Concurrent Access of Priority Queues

Andrew Milner

Overview

- Review
- New Results
- Java Pathfinder Results

Inserting and Deleting

- Issues arise when performing insertions and deletions at the same time.
- Deadlocks will occur as a result.

Solution

- Nageshwara and Kumar suggest insertions should be completed from the top down.

- Both procedures now perform actions from the top down and eliminate the potential for a deadlock to occur.

Top Down Insertions

- Two values are required in order to predicate the path the node takes through the heap.
  - LastElem: The node location of the last element + 1.
  - FullLevel: The node location of the first element at the deepest level of the heap.

- The different between the two values gives the path.
  - This is possible because the heap is a binary tree.

Top Down Insertions

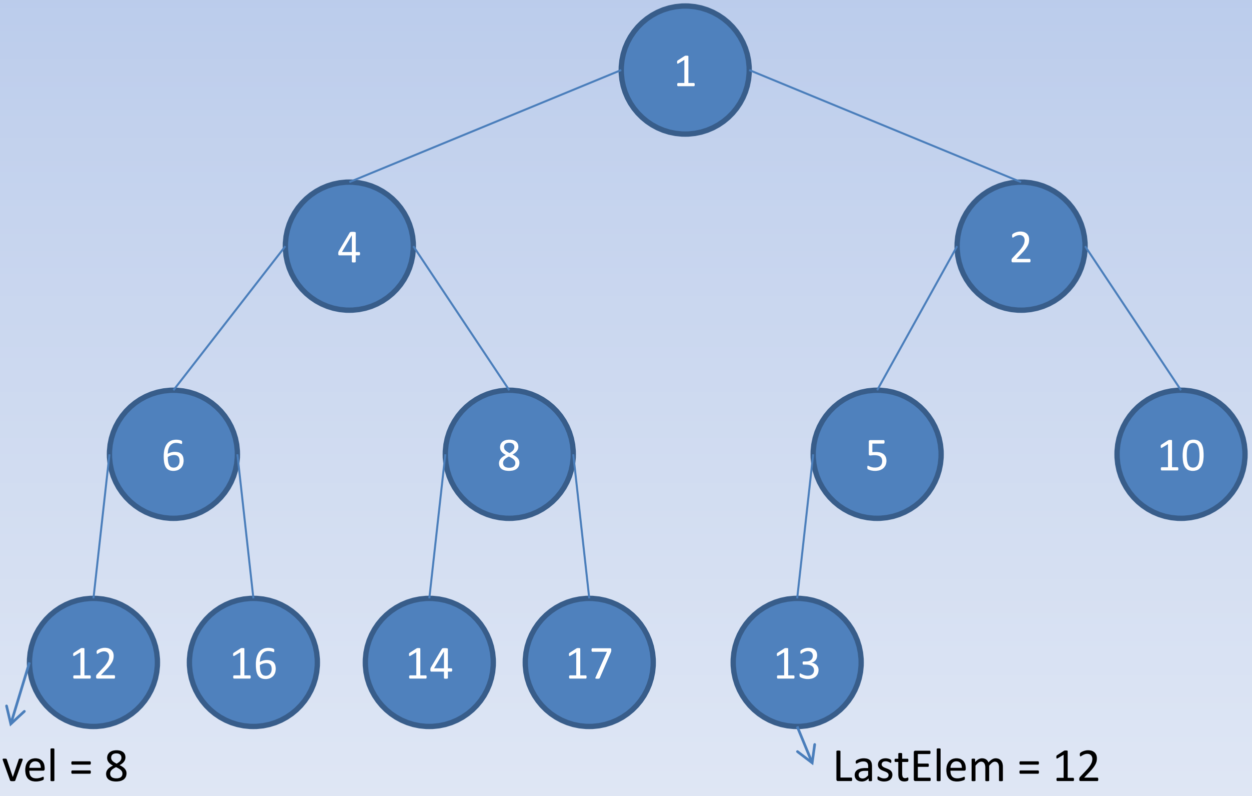
- The difference between LastElem and FullLevel is represented as a binary value.
- Each digit in the binary value represents a direction of travel through the heap.
- 1 indicates a right movement and 0 indicates a left movement.

Top Down Insertions

NodeLoc = (LastElem + 1) – FullLevel = 5

NodeLoc = 101

The path of the node through the heap is right, left, right.



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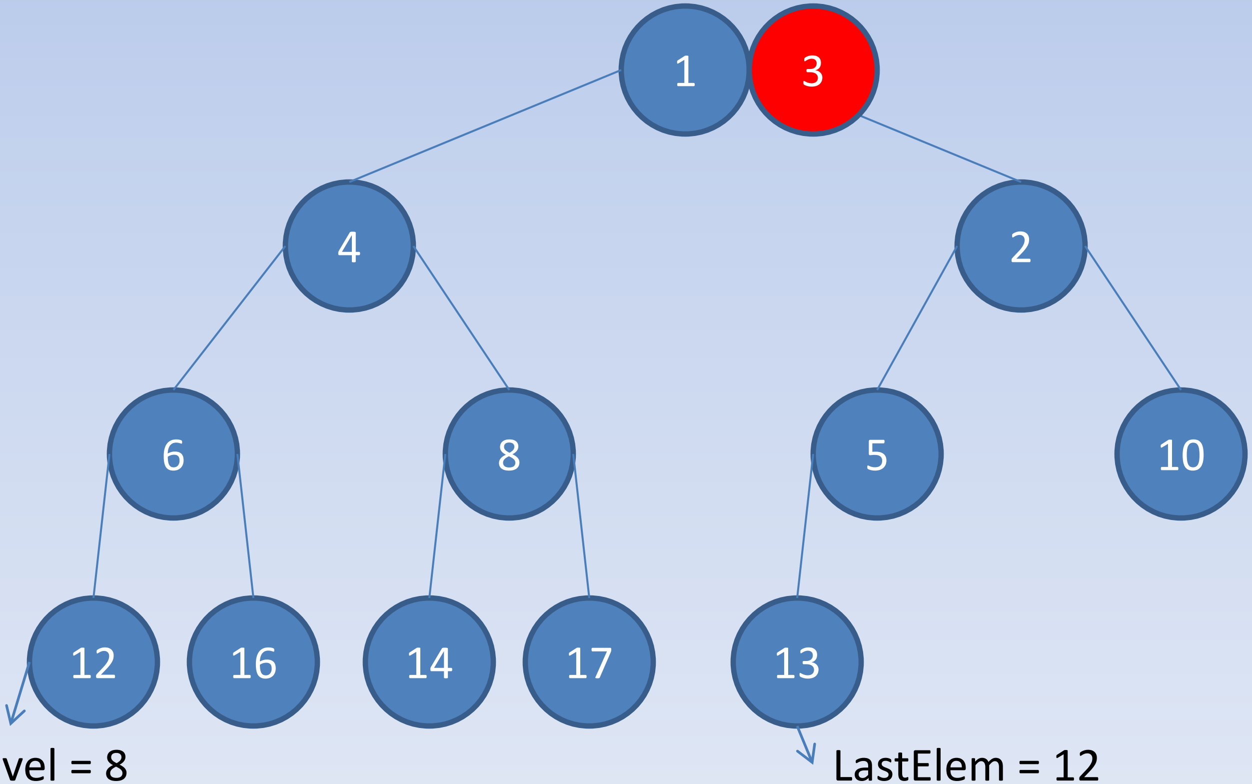

FullLevel = 8

LastElem = 12

Top Down Insertions

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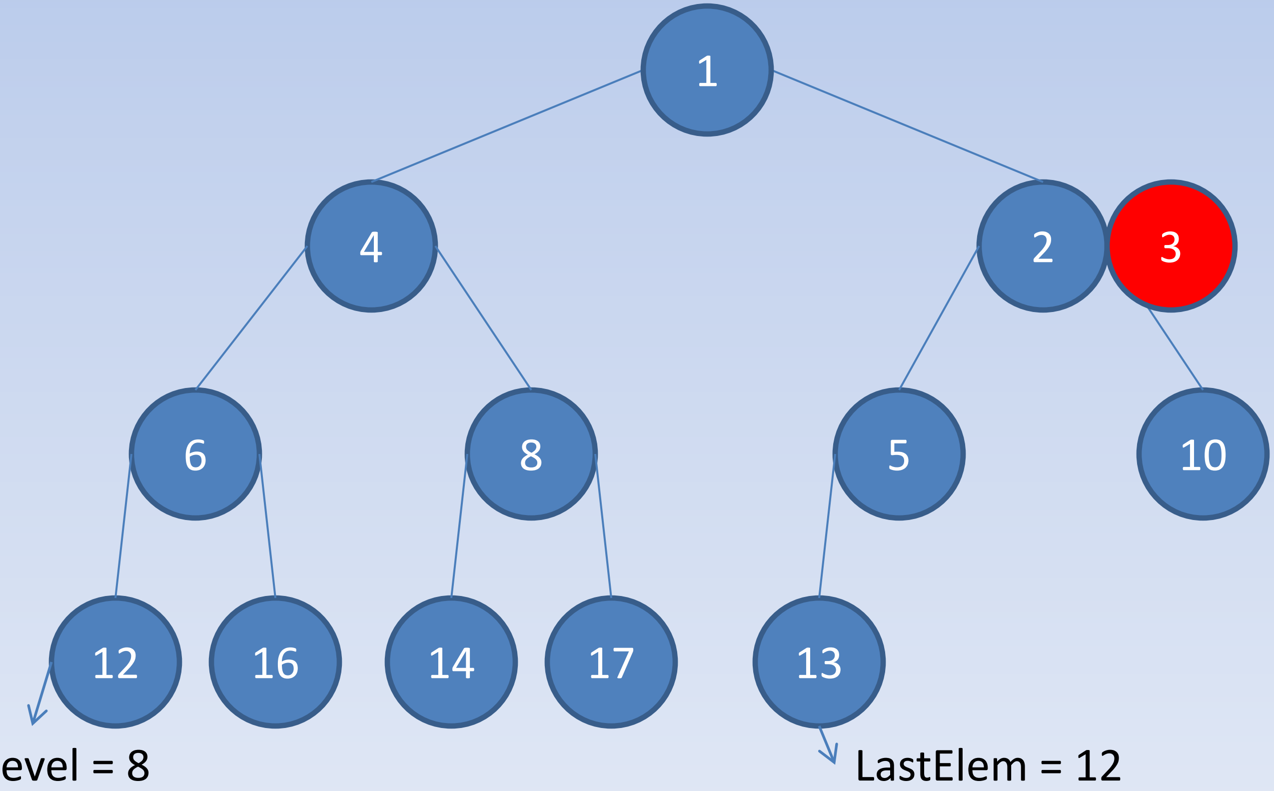

