CSE 332 : 22Su Final Pt. 1 Solutions

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Instructions

- The allotted time is **60** minutes. Please do not turn the page until the staff says so.
- This is a closed-book and closed-notes exam. You are not permitted to access electronic devices.
- Read directions carefully, especially for problems that require you to show work or provide an explanation.
- We can only give partial credit for work that you've written down.
- Unless otherwise noted, every time we ask for an O, Ω, or Θ bound, it must be simplified and tight.
- For answers that involve bubbling ◯ or ☐, make sure to fill in the shape completely: ● or ■.
- If you run out of room on a page, indicate that the answer continues on the back of that page. Try to avoid writing on the very edges of the pages: we scan your exams and edges often get cropped off.
- Make sure you also get a copy of the formula sheet.

Advice

- If you feel like you're stuck on a problem, you may want to skip it and come back at the end if you have time.
- Look at the question titles on the cover page to see if you want to start somewhere other than problem 1.
- Remember to take deep breaths.

Question	**Max points**
1. Amdahl's Law	5
2. Parallel Code	14
3. Parallel Prefix Sum	9
4. Concurrency Issues	13
5. Sorting	14
Total	**55**

1. Amdahl's Law [5 points]

(a) What ***fraction of a program must be parallizeable*** in order to get 5x speedup on 15 processors?

You must show your work for any credit. For full credit give your answer as a number or a simplified fraction (not a formula).

Solution:

Let p be the portion of the program that is parallelizable. By Amdahl's law,

$$\begin{aligned}
5 = \frac{T_1}{T_{15}} &= \frac{(1-p)+p}{(1-p)+\frac{p}{15}} \\
5 &= \frac{1}{(1-p)+\frac{p}{15}} \\
5(1-p)+\frac{p}{3} &= 1 \\
5-5p+\frac{p}{3} &= 1 \\
5-\frac{14p}{3} &= 1 \\
4 &= \frac{14p}{3} \\
\frac{6}{7} &= p
\end{aligned}$$

Therefore, $\frac{6}{7}$ of the program must be parallelizable.

2. Parallel Code [14 points]

In Java, using the ForkJoin Framework, write code to solve the following problem:
• Input: An array of Strings (does not contain duplicates).
• Output: The **greatest number of vowels** in a String and **its location** (index) in the Input array. In case of ties, the rightmost index is returned. If no Strings in the array contain any vowels, then return -1 as its index.

Examples:
• Input: [“bonjour”, “hola”, “howdy”, “guten tag”, “ciao”]
• Output: 3, 4

• Input: [“bnjr”, “hl”, “hwdy”, “gtn tg”, “c”]
• Output: 0, -1

• Input: [“bnjr”, “hl”, “hwdy”, “gtn tg”, “c”, “”]
• Output: 0, -1

• Do **not** employ a sequential cut-off: **the base case should process one element.**
(You can assume the input array will contain at least one element.)
• Give a class definition, FindMax, **along with any other code or classes needed.**
• We have provided some of the code for you, you should also fill in the _____ part.

You may not use any global data structures or synchronization primitives (locks)

Solution:

