CSCI 136
Data Structures & Advanced Programming

Lecture 14

Fall 2019

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Administration

- Lab 2 back, Lab 3 back soon
- Lab 5 out very soon
- Midterm next week--accommodations??

Last Time

- Implementation of Doubly Linked Lists
- The structure5 hierarchy so far

Today: Linear Structures

- The AbstractLinear and AbstractStack classes
- Stack Implementations
  - StackArray, StackVector, StackList,
- Stack applications
  - Expression Evaluation
  - PostScript: Page Description & Programming
  - Mazerunning (Depth-First-Search)

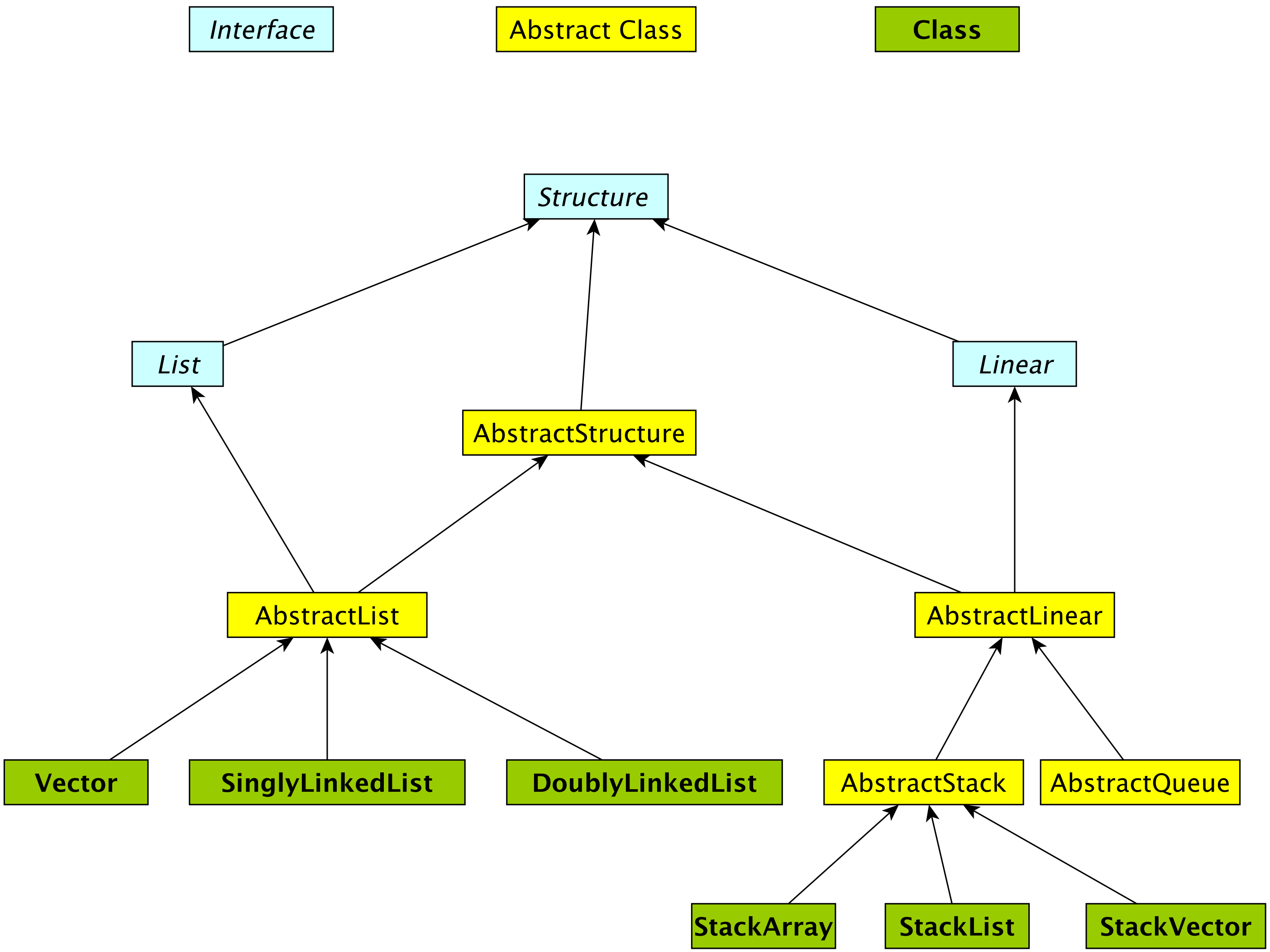
Linear Structures

- What if we want to impose *access restrictions* on our lists?
  - I.e., provide only one way to add and remove elements from list
  - No longer provide access to middle
- Key Examples: Order of removal depends on order elements were added
  - LIFO: Last In First Out
  - FIFO: First In First Out

Examples

- FIFO: First In – First Out (Queue)
  - Line at dining hall
  - Data packets arriving at a router
- LIFO: Last In – First Out (Stack)
  - Stack of trays at dining hall
  - Java Virtual Machine stack

The Structure5 Universe (next)



Linear Interface

- How should it differ from List interface?
  - Should have fewer methods than List interface since we are limiting access …
- Methods:
  - Inherits all of the Structure interface methods
    - add(E value) – Add a value to the structure.
    - E remove(E o) – Remove value o from the structure.
      - But this is awkward---why?
    - int size(), isEmpty(), clear(), contains(E value), …
  - Also:
    - E get() – Preview the next object to be removed.
