Recursion, DNA-Link Preview
Announcements

• Exam 1 – Ask for Regrade in Gradescope by March 1

• Regrades assignments
  • if you pushed to github but did not resubmit in gradescope, fill out regrade form and we can look at your github if you have not modified it!

• Assignment P3 last chance today on time

• Assignment P4 out today with a Part1 and Part2
  • Part 1 due March 5, Part 2 due March 19

• APT 4 due Tuesday!

• APT Quiz 1 – now on regular APT page
  • Not for credit, but finish if you didn’t
\textbf{N} is for …

- new
  - Allocating memory from the heap

- null
  - Value when nothing has been allocated
Introduction to Recursion

- Canonical problem-solving/programming tool
- Useful for lists, trees, and when structure is self-referential (algorithmic too, not today)

Review linked lists in context of P4: DNA-link

- You can work with a partner from your Discussion section
- Choose next week, run code, finish after break
Modify and Return linked list

• If we pass a pointer to first node and ..
  • Want to "remove first"
  • We must return a pointer to modified list
• \texttt{void change(ListNode first)}
  • Call \texttt{change(list)}
    • \texttt{first = first.next}
  • \texttt{list} not changed after call
Modify and Return linked list

- If we pass a pointer to first node and ..
  - Want to "remove first"
  - We must return a pointer to modified list
- **void change(ListNode first)**
  - Call **change(list)**
    - ```
      first = first.next
    ```
  - **list** not changed after call
What does pass-by-value mean?

- Java passes parameters by value
  - Pass a copy of the variable
  - A copy of list1 is passed

```java
list1 = ld.deleteAll(list1, "corn");
```

```java
list1 = ld.deleteAll(list1, "squash");
```
Idiom: pass-and-return

• Change the list passed in, return the list.
  • Assign in the call, e.g. \( x = \text{changeUp}(x) \)

```java
Thing xx = new Thing();
change(xx);
// can xx be different after call?
// can write xx.mutate()
// cannot assign to xx in change
xx = changeUp(xx);
```
Idiom: pass-and-return

- Change the list passed in, return the list.
  - Assign in the call, e.g. \( x = \text{changeUp}(x) \)

```java
Thing xx = new Thing();

X change(xx);
// can xx be different after call?
// can write xx.mutate()
// cannot assign to xx in change

✓ xx = changeUp(xx);
```
Invariants

• Class level: true before each method executes
  • Established at construction
  • Re-established by each method

• Loop level: true before each loop guard evaluation
  • Established before first iteration of loop
  • Re-established after each loop iteration

• Reason formally and informally about code
WOTO

Google (DYM): Recursion

- What is the Internet?
  - A network of networks ....

- What is PageRank?
  - What’s a good website link?

```java
public int calc(int n) {
    return n * calc(n-1);
}
```
Self Reference and Recursion

• Does a Node reference itself?
  • No, there’s a .next field, but …

• Does a recursive method call itself?
  • No, calls clones of itself
  • Careful, could make “infinite” number of calls …

• What’s in a folder?
  • Files and other folders. Is that self-referential?
Google recursion
Did you mean …?

• Those software engineers …
  • Did you mean invented by Noam Shazeer, Duke 1998: Math and CompSci
Noam Shazeer, Duke 2008

- https://www.newyorker.com/magazine/2018/12/10/the-friendship-that-made-google-huge

- Compsci 201 alum, passionate about problem-solving

There were inklings, early on, that Google was an A.I. company pretending to be a search company. In 2001, Noam Shazeer, who shared an office with Jeff and Sanjay, had grown frustrated with the spell-checker that Google was licensing from another company: it kept making embarrassing mistakes, such as telling users who’d typed “TurboTax” that they probably meant “turbot ax.” (A turbot is a flatfish that lives in the North Atlantic.) A spell-checker is only as good as its dictionary, and Shazeer realized that, in the Web, Google had access to the biggest dictionary there had ever been. He wrote a program that used the statistical properties of text on the Web to determine which words were likely misspellings. The software learned that “pritany spears” and “brinsley spears” both meant “Britney Spears.” When Shazeer demonstrated the program at Google’s weekly T.G.I.F. gathering, employees tried, but mostly failed, to fool it.
When to use recursion

