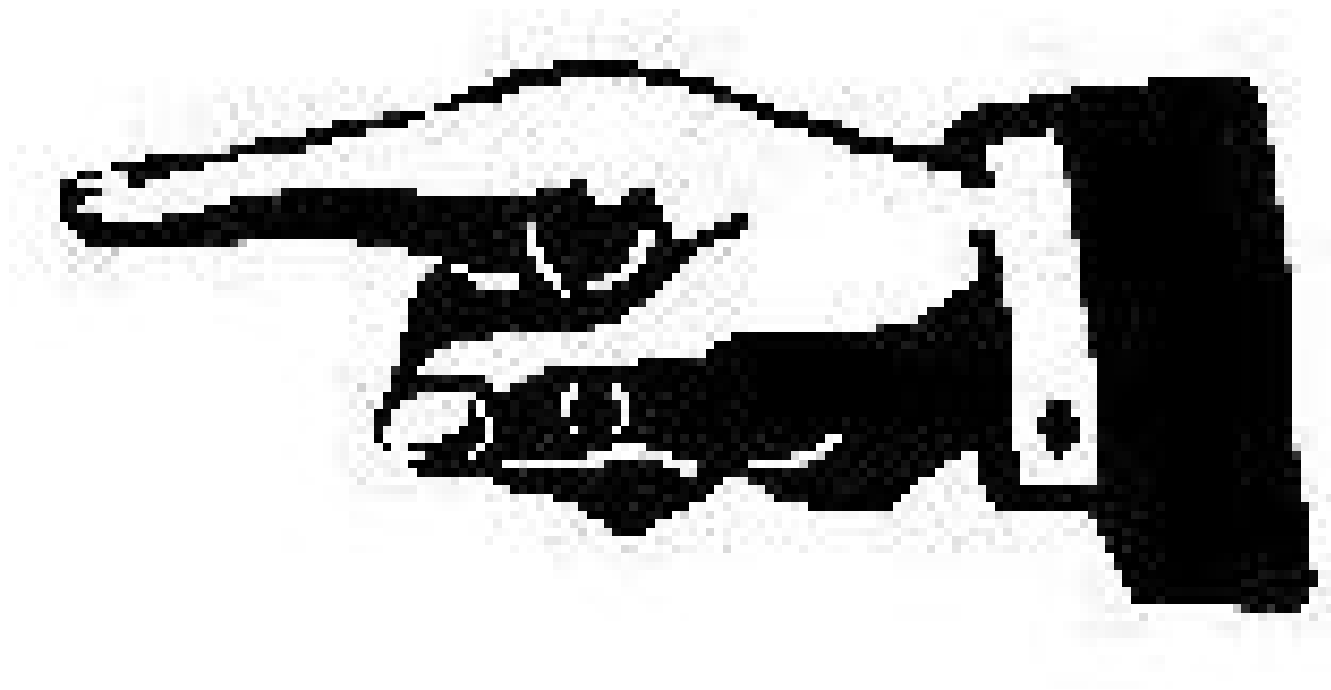


Algorithms and Analysis

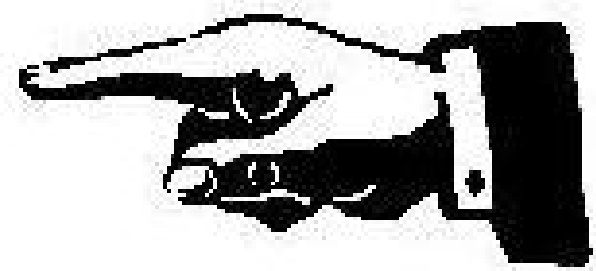
Lesson 5: *Point to where you are going: links*



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
 - ★ Graphs
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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;
    Node<T> *next;
}
```

- 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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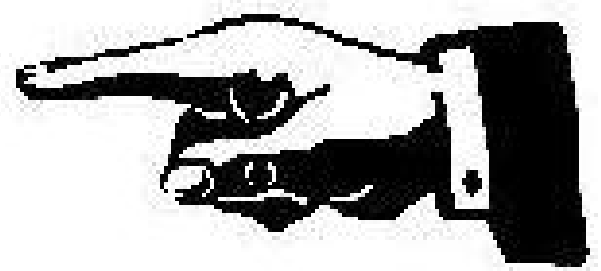
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Singly Linked List

- We can build a linked list by stringing nodes together



We don't show the “pointer” to `element`

- A singly linked list has a single “pointer” to the next element
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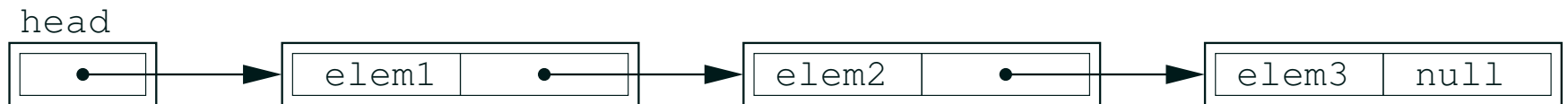


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Implementation

- 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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private:  
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Simple Methods

- The constructor is simple (and not strictly necessary)

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

```
unsigned size() const {return noElements;}
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```
bool empty() const {  
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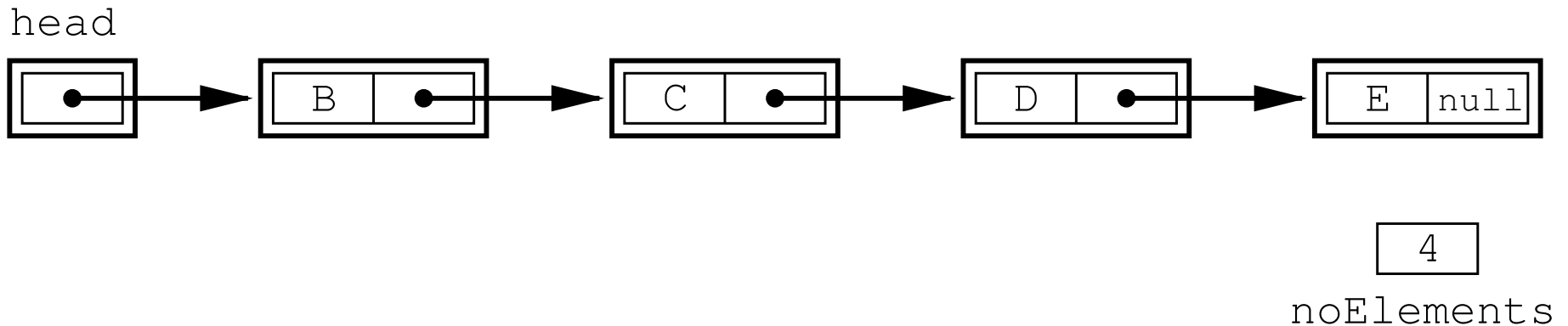
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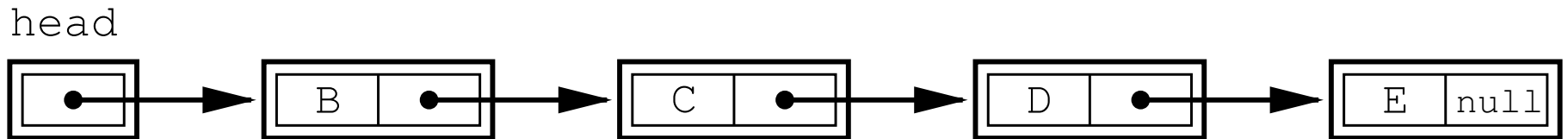
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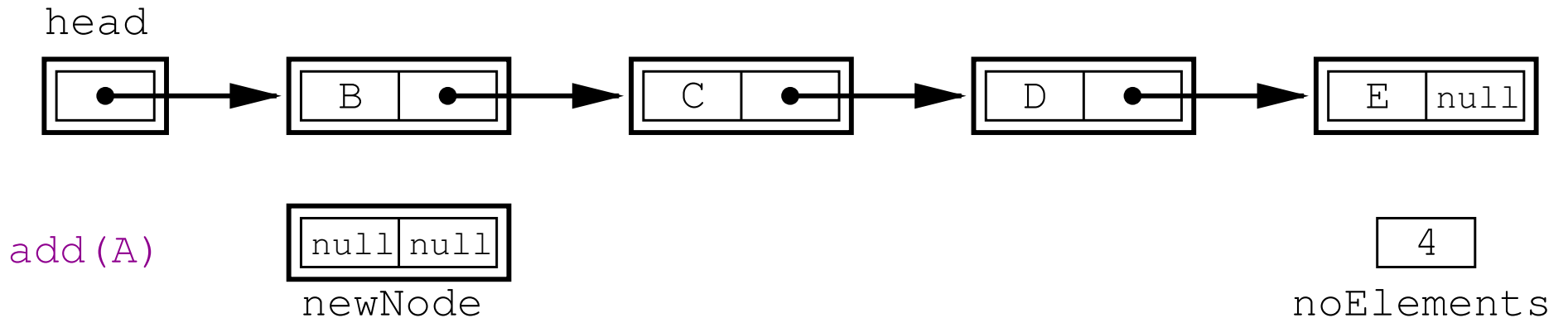


