NOVA SCHOOL OF SCIENCE & TECHNOLOGY
COMPUTER SCIENCE DEPARTMENT

Alternative Synchronization Strategies — Lock-Free Algorithms (1) —

lecture 19 (2021-05-24)

Master in Computer Science and Engineering

— Concurrency and Parallelism / 2020-21 —

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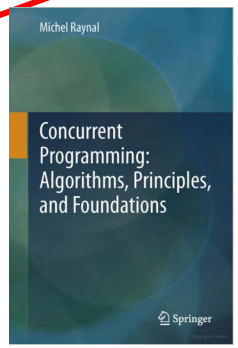
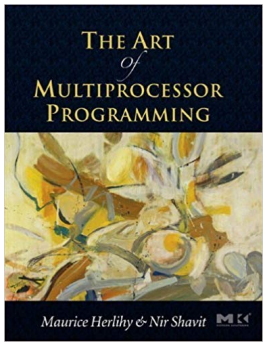
Alternative Synchronization Strategies

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

Past lectures

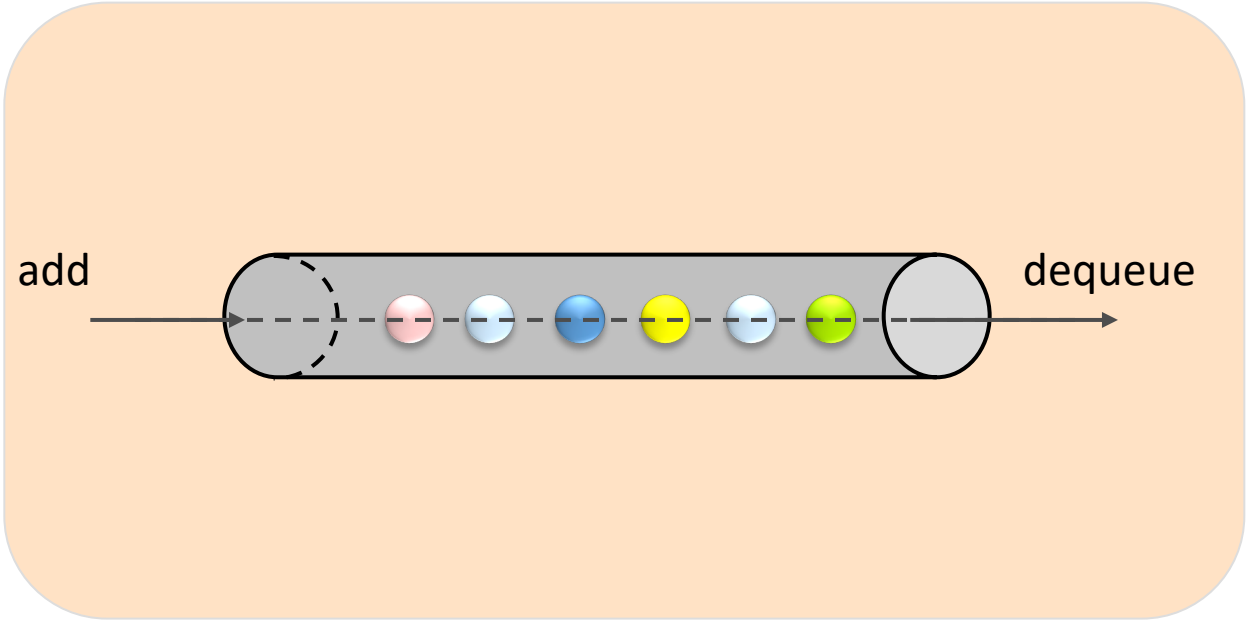
Today





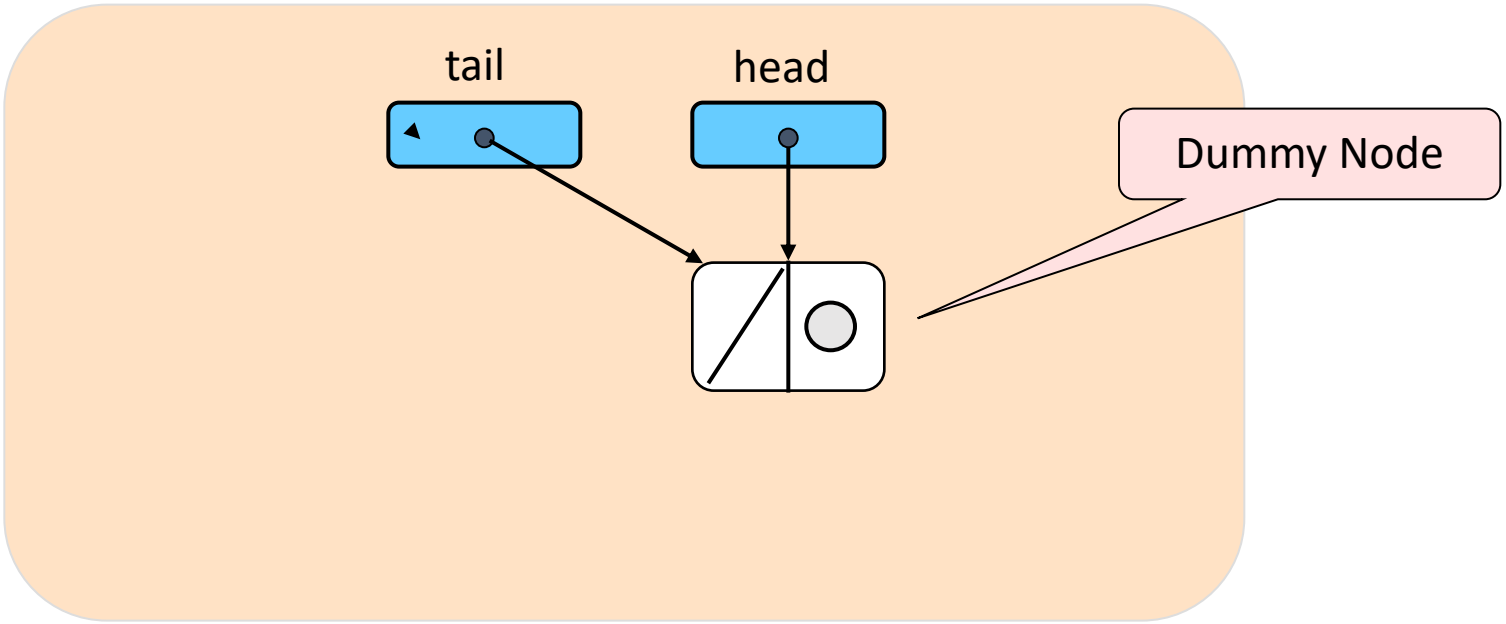
- Reading list:
  - chapter 5 of the Textbook
  - Chapter 9 of "The Art of Multiprocessor Programming" by Maurice Herlihy & Nir Shavit *(available at clip)*