    - E remove() – Remove the *next* value from the structure.
    - boolean empty() – same as isEmpty()

Linear Structures

- Why no "random access"?
  - I.e., no access to middle of list
- More restrictive than general List structures
  - Less functionality can result in
    - Simpler implementation
    - Greater efficiency
- Approaches
  - Use existing structures (Vector, LL), or
  - Use underlying organization, but simplified

Stacks

- Examples: stack of trays or cups
  - Can only take tray/cup from top of stack
- What methods do we need to define?
  - Stack interface methods
- New terms: push, pop, peek
  - Only use push, pop, peek when talking about stacks
  - Push = add to top of stack
  - Pop = remove from top of stack
  - Peek = look at top of stack (do not remove)

Notes about Terminology

- When using stacks:
  - pop = remove
  - push = add
  - peek = get
- In Stack interface, pop/push/peek methods call add/remove/get methods that are defined in Linear interface
- But "add" is not mentioned in Stack interface (it is inherited from Linear)
- Stack interface **extends** Linear interface
  - Interfaces *extend* other interfaces
  - Classes *implement* interfaces

Stack Implementations

- Array-based stack
  - int top, Object data[ ]
  - Add/remove from index top

+ all operations are O(1)
– wasted/run out of space

- Vector-based stack
  - Vector data
  - Add/remove from tail

+/– most ops are O(1) (add is O(n) in worst case)
– potentially wasted space

- List-based stack
  - SLL data
  - Add/remove from *head*

+ all operations are O(1)
+/– O(n) space overhead (no “wasted” space)

Stack Implementations

- structure5.StackArray
  - int top, Object data[ ]
  - Add/remove from index top

