases where an attempt is made to push onto a full stack (overflow) or to pop from an empty stack (underflow)
- Programs that use **`push`** and **`pop`** operations should do so from within a **`try`** block.
- **`catch`** block(s) should follow the **`try`** block to interpret what occurred and to inform the user.

19.2 Dynamic Stacks

- The storage for a stack can be implemented as a linked list
- There is no need to indicate the initial capacity of the stack. It can grow and shrink as necessary.
- It can't ever be full as long as memory is available, so there is no need to test for overflow.
- Testing for underflow (empty stack) is still needed.

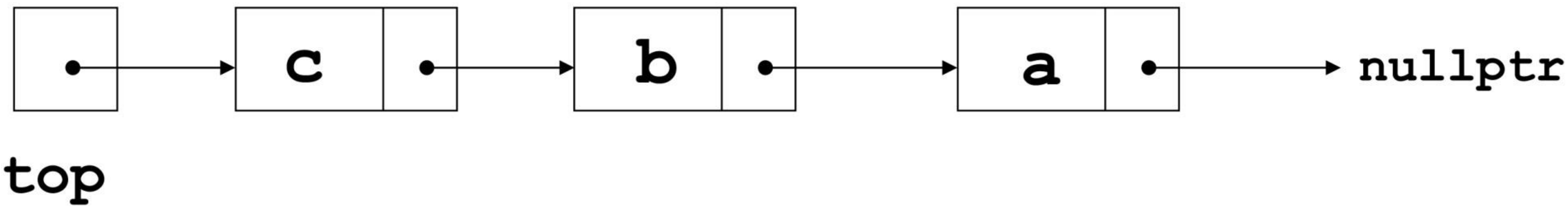
Dynamic Linked List Implementation

- Define a class for a dynamic linked list
- Within the class, define a private member class (**`LNode`**) for dynamic nodes in the list
- Define a node pointer to the beginning of the linked list, which will serve as the top of the stack

Linked List Implementation

A linked stack after three push operations:

```
push('a'); push('b'); push('c');
```



Operations on a Linked Stack 1 of 3

Check if stack is empty:

```
bool isEmpty()
{
        return (top == nullptr);
}
```

Operations on a Linked Stack 2 of 3

Add a new item to the stack

```
void push(char x)
{
   top = new LNode(x, top);
}
```

Operations on a Linked Stack 3 of 3

Remove an item from the stack

```
 void pop(char &x)
{
  if (isEmpty())
     throw STACK::Underflow();
  x = top->value;
  LNode *oldTop = top;
  top = top->next;
  delete oldTop;
}
```

19.3 The STL `stack` Container

- Stack template can be implemented using a **`vector`**, **`list`**, or a **`deque`**
- Implements **`push`**, **`pop`**, and **`empty`** member functions
- Implements other member functions:
  - **`size`**: number of elements on the stack
  - **`top`**: reference to element on top of the stack (must be used with **`pop`** to remove and retrieve top element)

Container Adapters

- A class that provides a new interface to an existing class is a container adapter.
- The purpose of a container adapter is to provide a specialized use of the existing class.
- The STL **`stack`** container, using either a **`vector`**, a **`list`**, or a **`deque`**, is an example of a container adapter.

Defining an STL-based Stack

- Defining a stack of **`char`**, named **`cstack`**, implemented using a **`vector`**:

```
stack< char, vector<char> > cstack;
```

- Implemented using a list:

```
stack< char, list<char> > cstack;
```

- Implemented using a **`deque`** (default):

```
stack< char > cstack;
```

- Prior to C++ 11, spaces are required between consecutive **`> >`** symbols to distinguish from stream extraction

18.4 Introduction to Queues

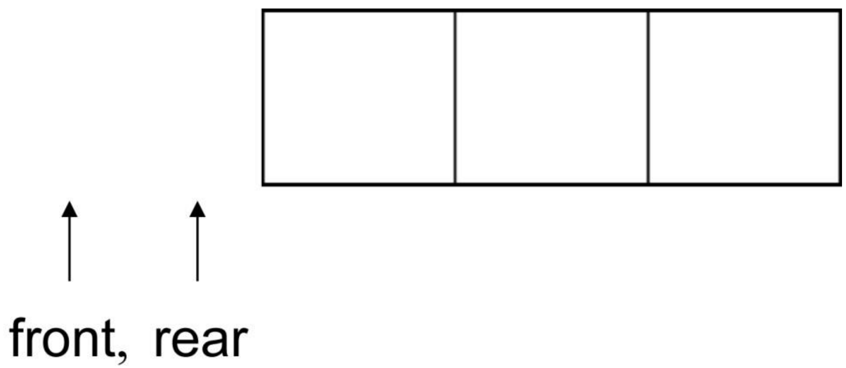
- Queue: a FIFO (first in, first out) data structure.
- Examples:
  - people waiting to use an ATM
  - cars lined up to pay and exit a parking structure
- Implementation:
  - static: fixed size, implemented as array
  - dynamic: variable size, implemented as linked list

