CS 241: Systems Programming
Lecture 19. Linked Lists

Spring 2020

Prof. Stephen Checkoway

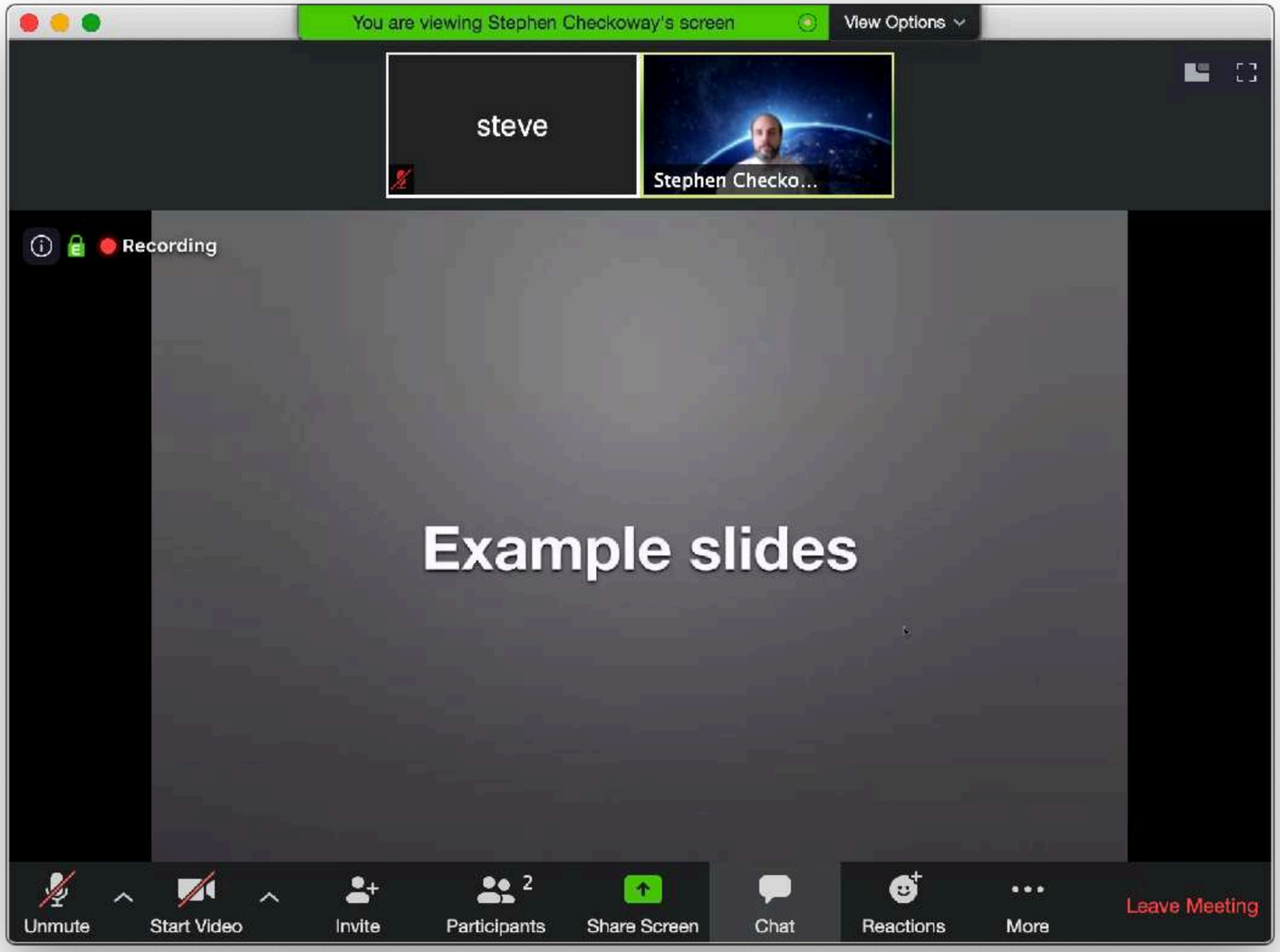
New lecture format

Ask questions in chat

Make sure you're asking everyone

Follow up by unmuting

Clicker questions via polls



Click Chat button

Aside: returning multiple values

In Python, functions can return multiple values (it returns a tuple)

```
def example():
    return "example", 5
```