Basics for a lock-free Queue

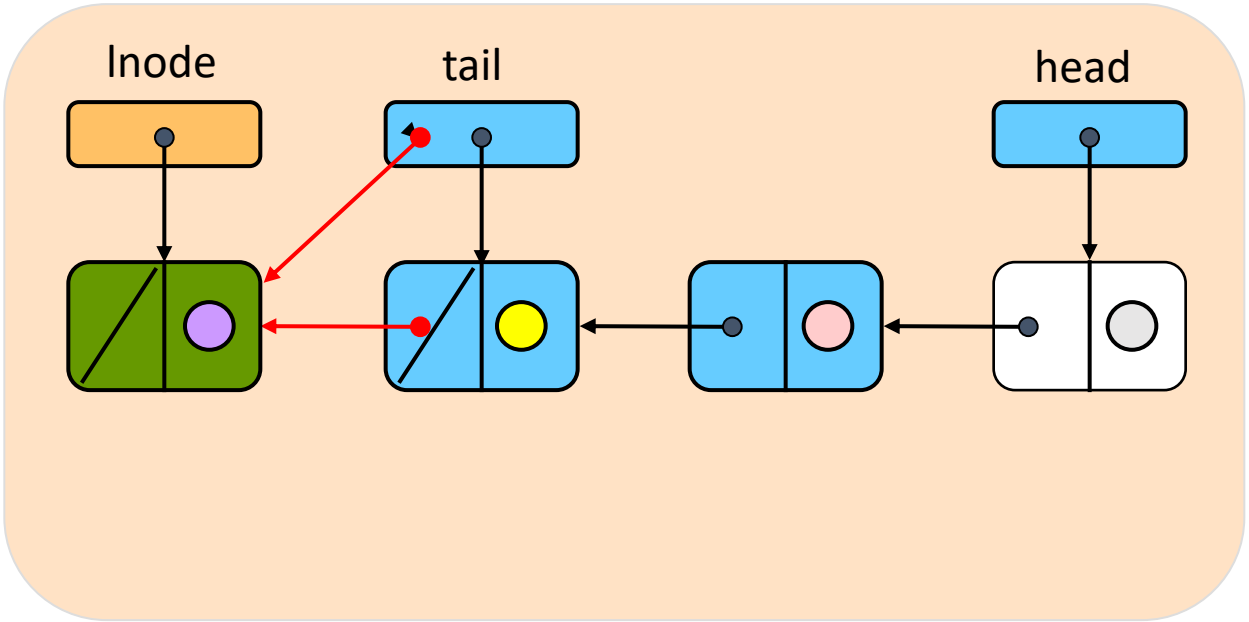


Basics for a lock-free Queue

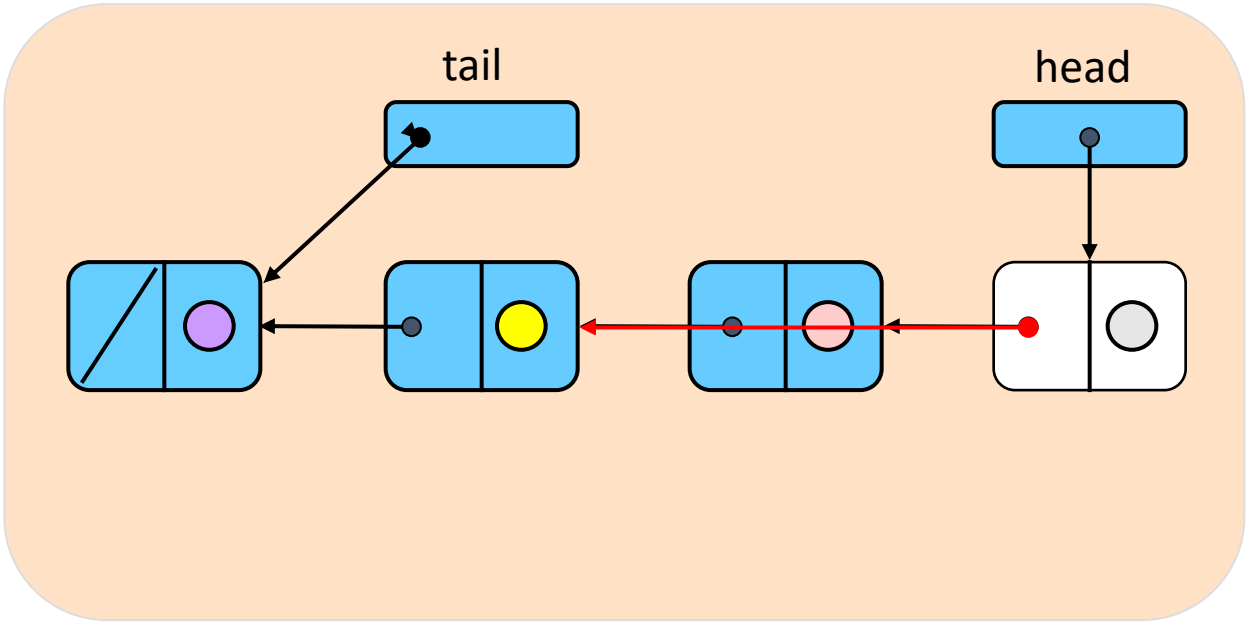
Empty queue



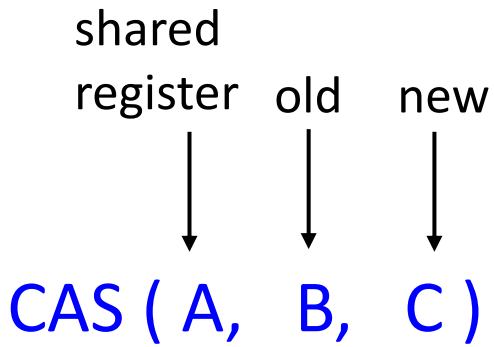
Enqueue



Dequeue



Compare & set(CAS)




```
if A==B then   A←C;   return(true)
       else    return(false)
```

Supported by Intel, AMD, Arm, …

Reminder: Lock-Free Data Structures

- No matter what …

- Guarantees minimal progress in any execution
  - i.e., some thread will always complete a method call