add(A)

4
noElements

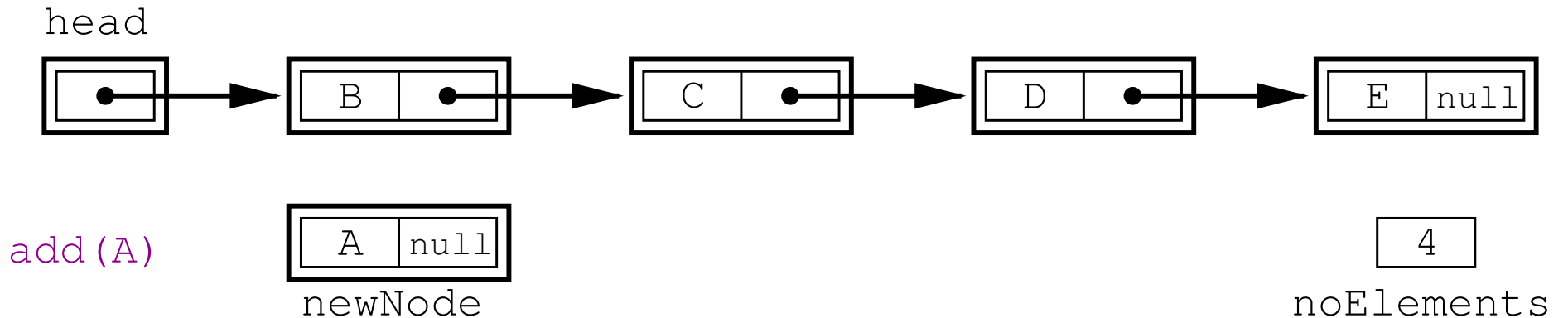
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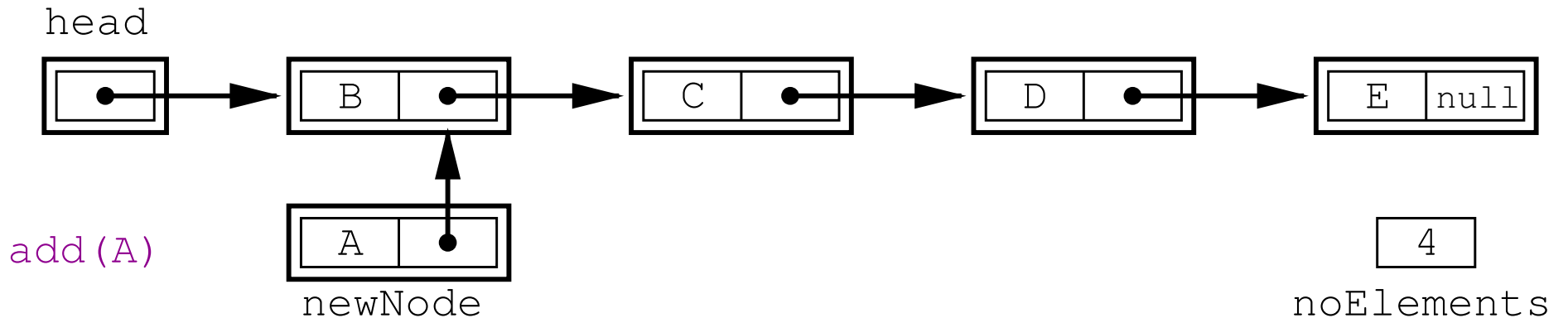
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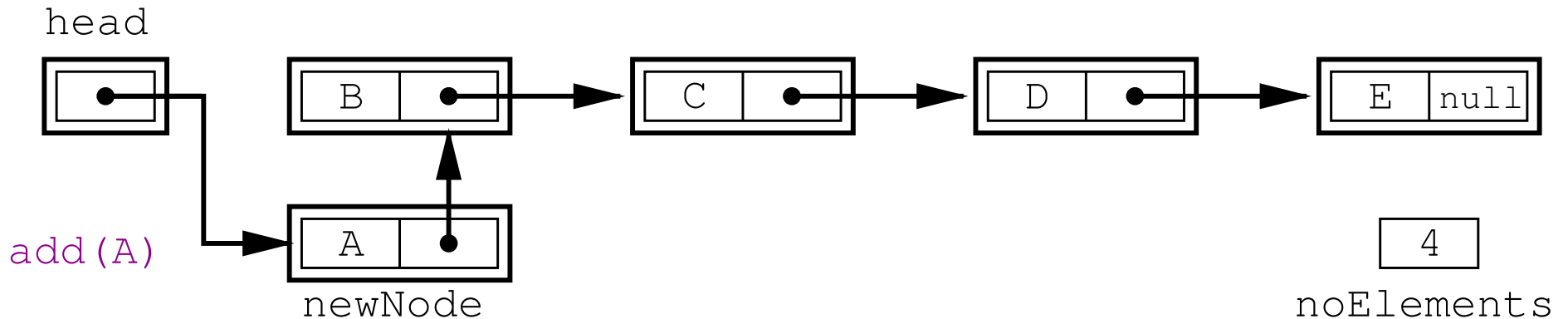
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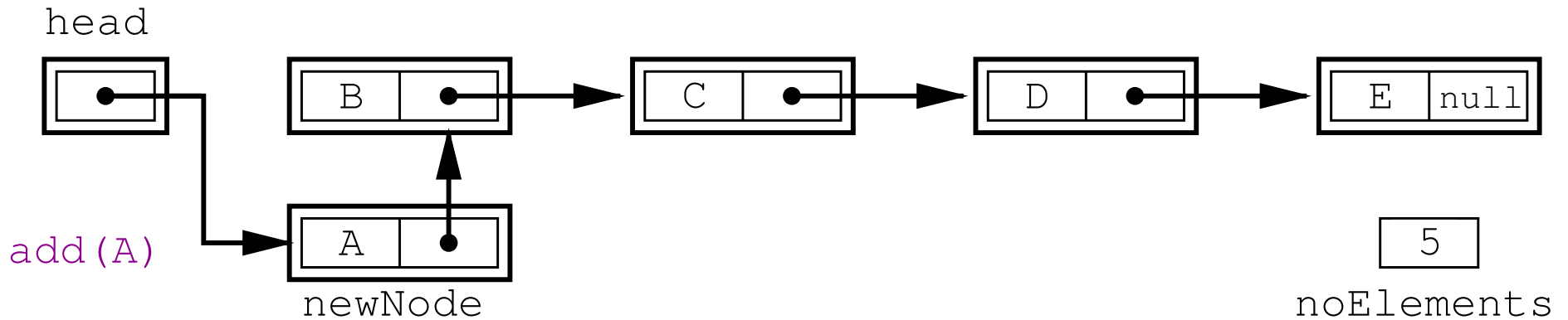
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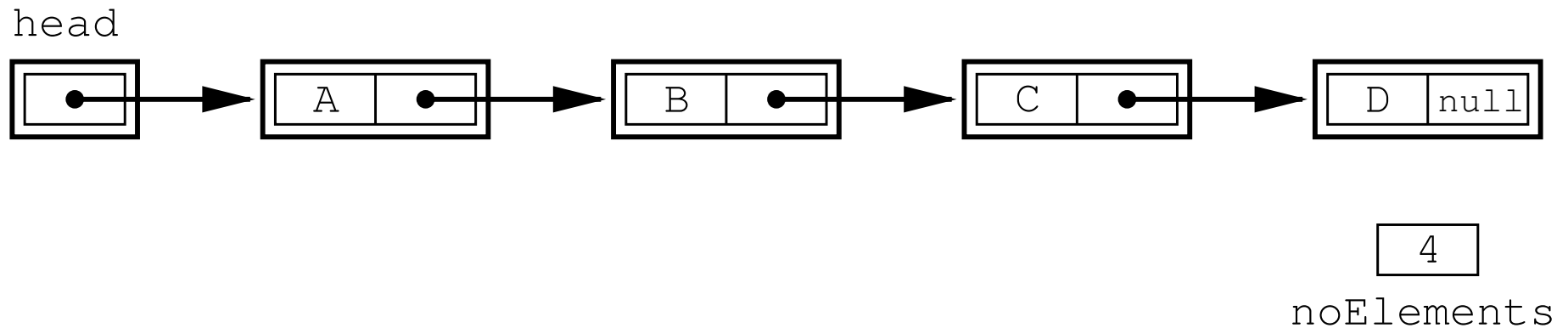


