CSE 332: Data Structures and Parallelism

Section 7: Parallel Primitives

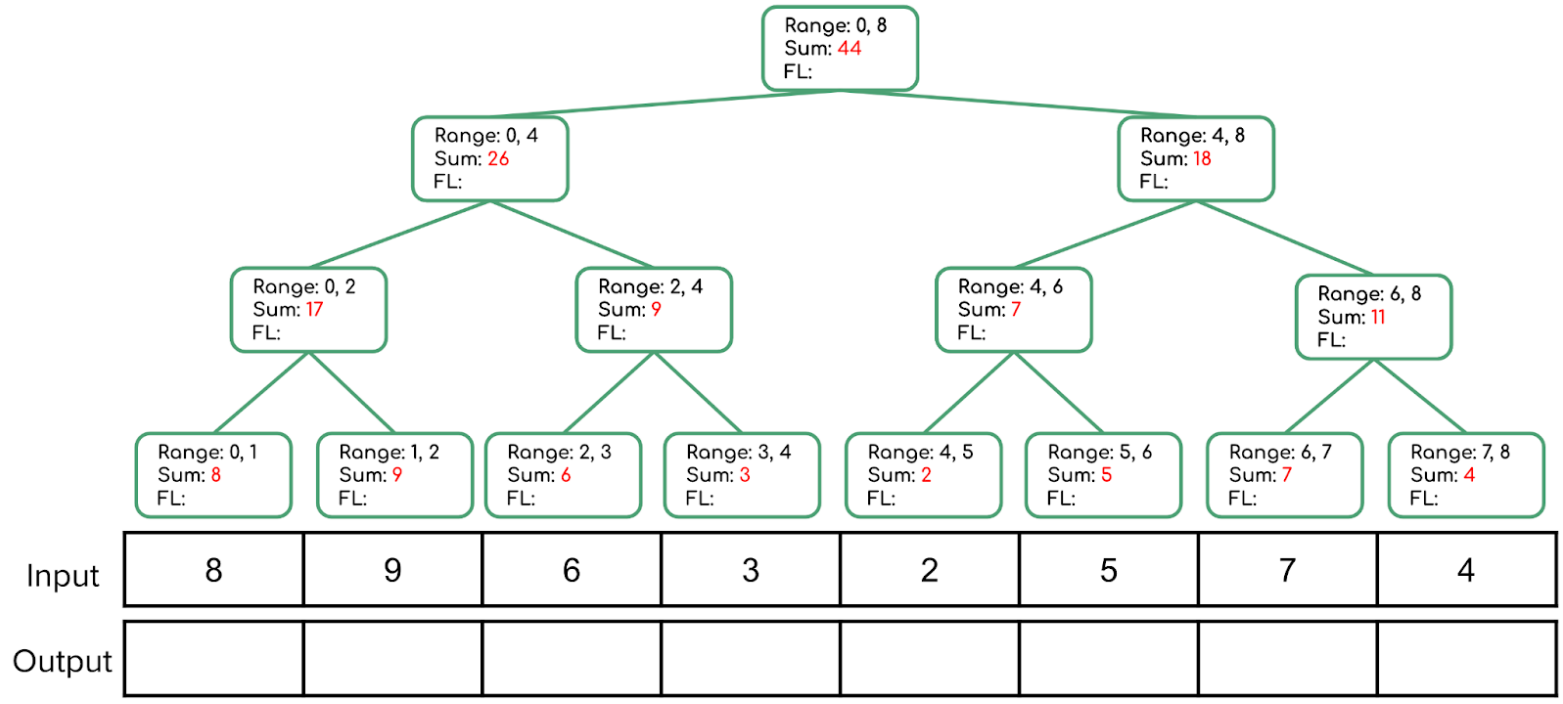
0. Parallel Prefix Sum

Given input array `[8, 9, 6, 3, 2, 5, 7, 4]`, output an array such that each `output[i] = sum(array[0], array[1], ..., array[i])`.

Use the Parallel Prefix Sum algorithm from lecture. Show the intermediate steps. Draw the input and output arrays, and for each step, show the tree of the recursive task objects that would be created (where a node's child is for two problems of half the size) and the fields each node needs. Do not use a sequential cut-off.

