Concurrent Red-Black Trees

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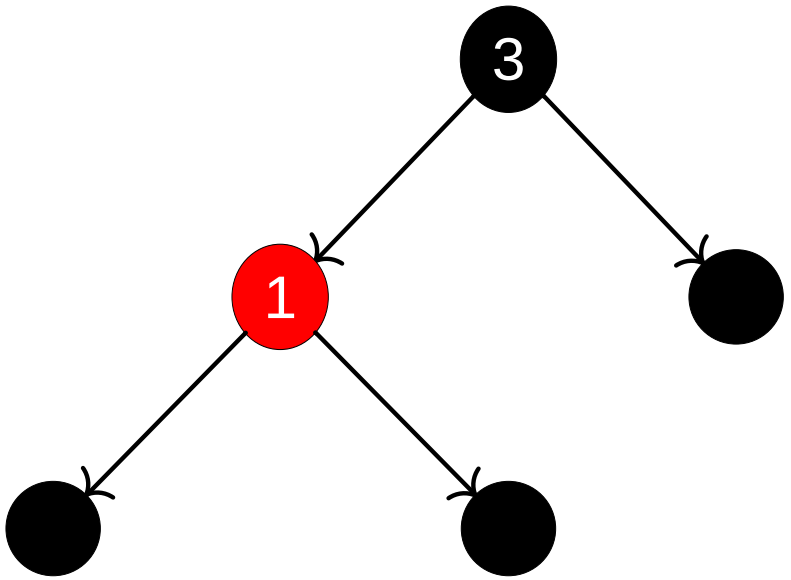
Red-Black Tree

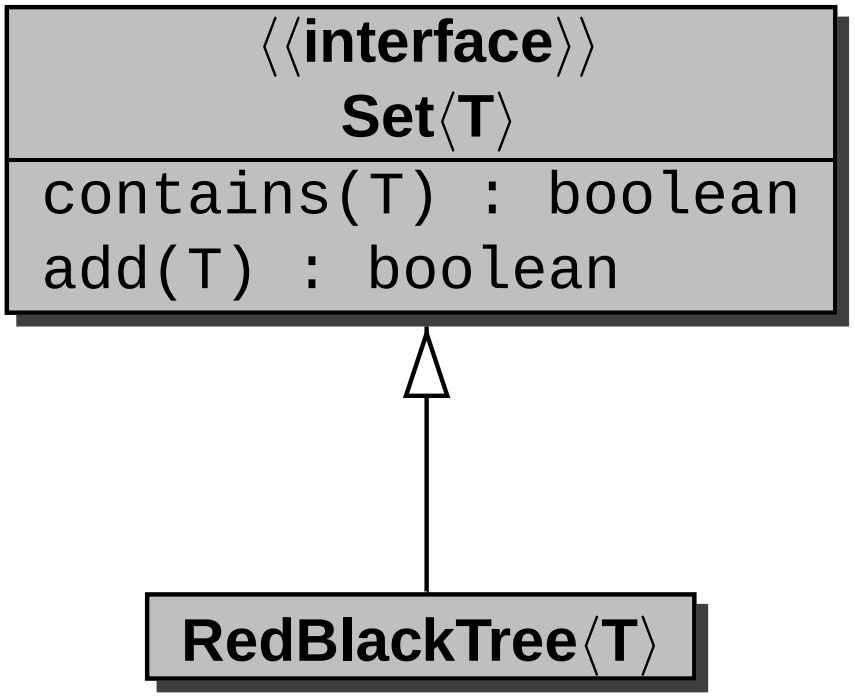
A red-black tree is a binary search tree the nodes of which are coloured either red or black and

- the root is black,
- every leaf is black,
- if a node is red, then both its children are black,
- for every node, every path from that node to a leaf contains the same number of black nodes.

[Bayer, 1972] and [Guibas and Sedgewick, 1978]



