Lab 3 - Validating Linearizability of Lock-free Skiplists

- Group 18
- Wenqi Cao

1. Measuring execution time

1.1 Measurement program

I modified the measurement program as follows for testing.

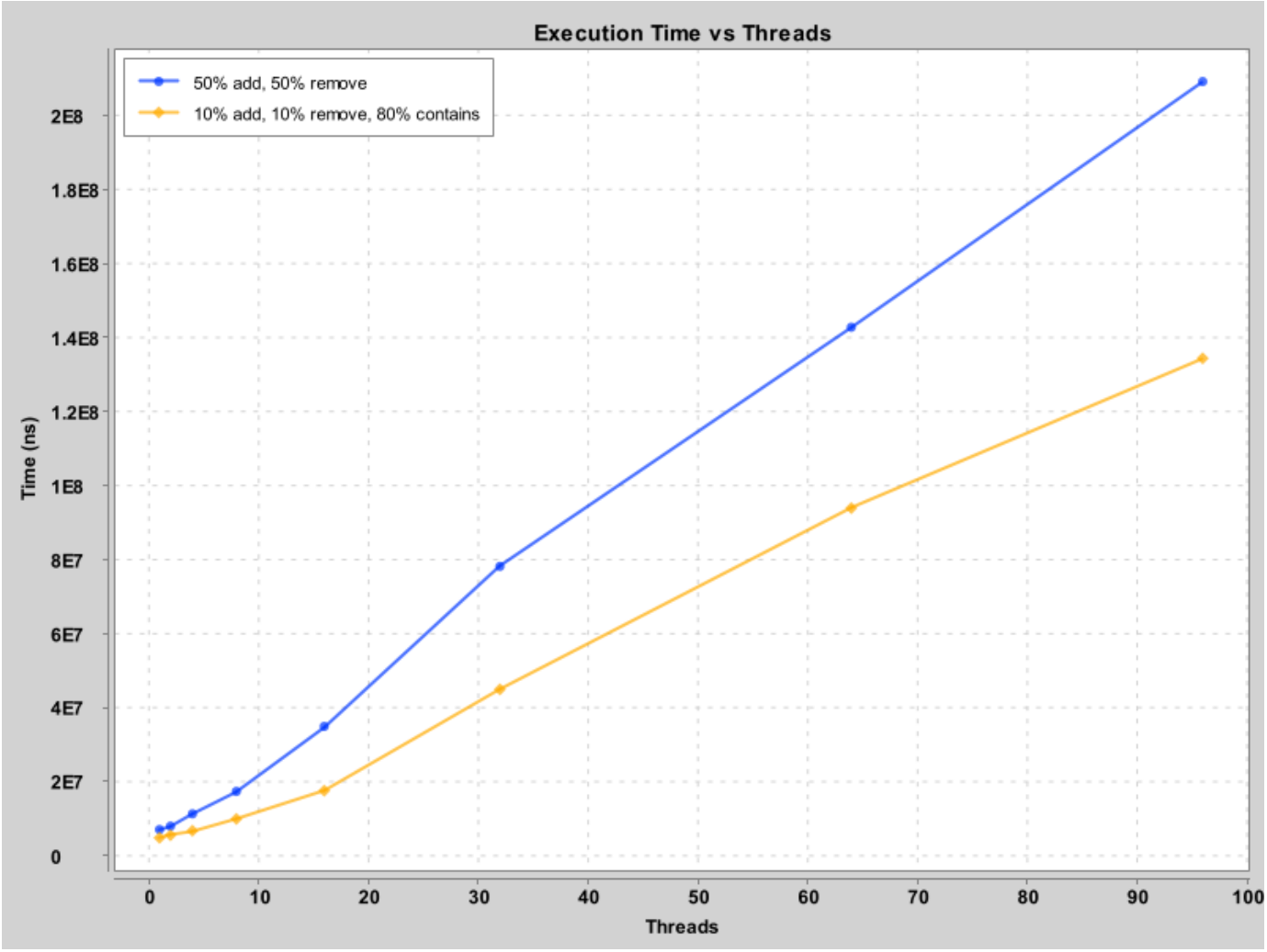
> java Main 2 Default Normal 1000 1:1:8 10000 5 10

Operations with 50% add & 50% remove seem to be slower.