Queue Locations and Operations

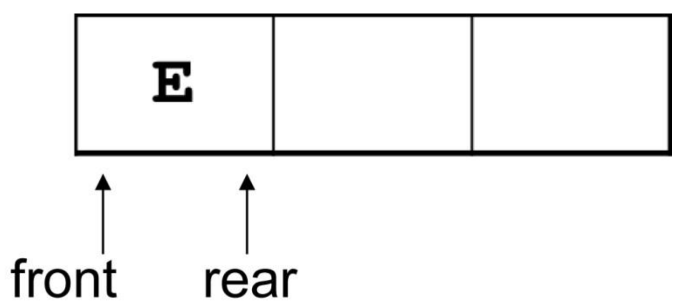
- rear: position where elements are added
- front: position from which elements are removed
- enqueue: add an element to the rear of the queue
- dequeue: remove an element from the front of a queue

Array Implementation of Queue 1 of 3

An empty queue that can hold **`char`** values:

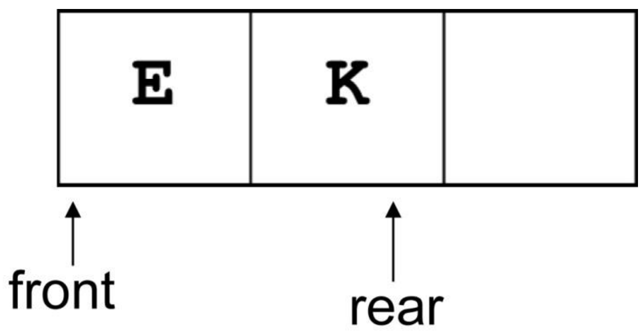


`enqueue('E');`

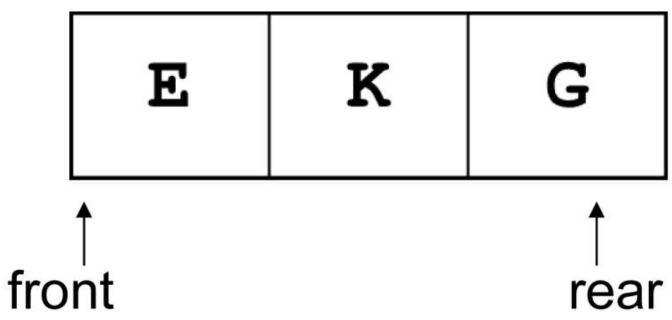


Array Implementation of Queue 2 of 3

```
enqueue('K');
```

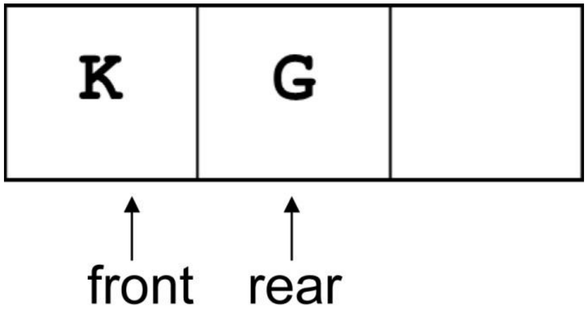



```
enqueue('G');
```

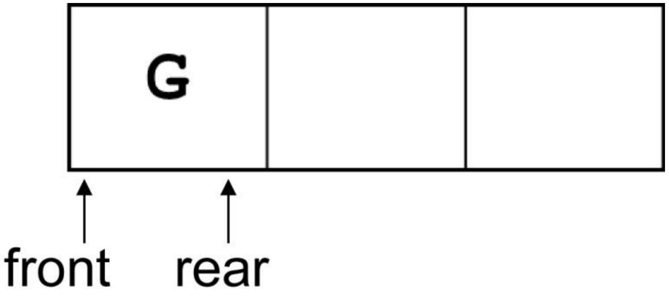


Array Implementation of Queue 3 of 3

`dequeue(); // remove E`



`dequeue(); // remove K`



Array Implementation Issues 1 of 2

- In the preceding example, front never moves.
- Whenever **`dequeue`** is called, all remaining queue entries move up one position. These moves takes time.
- Alternate approach:
  - –Use a ‘circular’ array: **`front`** and **`rear`** both move when items are added and removed. Both can ‘wrap around’ from the end of the array to the front if warranted.
- Other solutions are possible

Array Implementation Issues 2 of 2

- queue variables needed:
  - `int qSize;`
  - `unique_ptr<int []> q;`
  - `int front = -1;`
  - `int rear = -1;`
  - `int number = 0; //how many in queue`
- These could be members of a queue class, and queue operations would be member functions