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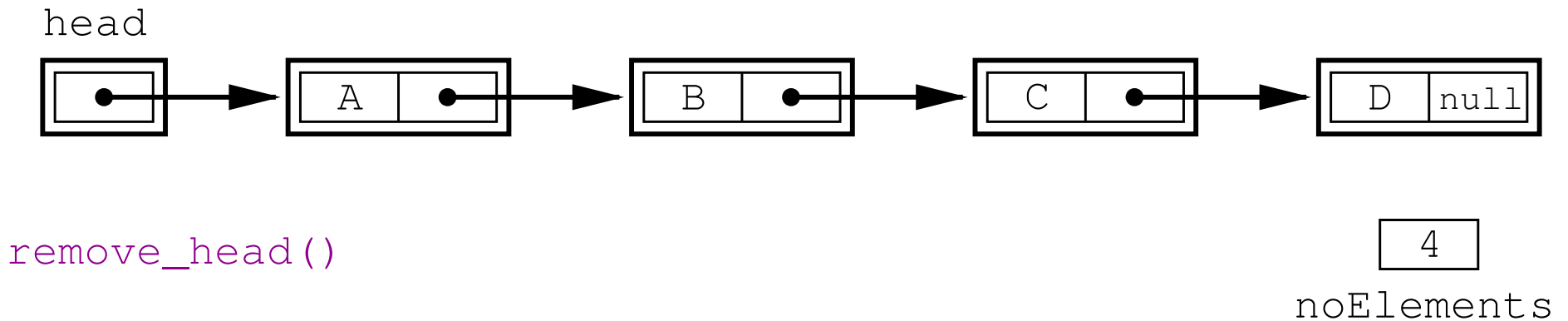
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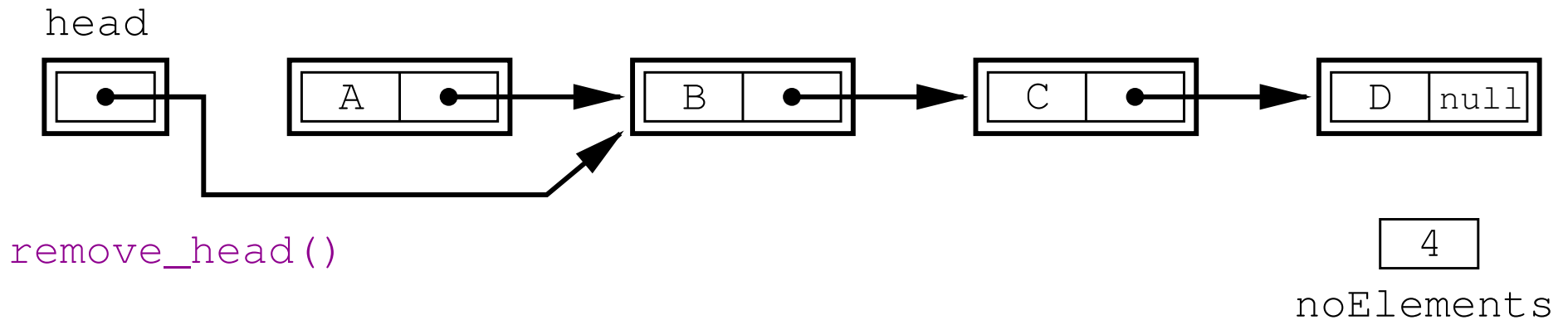
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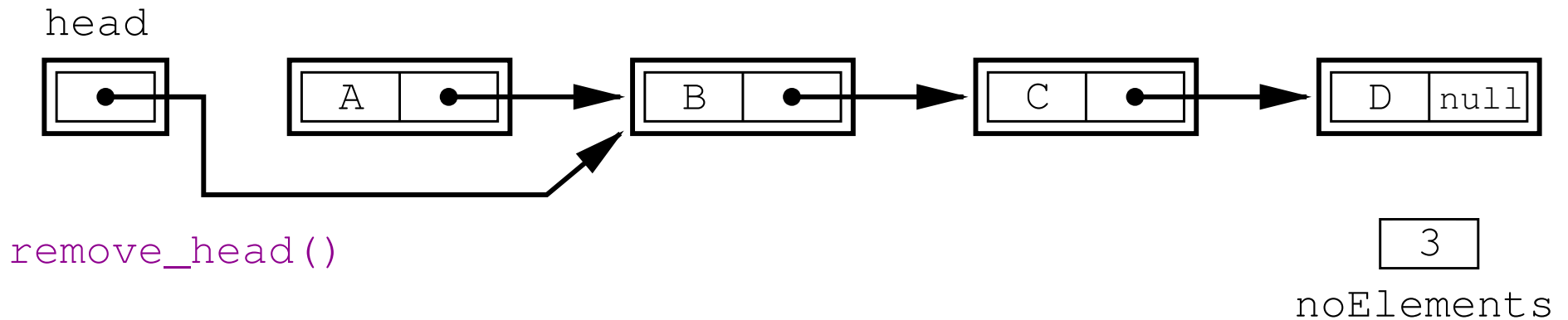
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 - ★ `get(int i)` —return i^{th} item in list
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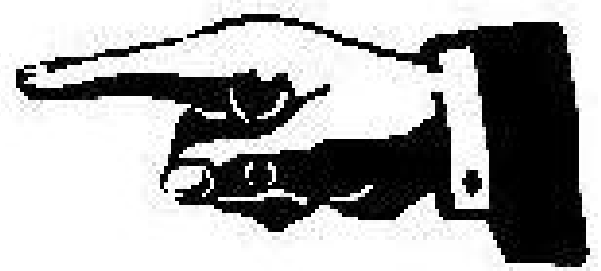
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Stack