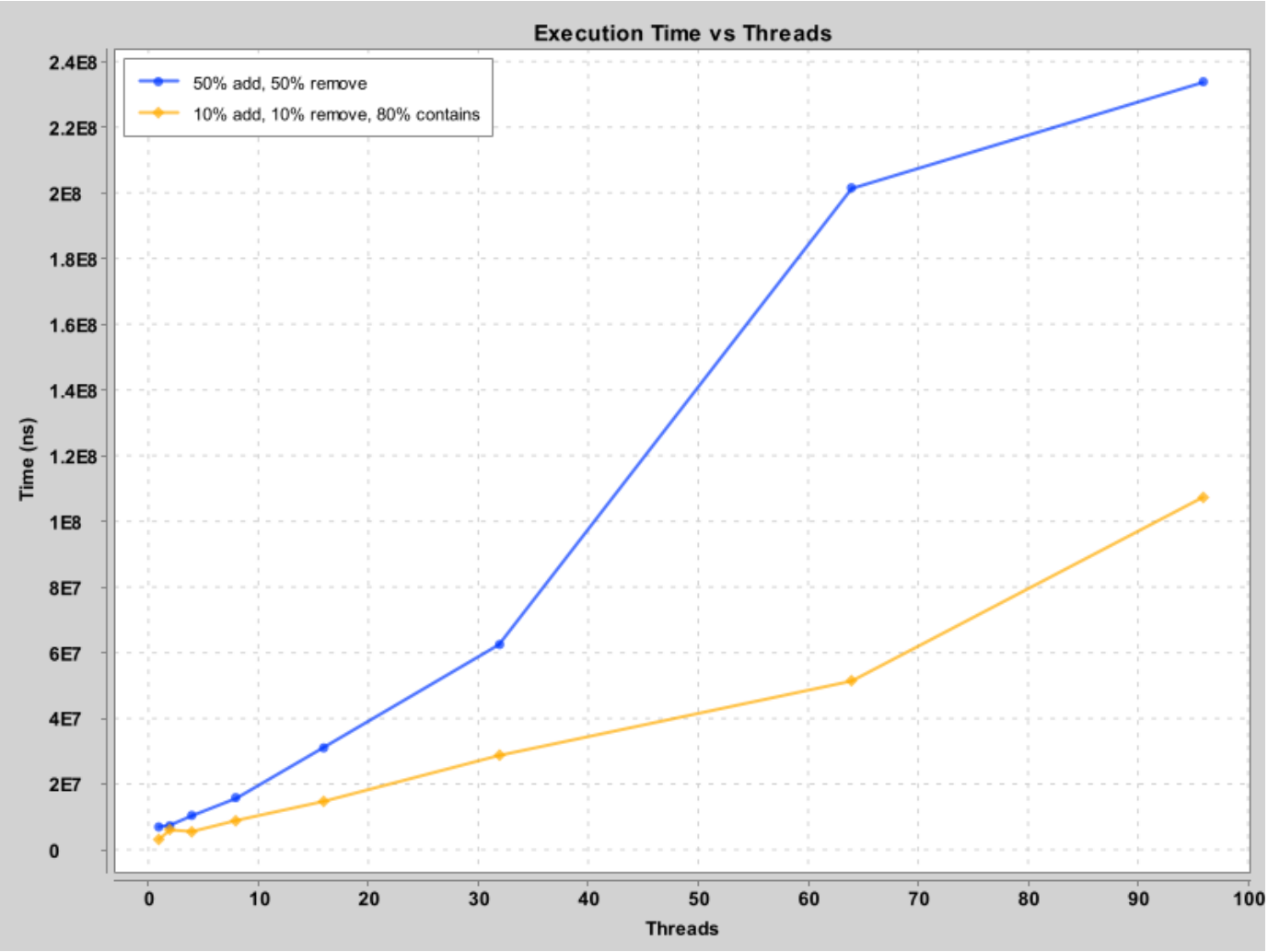
1.2 Dardel experiments

Source file:

- `src/Main.java` (Run on PDC)
- `plots/PDCPlot1.java` (Run on PDC)



- Fig above is the Normal Distribution.
- Fig below is the Uniform Distribution.



> Yes, they make sense.

> Uniform distribution is expected to be faster. In normal distribution, the concentration of operations in a small range of values causes contention being high and slows down performance.

> The 10:10:80 distribution should be faster than the 50:50 distribution because read-heavy workloads tend to have better performance in concurrent lock-free data structures like skip lists, as they involve less contention and fewer expensive operations.

2. Identify and validate linearization points

2.1 Identify linearization points

> Previously, I thought it would be like this:

> Generally speaking, the locations of these points are around the successful or unsuccessful call.
>
> - `add()` : The linearization point is where the node is successfully inserted into the list with compareAndSet() or when it is determined that the node already exists.
> - `remove()` : The linearization point is where the node is marked logically deleted or when it is found that the node is already removed or doesn't exist.
> - `contains()` : The linearization point is when the element is found in the list or determined to not be present.
>
> Well, if described in my own words, I would say that capture it "before the return".

However, the truth should be like this:

> Indeed, there should be 6 linearization points (LP), but they shouldn't be around any line of code.
>
> - `add()` : The LP of a successful `add()` is at the first CAS operation (node linked at bottom level). The LP of an unsuccessful `add()` is exactly when `find()` set `curr` at bottom level list that causes it to return `true` (already added).
> - `remove()` : The LP of a successful `remove()` is at the CAS operation where `iMarkedIt` returns `true` . The LP of an unsuccessful `remove()` is at the CAS operation where `iMarkedIt` returns `false` , or exactly at the point that `find()` set `curr` at bottom level list that causes it to return `false` (already removed).
> - `contains()` : The LP is at two lines of code `curr = pred.next[level].getReference();` when `curr` is set.
>
> Instead, they should be exactly on the CAS or at the moment when `curr` is changed.

2.2 Develop a validation method

Source file:

- `src/Main.java`
- `src/log.java`

> `Log.validate` is implemented with the help of `HashSet` .

> The `Log.validate` implementation is 100% correct (Approved by TA).

