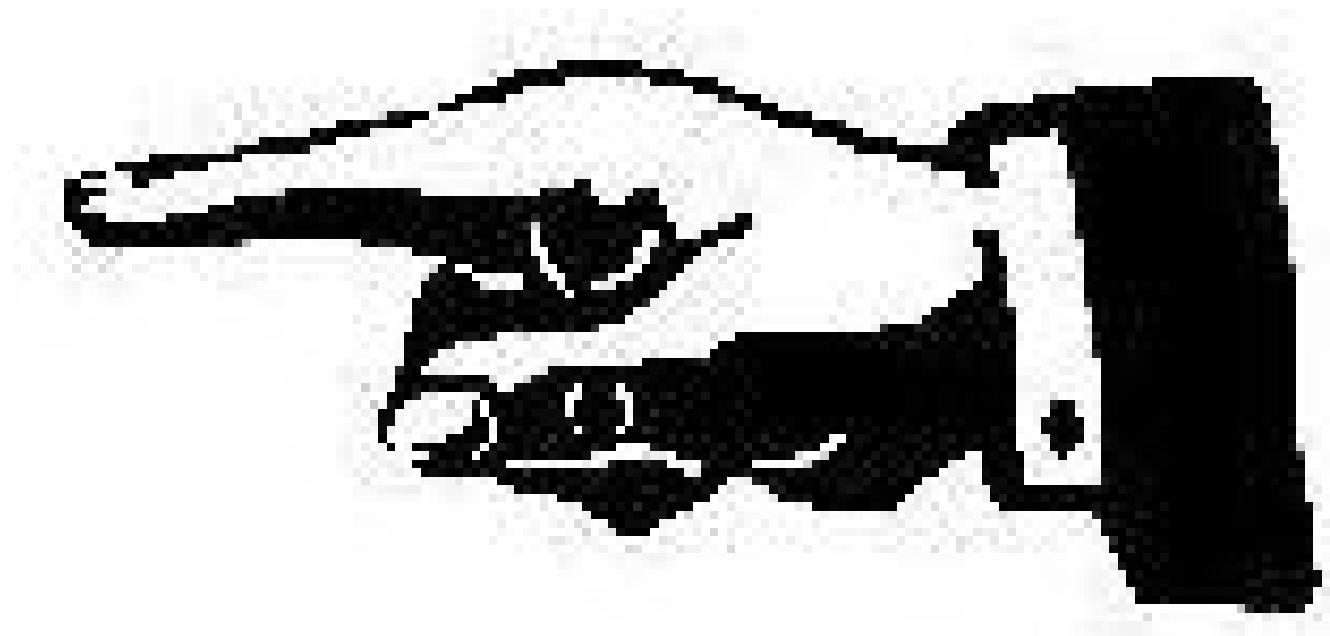


# Algorithms and Analysis

## Lesson 6: *Point to where you are going: links*



*Linked lists*

# Outline

1. References
2. Singly Linked List
3. Stacks and Queues
4. Doubly Linked List
5. Using Linked Lists
6. Skip Lists



# Non-Contiguous Data

- So far we have considered arrays where the data is stored in a contiguous chunk of memory
- This has the great advantage of allowing random access
- It has the disadvantage that it is expensive to add or remove data from the middle of the list or to rearrange the data
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- There are a lot of important data structures using non-contiguous memory
  - ★ Binary trees
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- This is a classic data structure
- However, it serves as a good introduction to much more useful data structures

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# Self-Referential Classes

- The building block for a linked list is a node class

```
struct Node<T>
{
    Node(U value, Node<U> *node) : value(value), next(node) {}
    T element;
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}
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- We create new nodes

```
Node<int> *node = new Node<int>(10, pt_to_next)
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- Note that `node` is the address of this node
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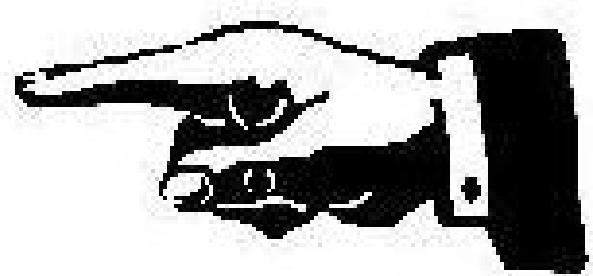
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# Singly Linked List

- We can build a linked list by stringing nodes together



We don't show the “pointer” to element

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# Implementation

- We consider a **lightweight implementation**
- The class will have a head, a size counter and have a Node as a nested class

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class MyList {  
private:  
    template <typename U>  
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# Simple Methods

- The constructor is simple (and not strictly necessary)

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MyList(): n(0), head(0) {}
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- Other simple methods are