- Even if others halt at malicious times
- Implies that implementation can't use locks

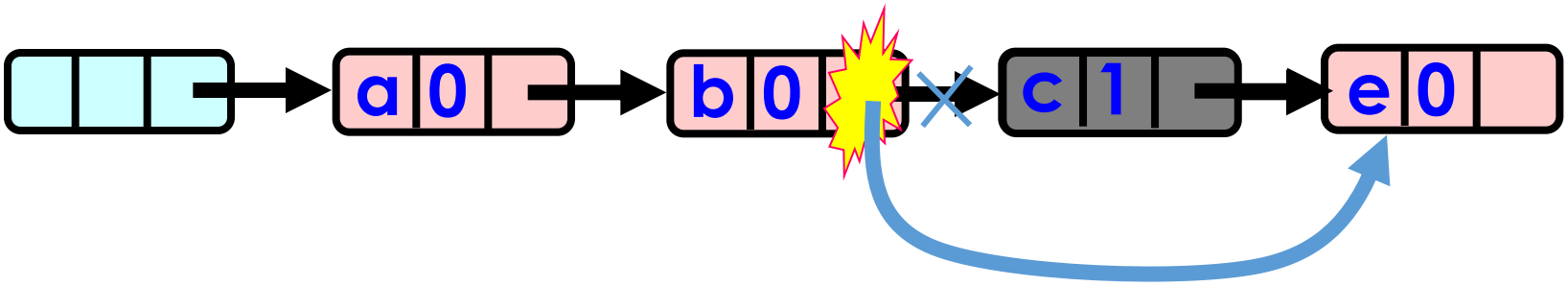
Lock-free Lists

- Next logical step (*after the lazy list*) is…
- Eliminate locking entirely
  - *contains()* wait-free
  - *add()* lock-free
  - *remove()* lock-free
- Use only *compareAndSet()*
- What could go wrong?

Remove Using CAS

- remove(c)

Logical Removal =
Set Mark Bit



Use CAS to verify
if pointer is correct

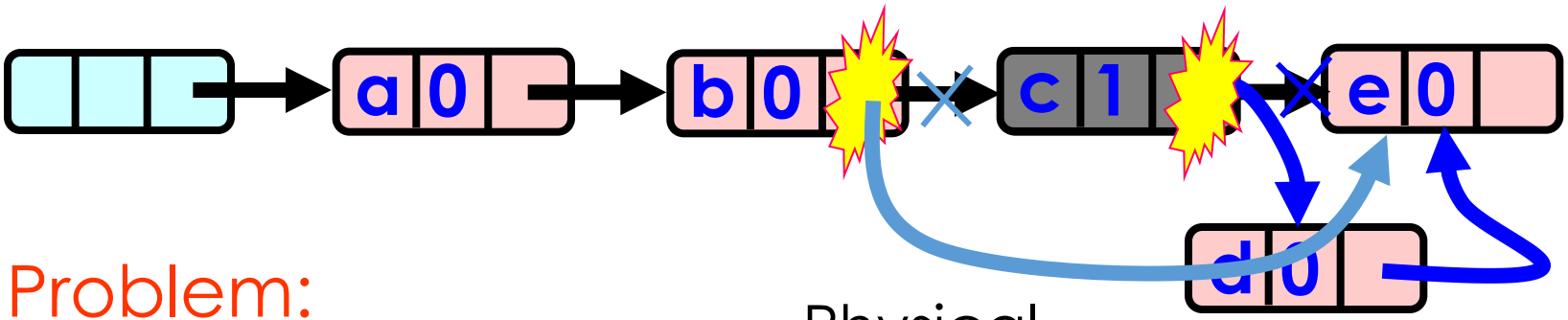
Not enough! Why?

