Linked Lists

Part Two

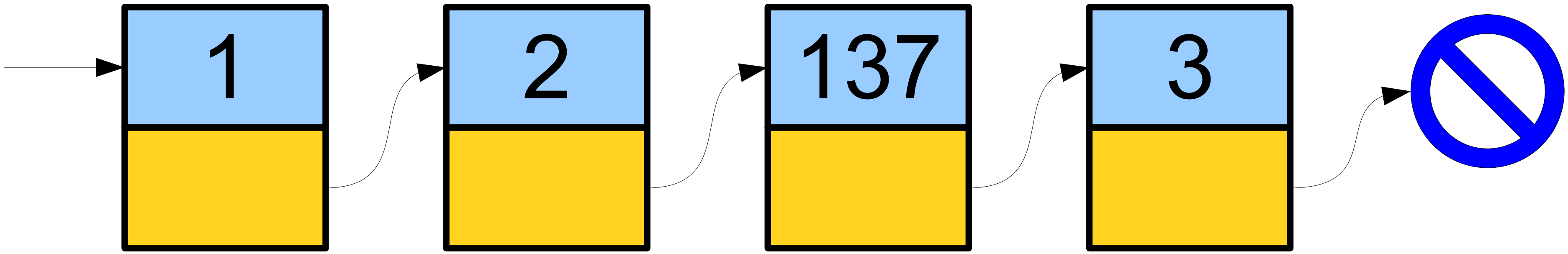
Outline for Today

- ***Pointers by Reference***
  - Changing where you’re looking.
- ***Tail Pointers***
  - Speeding up list operations.
- ***Doubly-Linked Lists***
  - A preview of things to come.

Recap from Last Time

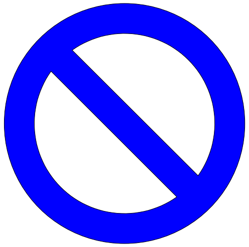
Linked Lists

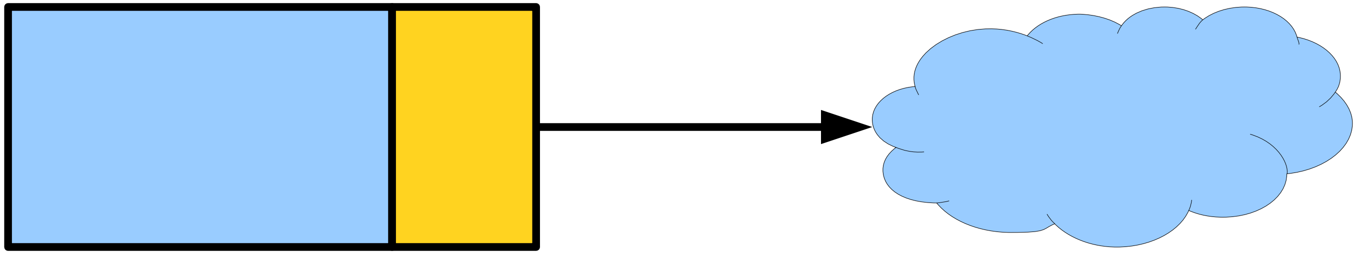
- A ***linked list*** is a data structure for storing a sequence of elements.
- Each element is stored separately from the rest.
- The elements are then chained together into a sequence.
- The end of the list is marked with some special indicator.