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unsigned size() const {return noElements;}
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bool empty() const {
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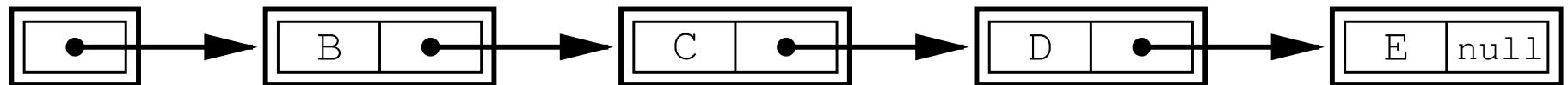
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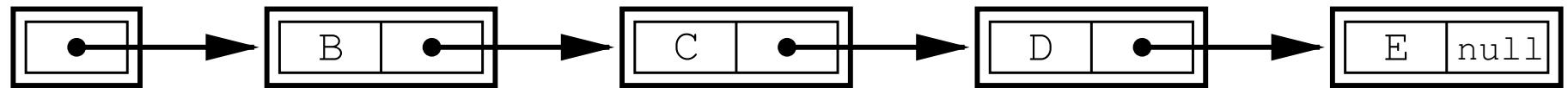
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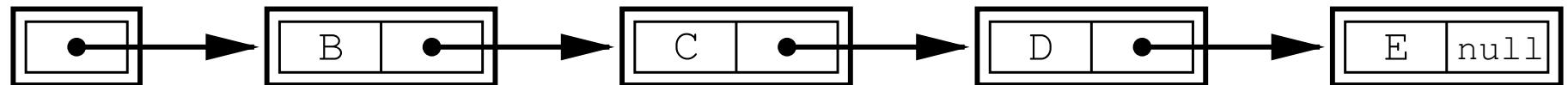
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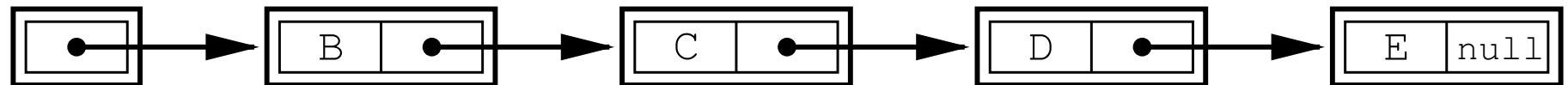
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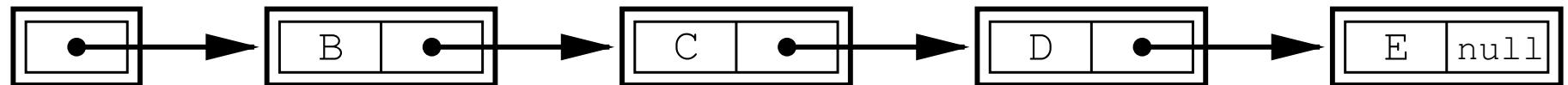
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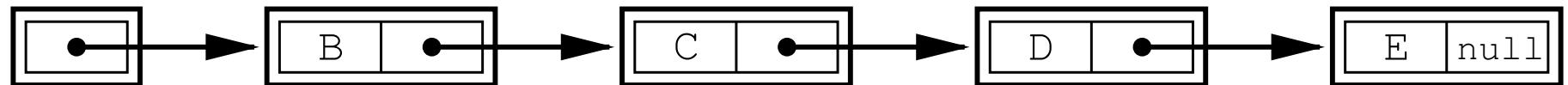
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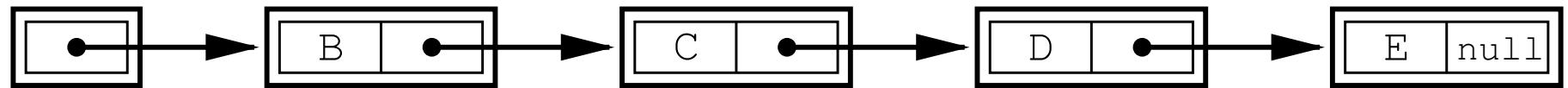
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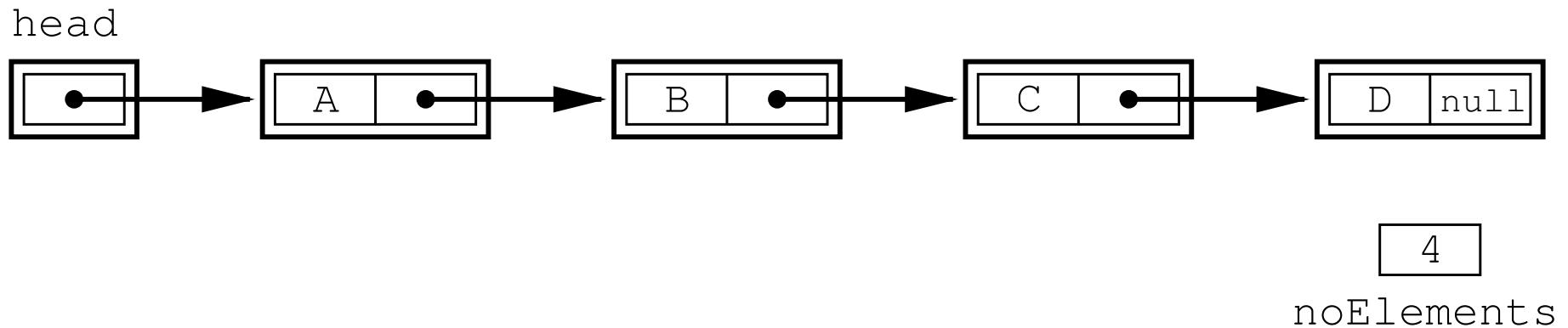
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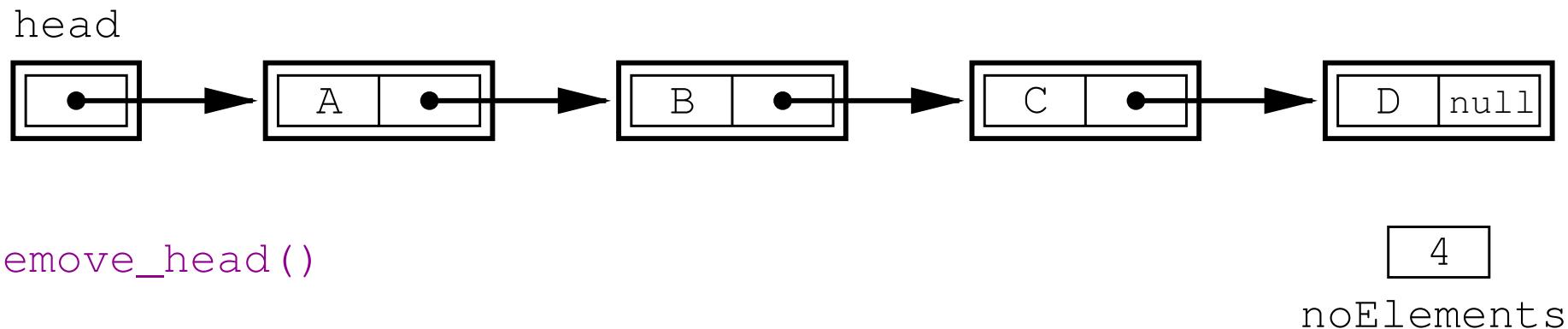
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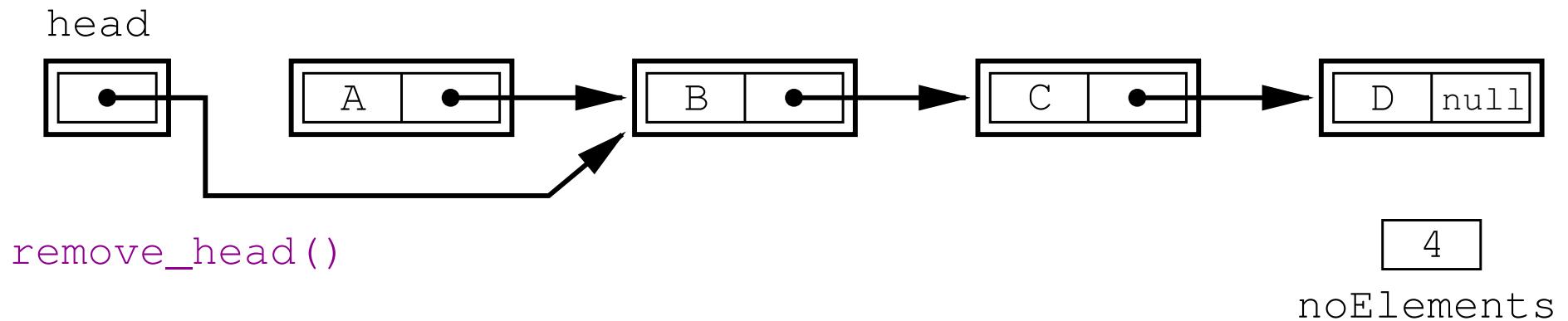
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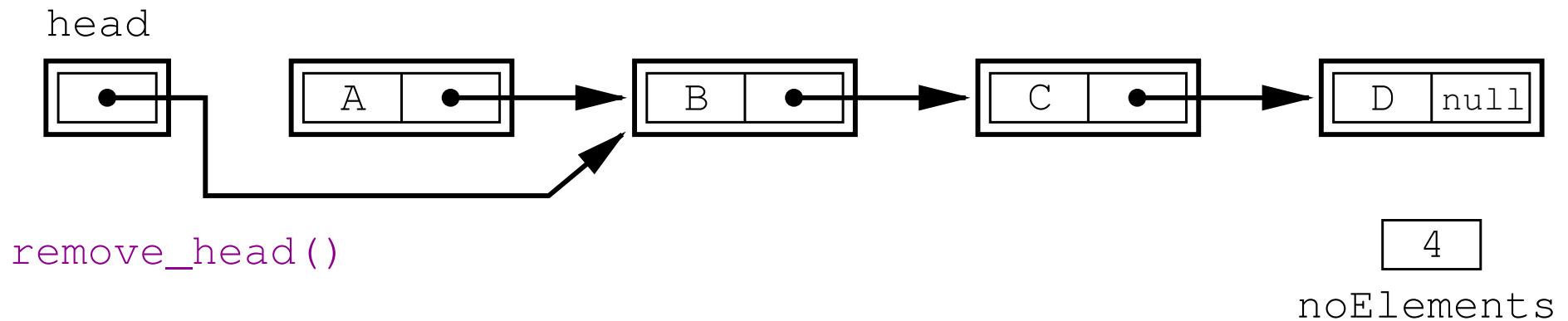
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  - ★ `get(int i)`—return  $i^{th}$  item in list
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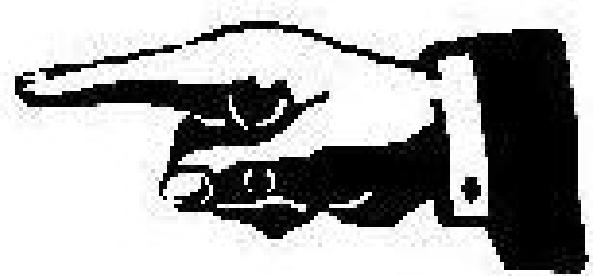
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# Stack