  + all operations are O(1)
  – wasted/run out of space

- structure5.StackVector
  - Vector data
  - Add/remove from tail

  +/– most ops are O(1) (add is O(n) in worst case)
  – potentially wasted space

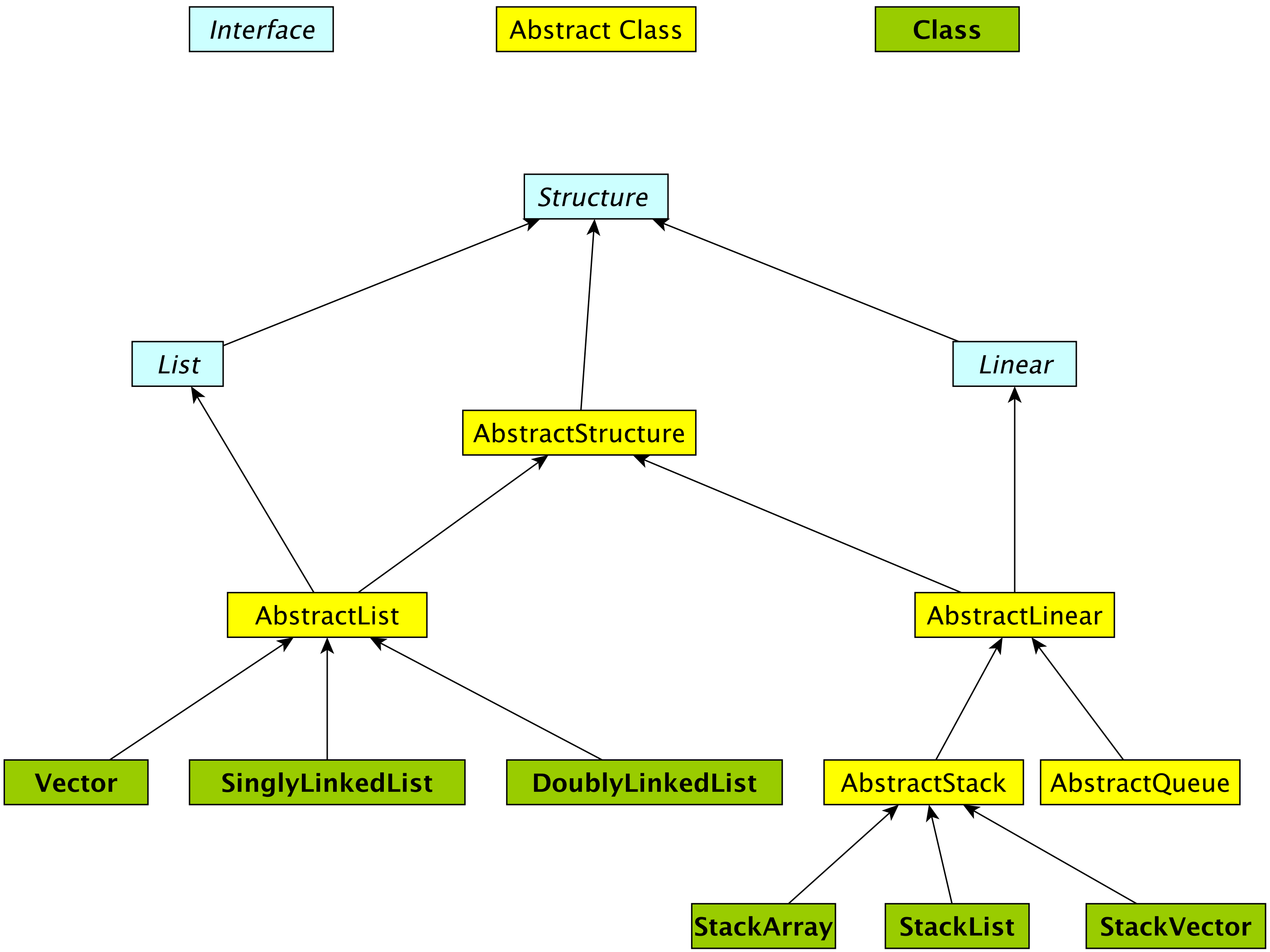
- structure5.StackList
  - SLL data
  - Add/remove from head

  + all operations are O(1)
  +/– O(n) space overhead (no "wasted" space)

Summary Notes on The Hierarchy

- Linear interface *extends* Structure
  - add(E val), empty(), get(), remove(), size()
- AbstractLinear (partially) implements Linear
- AbstractStack class (partially) *extends* AbstractLinear
  - Essentially introduces "stack-ish" names for methods
  - push(E val) is add(E val), pop() is remove(), peek() is get()
- Now we can extend AbstractStack to make "concrete" Stack types
  - StackArray<E>: holds an array of type E; add/remove at high end
  - StackVector<E>: similar, but with a vector for dynamic growth
  - StackList<E>: A singly-linked list with add/remove at head
  - We implement add, empty, get, remove, size directly
    - push, pop, peek are then indirectly implemented

The Structure5 Universe (so far)



Stack Applications

- Stack Implementation is simple, applications are many
  - "Bag" of items
  - Call stack
  - Evaluating mathematical expressions
  - Searching (Depth-First Search)
  - Removing recursion for optimization
  - ...

