Linked Lists

Part Two

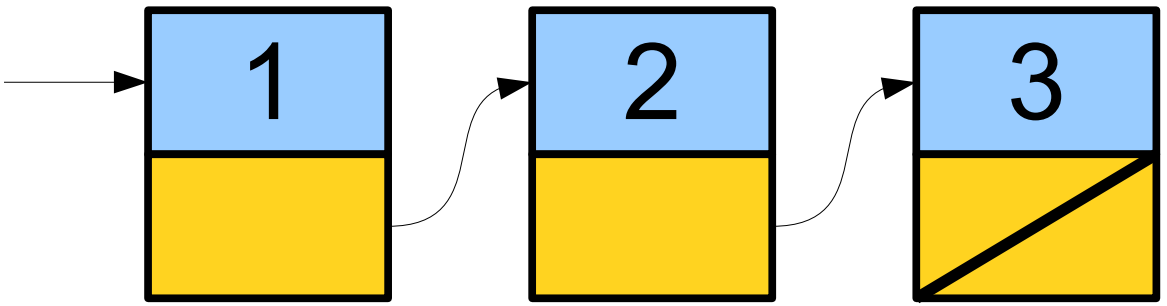
Announcements

- Assignment 4 due right now
- Assignment 5: **Priority Queue** out today!
  - Really important data structure for pathfinding.
- **PLEASE PICK UP YOUR MIDTERMS!**
  - Please let me know if you find any grading mistakes!
  - Reminder: Reduced points for infinite recursion.

Recap from Last Time

Linked Lists at a Glance

- 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.



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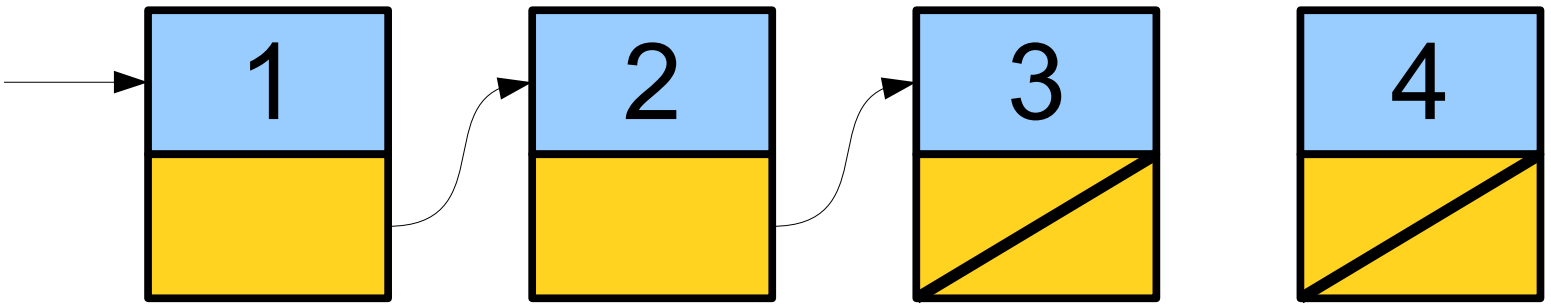

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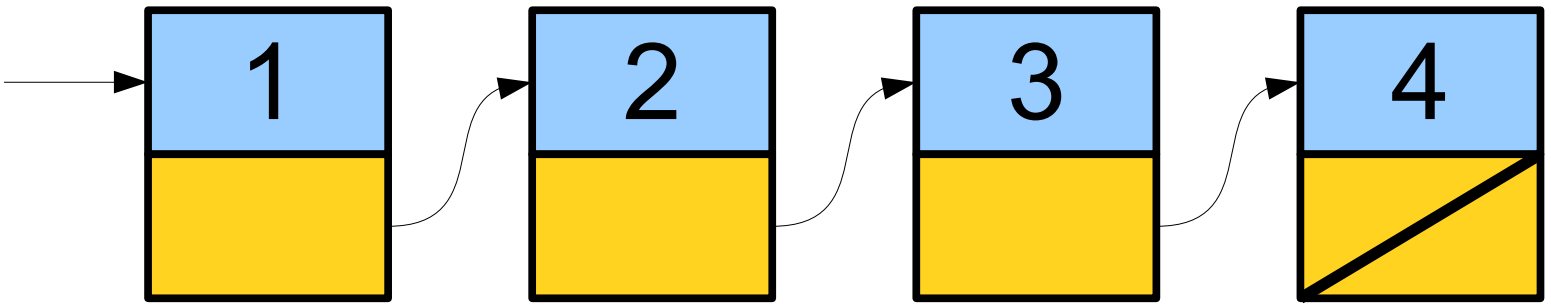

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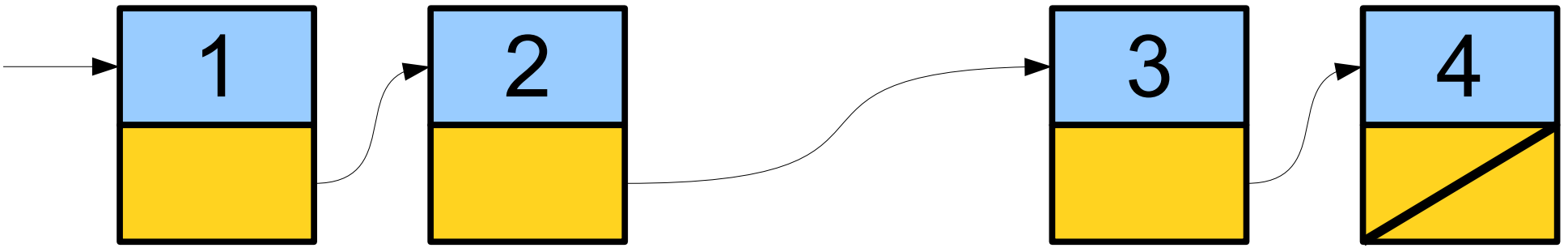

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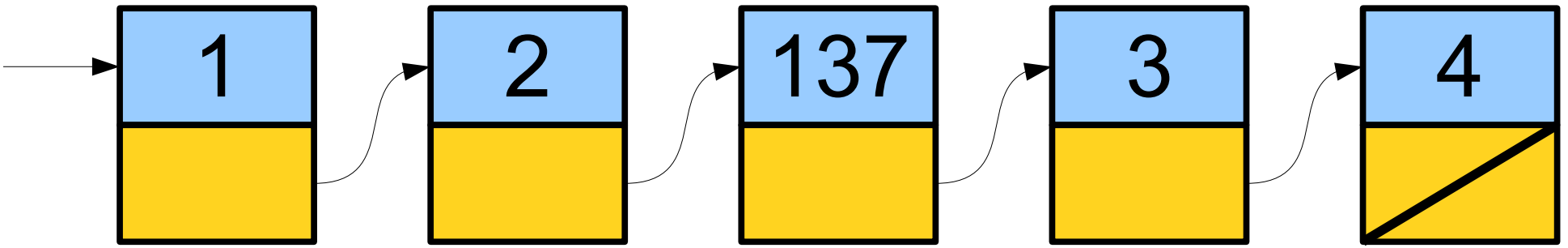

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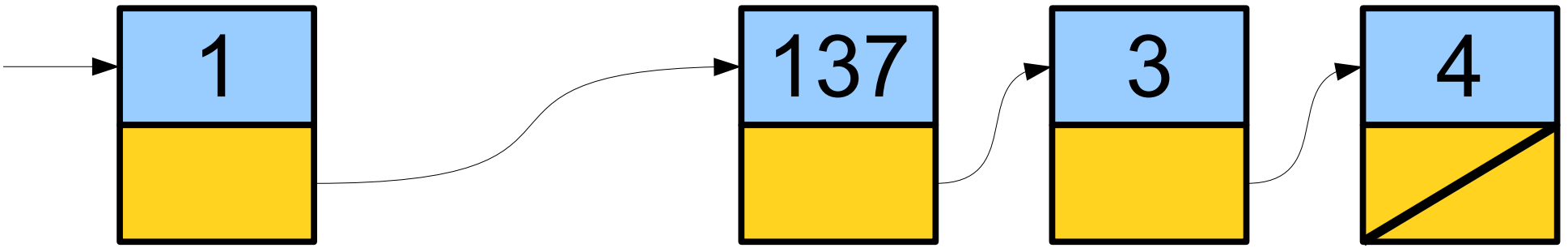

Linked List Cells

- A linked list is a chain of **cells**.
- Each cell contains two pieces of information:
  - Some piece of data that is stored in the sequence, and
  - A **link** to the next cell in the list.
- We can traverse the list by starting at the first cell and repeatedly following its link.

Representing a Cell

- For simplicity, let's assume we're building a linked list of **`string`**s.
- We can represent a cell in the linked list as a structure:

```
struct Cell {
    Type value;
    Cell* next;
};
```

- **The structure is defined recursively!**

Building a Linked List

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Cell* result = NULL;
while (true) {
   string line = getLine("Next entry? ");
   if (line == "") break;

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   cell->value = line;

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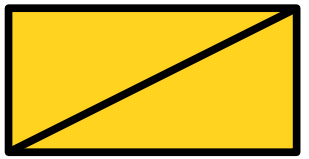

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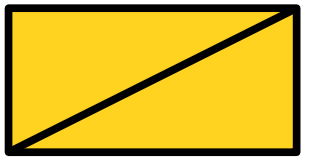

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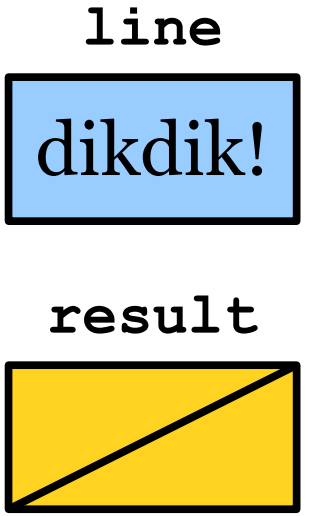

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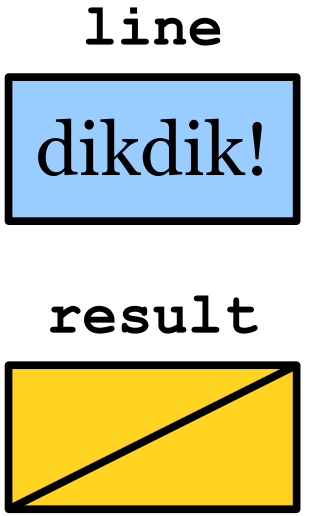

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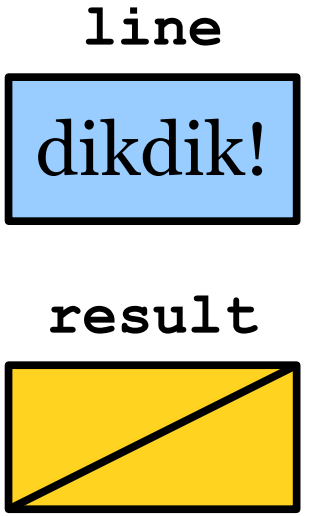

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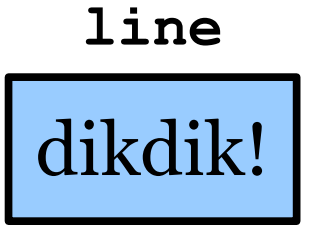

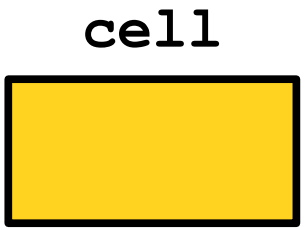

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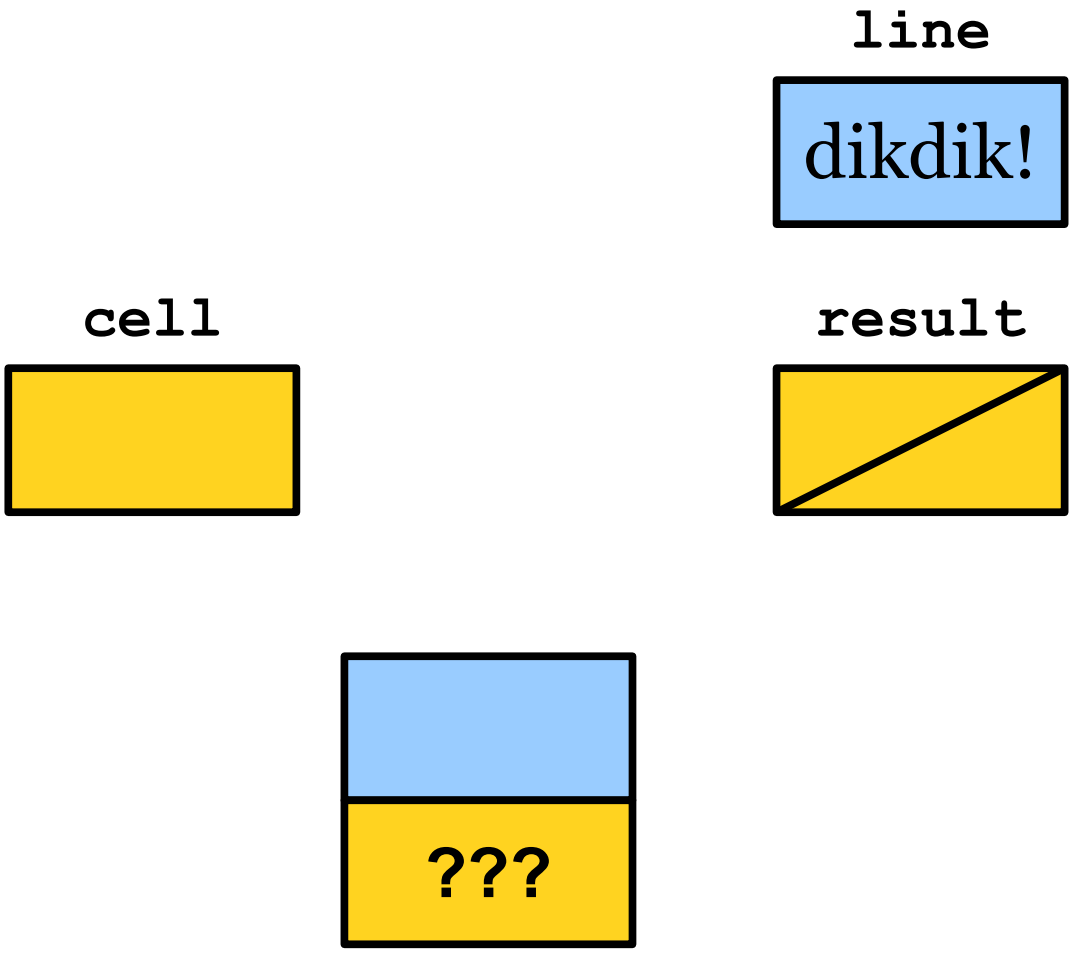

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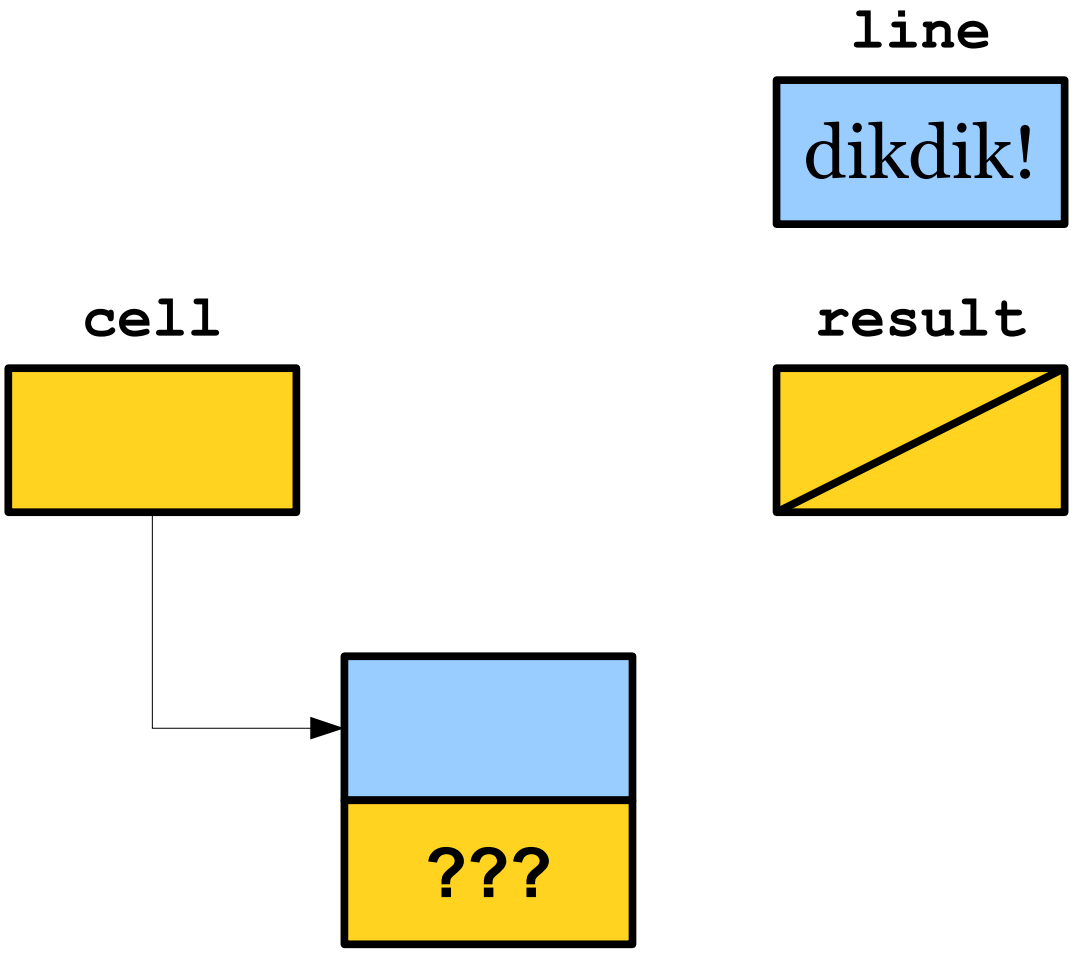

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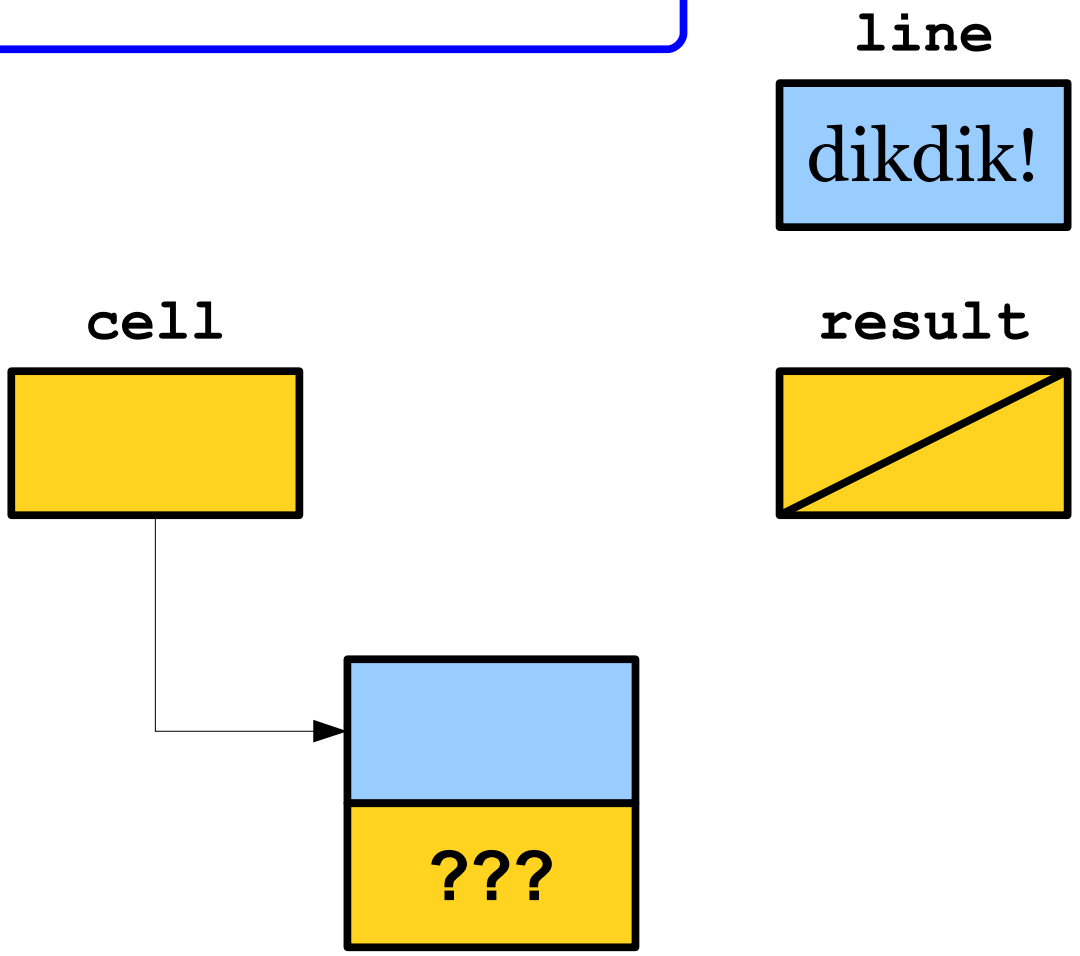

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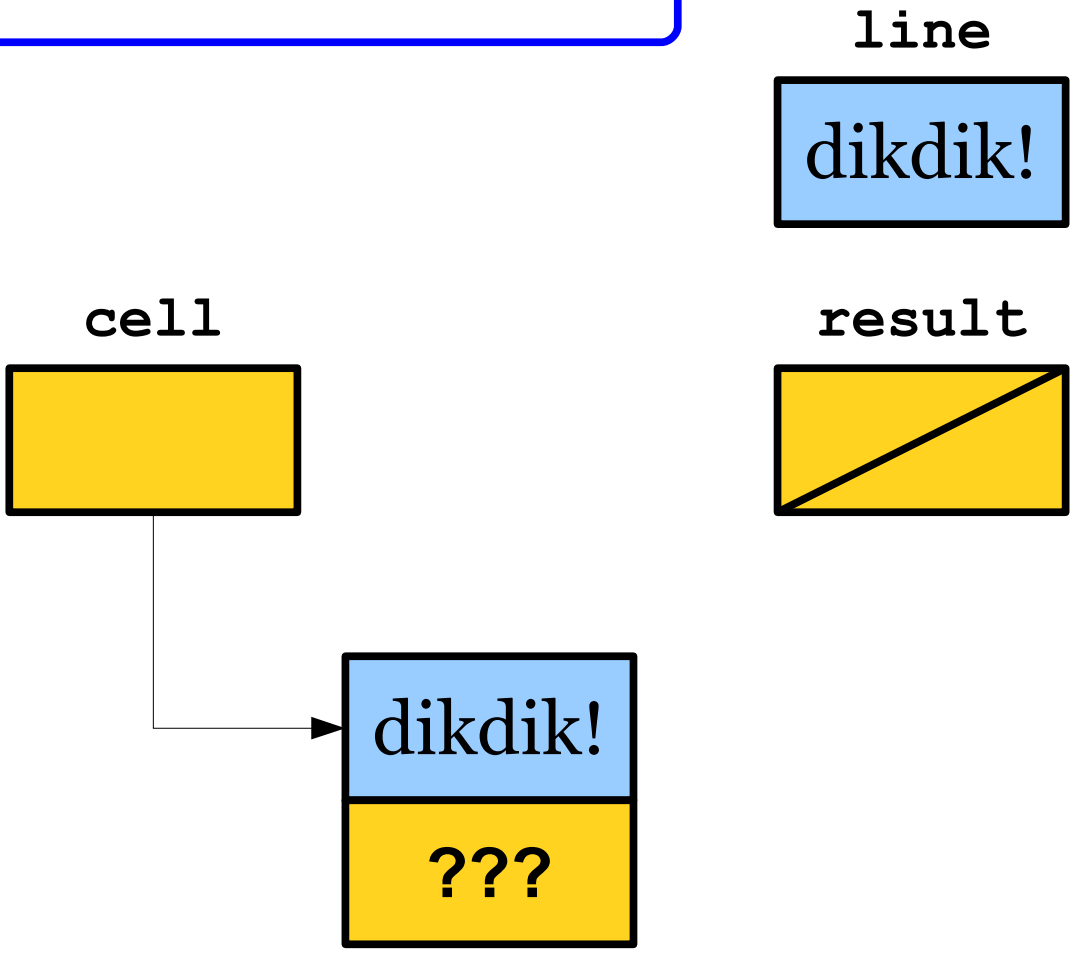