• The structure of the problem lends itself …
  • Folders/Directories contain …
  • Nodes in a linked list contain …

• The algorithmic structure lends itself …
  • Sorting algorithms as we’ll see …
  • Factorial? Just say no …
Size of a linked list

- You've seen a loop to do this
  - Goal: try to understand why this is correct
  - We'll use example from arithmetic too
- Vocabulary with both structure and algorithm

```java
public int count(ListNode list) {
    if (list == null) return 0;
    return 1 + count(list.next);
}
```
Vocabulary

- All recursive code has a *base case*
  - A simple case where no recursion necessary
  - Example in linked list? null, no recursion
    - sometimes one node case too
- Base case always identified with an if statement.
Understanding Recursion

• Visualize: RecDemo.java
  • The base case anchors the recursion
  https://coursework.cs.duke.edu/201spring20/classcode/blob/master/src/RecDemo.java

• There's no loop! Why?
  • Sequence of recursive calls
  • Stacked up until base returns

• The recursive call "decreases"
  • Must get toward **base case**
```java
public class RecDemo {

    public class ListNode {
        int info;
        ListNode next;
        ListNode(int val, ListNode link) {
            info = val;
            next = link;
        }
    }

    public ListNode create(int n) {
        ListNode front = null;
        for (int k=0; k < n; k++) {
            front = new ListNode(k, front);
        }
        return front;
    }

}
```java
public int count(ListNode list) {
    if (list == null) return 0;
    int allButMe = count(list.next);
    return 1 + allButMe;
}

public void doit() {
    ListNode list = create(4);
    int n = count(list);
    System.out.println(n);
}

public static void main(String[] args) {
    RecDemo rd = new RecDemo();
    rd.doit();
}
```
About to count # nodes in list

- Call `create(4)` finished, call `count(list)`
- What does `list` point to? `list.next`?
First recursive call made

- Each method on the stack/pile of methods has its own local state: what does list reference?
- Node 3 in doit/first call, node 2 in recursive call

```java
front = new ListNode(k, front);
}
return front;
}
public int count(ListNode list){
    if (list == null) return 0;
    int allButMe = count(list.next);
    return 1 + allButMe;
}
}
public void doit()
    ListNode list = create(4);
    int n = count(list);
    System.out.println(n);
}
public static void main(String[] args) {
    RecDemo rd = new RecDemo();
    rd.doit();
}
```
• Three calls of count made: where is active call?
• Parameter list points at 1, what happens?
What do we see?

- Each method invocation has its own state: parameter, local variables, line number

- Goal: trust recursion
  - Trust is hard
  - Debugging on trust? Not so easy
Last call: base case reached

• The active call has list == null
• Base case reached! Return 0
• Where is this value returned?
  • To the call: the stack frame "above"
• Addition happens back up call-chain

```java
public int count(ListNode list){
    if (list == null) return 0;
    int allButMe = count(list.next);
    return 1 + allButMe;
}
```
How did recursion work?

- Structure of a linked list is essential
  - For a non-null list, \# nodes is: count me, and recursively count the rest, add together

- Recursion in general: process one case, one number, one node. Make a recursive call, use result.
  - Code must use return value of recursive call
  - For lists? Deal with one node only in code
How do you calculate N!

• Multiply 1 x 2 x 3 x … x N

```java
public int fact(int n){
    int prod = 1;
    for(int k=2; k <= n; k++){
        prod *= k;
    }
    return prod;
}
```
Recursive Terminology

- Recursive methods must have a base case
  - Simple to do, don’t need “help”

- Recursive calls make progress toward base case
  - Some measure gets smaller, toward base case

- What’s n!
  - It’s n * (n-1)!
  - What’s the base case? 1! Is 1 (or 0! Is 1)
Don’t do this!

- int x = fact(4);
  - return 4*fact(3)

- The call of fact(3) calls a “clone” or “copy”
  - Doesn’t call “itself”, is re-entrant code

public int fact(int n){
    if (n == 1) return 1;
    return n*fact(n-1);
}

n=4
Don’t do this 2

- int x = fact(4);
- return 4*fact(3)

```java
public int fact(int n){
    if (n == 1) return 1;
    return n*fact(n-1);
}
```

n=4

```java
public int fact(int n){
    if (n == 1) return 1;
    return n*fact(n-1);
}
```

n=3