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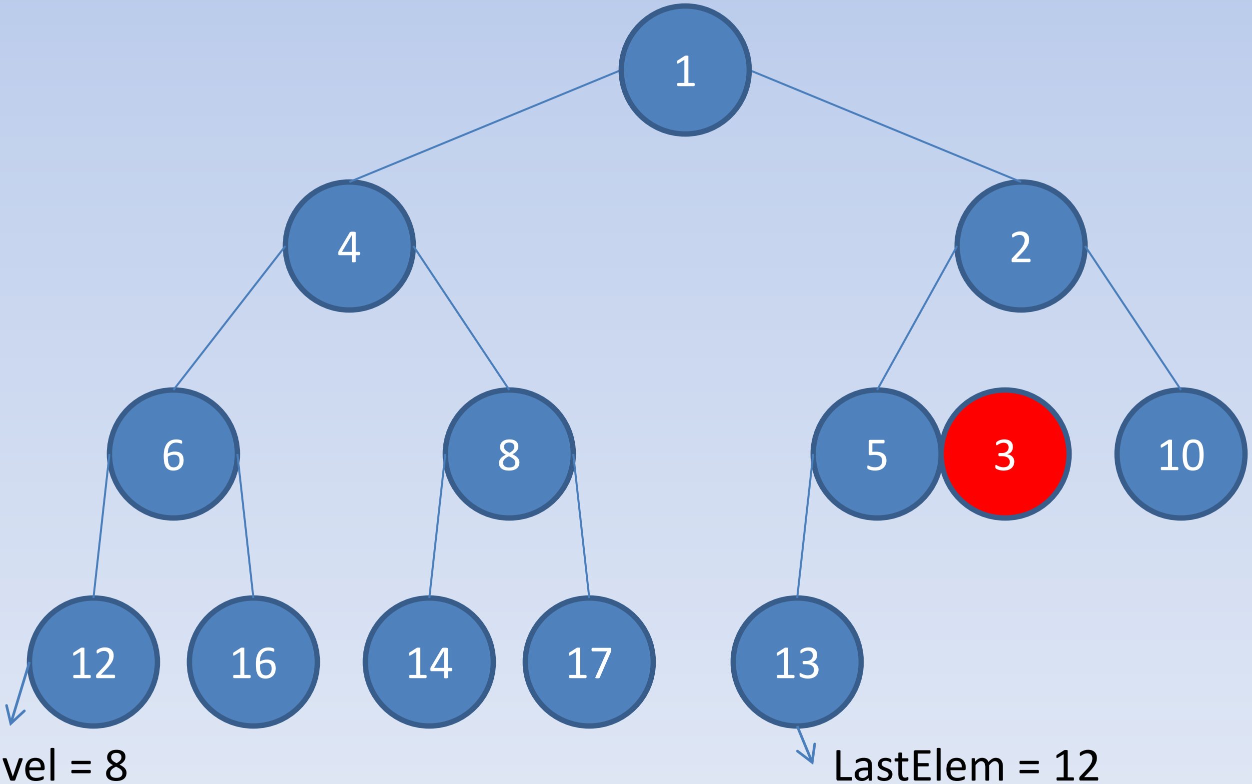

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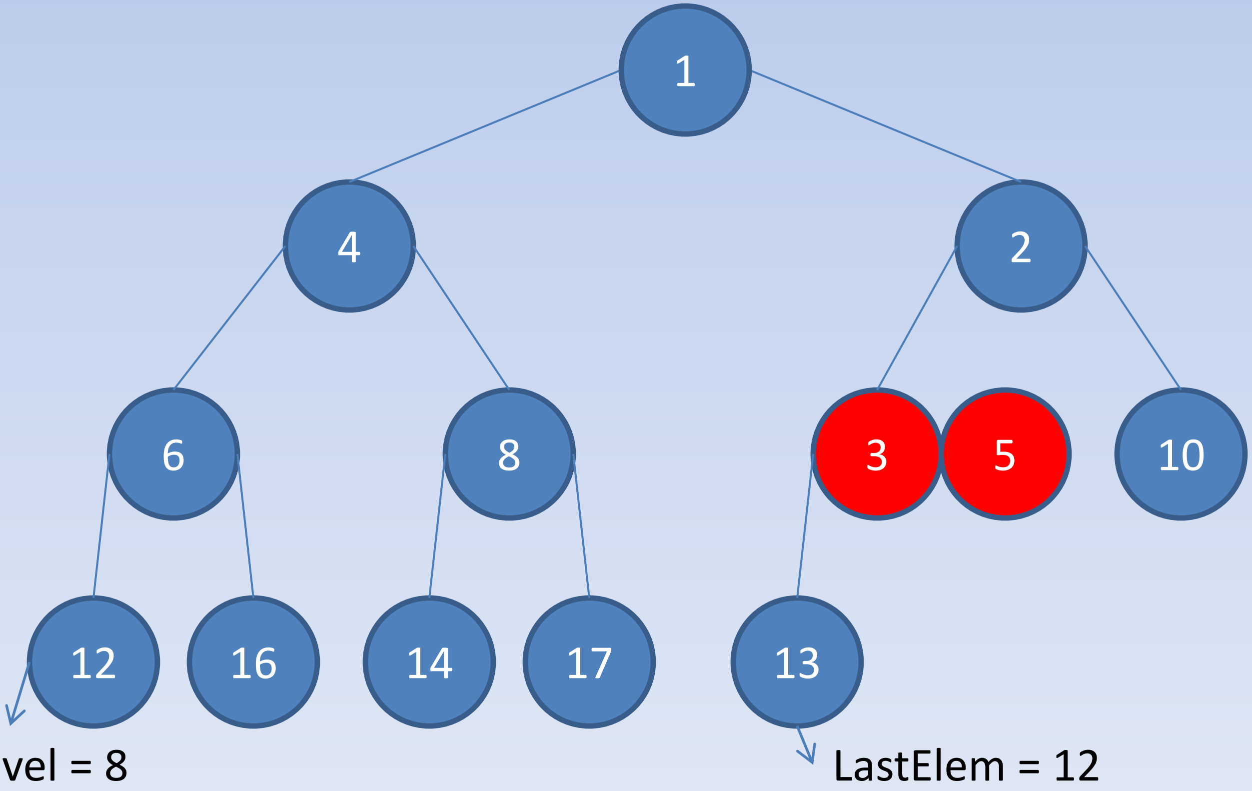

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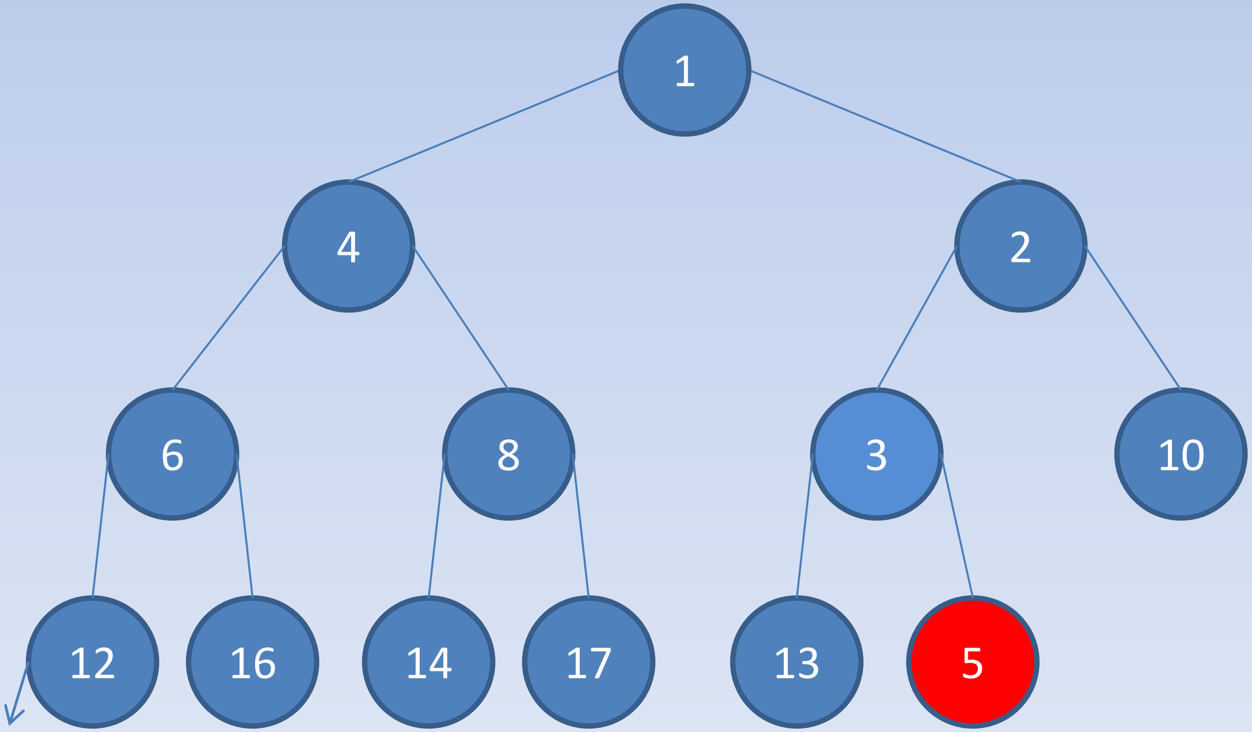