A Linked List is Either…

…an empty list,
represented by
nullptr, or…





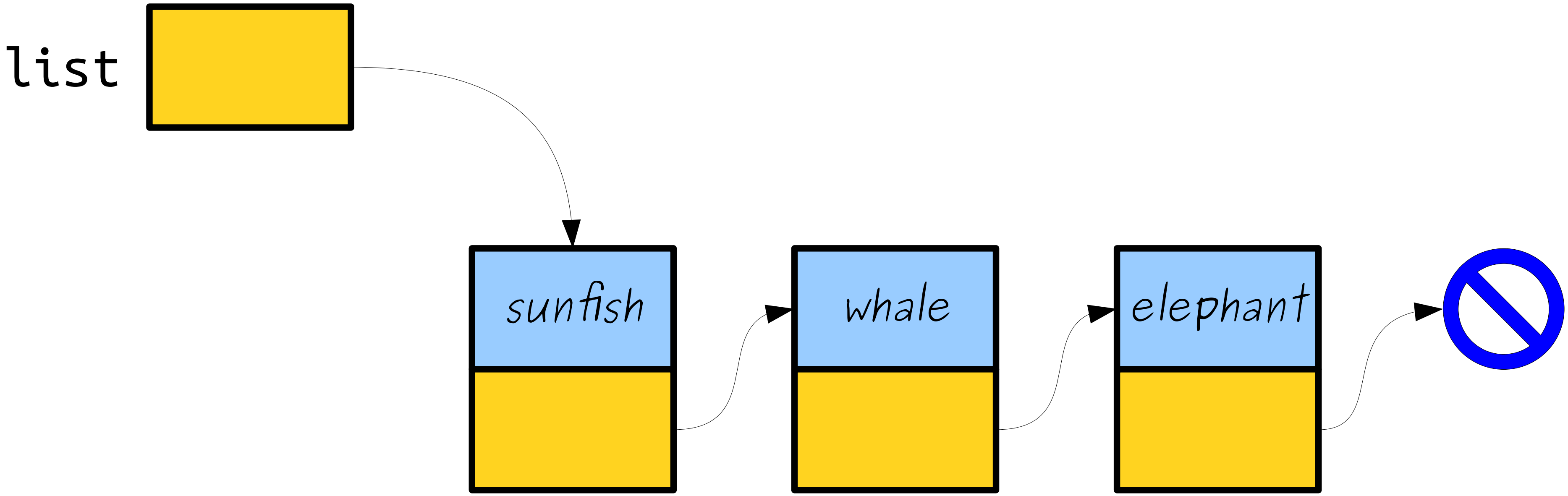
a single linked list
cell that points…

… at another linked
list.

Pointers and References

Prepending an Element

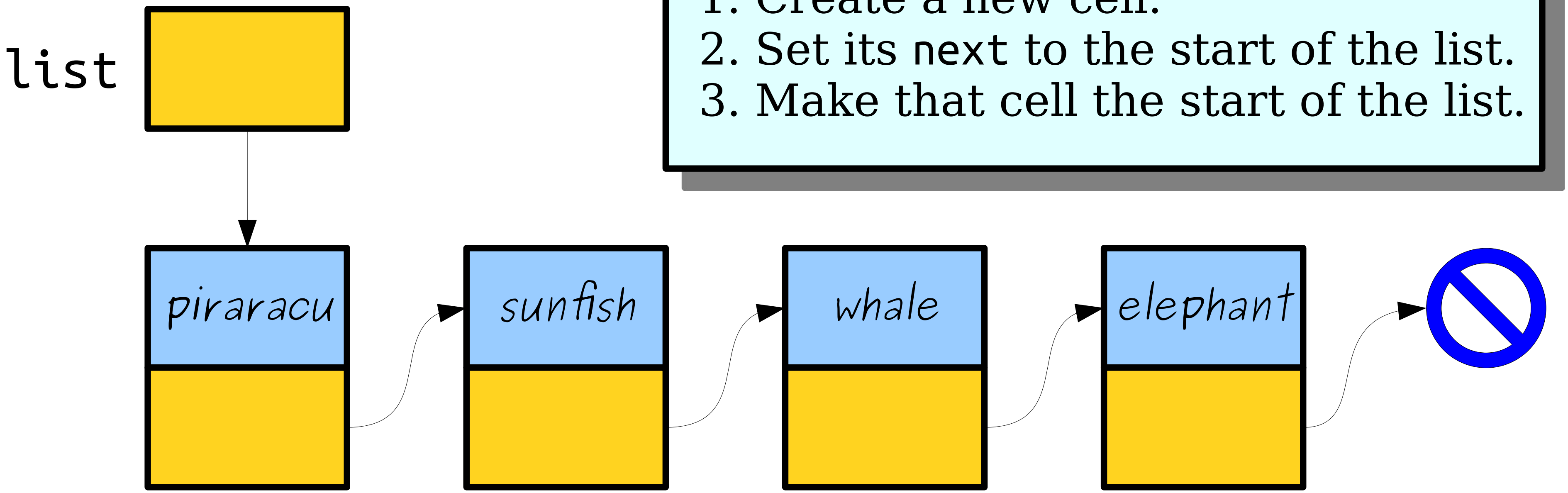
- Suppose that we want to write a function that will add an element to the front of a linked list.
- What might this function look like?