```java
public int fact(int n){
    if (n == 1) return 1;
    return n*fact(n-1);
}
```
Don’t do this 3

• int x = fact(4);
  • return 4*fact(3)

• return 3 * fact(2)
Don’t do this 3

- int x = fact(4);
  - return 4*fact(3)

- return 3 * fact(2)

- When n is 2 …?
  - return 2 * fact(1)
Base Case Reached

- return 2*fact(1)
  - Evaluates to 2*1
  - Return to call of fact(1)
Base Case Reached

- \( \text{int } x = \text{fact}(4) \)
  - \( n = 1 \) returns 1
  - \( n = 2 \) returns 2
  - \( n = 3 \) returns 6
  - \( n = 4 \) returns 24

\( x \) is now 24
WOTO

From Links to ...

- What is the P4: DNA/LinkStrand assignment about?
  - Why do we study linked lists
  - How do you work in a group?
    - Two people from the same Discussion section

Kary Mullis
From PCR to linked lists

• Polymerase Chain Reaction
  • Make copies of a specific DNA segment

• Recombinant DNA
  • Insert DNA using restriction enzymes

• Loosely forms basis for DNA/Linked assignment
  • Big gains in efficiency using Linked Lists
  • Compare to array of chars, e.g. Strings
But first! Let's look at strings…

• See StringPlay.java
  
  • [https://coursework.cs.duke.edu/201spring20/classcode/blob/master/src/StringPlay.java](https://coursework.cs.duke.edu/201spring20/classcode/blob/master/src/StringPlay.java)

• Runtime of `stringConcat("hello", N)`

• Depends on size of `ret`: 5, 10, 15, … 5*N

• $5(1 + 2 + \ldots + N)$ which is $O(N^2)$

```java
public String stringConcat(String s, int reps) {
    String ret = "";
    for(int k=0; k < reps; k++) {
        ret += s;
    }
    return ret;
}
```
StringBuilder Examined

- Just say no to quadratic, use StringBuilder
  - String is immutable, StringBuilder is not
- Runtime of `builderConcat("hello", N)`
  - $5 + 5 + 5 + \ldots + 5$ a total of $N$ times: $O(N)$