FullLevel = 8

LastElem = 13

Deleting/Inserting

- Only a small portion of the heap is locked.
- This locking window consists of three nodes for deletion (the parent and child nodes) and one node for insertions.
- Anytime a node is accessed it is locked in order to maintain mutual exclusion.
- FullLevel and LastElem are modified only during the initialization, after the root has been locked.

Deleting/Inserting

- One issue still exists which prevents insertions and deletions from working together.

- The deletion operation is forced to wait for an insertion operation to complete before it can begin.

Deleting/Inserting

- The problem is solved by associating a status field with each of the nodes.

Status Code	**Meaning**
PRESENT	A key exists at the node.
PENDING	An insertion is in progress which will ultimately insert a key at the node.
WANTED	A deleter is waiting for the key.
ABSENT	No key is present at the node.

Deleting/Inserting

- When an insertion operation begins the target status is set to PENDING.

- If the deletion operation is invoked while an insertion operation is still in progress, the status of the target is changed to WANTED.

- During each loop, the insertion operation checks to see if the target node’s status is WANTED.

Implementation

- The implementation of the concurrent heap was taken from Nageshwara and Kumar.
- Pseudo code was provided in the original paper.

Design Choices

- Pseudo code presented by Nageshwara and Kumar uses an integer based implementation.

- Array based heap data structure.
  - Parent location is represented by *i*.
  - The children are located at positions *i* x 2 and *i* x 2 + 1

Testing

- The correctness of the algorithm was tested using a single thread.
- A series of insertion and deletion operation were performed.
- The heap sizes ranged from 10 to 10,000.

Testing

- Check that the heap property was always maintained.

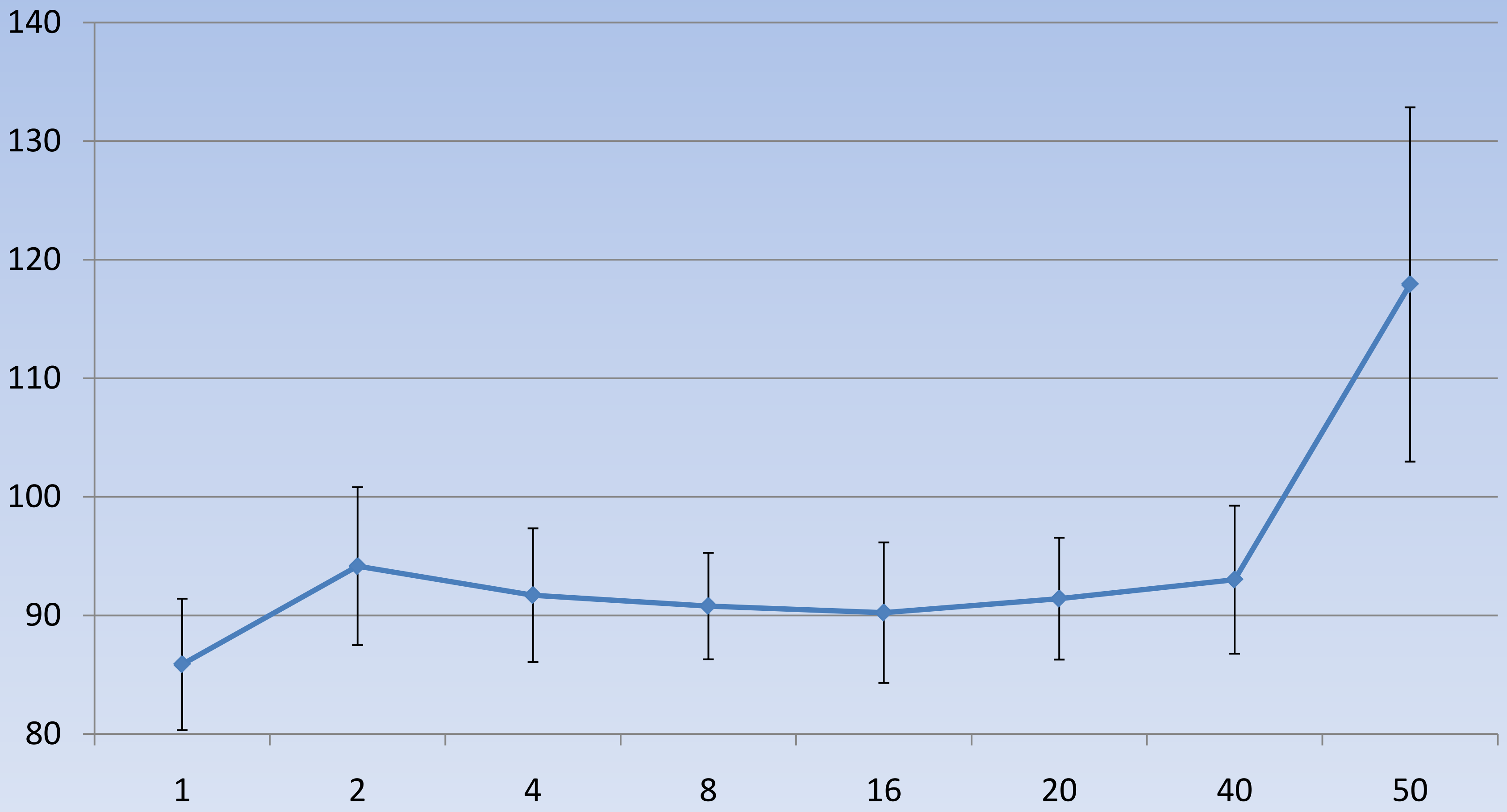
- Check for the occurrence of deadlock during insertion/deletion operations.

- Check if the node status was updated correctly.

