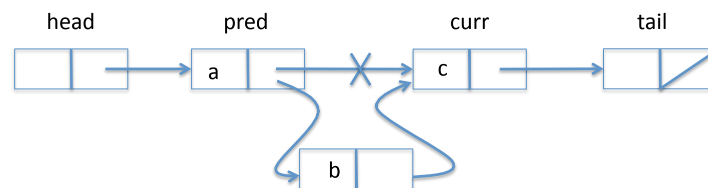
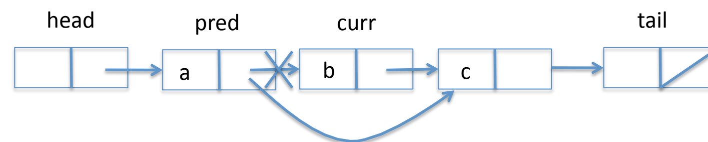
Advanced Locking Techniques

- Coarse-grained Synchronization
- Fine-grained Synchronization
- Optimistic Synchronization
- Lazy Synchronization

List-based Set






```
class node {
  T item; int key; Node next;
}
```

Coarse-grained Synchronization

- Take a sequential implementation, add a lock field, and ensure that each method call acquires and releases this lock
- Simple, and works well when levels of concurrency is low
- When too many threads try to access the object at the same time, the object becomes a sequential bottleneck

Coarse-grained Locking

```
public class CoarseList<T> {
    private Node head;
    private Lock lock = new ReentrantLock ();
    public CoarseList () {
        head = new Node (Integer.MIN_VALUE);
        head.next = new Node (Integer.MAX_VALUE);
    }
    public boolean add (T item) {
        Node pred, curr;
        int key = item.hashCode ();
        lock.lock ();
        try {
            pred = head;
            curr = pred.next;
            while (curr.key < key) {
                pred = curr; curr = curr.next;
            }
            if (key == curr.key) {
                return false;
            } else {
                Node node = new Node (item);
                node.next = curr; pred.next = node;
                return true;
            }
            finally {
                lock.unlock ();
            }
        }
      }
```

```
public boolean remove (T item) {
    Node pred, curr;
    int key = item.hashCode ();
    lock.lock ();
    try {
        pred = head;
        curr = pred.next;
        while (curr.key < key) {
            pred = curr; curr = curr.next;

        }
        if (key = curr.key) {
            pred.next = curr.next;
            return true;
        } else {
            return false;
        }
    } finally {
        lock.unlock ();
    }
}
```

Fine-grained Synchronization

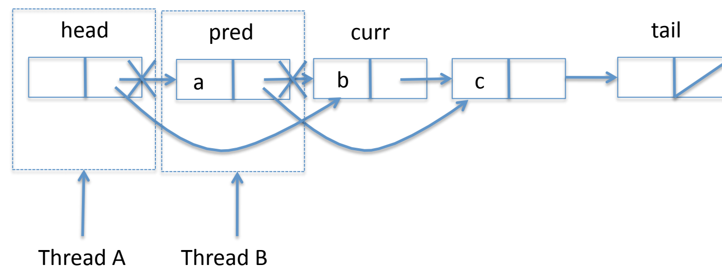
- Improve concurrency by locking individual nodes, instead of locking the entire list
- Operations interfere only when trying to access the same node at the same time
- Higher concurrency, but requires a lock to be added for each node

Fine-grained Locking

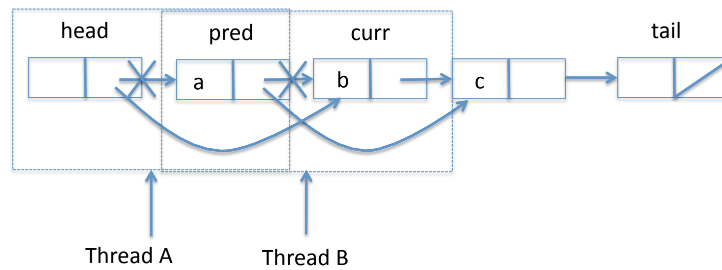
```
public class CoarseList<T> {
    private Node head;
    public CoarseList () {
        head = new Node (Integer.MIN_VALUE);
        head.next = new Node (Integer.MAX_VALUE);
    }
    public boolean add (T item) {
        int key = item.hashCode ();
        head.lock ();
        Node pred = head;
        try {
            Node curr = pred.next;
            curr.lock ();
            try {
                while (curr.key < key) {
                    pred.unlock();
                    pred = curr; curr = curr.next;
                    curr.lock ();
                }
                if (key == curr.key) {
                    return false;
                }
                Node newNode = new Node (item);
                newNode.next = curr;
                pred.next = newNode;
                return true;
            } finally {
                curr.unlock ();
            }
        } finally {
            pred.unlock ();
        }
    }
```

```
    public boolean remove (T item) {
        Node pred = null, curr = null;
        int key = item.hashCode ();
        head.lock ();
        try {
            pred = head;
            curr = pred.next;
            curr.lock();
            try {
                while (curr.key < key) {
                    pred.unlock ();
                    pred = curr; curr = curr.next;
                    curr.lock ();
                }
                if (key = curr.key) {
                    pred.next = curr.next;
                    return true;
                }
                return false;
            } finally {
                curr.unlock ();
            }
        } finally {
            pred.unlock ();
        }
    }
}
```

Why Two Locks?