- 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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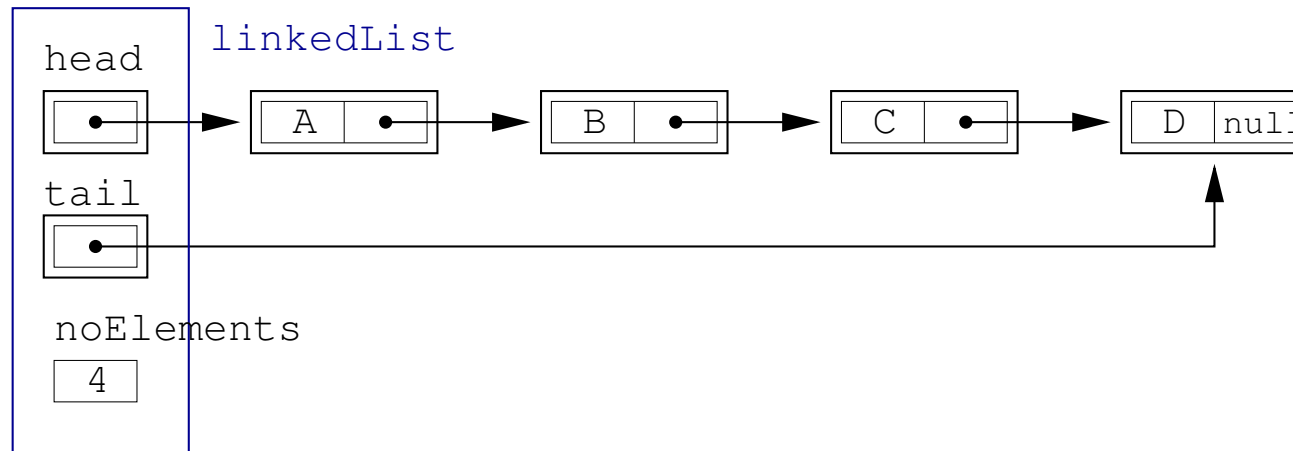
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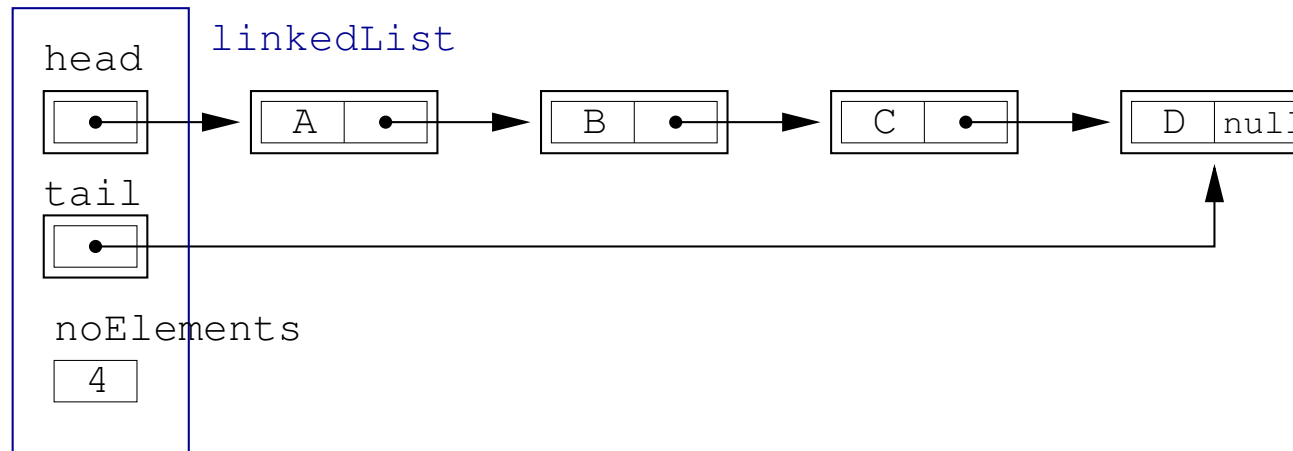
Point to the Back

- 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



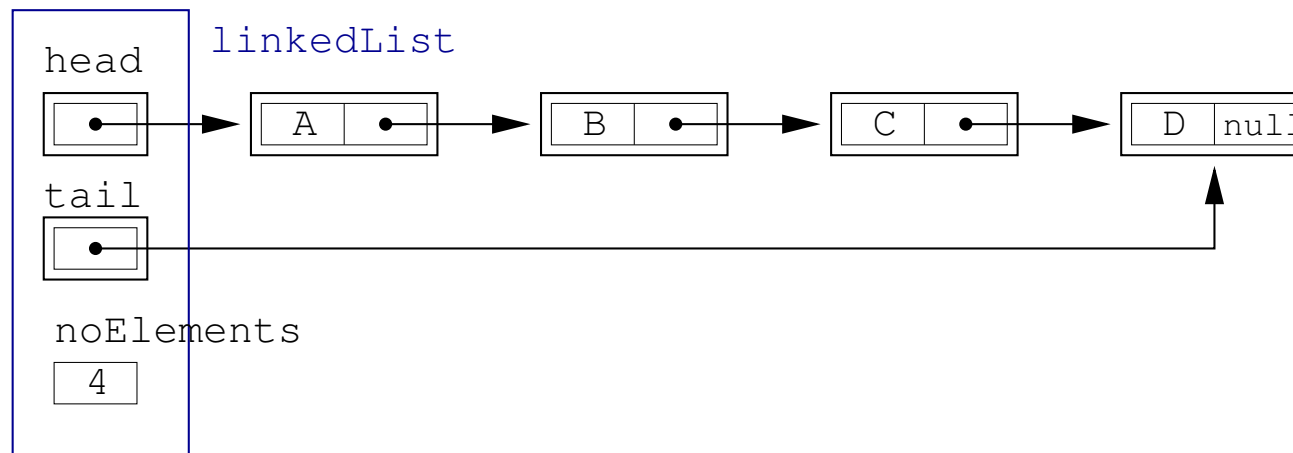
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Implementing a Queue

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- We can then implement a queue in $O(1)$ time by
 - ★ enqueueing at the back
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- I leave the implementation details as an exercise for you
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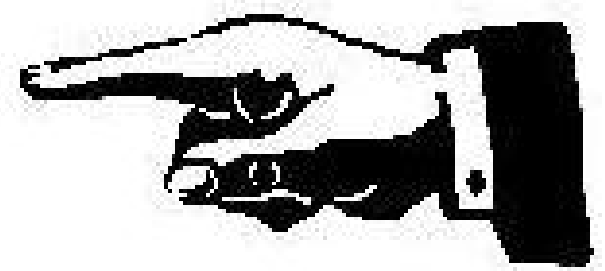
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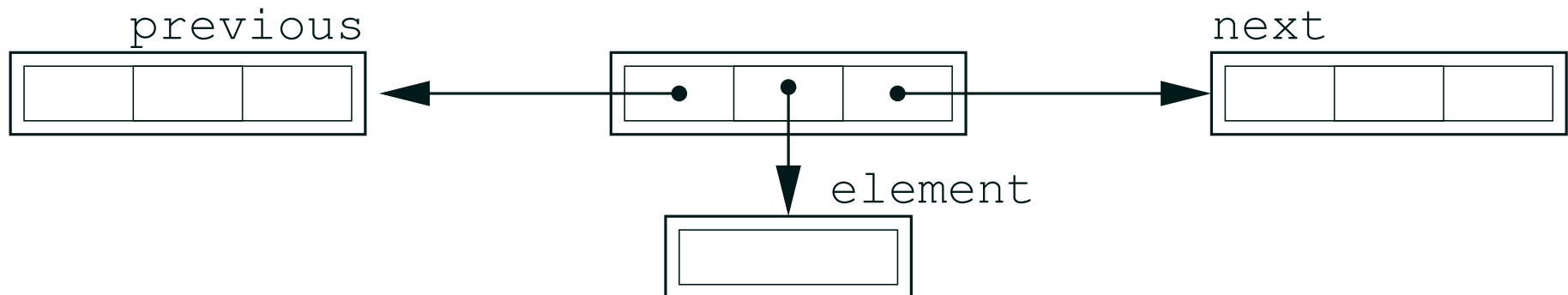
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Doubly linked list