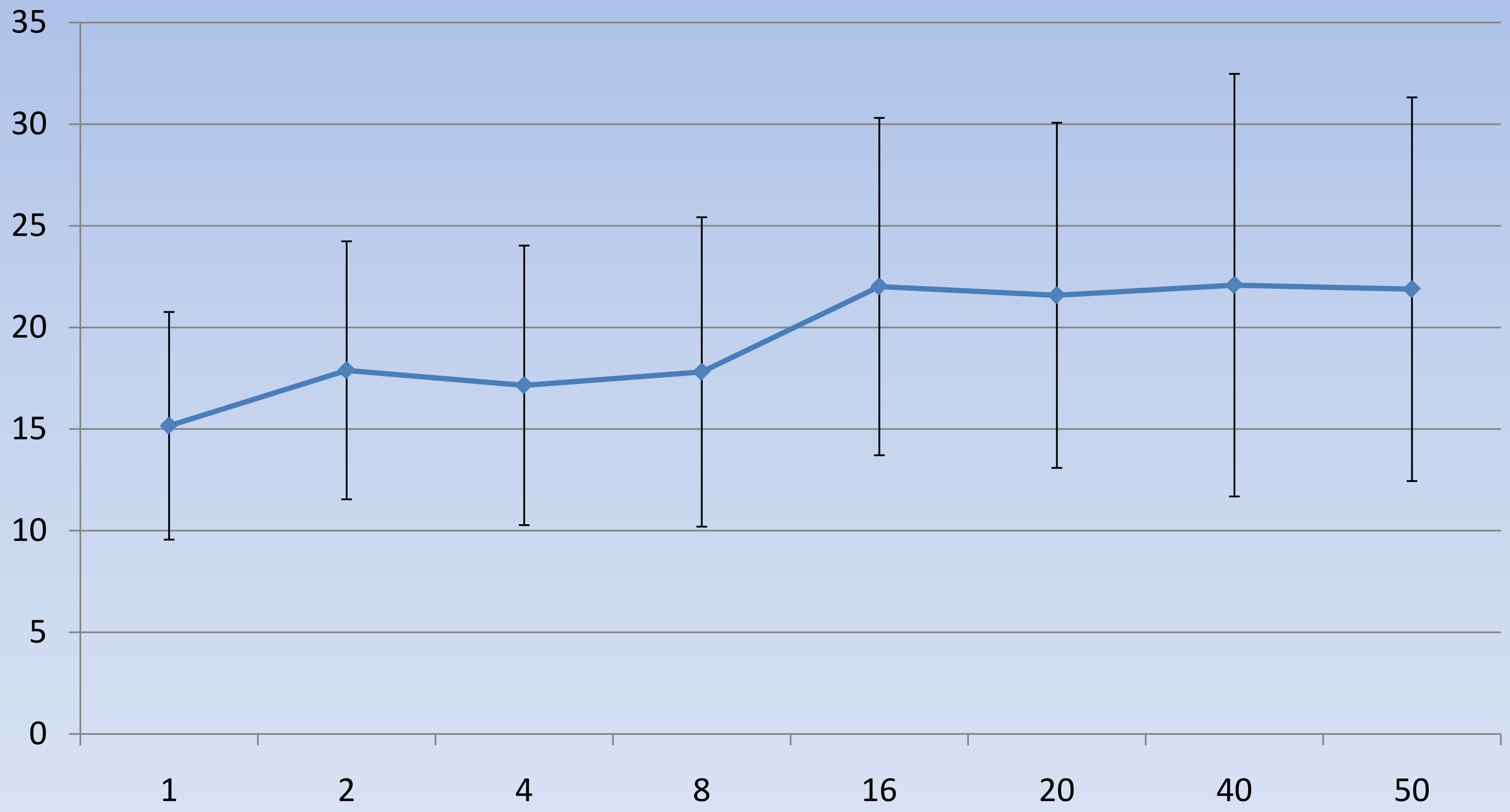
Testing

- Initial insertion and random test heap size 5,000.
- Initial deletion test heap size 15,000.
- Values were randomly determined between 1 and the max value.
- Work was split up evenly between threads.
- Each thread test was run 100 times.