First pass: fill out the *sum* field starting from leaf nodes to the top by starting with each leaf node's value as its *sum*, then combining parallel subproblems by taking the sum of each side. This can be calculated with the following expressions:

leaves[i].sum = input[i]
p.sum = p.left.sum + p.right.sum



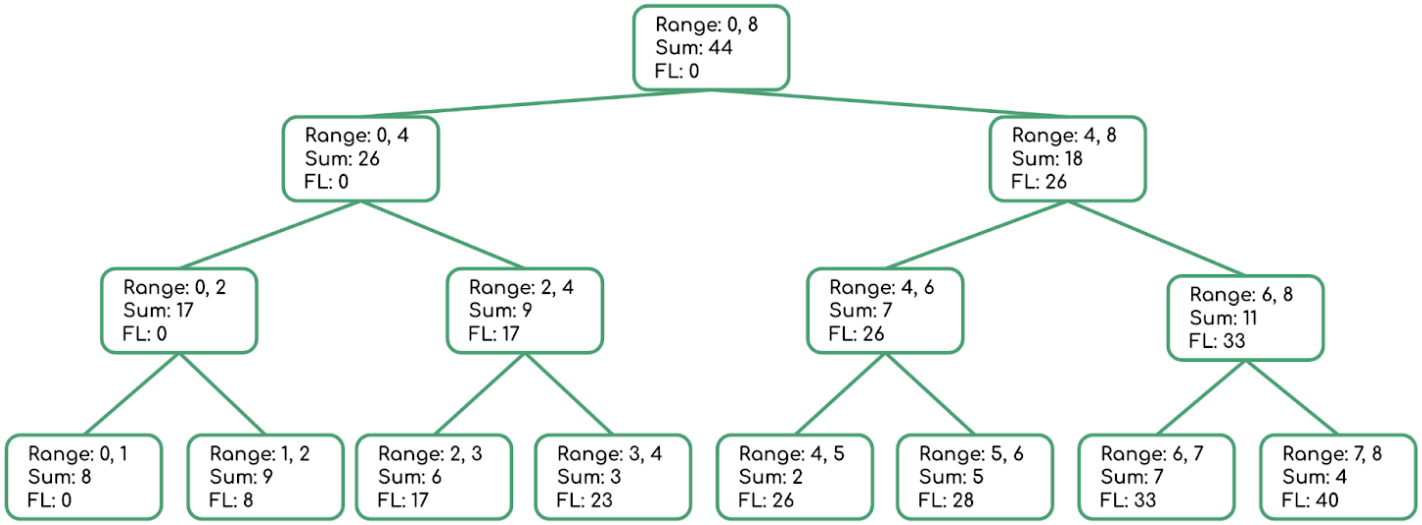
Second pass: fill out the *FL* (“from left”) field starting from the top down to the leaf nodes to represent the sum of the *prefix* of this subproblem’s range, that is, the sum of everything to the *left* of this node. This can calculated with the following expressions:

p.right.FL = p.FL + p.left.sum

p.left.FL = p.FL

Then fill the output array with the *sum* and *FL* fields at the leaf node level:

output[i] = leaves[i].FL + input[i]