- It is easy to implement a stack using a linked list

```
template <typename T>
class Stack<E>
{
    private Mylist<T> list = new mylist<T>();

    boolean push(E obj) {list.add(obj);}

    E top() {return list.get_head();} // throw exception

    E pop() {
        T tmp = list.get_head();
        list.remove_head();
        return tmp;
    }

    boolean empty() {return list.empty();}
}
```

# Complexity of Stack

- All operations of the stack is constant time, i.e.  $O(1)$
- This is the same time complexity as an array implementation
- Memory requirement is approximately  $2 \times n$  reference and  $n$  objects—same as worst case for an array
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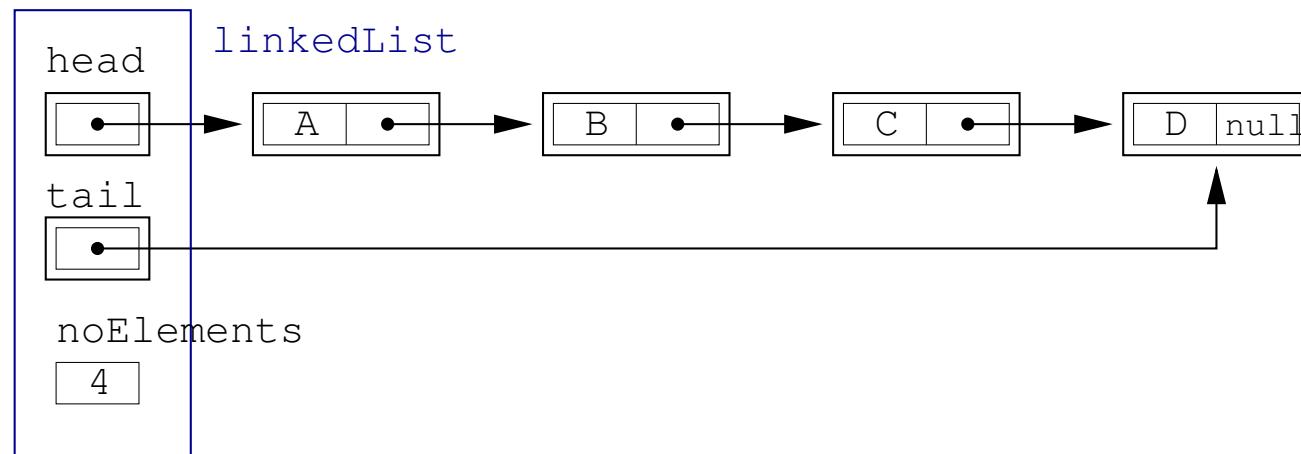
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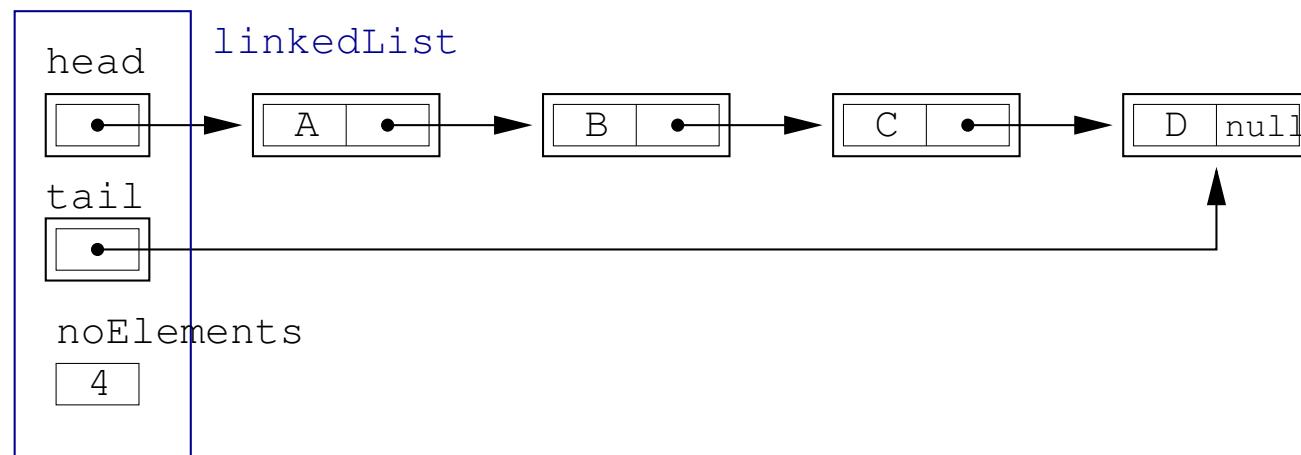
# Point to the Back

- To find the end of the queue takes  $n$  jumps
- Thus our linked list isn't the right data structure to implement a queue
- However, we could include a pointer to the end of the queue