In C, functions cannot; instead

- Return a struct

```
struct ret_val { char const *s; int i; };
struct ret_val example1(void) {
  struct ret_val r = { .s = "example", .i = 5 };
  return r;
}
```

Returning multiple values (cont)

- Add pointer parameters

```
char const *example2(int *out) {
  *out = 5;
  return "example";
}
```

- Use global variables

```
int example_ret;
char const *example3(void) {
  example_ret = 5;
  return "example";
}
```

Aside 2: Avoid globals

Avoid global variables when practical

Globals

- make your code difficult to reason about
- make writing correct multi-threaded code extremely difficult
- make testing individual functions difficult
- pollute the namespace because they are available everywhere
- can cause implicit coupling between separate functions

Sometimes globals are fine…but they're often not what you want

How should a function return multiple values (in most cases)

A. Return a struct

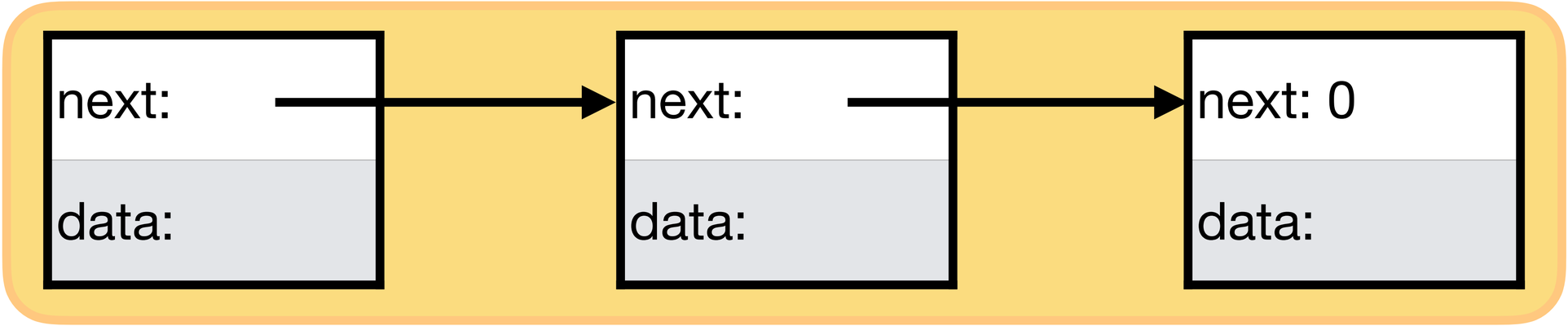
B. Using pointer parameters

C. Using global variables

D. A or B

E. A, B, or C

Review from Data Structures



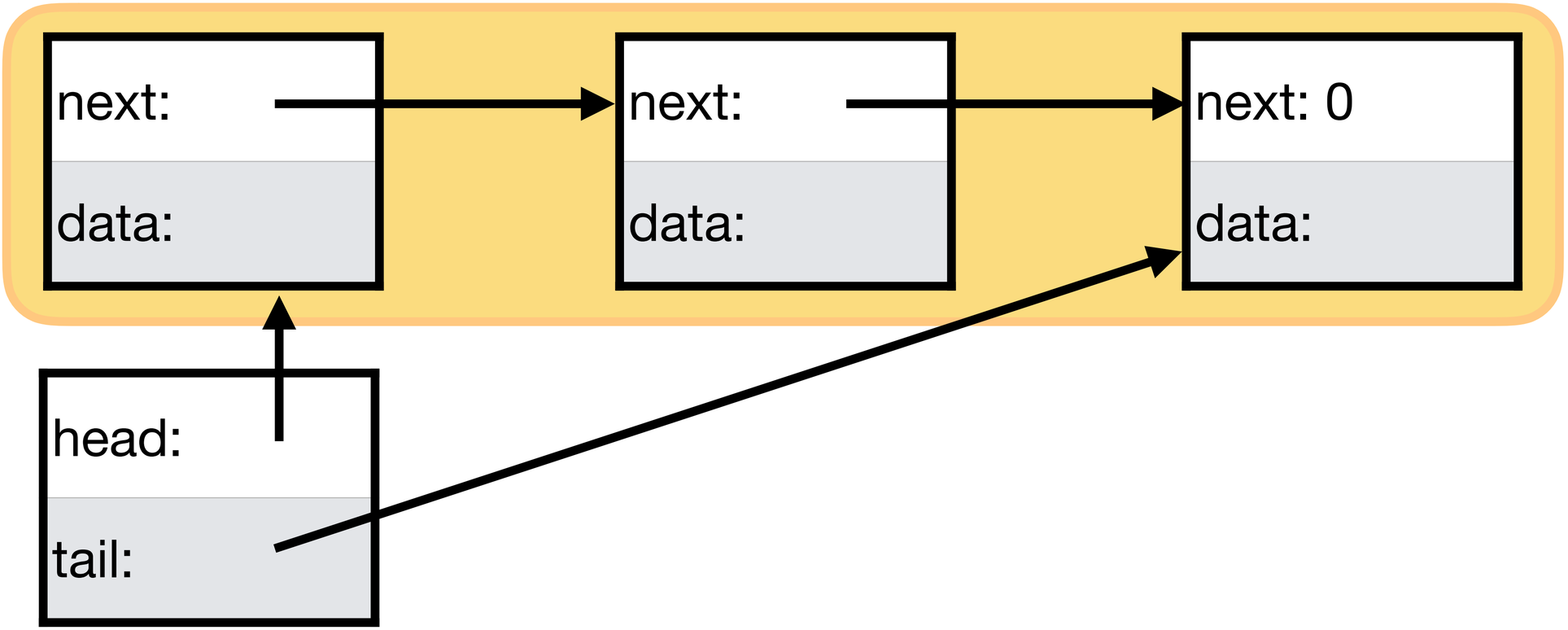
A (singly) linked list is a data structure that implements the List ADT

- Add, insert, remove elements
- Ordered by position in the list

Each node contains

- An element of the list
- A pointer to the next element in the list or 0 (`NULL`) for the last node