Input	8	9	6	3	2	5	7	4
Output	8	17	23	26	28	33	40	44

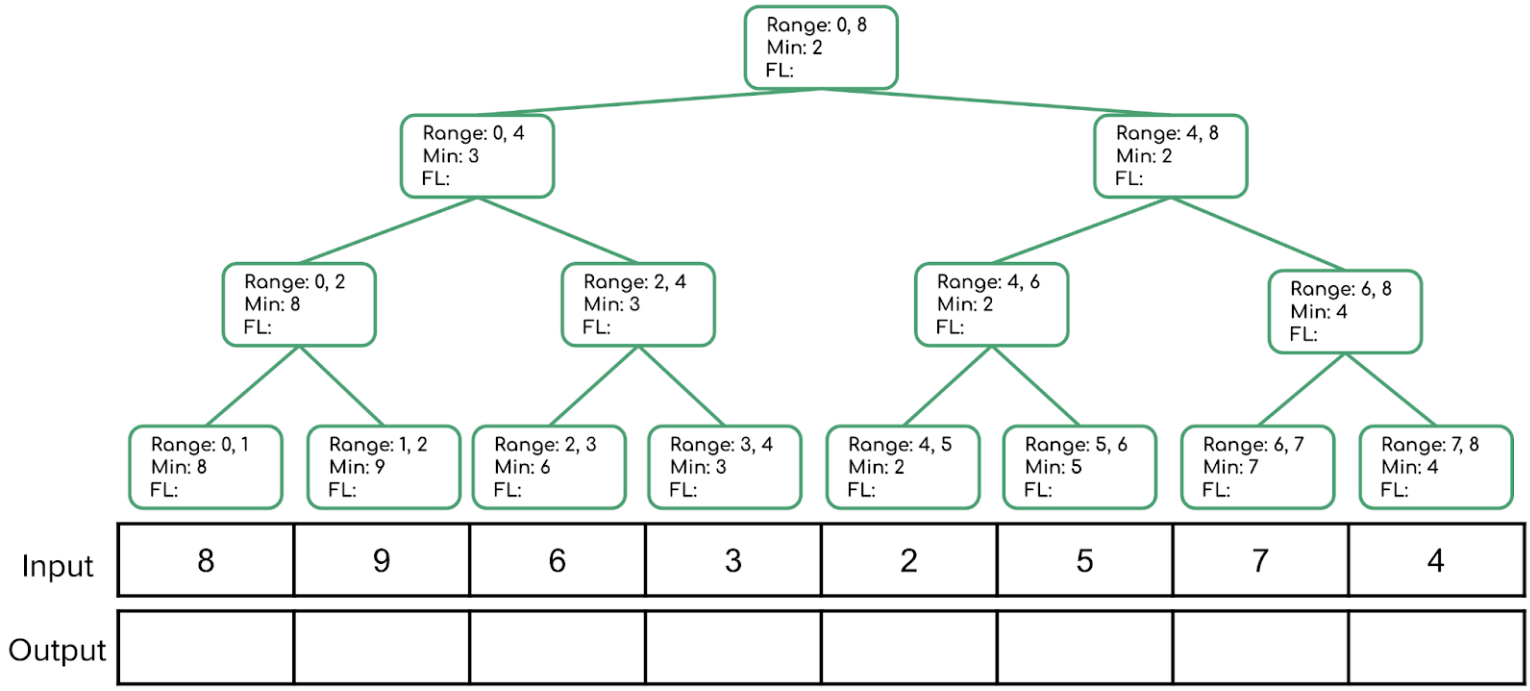
1. Parallel Prefix FindMin

Given input array `[8, 9, 6, 3, 2, 5, 7, 4]`, output an array such that each `output[i] = min(array[0], array[1], ..., array[i])`. Show all steps, as above.

First pass: fill out the *min* field starting from leaf nodes to the top by starting with each leaf node's value as its *min*, then combining parallel subproblems by taking the min of each side. This can be calculated with the following expressions:

leaves[i].min = input[i]

p.min = min(p.left.min, p.right.min)