Physical
Removal
CAS pointer

Problem…

- remove(c) | add(d)

Logical Removal =
Set Mark Bit



Problem:
'd' not added to list…
Must Prevent manipulation of removed node's pointer

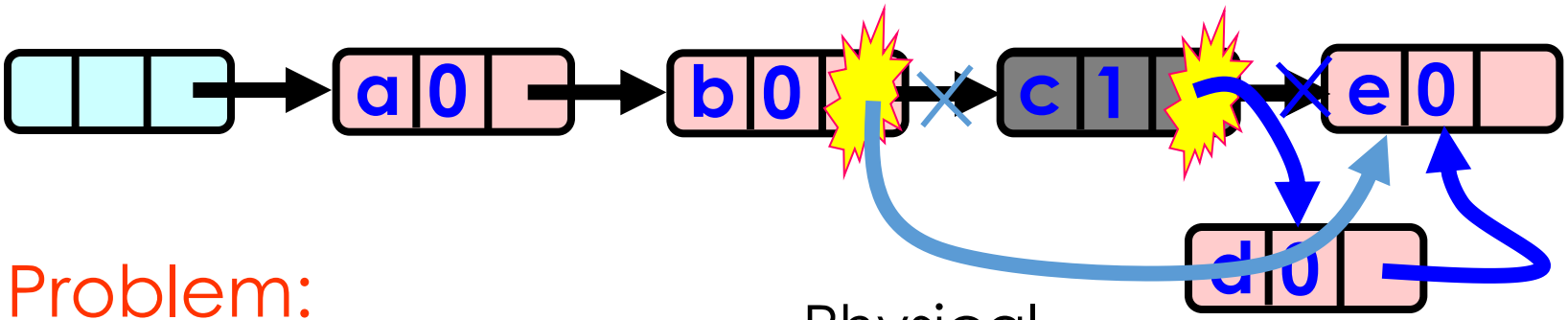
Physical Removal CAS

Node added Before Physical Removal CAS

Problem…

- remove(c) | add(d)

Logical Removal =
Set Mark Bit

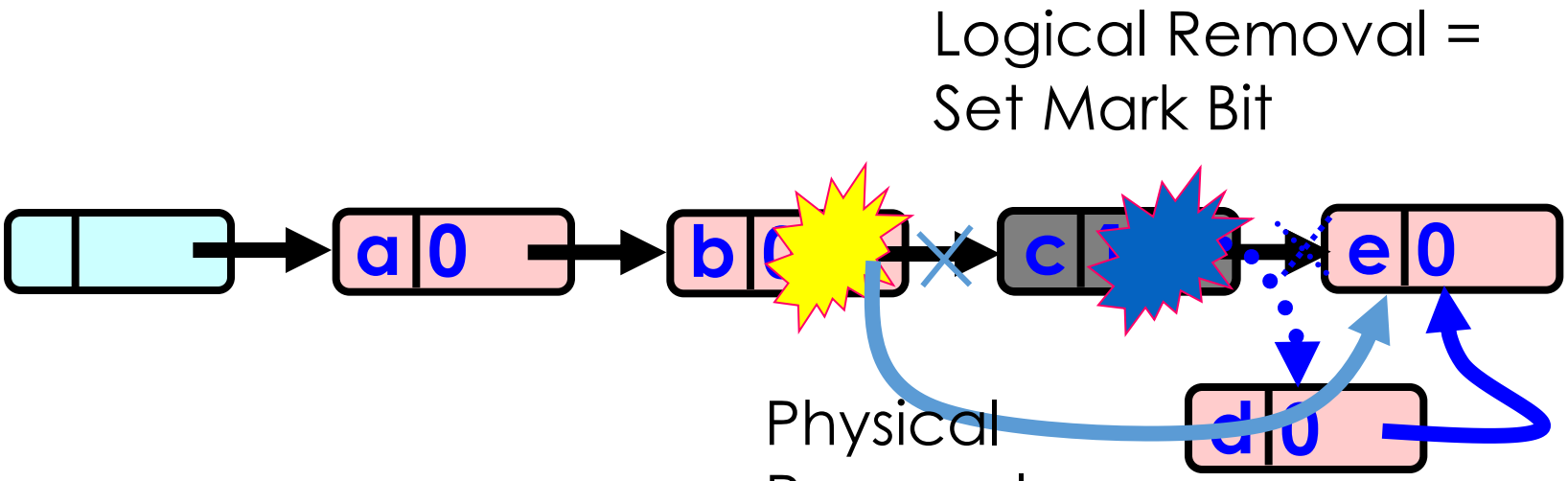


Problem:
'd' not added to list…
Must Prevent manipulation of removed node's pointer

Physical Removal CAS

Node added Before Physical Removal CAS

The Solution: Combine Bit and Pointer



Mark-Bit and Pointer are CASed together (AtomicMarkableReference)

Solution

- Use *AtomicMarkableReference*
- Atomically
  - Swing reference and
  - Update flag
- Remove in two steps
  - Set mark bit in next field
  - Redirect predecessor's pointer with a CAS