Review from Data Structures



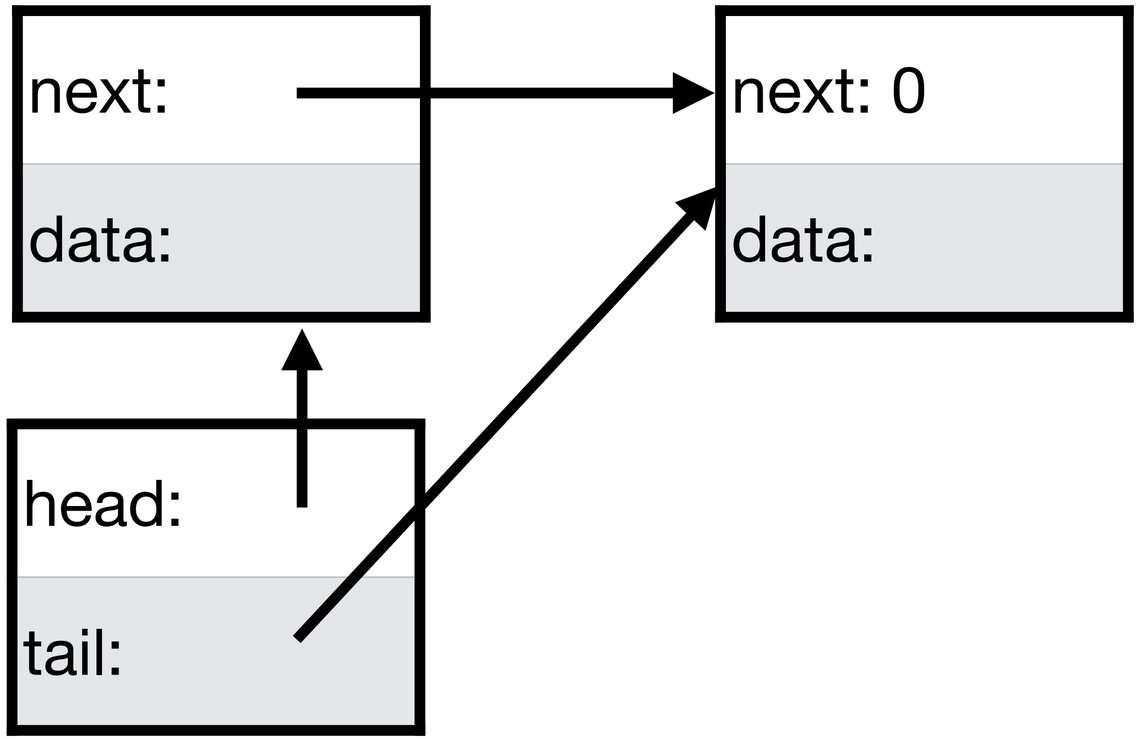
The list itself usually contains a pointer to the head of the list (first node) and the tail of the list (last node)

