



departamento de informática
FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

Alternative Synchronization Strategies — Lock-Free Algorithms (2) —

lecture 20 (2020-05-12)

Master in Computer Science and Engineering

— Concurrency and Parallelism / 2019-20 —

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Alternative Synchronization Strategies

- Contents:

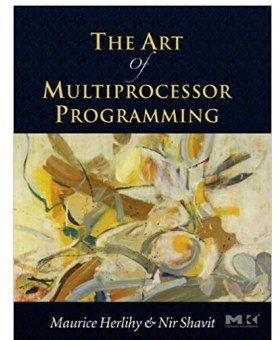
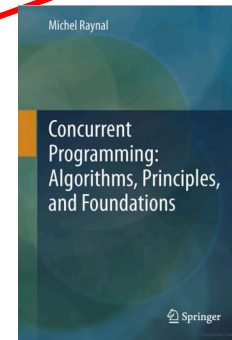
- Liveness: Types of Progress
- Coarse-Grained Synchronization
- Fine-Grained Synchronization
- Optimistic Synchronization
- Lazy Synchronization
- Lock-Free Synchronization

Past lectures

Today

- Reading list:

- chapter 5 of the Textbook
- Chapter 9 of “The Art of Multiprocessor Programming” by Maurice Herlihy & Nir Shavit *(available at clip)*

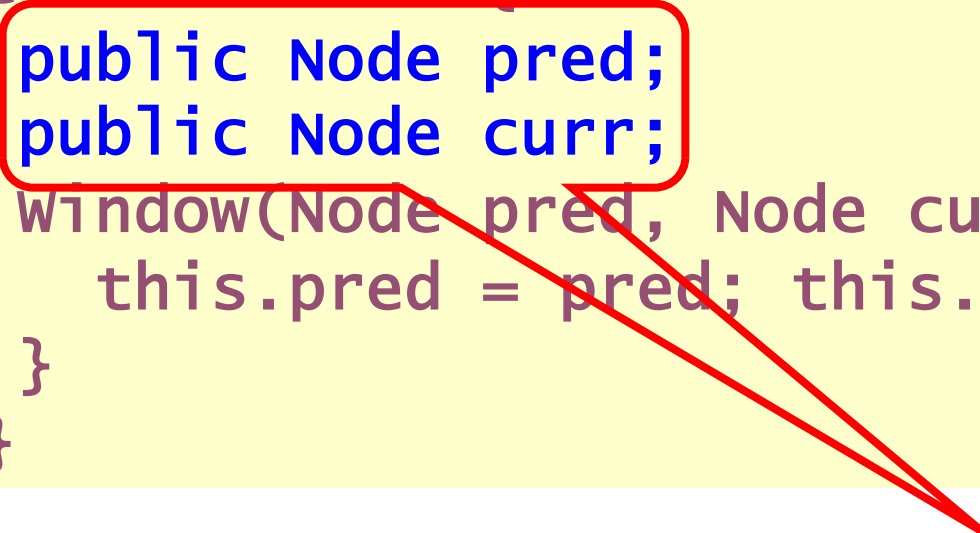


The Window Class

```
class window {  
    public Node pred;  
    public Node curr;  
    window(Node pred, Node curr) {  
        this.pred = pred; this.curr = curr;  
    }  
}
```

The Window Class

```
class Window {  
    public Node pred;  
    public Node curr;  
    Window(Node pred, Node curr) {  
        this.pred = pred; this.curr = curr;  
    }  
}
```



**A container for pred
and current values**

Using the Find Method

```
window window = find(head, key);  
Node pred = window.pred;  
Node curr = window.curr;
```

Using the Find Method

```
Window window = find(head, key);
```

```
Node pred = window.pred;
```

```
Node curr = window.curr;
```

Find returns window

Using the Find Method

```
window window = find(head, key);
```

```
Node pred = window.pred;
```