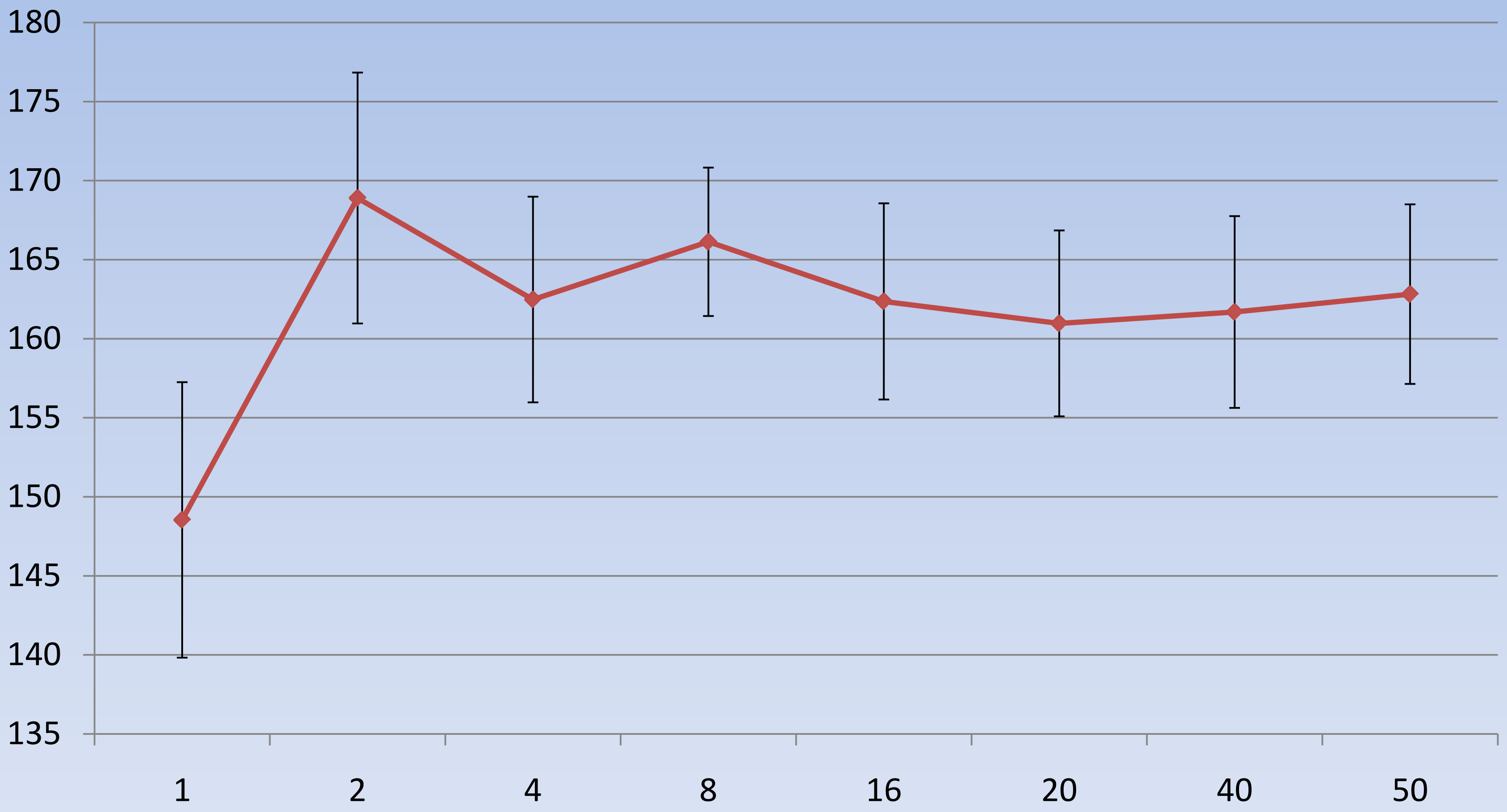
Semaphore Insertion Results



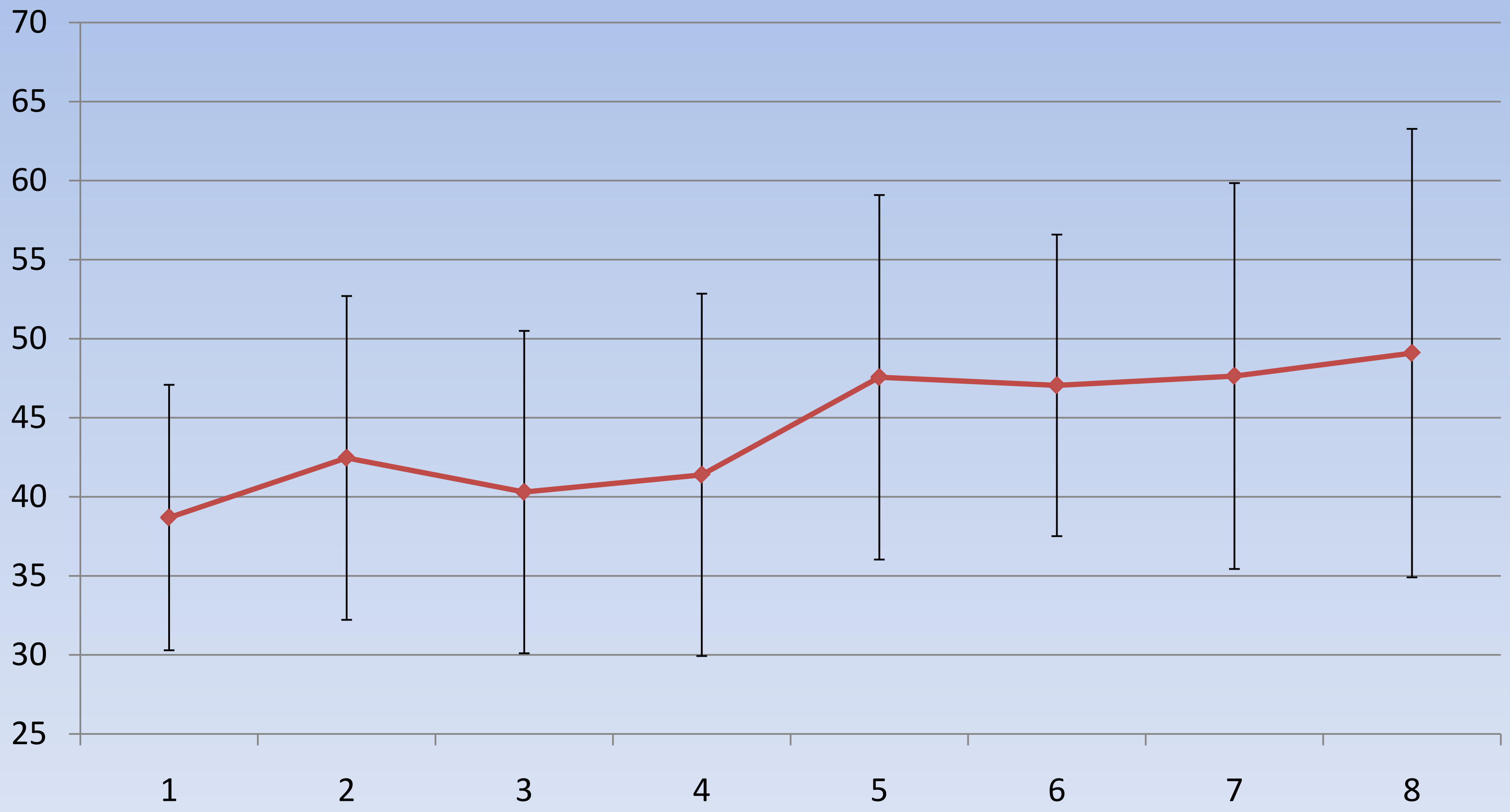
Lock Insertion Results



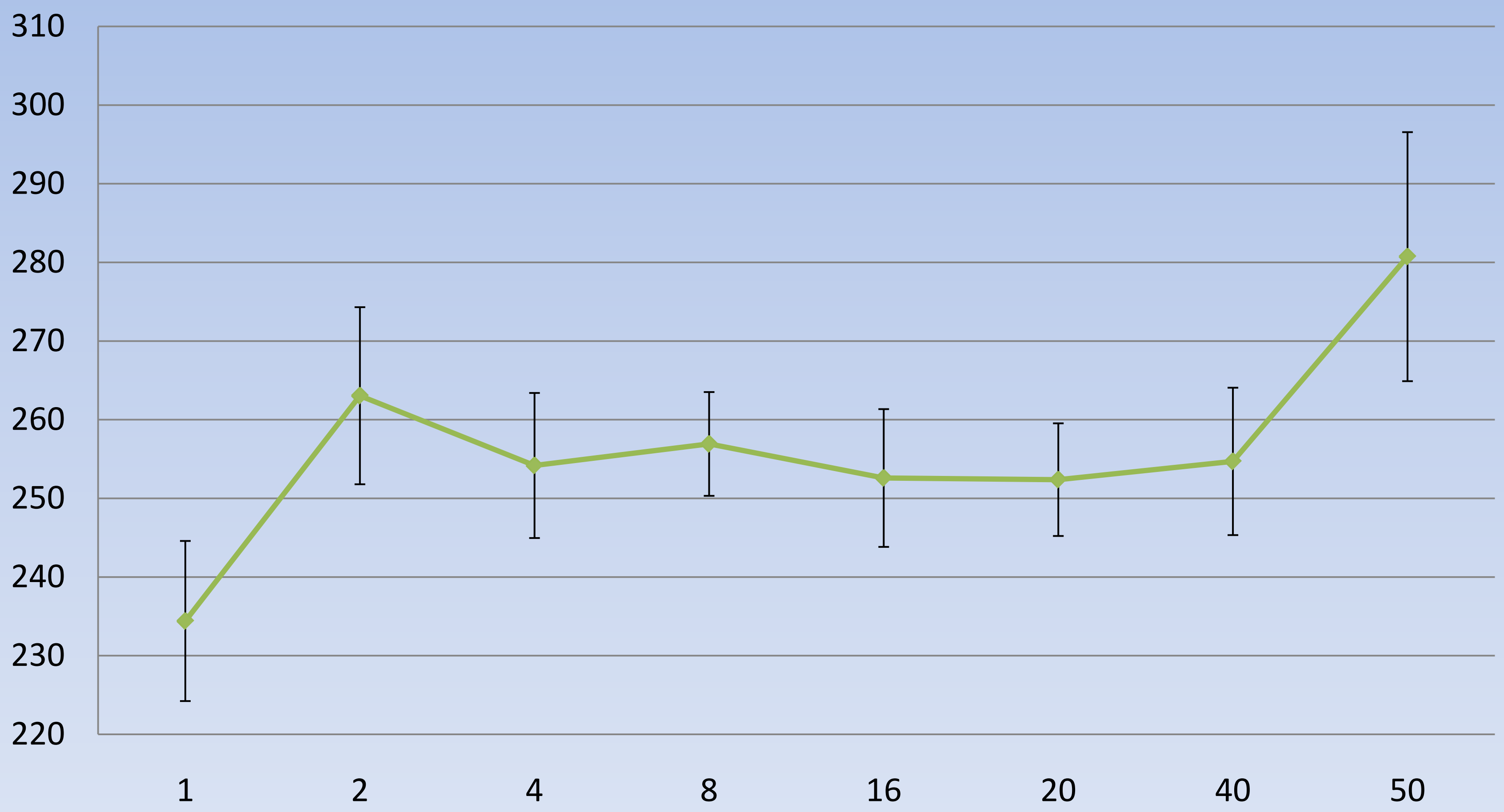
Semaphore Deletion Results



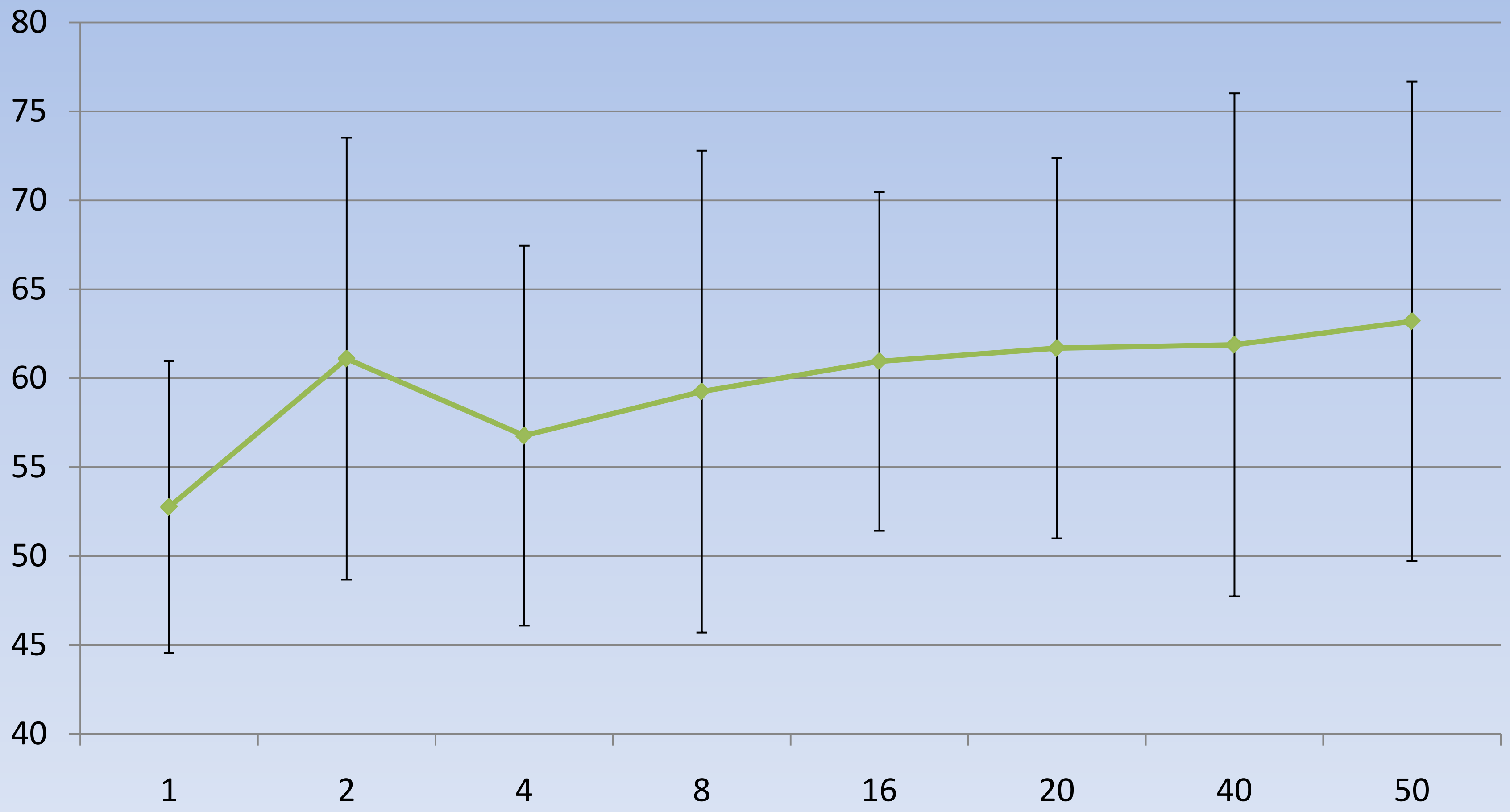
Lock Deletion Results



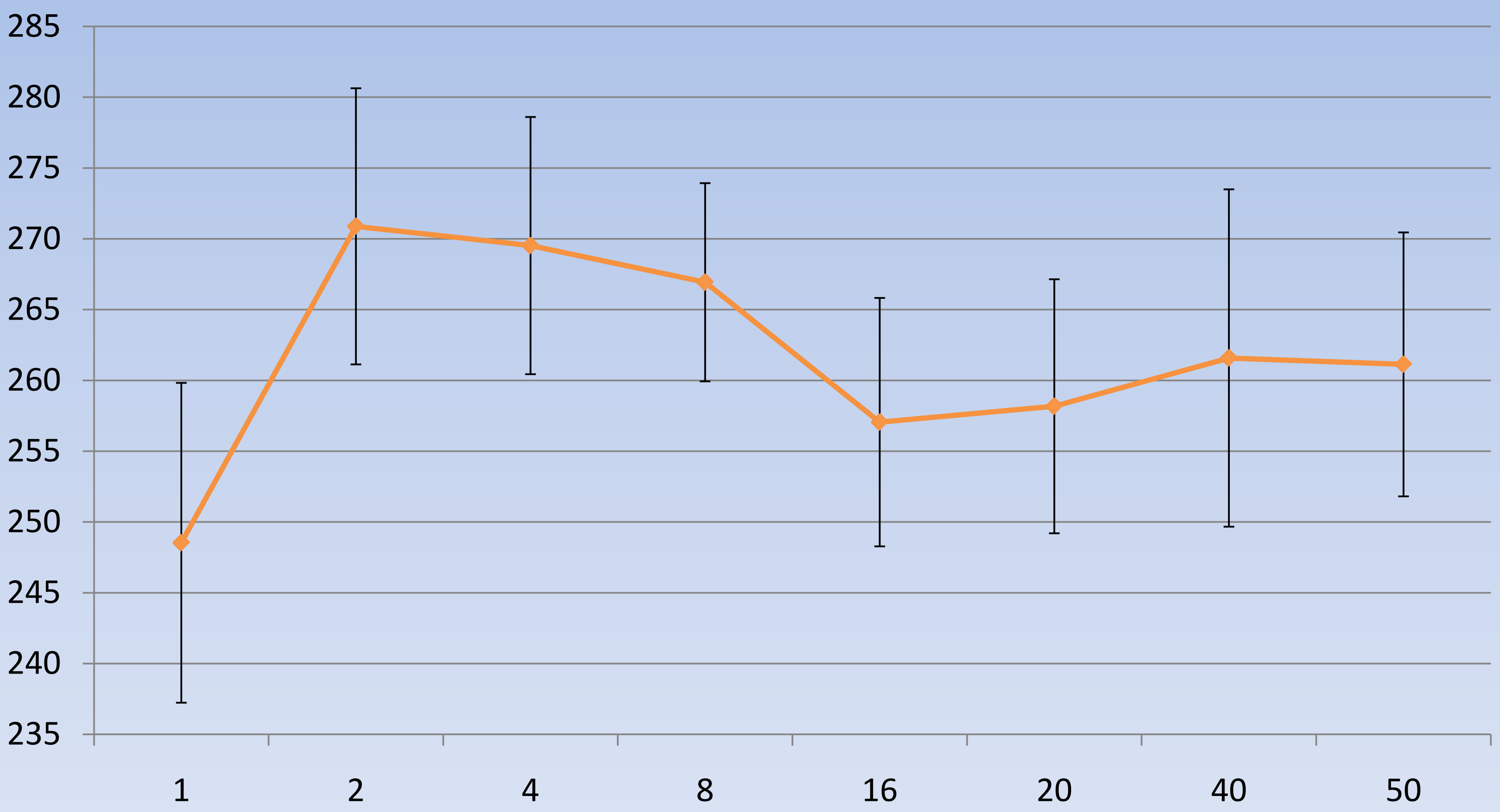