Marking a Node

- AtomicMarkableReference class
  - java.util.concurrent.atomic package

Extracting Reference & Mark

```
public Object get(boolean[] marked);
```

Extracting Reference & Mark

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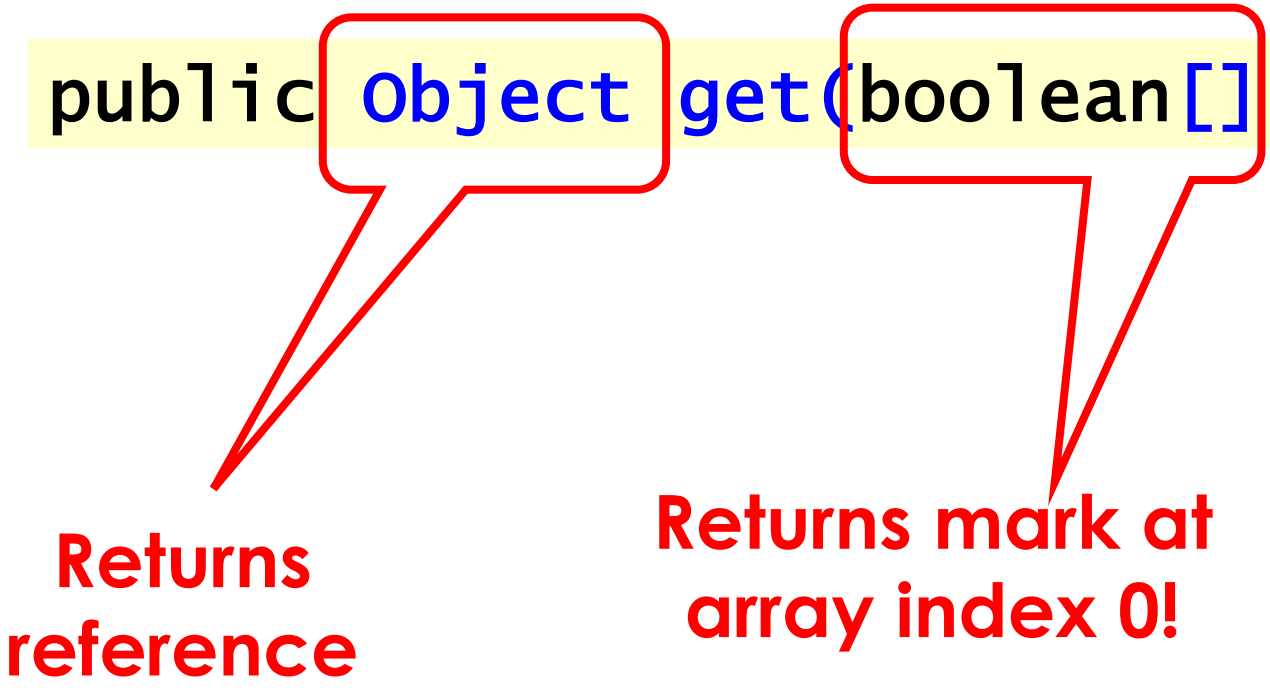
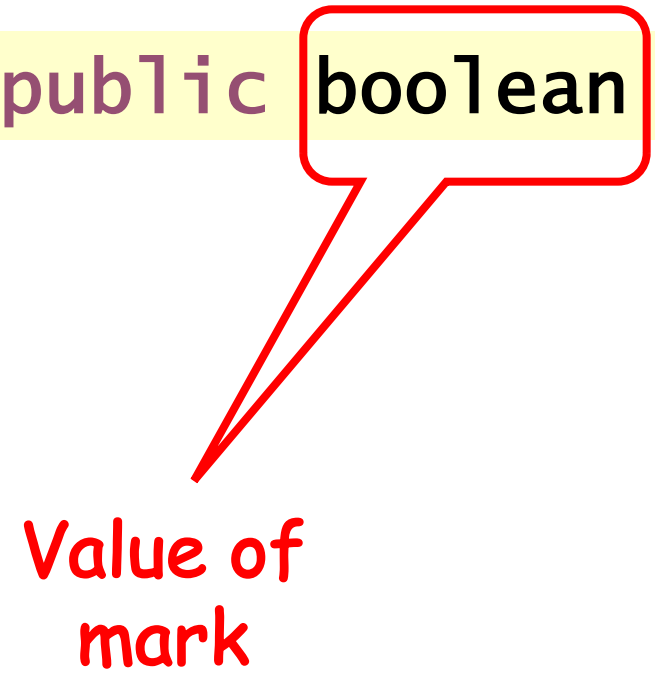


Extracting Reference Only

```
public boolean isMarked();
```



Changing State

```
public boolean compareAndSet(
  Object expectedRef,
  Object updateRef,
  boolean expectedMark,
  boolean updateMark);
```

Changing State

- □

If this is the current reference …

```
public boolean compareAndSet(
  Object expectedRef,
  Object updateRef,
  boolean expectedMark,
  boolean updateMark);
```

And this is the current mark …

Changing State

- ☐

```
public boolean compareAndSet(
  Object expectedRef,
  Object updateRef,
  boolean expectedMark,
  boolean updateMark);
```

…then change to this new reference …

… and this new mark

Changing State

```
public boolean attemptMark(
  Object expectedRef,
  boolean updateMark);
```

Changing State

```
public boolean attemptMark(
  Object expectedRef,
   boolean updateMark);
```