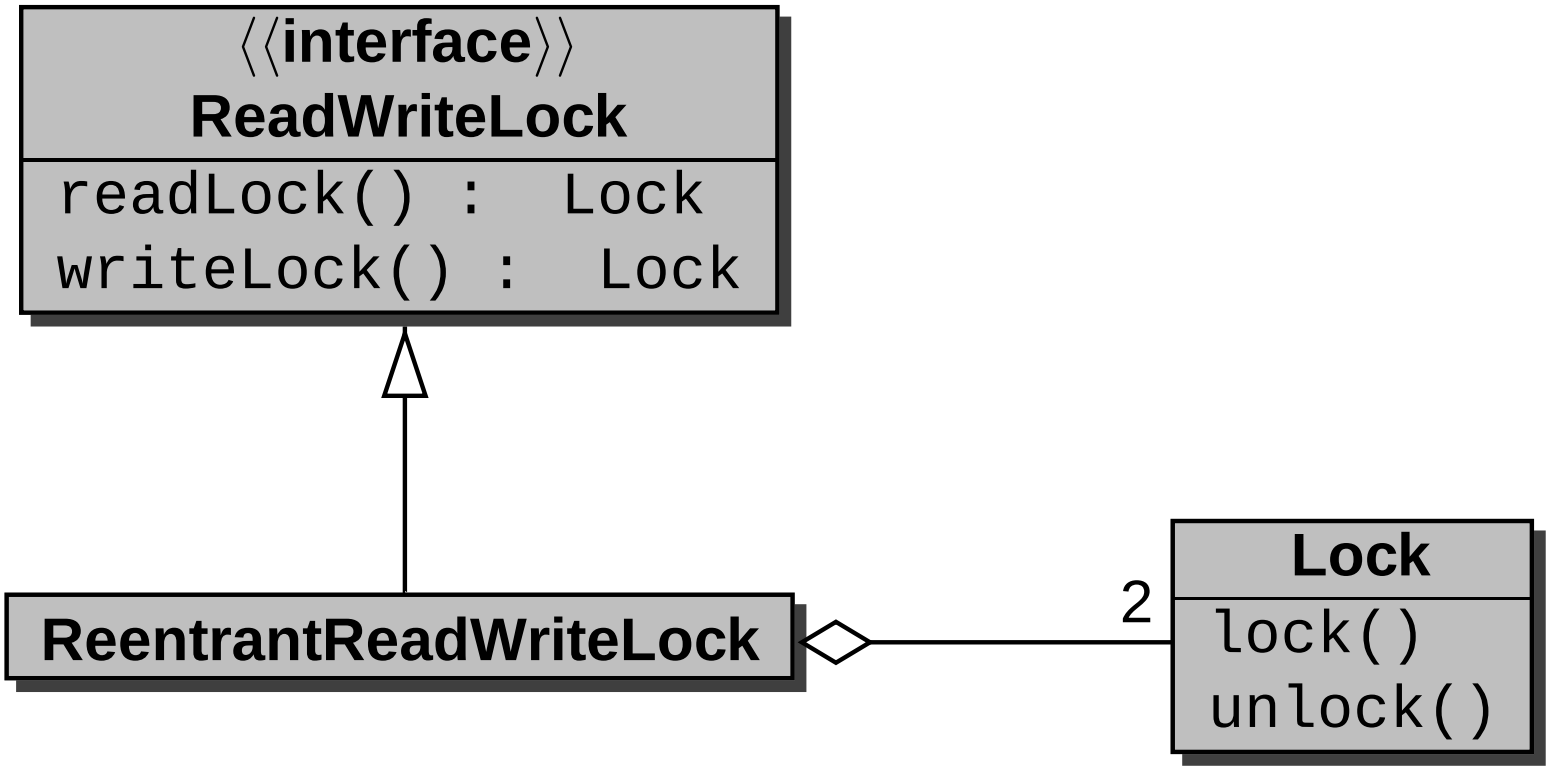
Three Implementations



The Monitor Solution

```
1  package monitor;
2
3  public class RedBlackTree<T extends Comparable<T>>
4    implements Set<T>
5  {
6    public synchronized boolean contains(T element)
7    {
8      ...
9    }
10
11   public synchronized boolean add(T element)
12   {
13     ...
14   }
15 }
```

The Readers-Writers Solution



The Readers-Writers Solution

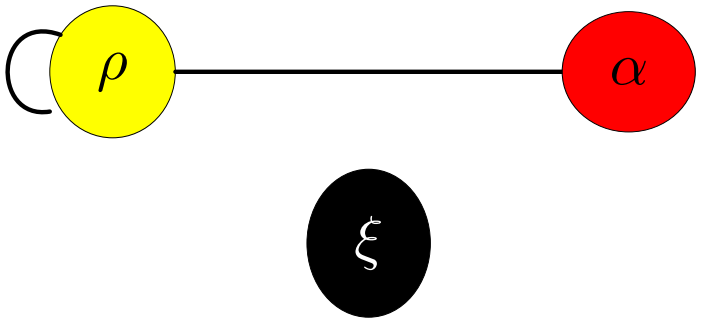
```
1  private ReadWriteLock lock;
2
3  public RedBlackTree()
4  {
5     this.lock = new ReentrantReadWriteLock();
6     ...
7  }
8
9  public boolean contains(T element)
10 {
11    this.lock.getReadLock().lock();
12    ...
13    this.lock.getReadLock().unlock();
14 }
15 ...
```