Semaphore Insert/Delete Results



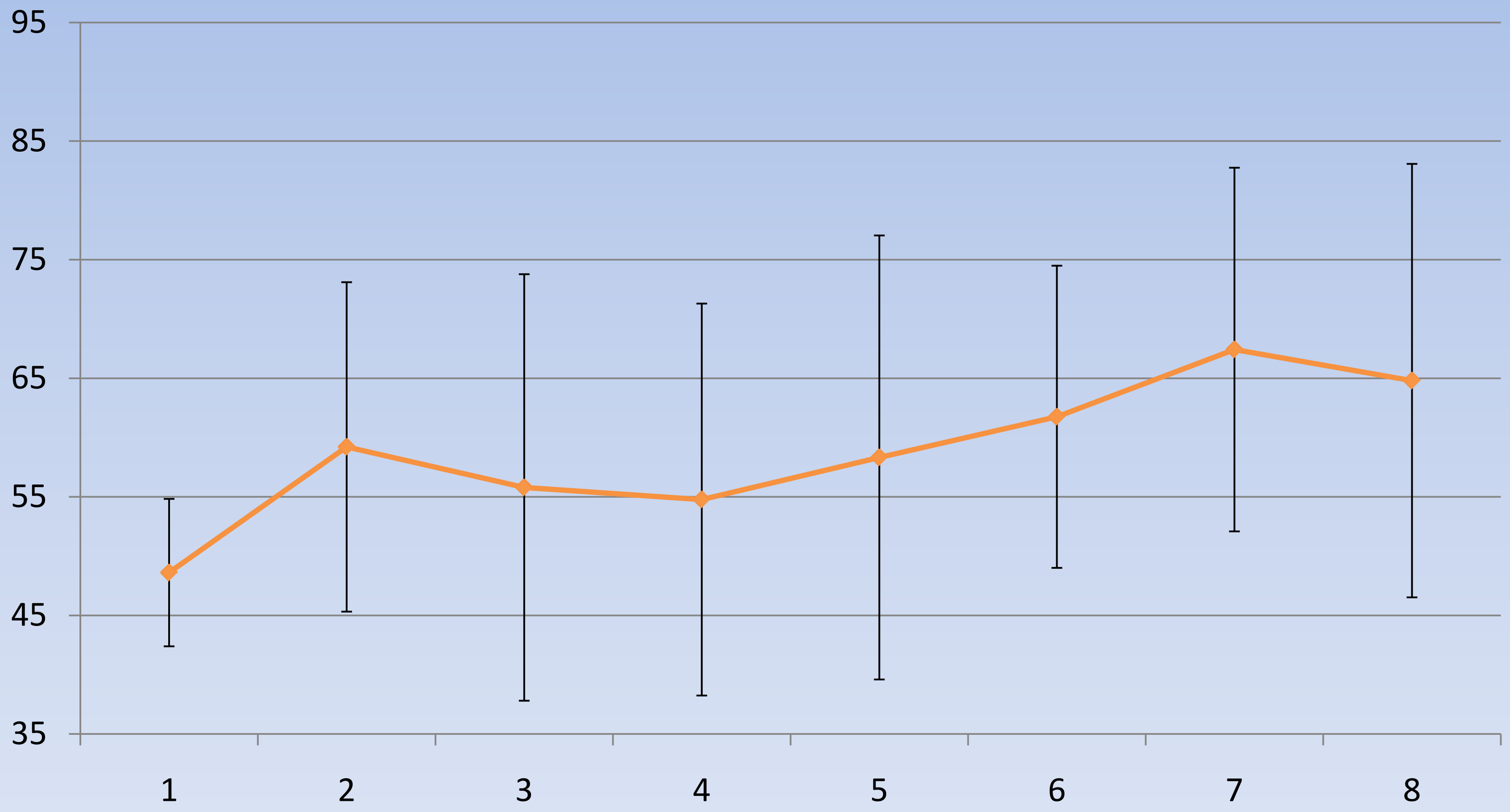
Lock Insert/Delete Results



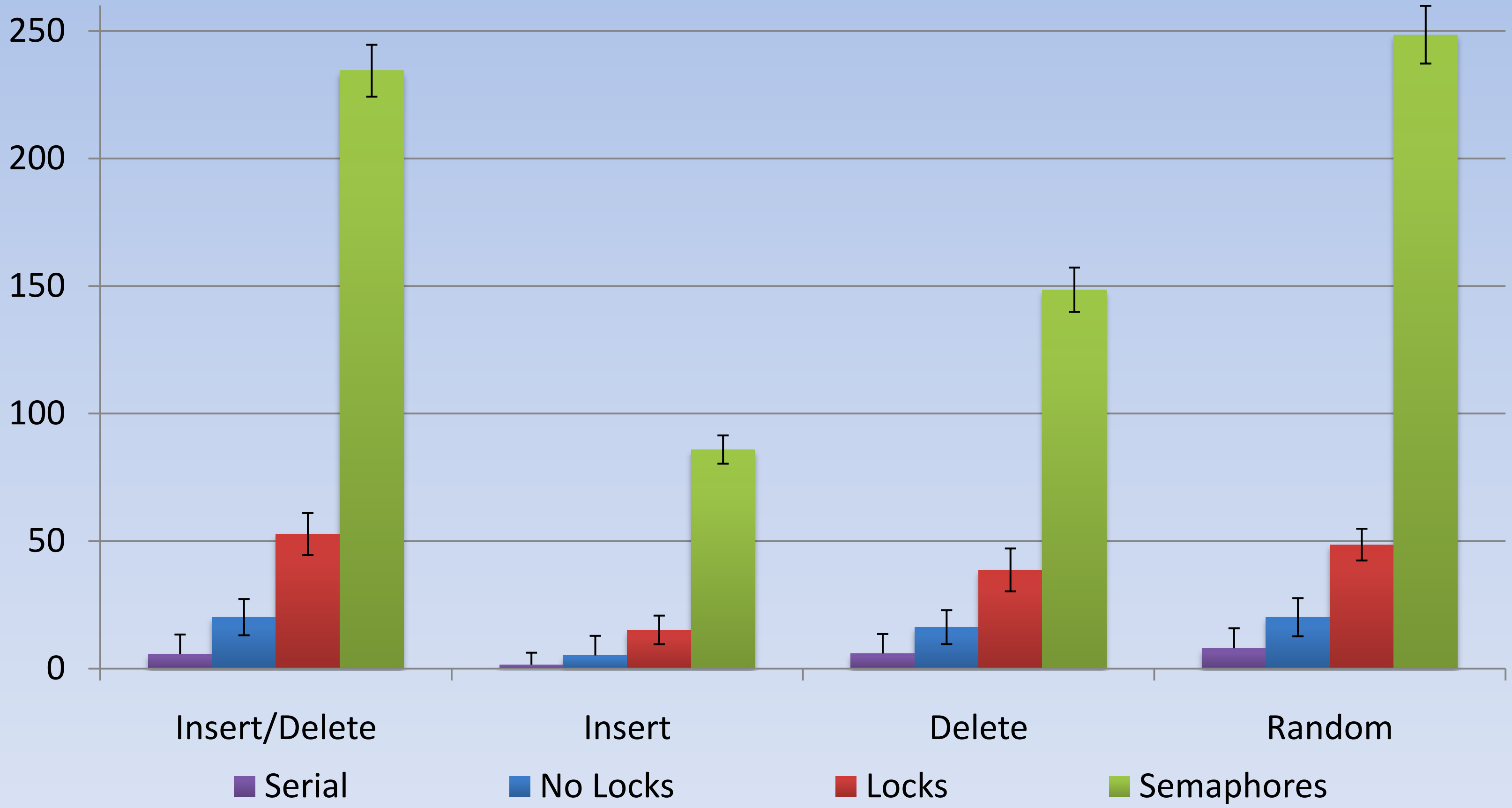
Semaphore Random Results



Lock Random Results



Comparison of Results



Results

- Results did not support the predicated performance by Nageshwara and Kumar.