- 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

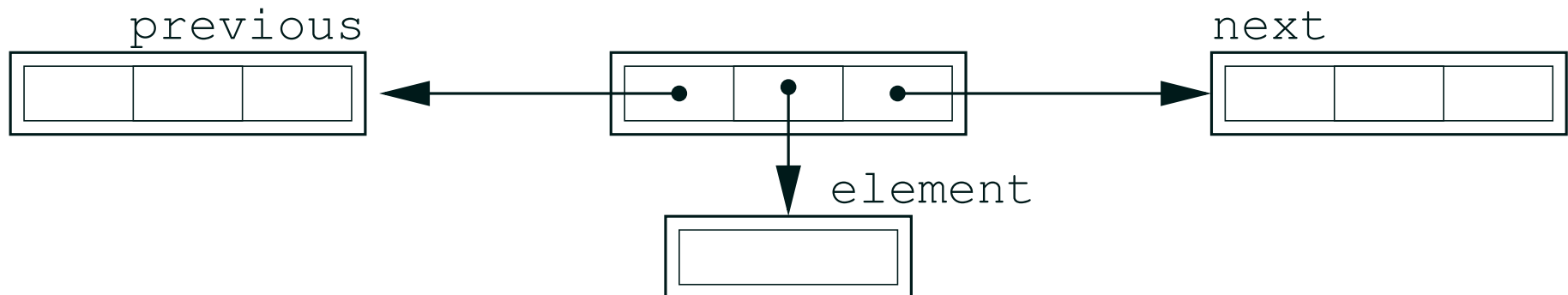
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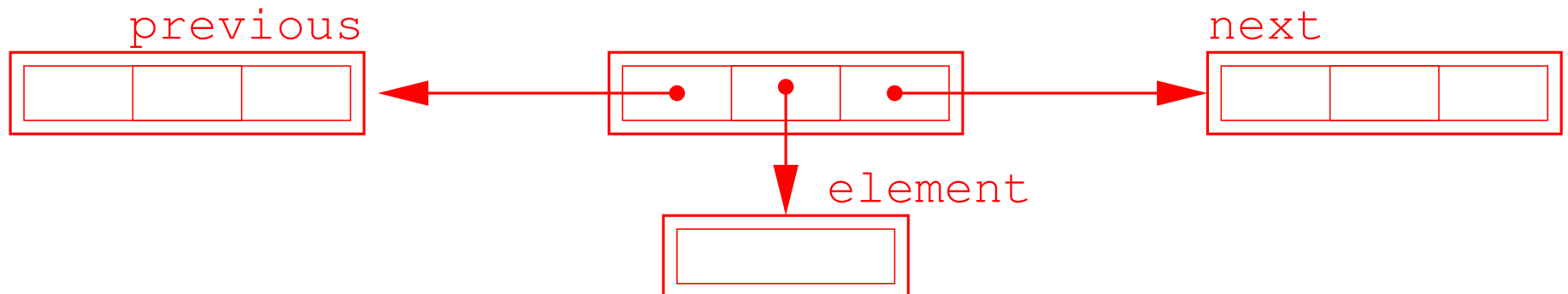
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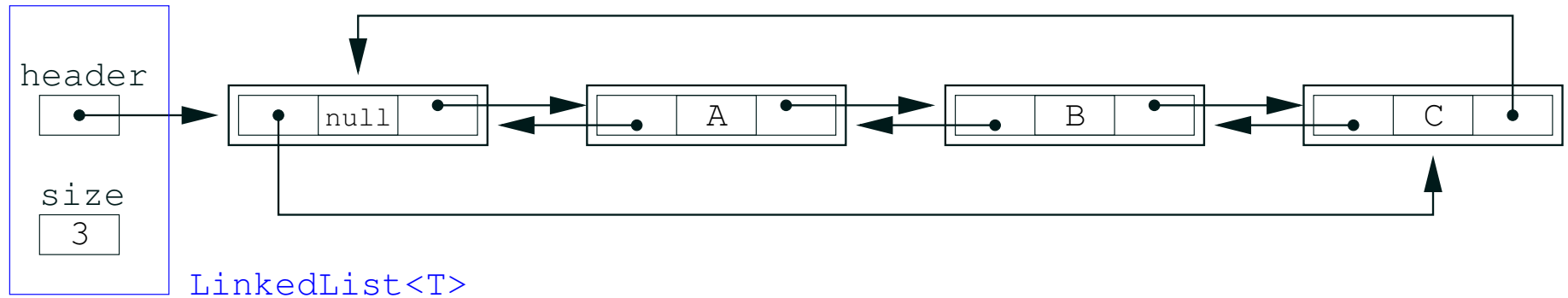
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Dummy Node

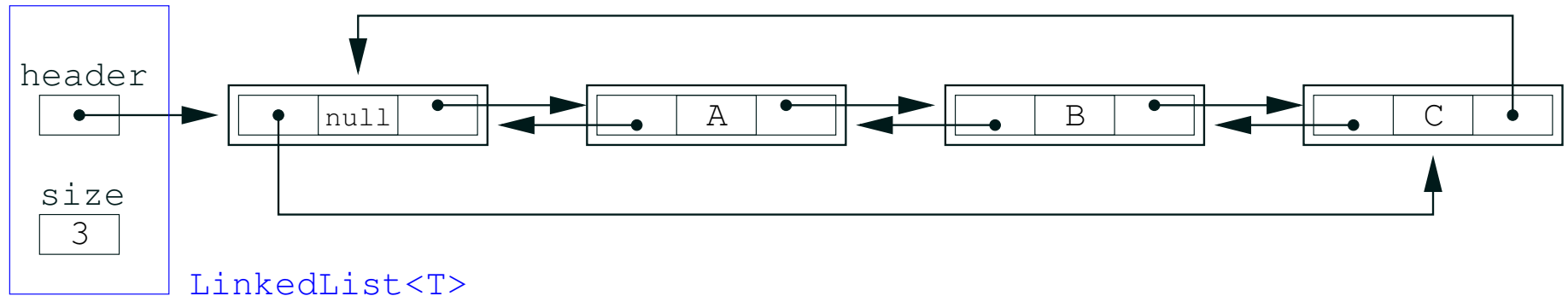
- List includes a dummy node—this make the implementations slicker



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

Dummy Node

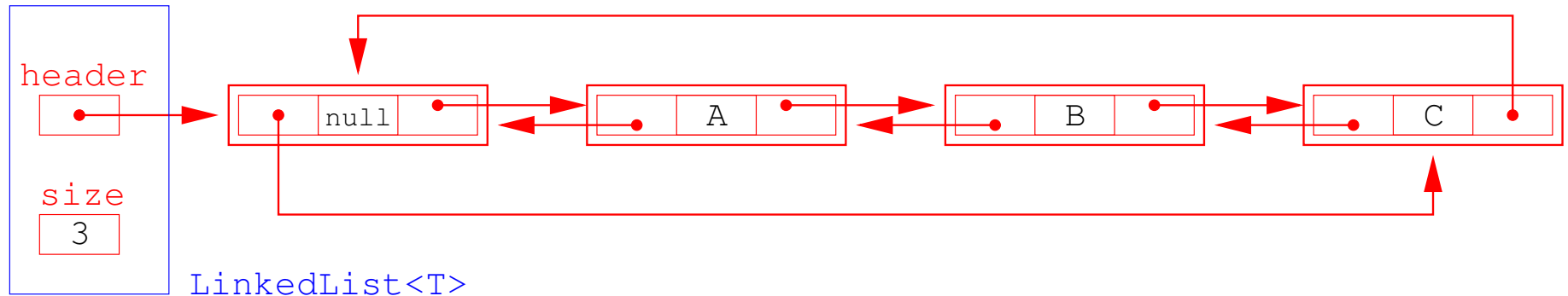
- List includes a dummy node—this make the implementations slicker



