2674. Split a Circular Linked List

Medium

Leetcode Link

Problem Description

The given problem requires us to take a circular linked list and split it into two separate circular linked lists. The circular linked list is a sequence of nodes interconnected in such a way that each node points to the next node, and the last node points back to the first node, forming a circle. We must divide this list into two halves: the first half should contain the first part of the nodes, while the second half should contain the remaining nodes. Importantly, the split is not necessarily into two equal halves; if the list has an odd number of nodes, the first half should have one more node than the second half (ceiling of half the length of the list). This split must maintain the original order of the nodes.

The resulting sublists should also be circular linked lists, where each one ends by pointing to its own first node. The output should be an array with two elements, each representing one of the halves as a circular linked list.

Intuition

To find the solution for splitting the linked list, we need to determine the point where the first list ends and the second list begins. As the linked list is circular, we can utilize the Fast and Slow pointer technique, which involves two pointers moving through the list at different speeds. The slow pointer, `a`, advances one node at a time, while the fast pointer, `b`, moves two nodes at a time.

By the time the fast pointer completes its cycle (either by reaching the initial node or the one just before it), the slow pointer, `a`, will be at the midpoint of the list. This is because when the fast pointer has traveled twice as far, the slow pointer has covered half the distance in the same time. The node where the slow pointer stops is where the first list will end, and the second list will begin.

Once we determine the midpoint, we then create the split. This is done by having the next node after the slow pointer be the beginning of the second linked list (`list2`). We must then fix the `next` pointers to maintain the circular nature of both lists. The next pointer of the fast pointer (`b`) should point to the beginning of the second list (`list2`), forming the second circular list. The slow pointer (`a`)'s next pointer should point back to the beginning of the first list, maintaining its circular nature. Finally, we return an array containing the start points of both halves of the list, preserving their circular linked list structure.

Solution Approach

In the provided Python solution, the circular linked list is split into two halves using Floyd's Tortoise and Hare approach, which is also known for detecting cycles within linked lists. The algorithm employs two pointers: a slow pointer (`a`) and a fast pointer (`b`), as described in the intuition section.

Initially, both pointers are set to the start of the list. Then we use a while loop to continue iterating through the list as long as `b` (the fast pointer) doesn't meet the following conditions:

- `b.next` is not the start of the list (indicating that it's not run through the entire list yet), and
- `b.next.next` is not the start of the list (checking two steps ahead for the fast pointer).

Inside the loop:

- We increment the slow pointer `a` by one step (`a = a.next`).
- The fast pointer `b` increments by two steps (`b = b.next.next`).

When the loop exits, the slow pointer `a` will be at the midpoint, and the fast pointer `b` will be at the end of the list (or one before the end if the number of nodes is even). The `if` condition: `if b.next != list:` checks if the number of nodes is odd. If it is, then we move the fast pointer `b` one more node forward.

The line `list2 = a.next` marks the beginning of the second list by taking the node next to where the slow pointer `a` stopped. To form the second circular list, we set `b.next = list2`, linking the end of the first list to the start of the second list.

To complete the first circular list, we need to point `a.next` back to the head of the list (`list`), closing the loop on the first half of the split with `a.next = list`.

Finally, we return both `list` and `list2` within an array, which are the heads of the two split circular linked lists.

To recap, here are the exact steps:

1. Initialize two pointers `a` and `b` to the head of the circular linked list.
2. Move `a` one node at a time and `b` two nodes at a time until `b` is at the end of the list or one node before the end.
3. If the list has an odd length, increment `b` to point to the last node.
4. Set `list2` to the node after `a`, which will be the head of the second circular linked list.
5. Link the last node of the original list to the head of the second list, forming a circular structure for the second half.
6. Update the `next` pointer of the slow pointer `a` to the original head, forming the circular structure for the first half.
7. Return the array `[list, list2]` where `list` is the head of the first circular list and `list2` is the head of the second.

These steps allow us to achieve the desired splitting of the circular linked list while maintaining the circular nature of both resulting lists.