2.3. Locked time sampling

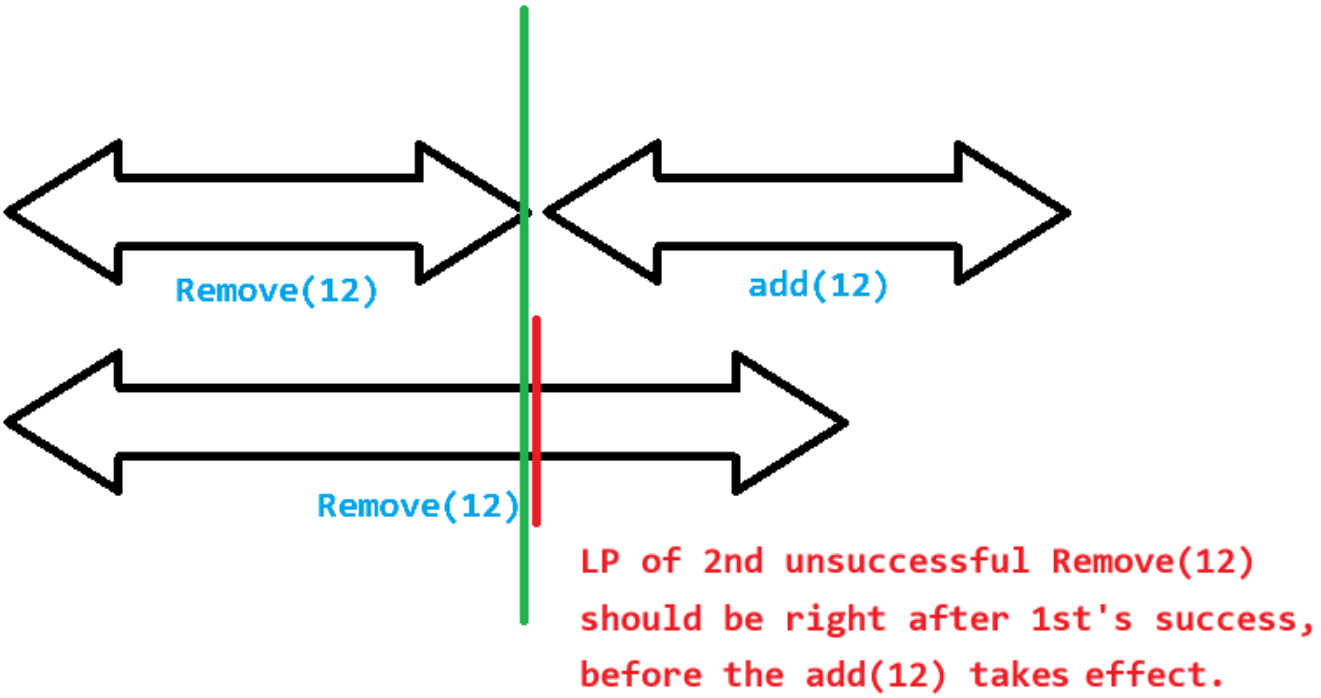
Source file:

- `src/Main.java`
- `src/LockFreeSkipListLocked.java`

> Though the locked version is more accurate, it introduces large delays, especially as the number of threads increases. The lock contention causes performance to degrade in multithreading scenarios.

> One possible solution is to create a list and record the assignment time of 'curr' within the lock, then the latest one will be the correct linearization point in `find()` .

> For linearization point in `remove()` , create a fake_remove enum and then substitute it with the most recent remove.



> For simplicity, this is implemented in lock-free version only.

2.4. Lock-free time sampling with local log

Source file:

- `src/Main.java`
- `src/LockFreeSkipListLocalLog.java`

> The absence of locks means reduced contention and improved throughput. However, it brings some trade-offs in accuracy, particularly in the ordering of timestamps due to the lack of precise synchronization between threads.

2.5. Lock-free Time Sampling with Global Log

Source file:

- `src/Main.java`
- `src/LockFreeSkipListGlobalLog.java`

> The absence of locks means reduced contention and improved throughput. However, it brings some trade-offs in accuracy, particularly in the ordering of timestamps due to the lack of precise synchronization between threads.

2.5.Extra

Source file:

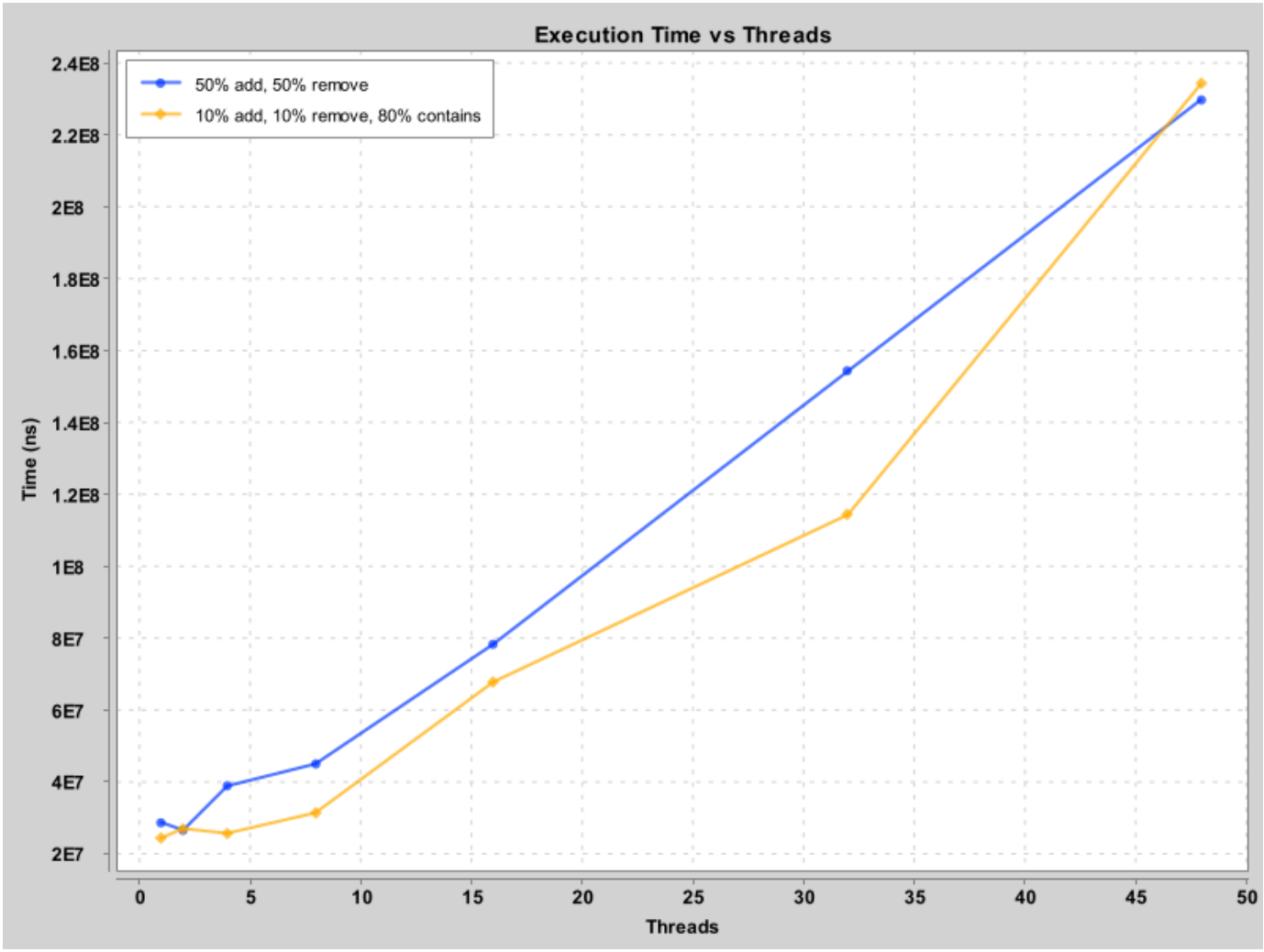
- `src/LockFreeQueue.java`

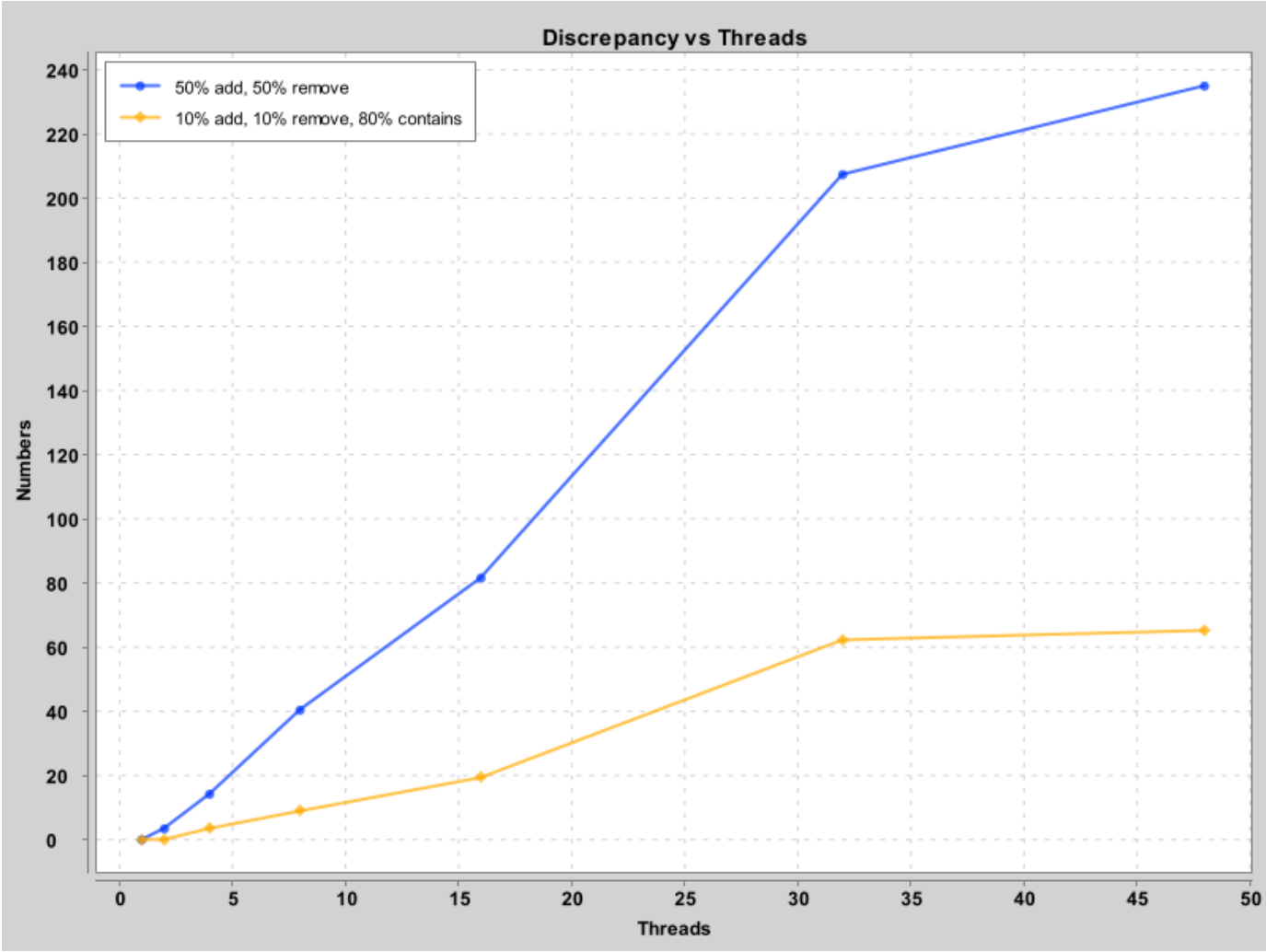
> Reference: HSLS Chapter 10 Page 237-238 LockFreeQueue.