```java
public String builderConcat(String s, int reps) {
    StringBuilder ret = new StringBuilder();
    for(int k=0; k < reps; k++) {
        ret.append(s);
    }
    return ret.toString();
}
```
Summary of Concatenation

• Using s + t for two strings
  • Takes time \texttt{s.length()} + \texttt{t.length()}
  • Makes a new string, doesn't change s or t

• Using StringBuilder is more efficient
  • Time for \texttt{s.append(t)} is \texttt{t.length()}
  • Why? Just add \texttt{t.length()} characters to s – backed by array in s
Output from StringPlay

- Which is $O(N)$ and which is $O(N^2)$

<table>
<thead>
<tr>
<th>size</th>
<th>string</th>
<th>size</th>
<th>builder</th>
</tr>
</thead>
<tbody>
<tr>
<td>50000</td>
<td>0.169</td>
<td>50000</td>
<td>0.000</td>
</tr>
<tr>
<td>100000</td>
<td>0.314</td>
<td>100000</td>
<td>0.000</td>
</tr>
<tr>
<td>150000</td>
<td>0.533</td>
<td>150000</td>
<td>0.001</td>
</tr>
<tr>
<td>200000</td>
<td>0.784</td>
<td>200000</td>
<td>0.001</td>
</tr>
<tr>
<td>250000</td>
<td>1.341</td>
<td>250000</td>
<td>0.001</td>
</tr>
<tr>
<td>300000</td>
<td>1.769</td>
<td>300000</td>
<td>0.002</td>
</tr>
<tr>
<td>350000</td>
<td>2.496</td>
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<td>0.001</td>
</tr>
<tr>
<td>400000</td>
<td>3.326</td>
<td>400000</td>
<td>0.001</td>
</tr>
<tr>
<td>450000</td>
<td>4.371</td>
<td>450000</td>
<td>0.001</td>
</tr>
<tr>
<td>500000</td>
<td>5.437</td>
<td>500000</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Dr. danah boyd is a Senior Researcher at Microsoft Research, … a Visiting Professor at NYU, … Her work examines everyday practices involving social media, with specific attention to youth engagement, privacy, and risky behaviors. She recently wrote *Engaging the Ethics of Data Science in Practice*; coauthored *Isomorphism through algorithms: Institutional Dependencies in the case of Facebook*

"Building new connections is a critical part of building a new economy. The American education system, as flawed as it is, is great for the creative class because of the way it mixes up networks."
DNA Cut and Splice

• Find enzyme like ‘gat’
  • Replace with *splice* like ‘gggtttaaa’
• Strings and StringBuilder for creating new strings
  • Complexity of “hello” + “world”, or A+B
  • String: A + B, StringBuilder: B
What do linked lists get us?

- Faster run-time, much better use of memory
  - We splice in constant time? Re-use strings
  - Same as previous slide: sequential char view
linked list improvement: memory

- Suppose we have B "gat" (blue), in strand size N
  - Inserting size S "ggttttaaa" (green) splicees
  - For String/StringBuilder: memory: B*S (+ N)
  - For LinkedList: memory: S (re-use green!) (+ N)
linked list improvement: time

• Suppose we have B "gat" (blue), in strand size N
  • Inserting size S "gggttttaaa" (green) splicees
  • For String: time: B^2S + N, builder: BS + N
• For LinkedList: B + N
Theory and Practice

• The JVM can sometimes optimize your code
  • Don’t optimize what you don’t have to …

• Timings with `System.nanoTime()` are suspect
  • Other things going on in computer
  • JVM can go into garbage-collection mode
  • Other considerations
Thoughts on Exam 1

• Exam 1 – 80 points

Review Grades for Exam 1 CompSci 201 Spring 2020

- Minimum: 27.5
- Median: 61.0
- Maximum: 78.5
- Mean: 60.65
- STD DEV: 9.94

2/28/2020
Compsci 201, Spring 2020
Survey on Exam 1
How much time did you spend preparing/studying for the exam outside of attending 201 and the discussion section this week. This includes preparing your notes if you brought them.

238 responses

- 37% less than 1 hour
- 21.4% between one and three hours
- 12.2% between three and six hours
- 21.4% between six and nine hours
- 12.2% between nine and twelve hours
- 3% more than twelve hours
Thoughts Before Exam 1

1 is confident I would fail in a big way
5 is confident I'd get close to 100 percent

As you sat down before the exam started, how did you think you'd do on the exam?

238 responses

![Bar chart showing responses]

- 2 (0.8%) scored 1
- 17 (7.1%) scored 2
- 103 (43.3%) scored 3
- 94 (39.5%) scored 4
- 22 (9.2%) scored 5
Thoughts on Leaving Exam 1

1 - think I did very, very poorly -- the exam did not go well at all
5 - think I did very well, came away confident I'll get close to a 90% or better

When you left the exam, how do you think you did?

- 1: 11 (4.6%)
- 2: 55 (23.1%)
- 3: 81 (34%)
- 4: 66 (27.7%)
- 5: 25 (10.5%)
Was Exam 1 Fair?

Was the exam fair in terms of the questions asked based on what was covered in class?

238 responses

- 49.2% extremely unfair
- 12.2% unfair
- 12.6% neutral
- 25.2% it was fair enough
- 2.4% it was extremely fair
Big-Oh Questions

• Need to explain every line
• We will do big-Oh almost every day
• The more you do the better you will get at these
Storage Question

- Class has state – four items define an object
  - Int mySize
  - Int myCapacity
  - String[] myItems
  - HashSet<String> myUniqueItems
- Methods should update state appropriately
- Lot of points, but broken into small parts
Exam 1 Takeaways

• First, understand everything you missed
  • Get a blank sheet of paper, can you now write the code.
  • Need to do this before moving on
• Exam and solutions are on the Old Tests page
• Come in for office hours – go over your exam, concepts you are not solid on
  • Go on nights when an assignment/APT not due
  • Free four hours a night office hours
More Exam 1 Takeaways

• Midterm grades – most will pull up your grade with other things
  • A range – 119
  • B range – 135
  • C range – 30

• Help
  • Understand what you missed
  • Consulting/Office hours – it is free!
  • Peer Tutoring Center – group tutoring
Want to read more on topics?

• Free online textbooks from OpenDSA

• Topics
  • We cover some topics from both books such as Linked lists and more!