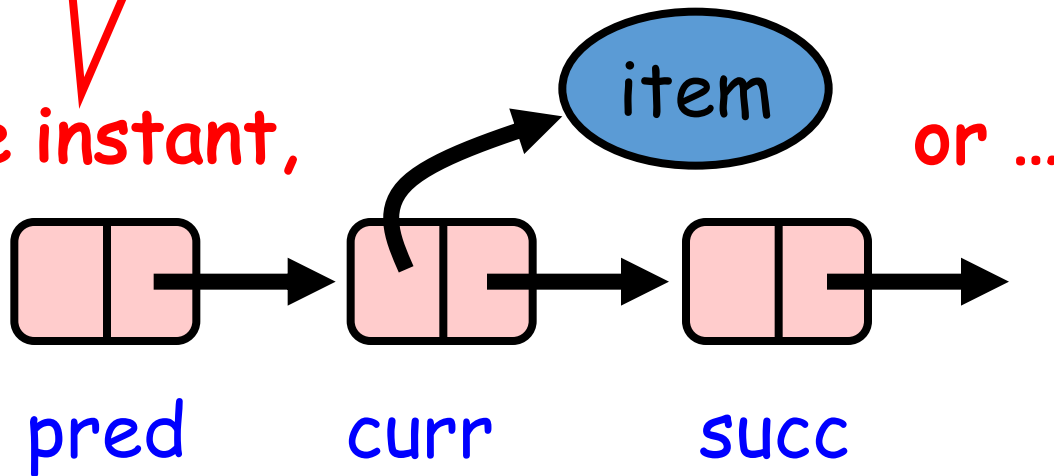
```
Node curr = window.curr;
```

Extract pred and curr

The Find Method

```
window window = find(head, key);
```

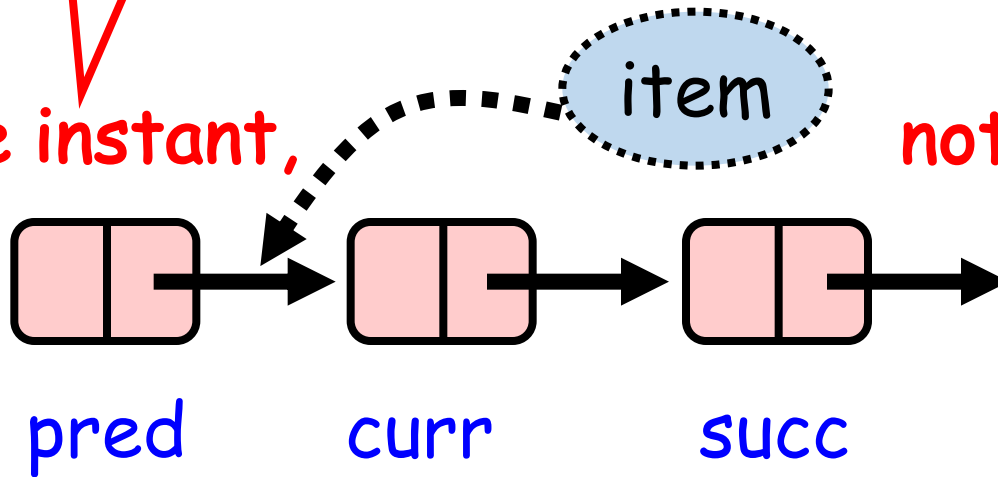
At some instant,



The Find Method

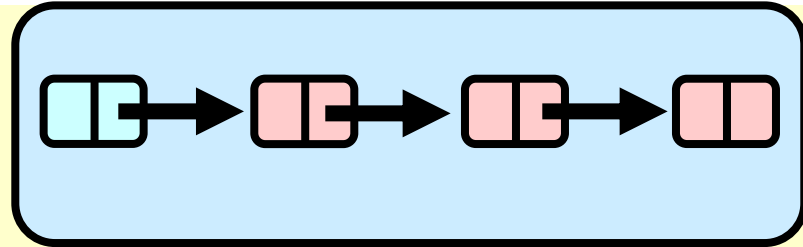
```
window window = find(head, key);
```

At some instant,



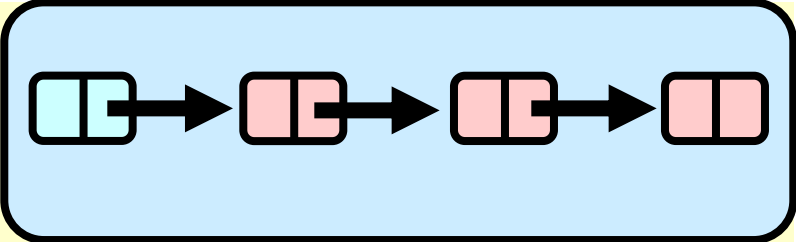
Remove (lock-free)

```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {  
            return false;  
        } else {  
            Node succ = curr.next.getReference();  
            snip = curr.next.attemptMark(succ, true);  
            if (!snip) continue;  
            pred.next.compareAndSet(curr, succ, false, false);  
            return true;  
        }  
    }  
}
```



Remove (lock-free)

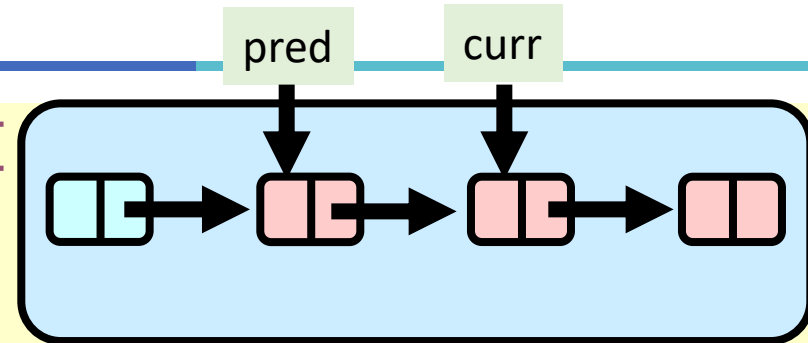
```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {  
            return false;  
        } else {  
            Node succ = curr.next.getReference();  
            snip = curr.next.attemptMark(succ, true);  
            if (!snip) continue;  
            pred.next.compareAndSet(curr, succ, false, false);  
            return true;  
        }  
    }  
}
```



Keep trying

Remove (lock-free)

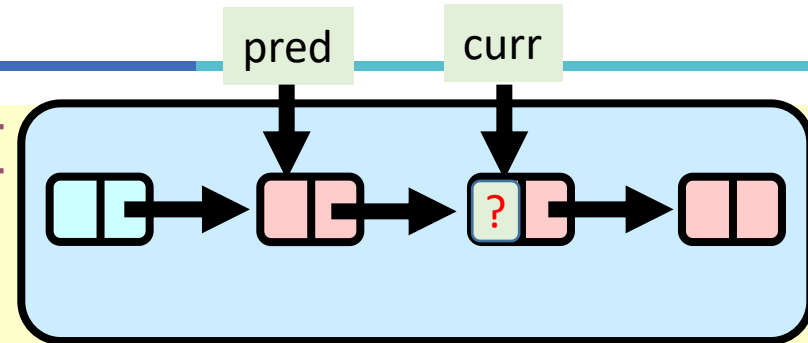
```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {  
            return false;  
        } else {  
            Node succ = curr.next.getReference();  
            snip = curr.next.attemptMark(succ, true);  
            if (!snip) continue;  
            pred.next.compareAndSet(curr, succ, false, false);  
            return true;  
        }  
    }  
}
```



Find neighbors

Remove (lock-free)

```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {  
            return false;  
        } else {  
            Node succ = curr.next.getReference();  
            snip = curr.next.attemptMark(succ, true);  
            if (!snip) continue;  
            pred.next.compareAndSet(curr, succ, false, false);  
            return true;  
        }  
    }  
}
```



It is not there ...