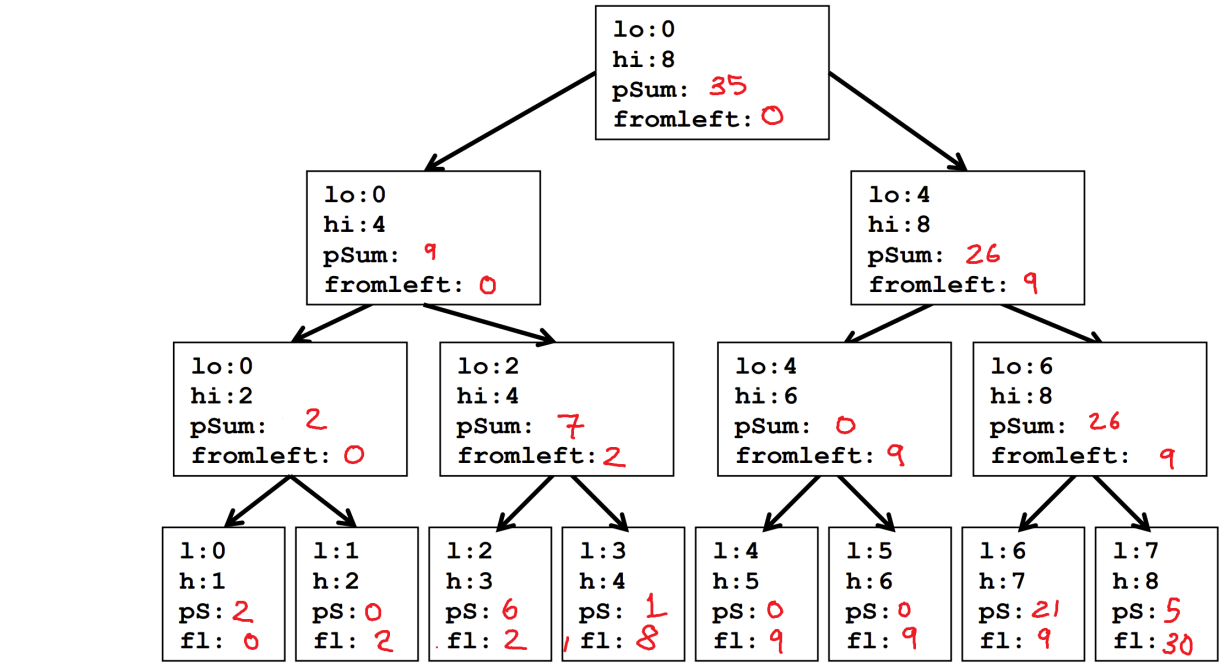
```
class Pair { // You are not required to use this class
    int numVowels;
    int index;
    public Pair (int numVowels, int index) {
        this.numVowels = numVowels;
        this.index = index;
    }
}

class Main{
    static final ForkJoinPool fjPool = new ForkJoinPool();
    Pair findMax (int[] array) {
        return fjPool.invoke(new FindMax(0, array.length, array));
    }
}


public class FindMax extends RecursiveTask<Pair> {
    /*
    * Returns the number of vowels in the given String str
    */
    private int countNumVowels(String str) { // You are not required to use this method
        for (int i = 0 ; i < str.length(); i++){
            char ch = str.charAt(i);
            if(ch == 'a' || ch == 'e' || ch == 'i' || ch == 'o' || ch == 'u' ||
               ch == 'A' || ch == 'E' || ch == 'I' || ch == 'O' || ch == 'U'){
                count++;
            }
        }
```

```
        return count;
    }

    int low;
    int high;
    int[] array;

    public FindMax(int low, int high, int[] array) {
        this.low = lo;
        this.high = hi;
        this.array = array
    }

    protected Pair compute() {
        if (high - low < 2) {
            // Get the number of vowels
            int numVowels = countNumVowels(array[lo])

            // If the String has no vowels, then index should be -1
            int index = low;
            if (numVowels == 0) {
                index = -1;
            }

            return new Pair(numVowels, index);
        } else {
            int mid = low + (high - low) / 2;
            FindMax left = new FindMax(low, mid, array);
            FindMax right = new FindMax(mid, high, array);

            left.fork();
            Pair rightResult = right.compute();
            Pair leftResult = left.join();

            // We want the right-most String with the greatest number of vowels, thus >=
            if (rightResult.numVowels >= leftResult.numVowels) {
                return rightResult;
            } else { // leftResult.numVowels < rightResult.numVowels
                return leftResult;
            }
        }
    }
}
```

3. Parallel Prefix Sum [9 points]

(a) (4 points) Dara has been training all year to climb Mt. Everest and she needs your help calculating if she will have enough energy to do so! In this particular problem, positive numbers will give Dara an energy boost and negative numbers will have no effect. Given the following array as input, perform the parallel prefix algorithm to fill the output array with the sum of **only the positive values contained in all of the cells to the left** (including the value contained in that cell) in the input array. Negative values in the input array should not contribute to the sum. Fill in the values for: **pSum, fromLeft**, and the **Output Array** in the tree and output array. Do not use a sequential cutoff.

Solution:



Index	0	1	2	3	4	5	6	7
Input	2	-3	6	1	-4	-17	21	5
Output	2	2	8	9	9	9	30	35

(b) (3 points) Give formulas for the following values where **p** is a reference to a tree node other than a leaf node and **leaves[i]** refers to the leaf node in the tree visible just above the corresponding location in the **input** and **output** arrays in the picture above.