Prepending an Element

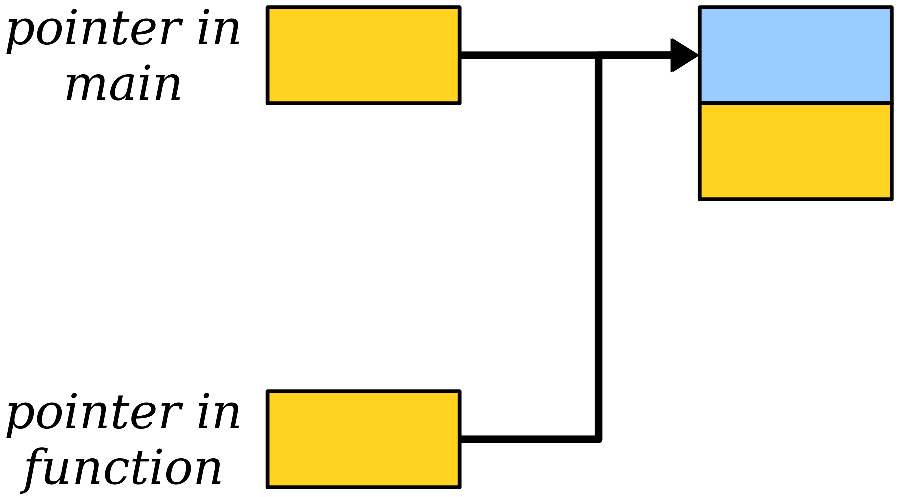
- Suppose that we want to write a function that will add an element to the front of a linked list.
- What might this function look like?

1. Create a new cell.
2. Set its `next` to the start of the list.
3. Make that cell the start of the list.



Pointers By Value

- Unless specified otherwise, function arguments in C++ are passed by value.
- This includes pointers!
- A function that takes a pointer as an argument gets a copy of the pointer.
- We can change where the *copy* points, but not where the original pointer points.



Pointers by Reference

- To resolve this problem, we can pass the linked list pointer by reference.
- Our new function:

```
void prependTo(Cell*& list, const string& value) {
    Cell* cell = new Cell;
    cell->value = value;
    cell->next = list;
    list = cell;
}
```

Pointers by Reference

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- Our new function:

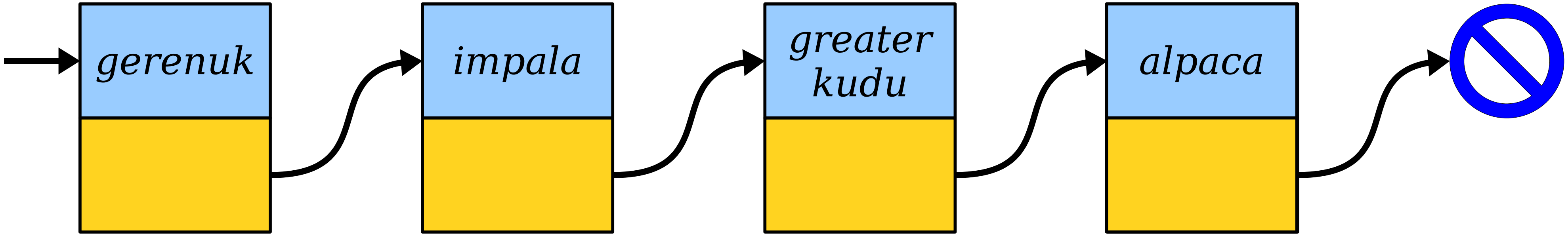
```
void prependTo(Cell*& list, const string& value) {
    Cell* cell = new Cell;
    cell->value = value;
    cell->next = list;
    list = cell;
}
```

This is a reference to a pointer to a Cell. If we change where list points in this function, the changes will stick!