Example Walkthrough

Let's walk through a small example to illustrate the solution approach for splitting a circular linked list into two halves. Suppose our circular linked list looks like this:

`(Head) A -> B -> C -> D -> A`

Here `A` is the head of the list, and the list contains four nodes. Following the steps outlined in the solution approach:

1. Initialize two pointers `a` and `b` to the head of the circular linked list. So `a = A` and `b = A`.

2. Start moving both pointers forward. `a` moves one node, and `b` moves two nodes at a time until `b` is at the end of the list or one node before the end. After the first iteration, `a = B` and `b = C`. After the second iteration, `a = C` and `b = A` (since `b` has moved two nodes from `C` and we have a circular list, it comes back to `A`).

3. The list has an even length, so we don't have to increment `b`.

4. Set `list2` to the node after `a`, which will be the head of the second circular linked list. Therefore, `list2 = D`.

5. Link the last node of the original list to the head of the second list to maintain the circular structure. This means we'll have `C -> D -> C`.

6. Update the `next` pointer of the slow pointer `a` to the original head, which closes the loop of the first half. This means `A -> B -> C -> A`.

7. Return the array `[list, list2]` where `list` is the head of the first circular list and `list2` is the head of the second. As a result, we have two circular linked lists:

   - First list: `(Head) A -> B -> C -> A`
   - Second list: `(Head) D -> C -> D`

These steps demonstrate how the original circular linked list was split into two halves while ensuring that both sublists remained circular.

Python Solution

```python
# Definition for singly-linked list.
class ListNode:
    def __init__(self, val=0, next=None):
        self.val = val
        self.next = next

class Solution:
    def splitCircularLinkedList(self, head: Optional[ListNode]) -> List[Optional[ListNode]]:
        # Fast pointer for moving two steps at a time
        fast_pointer = head
        # Slow pointer for moving one step at a time
        slow_pointer = head

        # Move pointers until the fast pointer reaches the end of the list
        while fast_pointer.next != head and fast_pointer.next.next != head:
            slow_pointer = slow_pointer.next
            fast_pointer = fast_pointer.next.next

        # If the fast pointer is one step away from completing the cycle, move it once more
        if fast_pointer.next != head:
            fast_pointer = fast_pointer.next

        # The slow pointer now points to the middle of the list,
        # so we will start the second half from the next node
        second_half_head = slow_pointer.next

        # The fast pointer should now point to the second half, making it a circular list
        fast_pointer.next = second_half_head

        # The slow pointer should point to the head of the first half, completing the first circular list
        slow_pointer.next = head

        # Return the two halves, both are now circular linked lists
        return [head, second_half_head]

```

Java Solution

```java
class Solution {
    // The method splits a circular linked list into two halves.
    // If the number of nodes is odd, the extra node goes to the first half.
    public ListNode[] splitCircularLinkedList(ListNode head) {
        if (head == null) {
            return new ListNode[]{null, null};
        }

        // 'slow' will eventually point to the end of the first half of the list
        // 'fast' will be used to find the end of the list to determine the midpoint
        ListNode slow = head, fast = head;

        // Traverse the list to find the midpoint. Since it's a circular list,
        // the conditions check if the traversed list has returned to the head.
        while (fast.next != head && fast.next.next != head) {
            slow = slow.next;          // move slow pointer one step
            fast = fast.next.next;    // move fast pointer two steps
        }

        // If there are an even number of elements, move 'fast' to the very end of the list
        if (fast.next != head) {
            fast = fast.next;
        }

        // The 'secondHead' points to the start of the second half of the list
        ListNode secondHead = slow.next;

        // Split the list into two by reassigning the 'next' pointers
        fast.next = secondHead;  // Complete the second circular list
        slow.next = head;        // Complete the first circular list

        // Return an array of the two new list heads
        return new ListNode[]{head, secondHead};
    }
}