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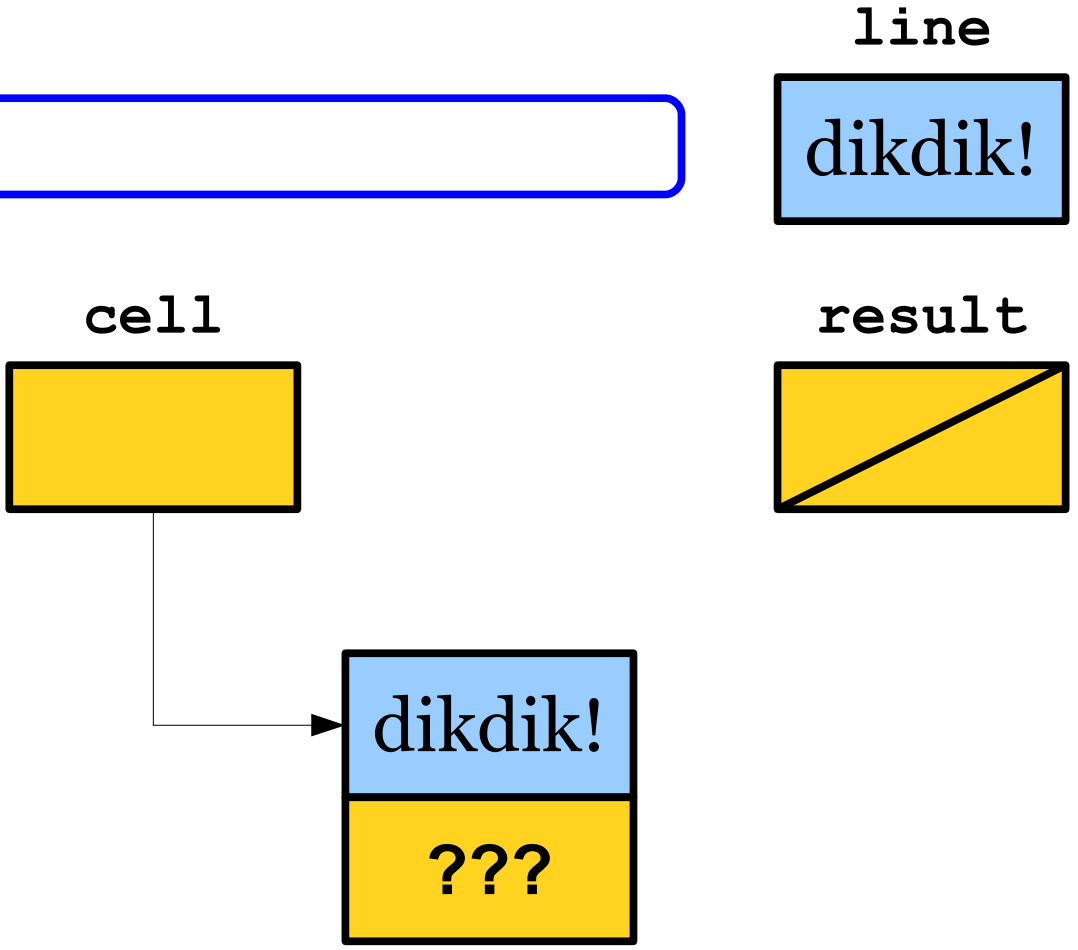

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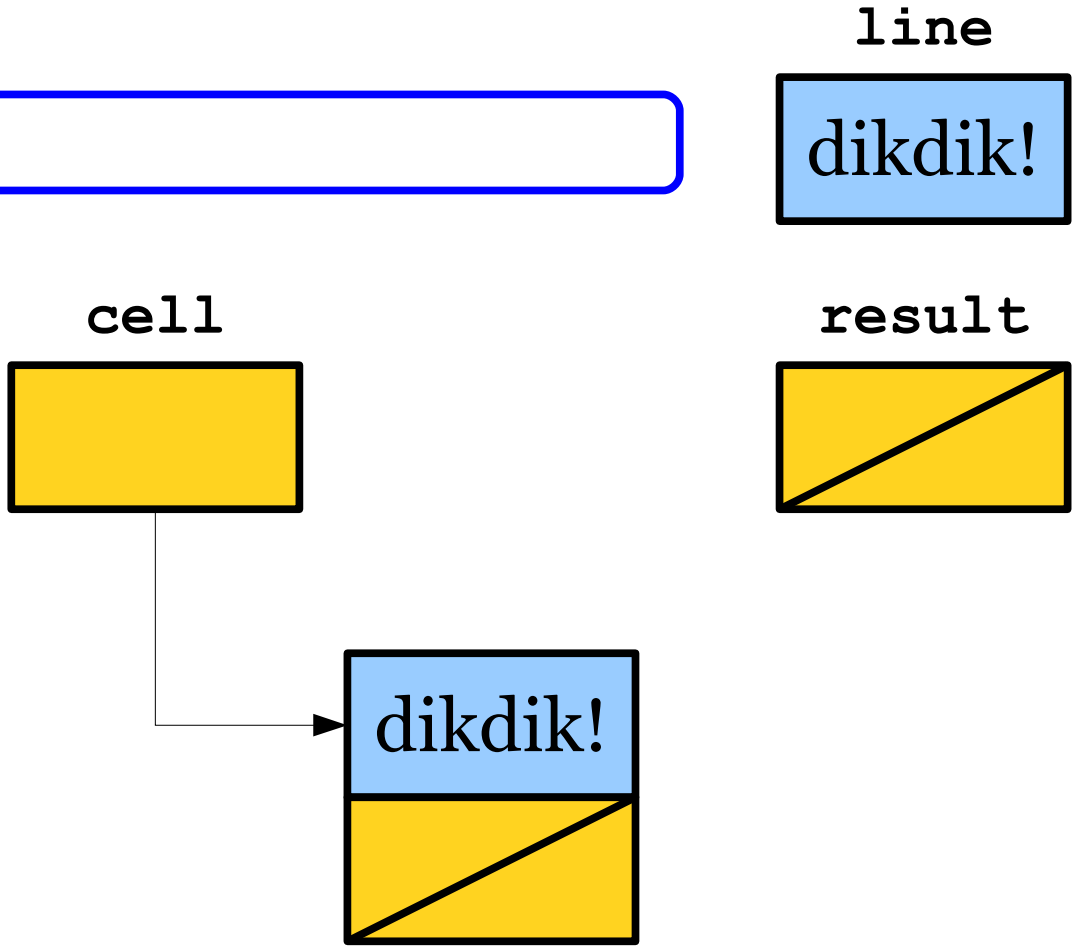

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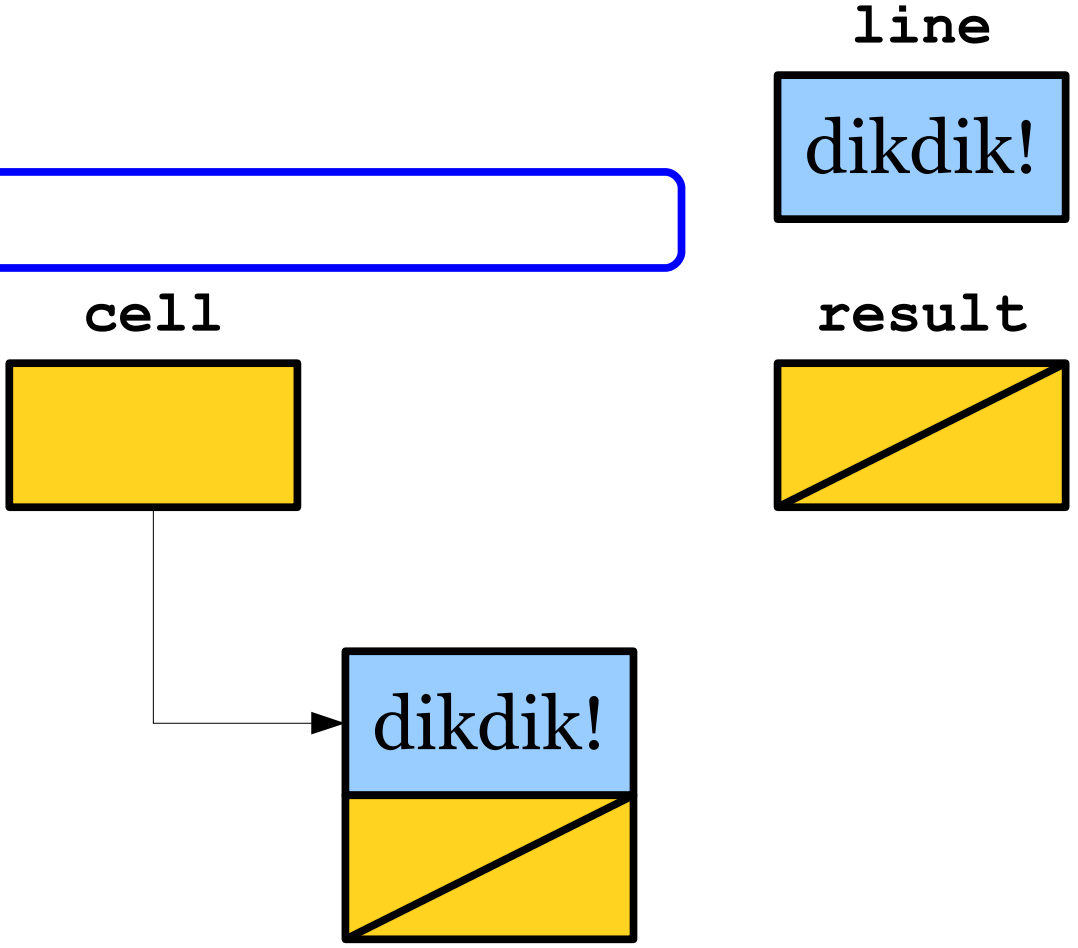

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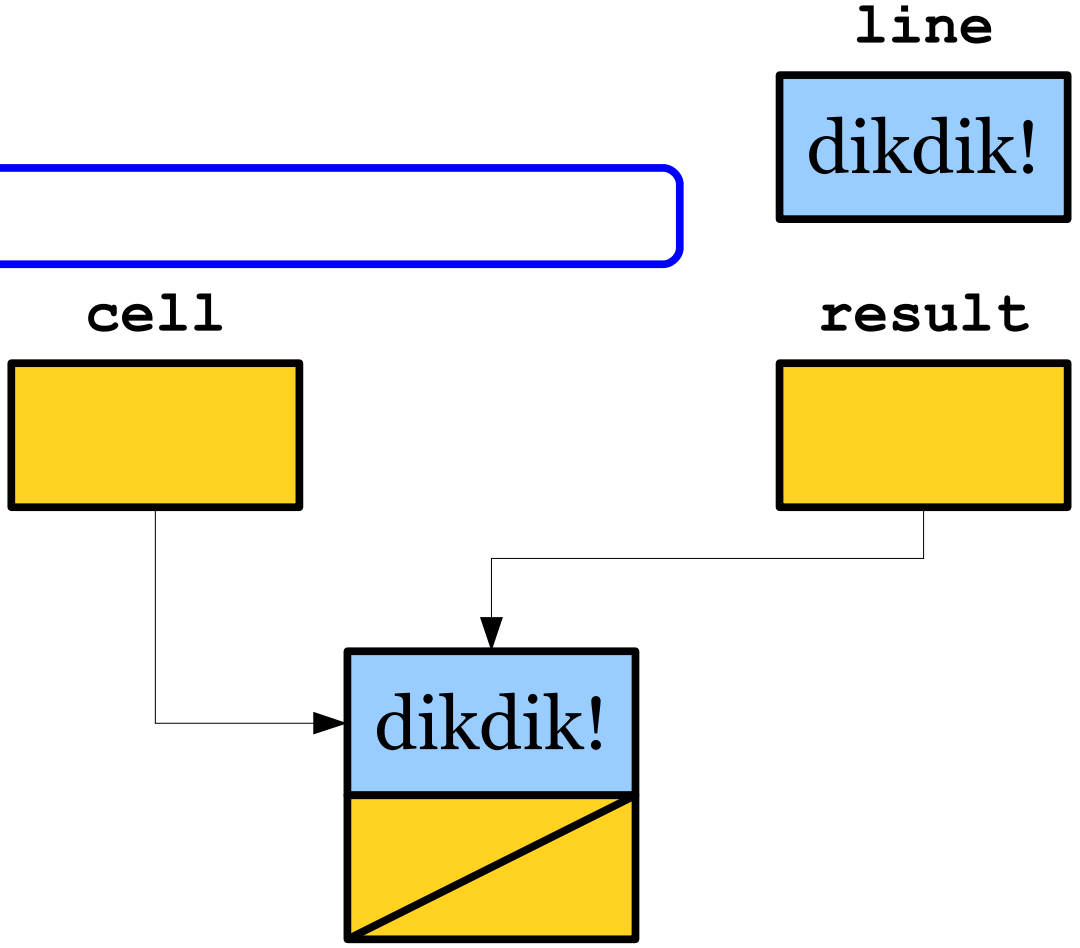

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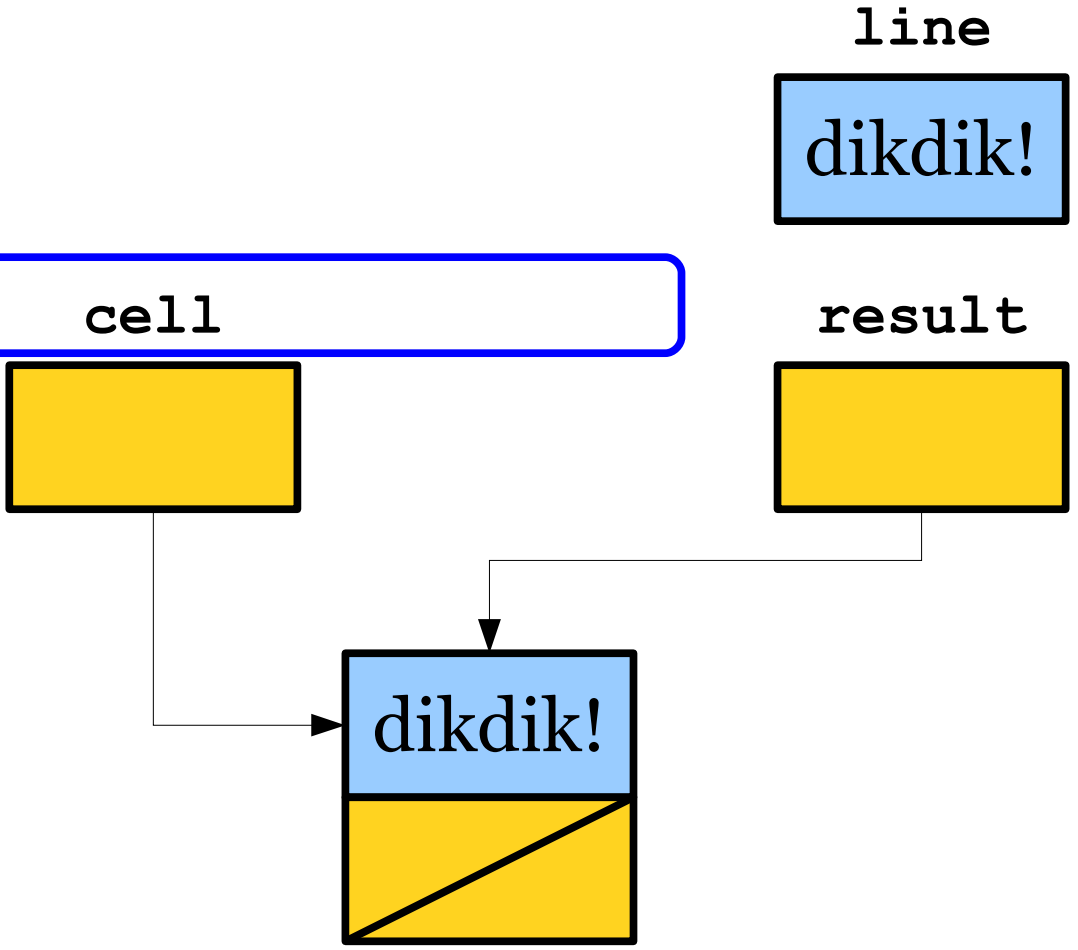

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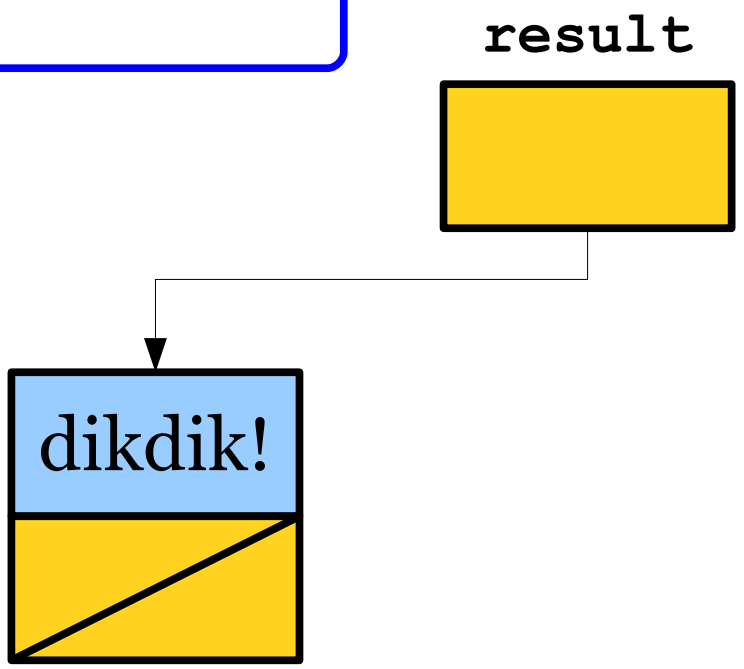

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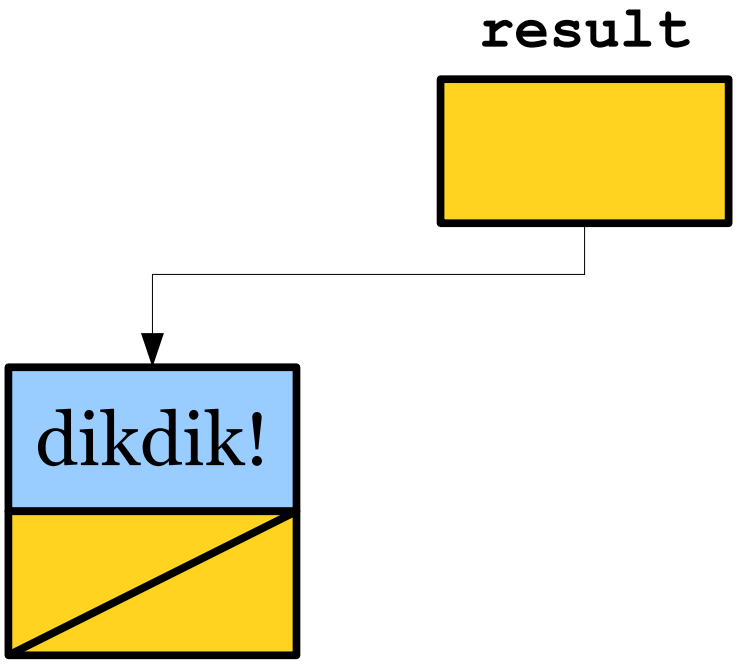

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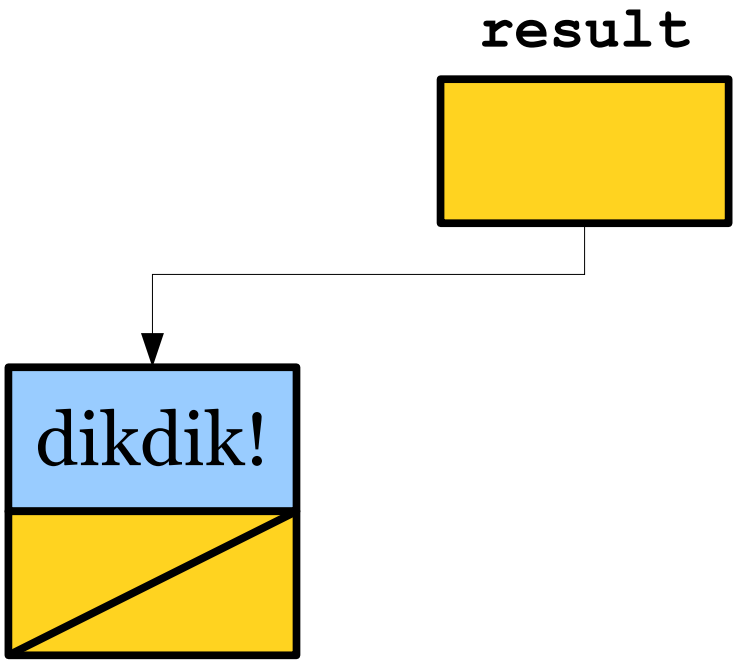

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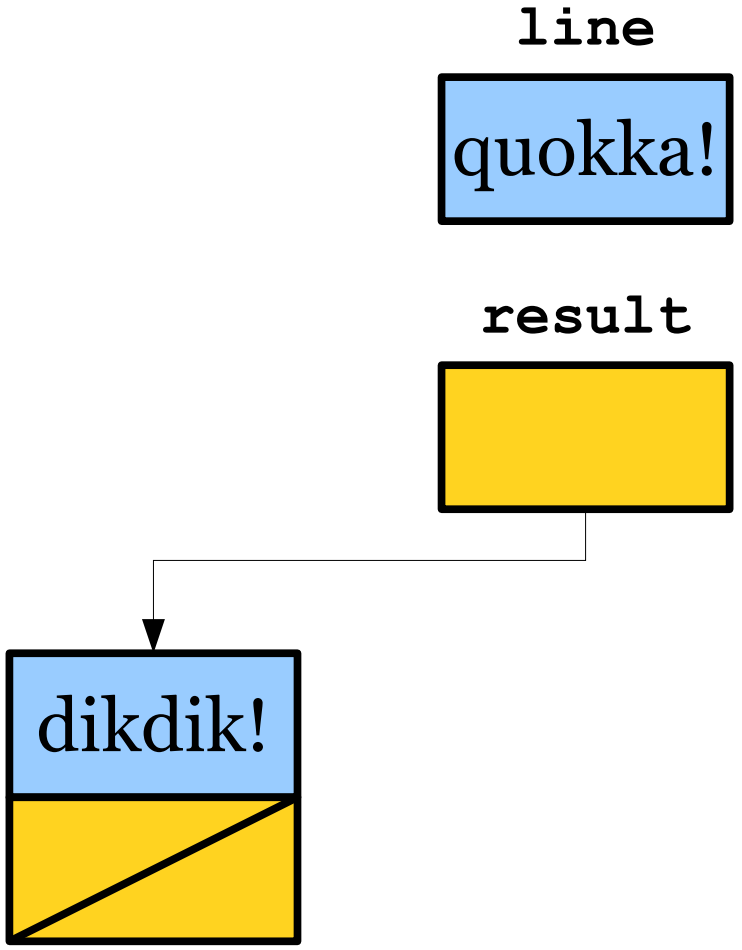

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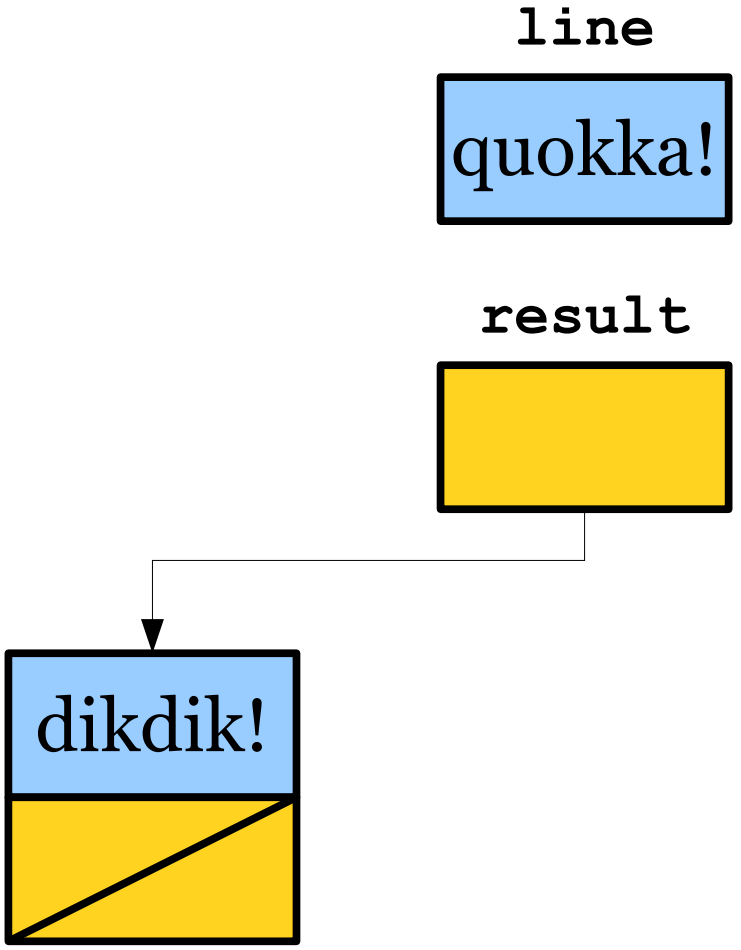

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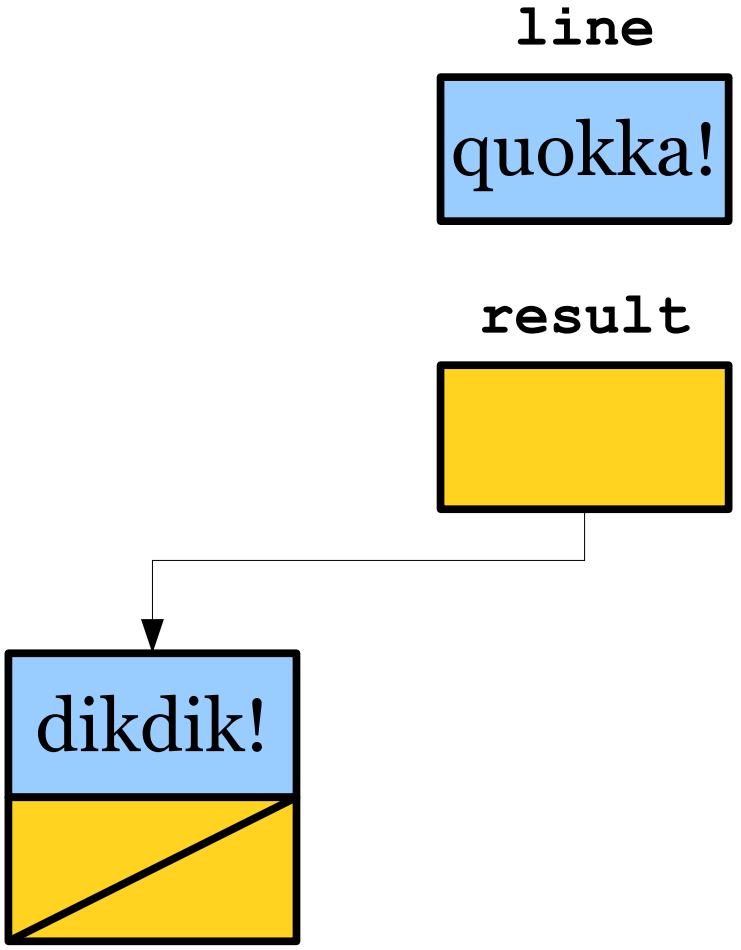