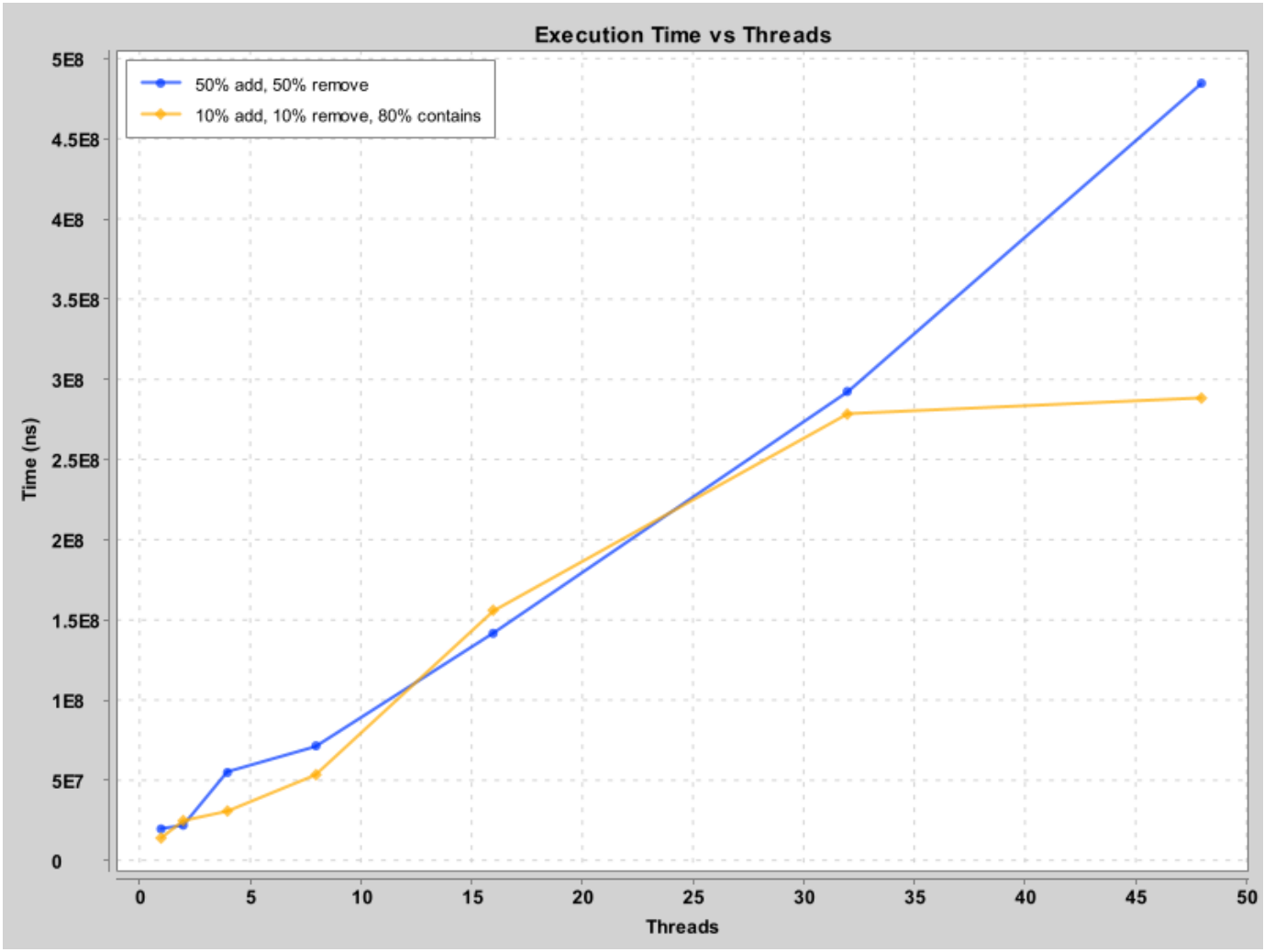
2.6. Dardel experiments

Source file:

- `plots/PDCPlot1.java` (Run on PDC)
- `plots/PDCPlot2.java` (Run on PDC)


Execution Time vs Threads
50% add, 50% remove
10% add, 10% remove, 80% contains
Time (ns)
2.4E8
2.2E8
2E8
1.8E8
1.6E8
1.4E8
1.2E8
1E8
8E7
6E7
4E7
2E7
0
5
10
15
20
25
30
35
40
45
50
Threads


Discrepancy vs Threads
50% add, 50% remove
10% add, 10% remove, 80% contains
Numbers
Threads
0
20
40
60
80
100
120
140
160
180
200
220
240
0
5
10
15
20
25
30
35
40
45
50