Solution:

p.left.fromLeft = p.fromLeft
p.right.fromLeft = p.fromLeft + p.left.pSum
output[i] = leaves[i].psum + leaves[i].fromLeft

(c) (2 points) Describe how you assigned a value to **leaves[i].pSum**.

Solution:

leaves[i].pSum = max(0, input[i])

4. Concurrency [13 points]

After finishing up all of the grading for summer quarter, the Allen School TAs decide to celebrate by eating at their favorite restaurant on the Ave! The Restaurant class manages a restaurant's seating capacity through reservations and walk-ins. Multiple threads (TAs) could be accessing the same Restaurant object, which means two TAs could be making reservations or walk-ins at the same time. Assume the Queue objects ARE THREAD-SAFE, have enough space, and operations on them will not throw an exception.

```
public class Restaurant {

    private Queue<Integer> reservations = new Queue<Integer>();
    private Queue<Integer> walkIns = new Queue<Integer>();
    private final int maxCapacity = 50; //Max capacity of people in restaurant

    // Calculates current restaurant capacity
    public int getTotal() {
        int total = 0;

        for (Integer group : reservations) {
            total += group;
        }

        for (Integer group : walkIns) {
            total += group;
        }

        return total;
    }

    // Adds list of reservation groups to the restaurant
    public void addReservations(List<Integer> groups) {
        for (int i = 0; i < groups.size(); i++) {
            if (getTotal() + groups.get(i) <= maxCapacity) {
                reservations.push(groups.get(i));
            }
        }
    }

    // Adds walkIn group to the restaurant
    public void addWalkIn(int walkInSize) {
        if (getTotal() + walkInSize <= maxCapacity) {
           walkIns.push(groupSize);
        }
    }

}
```

(a) (4 points) Neel and Thien (think of them as two threads) are both trying to access the same Restaurant object at the same time, but this potentially could cause some issues. If there are any problems, give an example of when and where they could occur. Be specific.

Does the `Restaurant` class as shown above have (bubble all that apply):

☐ a race condition ☐ potential for deadlock ☐ a data race ☐ none of these

Solution:

There are race conditions in this code.

Two threads may both try to make a reservation, but there can be a bad interleaving where Neel and Thien can both pass lines 31 and 32, but then exceed the maxCapacity count when they add their list of reservations.

Similar idea for addWalkIn method above.

There is no data race since the Queue is assumed to be thread-safe and maxCapacity is only ever read.

(b) (4 points) Hans proposes that we make the `addWalkIn` method synchronized in order to potentially eliminate any concurrency issues in the code, and change nothing else.

Does this modified `Restaurant` class have (bubble all that apply):

☐ a race condition ☐ potential for deadlock ☐ a data race ☐ none of these

If there are any FIXED problems, describe why they are FIXED. If there are any NEW problems, give an example of when those problems could occur. Be specific!

Solution:

Assuming the queue is thread-safe, a race condition still exists as described above, but not in the walk-in method

(c) (5 points) Modify the code on the **next page** to use locks to allow the most concurrent access and to avoid all of the potential problems listed above. For full credit you must allow the most concurrent access possible without introducing any errors. Create locks as needed. Use any reasonable names for the locking methods you call. DO NOT use synchronized. You should create re-entrant lock objects as follows:

```
ReentrantLock lock = new ReentrantLock();
lock.acquire();
lock.release();
```