Evaluating Arithmetic Expressions

- Computer programs regularly use stacks to evaluate arithmetic expressions
- Example: x*y+z
  - First rewrite as xy*z+ (we'll look at this rewriting process in more detail soon)
  - Then:
    - push x
    - push y
    - * (pop twice, multiply popped items, push result)
    - push z
    - + (pop twice, add popped items, push result)

Converting Expressions

- We (humans) primarily use "infix" notation to evaluate expressions
  - (x+y)*z
- Computers traditionally used "postfix" (also called Reverse Polish) notation
  - xy+z*
  - Operators appear after operands, parentheses not necessary
- How do we convert between the two?
  - Compilers do this for us

Converting Expressions

- Example: x*y+z*w
- Conversion

1) Add full parentheses to preserve order of operations

   ((x*y)+(z*w))

2) Move all operators (+-*/) after operands

   ((xy*)(zw*)+)

3) Remove parentheses

   xy*zw*+

Use Stack to Evaluate Postfix Exp

- While there are input “tokens” (i.e., symbols) left:
  - Read the next token from input.
  - If the token is a value, push it onto the stack.
  - Else, the token is an operator that takes n arguments.
    - (It is known a priori that the operator takes n arguments.)
    - If there are fewer than n values on the stack → error.
    - Else, pop the top n values from the stack.
      - Evaluate the operator, with the values as arguments.
      - Push the returned result, if any, back onto the stack.
  - The top value on the stack is the result of the calculation.
  - Note that results can be left on stack to be used in future computations:
    - Eg: 3 2 * 4 + followed by 5 / yields 2 on top of stack

Example

- $(x*y)+(z*w) \rightarrow xy*zw*+$
- Evaluate:
  - Push x
  - Push y
  - Mult: Pop y, Pop x, Push x*y
  - Push z
  - Push w
  - Mult: Pop w, Pop z, Push z*w
  - Add: Pop x*y, Pop z*w, Push (x*y)+(z*w)
  - Result is now on top of stack

Lab Preview: PostScript

- PostScript is a programming language used for generating vector graphics
  - Best-known application: describing pages to printers
- It is a stack-based language
  - Values are put on stack
  - Operators pop values from stack, put result back on
  - There are numeric, logic, string values
  - Many operators
- Let's try it: The 'gs' command runs a PostScript interpreter….
- You'll be writing a (tiny part of) gs after midterm....

Lab Preview: PostScript

- Types: numeric, boolean, string, array, dictionary
- Operators: arithmetic, logical, graphic, …
- Procedures
- Variables: for objects and procedures
- PostScript is just as powerful as Java, Python, ...
  - Not as intuitive
  - Easy to automatically generate
- Example: Recursive factorial procedure

```
/fact { dup 1 gt { dup 1 sub fact mul } if } def
```

- Example: Drawing (see picture.ps)

Mazes

- How can we use a stack to solve a maze?
  - http://www.primaryobjects.com/maze/
- Properties of mazes:
  - We model a maze as a rectangular grid of cells
  - There is a *start* cell and one or more *finish* cells
  - Goal: Find path of *adjacent* free cells from *start* to *finish*
- Strategy: Consider unvisited cells as "potential tasks"
  - Use linear structure (stack) to keep track of current path being explored

Solving Mazes

- We'll use two objects to solve our maze:
  - Position: Info about a single cell
  - Maze: Grid of Positions
- General strategy:
  - Use stack to keep track of path from start
  - If we hit a dead end, backtrack by popping location off stack
  - Mark discarded cells to make sure we don't visit the same paths twice