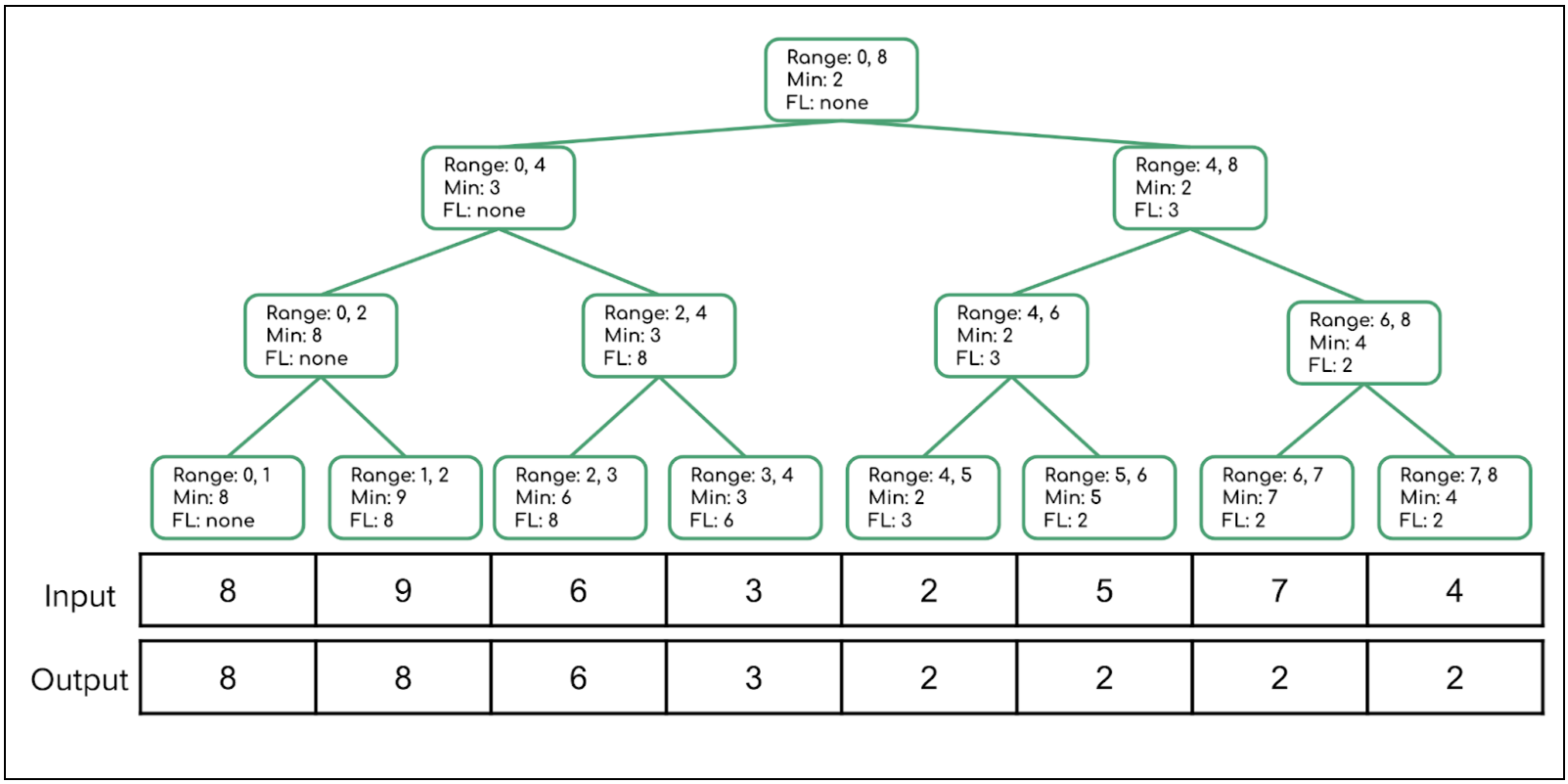
Second pass: fill out the *FL* ("from left") field starting from the top down to the leaf nodes to represent the minimum value of the *prefix* of this subproblem's range, that is, the min of everything to the *left* of this node. This can calculated with the following expressions:

p.right.FL = min(p.FL, p.left.min)

p.left.FL = p.FL

Then fill the output array with the *min* and *FL* fields at the leaf node level:

output[i] = min(leaves[i].FL, input[i])



2. Work it Out [the Span]

a) Define work and span

> Work - how long the running time of a program would be with just one processor
> Span - the running time with an infinite number of processors

b) How do we calculate work and span?

> Work - sum all the work done by each processor
> Span - calculate the longest dependence chain (the longest 'branch' in the parallel 'tree')

c) Does adding more processors affect the work or span?

> Neither - both work and span are defined by a fixed number of processors (1 for work and infinity for
> span) so adding more processors won't affect them

3. User Profile

You are designing a new social-networking site to take over the world. To handle all the volume you expect, you want to support multiple threads with a fine-grained locking strategy in which each user's profile is protected with a different lock. At the core of your system is this simple class definition:

```
1  class UserProfile {
2      static int id_counter;
3      int id; // unique for each account
4      int[] friends = new int[9999]; // horrible style
5      int numFriends;
6      Image[] embarrassingPhotos = new Image[9999];
7
8      UserProfile() { // constructor for new profiles
9          id = id_counter++;
10         numFriends = 0;
11     }
12
13     synchronized void makeFriends(UserProfile newFriend) {
14         synchronized(newFriend) {
15             if(numFriends == friends.length
16             || newFriend.numFriends == newFriend.friends.length)
17                 throw new TooManyFriendsException();
18                 friends[numFriends++] = newFriend.id;
19                 newFriend.friends[newFriend.numFriends++] = id;
20         }
21     }
22
23     synchronized void removeFriend(UserProfile frenemy) {
24         ...
25     }
26 }
```

a) The constructor has a concurrency error. What is it and how would you fix it? A short English answer is enough - no code or details required.

There is a data race on `id_counter`. Two accounts could get the same `id` if they are created simultaneously by different threads. Or even stranger things could happen. You could synchronize on a lock for `id_counter`.

b) The `makeFriends` method has a concurrency error. What is it and how would you fix it? A short English answer is enough no code or details required.

