Analysis Report: Boyer-Moore Majority Vote Algorithm

Partner Implementation Review

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Algorithm: Boyer-Moore Majority Vote
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1. Algorithm Overview

Hey Rasul! Nice work on the Boyer-Moore implementation. This algorithm solves the majority element problem - finding an element that appears more than $\lfloor n/2 \rfloor$ times in an array.

How It Works

Your implementation uses a smart two-phase approach:

Phase 1 - Voting (findCandidate): Uses a cancellation mechanism where different elements "cancel out" votes. Since the majority appears more than n/2 times, it survives this process.

Phase 2 - Verification (verifyAndTrackCandidate): Counts actual occurrences to confirm the candidate is truly a majority, while also tracking first/last positions.

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2. Complexity Analysis

2.1 Time Complexity

Best Case: Θ(n)

Scenario: All elements identical [5, 5, 5, 5, 5]

- Phase 1: n iterations (candidate never changes)
- Phase 2: n iterations (verify all matches)
- **Total: 2n = Θ(n)**

Worst Case: Θ(n)

Scenario: Alternating elements [1, 2, 1, 2, 1] causing maximum candidate changes

- Phase 1: n iterations with frequent swaps
- Phase 2: n iterations for verification
- **Total: ~3n comparisons = Θ(n)**

Average Case: Θ(n)

Scenario: Random array with scattered majority element

- Phase 1: n array accesses + ~1.5n comparisons
- Phase 2: n array accesses + n comparisons
- **Total: ~3.5n = Θ(n)**

Mathematical Justification:

T(n) = n (Phase 1) + n (Phase 2)

= 2n + c (constant overhead)

= Θ(n)

Lower Bound Ω(n): Must read every element

Upper Bound O(n): Never more than 4n operations

Tight Bound Θ(n): Always linear ✓

Your algorithm is optimal! Can't solve this problem faster than O(n) since you must examine all elements.

2.2 Space Complexity: Θ(1)

Variables used:

- candidate, count: 8 bytes
- firstPos, lastPos: 8 bytes
- Loop variables: 4 bytes

Total: ~20 bytes regardless of input size - excellent constant space usage!

Comparison:

- HashMap approach: O(n) space
- Sorting: O(n log n) time
- Your solution: O(n) time + O(1) space = **Optimal!** ✓

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3. Code Review

3.1 What You Did Great!

1. Clean Structure

// Nice separation of concerns!

int candidate = findCandidate(arr);

```
Optional<MajorityResult> result = verifyAndTrackCandidate(arr, candidate);
```

2. Excellent Edge Case Handling

```
if (arr == null) throw new IllegalArgumentException(...);

if (arr.length == 0) return Optional.empty();

if (arr.length == 1) return Optional.of(new MajorityResult(...));
```

3. Smart Use of Optional Using Optional<MajorityResult> instead of null is professional and forces callers to handle the "no majority" case.

4. Comprehensive Testing 23 tests covering edge cases, properties, and even complexity verification. Your testLinearTimeComplexity() is particularly clever!

5. Great CLI Interface The interactive mode with different input distributions is really nice - more sophisticated than mine!

3.2 Mini Issues Found

Issue #1: Comparison Counting Inconsistency

Location: findCandidate() method

```
// Current:

if (count == 0) {

  tracker.incrementComparisons(1);

} else {

  tracker.incrementComparisons(2);  // Always 2?

  if (arr[i] == candidate) { ... }

}
```

Problem: You're always doing count == 0 check, but only incrementing by 1 in the if-branch. In the else-branch, you increment by 2, but actually you're doing 1 (count check) + 1 (candidate comparison) = 2 total, not just in the else block.

Impact: Minor - just makes metrics more accurate (~10-15% difference in comparison counts).

Issue #2: Repeated Division

Location: verifyAndTrackCandidate()

```
if (count > arr.length / 2) { ... }
```

Impact: Tiny performance gain, more about clean code.

3.3 Code Quality Score

Strengths:

- Clear variable naming
- Good method decomposition
- Professional error handling
- Excellent test coverage
- Well-documented README

Minor Improvements:

Extract magic numbers (arr.length / 2 → MAJORITY_THRESHOLD)

Overall Grade: A- (92/100)

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2. Extract Constants

private static final double MAJORITY_THRESHOLD = 0.5;

int threshold = (int)(arr.length * MAJORITY_THRESHOLD);

3.2 Time/Space Complexity - Already Optimal!

Your algorithm is **theoretically optimal**. Both time O(n) and space O(1) cannot be improved without changing the problem itself. Well done!

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4. Empirical Validation

4.1 Expected Performance

Operations per element (theoretical):

- Array Accesses: ~2 per element
- Comparisons: ~2-3 per element

Expected results for different sizes:

Size	Comparisons	Accesses	Time
100	200-300	~200	< 0.1 ms
1,000	2,000-3,000	~2,000	< 0.5 ms
10,000	20,000-30,000	~20,000	~3-5 ms
100,000	200,000-300,000	~200,000	~30-50 ms

4.2 Verification Methods

Linear Growth Test: Time should scale linearly with input size

- 10x size increase → ~10x time increase

4.3 Comparison: Boyer-Moore vs. Kadane's

Metric	Boyer-Moore (You)	Kadane's (Me)
Time Complexity	Θ(n) - 2 passes	Θ(n) - 1 pass
Space Complexity	Θ(1)	Θ(1)
Passes Required	2 (vote + verify)	1
Comparisons/n	~2-3	~2
Must Verify	Yes	No

Key Differences:

- **You:** Must verify candidate in Phase 2 (correctness requirement)
- **Me:** Single pass sufficient (running sum always correct)
- **Both:** Optimal for our respective problems!

Practical performance (n=10,000):

- Your expected: ~3-5 ms, ~20,000 accesses
- Mine measured: ~0.548 ms, ~10,000 accesses

The difference is the verification phase - unavoidable for your algorithm's correctness.

Conclusion

6.1 Summary

Algorithm Correctness: ✓ Excellent

- Properly implements two-phase Boyer-Moore
- Handles all edge cases
- Verification ensures correctness

Performance: ✓ Optimal

- Θ(n) time - can't be improved
- Θ(1) space - already minimal
- Matches theoretical predictions

Code Quality: A- (92/100)

- Professional structure
- Comprehensive testing
- Minor metric tracking issue (easy fix)

6.2 Final Recommendations

Should Do (15 minutes): Extract magic numbers to constants

Nice to Have: 6. Separate MajorityResult into own file

6.3 What I Learned

Analyzing your code taught me:

- The elegance of the **cancellation principle**
- Why **verification phases** are sometimes necessary
- Different approaches to **CLI design** (yours is better than mine!)
- The importance of comprehensive **input distribution testing**

Great work, Rasul! Your implementation is solid and production-ready. Just run those benchmarks and you're all set. Good job Рася!

Reviewed by: Usen Asylan
For: DAA - Assignment 2