Backtracking Search

- Try one way (favor north and east)
- If we get stuck, go back and try a different way
- We will eventually either find a solution or exhaust all possibilities
- Also called a "depth first search"

- Lots of other algorithms that we will not explore: http://www.astrolog.org/labyrnth/algrithm.htm

A "Pseudo-Code" Sketch

```
// Initialization
Read cell data (free/blocked/start/finish) from file data
Mark all free cells as unvisited
Create an empty stack S
Mark start cell as visited and push it onto stack S

While (S isn't empty && top of S isn't finish cell)
    current ← S.peek()                          // current is top of stack
    If (current has an unvisited neighbor x)
        Mark x as visited ; S.push(x)           // x is explored next
    Else S.pop()
If finish is on top of S then success else no solution
```

Is Pseudo-Code Correct?

- Tools
  - Concepts: *adjacent cells; path; simple path; path length; shortest path; distance between cells*; *reachable from cell*
  - Solving a maze: is *finish* reachable from *start*?
- Theorem: The pseudo-code will either visit *finish* or visit every free cell reachable from *start*
- Proof: Prove that if algorithm does *not* visit *finish* then it *does* visit every free cell reachable from *start*
  - Do this by induction on distance of free cell from *start*
  - Base case: distance 0. Easy
  - Induction: Assume every reachable free cell of distance at most $k \geq 0$ from *start* is visited. Prove for k+1

Is Pseudo-Code Correct?

- Induction Hyp: Assume every reachable free cell of distance at most k $\geq$ 0 from *start* is visited.
- Induction Step: Prove that every reachable free cell of distance k+1 from *start* is visited.
  - Let *c* be a free cell of distance k+1 reachable from *start*
  - Then *c* has a free neighbor *d* that is distance k from *start* and reachable from *start*
  - But then by induction, *d* is visited, so it was put on stack
  - So each free neighbor of *d* is visited by algorithm
- Done!

Recursive "Pseudo-Code" Sketch

Boolean RecSolve(Maze m, Position current)

If (current equals finish) return true

Mark current as visited

next ← some unvisited neighbor of current (or null if none left)

While (next does not equal null && recSolve(m, next) is false)

next← an unvisited neighbor of current (null if none left)

Return next != null

- To solve maze, call: *Boolean recSolve(*m, start*)*
- To prove correct: Induction on distance from *current* to *finish*
- How could we generate the actual solution?

Implementing A Maze Solver

- Iteratively: Maze.java
- Recursively: RecMaze.java
  - Recursive method keeps an implicit stack
    - The method call stack
  - Each recursive call adds to the stack

Implementation: Position class

- Represent position in maze as (x,y) coordinate
- class Position has several relevant methods:
  - Find a neighbor
    - `Position getNorth(), getSouth(), getEast(), getWest()`
  - `boolean equals()`
  - Check states of position
    - `boolean isVisited(), isOpen()`
  - Set states of position
    - `void visit(), setOpen(boolean b)`

Maze class

- Relevant Maze methods:
  - `Maze(String filename)`
    - Constructor; takes file describing maze as input
  - `void visit(Position p)`
    - Visit position p in maze
  - `boolean isVisited(Position p)`
    - Returns true iff p has been visited before
  - `Position start(), finish()`
    - Return start /finish positions
  - `Position nextAdjacent(Position p)`
    - Return next unvisited neighbor of p---or null if none
  - `boolean isClear(Position p)`
    - Returns true iff p is a valid move and is not a wall

Method Call Stacks

- In JVM, need to keep track of method calls
- JVM maintains stack of method invocations (called frames)
- Stack of frames
  - Receiver object, parameters, local variables
- On method call
  - Push new frame, fill in parameters, run code
- Exceptions print out stack
- Example: StackEx.java
- Recursive calls recurse too far: StackOverflowException
  - Overflow.java

Recursive Call Stacks

```
public static long factorial(int n) {
  if (n <= 1) // base case
      return 1;
  else
      return n * factorial(n - 1);
}

public static void main(String args[]) {
  System.out.println(factorial(3)};
}
```