Remove (lock-free)

```
public boolean remove(T item) {  
    Boolean snip;
```

```
    int key = item.hashCode();
```

```
    while (true) {
```

```
        window = window.find(head, key);
```

```
        Node pred = window.pred, curr = window.curr;
```

```
        if (curr.key != key) {
```

```
            return false;
```

```
        } else {
```

```
            Node succ = curr.next.getReference();
```

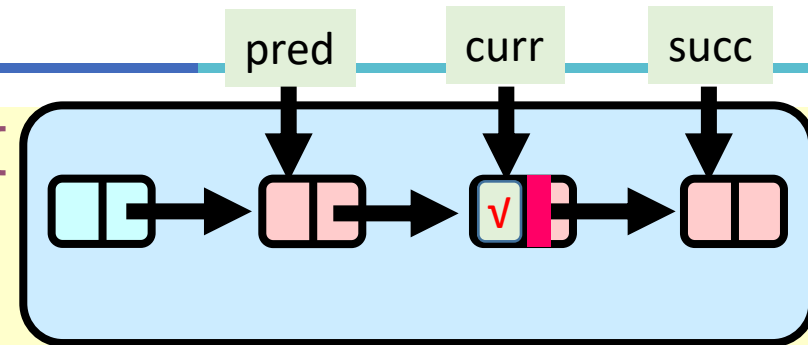
```
            snip = curr.next.attemptMark(succ, true);
```

```
            if (!snip) continue;
```

```
            pred.next.compareAndSet(curr, succ, false, false);
```

```
            return true;
```

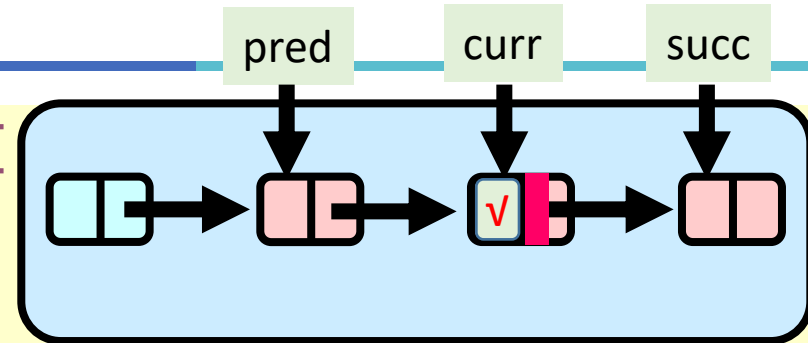
```
    }  
}
```



Try to mark node
as deleted

Remove (lock-free)

```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();
```



If it doesn't work, just
retry, if it does, job
essentially done

```
    while (true) {  
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {  
            return false;  
        } else {  
            Node succ = curr.next.getReference();  
            snip = curr.next.attemptMark(succ, true);  
            if (!snip) continue;  
            pred.next.compareAndSet(curr, succ, false, false);  
            return true;  
        }  
    }  
}
```

Remove (lock-free)

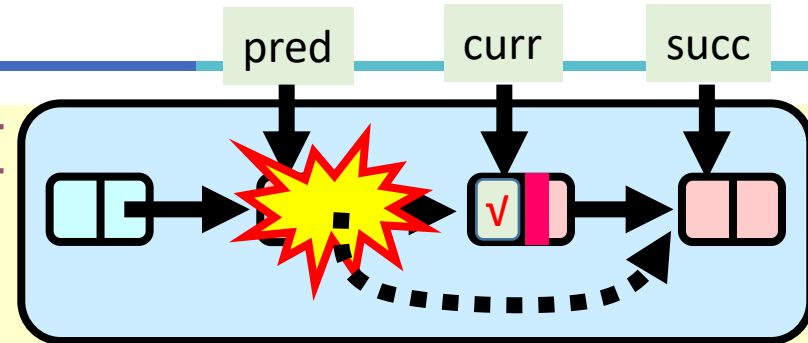
```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {
```

Try to advance reference

(if we don't succeed, someone else did or will do).

```
        snip = curr.next.attemptMark(succ, true);  
        if (!snip) continue;
```

```
        pred.next.compareAndSet(curr, succ, false, false);  
        return true;
```



Remove (lock-free)

```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {
```

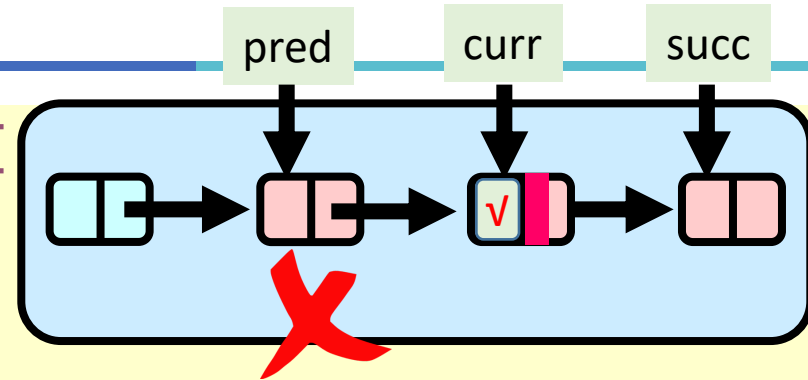
```
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {
```