Data types for a list of ints

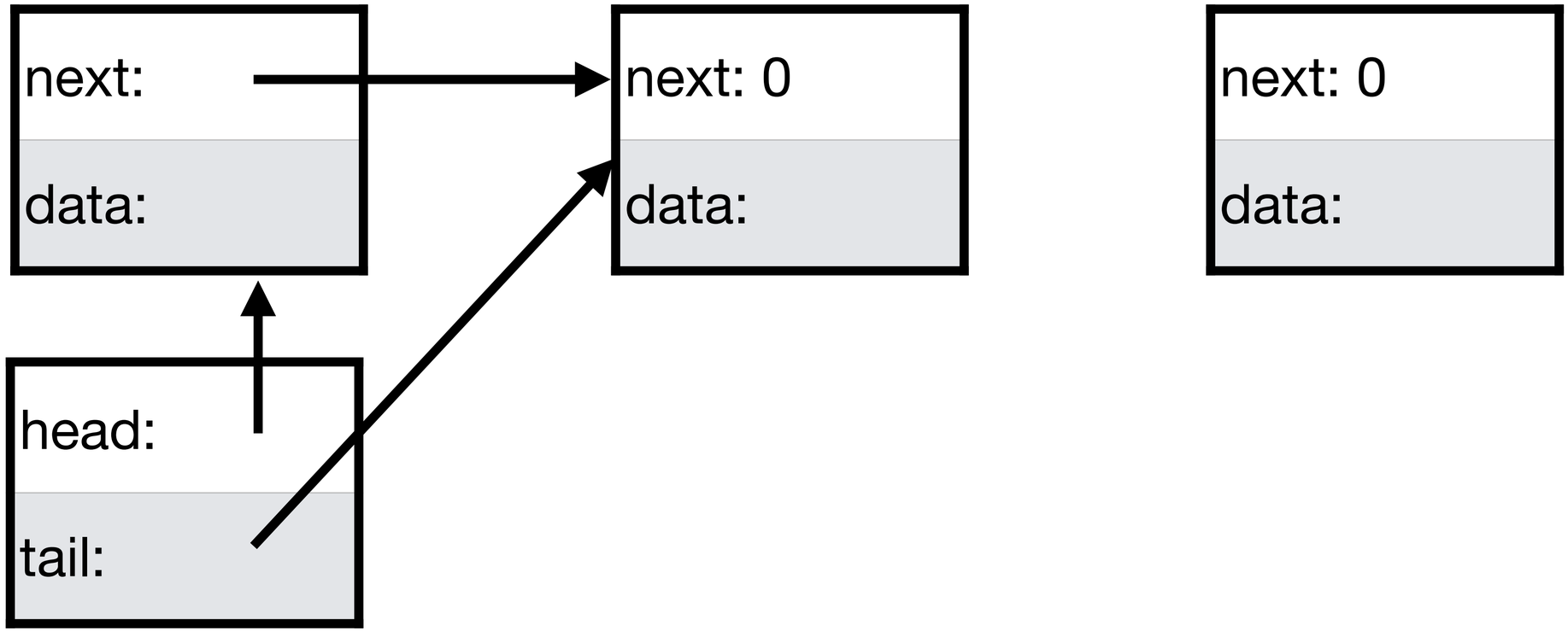
```
typedef struct Node {
  struct Node *next;
  int data;
} Node;

typedef struct List {
  Node *head;
  Node *tail;
} List;
```