Execution Time vs Threads
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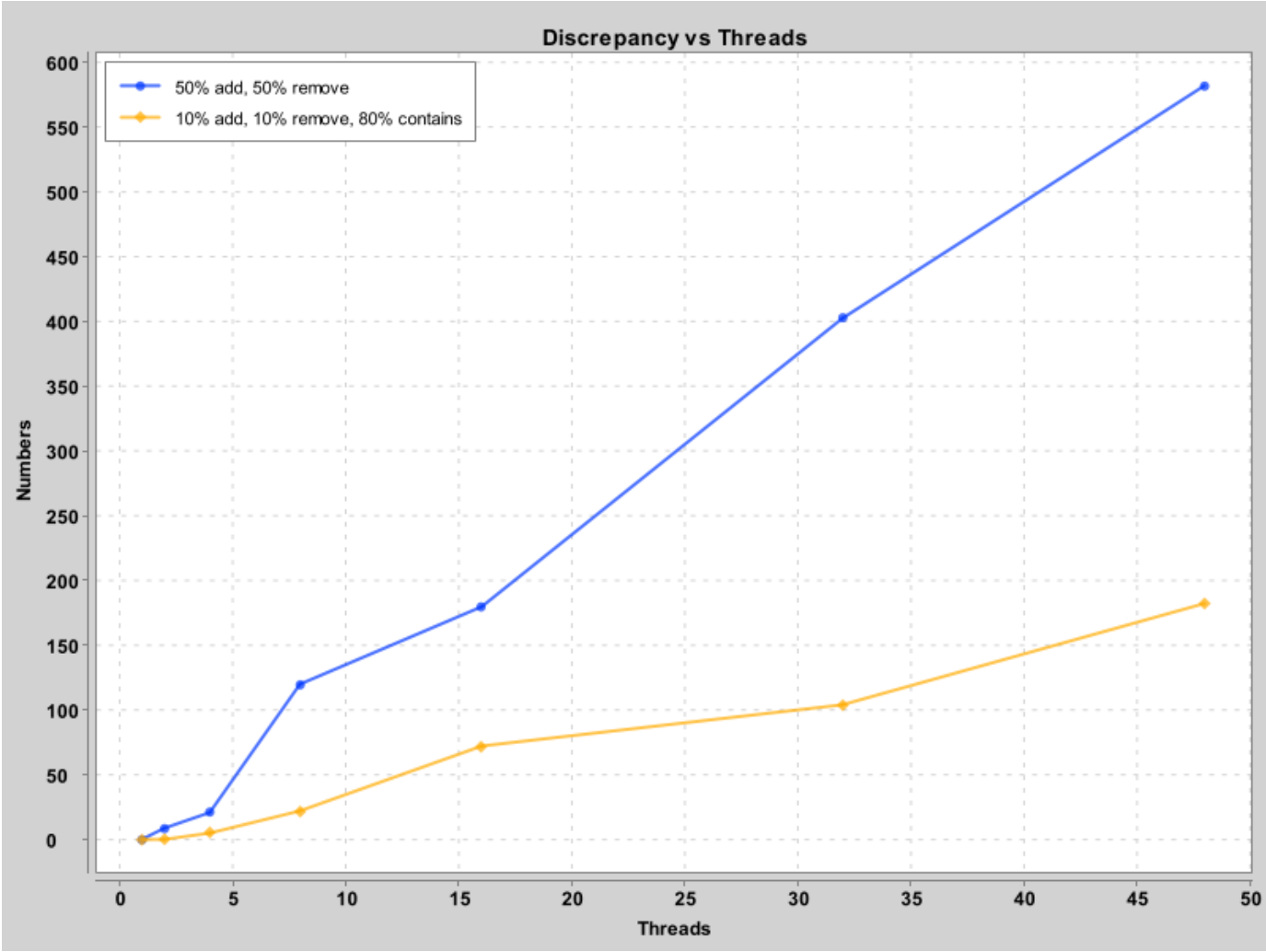
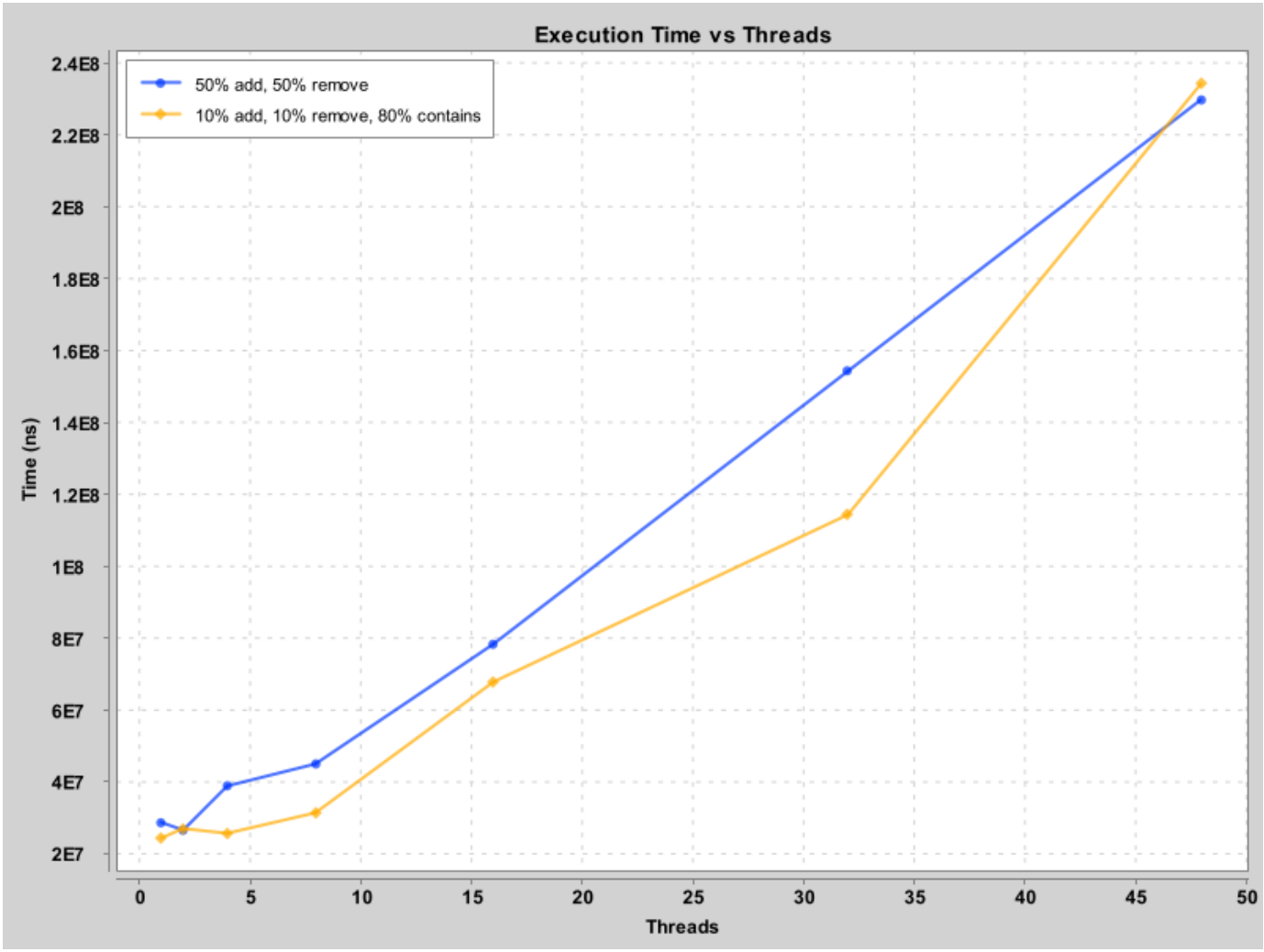
10% add, 10% remove, 80% contains
Time (ns)
5E8
4.5E8
4E8
3.5E8
3E8
2.5E8
2E8
1.5E8
1E8
5E7
0
0
5
10
15
20
25
30
35
40
45
50
Threads