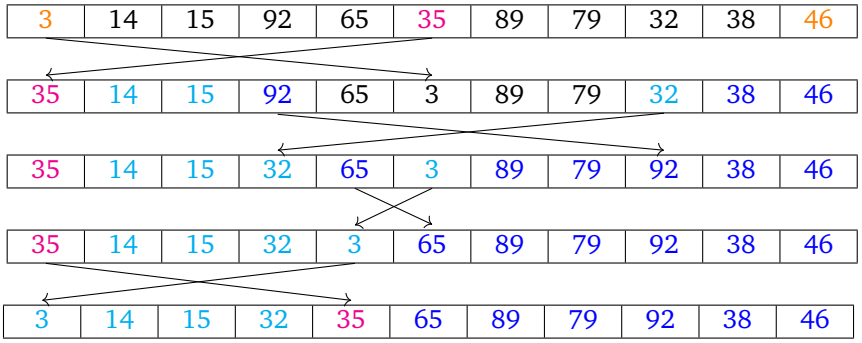
Solution:

```
public class Restaurant {

    private Queue<Integer> reservations = new Queue<Integer>();
    private Queue<Integer> walkIns = new Queue<Integer>();
    private final int maxCapacity = 50; //Max capacity of people in restaurant
    ReentrantLock lock = new ReentrantLock();

    // Calculates current restaurant capacity
    public int getTotal() {
        int total = 0;

        for (Integer group : reservations) {
            total += group;
        }

        for (Integer group : walkIns) {
            total += group;
        }

        return total;
    }

    // Adds list of reservation groups to the restaurant
    public void addReservations(List<Integer> groups) {
        lock.acquire();
        for (int i = 0; i < groups.size(); i++) {
            if (getTotal() + groups.get(i) <= maxCapacity) {
                reservations.push(groups.get(i));
            }
        }
        lock.release();
    }

    // Adds walkIn group to the restaurant
    public void addWalkIn(int walkInSize) {
        lock.acquire();
        if (getTotal() + walkInSize <= maxCapacity) {
           walkIns.push(groupSize);
        }
        lock.release();
    }

}
```

5. Sorting [14 points]

(a) (3 points) Perform **one pass** of Hoare's partition on a following data. We already swapped the pivot, 35, to the first cell for you (the first to the second row). Show every swap, one per row. Don't forget to swap the pivot back.

Solution:



(b) (4 points) Perform a radix sort on the following data.

Solution:

23	14	6	92	63	27	79	26	90	5

0	1	2	3	4	5	6	7	8	9
90		92	23	14	5	6	27		79
			63			26			

90	92	23	63	14	5	6	26	27	79

0	1	2	3	4	5	6	7	8	9
5	14	23				63	79		90
6		26							92
		27							

5	6	14	23	26	27	63	79	90	92

(c) (4 points) Nathan wants to create a new data structure for priority queue operation, SuperQueue, with runtime of $\Theta(1)$ for insert() and $\mathcal{O}(\log \log n)$ for removeMin(). Do you think this is possible? Explain briefly. (**Hint:** This is a sorting question.)

Solution:

It's impossible. If it were to be possible, then we can sort n elements by insert all into SuperQueue and removeMin all n elements in order. This would result in $\mathcal{O}(n \log \log n)$ runtime, which contradicts with the well-known lower bound runtime of comparison sorting of $\Omega(n \log n)$.

(d) (3 points) Give the **recurrence** for the PARALLEL MERGE discussed in lecture — **worst case span**.
Note: We are NOT asking for the closed form. This is just a merge routine, *not full Mergesort*.
For any credit, explain all parts of your answer briefly.

Solution:

$$T(N) = \mathcal{O}(\log n) + T\left(\frac{3N}{4}\right)$$

$\mathcal{O}(\log n)$ is from binary searching median of the bigger array in the smaller one. For the worst case, the median is either smaller or bigger than all of the other half, resulting in merging two sorted arrays with combined size $\frac{3N}{4}$, taking $T(\frac{3N}{4})$ time.

Extra piece of paper for scratch work

Reference Sheet

Geometric series identities

$$\sum_{i=0}^{k} c^i = \frac{c^{k+1}-1}{c-1} \qquad \sum_{i=0}^{\infty} c^i = \frac{1}{1-c} \text{ if } |c| < 1$$

Sums of polynomials

$$\sum_{i=0}^{n} i = \frac{n(n+1)}{2} \qquad \sum_{i=0}^{n} i^2 = \frac{n(n+1)(2n+1)}{6} \qquad \sum_{i=0}^{n} i^3 = \frac{n^2(n+1)^2}{4}$$

Log identities

$$b^{\log_b(a)} = a \qquad \log_b(x^y) = y \cdot \log_b(x) \qquad a^{\log_b(c)} = c^{\log_b(a)} \qquad \log_b(a) = \frac{\log_d(a)}{\log_d(b)}$$

Exponent properties

$$(a^m)^n = a^{m \cdot n} = (a^n)^m$$