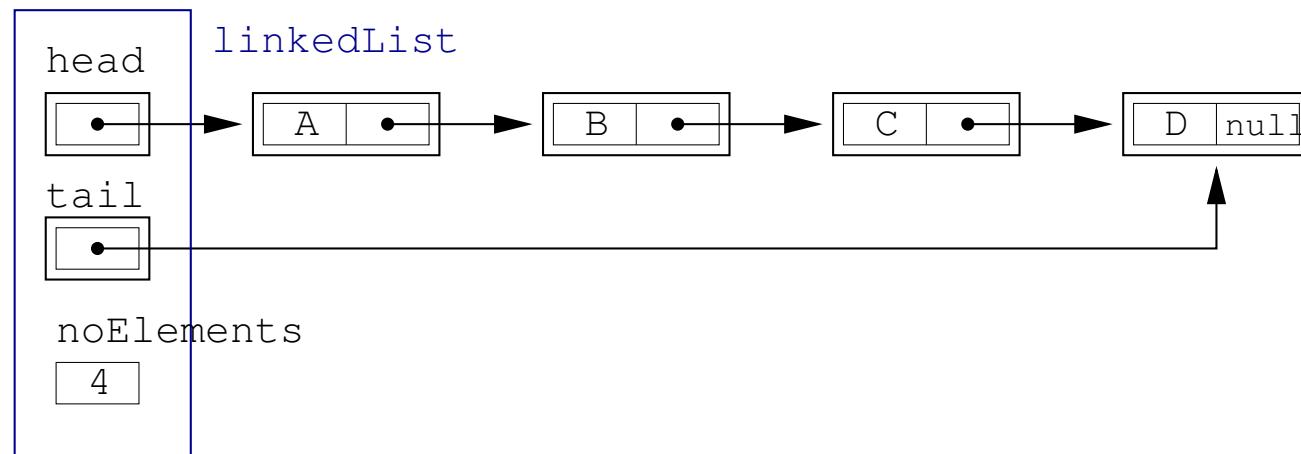
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# Implementing a Queue

- We can then add elements to the tail in constant time
- We can implement a queue in  $O(1)$  time by
  - ★ enqueueing at the back
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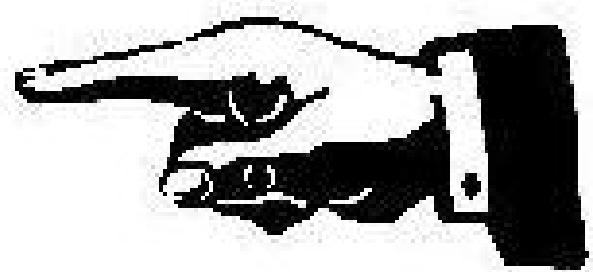
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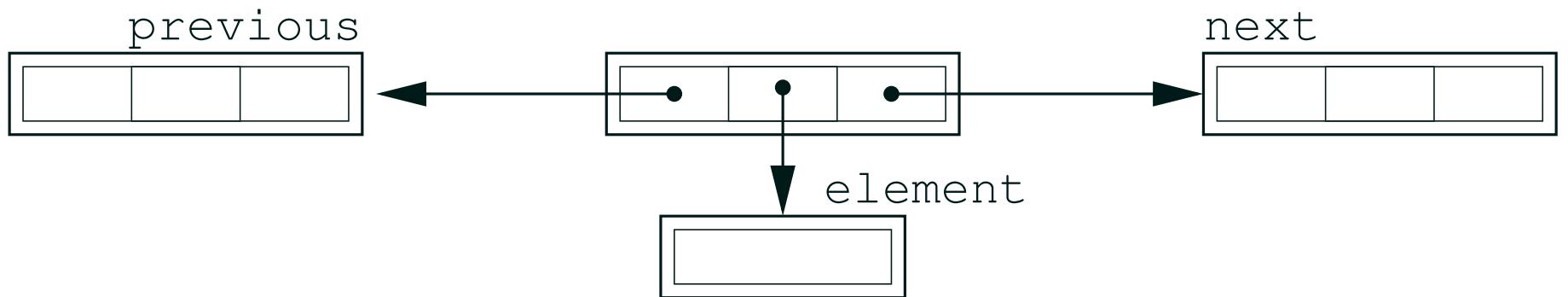
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# Doubly linked list

- In a more powerful linked list we would like to navigate the list in either direction
- To achieve this it uses a doubly-linked lists with elements to next and previous

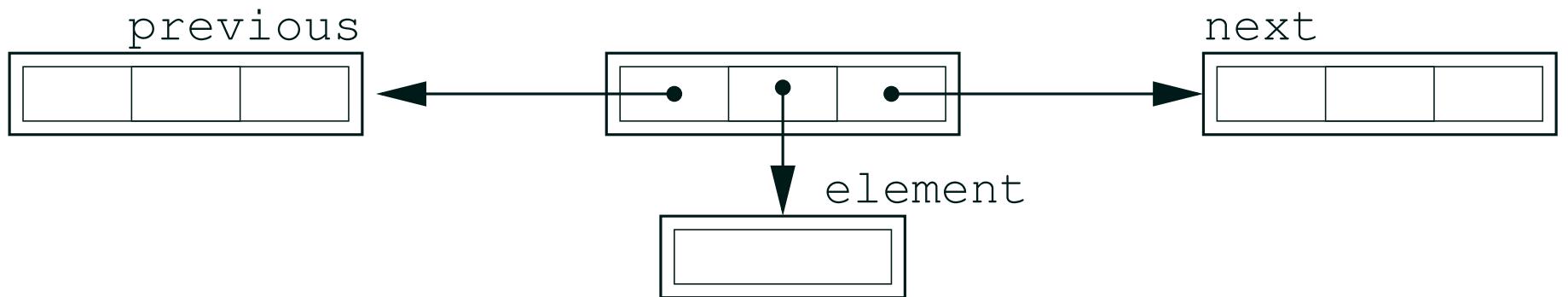
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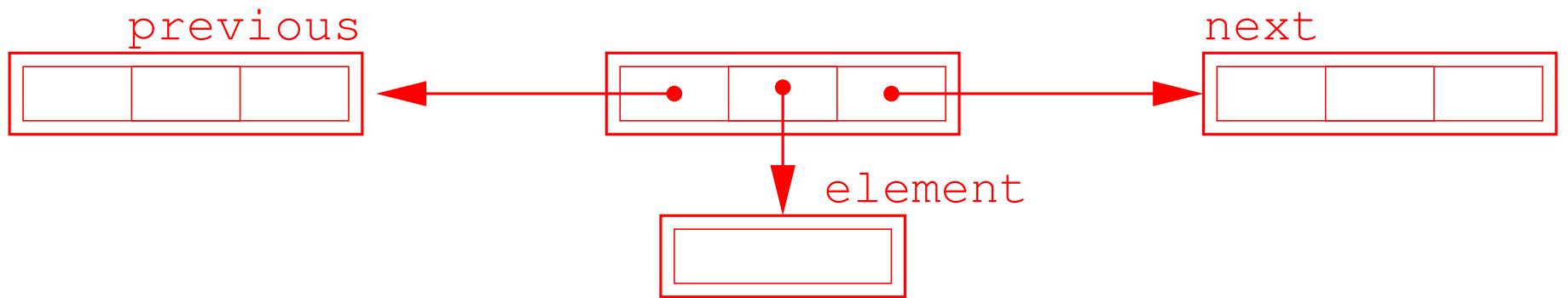
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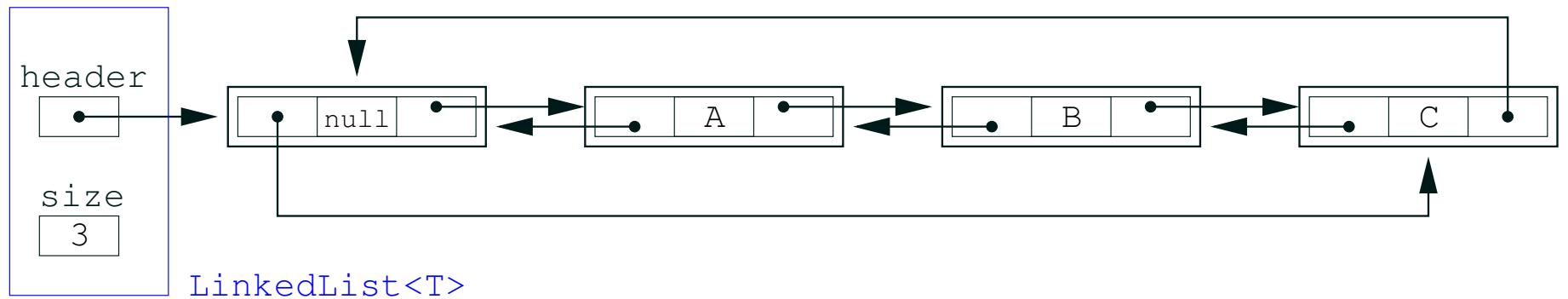
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# Dummy Node