- Performed only 1000 operations.

- Results did predict a fall off in performance as the number of threads increased.

Java Pathfinder

- Testing was completed to verify:
  - Deadlock freedom
  - Race conditions
  - Removal of locks
  - Correctness of behaviour

- Execution time was much longer than expected.
  - Even for small heaps verification took a very long time.

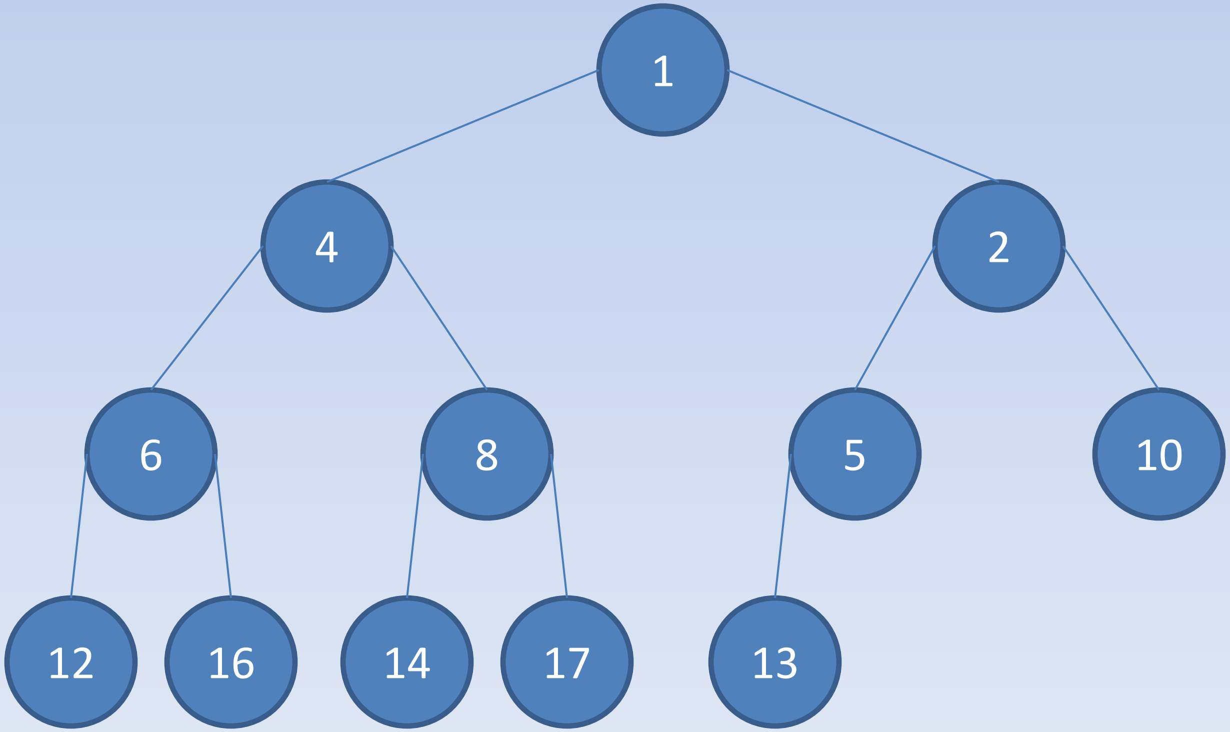
Deadlock Free

- Checks were performed for the occurrence of deadlocks.

- No deadlocks reported!

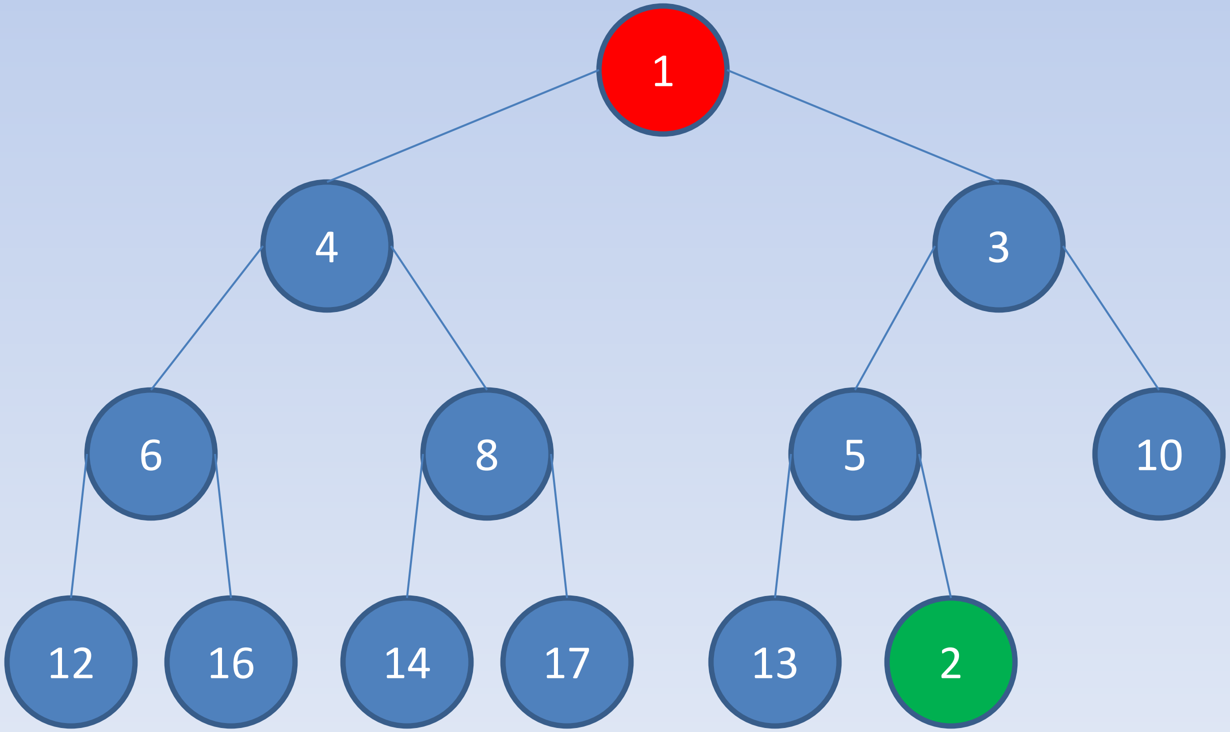
- The risk of deadlock was unlikely as the code implementation prevents this.