Appending to the list

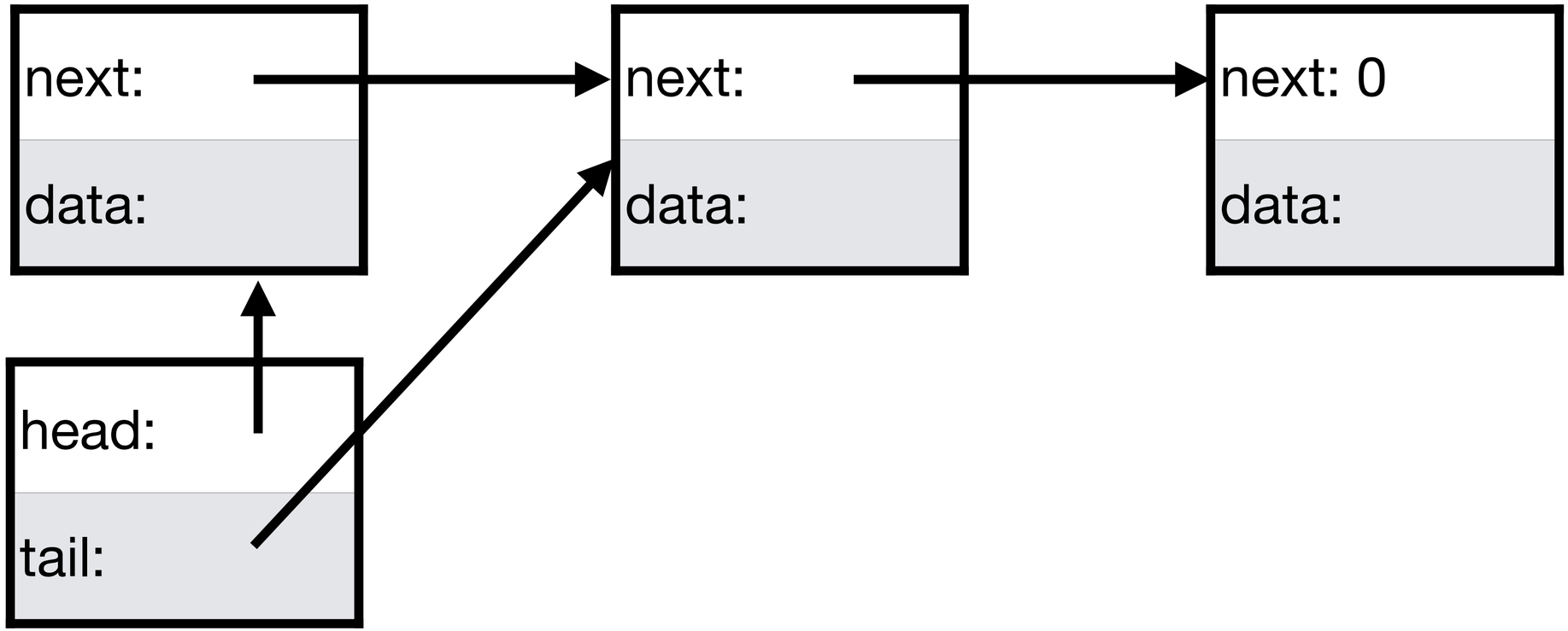


Appending to the list



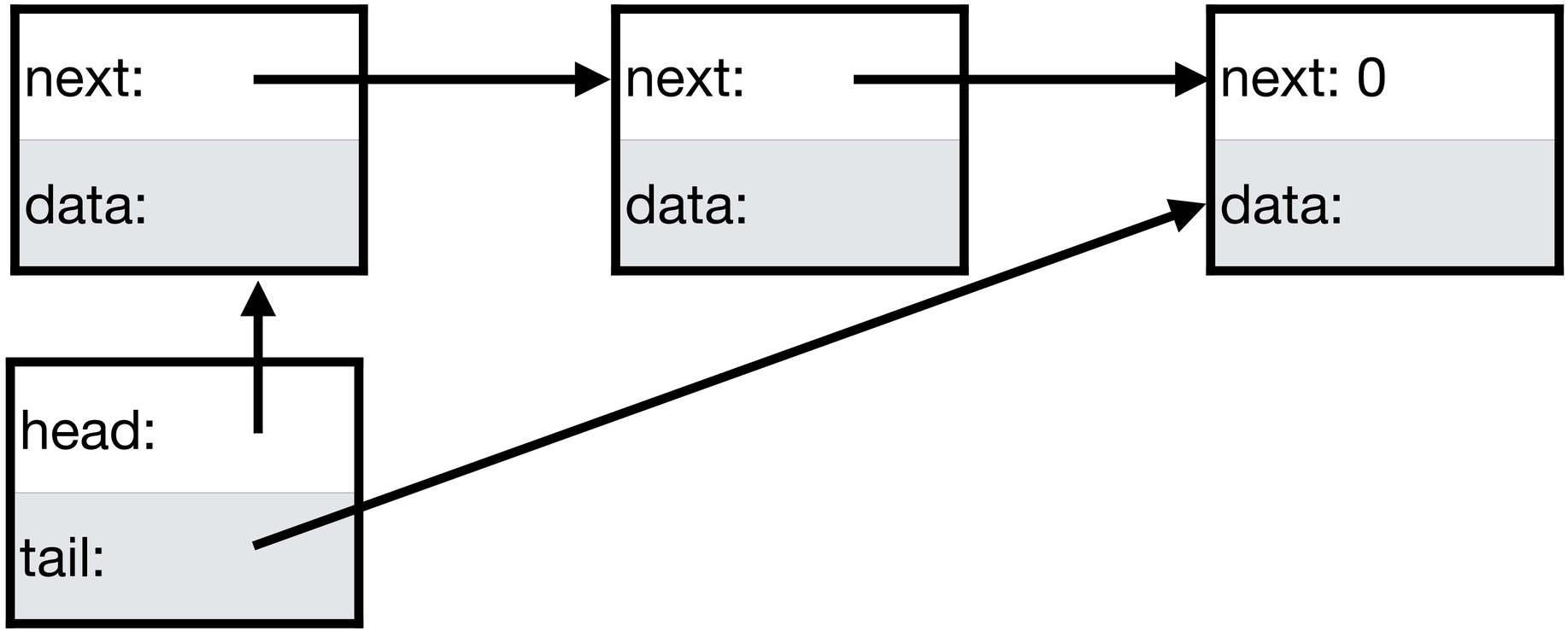
1. Create a new node with next = 0 and data set to the new element

Appending to the list



1. Create a new node with next = 0 and data set to the new element
2. Update tail->next to point to the new node

Appending to the list



1. Create a new node with next = 0 and data set to the new element
2. Update tail->next to point to the new node
3. Update tail to point to the new node