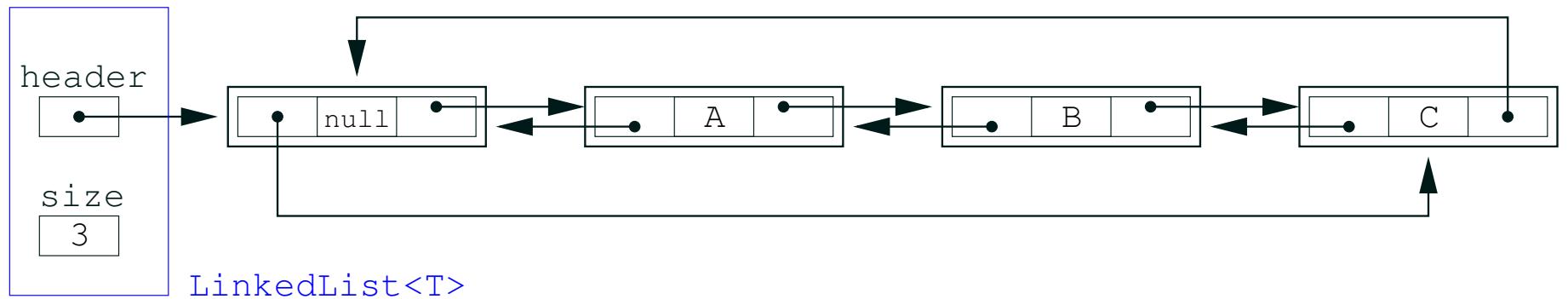
- List includes a dummy node—this make the implementations slicker