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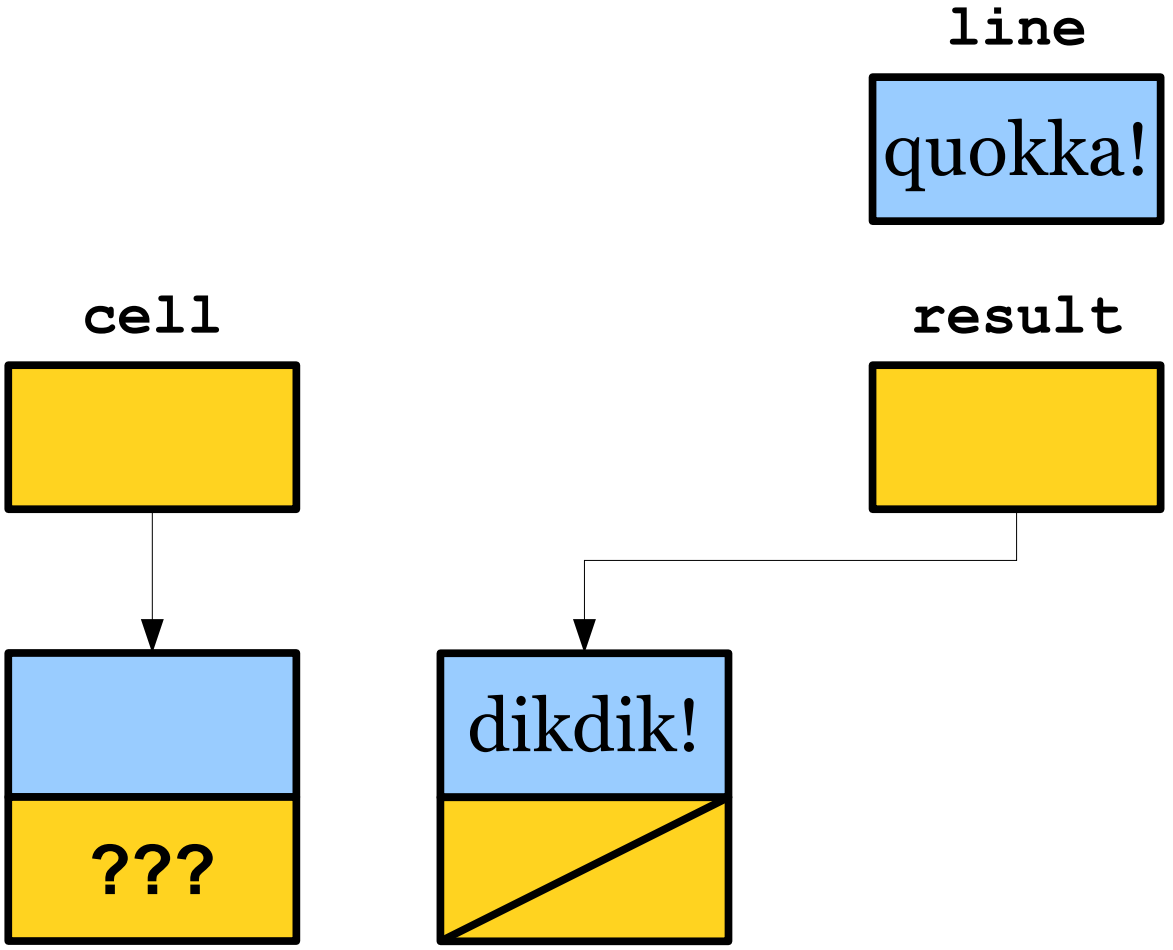

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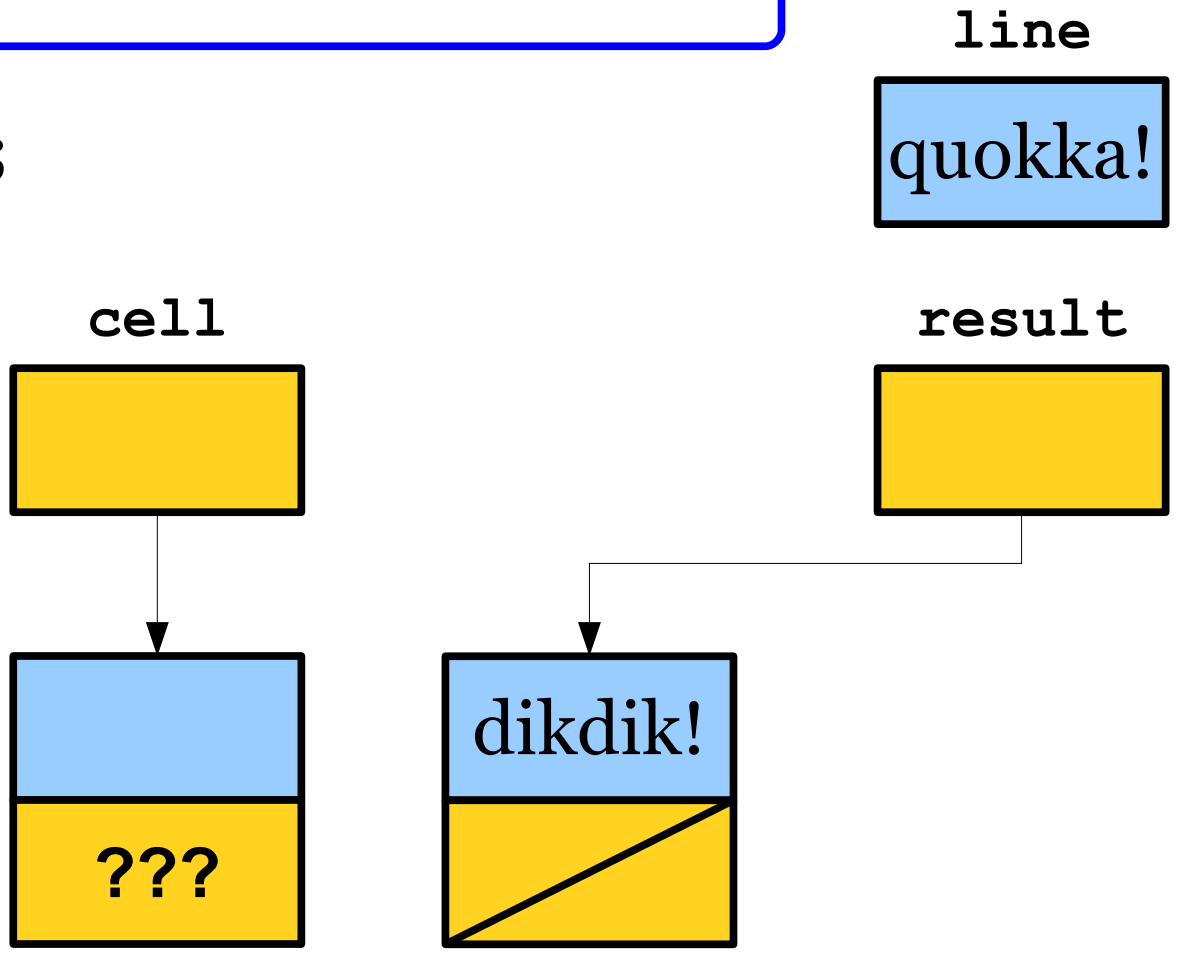

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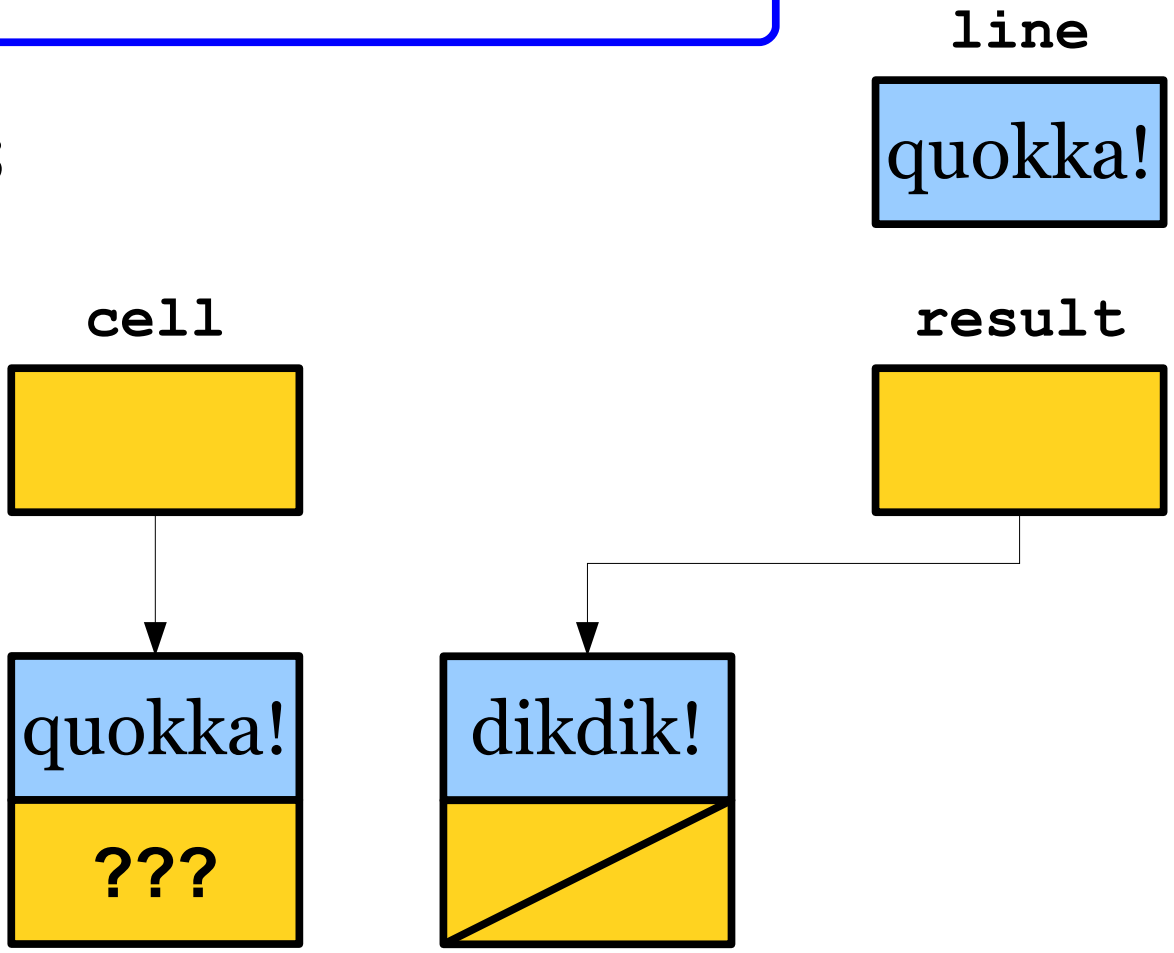

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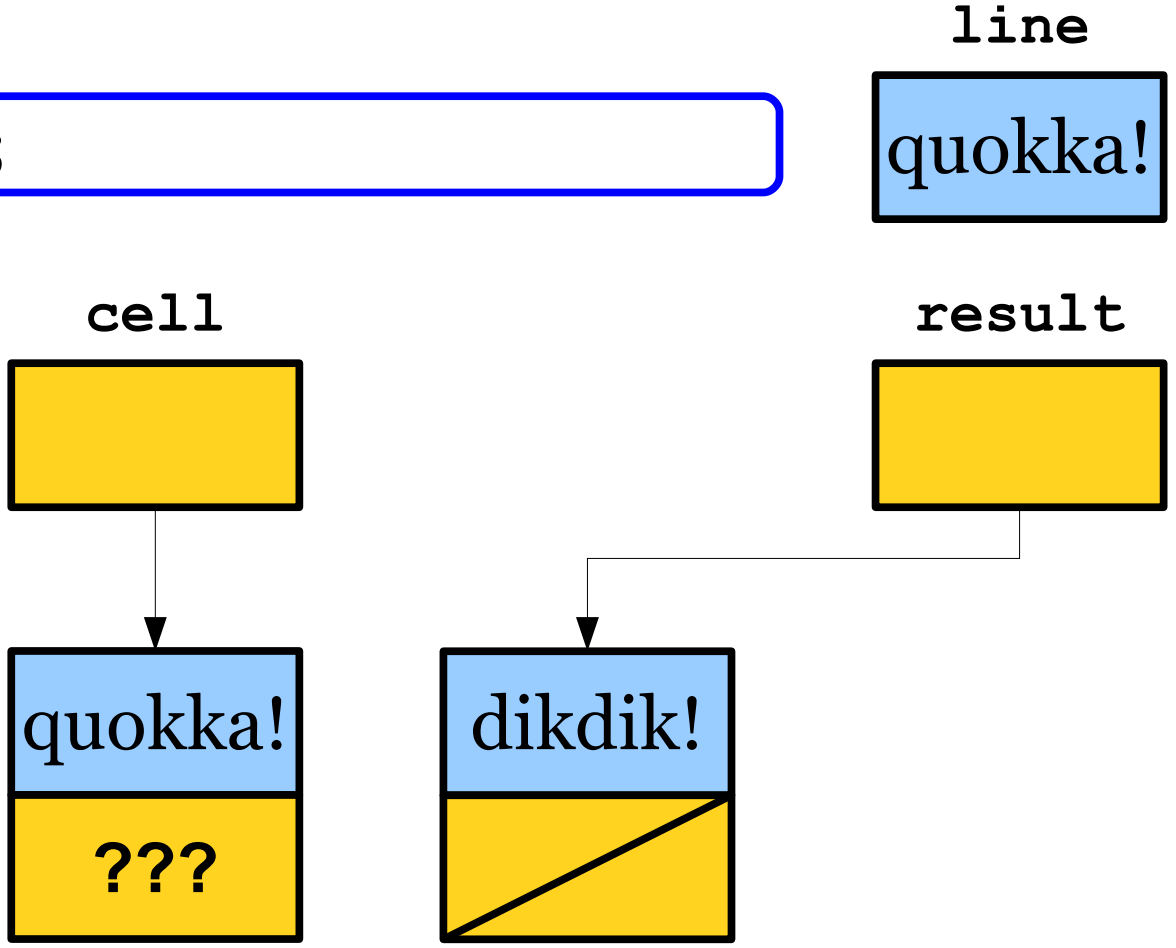

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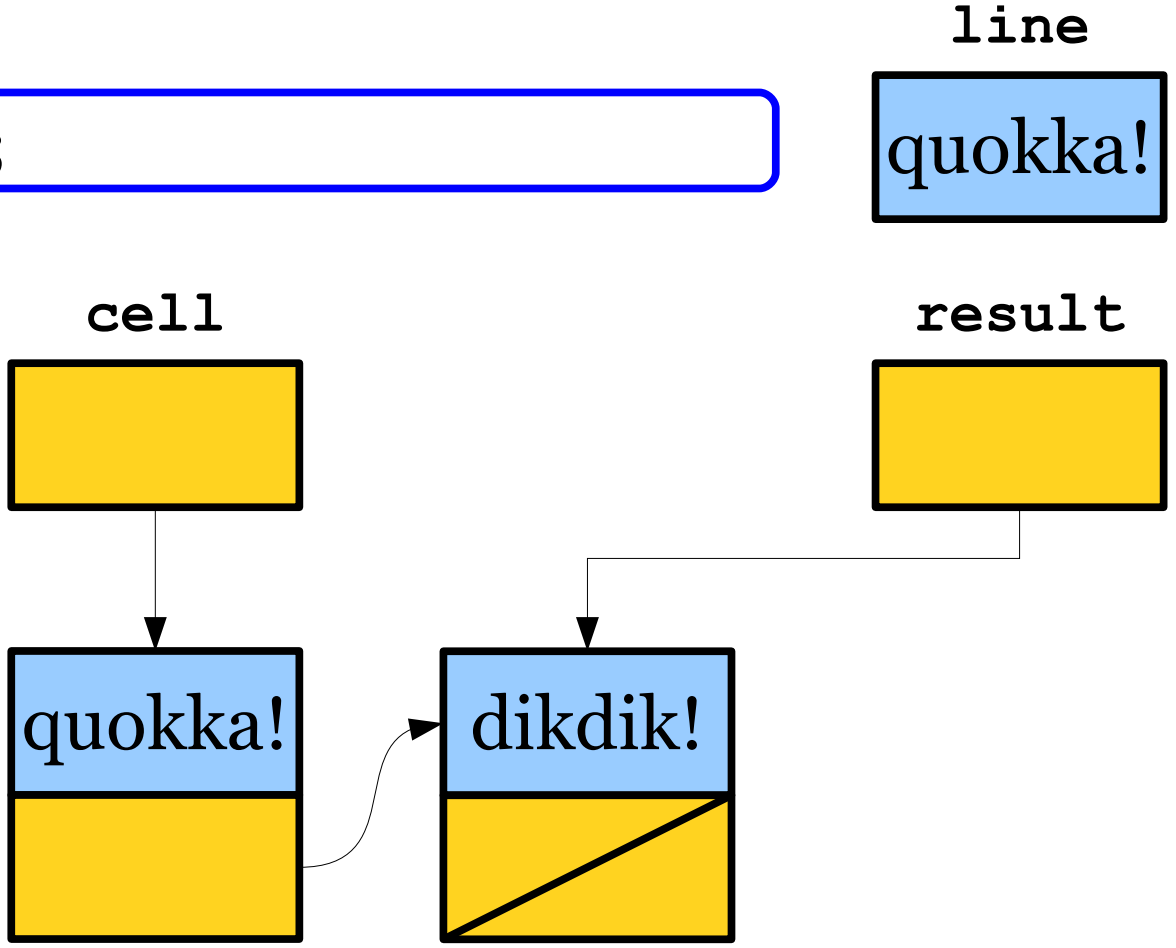

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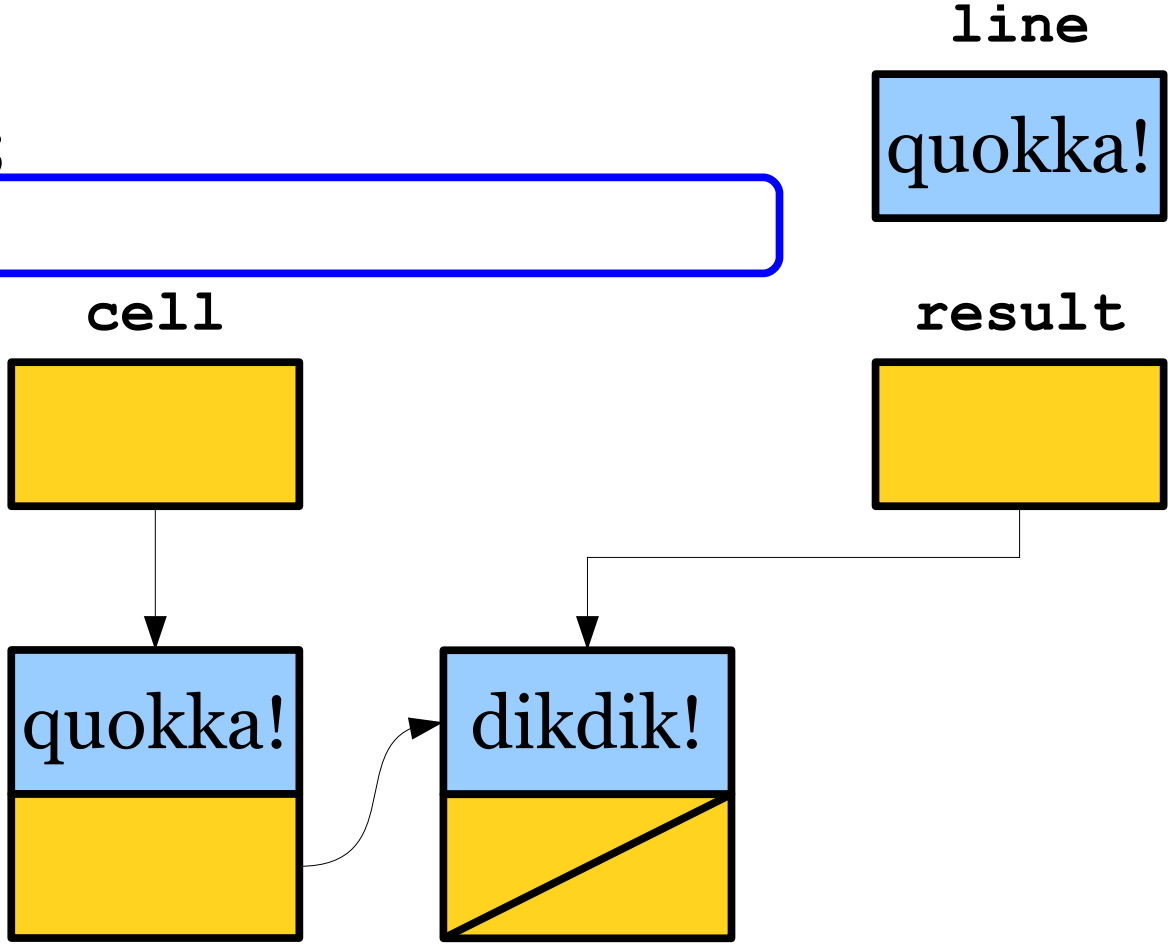

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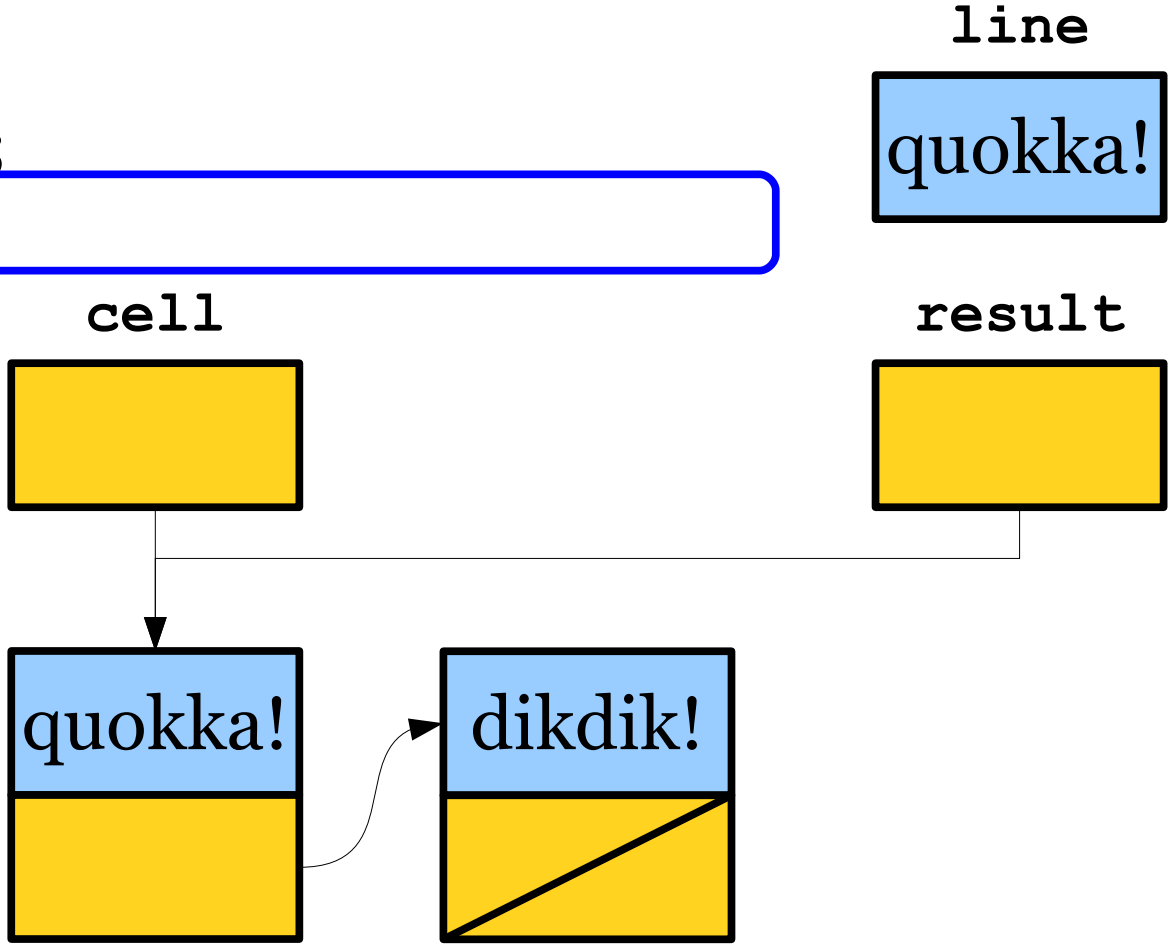