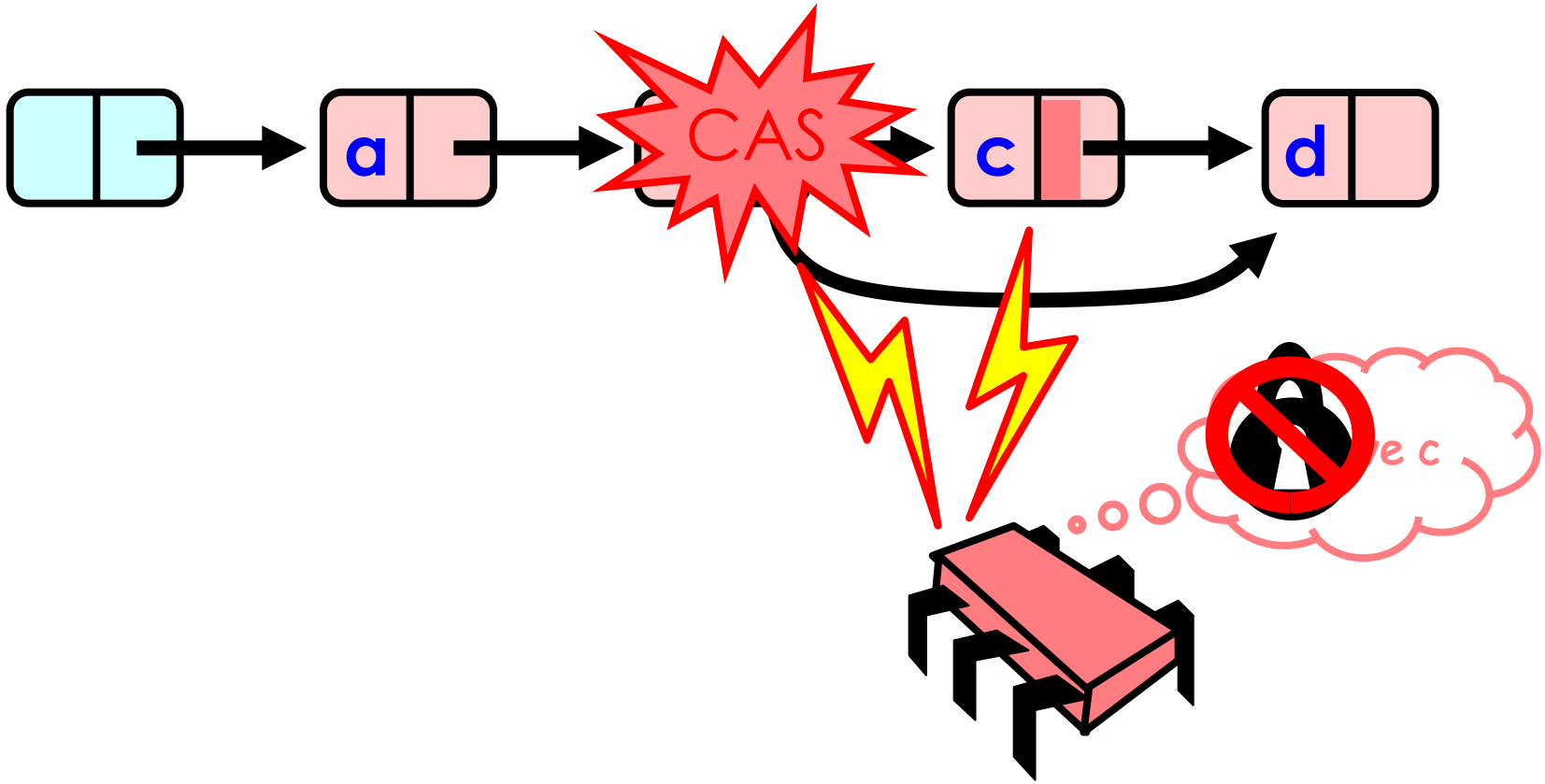
If this is the current reference …

Changing State

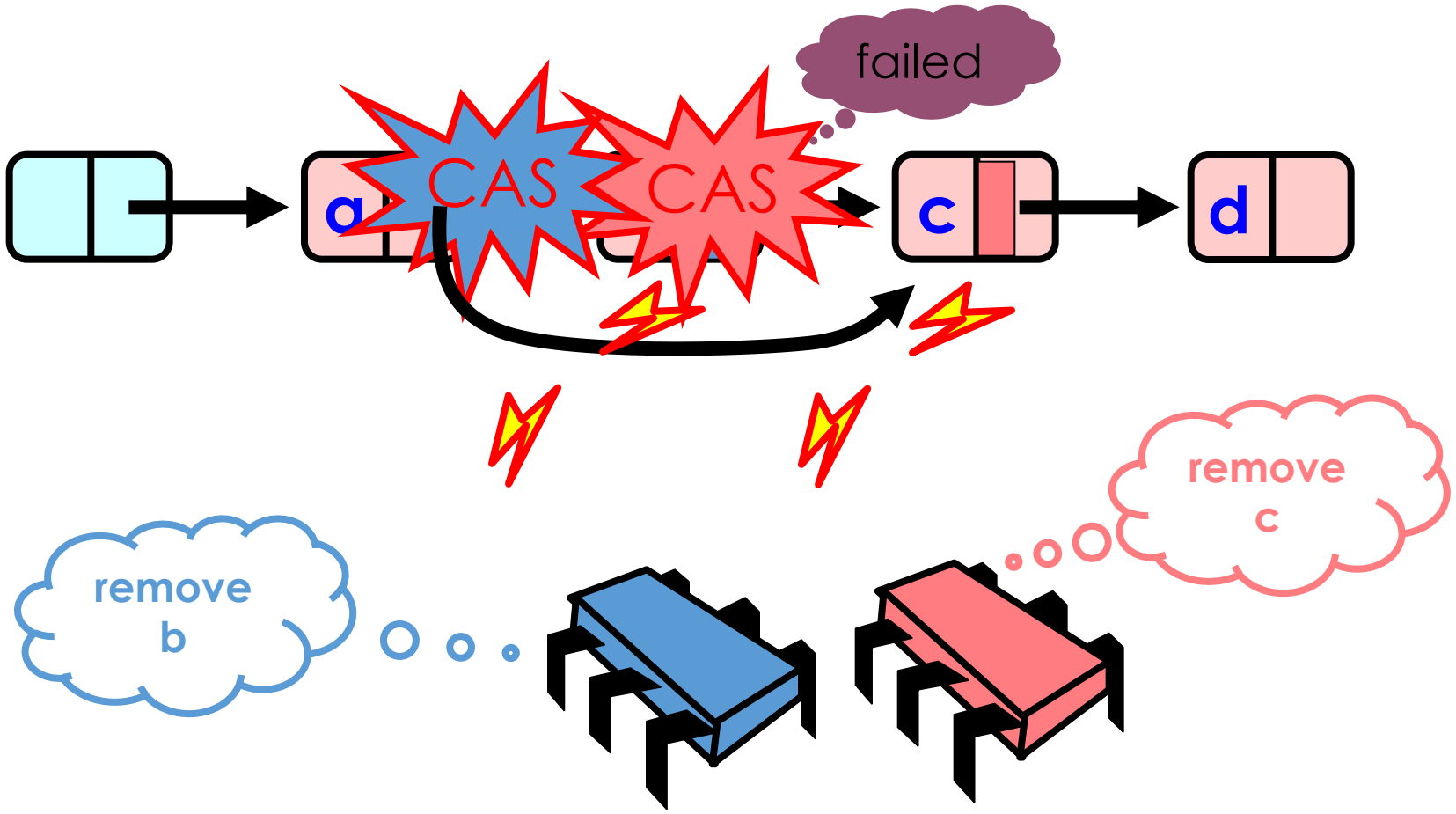
```
public boolean attemptMark(
   Object expectedRef,
   boolean updateMark);
```

.. then change to this new mark.