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

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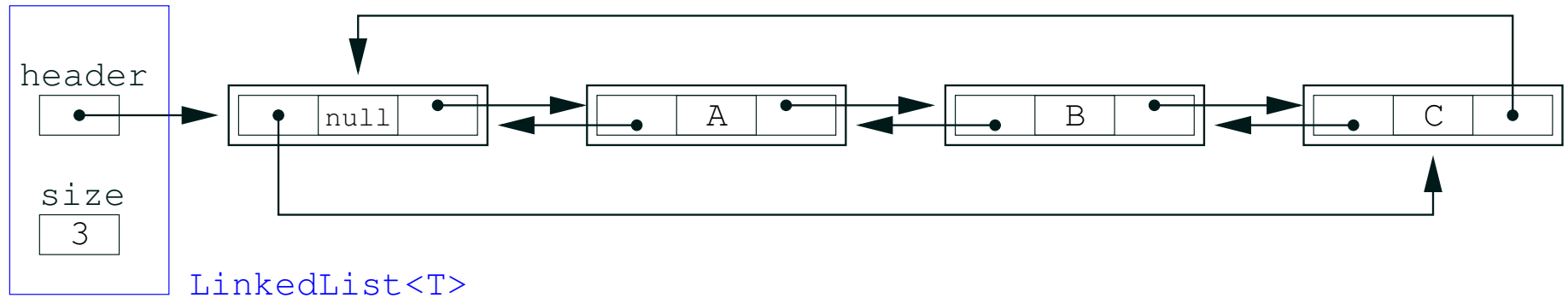
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- find $O(n)$ and slow
- insert and delete $O(1)$ (faster than an array list) once position is found

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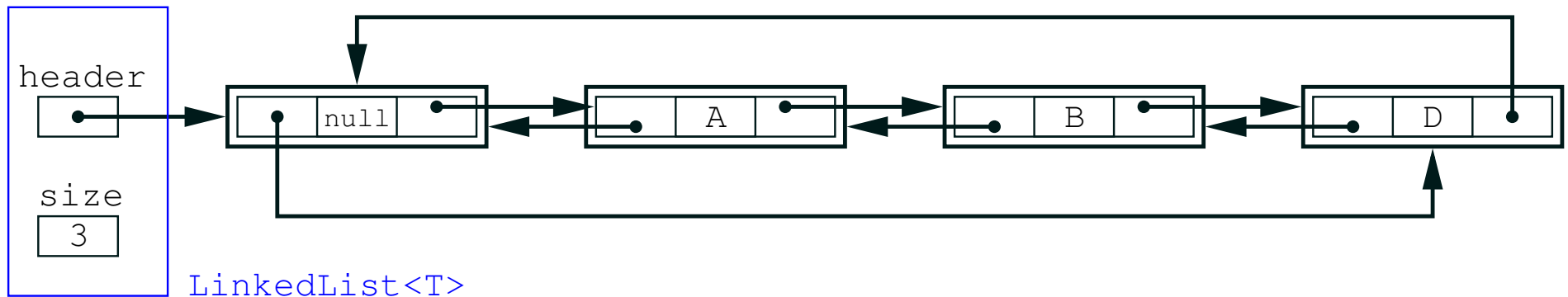
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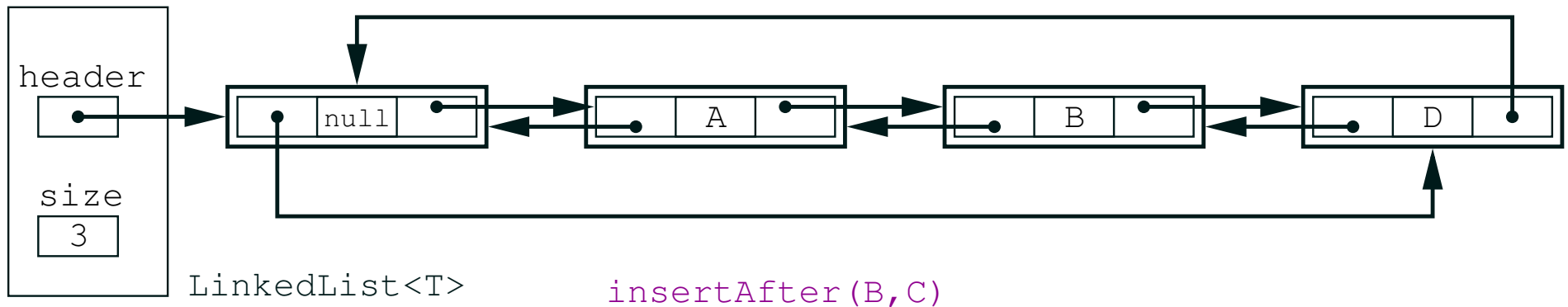