Appending to a List

Appending to a List

- Think about which link needs to get changed to append something to this list:



Appending to a List

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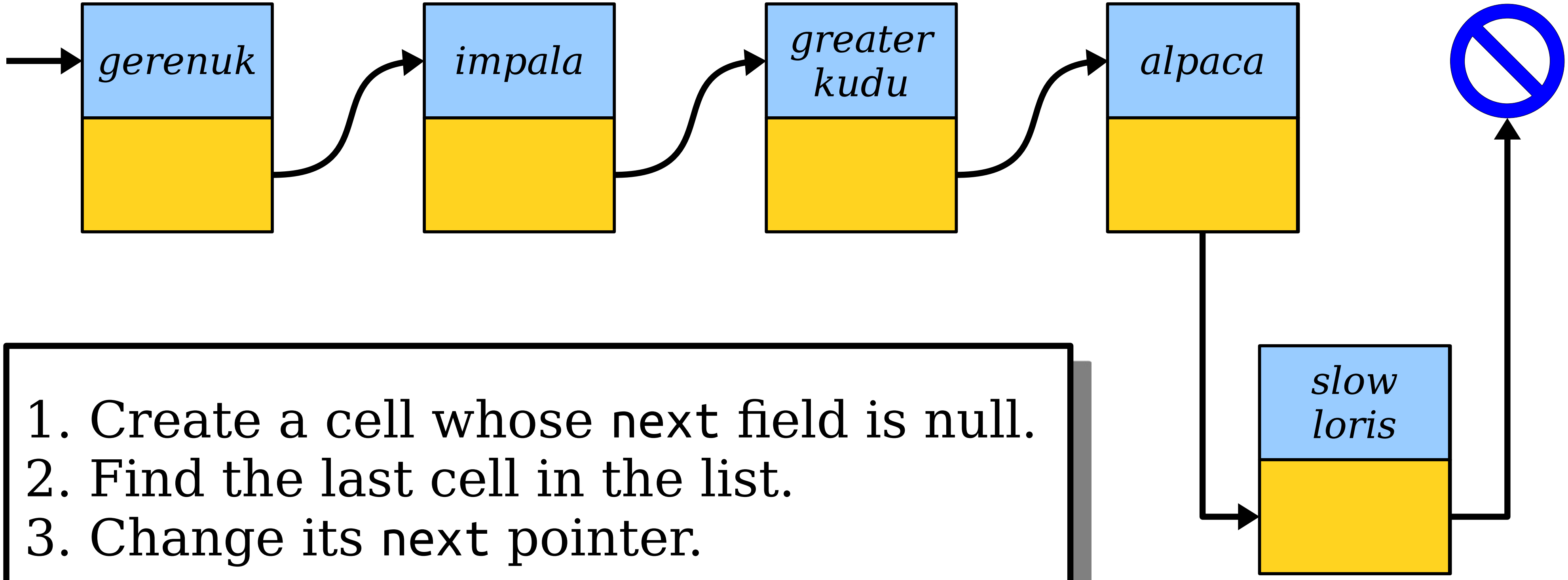