Try to advance reference

(if we don't succeed, someone else did or will do).

```
            snip = curr.next.attemptMark(succ, true);  
            if (!snip) continue;
```

```
            pred.next.compareAndSet(curr, succ, false, false);  
            return true;
```



Remove (lock-free)

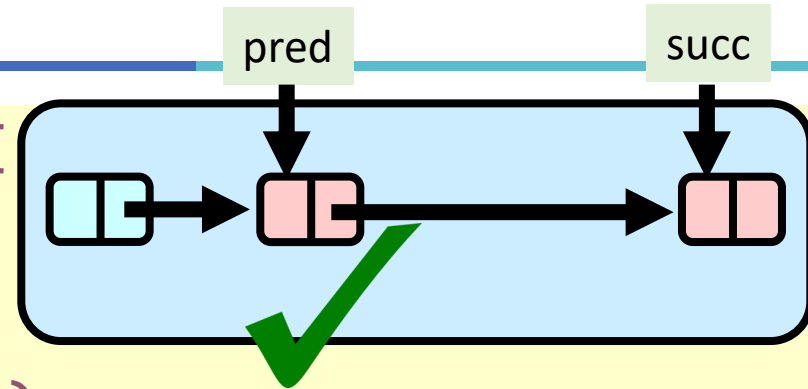
```
public boolean remove(T item) {  
    Boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key != key) {
```

Try to advance reference

(if we don't succeed, someone else did or will do).

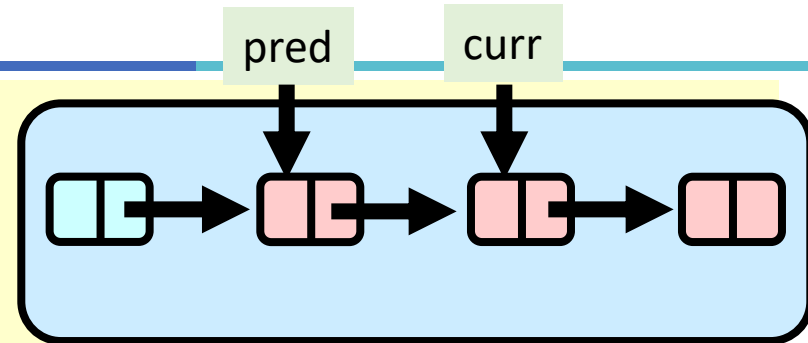
```
        snip = curr.next.attemptMark(succ, true);  
        if (!snip) continue;
```

```
        pred.next.compareAndSet(curr, succ, false, false);  
        return true;
```



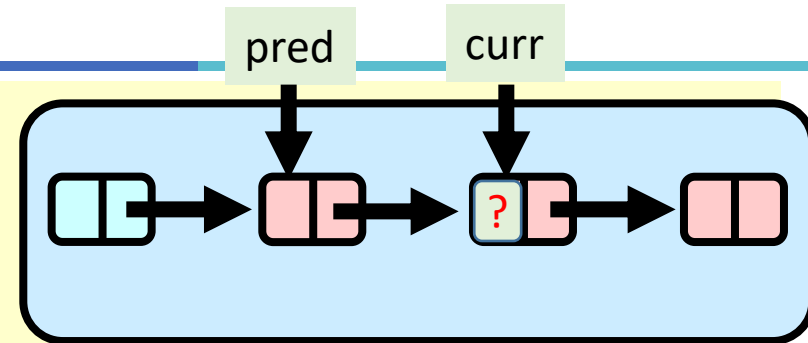
Add (lock-free)

```
public boolean add(T item) {  
    boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        Window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key == key) {  
            return false;  
        } else {  
            Node node = new Node(item);  
            node.next = new AtomicMarkableRef(curr, false);  
            if (pred.next.compareAndSet(curr, node,  
                                        false, false)) {return true;}  
        }  
    }  
}
```



Add (lock-free)

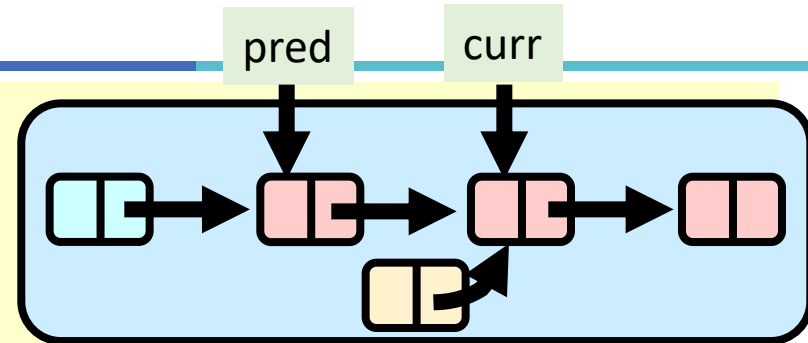
```
public boolean add(T item) {  
    boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key == key) {  
            return false;  
        } else {  
            Node node = new Node(item);  
            node.next = new AtomicMarkableRef(curr, false);  
            if (pred.next.compareAndSet(curr, node,  
                false, false)) {return true;}  
        }  
    }  
}
```



Item already there.