```

C++ Solution

```cpp
#include <vector>

// Definition for a node in a singly-linked list.
struct ListNode {
    int val;            // Value of the node.
    ListNode *next;     // Pointer to the next node.

    ListNode() : val(0), next(nullptr) {}                           // Default constructor.
    ListNode(int x) : val(x), next(nullptr) {}                      // Constructor initializing with a value.
    ListNode(int x, ListNode *next) : val(x), next(next) {}         // Constructor initializing with a value and the next node.
};

class Solution {
public:
    // Function to split a circular linked list into two halves.
    std::vector<ListNode*> splitCircularLinkedList(ListNode* head) {
        ListNode *slow_ptr = head;  // 'slow_ptr' will eventually point to the mid-point of the list.
        ListNode *fast_ptr = head;  // 'fast_ptr' will be used to find the end of the list.

        // Move 'fast_ptr' twice as fast as 'slow_ptr'. When 'fast_ptr' reaches the end of the list,
        // 'slow_ptr' will be in the middle.
        while (fast_ptr->next != head && fast_ptr->next->next != head) {
            slow_ptr = slow_ptr->next;
            fast_ptr = fast_ptr->next->next;
        }

        // If there are an even number of nodes, move 'fast_ptr' to the end of the list
        if (fast_ptr->next != head) {
            fast_ptr = fast_ptr->next;
        }

        // 'slow_ptr' is now at the splitting point so we create the second list starting after 'slow_ptr'.
        ListNode* head2 = slow_ptr->next;
        // The list is now split into two, with 'head2' as the head of the second list
        // and 'head' as the head of the first list.
        fast_ptr->next = head2;   // End of first list is now connected to the start of the second.
        slow_ptr->next = head;    // End of second list is now connected to the start of the first.

        // Return the heads of the two halves in a vector.
        return {head, head2};
    }
};

```

Typescript Solution

```typescript
// This function takes a circular singly-linked list and splits it into two halves.
// It returns an array containing the two halves of the list.
function splitCircularLinkedList(head: ListNode | null): Array<ListNode | null> {
    if (!head) {
        // If the list is empty, just return an array with two null elements.
        return [null, null];
    }

    let slowPointer: ListNode | null = head; // This will move one step at a time.
    let fastPointer: ListNode | null = head; // This will move two steps at a time.

    // Move through the list to find the middle
    // Fast pointer moves twice as fast as the slow pointer.
    // When the fast pointer reaches the end, slow pointer will be at the middle.
    while (fastPointer.next !== head && fastPointer.next.next !== head) {
        slowPointer = slowPointer.next;
        fastPointer = fastPointer.next.next;
    }

    // In case of an even number of elements
    // move the fast pointer one more step to reach the end of the list.
    if (fastPointer.next !== head) {
        fastPointer = fastPointer.next;
    }

    // Now, slowPointer is at the end of the first half of the list.
    // The node following slowPointer starts the second half.
    const secondHalfHead: ListNode | null = slowPointer.next;

    // Split the list into two halves.
    // The first half will end at the slowPointer and should circle back to the head.
    slowPointer.next = head;

    // The second half starts at secondHalfHead and will end at the fastPointer.
    fastPointer.next = secondHalfHead;

    // Return the two halves of the list.
    return [head, secondHalfHead];
}

// Definition for singly-linked list (provided for context).
class ListNode {
    val: number;
    next: ListNode | null;
    constructor(val?: number, next?: ListNode | null) {
        this.val = (val === undefined ? 0 : val);
        this.next = (next === undefined ? null : next);
    }
}

```

Time and Space Complexity

The given code snippet is designed to split a circular singly linked list into two halves. The algorithm uses the fast and slow pointer technique, also known as Floyd's cycle-finding algorithm, to identify the midpoint of the list.

Time Complexity:

The time complexity of this algorithm can be determined by analyzing the while loop, which continues until the fast pointer (`b`) has either completed a cycle or is at the last node.

- In each iteration of the loop, the slow pointer (`a`) moves one step, and the fast pointer (`b`) moves two steps.
- In the worst case scenario, the fast pointer might traverse the entire list before the loop terminates. This would be the case if the number of elements in the list is odd.
- If the list has `n` nodes, and since the fast pointer moves two steps at a time, it will take `O(n/2)` steps for the fast pointer to traverse the entire list.
- Therefore, the time complexity of the loop is `O(n)`.

Space Complexity:

The space complexity of this algorithm refers to the additional space used by the algorithm, not including space for the input itself.

- The only extra variables used are the two pointers, `a` and `b`. These do not depend on the size of the input list but are rather fixed.
- Therefore, the space complexity of the algorithm is `O(1)`.

In summary, the time complexity is `O(n)` and the space complexity is `O(1)`.