Hand-Over-Hand Locking



Except for the initial head node, acquire the lock for curr only while holding the lock for pred

Optimistic Synchronization

- Search a component without acquiring any locks
- When a node is found, it locks the component, and then checks whether the component has been changed
- Optimistic about the possibility of conflicting

Optimistic Locking (1)

```
public boolean add (T item) {
    int key = item.hashCode ();
    while (true) {
        Node pred = head;
        Node curr = pred.next;
        while (curr.key <= key) {
            pred = curr; curr = curr.next;
        }
        pred.lock(); curr.lock ();
        try {
            if (validate(pred, curr)) {
                if (curr.key == key) {
                    return false;
                } else {
                    Node node = new Node (item);
                    node.next = curr; pred.next = node;
                    return true;
                }
            }
        } finally {
            pred.unlock (); curr.unlock();
        }
    }
}
```

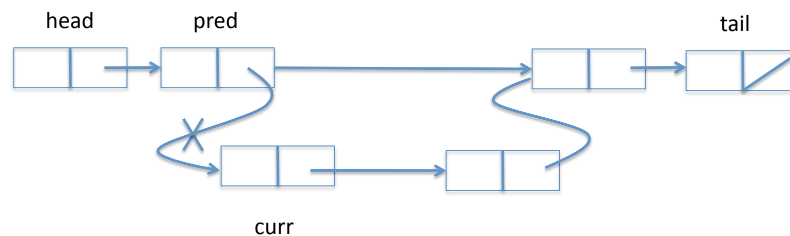
```
public boolean remove (T item) {
    int key = item.hashCode ();
    while (true) {
        Node pred = head;
        Node curr = pred.next;
        while (curr.key < key) {
            pred = curr; curr = curr.next;
        }
        pred.lock(); curr.lock ();
        try {
            if (validate(pred, curr)) {
                if (curr.key == key) {
                    pred.next = curr.next;
                    return true;
                } else {
                    return flase;
                }
            }
        } finally {
            pred.unlock (); curr.unlock();
        }
    }
}
```

Optimistic Locking (2)

```
public boolean contains (T item) {
    int key = item.hashCode ();
    while (true) {
        Node pred = head;
        Node curr = pred.next;
        while (curr.key < key) {
            pred = curr; curr = curr.next;
        }
        try {
            pred.lock(); curr.lock ();
            if (validate(pred, curr)) {
                return (curr.key = key);
            }
        } finally {
            pred.unlock (); curr.unlock();
        }
    }
  }
```

```
public boolean validate (Node pred, Node
curr) {
    Node node = head;
    while (node.key <= pred.key) {
        if (node == pred)
            return pred.next = curr;
        node = node.next;
    }
    return false;
}
```

Why validation?



Lazy Synchronization

- Postpone significant changes, e.g., physically removing a node from a linked list
- Allow a list to be traversed only once without locking, and contains() is wait-free.
- Require a new field *marked* to be added into each node

Lazy Locking (1)

```
public boolean add (T item) {
    int key = item.hashCode ();
    while (true) {
        Node pred = head;
        Node curr = pred.next;
        while (curr.key < key) {
            pred = curr; curr = curr.next;
        }
        pred.lock();
        try {
            curr.lock();
            try {
                if (validate(pred, curr)) {
                    if (curr.key == key) {
                        return false;
                    } else {
                        Node node = new Node (item);
                        node.next = curr;
                        pred.next = node;
                        return true;
                    }
                }
            } finally {
                curr.unlock();
            }
        } finally {
            pred.unlock ();
        }
    }
}
```

```
public boolean remove (T item) {
    int key = item.hashCode ();
    while (true) {
        Node pred = head;
        Node curr = pred.next;
        while (curr.key < key) {
            pred = curr; curr = curr.next;
        }
        pred.lock();
        try {
            curr.lock ();
            try {
                if (validate(pred, curr)) {
                    if (curr.key != key) {
                        return false;
                    } else {
                        curr.marked = true;
                        pred.next = curr.next;
                        return flase;
                    }
                }
            } finally {
                curr.unlock ();
            }
        } finally {
            pred.unlock ();
        }
    }
}
```

Lazy Locking (2)

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

```
private boolean validate (Node pred,
Node curr) {
    return !pred.marked && !curr.marked &&
pred.next = curr;
}
```

Can we do better?

- Non-blocking synchronization: eliminate locks entirely, relying on built-in atomic operations such as compareAndSet() for synchronization