Locking Nodes

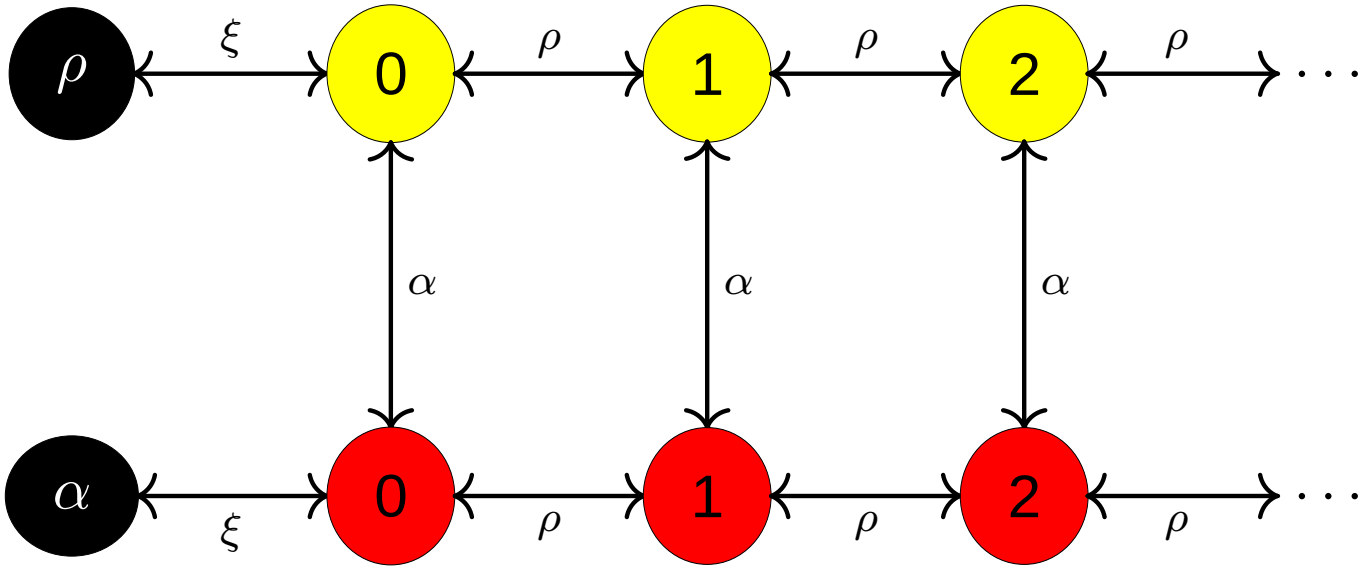
Processes lock the nodes of the red-black tree in three different ways:

- ρ-lock: lock to read
- α-lock: lock to exclude writers
- ξ-lock: exclusive lock

Although a node can be locked by multiple processes, there are some restrictions.