Add (lock-free)

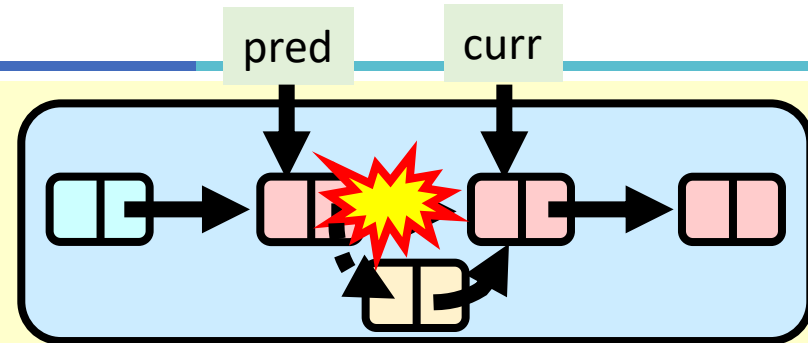
```
public boolean add(T item) {  
    boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key == key) {  
            return false;  
        } else {  
            Node node = new Node(item);  
            node.next = new AtomicMarkableRef(curr, false);  
            if (pred.next.compareAndSet(curr, node,  
                false, false)) {return true;}  
        }  
    }  
}
```



create new node

Add (lock-free)

```
public boolean add(T item) {  
    boolean snip;  
    int key = item.hashCode();  
    while (true) {  
        window window = find(head, key);  
        Node pred = window.pred, curr = window.curr;  
        if (curr.key == key) {  
            // Install new node,  
            // else retry loop  
            Node node = new Node(item);  
            node.next = new AtomicMarkableRef(curr, false);  
            if (pred.next.compareAndSet(curr, node,  
                                         false, false)) {return true;}  
        }  
    }  
}
```



Contains (wait-free)

```
public boolean contains(T item) {  
    boolean[] marked;  
    int key = item.hashCode();  
    Node curr = this.head;  
    while (curr.key < key)  
        curr = curr.next;  
    Node succ = curr.next.get(marked);  
    return (curr.key == key && !marked[0])  
}
```

Contains (wait-free)

```
public boolean contains(T item) {  
    boolean[] marked;  
    int key = item.hashCode();  
    Node curr = this.head;  
    while (curr.key < key)  
        curr = curr.next;  
    Node succ = curr.next.get(marked);  
    return (curr.key == key && !marked[0])  
}
```

Only diff is that we
get and check
marked

Find (lock-free)

```
public Window find(Node head, int key) {  
    Node pred = null, curr = null, succ = null;  
    boolean[] marked = {false}; boolean snip;  
    retry: while (true) {  
        pred = head;  
        curr = pred.next.getReference();  
        while (true) {  
            succ = curr.next.get(marked);  
            while (marked[0]) {  
                ...  
            }  
            if (curr.key >= key)  
                return new Window(pred, curr);  
            pred = curr;  
            curr = succ;  
        }  
    }  
}
```

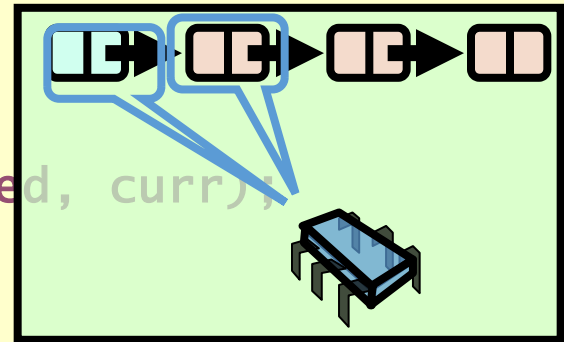
Find (lock-free)

```
public window find(Node head, int key) {  
    Node pred = null, curr = null, succ = null;  
    boolean[] marked = {false}; boolean snip;  
    retry: while (true) {  
        pred = head;  
        curr = pred.next.getReference();  
        while (true) {  
            succ = curr.next.get(marked);  
            while (marked[0]) {  
                ...  
            }  
            if (curr.key >= key)  
                return new window(pred, curr);  
            pred = curr;  
            curr = succ;  
        }  
    }  
}
```

**If list changes while
traversed, start over
Lock-Free because we
start over only if
someone else makes
progress**

Find (lock-free)

```
public Window find(Node head, int key) {  
    Node pred = null; Start looking from head  
    boolean[] marked = {false}; boolean snip;  
    retry: while (true) {  
        pred = head;  
        curr = pred.next.getReference();  
        while (true) {  
            succ = curr.next.get(marked);  
            while (marked[0]) {  
                ...  
            }  
            if (curr.key >= key)  
                return new Window(pred, curr);  
            pred = curr;  
            curr = succ;  
        }  
    }  
}
```



Find (lock-free)

```
public Window find(Node head, int key) {  
    Node pred = null, curr = null, succ = null;  
    boolean[] marked = {false}; boolean snip;  
    retry: while (true) { Move down the list  
        pred = head;  
        curr = pred.next.getReference();  
        while (true) {  
            succ = curr.next.get(marked);  
            while (marked[0]) {  
                ...  
            }  
            if (curr.key >= key)  
                return new Window(pred, curr);  
            pred = curr;  
            curr = succ;  
        }  
    }  
}
```

Find (lock-free)

```
public Window find(Node head, int key) {
    Node pred = null, curr = null, succ = null;
    boolean[] marked = {false};
    boolean snip;
    retry: while (true) {
        pred = head;
        curr = pred.next.getReference();
        while (true) {
            succ = curr.next.get(marked);
            while (marked[0]) {
                ...
            }
            if (curr.key >= key)
                return new Window(pred, curr);
            pred = curr;
            curr = curr.next.getReference();
        }
    }
}
```