`isEmpty` Member Function

Check if queue is empty:

```
bool isEmpty()
{
    return (number == 0);
}
```

isFull Member Function

Check if queue is full:

```
bool isFull()
{

    return (number == qSize);

}
```

enqueue and dequeue 1 of 4

- To enqueue, we need to add an item `x` to the rear of the queue
- Queue convention says `q[rear]` is already occupied. Execute

```
if(!isFull)
 { rear = (rear + 1) % qSize;
// mod operator for wrap-around
   q[rear] = x;
   number ++;
}
```

enqueue and **dequeue** 2 of 4

- To dequeue, we need to remove an item **x** from the front of the queue
- Queue convention says **q[front]** has already been removed. Execute

```
   if(!isEmpty)
{   front = (front + 1) % qSize;
    x = q[front];
    number--;
}
```

`enqueue` and `dequeue` 3 of 4

- `enqueue` moves `rear` to the right as it fills positions in the array
- `dequeue` moves `front` to the right as it empties positions in the array
- When `enqueue` gets to the end, it wraps around to the beginning to use those positions that have been emptied
- When `dequeue` gets to the end, it wraps around to the beginning use those positions that have been filled

enqueue and dequeue 4 of 4

- Enqueue wraps around by executing

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

- Dequeue wraps around by executing

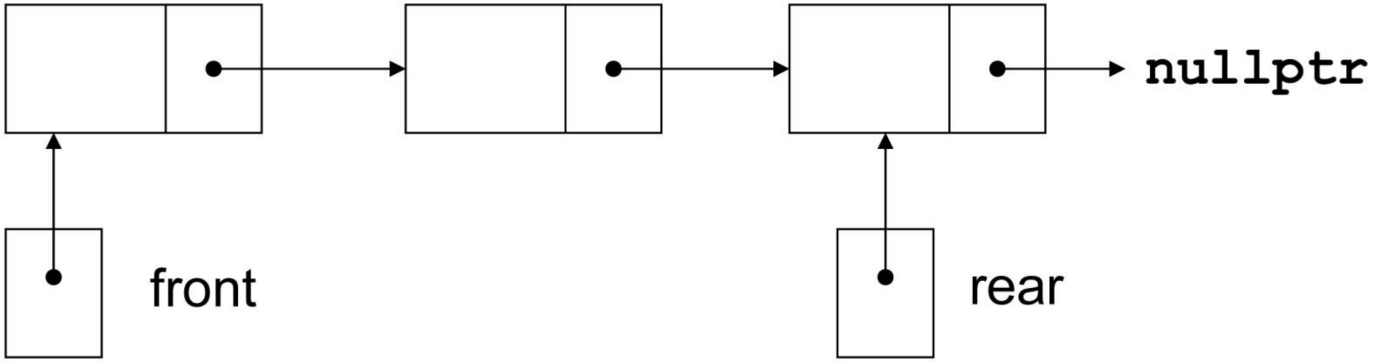
```
front = (front + 1) % qSize;
```

Exception Handling in Static Queues

- As presented, the static queue class will encounter an error if an attempt is made to enqueue an element to a full queue, or to dequeue an element from an empty queue
- A better design is to throw an underflow or an overflow exception and allow the programmer to determine how to proceed
- Remember to throw exceptions from within a **`try`** block, and to follow the **`try`** block with a **`catch`** block

19.5 Dynamic Queues

- Like a stack, a queue can be implemented using a linked list
- This allows dynamic sizing and avoids the issue of wrapping indices



Dynamic Queue Implementation Data Structures

- Define a class for the dynamic queue
- Within the dynamic queue, define a private member class for a dynamic node in the queue
- Define node pointers to the front and rear of the queue

Dynamic queue: isEmpty Member Function

To check if queue is empty:

```
bool isEmpty()
{

    return (front == NULL);

}
```

enqueue Member Function Details

To add item at rear of queue

```
if (isEmpty())
    {
      front = new QNode(x);
      rear = front;
    }
  else
    {
      rear->next = new QNode(x);
      rear = rear->next;
    }
```

dequeue Member Function

To remove item from front of queue

```
if (isEmpty())
{
    // throw exception or print
    // a message
} else {
x = front->value;
QNode *oldfront = front;
front = front->next;
delete oldfront;
}
```

19.6 The STL `deque` and `queue` Containers

- **`deque`**: a double-ended queue (DEC). Has member functions to enqueue (**`push_back`**) and dequeue (**`pop_front`**)

- **`queue`**: container ADT that can be used to provide a queue based on a **`vector`**, **`list`**, or **`deque`**. Has member functions to enqueue (**`push`**) and dequeue (**`pop`**)

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Defining a Queue

- Defining a queue of **`char`**, named cQueue, based on a **`deque`**:

```
deque<char> cQueue;
```

- Defining a **`queue`** with the default base container

```
queue<char> cQueue;
```

- Defining a queue based on a **`list`**:

```
queue<char, list<char> > cQueue;
```

- Prior to C++ 11, spaces are required between consecutive **`> >`** symbols to distinguish from stream extraction

19.7 Eliminating Recursion

- Recursive solutions to problems are often elegant but inefficient
- A solution that does not use recursion is more efficient for larger sizes of inputs
- Eliminating the recursion: re-writing a recursive algorithm so that it uses other programming constructs (stacks, loops) rather than recursive calls

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