Discrepancy vs Threads
50% add, 50% remove
10% add, 10% remove, 80% contains
Numbers
Threads
600
550
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50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1E8
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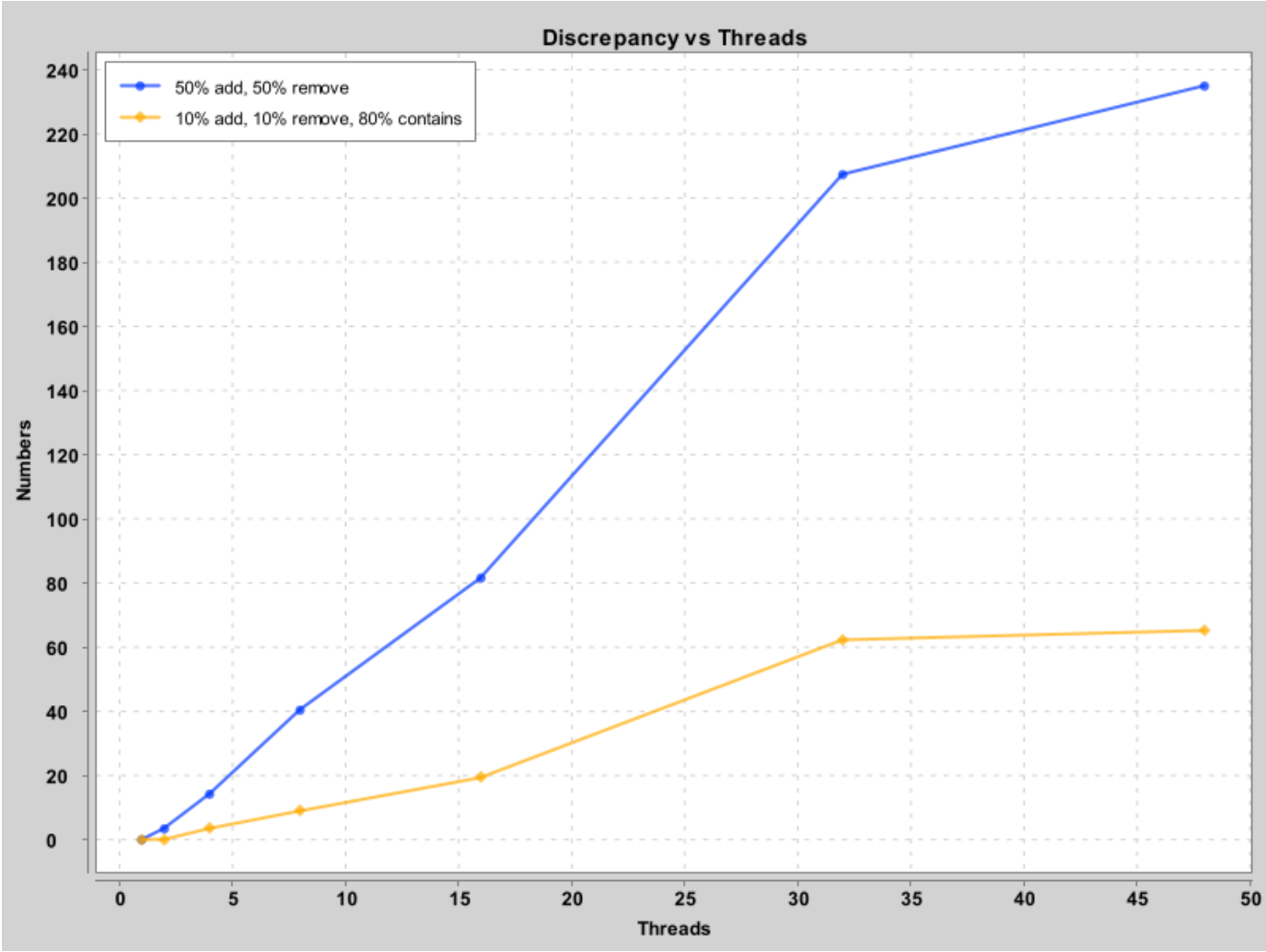
6E7
4E7
2E7
0
5
10
15
20
25
30
35
40
45
50
Threads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5