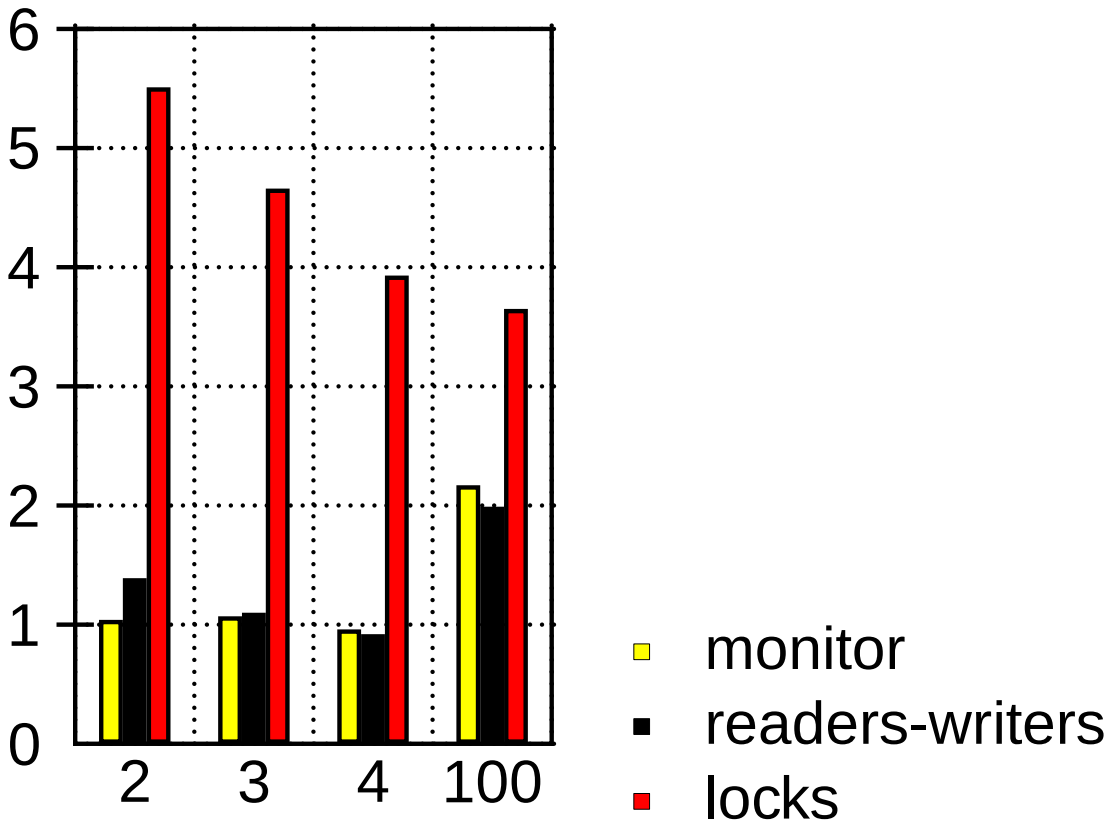
Locking Nodes



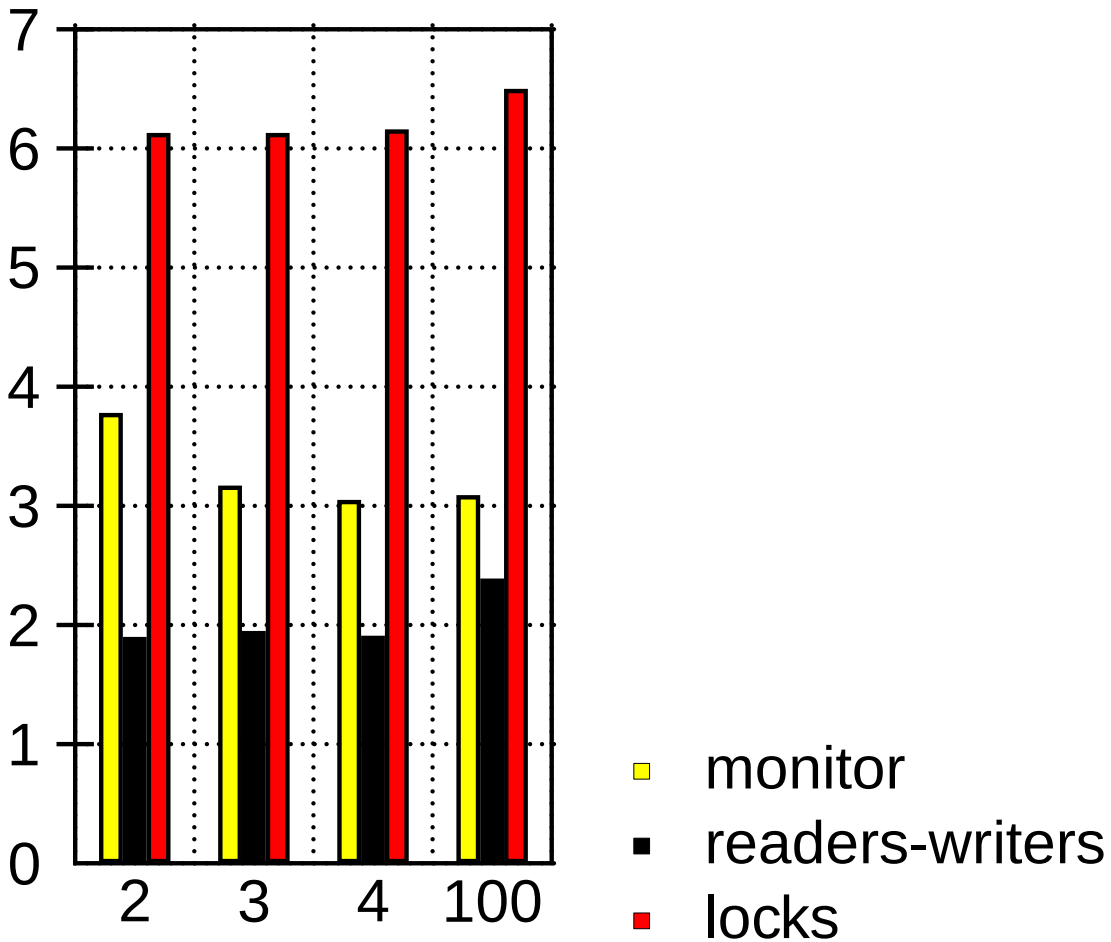
Locking Nodes

```
1  public class Node<T>
2  {
3     private int containers;
4     private int state;
5     private boolean writing;
6
7     public void readLock() { ... }
8     public void readUnlock() { ... }
9     public void writeLock() { ... }
10    public void writeUnock() { ... }
11    public void exclusiveLock() { ... }
12    public void exclusiveUnlock() { ... }
13 }
```