Appending to the list

```
void list_append(List *list, int data) {
  // Create a new node.
  Node *node = malloc(sizeof *node);
  node->next = 0;
  node->data = data;
  // Update tail->next to point to the new node.
  list->tail->next = node;
  // Update tail to point to the new node.
  list->tail = node;
}
```

What happens if we append to an empty list using this code?

```
void list_append(List *list, int data) {
  // Create a new node.
  Node *node = malloc(sizeof *node);
  node->next = 0;
  node->data = data;
  // Update tail->next to point to the
  // new node.
  list->tail->next = node;
  // Update tail to point to the new node.
  list->tail = node;
}
```

A. head and tail both point to the new node

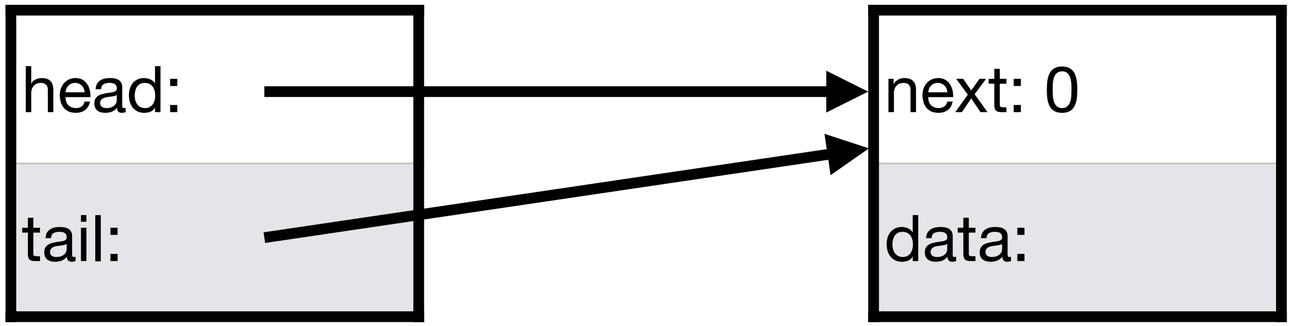
B. head points to the new node and tail is 0

C. tail points to the new node and head is 0

D. head and tail are both 0

E. Undefined behavior

Appending the first element



Set the head and tail pointers to point to the new node

Appending to the list

```
void list_append(List *list, int data) {
  // Create a new node.
  Node *node = malloc(sizeof *node);
  node->next = 0;
  node->data = data;
  if (list_isempty(list)) {
    // Insert the first element in the list.
    list->head = node;
    list->tail = node;
  } else {
    // Update tail->next to point to the new node.
    list->tail->next = node;
    // Update tail to point to the new node.
    list->tail = node;
  }
}
```

isempty and size

```
// Returns true if the list is empty.
bool list_isempty(List const *list) {
  return list->head == 0;
}

// Return the list size.
size_t list_size(List const *list) {
  size_t size = 0;
  for (Node const *node = list->head; node; node = node->next)
    ++size;
  return size;
}
```

What steps should we follow to prepend an element to the beginning of a nonempty linked list

```
void list_prepend(List *list, int data);
```

A. – Create a new node `n` containing the element
   – Set `n->next` to `list->head`
   – Set `list->head` to `n`

B. – Create a new node `n` containing the element
   – Set `list->head` to `n`
   – Set `n->next` to `list->head`

C. – Create a new node n containing the element
   – Set `list->head` to `n`
   – Set `list->tail` to `n`

In-class exercise

https://checkoway.net/teaching/cs241/2029-spring/exercises/Lecture-19.html

Grab a laptop and a partner and try to get as much of that done as you can!

Update: Spend some time working on these by yourself or with a partner for the "participation points" during the week

Ask questions via Piazza (and post code)

A place to record the exercises you have done for the week will be on Blackboard on Friday and will be available for another week

You don't need to complete the exercise to get credit, but I recommend it