1. Create a cell whose `next` field is null.
2. Find the last cell in the list.
3. Change its `next` pointer.

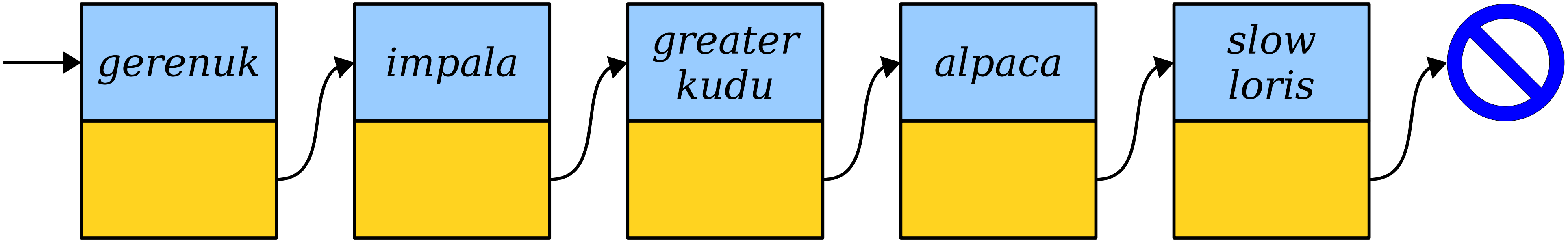
When passing in pointers by reference,
be careful not to change the pointer
unless you really want to change where it’s
pointing!

What Went Wrong (Yet Again)?

A Question of Efficiency

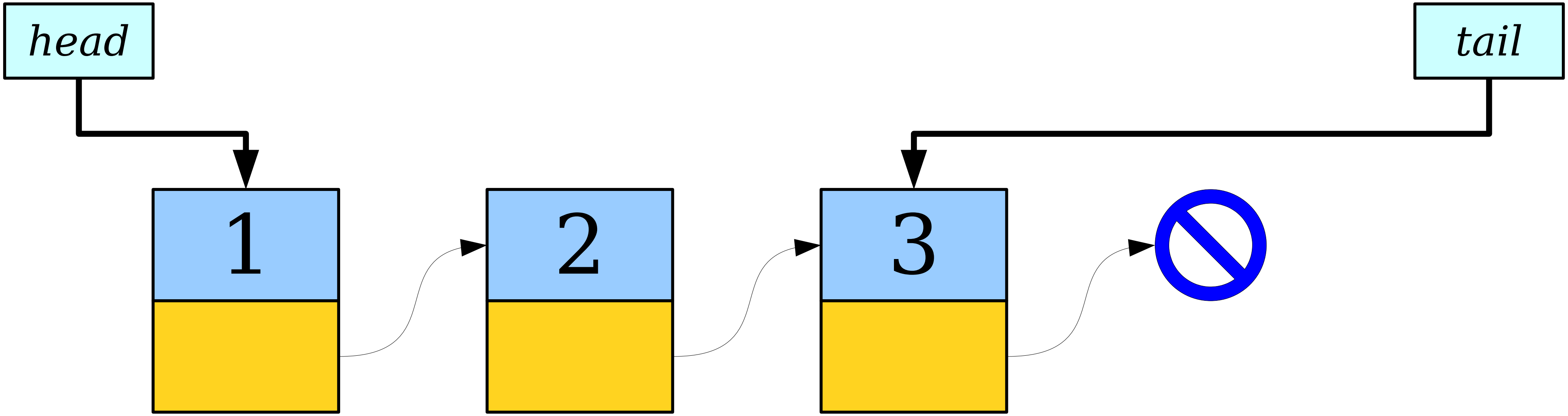
Appending to a List

- What is the big-O complexity of appending to the back of a linked list using our algorithm?
- ***Answer:*** **O(*n*)**, where *n* is the number of elements in the list, since we have to find the last position each time.



Tail Pointers

- A ***tail pointer*** is a pointer to the last element of a linked list.
- Tail pointers make it easy and efficient to add new elements to the back of a linked list.