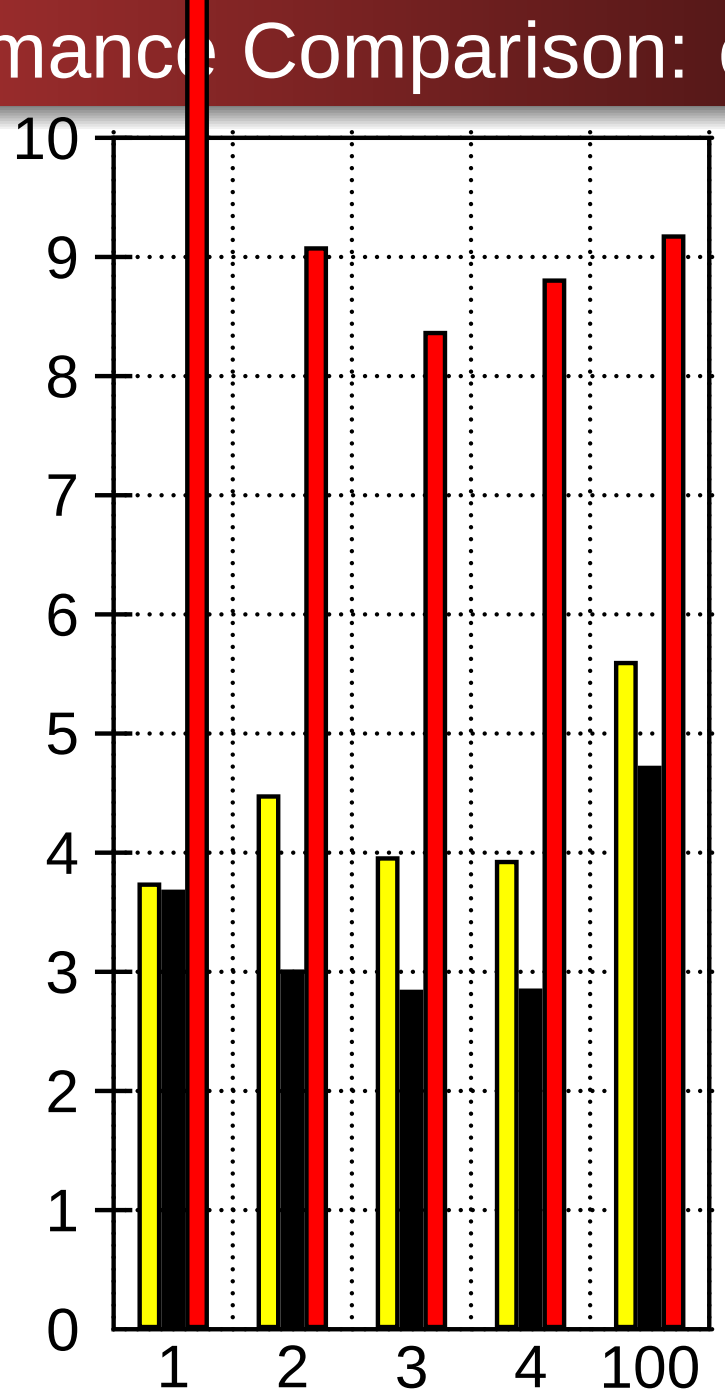
Performance Comparison: add only



Performance Comparison: contains only



Performance Comparison: contains and add



- monitor
- readers-writers
- locks

Room for Improvement

- lock only “half a node”
- lock granularity

Looking Ahead

Plan

- verify some properties, such as deadlock freedom, of all three concurrent implementations by means of Java PathFinder
- show undesirable behaviour of

```
1 add(3);
2 add(1);
3 (add(2) || print(contains(1)))
```

in case no synchronization is used

Challenges

- state space explosion
- native code