- Symmetric data structure so processing head and tail is equally efficient

# Dummy Node

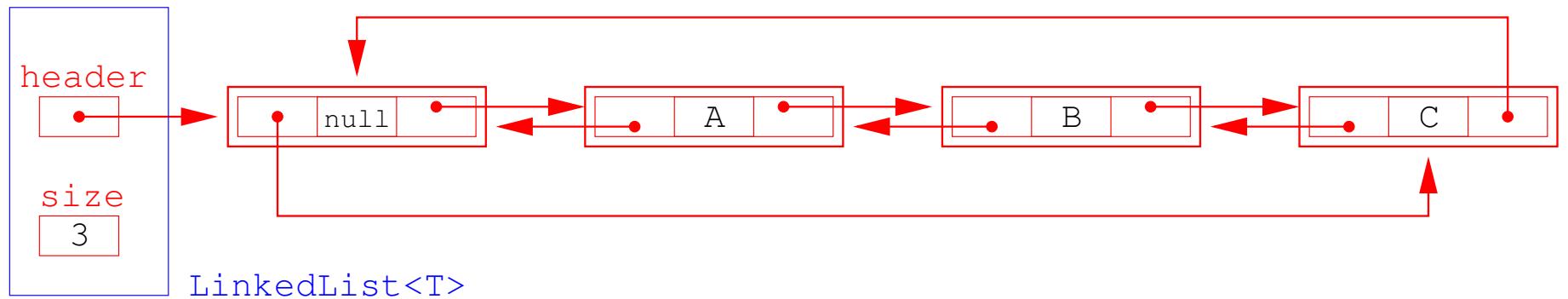
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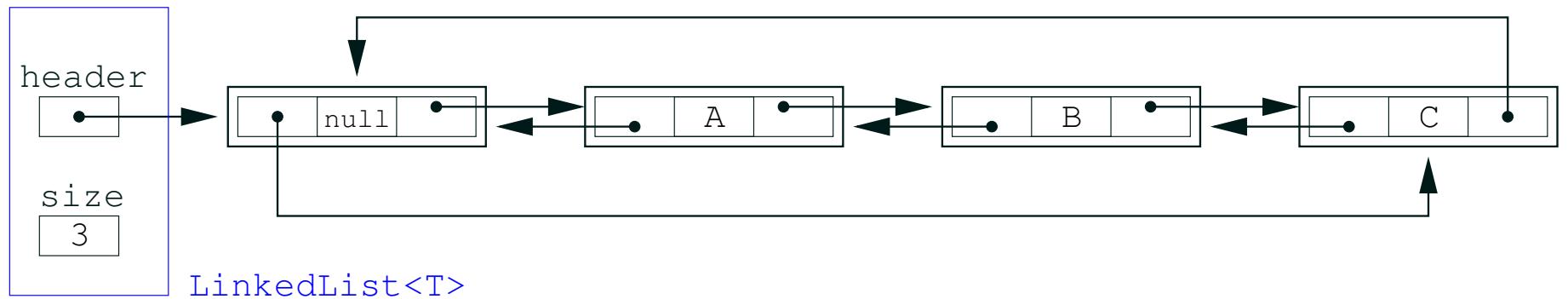
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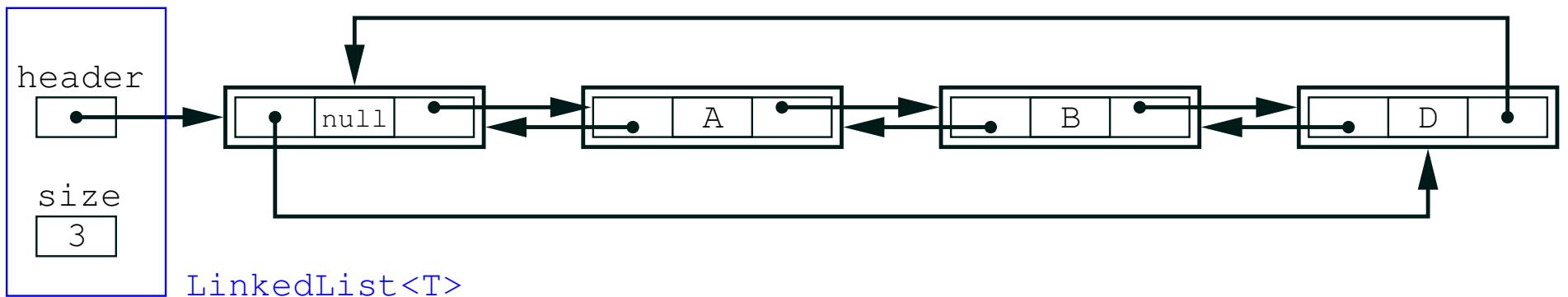
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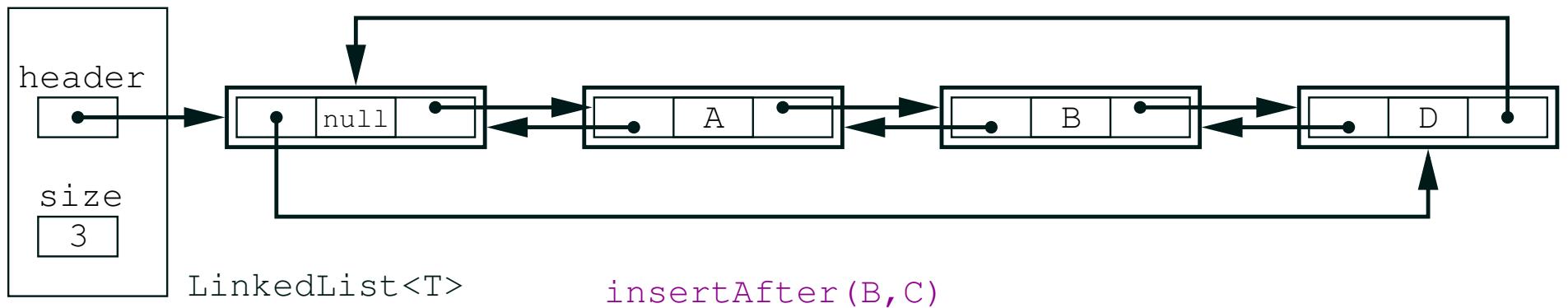
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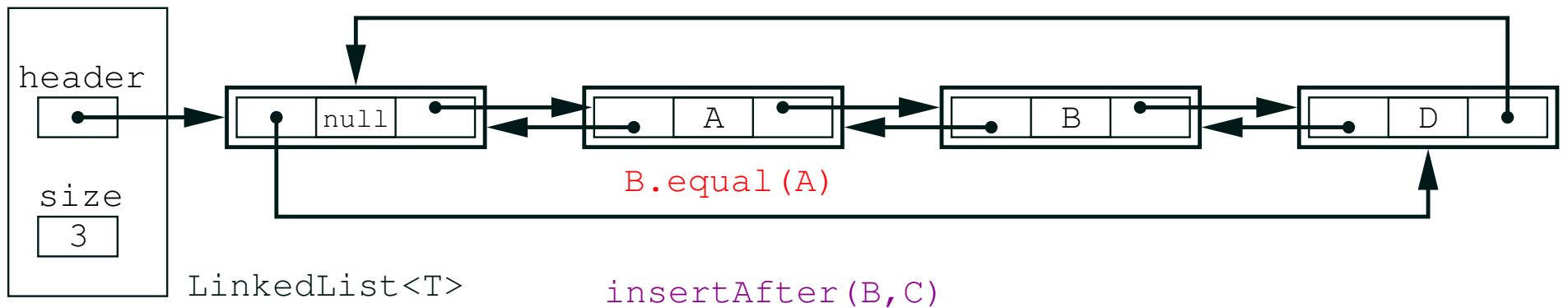