There is a potential deadlock if there are two objects `obj1` and `obj2` and one thread calls `obj1.makeFriends(obj2)` when another thread calls `obj2.makeFriends(obj1)`. The fix is to acquire locks in a consistent order based on the `id` fields, which are unique.

4. Bubble Tea

The `BubbleTea` class manages a bubble tea order assembled by multiple workers. Multiple threads could be accessing the same `BubbleTea` object. Assume the Stack objects are thread-safe, have enough space, and operations on them will not throw an exception.

```
1  public class BubbleTea {
2      private Stack<String> drink = new Stack<String>();
3      private Stack<String> toppings = new Stack<String>();
4      private final int maxDrinkAmount = 8;
5
6      // Checks if drink has capacity
7      public boolean hasCapacity() {
8          return drink.size() < maxDrinkAmount;
9      }
10
11     // Adds liquid to drink
12     public void addLiquid(String liquid) {
13         if (hasCapacity()) {
14             if (liquid.equals("Milk")) {
15                 while (hasCapacity()) {
16                     drink.push("Milk");
17                 }
18             } else {
19                 drink.push(liquid);
20             }
21         }
22     }
23
24     // Adds newTop to list of toppings to add to drink
25     public void addTopping(String newTop) {
26         if (newTop.equals("Boba") || newTop.equals("Tapioca")) {
27              toppings.push("Bubbles");
28         } else {
29             toppings.push(newTop);
30         }
31     }
32 }
```

a) Does the `BubbleTea` class above have (circle all that apply):

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

If there are any problems, give an example of when those problems could occur. Be specific!

a race condition

Assuming `Stack` is thread-safe, a race condition still exists. If two threads attempt to call `addLiquid()` at the same time, they could potentially both pass the `hasCapacity()` test with a value of 7 for `drink.size()`. Then both threads would be free to attempt to push onto the drink stack, exceeding `maxDrinkAmount`. Although this is not a data race, since a thread-safe stack can't be modified from two threads at the same time, it is definitely a bad interleaving (because exceeding `maxDrinkAmount` violates the expected behavior of the class).

b) Suppose we made the addTopping method synchronized, and changed nothing else in the code. Does this modified BubbleTea class above have (circle 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!

a race condition

Assuming `Stack` is thread-safe, a race condition still exists as described above. This change does reduce the effective concurrency in the code, however, so it actually makes things slightly worse.

5. Phone Monitor

The `PhoneMonitor` class tries to help manage how much you use your cell phone each day. Multiple threads can access the same `PhoneMonitor` object. Remember that synchronized gives you reentrancy.

```
1  public class PhoneMonitor {
2      private int numMinutes = 0;
3      private int numAccesses = 0;
4      private int maxMinutes = 200;
5      private int maxAccesses = 10;
6      private boolean phoneOn = true;
7      private Object accessesLock = new Object();
8      private Object minutesLock = new Object();
9
10     public void accessPhone(int minutes) {
11         if (phoneOn) {
12             synchronized (accessesLock) {
13                 synchronized (minutesLock) {
14                     numAccesses++;
15                     numMinutes += minutes;
16                     checkLimits();
17                 }
18             }
19         }
20     }
21
22     private void checkLimits() {
23         synchronized (minutesLock) {
24             synchronized (accessesLock) {
25                 if (numAccesses >= maxAccesses
26                   || numMinutes >= maxMinutes) {
27                     phoneOn = false;
28                 }
29             }
30         }
31     }
32 }
```

a) Does the `PhoneMonitor` class as shown above have (circle all that apply):

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

If there are any problems, give an example of when those problems could occur. Be specific!

a race condition, a data race

There is a data race on `phoneOn`. Thread 1 (not needing to hold any locks) could be at line 11 reading phoneOn, while Thread 2 is at line 27 (holding both of the locks) writing `phoneOn`. A data race is by definition a type of race condition.

b) Suppose we made the `checkLimits` method public, and changed nothing else in the code. Does this modified `PhoneMonitor` class have (circle 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!

a race condition, potential for deadlock, a data race

The same data race still exists, and thus so does the race condition. By making `checkLimits` method public, it is possible for Thread 1 to call `accessPhone` and be at line 13 holding the `accessesLock` lock and trying to get the `minutesLock` lock. Thread 2 could now call `checkLimits` and be at line 24, holding the `minutesLock` lock and trying to get the `accessesLock` lock. Therefore, now there is also potential for deadlock.