Inserting and Deleting



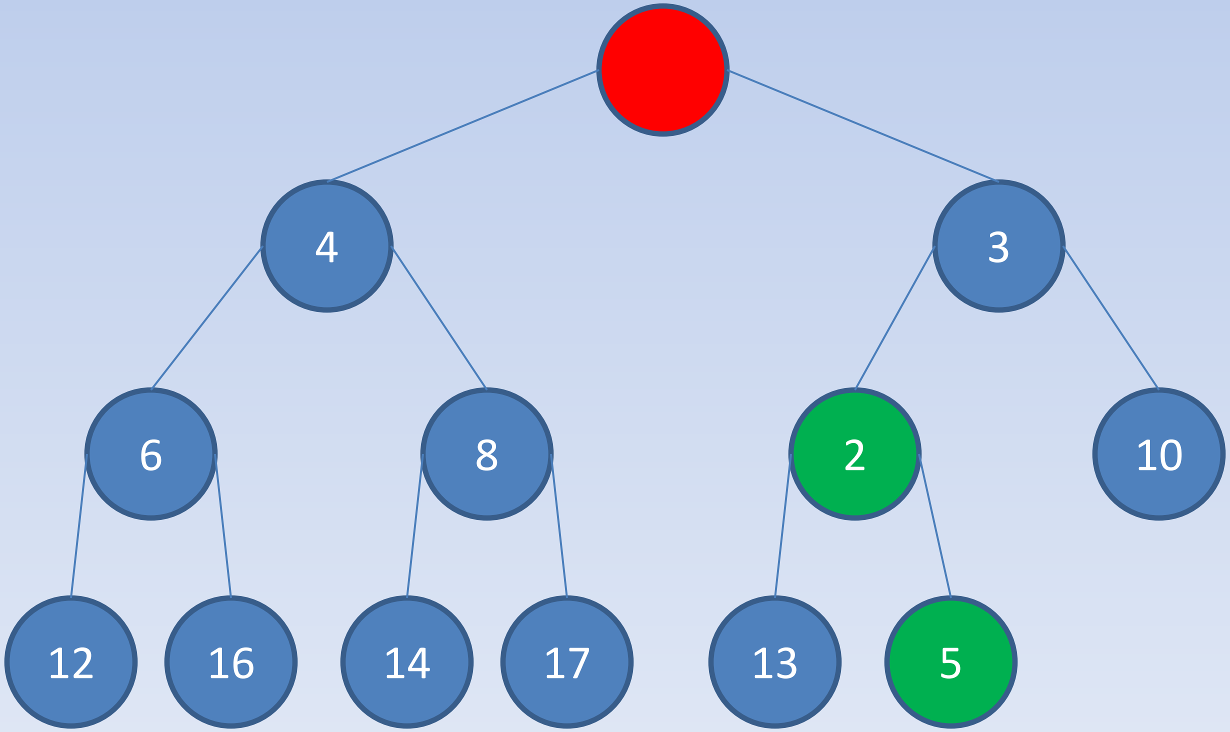
Inserting and Deleting

- The algorithm attempts to perform and insertion and deletion at the same time.



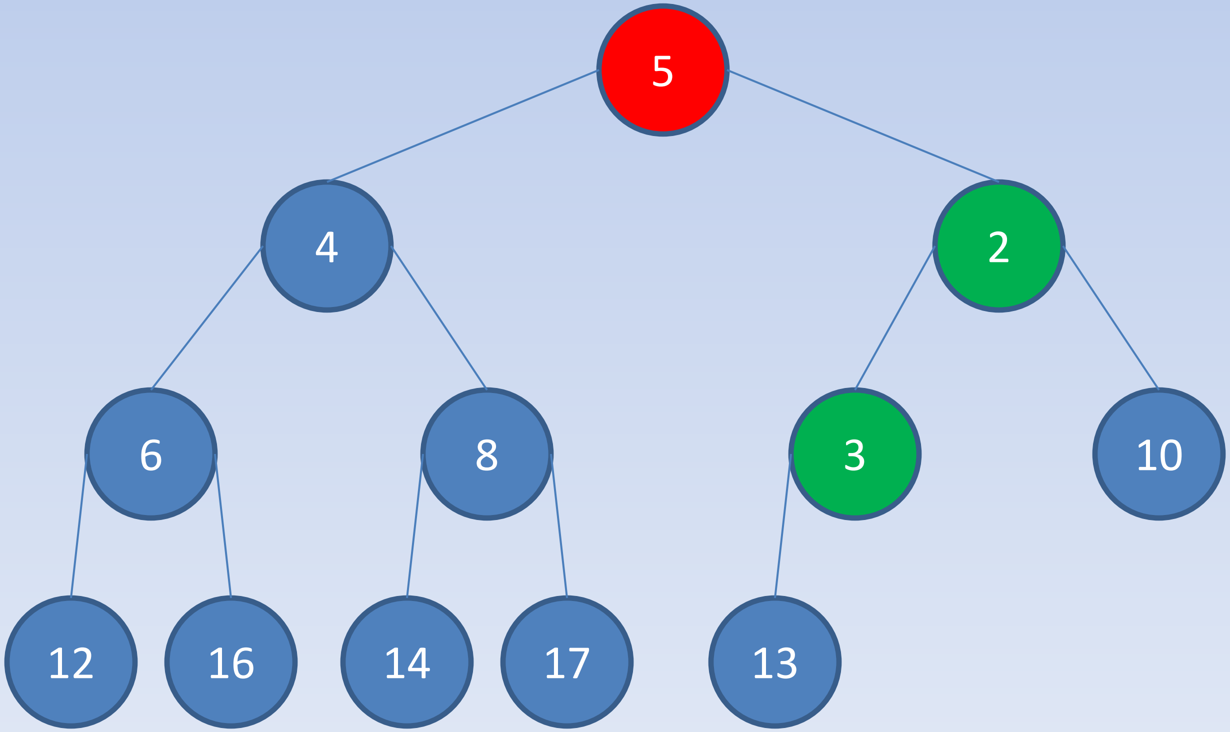
Inserting and Deleting

- The top node is deleted but cannot get the last node until it is unlocked.



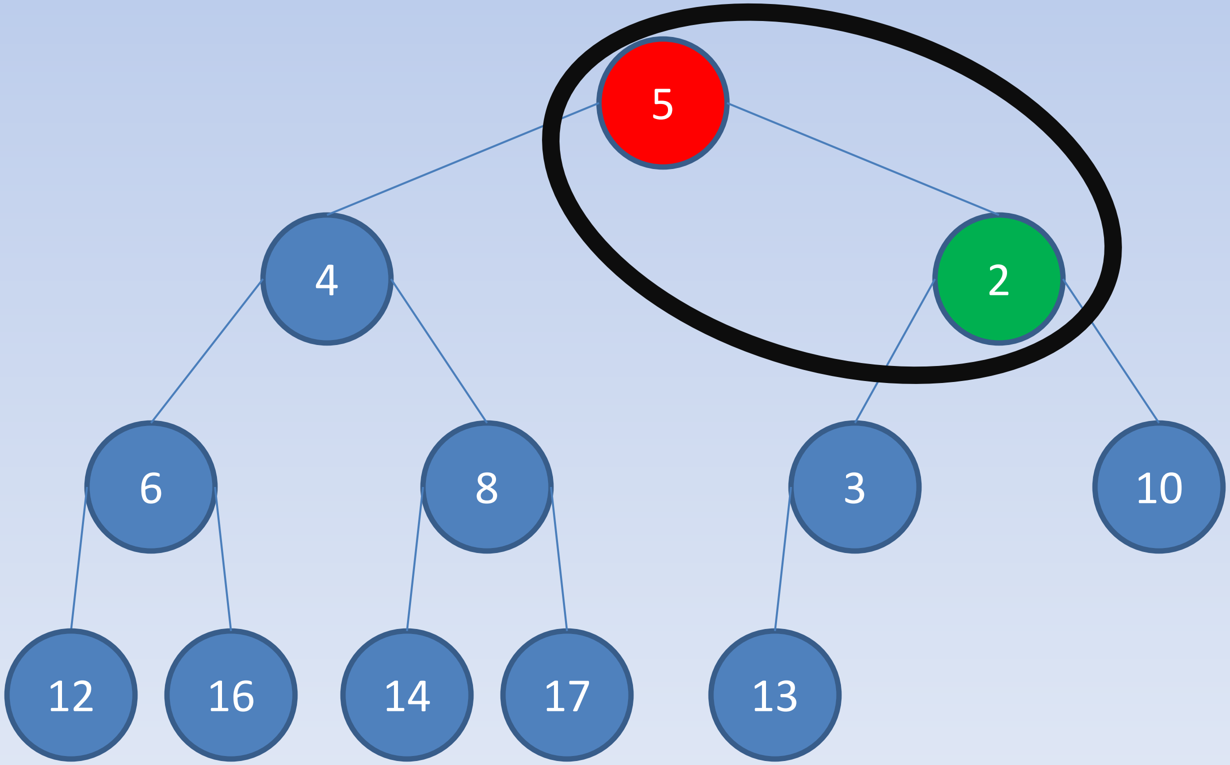
Inserting and Deleting

- The last node is unlocked and moved to the top. The newly inserted node continues to move up through the heap.



Inserting and Deleting

- The two nodes are now deadlocked! Both nodes are waiting for the other to unlock and the algorithm is now stuck.



Race Conditions

- Likely the only problem to exist.
  - Nodes are not protected correctly.
- Node status codes could be cause a problem.
- Both the deletion and insertion operation have access to the status.
  - Status code is updated when a node is wanted.

Race Conditions

- Race conditions probably will not occur.
  - The root and target are locked when a status update occurs.
- No exceptions were raised by the race condition listener.

Removal of Locks

- Does the data structure already utilize the minimum number of locks?

- One lock is associated with each node.
  - Global variables are only accessed when the root is locked.

- Data races were present in the execution.

Removal of Locks

- The test showed that the heap uses the minimum number of locks.

- The heap cannot function properly without one lock per node.

Behaviour Correctness

- Several assertion tests were created to check the data structure.
  - Insertion operation
  - Deletion operation
  - Heap property

Behaviour Correctness

- Insertion tests
  - Heap size increased
  - Node status updates
  - Target location is filled
  - Heap property maintained

- No exceptions were raised during execution.

Behaviour Correctness

- Deletion tests
  - Heap size decreased
  - Root node is removed
  - Node status updates
  - Heap property maintained

- Again no exceptions were raised.

Behaviour Correctness

- Was the heap property maintained?

- A heap property test was run during the insertion and deletion loops.
  - Also run after the operation was completed.

- No exceptions were raised.

Conclusions

- Execution time was very very very long.

- The data structure functioned as expected.
  - Still not as effective as a serial implementation.

Sources

R.V. Nageshwara, V. Kumar. *Concurrent Access of Priority Queues. IEEE Transactions on Computers,* 37(12): 1657-1665, December 1988.

Questions?