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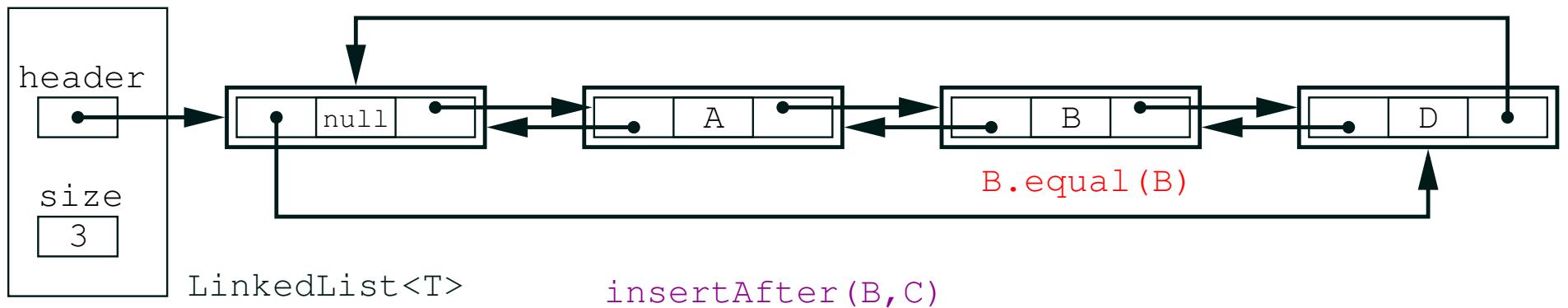
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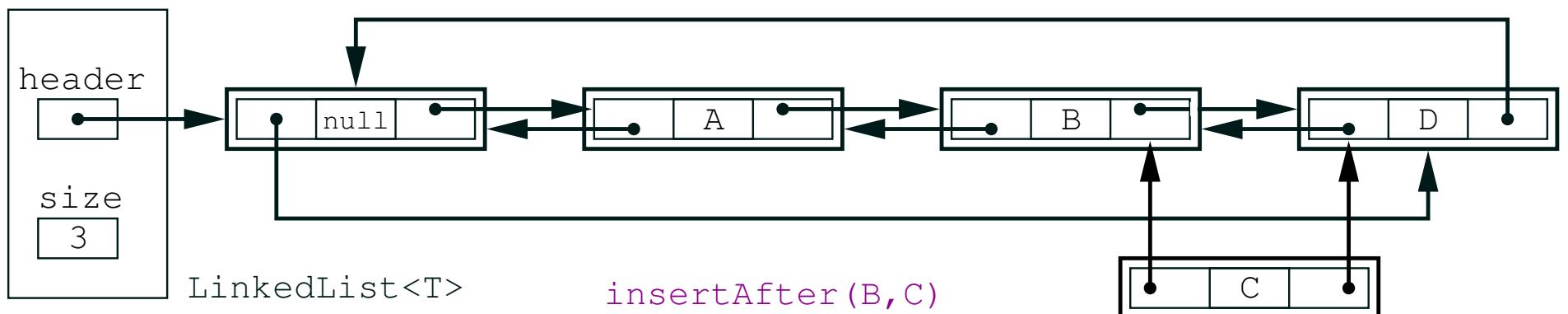
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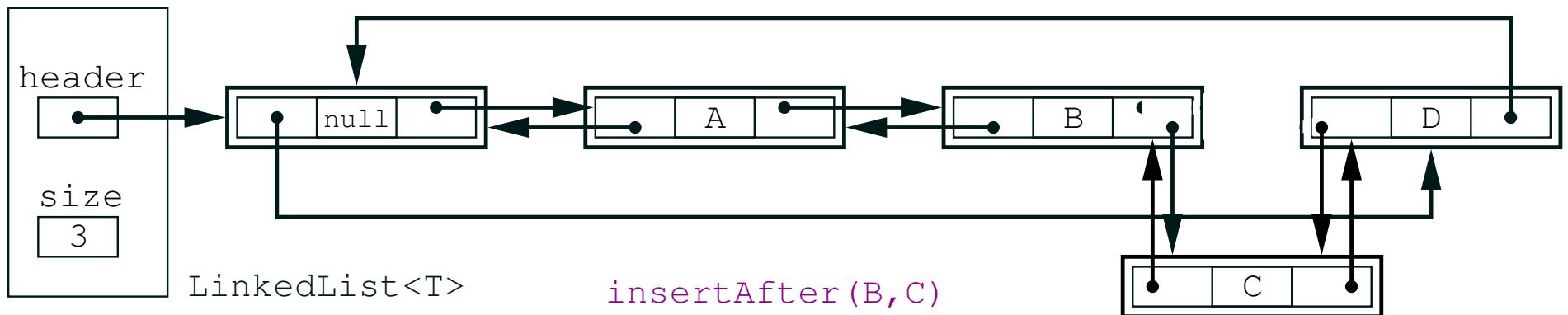
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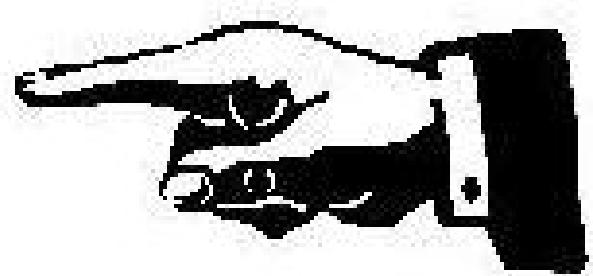
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# Outline