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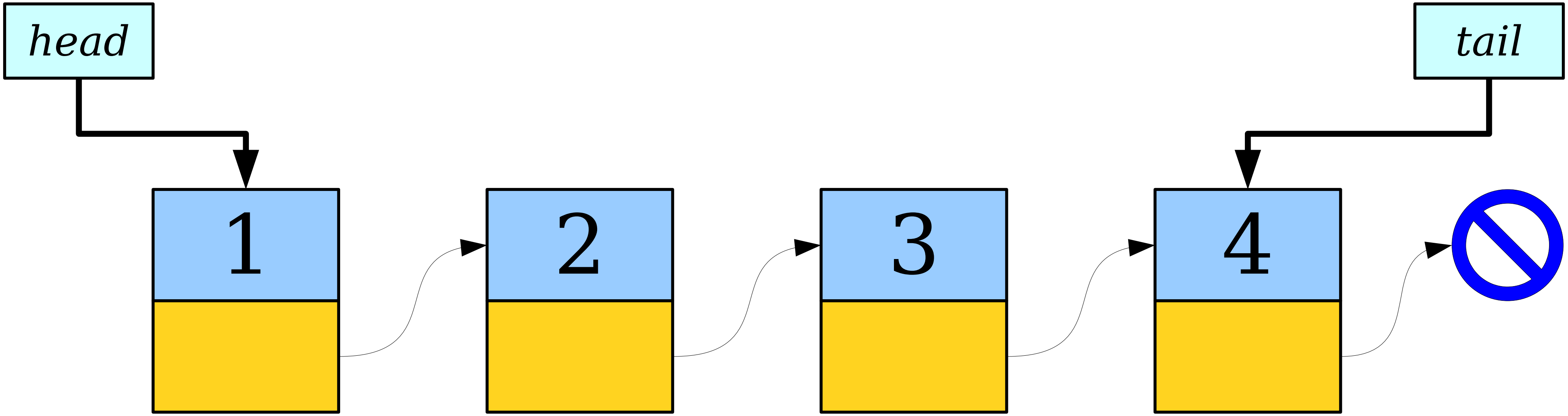
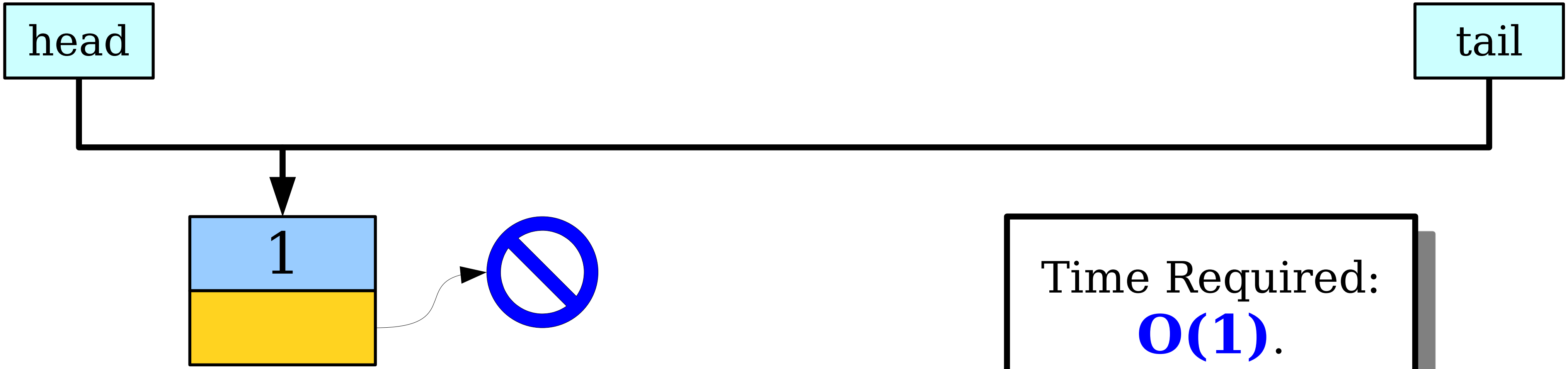