Get ref to successor and current deleted bit

Find (lock-free)

```
public Window find(Node head, int key) {
    Node pred = null, curr = null, succ = null;
    boolean[] marked = {false}; boolean snip;
    retry: while (true) {
        pred = head;
        curr = pred.next.getReference();
        while (true) {
            succ = curr.next.get(marked);
            while (marked[0]) {
                ...
            }
            if (curr.key >= key)
                return new Window(pred, curr);
            pred = curr;
        }
    }
}
```

Try to remove deleted nodes in path... code details soon

Find (lock-free)

```
public Window find(Node head, int key) {
    Node pred = null, curr = null, succ = null;
    boolean[] marked = {false};
    boolean snip;
    retry: while (true) {
        pred = head;
        curr = pred.next.getReference();
        succ = curr.next.get(marked);
        while (marked[0]) {
            ...
        }
        if (curr.key >= key)
            return new Window(pred, curr);
        pred = curr;
        curr = succ;
    }
}
```

If curr key is greater or equal,
return pred and curr

Find (lock-free)

```
public Window find(Node head, int key) {  
    Node pred = null, curr = null, succ = null;  
    boolean[] marked = {false};  
    boolean snip;  
    retry: while (true) {  
        pred = head;  
        curr = pred.next.getReference();  
        while (true) {
```

Otherwise advance window and
loop again

```
            succ = curr.next.get(marked);  
            while (marked[0]) {  
                ...  
            }  
            if (curr.key >= key)  
                return new Window(pred, curr);  
            pred = curr;  
            curr = succ;  
        }  
    }  
}
```


Find (lock-free)

```
public Window find(Node head, int key) {
    Node pred = null, curr = null, succ = null;
    boolean[] marked = {false}; boolean snip;
    retry: while (true) {
        pred = head;
        curr = pred.next.getReference();
        while (true) {
            succ = curr.next.get(marked);
            while (marked[0]) {
                ...
            }
            if (curr.key >= key)
                return new Window(pred, curr);
            pred = curr;
        }
    }
}
```

Try to remove deleted nodes in path... Let's see how it works!

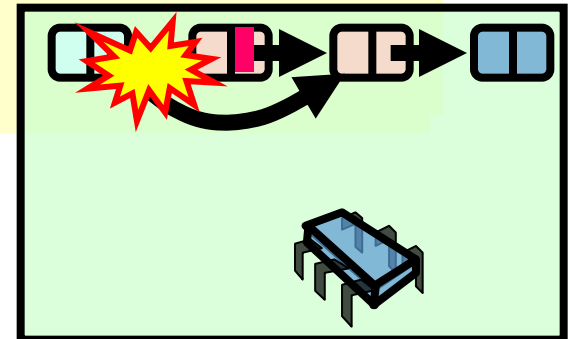
Find (lock-free)

```
retry: while (true) {  
    ...  
    while (marked[0]) {  
        snip = pred.next.compareAndSet(curr,  
                                         succ, false, false);  
        if (!snip) continue retry;  
        curr = succ;  
        succ = curr.next.get(marked);  
    }  
    ...  
}
```

Find (lock-free)

Try to snip out node

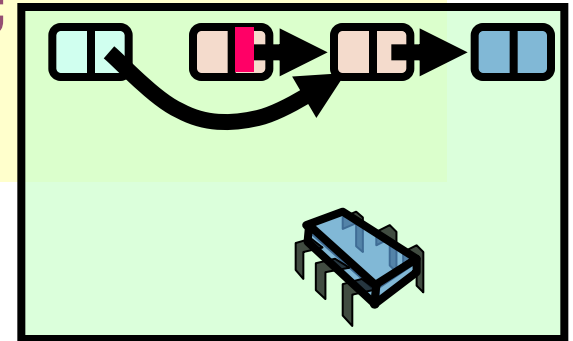
```
retry: while (true) {  
    ...  
    while (marked[0]) {  
        snip = pred.next.compareAndSet(curr,  
                                         succ, false, false);  
        if (!snip) continue retry;  
        curr = succ;  
        succ = curr.next.get(marked);  
    }  
    ...  
}
```



Find (lock-free)

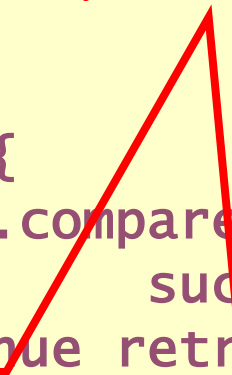
if predecessor's next field changed must retry whole

```
retry: while (true) {  
    ...  
    while (marked[0]) {  
        snip = pred.next.compareAndSet(curr,  
                                         succ, false, false);  
        if (!snip) continue retry;  
        curr = succ;  
        succ = curr.next.get(marked);  
    }  
    ...  
}
```



Find (lock-free)