1. References
2. Singly Linked List
3. Stacks and Queues
4. Doubly Linked List
5. **Using Linked Lists**
6. Skip Lists



# When To Use Linked Lists

- It is difficult to think of applications where linked lists are the best data structure
- lists—variable length arrays are usually better
- queues—linked list OK, but circular arrays are probably better
- sorted lists—binary trees much better
- linked lists have efficient insertion and deletion but it is difficult to think of an application where this matters

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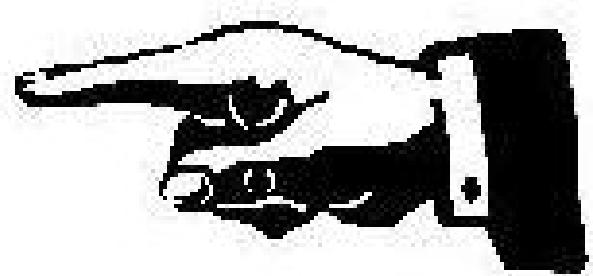
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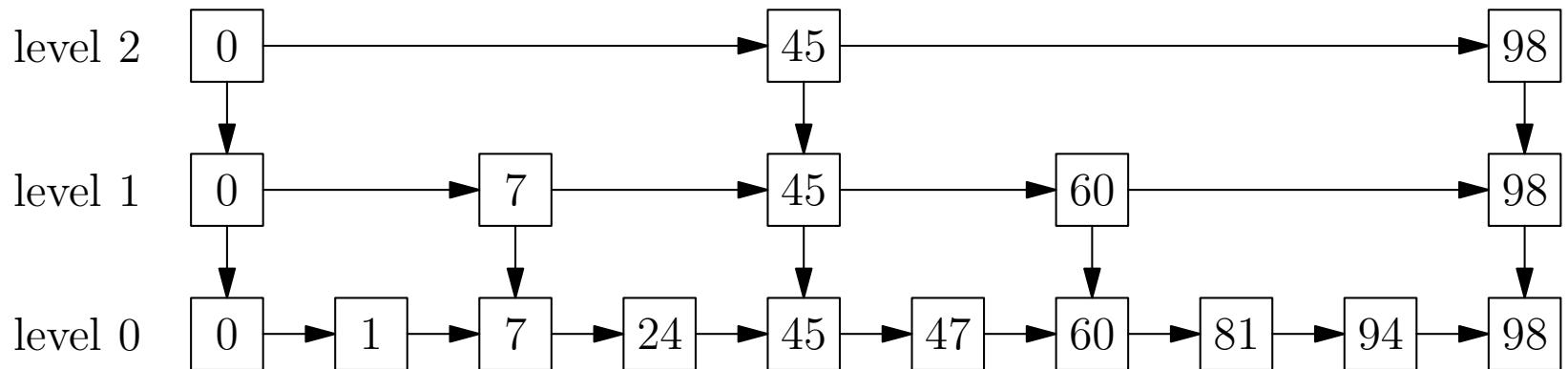
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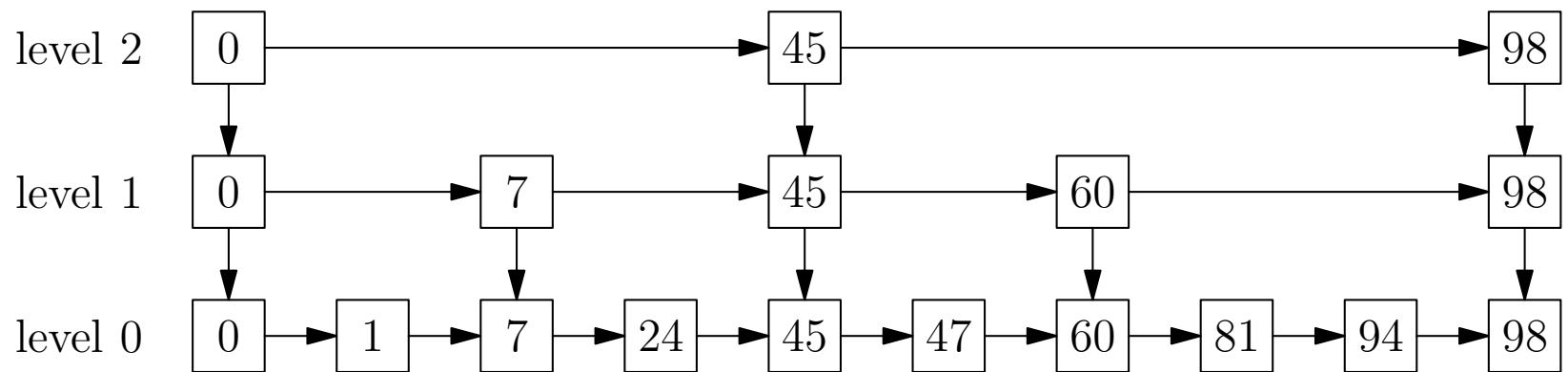
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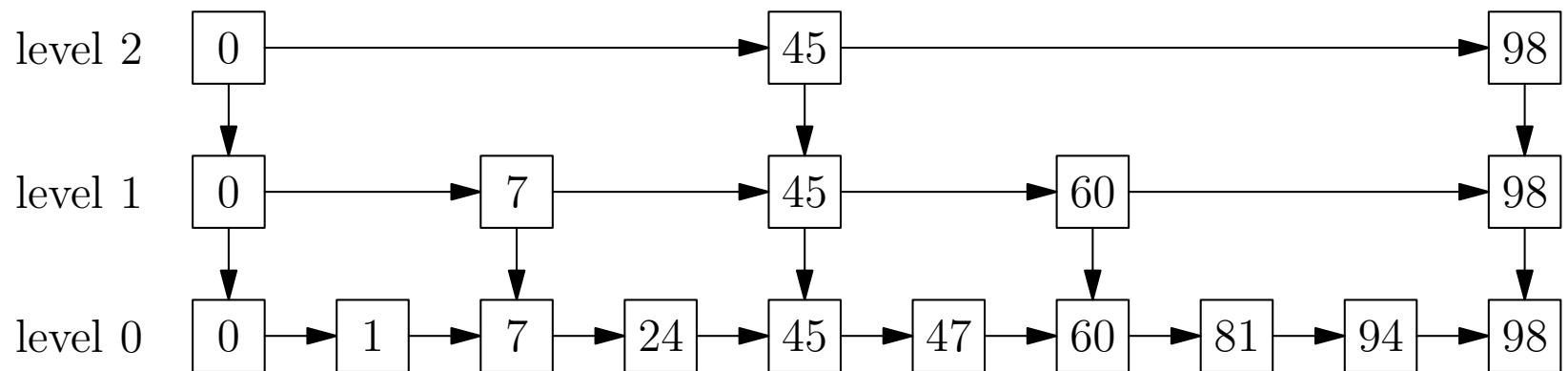
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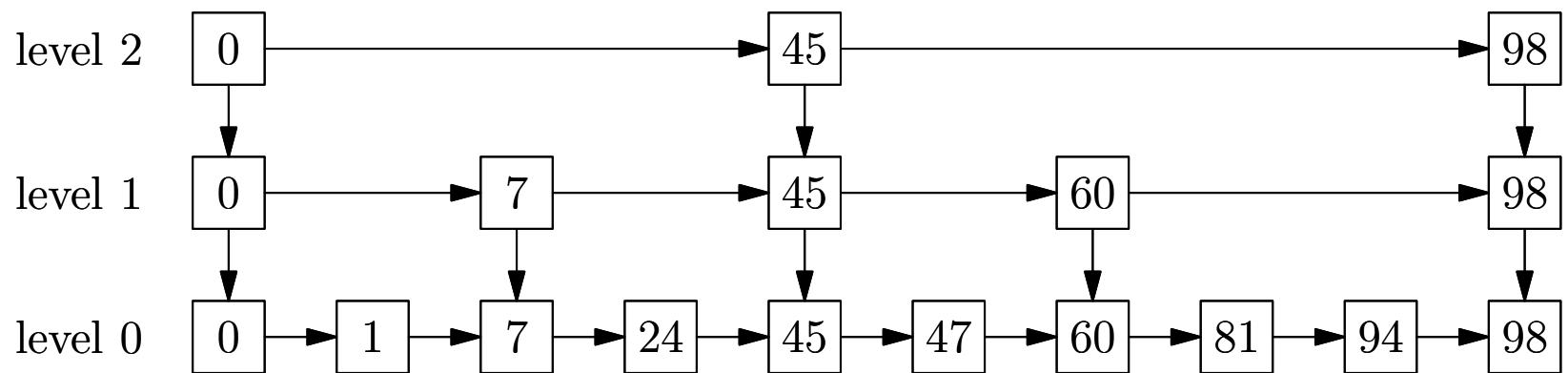
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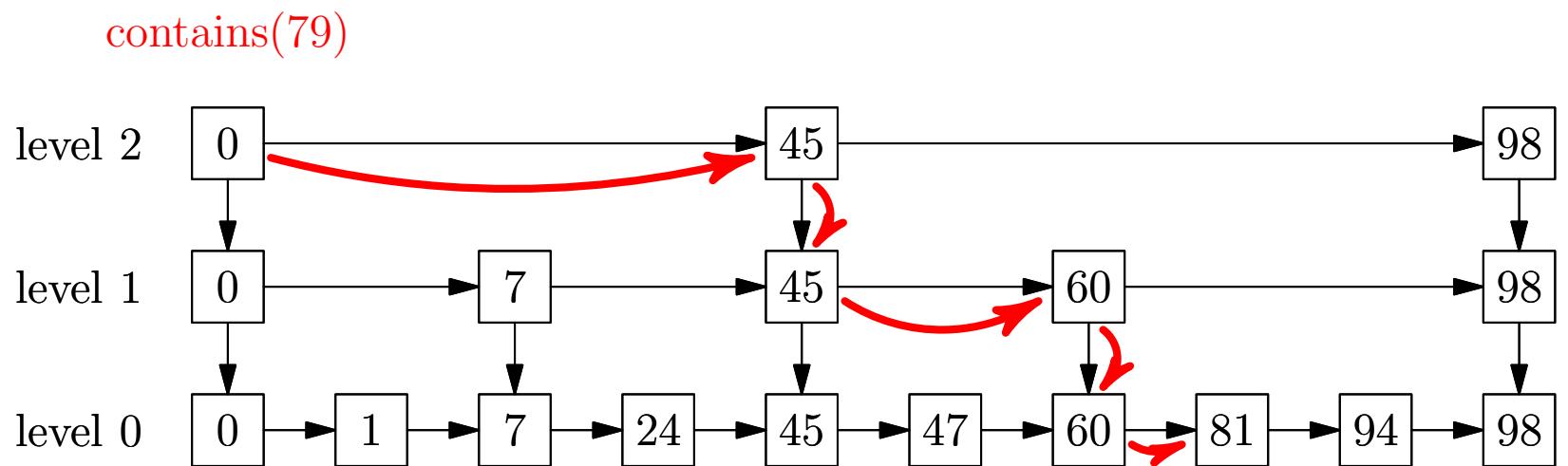
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contains(79)



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# Lessons

- Node structures that point to other Node structures are used in many important data structures
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