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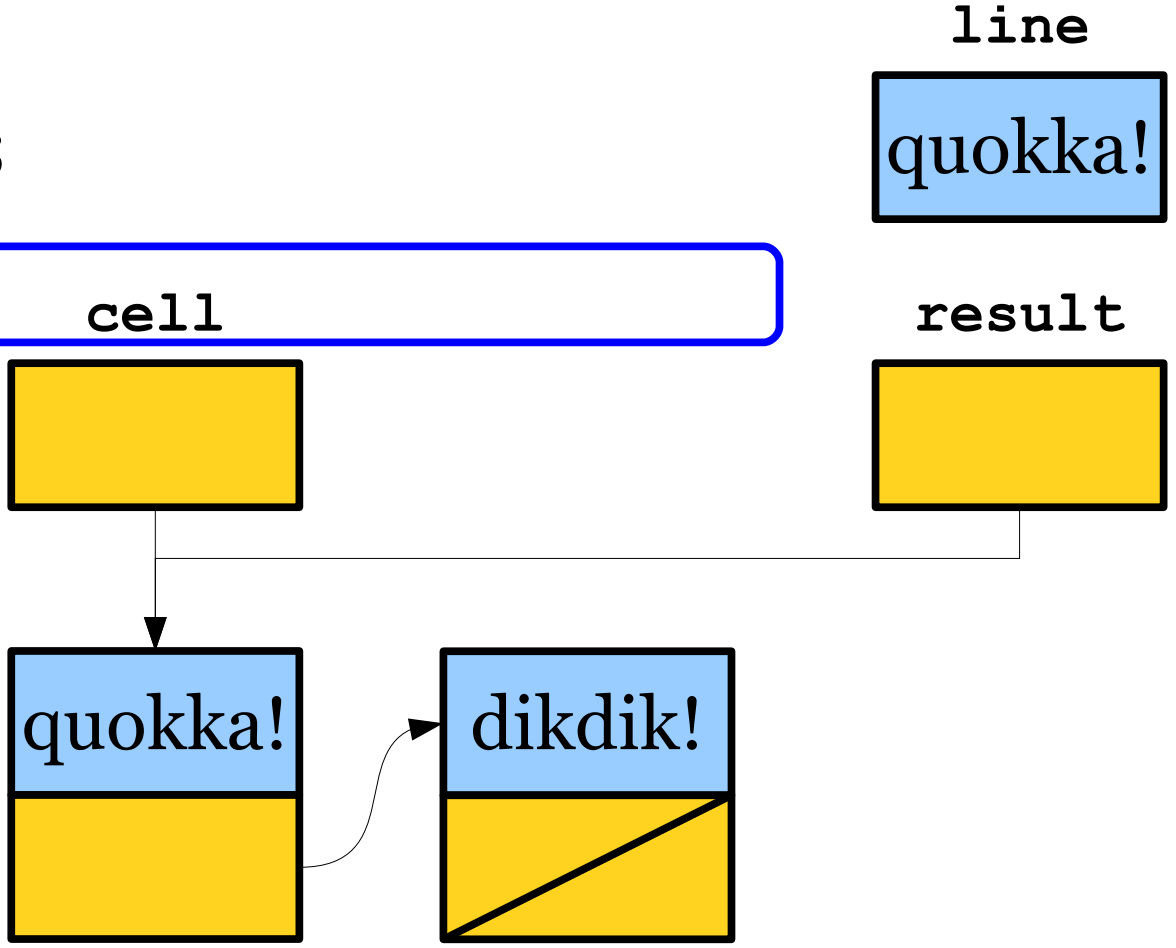

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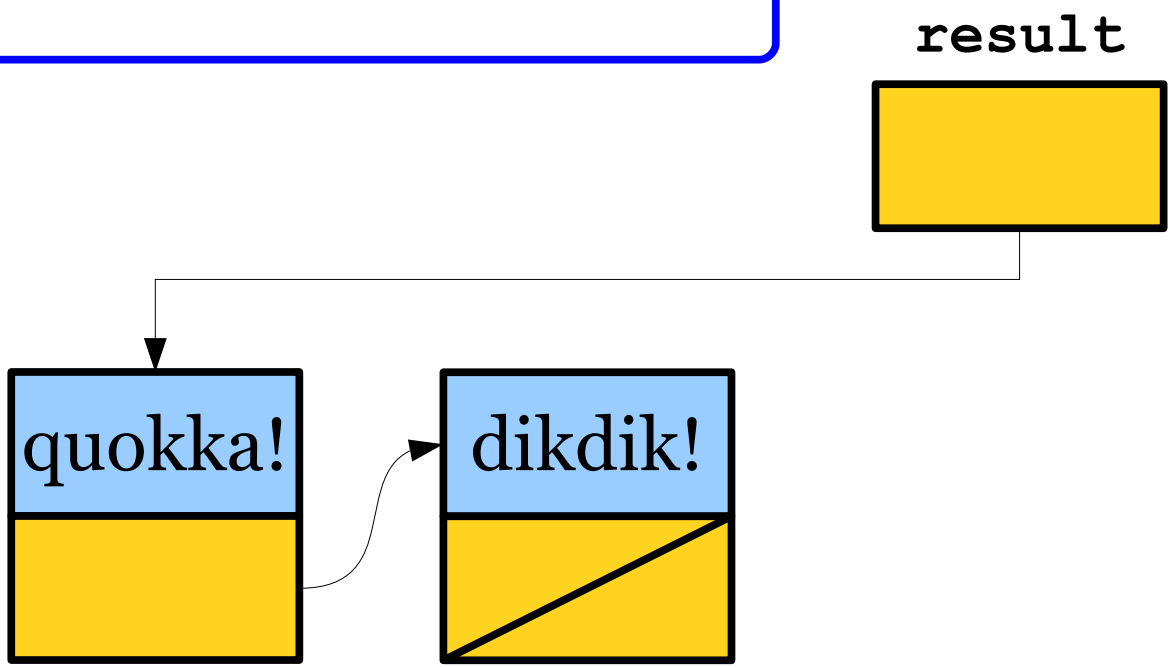

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while (true) {
    string line = getLine("Next entry? ");
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    Cell* cell = new Cell;
    cell->value = line;

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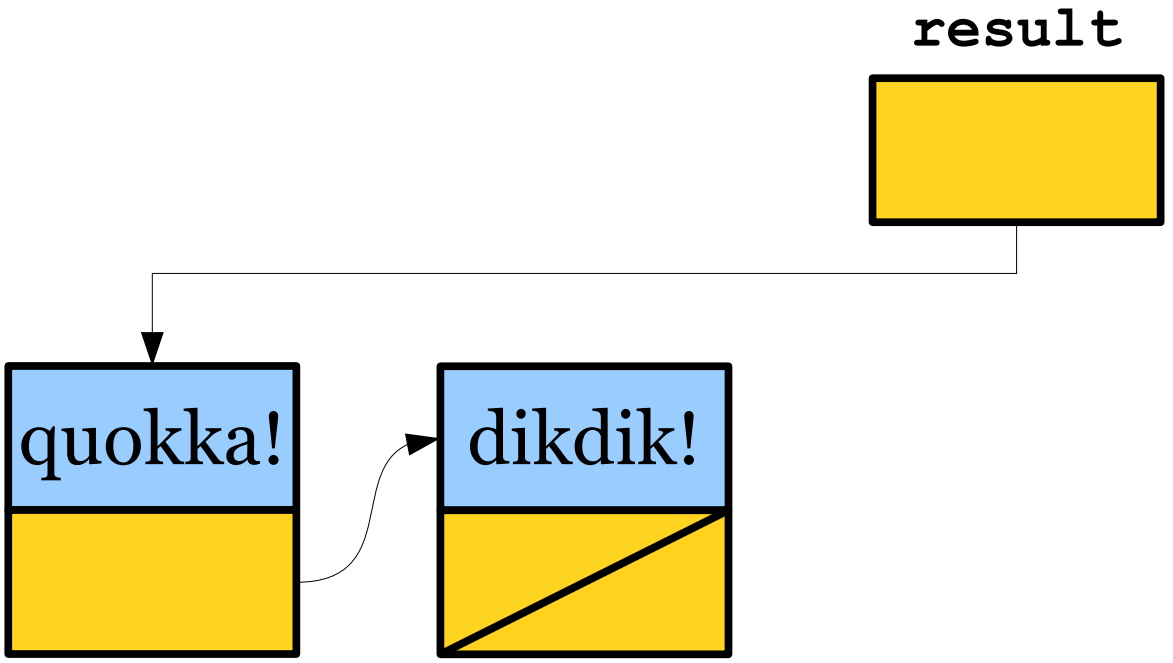

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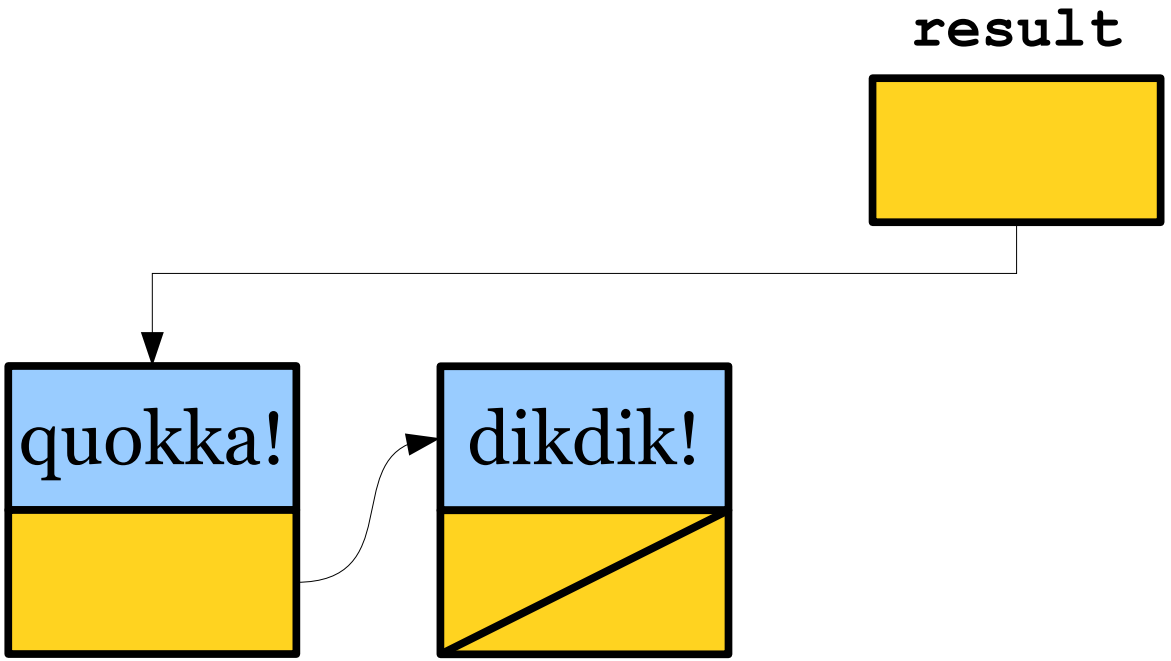

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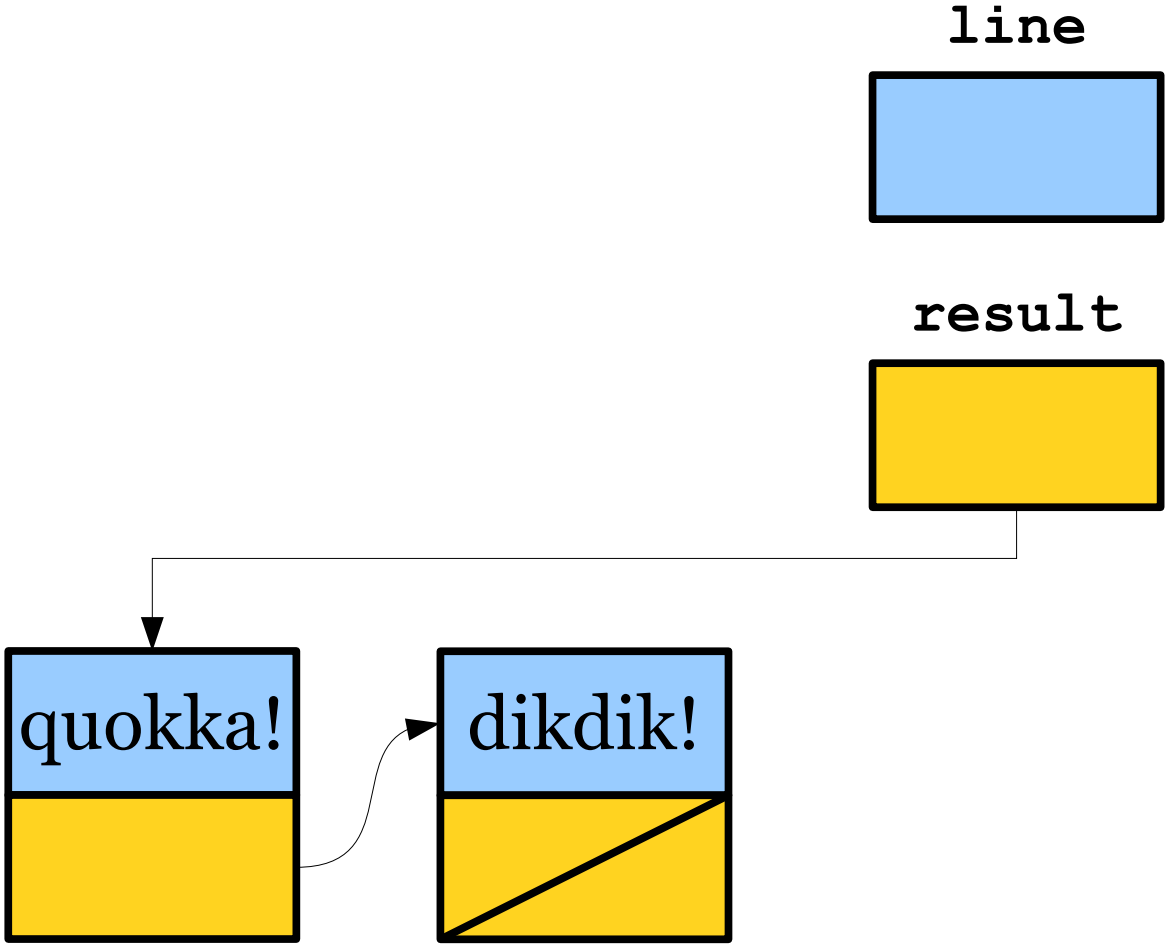

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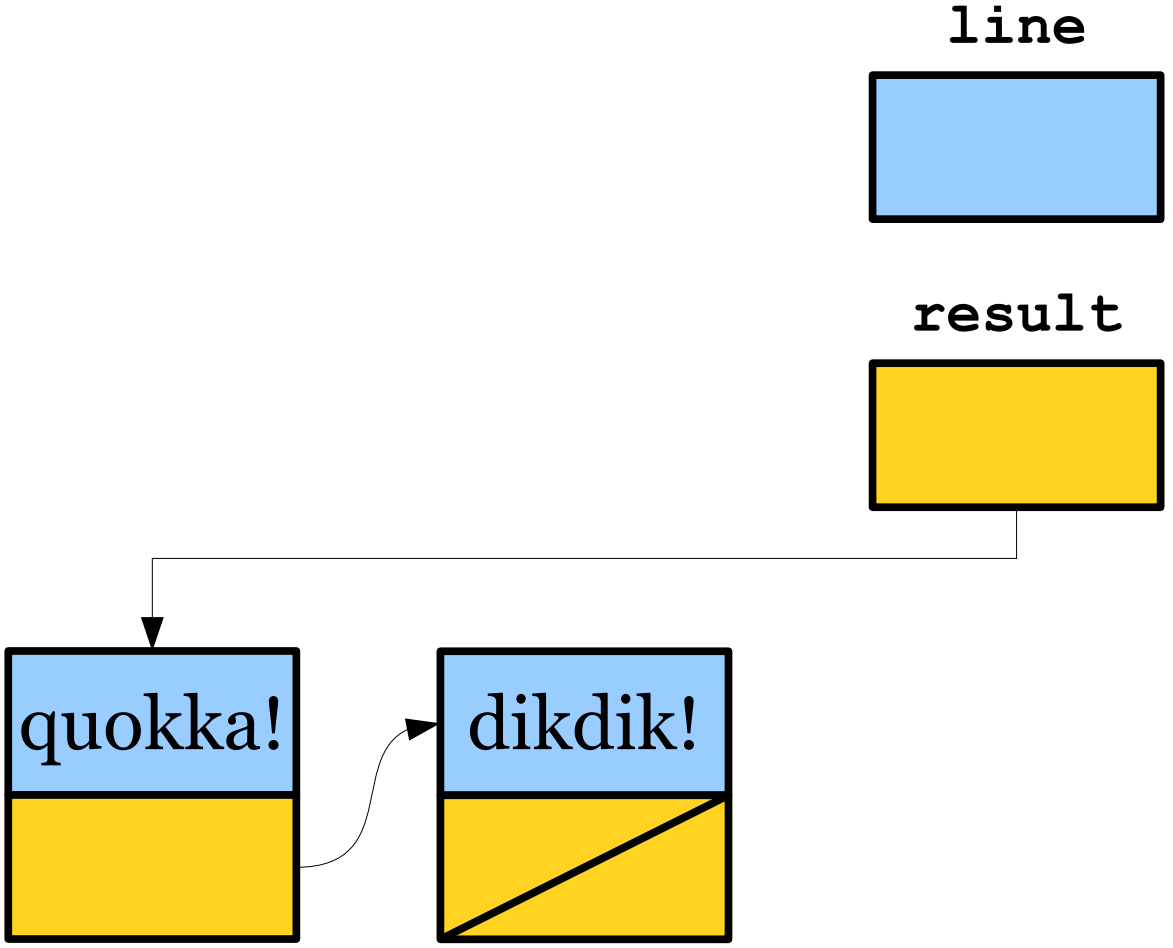

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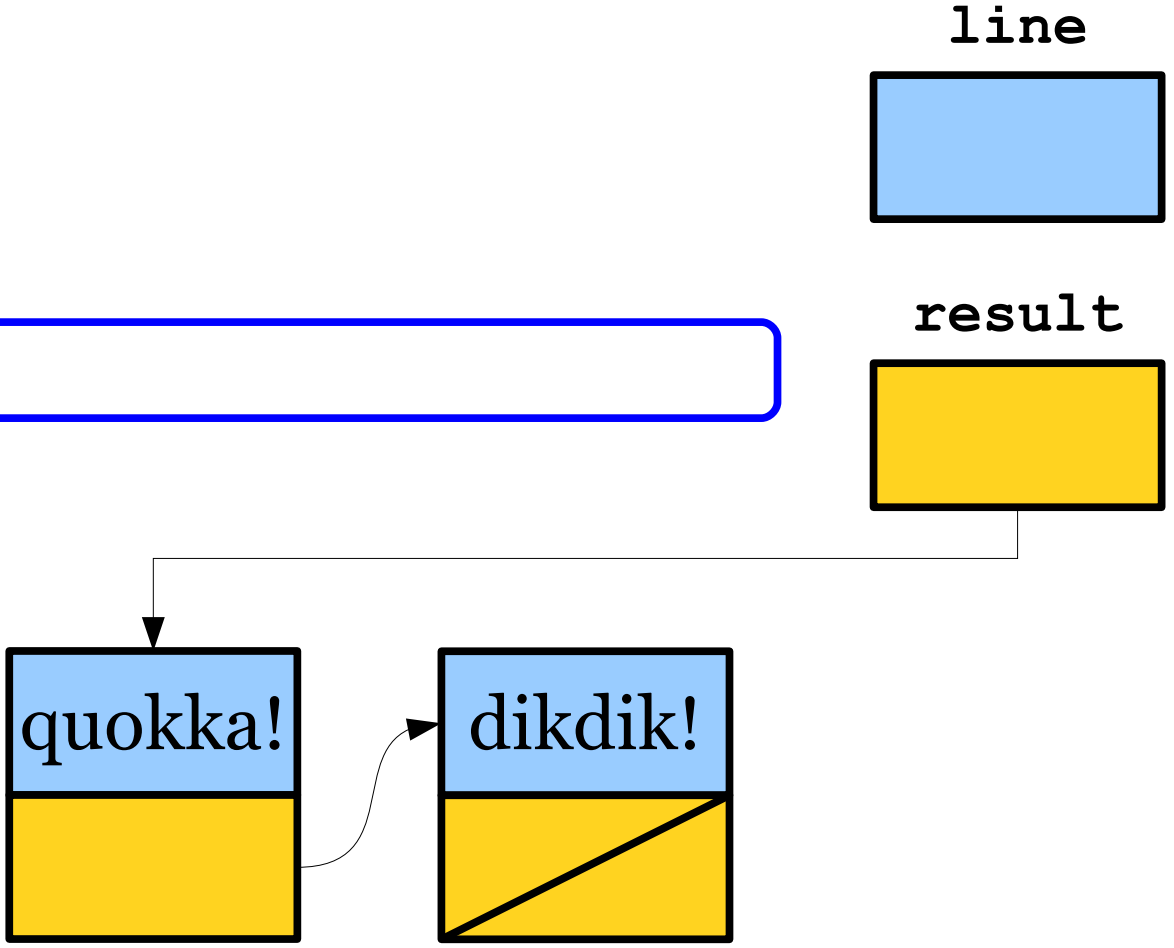

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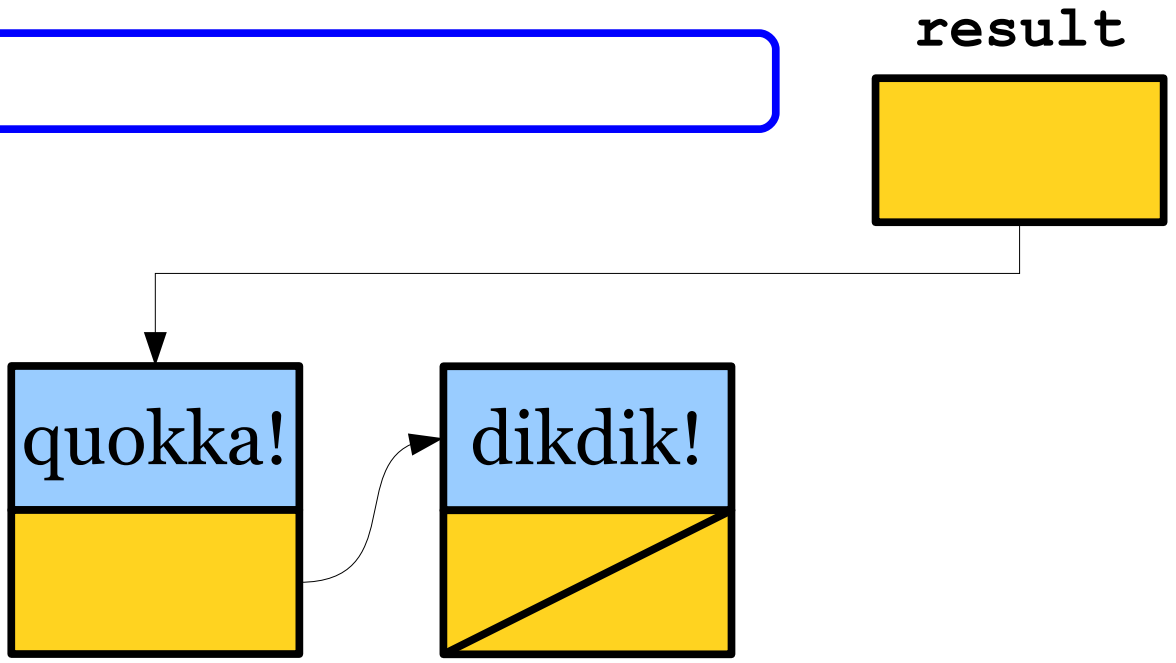
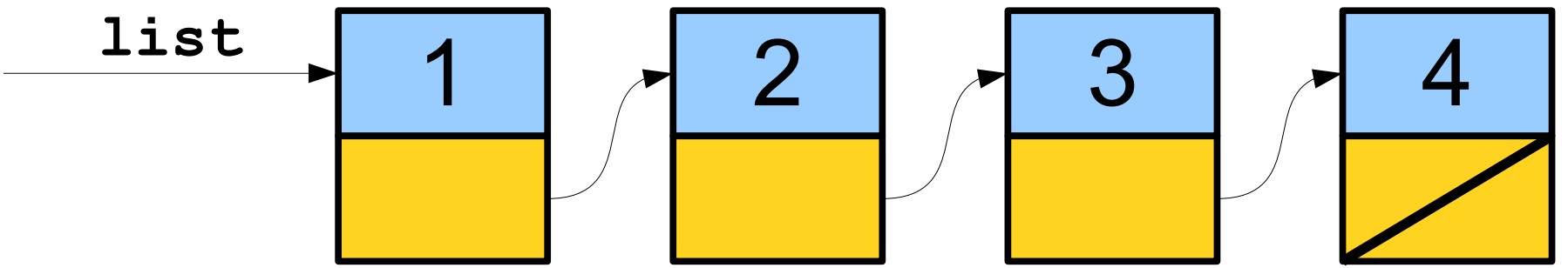


New Stuff

Traversing a Linked List

- Once we have a linked list, we can traverse it by following the links one at a time.

```
for (Cell* ptr = list; ptr != NULL; ptr = ptr->next) {
    /* … use ptr … */
}
```