Otherwise move on to check
if next node deleted

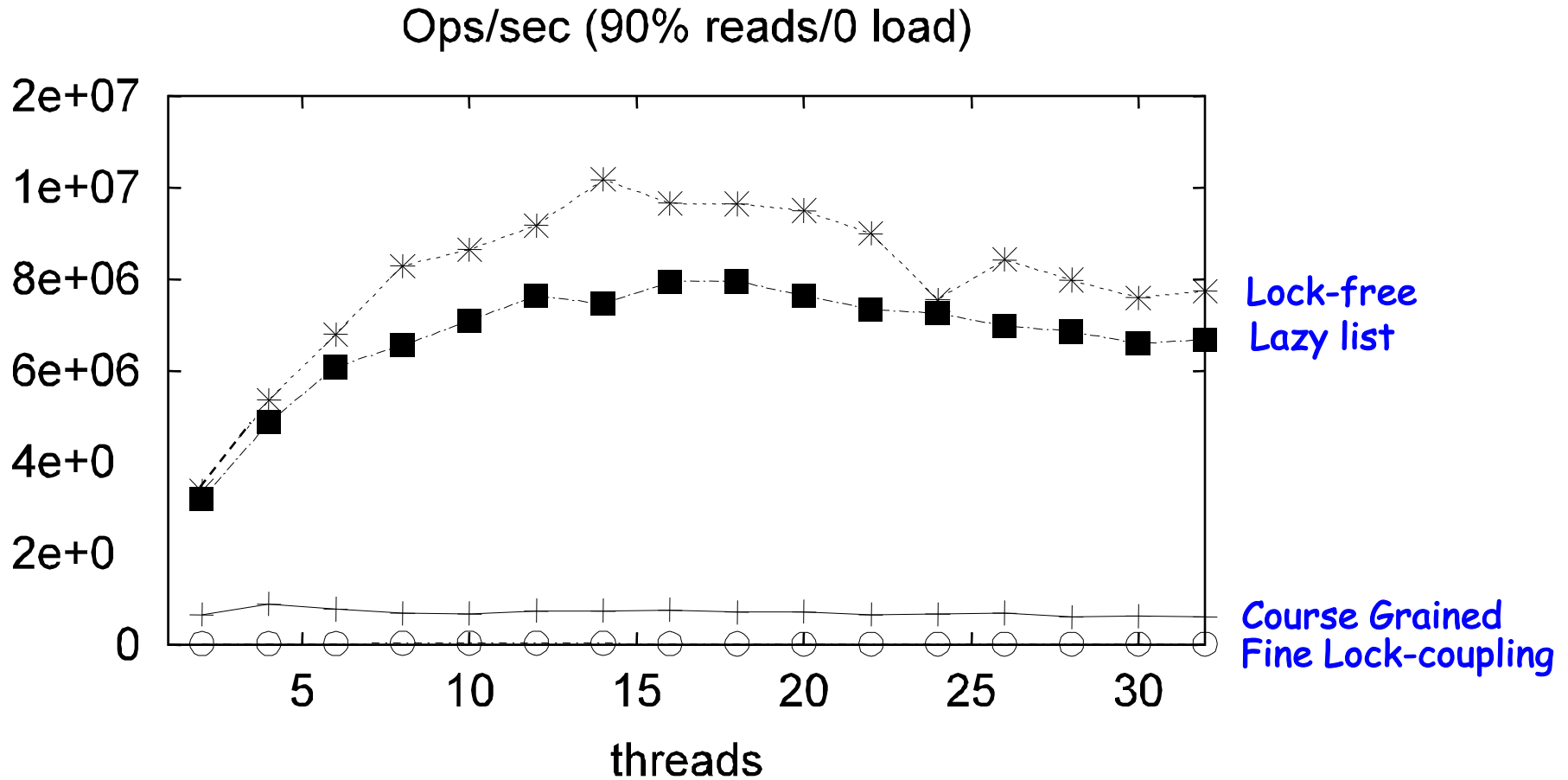


```
retry: while (true) {  
    ...  
    while (marked[0]) {  
        snip = pred.next.compareAndSet(curr,  
                                         succ, false, false);  
        if (!snip) continue retry;  
        curr = succ;  
        succ = curr.next.get(marked);  
    }  
    ...  
}
```