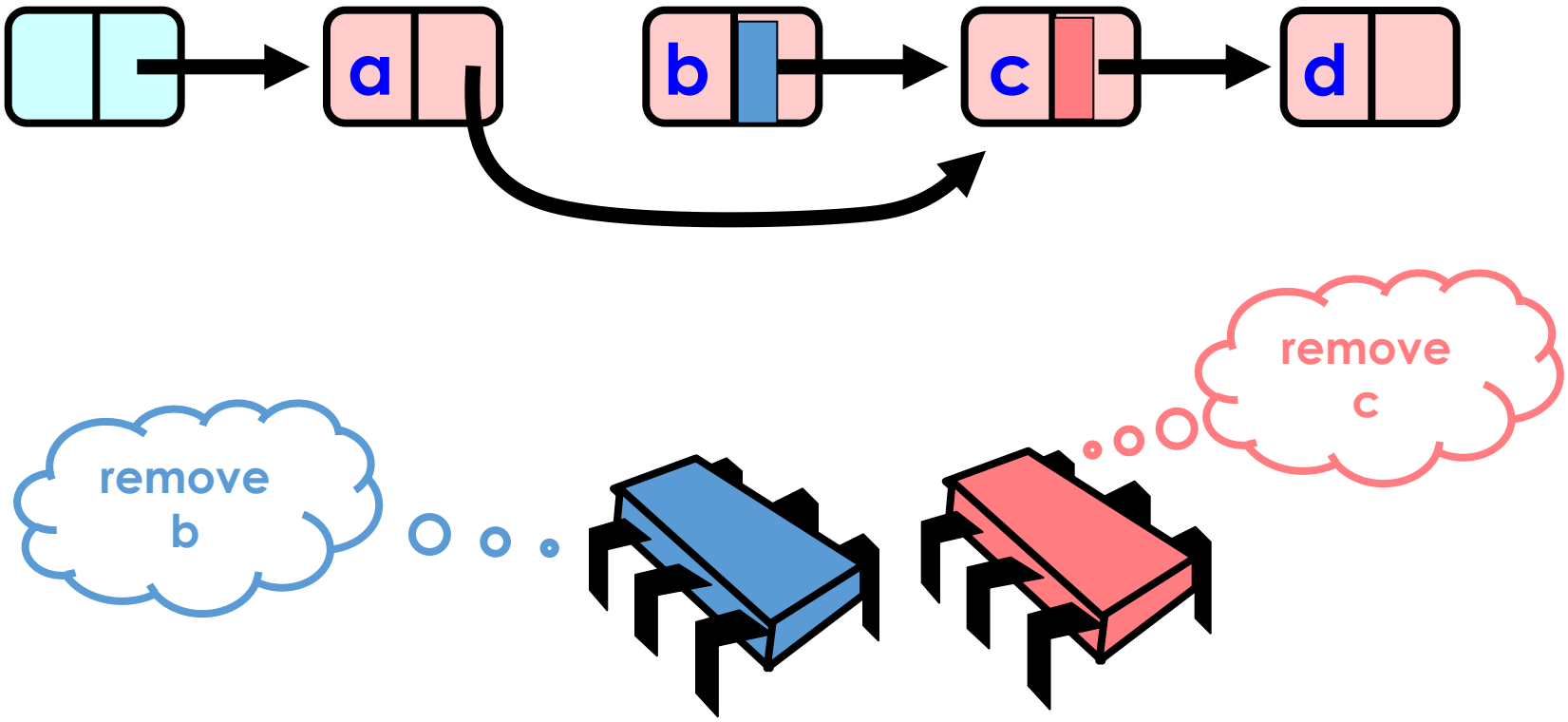
Removing a Node



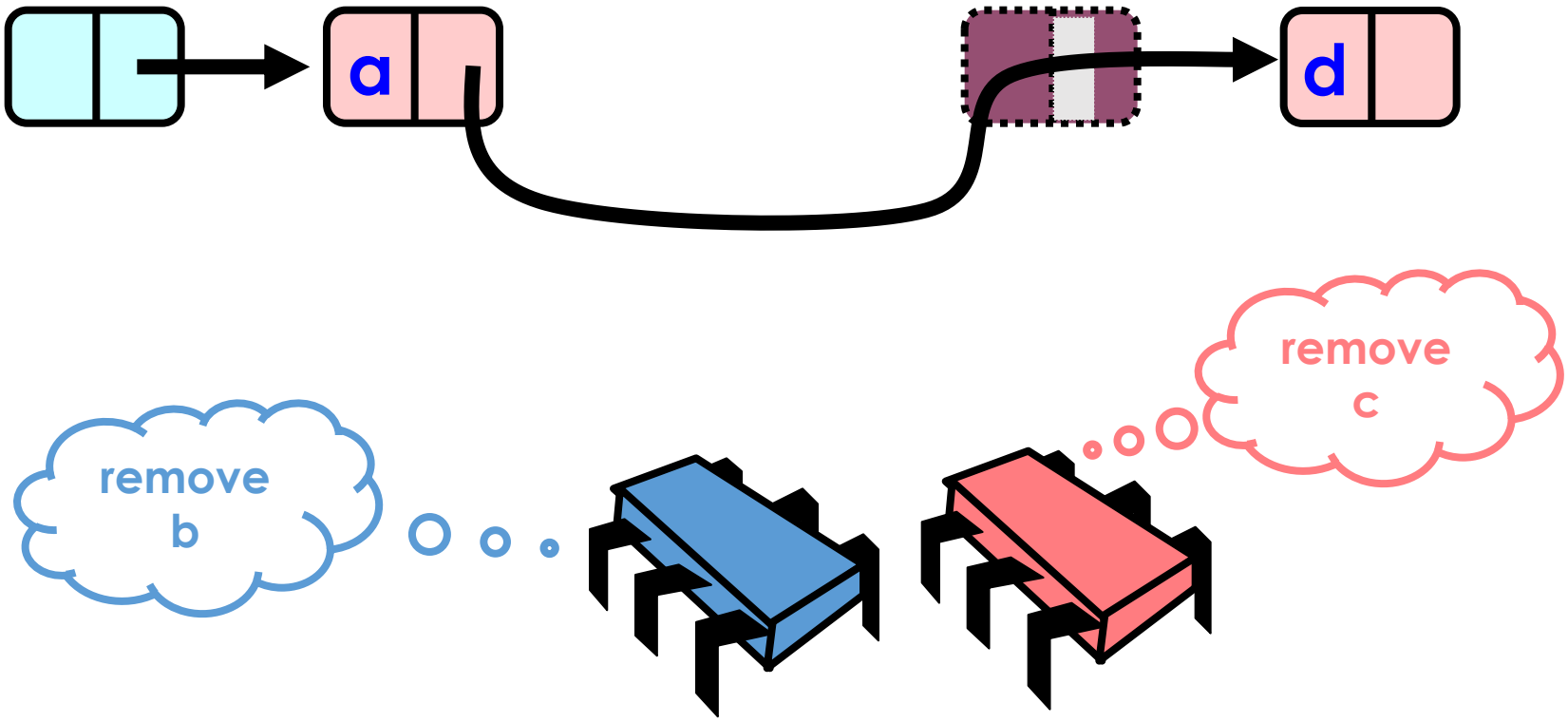
Removing a Node



Removing a Node



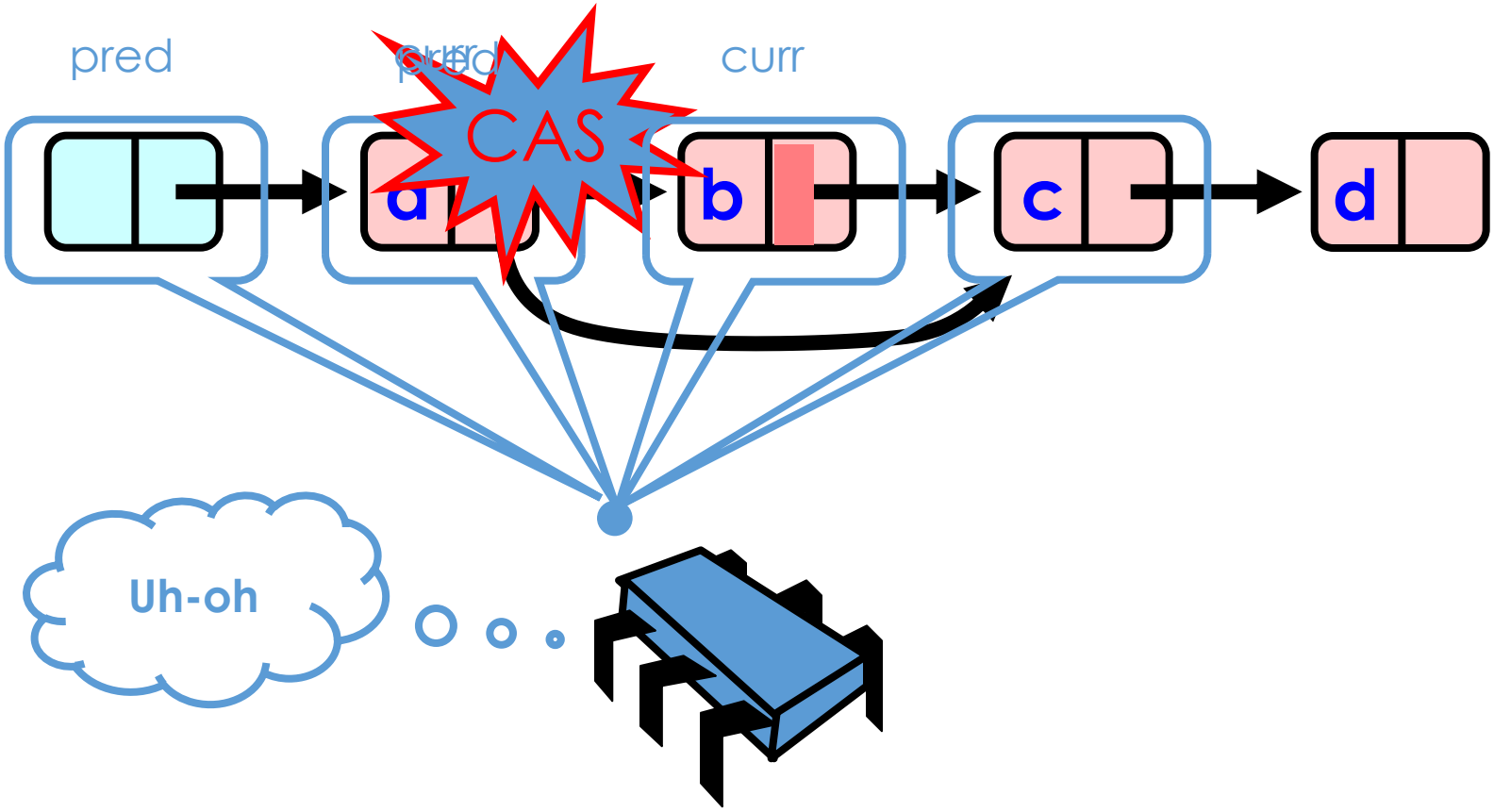
Removing a Node



Traversing the List

- Q: what do you do when you find a "logically" deleted node in your path?
- A: finish the job.
  - CAS the predecessor's next field
  - Proceed (repeat as needed)

Lock-Free Traversal (only Add and Remove)



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