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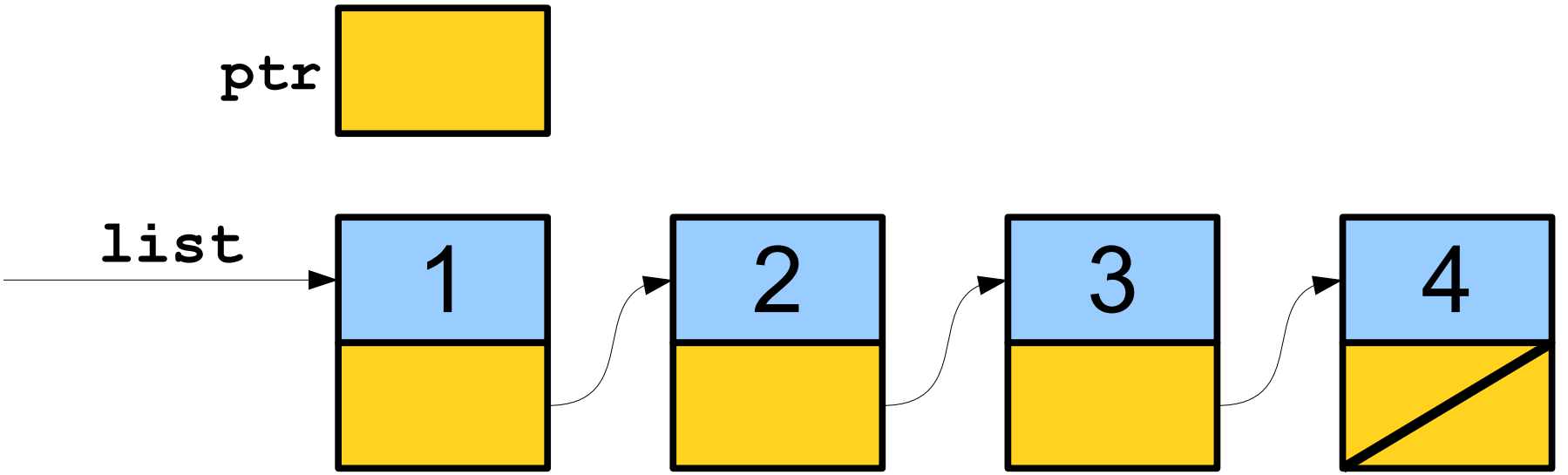

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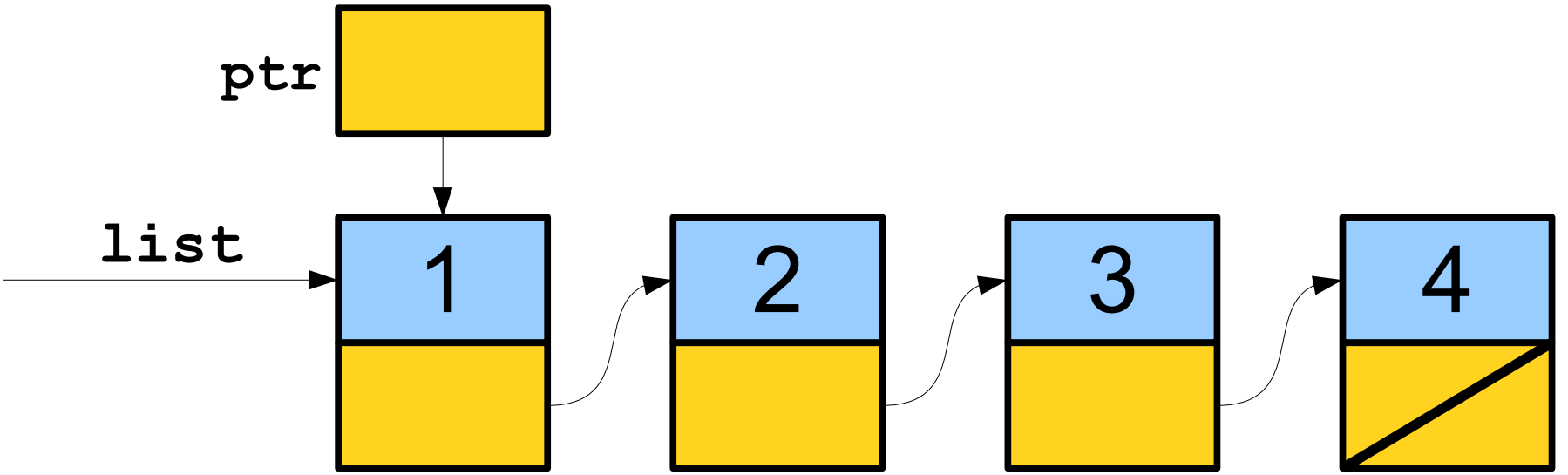

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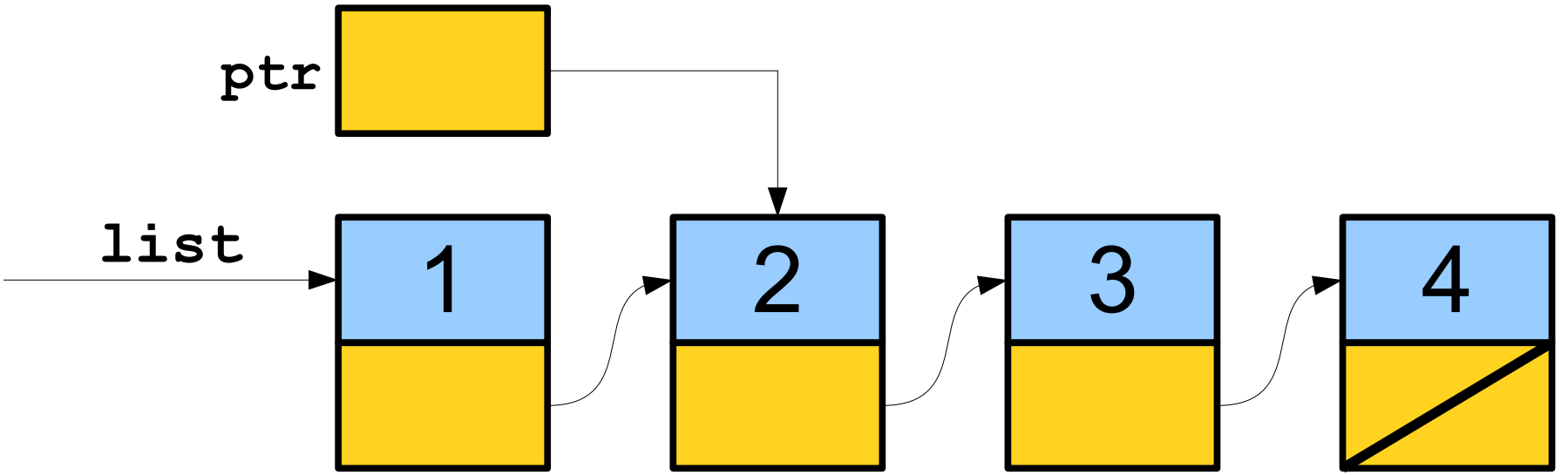

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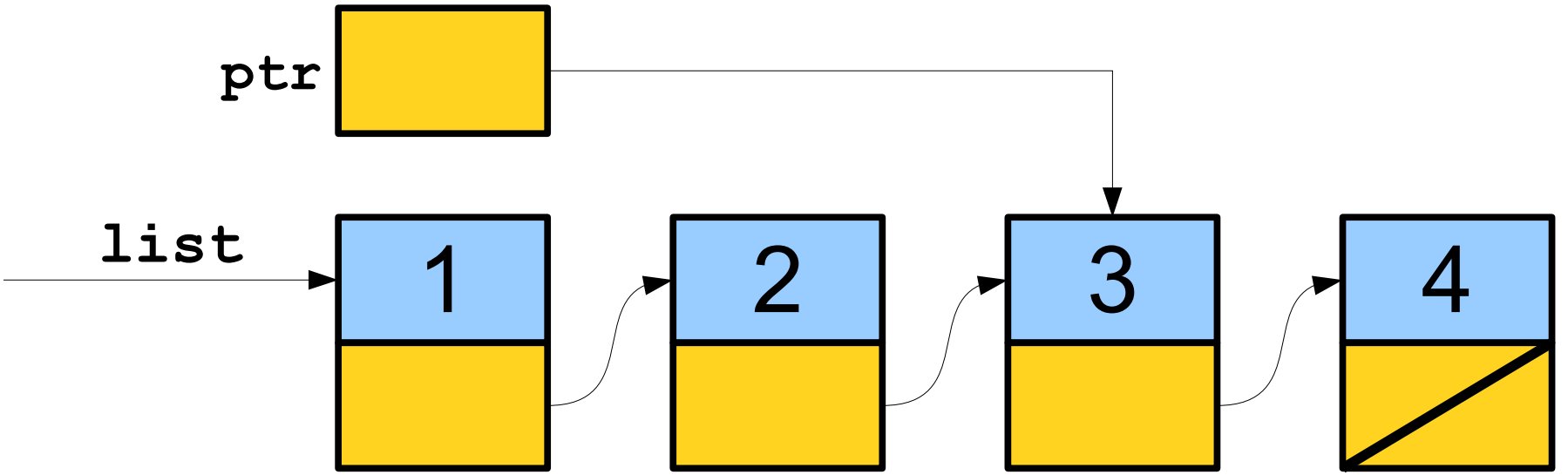

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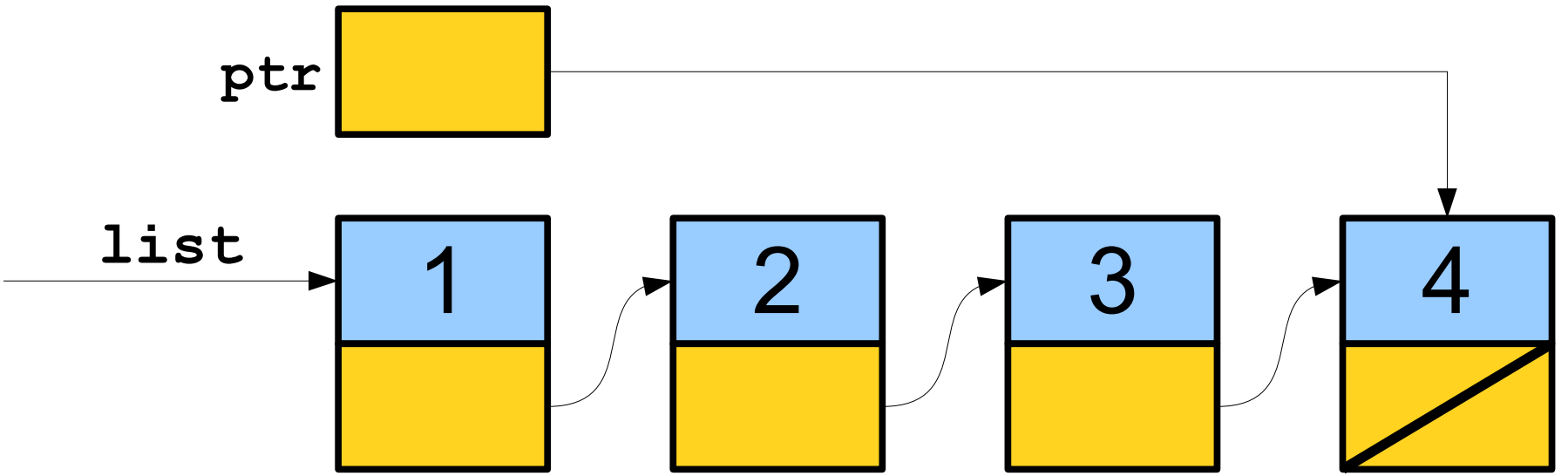

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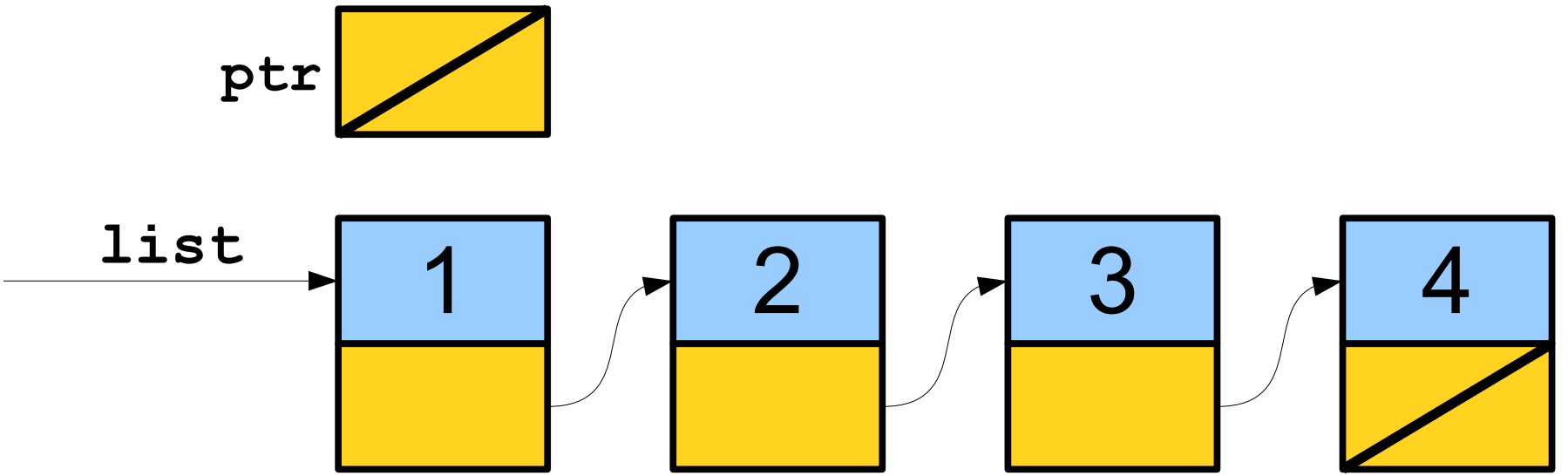

`printList()`
(Code)

Once More With Recursion

- Linked lists are defined recursively, and we can traverse them using recursion!

```
void recursiveTraverse(Cell* list) {
    if (list == NULL) return;
    /* … do something with list … */
    recursiveTraverse(list->next);
}
```

Freeing a Linked List

- All good things must come to an end, and we eventually need to reclaim the memory for a linked list.
- Here's an ***Extremely Bad Idea***:

```
for (Cell* ptr = list; ptr != NULL; ptr = ptr->next) {
    delete ptr;
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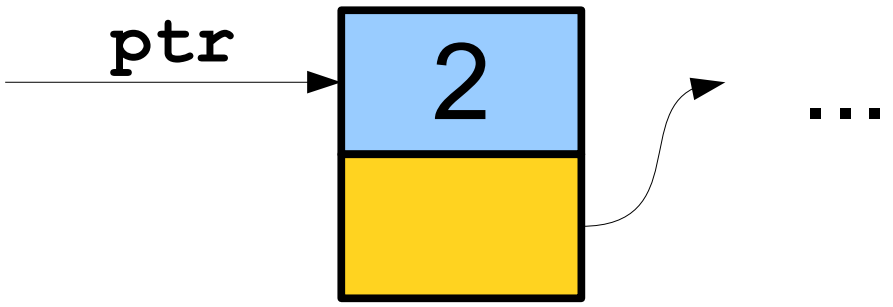

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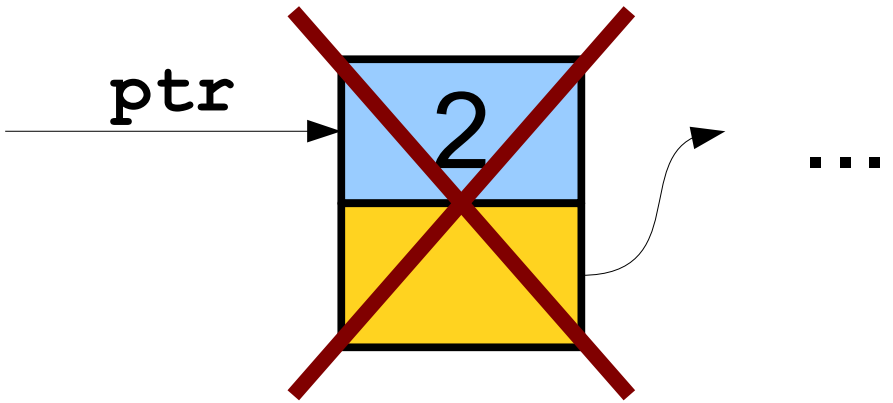

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}
```

Freeing a Linked List Properly

- To properly free a linked list, we have to be able to
  - Destroy a cell, and
  - Advance to the cell after it.
- How might we accomplish this?

`deleteList()`
(Code)

Linked Lists: The Tricky Parts

- 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?

`listInsert()`
(Code)

What went wrong?

```
int main() {
    Cell* list = NULL;
    listInsert(list, 137);
    listInsert(list, 42);
    listInsert(list, 271);
}
```

```
int main() {
    Cell* list = NULL;
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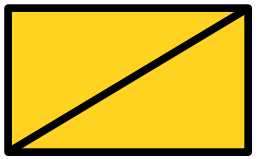
}
```

list 

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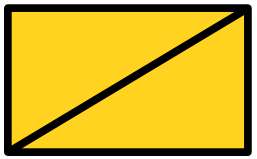
list 

```
int main() {
}
```

```
void listInsert(Cell* list, int value) {
    Cell* newCell = new Cell;
    newCell->value = value;
    newCell->next = list;
    list = newCell;
}
```

```
int main() {
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void listInsert(Cell* list, int value) {
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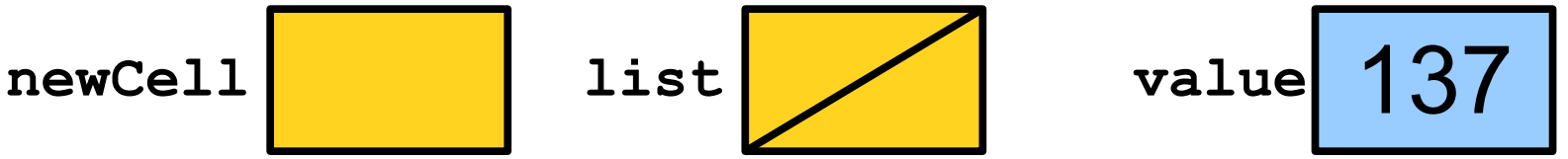

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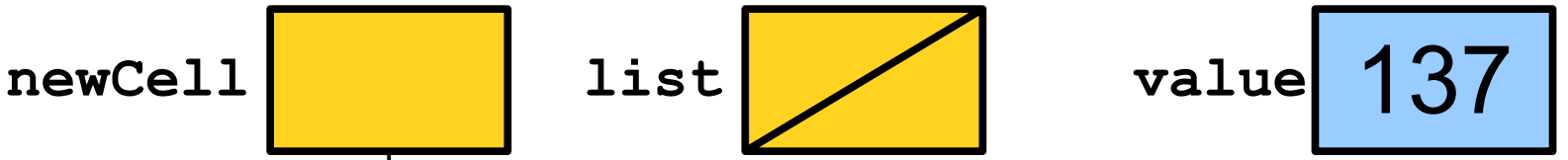

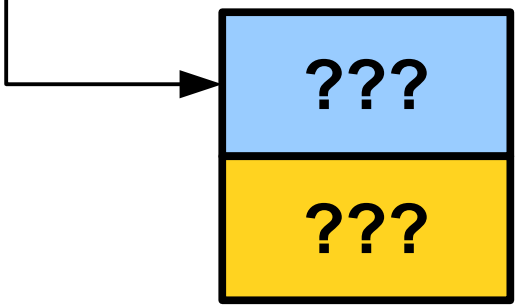

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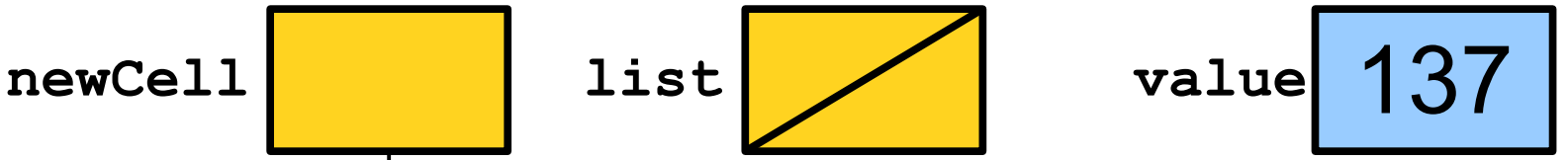

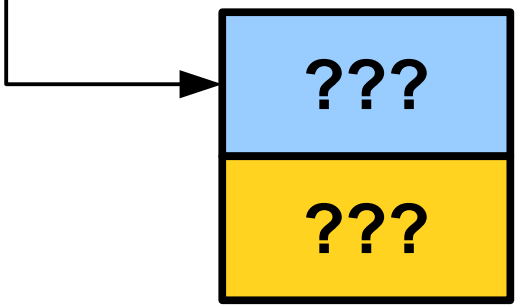

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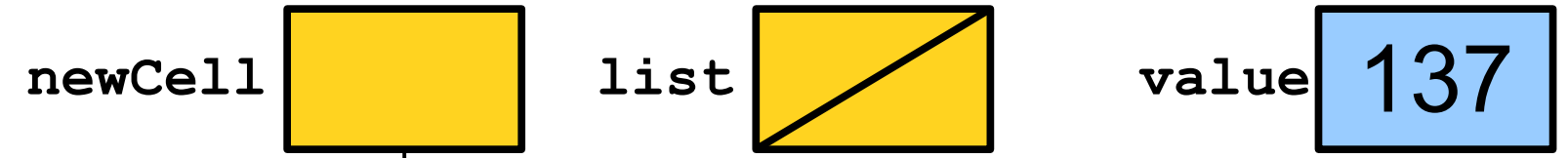

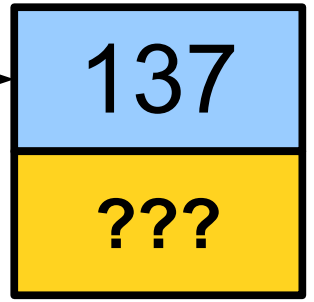

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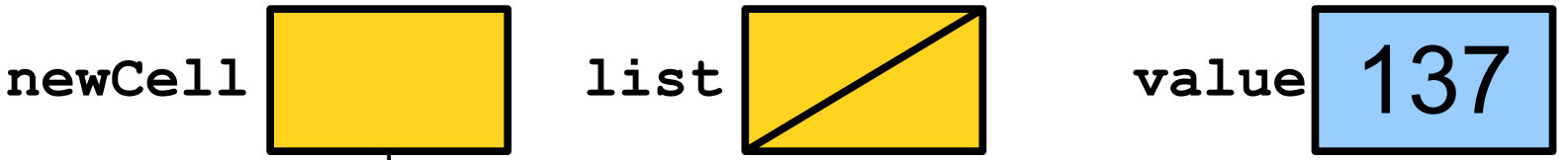

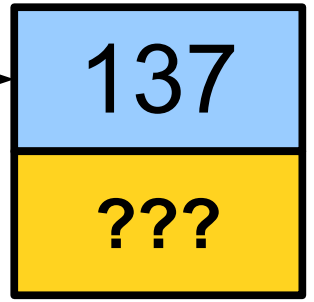

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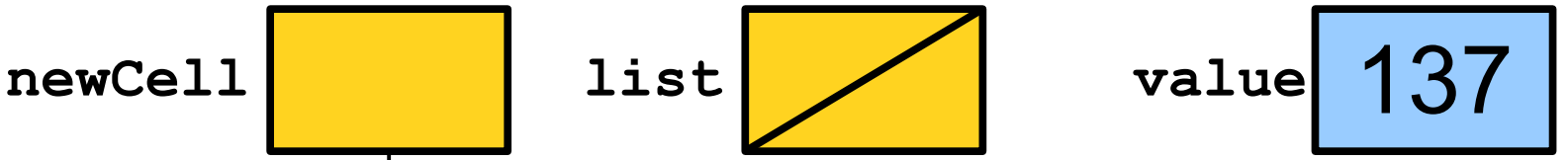

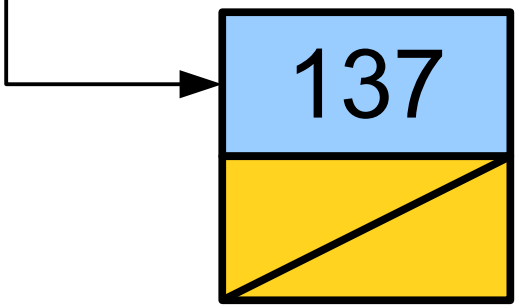

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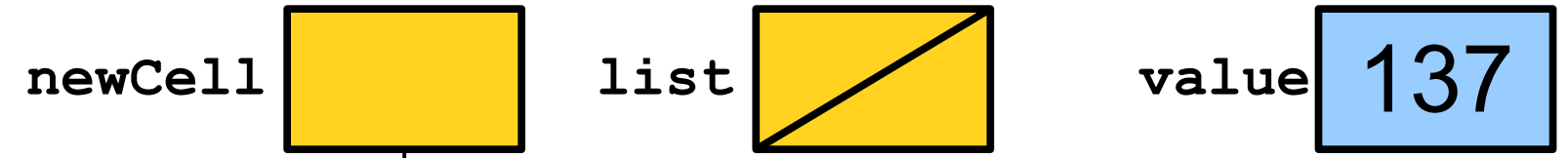

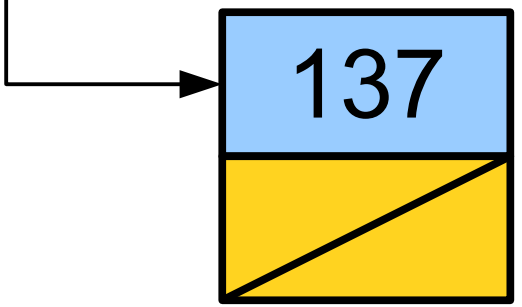

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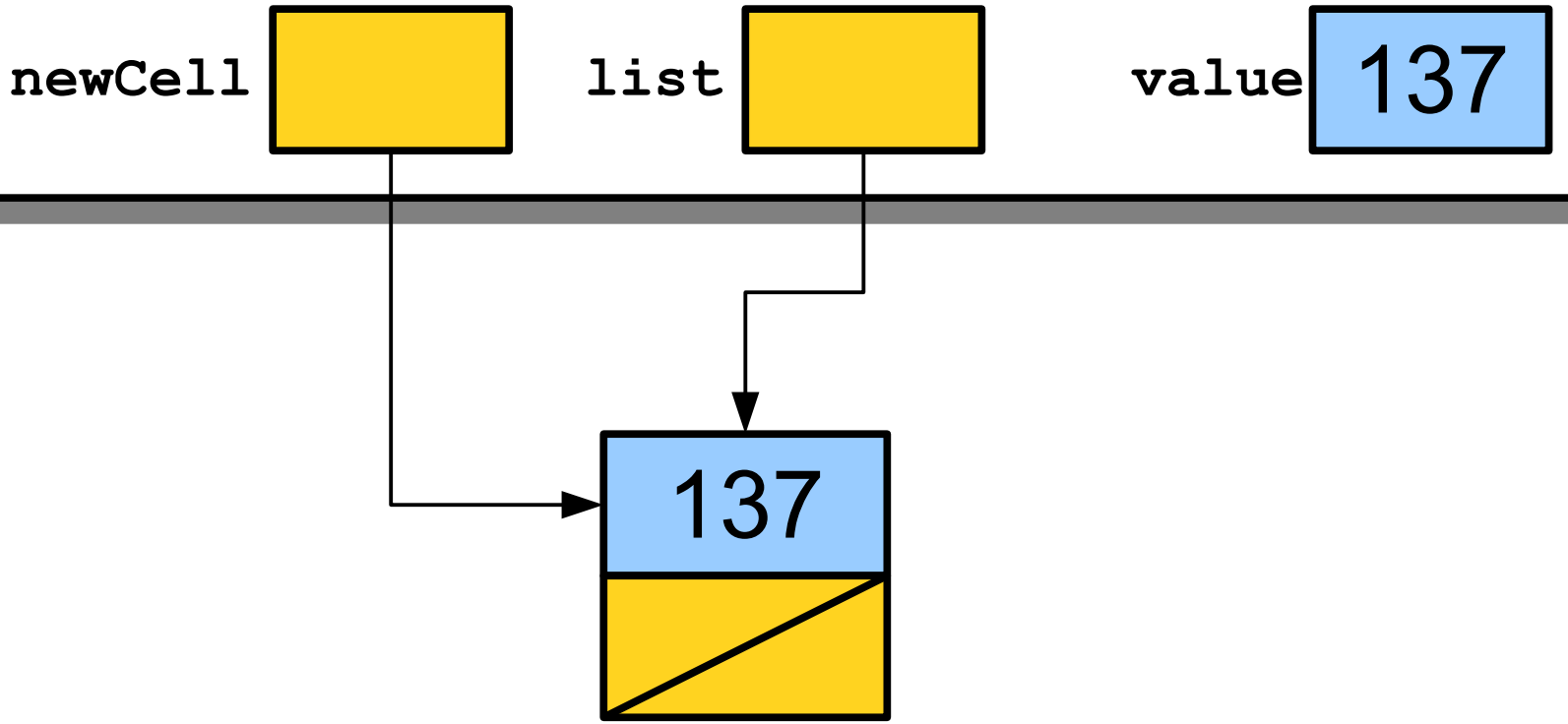

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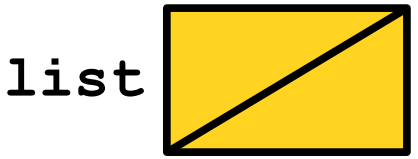

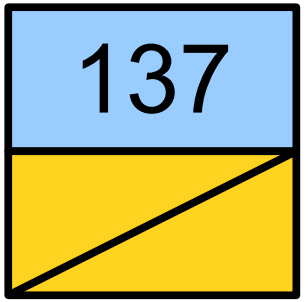

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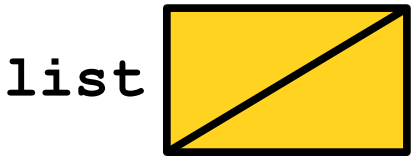

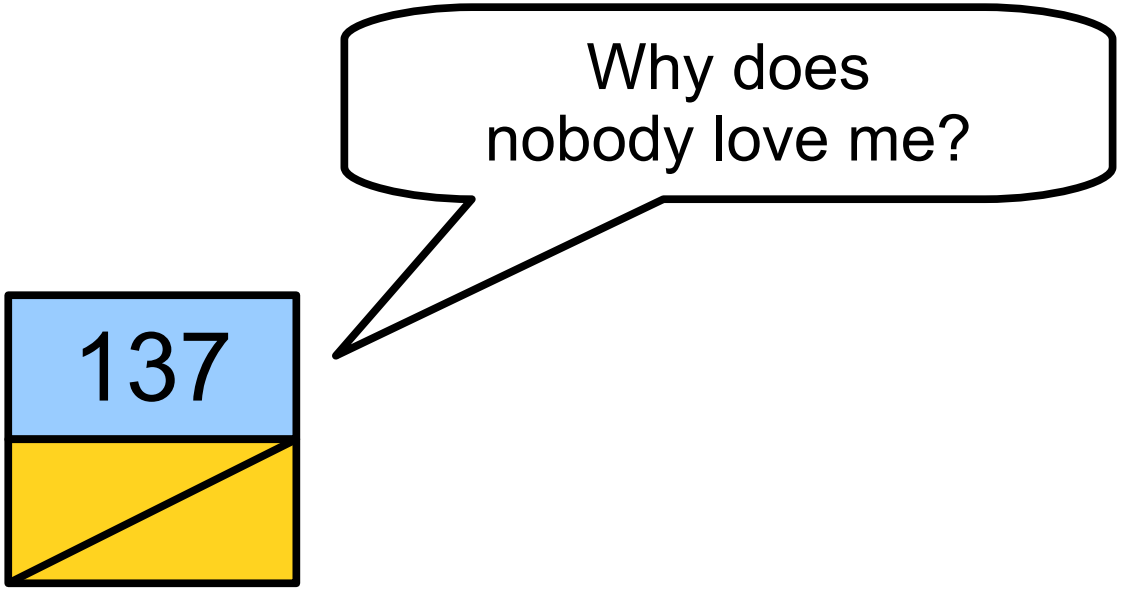

Pointers by Reference

- In order to resolve this problem, we must pass the linked list pointer by reference.
- Our new function:

```
void listInsert(Cell*& list, int value) {
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This is a **reference to a pointer to a Cell**. It's often useful to read this from the right to the left.

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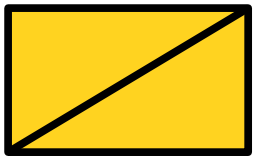
list 

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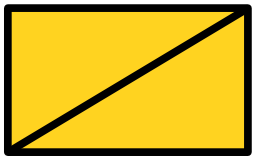
list 

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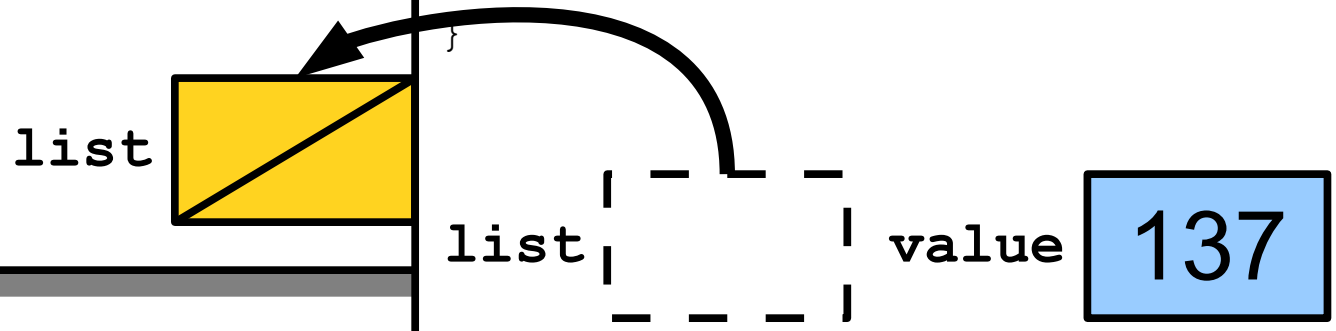

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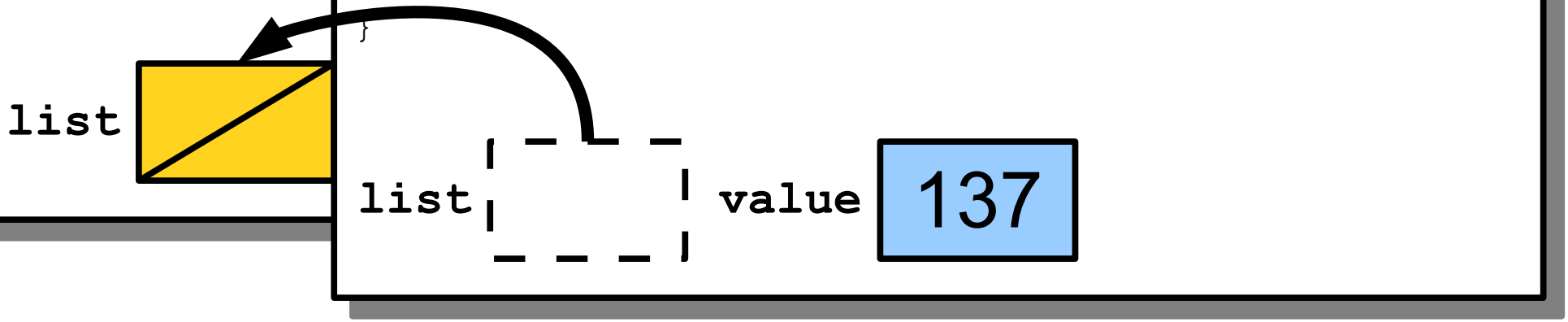

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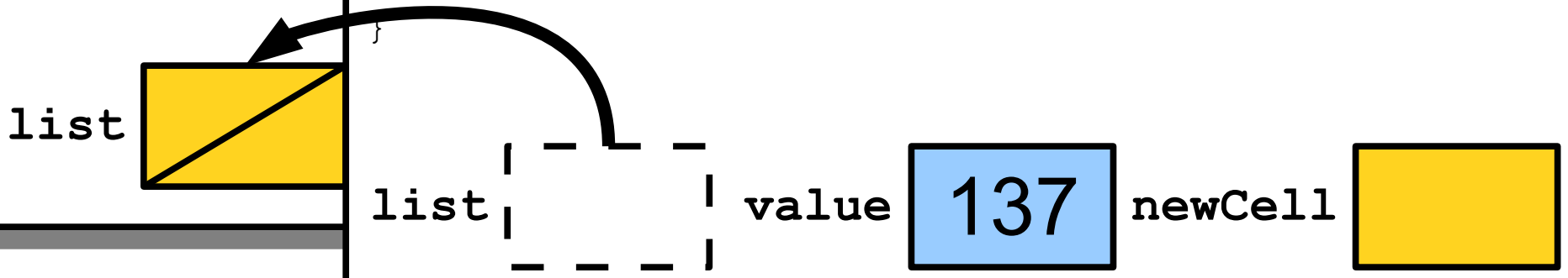

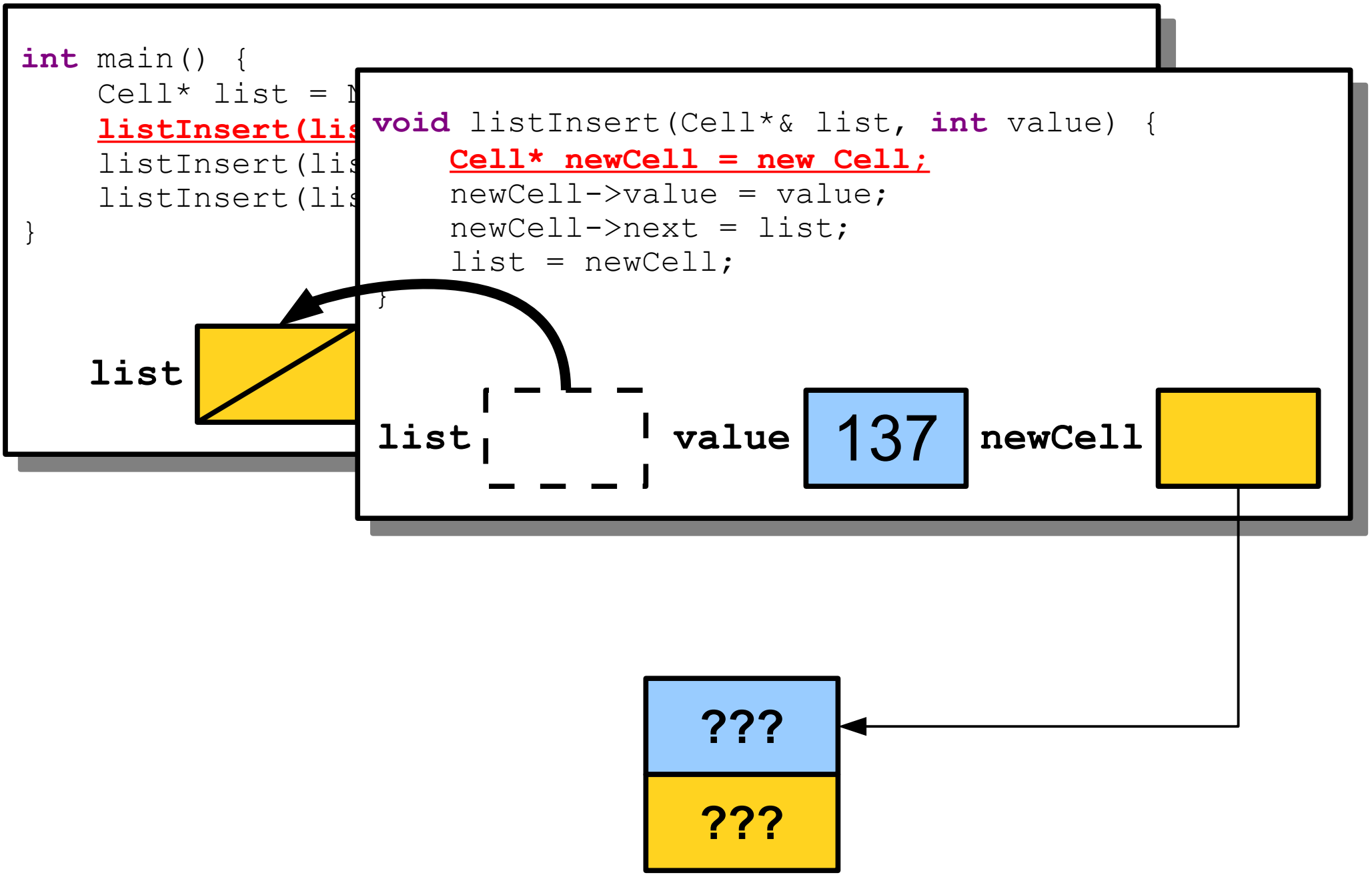
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???
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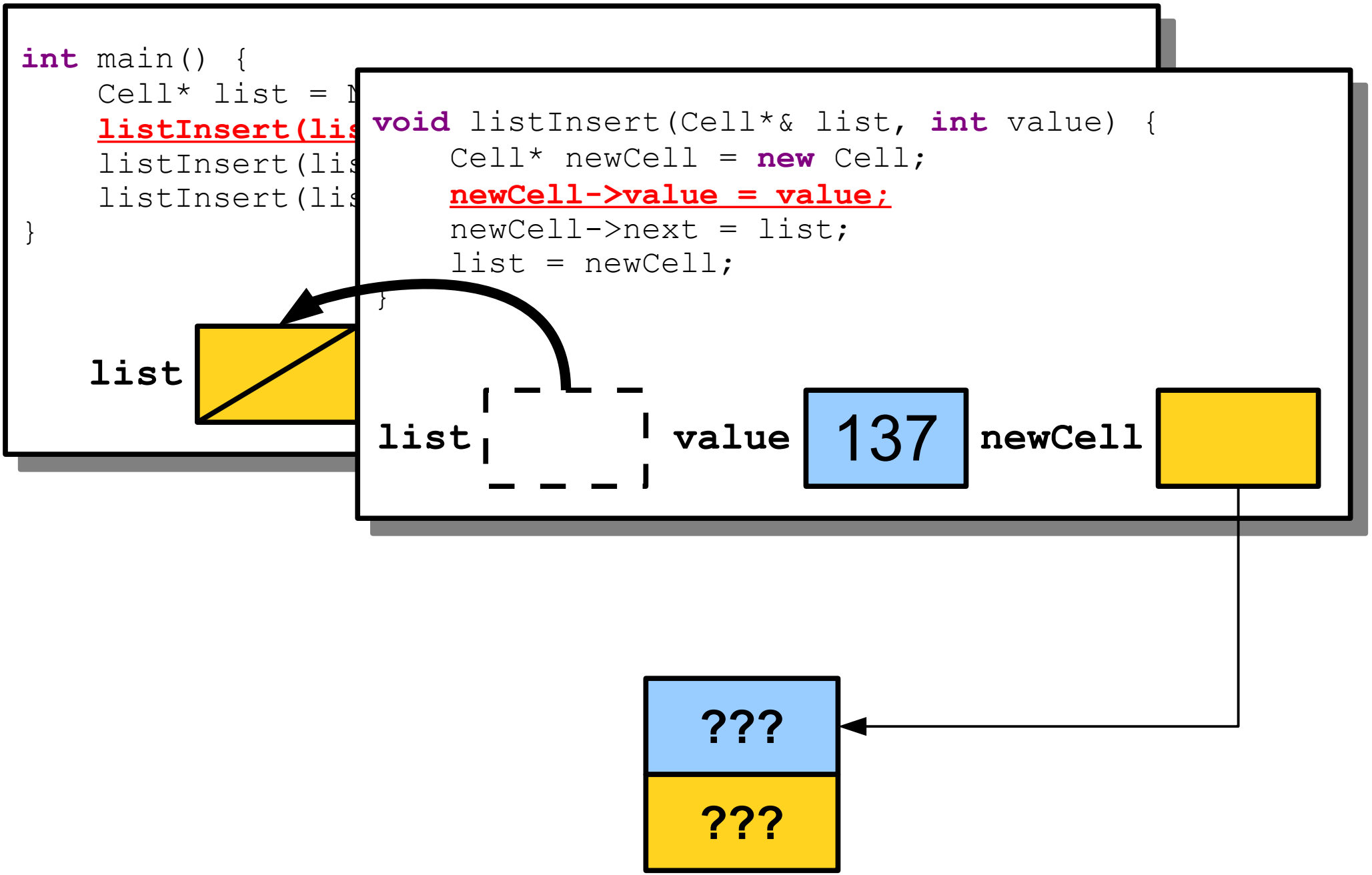
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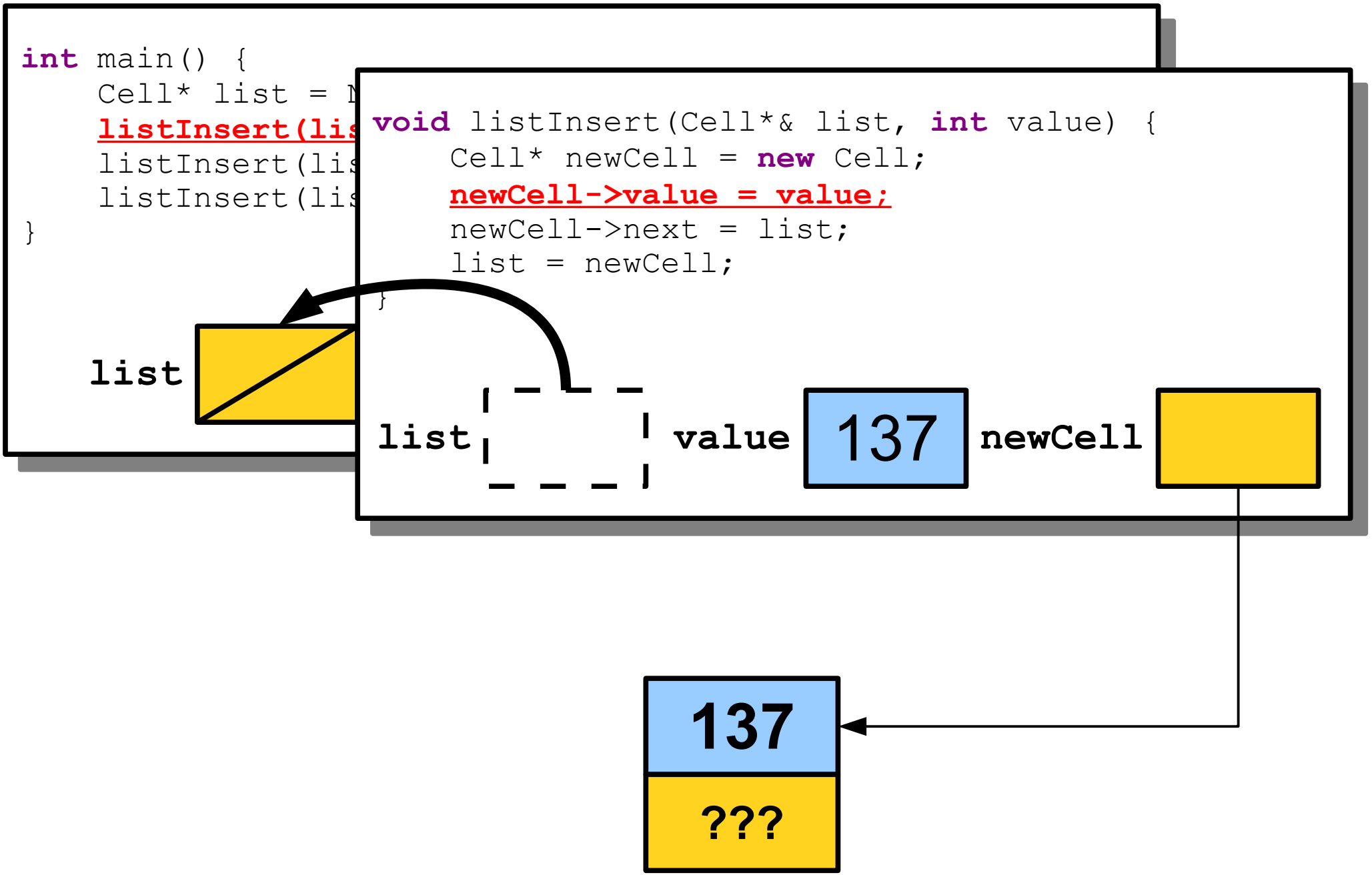
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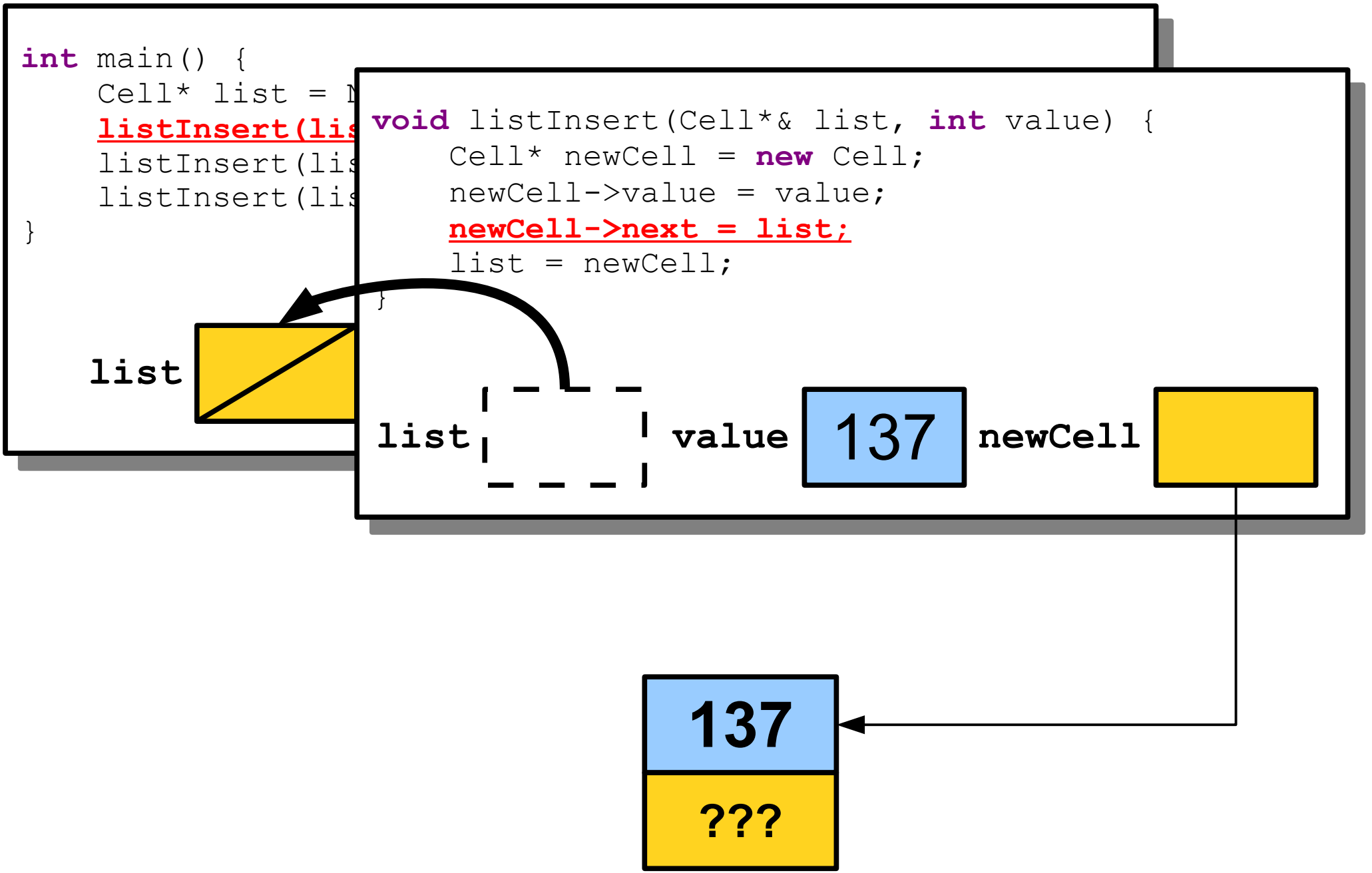
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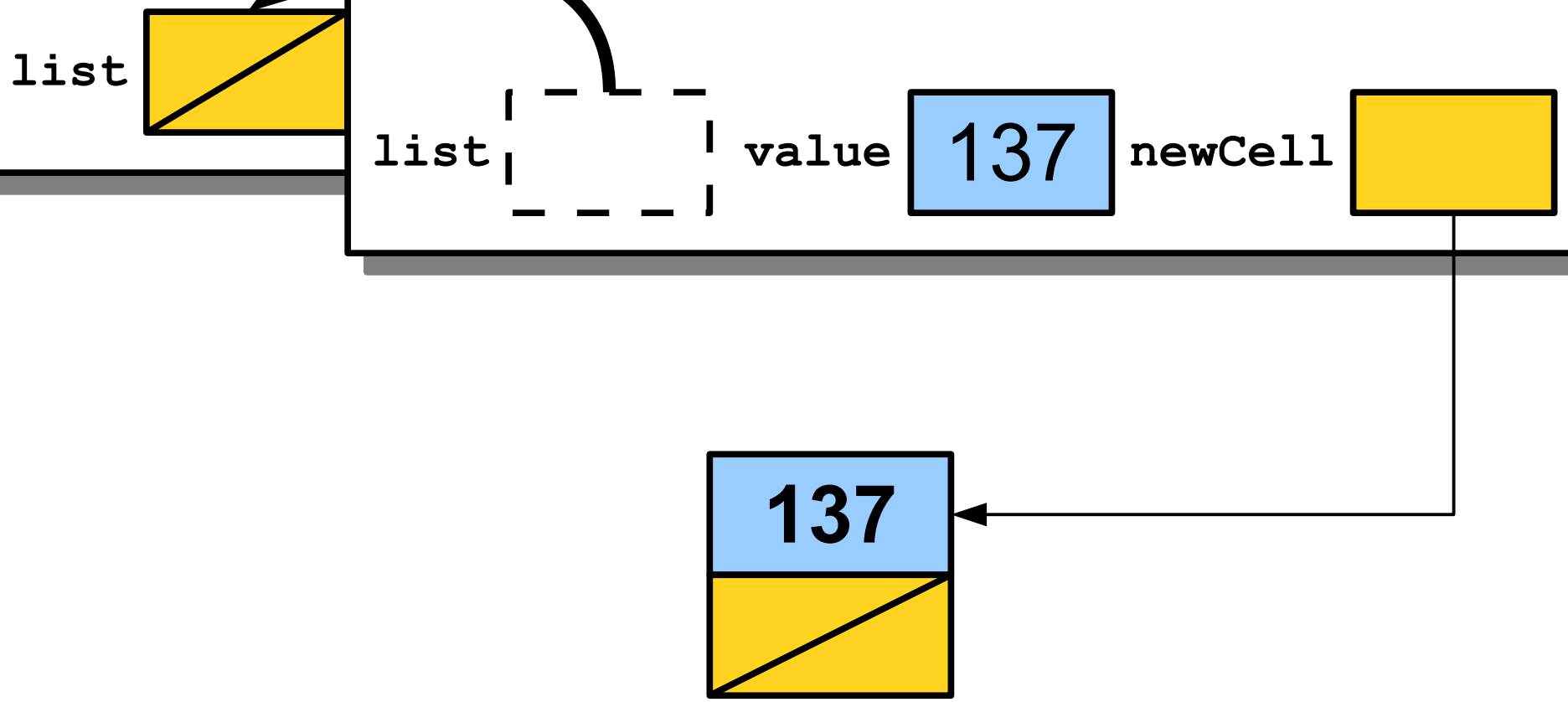