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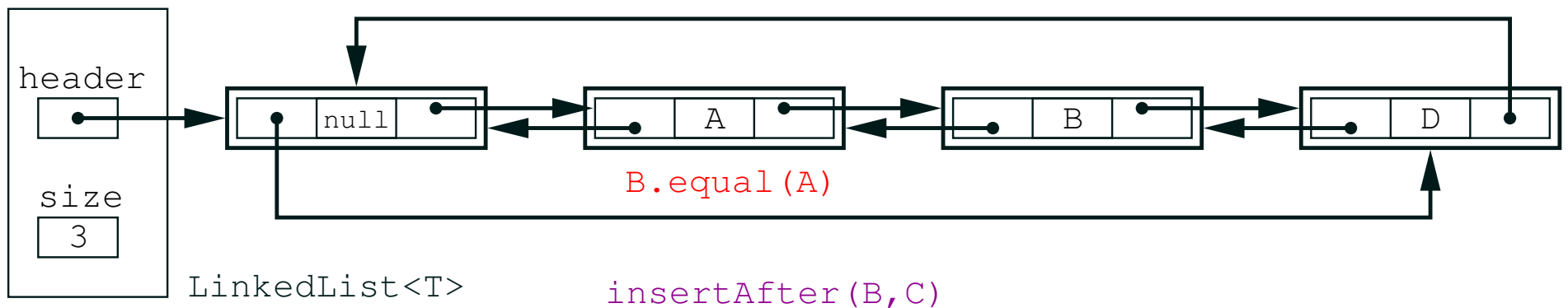
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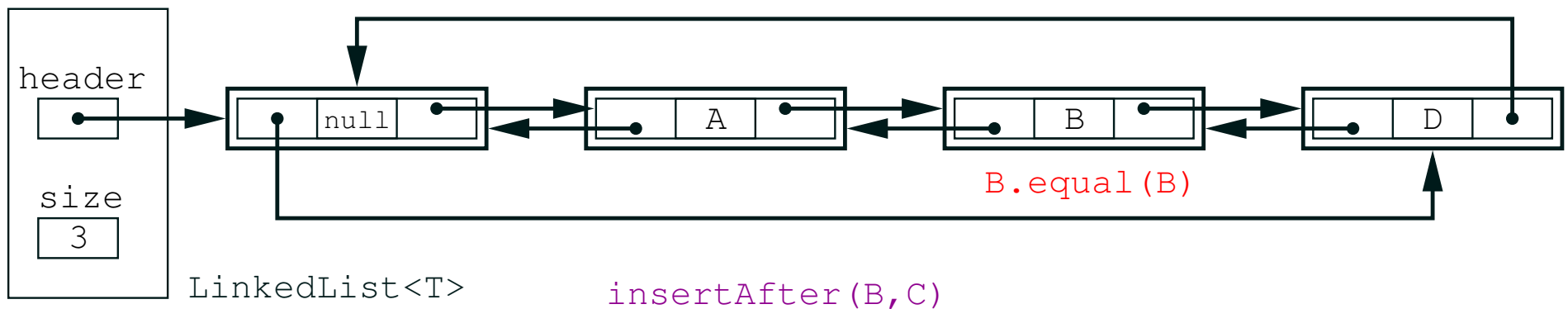
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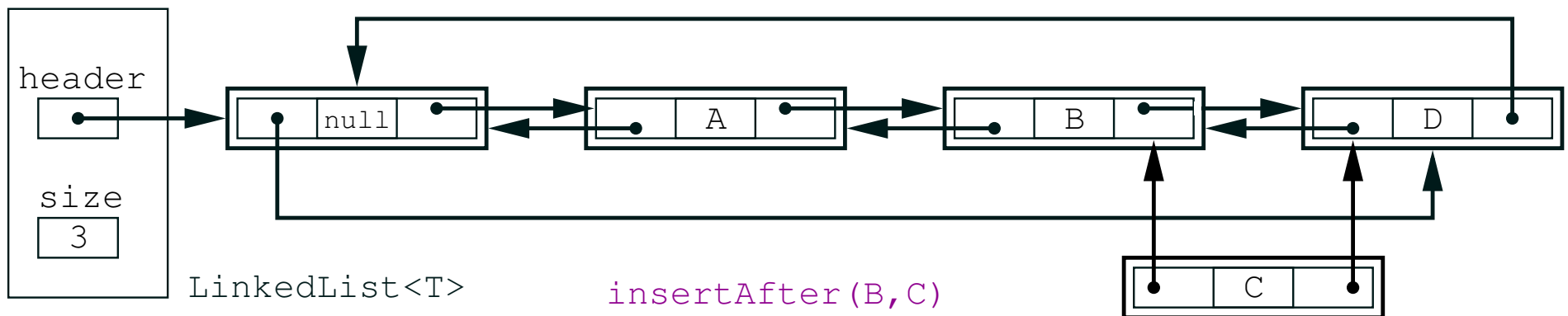
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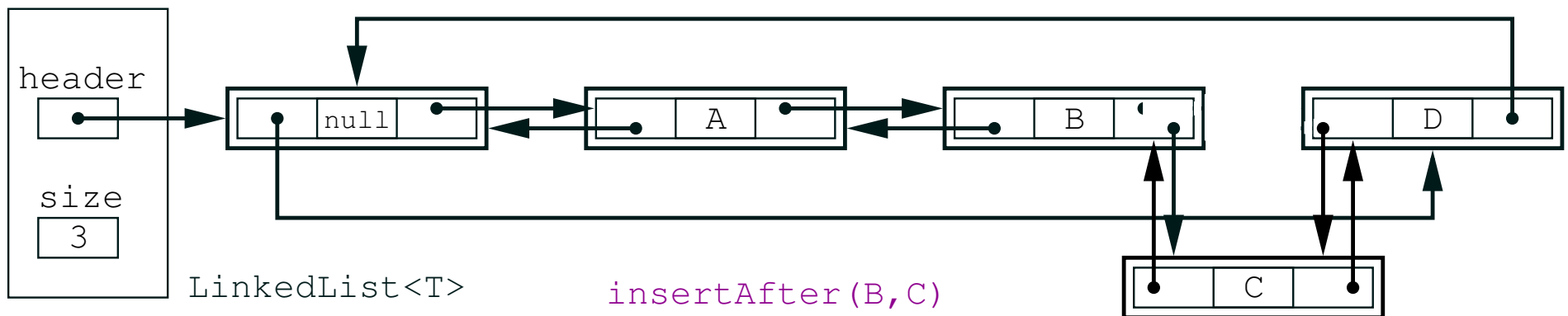
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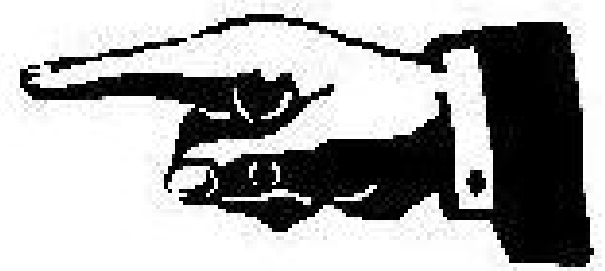
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Outline