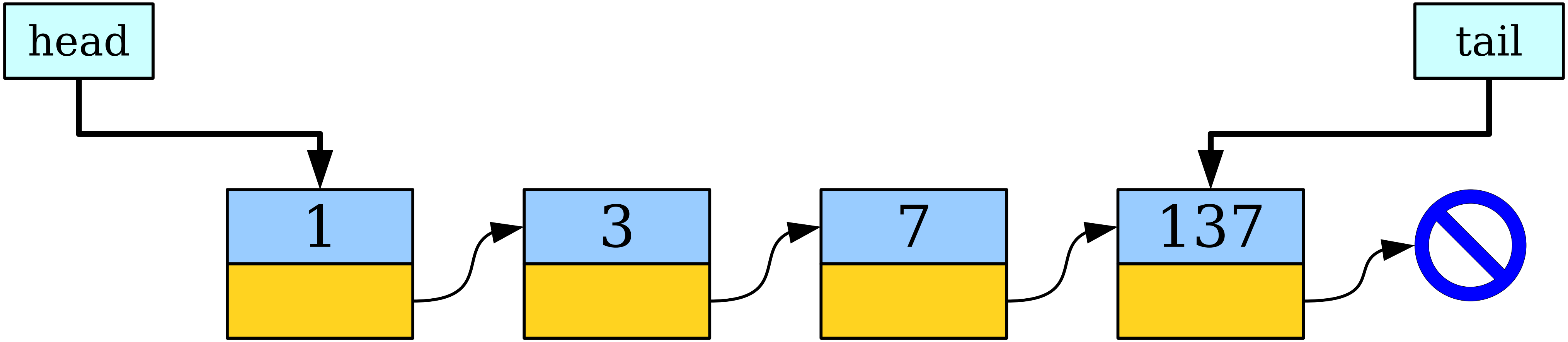
Appending Things Quickly

- ***Case 1:*** The list is empty.



Time Required: **O(1)**.

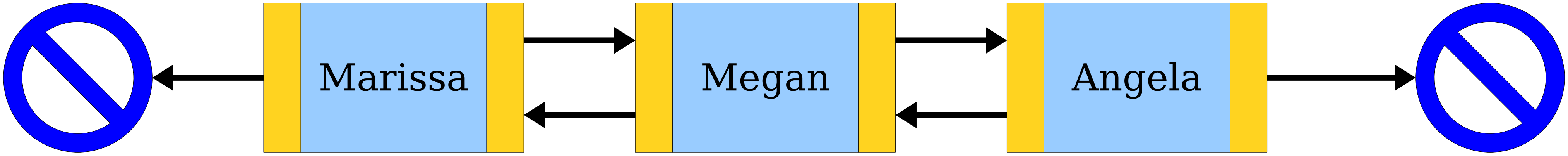
- ***Case 2:*** The list is not empty.



Coda: Doubly-Linked Lists

Doubly-Linked Lists

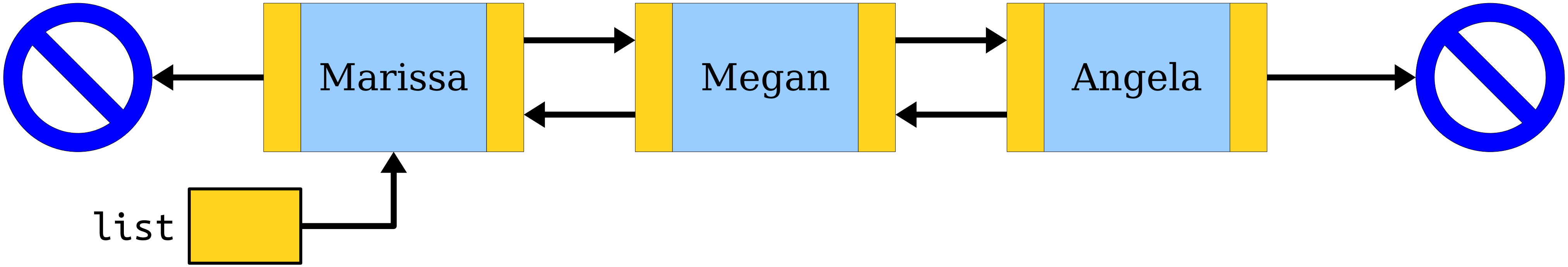
- There's a strange asymmetry in a linked list: you can easily move forward in a list, but there's no easy way to move backwards.
- A ***doubly-linked list*** is a list where each cell stores two pointers: one to the next element in the list, and one to the previous element.