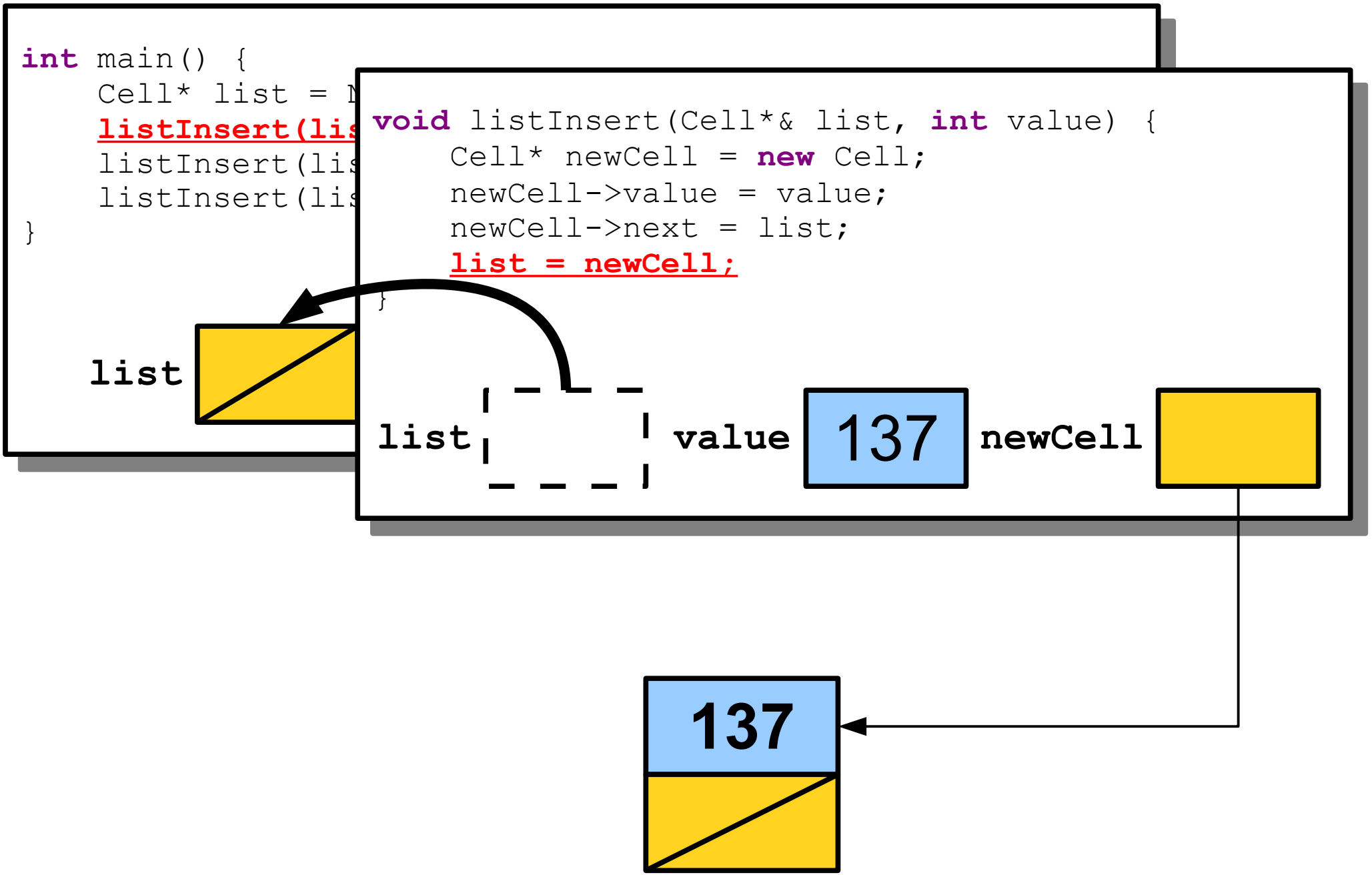
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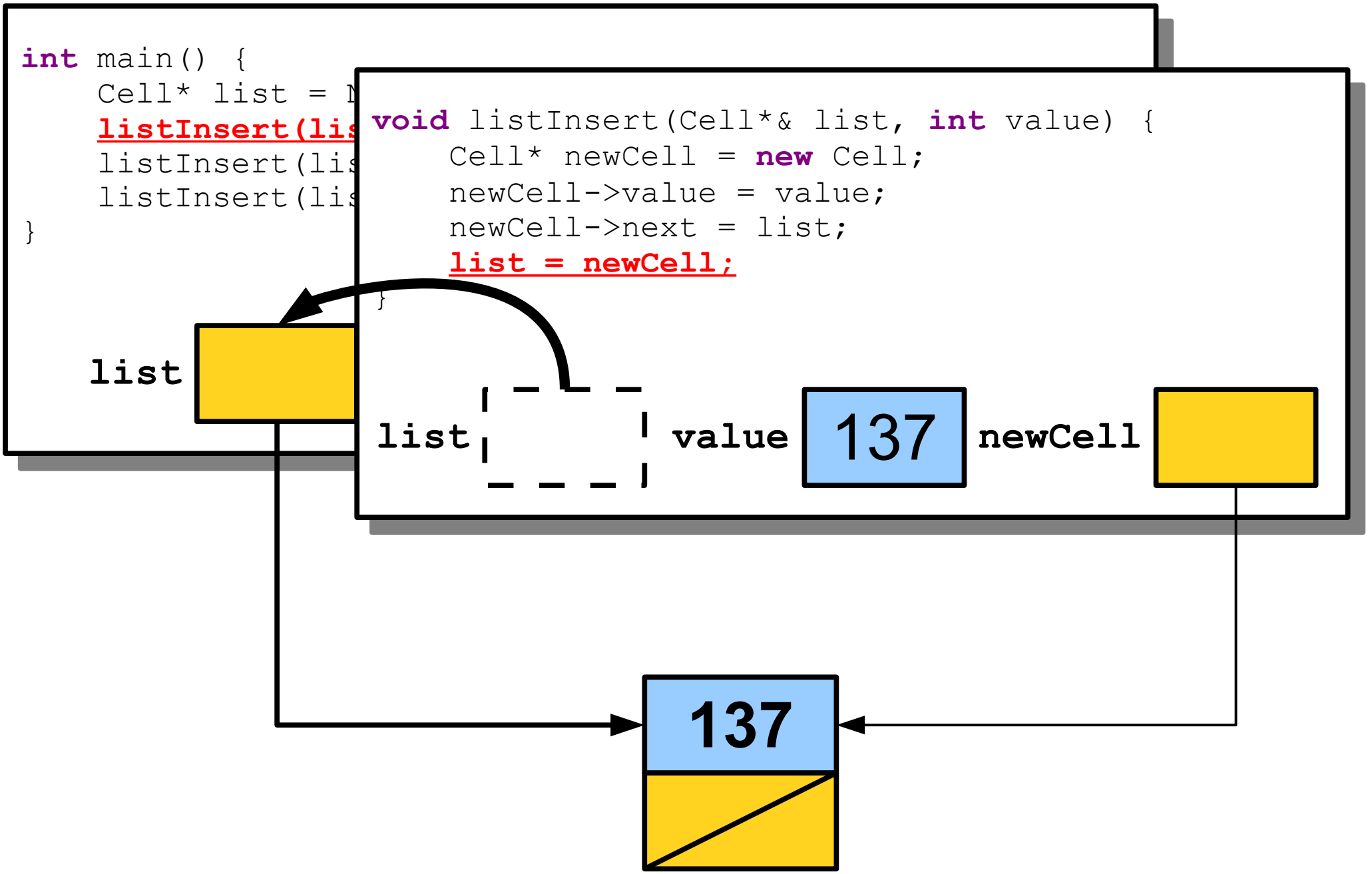
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int main() {
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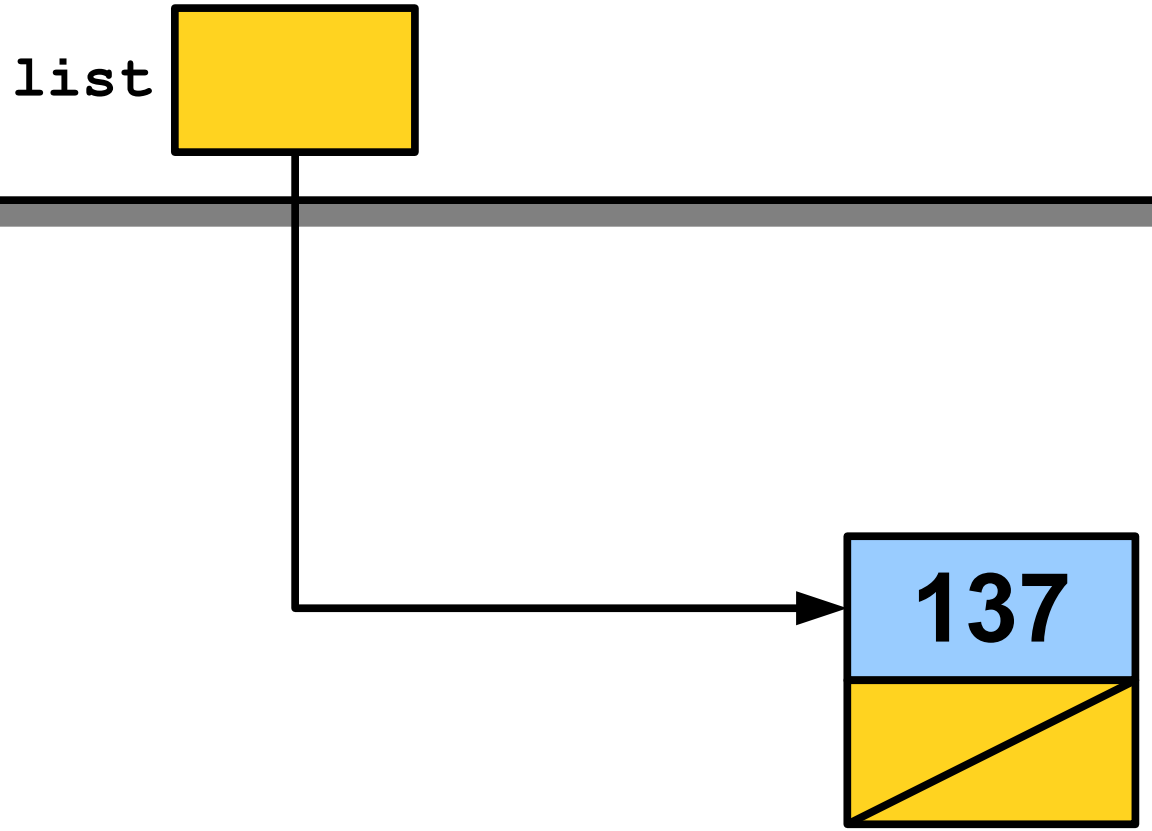
    listInsert(list, 137);
    listInsert(list, 42);
    listInsert(list, 271);
}
```



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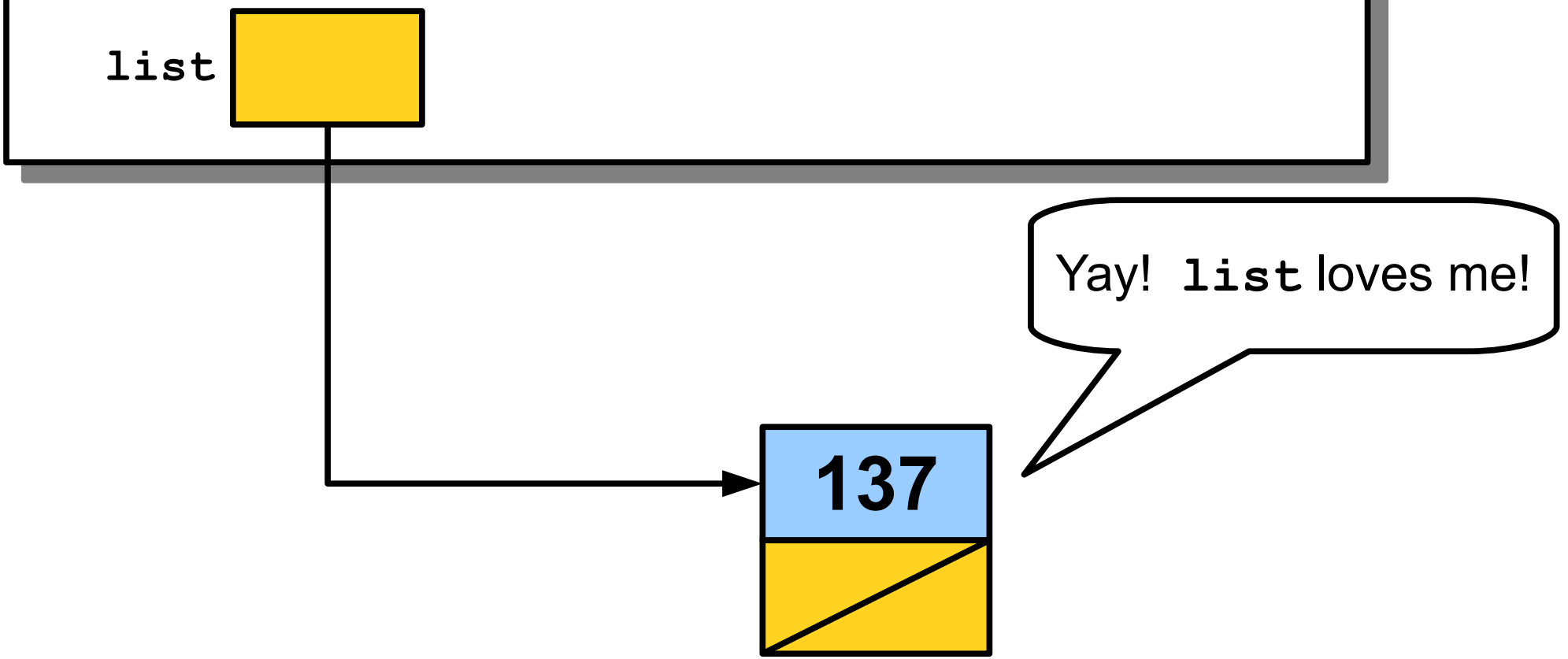

Pointers by Reference

- If you pass a pointer into a function *by value,* you can change the contents at the object you point at, but not *which* object you point at.
- If you pass a pointer into a function *by reference,* you can *also* change *which* object is pointed at.

Implementing `Queue`

- Earlier, we implemented a queue using two stacks.
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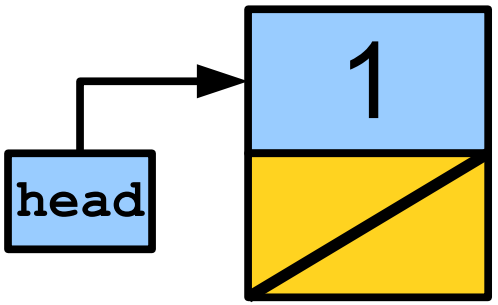

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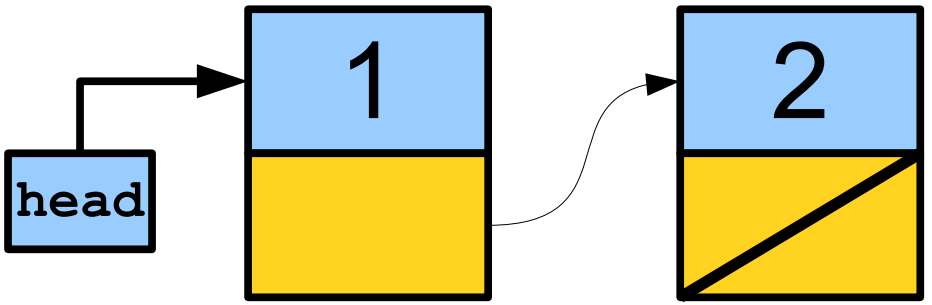

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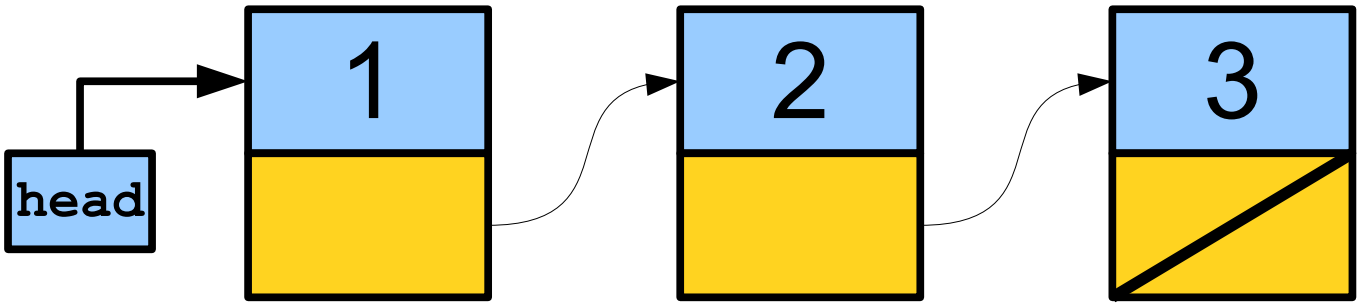

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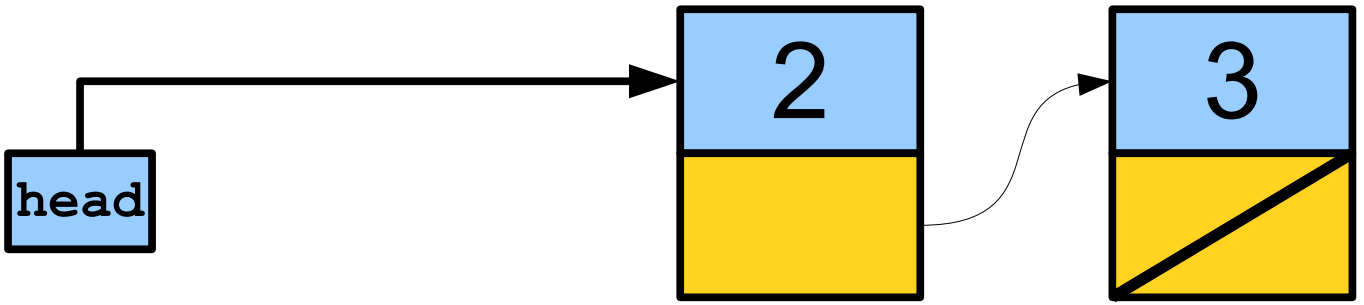

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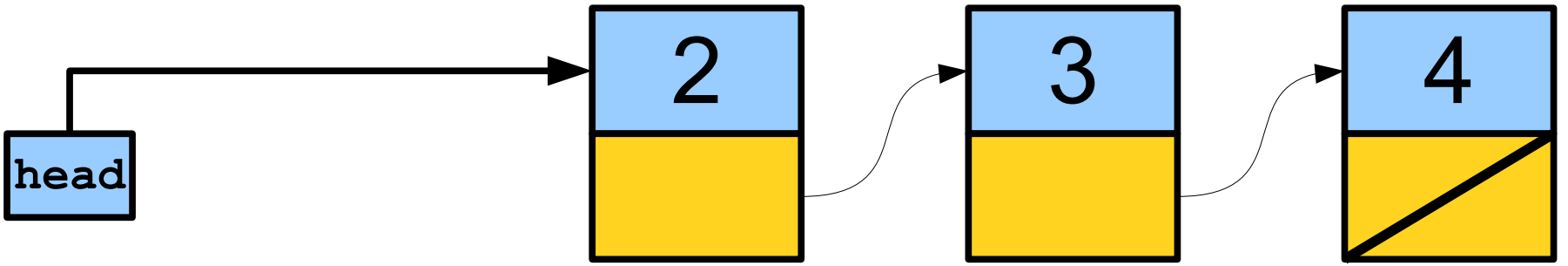

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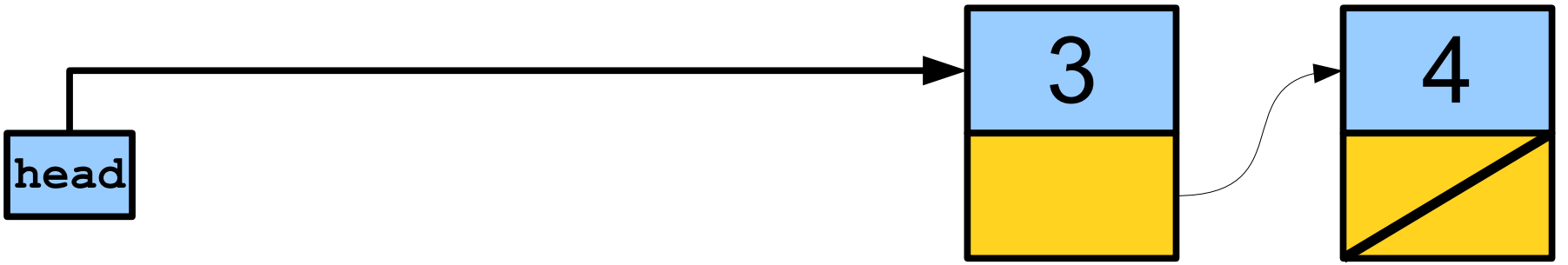

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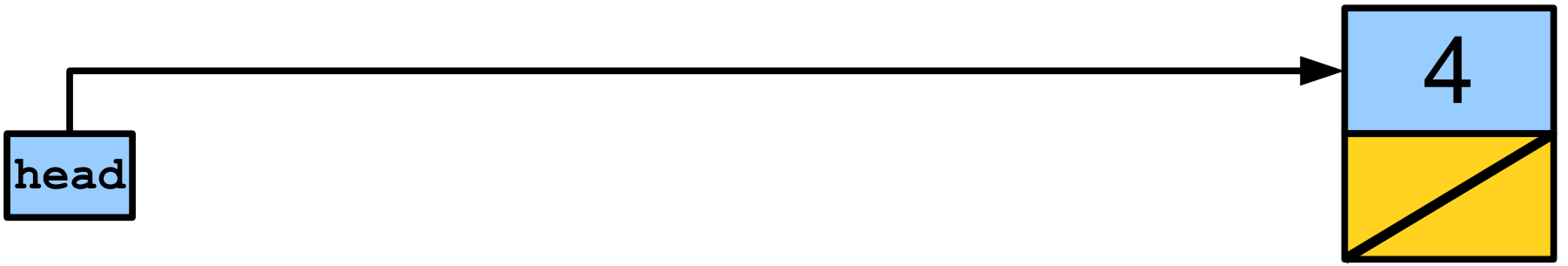

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`Queue Data`

`Queue::Queue()`

`Queue::~Queue()`

(Code)

`Queue::enqueue()`
`Queue::dequeue()`
(Pseudocode)

`Queue::enqueue()`
`Queue::dequeue()`
(Code)

Analyzing Efficiency

- What is the big-O complexity of a dequeue?
- Answer: **O(1)**.
- What is the big-O complexity of an enqueue?
- Answer: **O(*n*)**.

Improving Efficiency

- The O(n) work in enqueue comes from scanning the list to find the end.