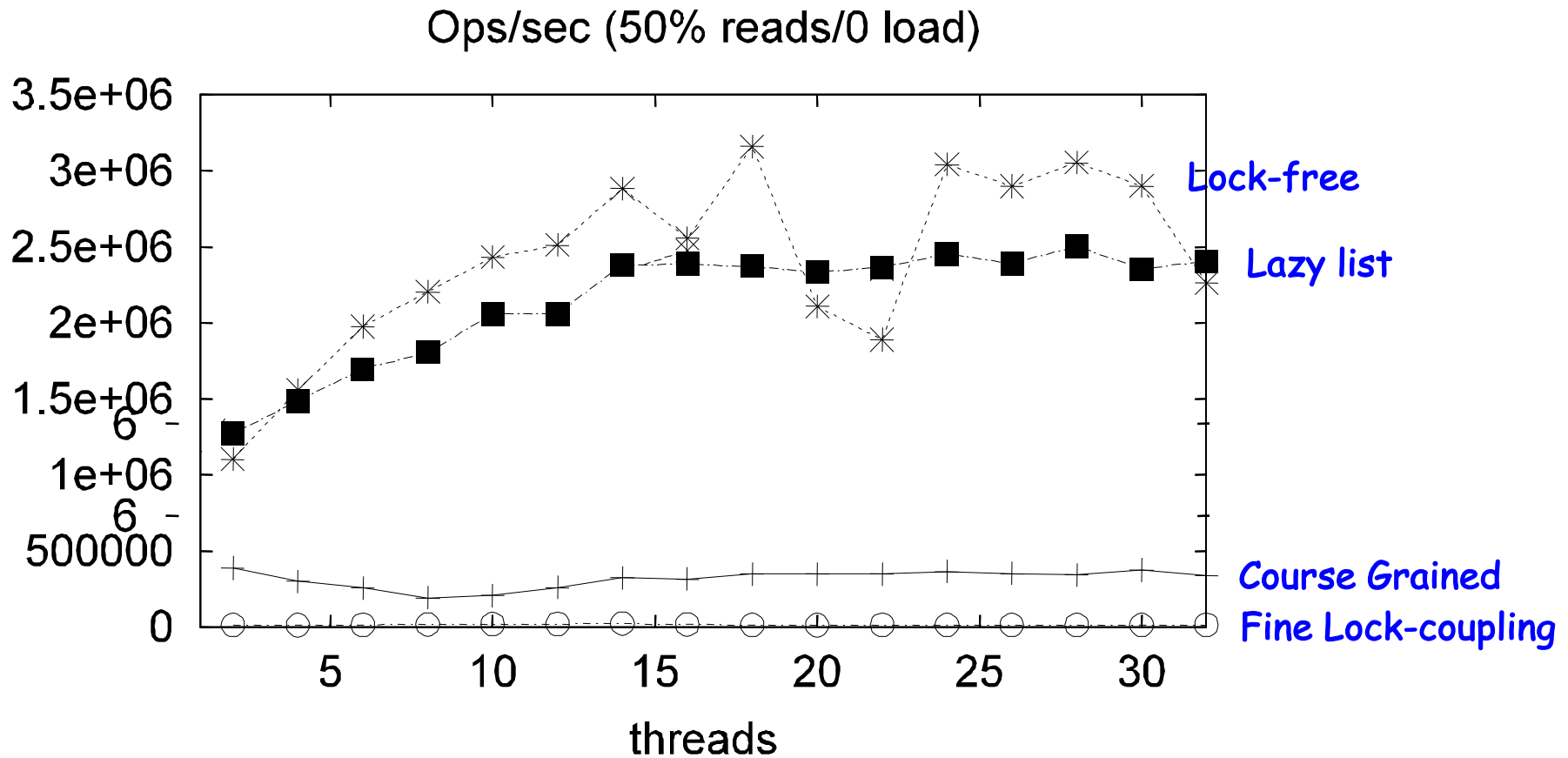
Performance

- On 16 node shared memory machine
- Benchmark throughput of Java List-based Set
- Algs. vary % of *Contains()* method Calls

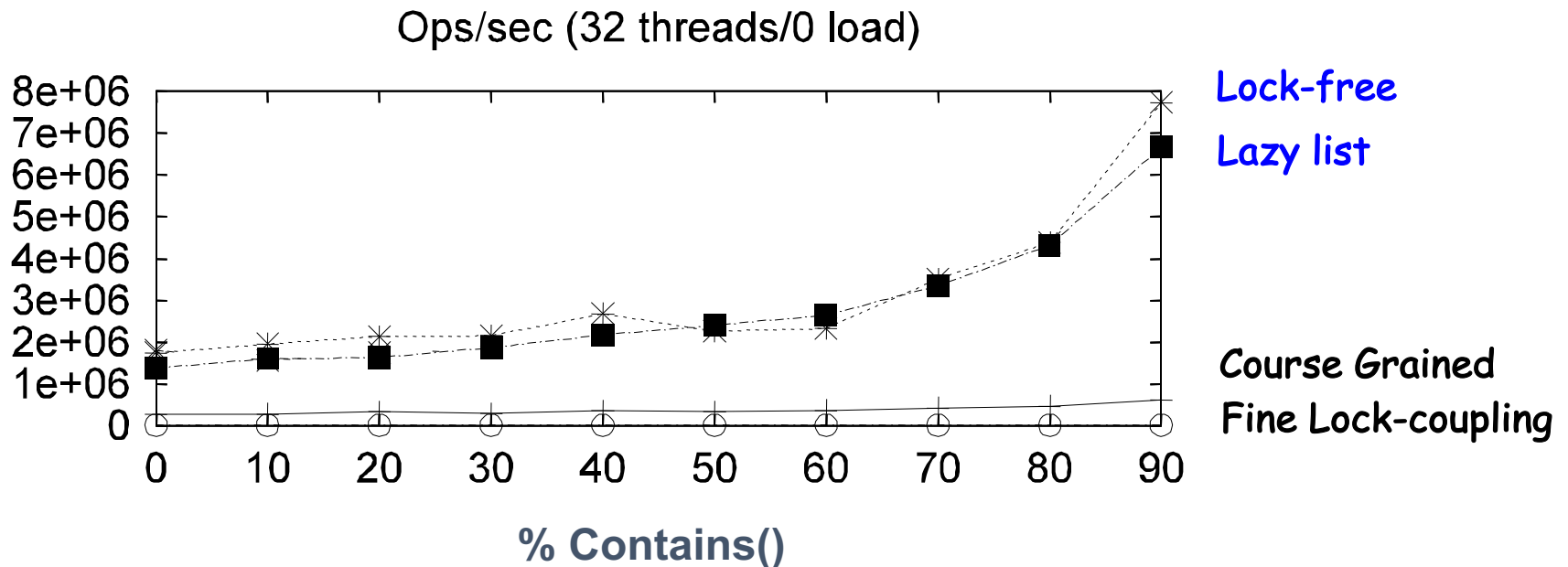
High Contains Ratio



Low Contains Ratio



As Contains Ratio Increases



Summary

- Contents:
 - Coarse-Grained Synchronization
 - Fine-Grained Synchronization
 - Optimistic Synchronization
 - Lazy Synchronization
 - Lock-Free Synchronization
- Reading list:
 - chapter 5 of the Textbook
 - Chapter 9 of “The Art of Multiprocessor Programming” by Maurice Herlihy & Nir Shavit (*available at clip*)

“To Lock or Not to Lock”

- Locking vs. Non-blocking: Extremist views on both sides
- The answer: nobler to compromise, combine locking and non-blocking
 - Example: Lazy list combines blocking `add()` and `remove()` and a wait-free `contains()`
 - Remember: Blocking/non-blocking is a property of a method

The END