Doubly-Linked Lists

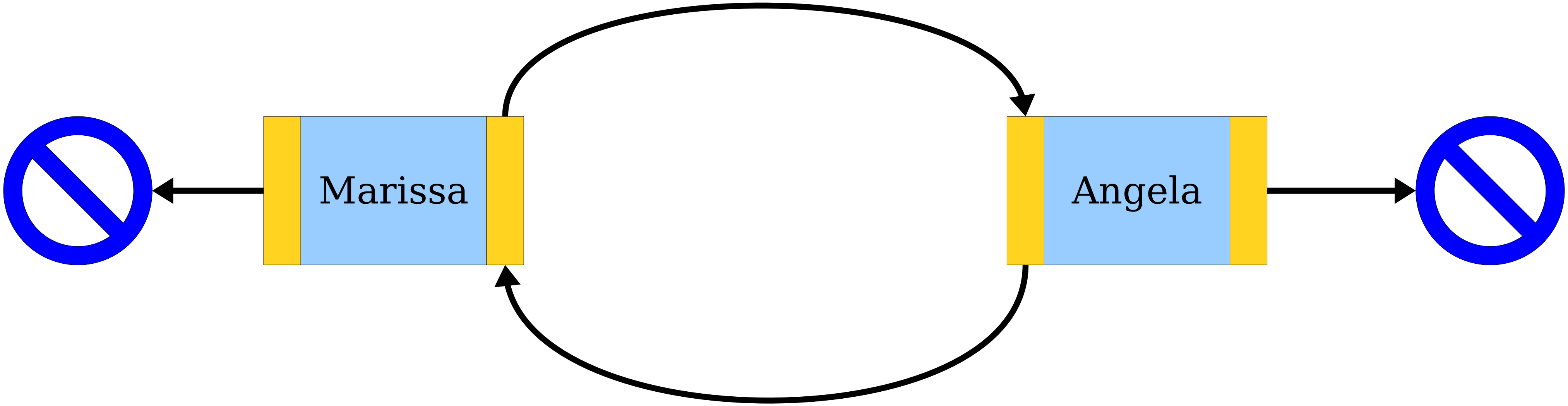
- We can also move backwards in a doubly-linked list.
- Many algorithms are a lot easier to write if you can do this!

```
Cell* list = /* first cell */;
list = list->next;
list = list->prev;
```



Doubly-Linked Lists

- It’s easy to remove a cell from a doubly-linked list: just wire the nodes next to it around it.
- (Don’t forget to handle edge cases!)



For more on doubly-linked lists, check ***Section Problems 7*** and ***Chapter 13*** of the textbook.

To Recap

- If you want a function to change *which object* a pointer points to, pass that pointer in by reference.
- When passing pointers by reference, don’t change the pointer unless you really mean it.
- Tail pointers make it easy to find the end of a linked list – a handy tool to keep in mind!
- Doubly-linked lists have each cell store pointers to both the next and previous cells in the list. They’re useful for when you need to remove out of a list.

Your Action Items

- ***Read Chapter 13.***
  - It's all about different representations for data and the relative tradeoffs. And there's some great coverage of linked lists in there!
- ***Finish Assignment 6.***
  - If you're following our suggested timeline, you'll have completed your implementation of Linear Probing by today.
  - Remember to leave appropriate buffer time for the performance analysis section!

Next Time

- ***Tree Structures***
    - Representing branching structures in code.
- ***Binary Search Trees***
    - Maintaining order at a low cost!