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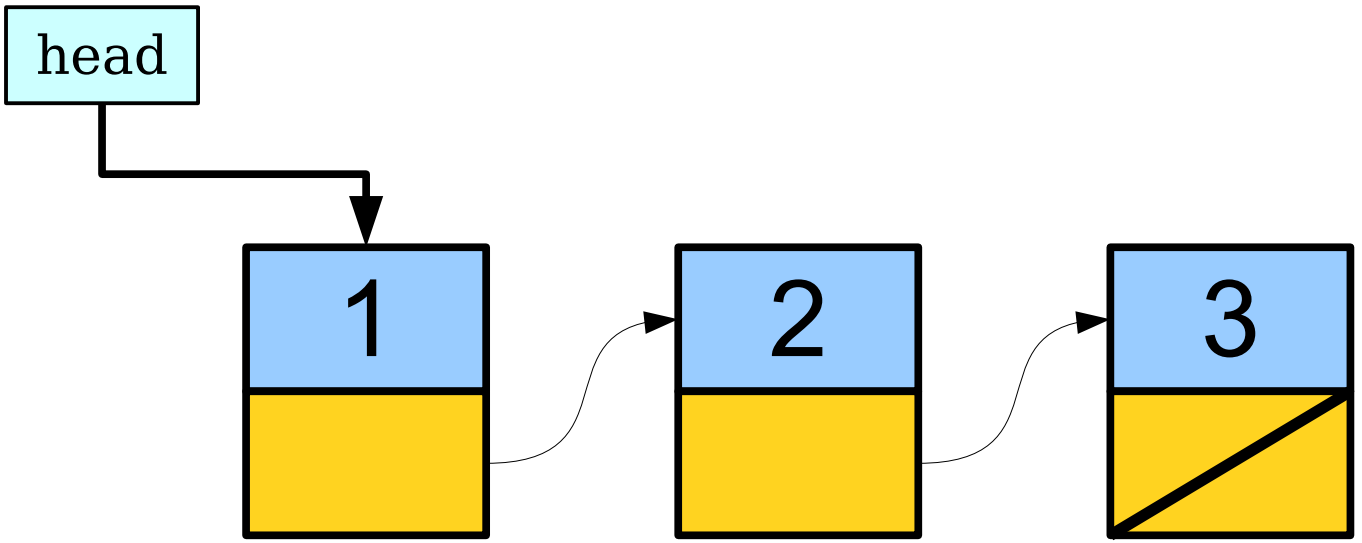

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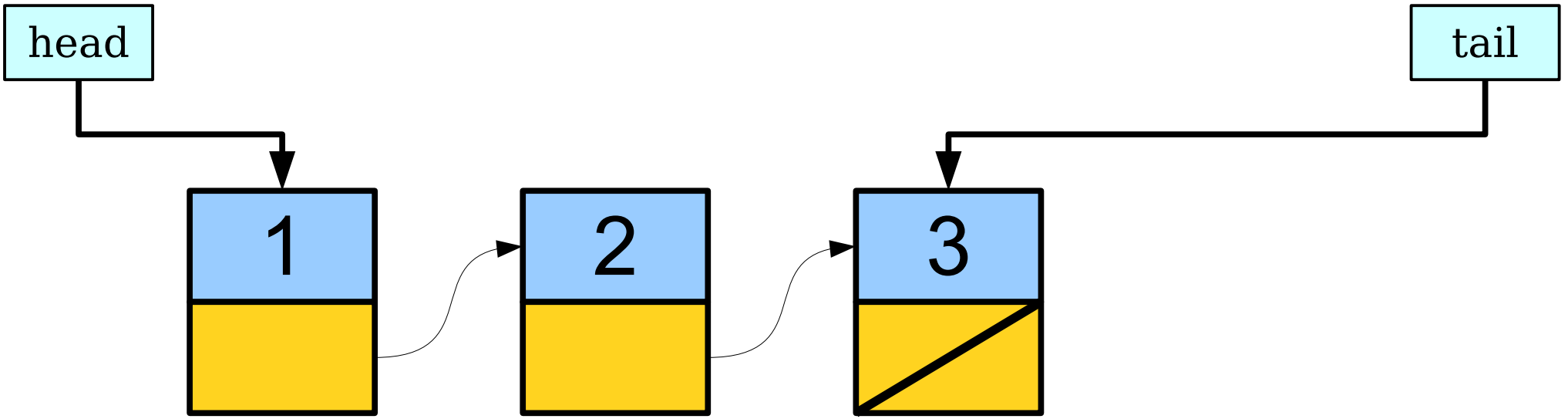

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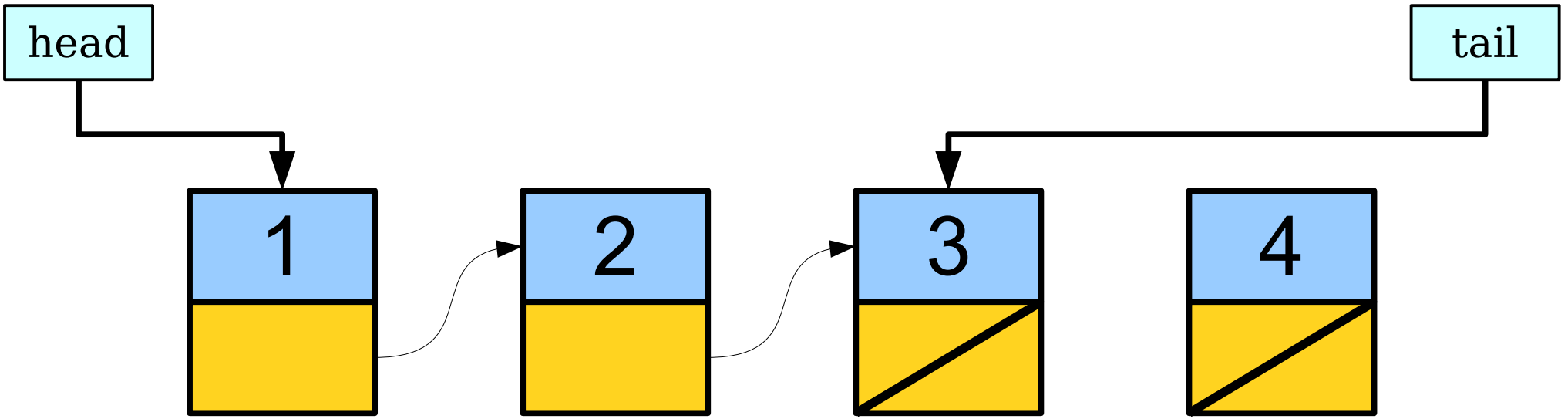

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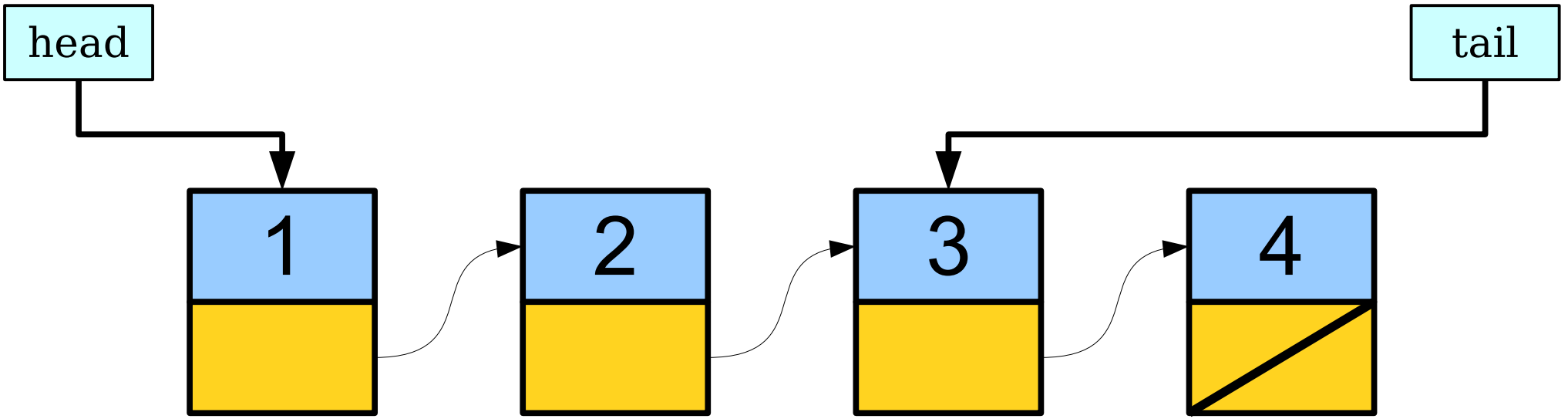

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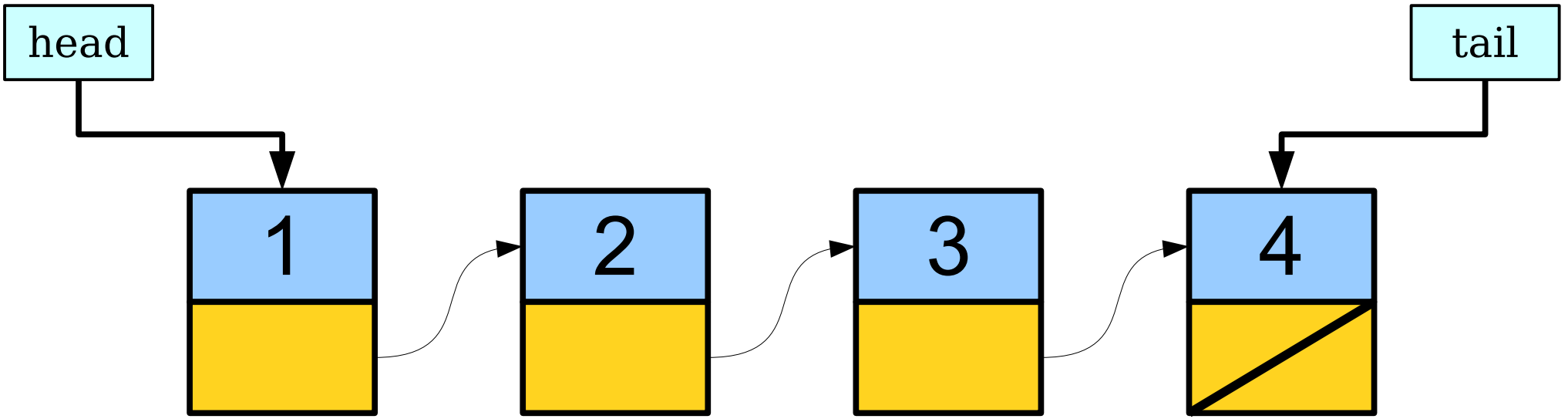

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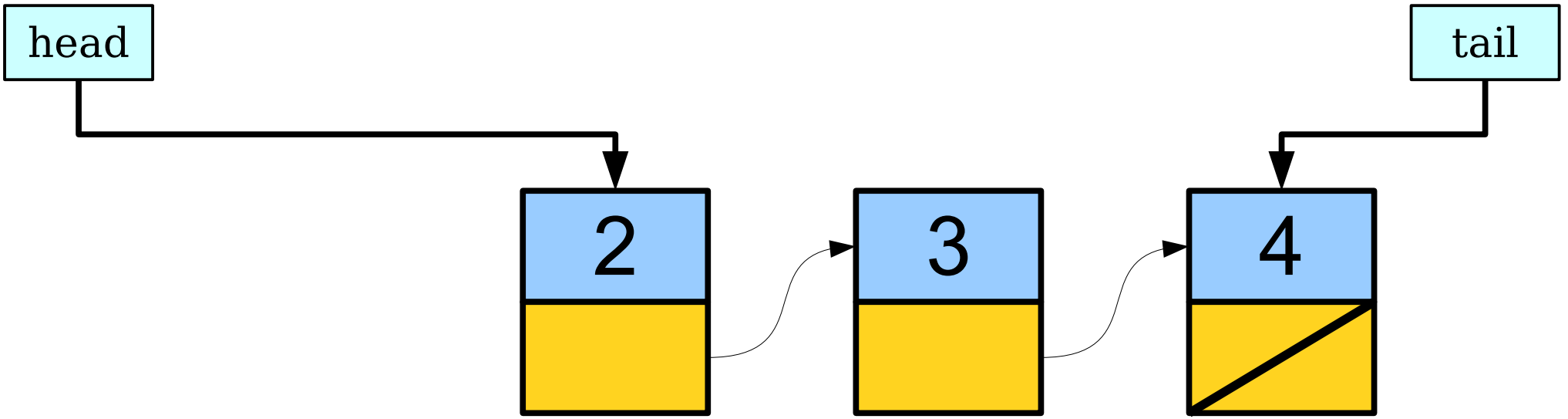

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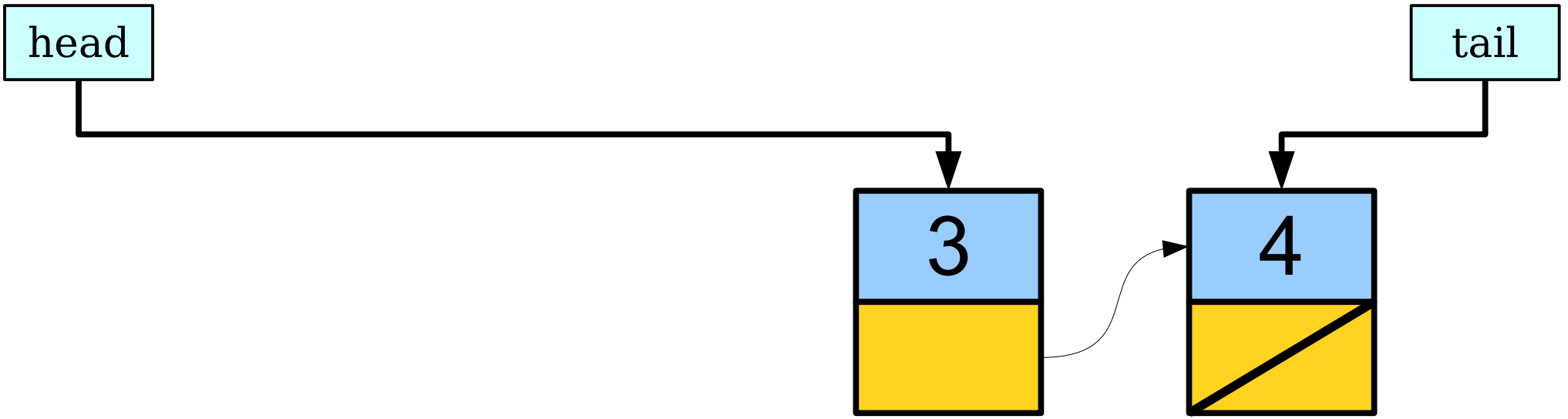

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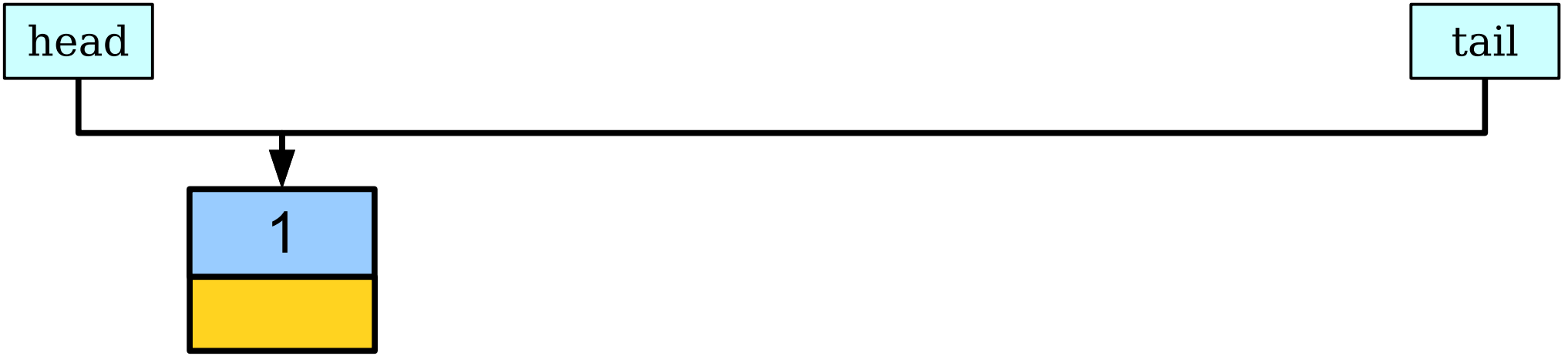

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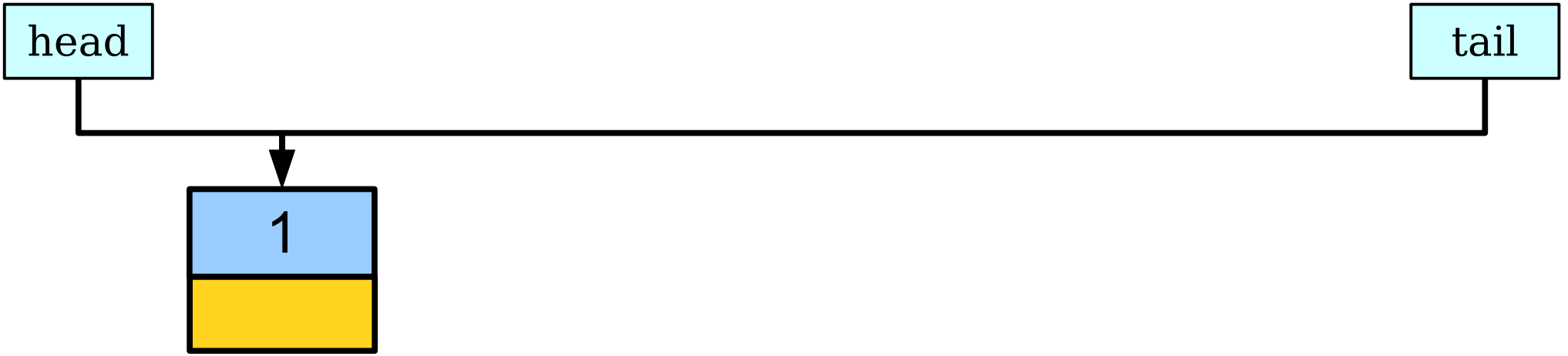

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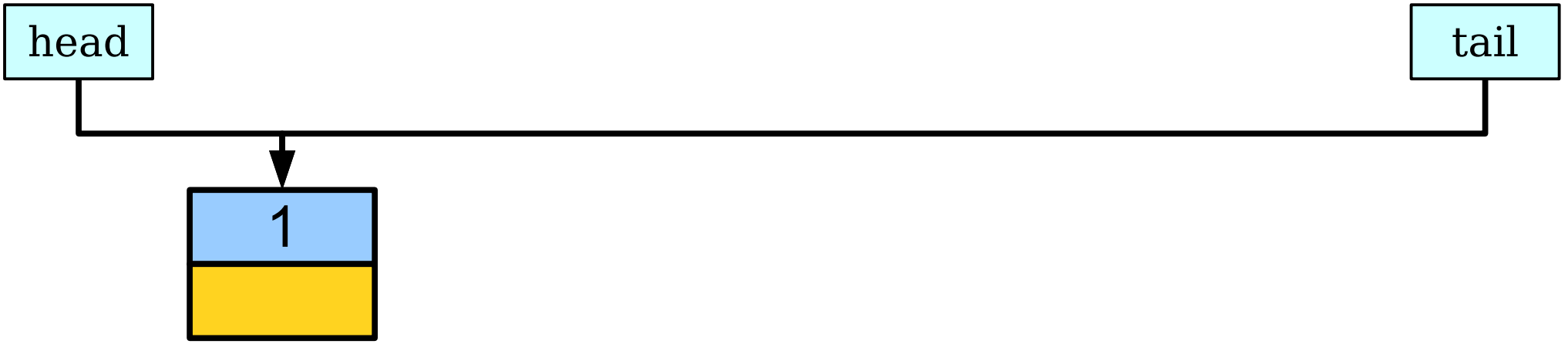

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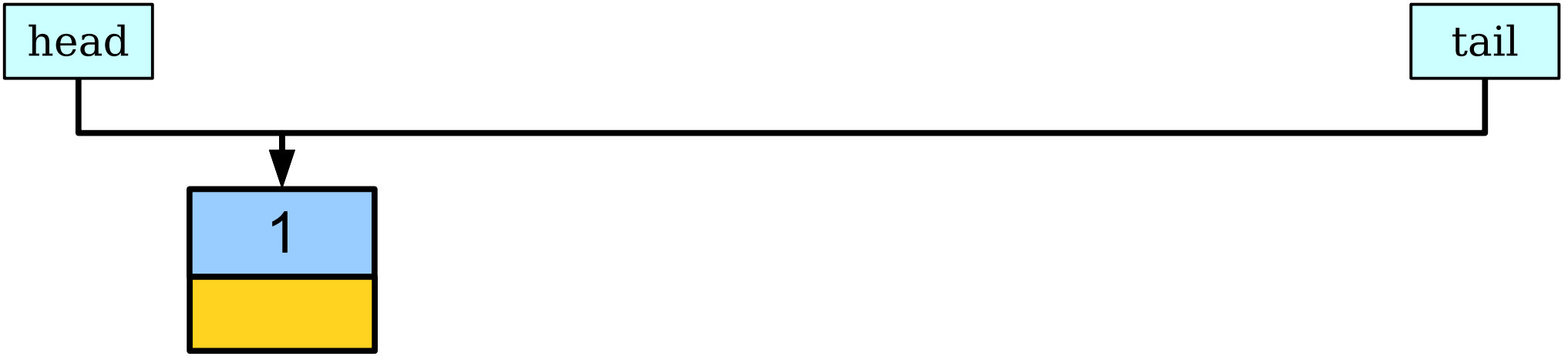

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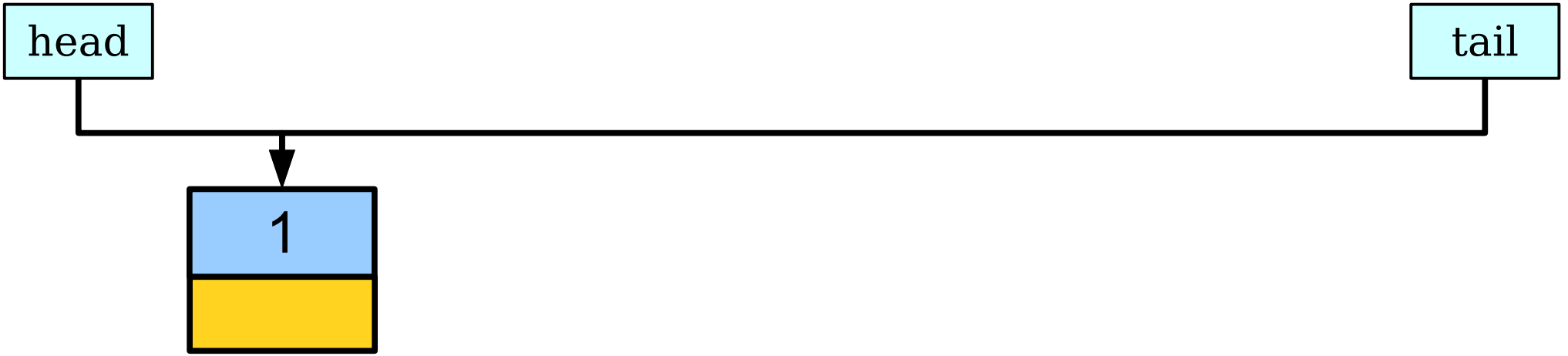

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`Queue::enqueue()`
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(Code)

Analyzing Efficiency

- What is the big-O complexity of a dequeue?
- Answer: **O(1)**.
- What is the big-O complexity of an enqueue?
- Answer: **O(1)**.

Analyzing our Queue

- Enqueue and dequeue are now **worst-case** O(1) instead of **average-case** O(1).
- What about the total runtime?

`OurQueue` (linked list)

vs.

`Queue<int>` (dynamic array)

Speed Test

Analyzing our Queue

- Enqueue and dequeue are now **worst-case** O(1) instead of **average-case** O(1).
- What about the total runtime?
- **Slower than before**.
- Why?
  - Cost of allocating individual linked list cells exceeds cost of allocating very few blocks and copying values over.
  - Trade average-case for worst-case speed.

Tomorrow: Hashing!