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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- We are usually working at a particular location in the text
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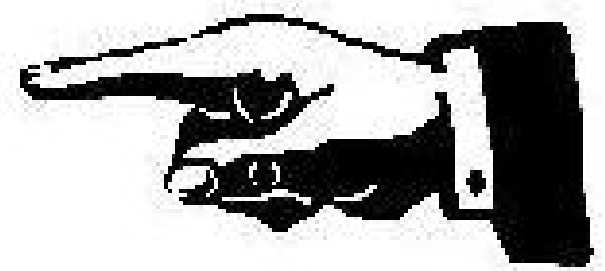
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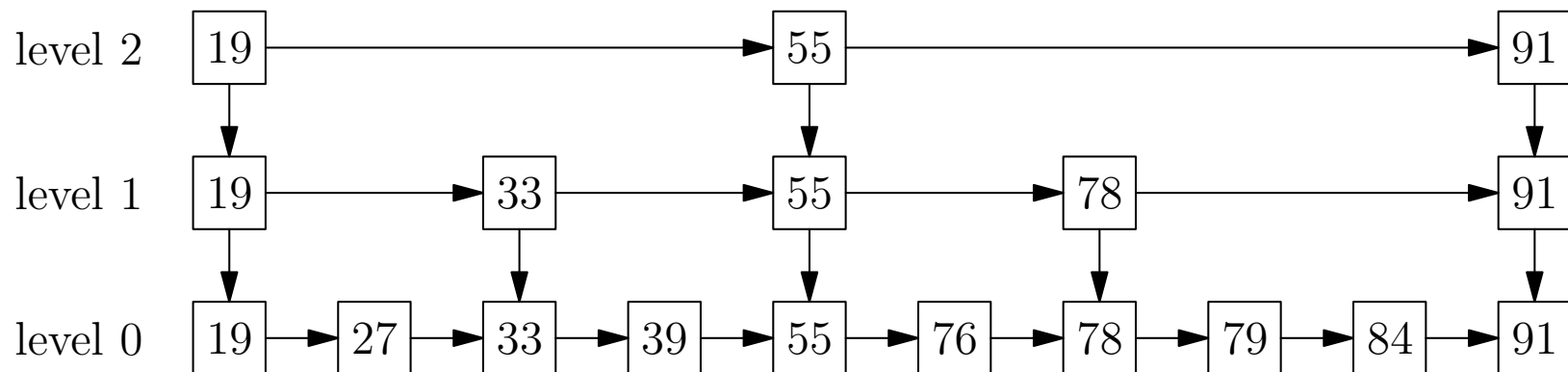
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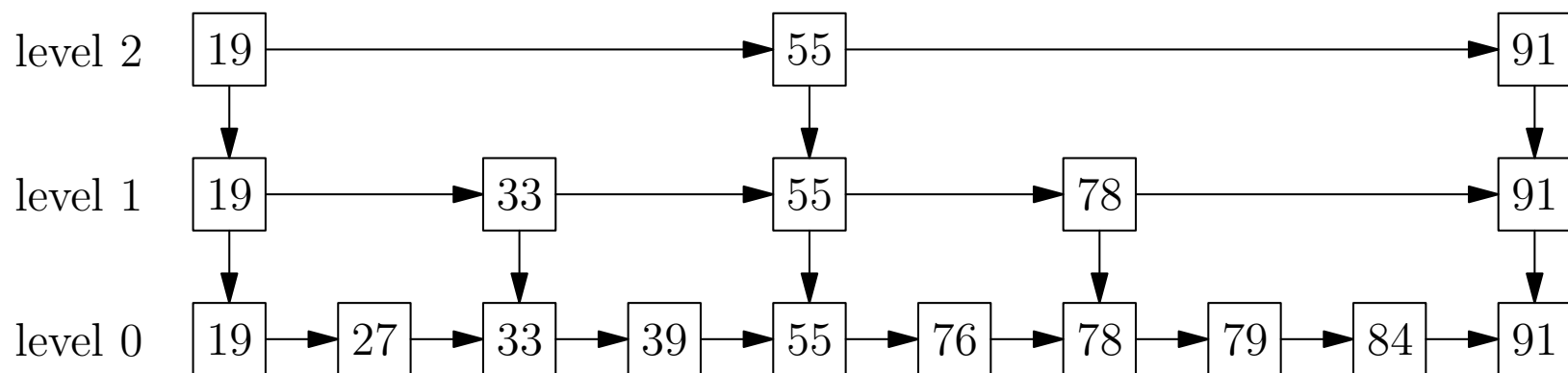
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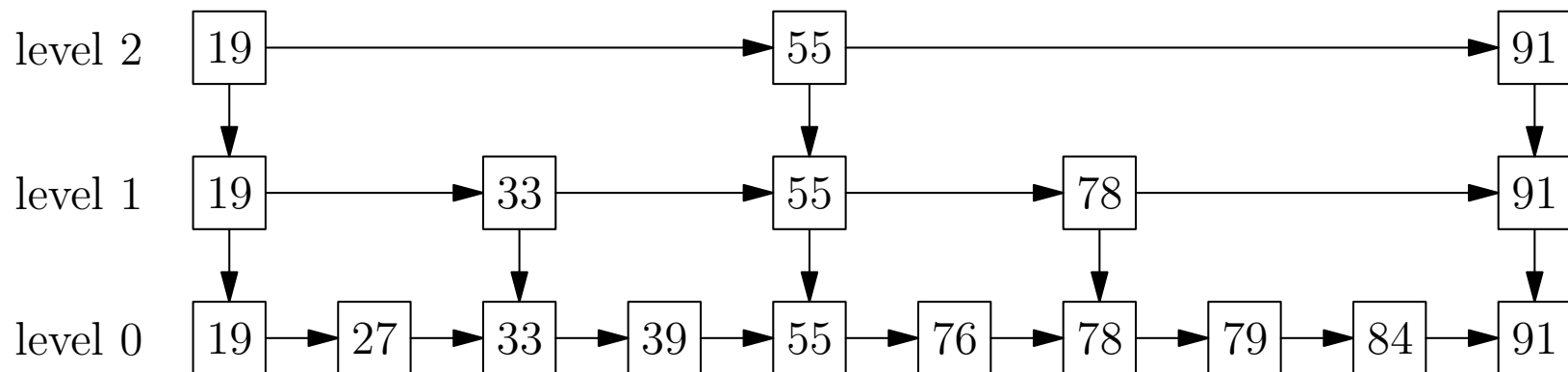
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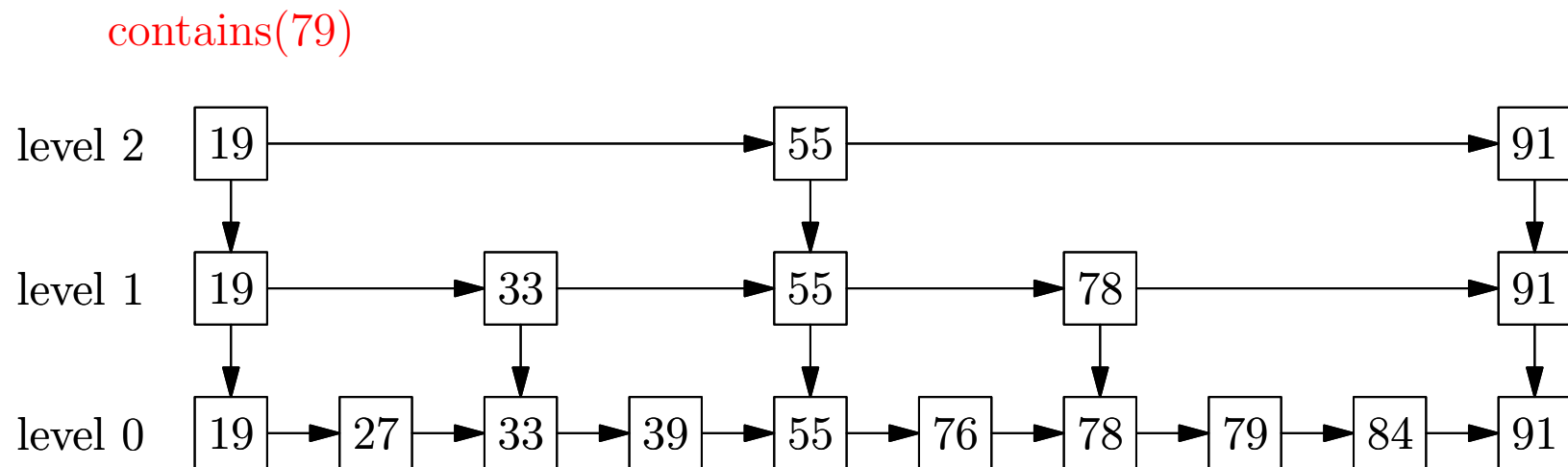
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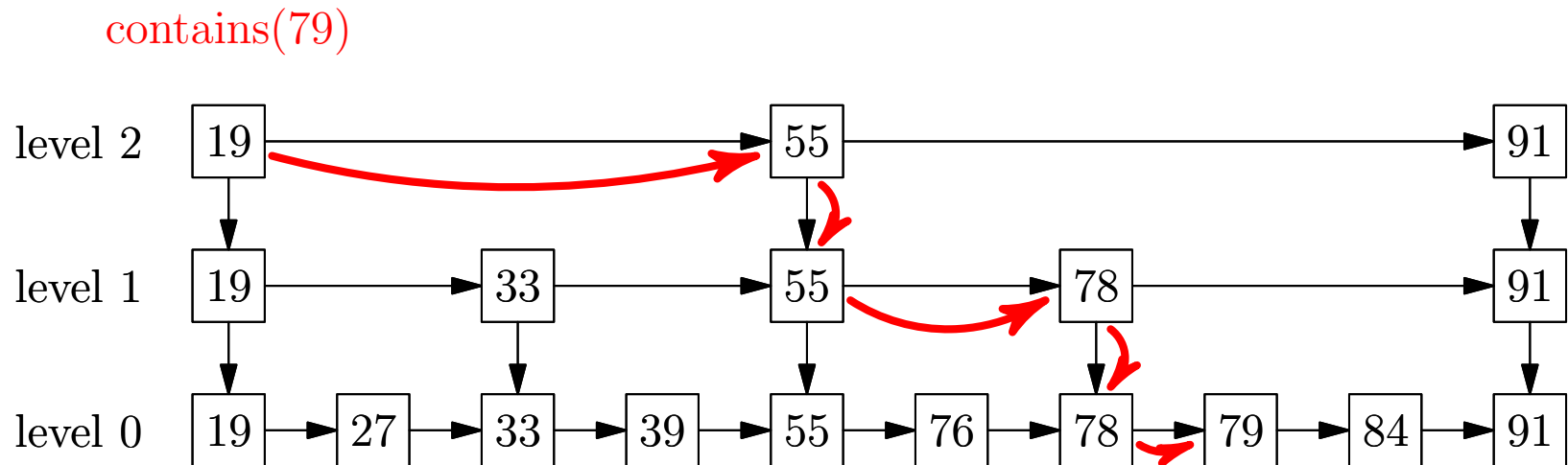
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- Skip lists provide $\Theta(\log_2(n))$ search as opposed to $\Theta(n)$
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Lessons

- Node structures that point to other Node structures are used in many important data structures
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- In practice linked lists are seldom the data structure of choice—before choosing to use a linked list consider the alternatives
- There are some important uses for linked lists, e.g. skip lists and hash tables (see lecture on hashing)

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