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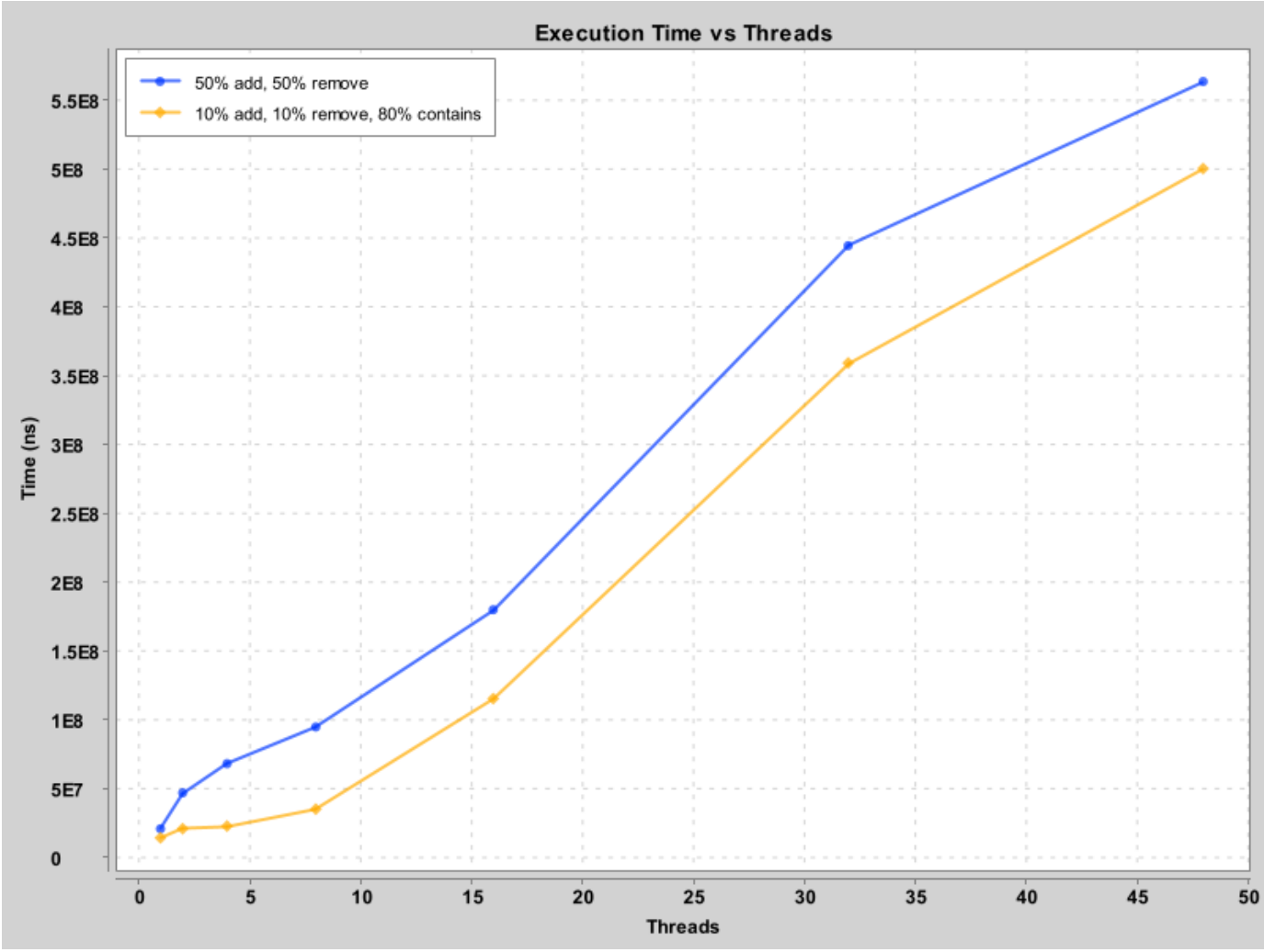
45
50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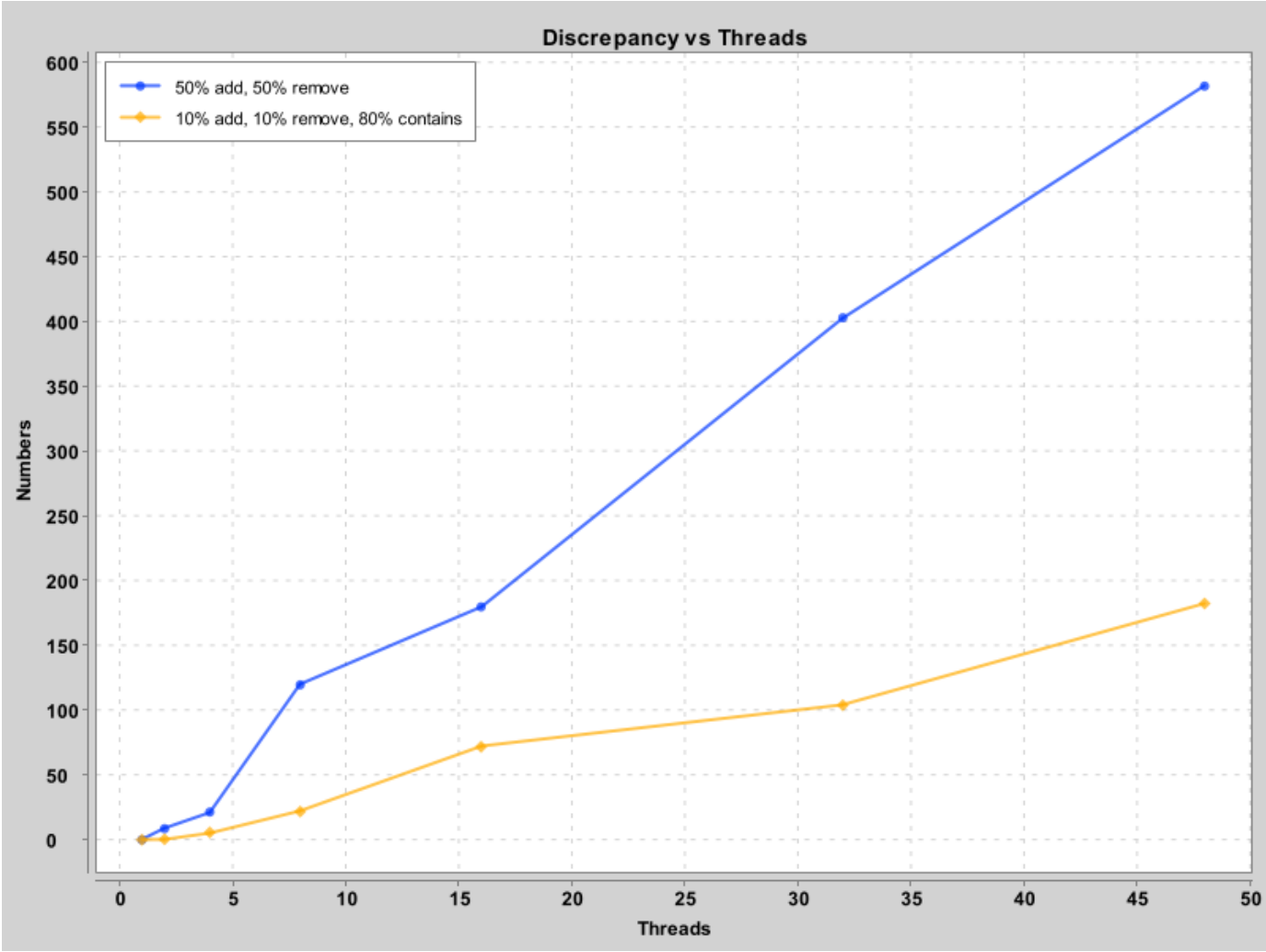
3E8
2.5E8
2E8
1.5E8
1E8
5E7
0
0
5
10
15
20
25
30
35
40
45
50
Threads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0
0
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10
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25
30
35
40
45
50