CSE 303
Concepts and Tools for Software Development

Magdalena Balazinska
Winter 2010
Lecture 13 – Data Structures and Memory Management

Assignment 4

- Assignment 4 will be released later today
- It is the most difficult assignment this quarter
- It is the longest assignment this quarter
- Suggested schedule
  - Work on problems 1, 2, 3, 4, and 6 before Monday
  - Focus on the midterm next week
  - Finish the assignment after the midterm
- This assignment will give you great programming experience! You will see the difference.

Where We Are

- We have seen
  - The concept of a struct
  - Dynamic memory allocation (malloc/free)

- Given these two concepts, we can now create dynamic data structures
  - Structures whose size grows and shrinks during program execution
  - Concrete examples today: stack in class
    - (and queue on your own)
  - You will create a list and a tree in assignment 4

Program Modules

- Our program is longer today, so we will split it into two modules: stack and main-stack
  - Such a split will also allow us to reuse the stack module in different programs
- Overall, we will have three files
  - `stack.c`: Functions that implement the stack
    - push, pop, is_empty, and print
  - `stack.h`: All the function prototypes
  - `main-stack.c`: A program that uses the stack
    - Must include stack.h

Self-Referential Structures

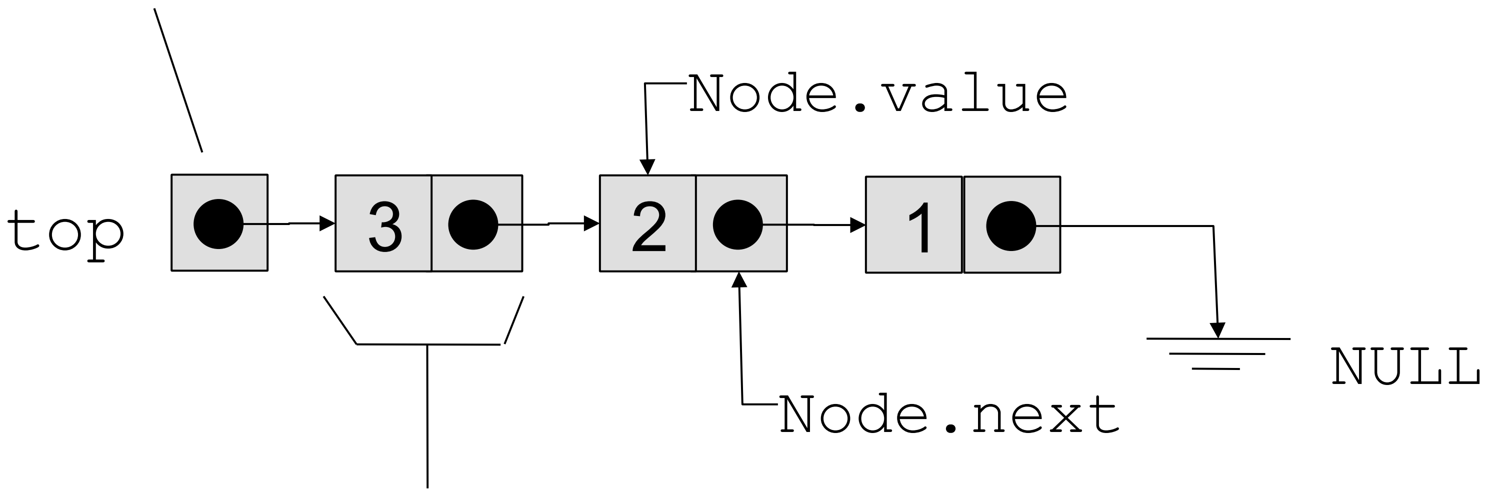
- Contains a pointer to a struct of the same type

```
typedef struct node {
  int value;
  struct node *next;
} Node;
```

- Can contain more than one pointer
  - Example: a double-linked list will have 2 pointers
- These pointers are called links
- Typical building block for data structures
- Let's build a stack and, on your own, a queue...

Stack Data Structure

`Node *top;`
Pointer to a `Node` structure



`top`

3 2 1

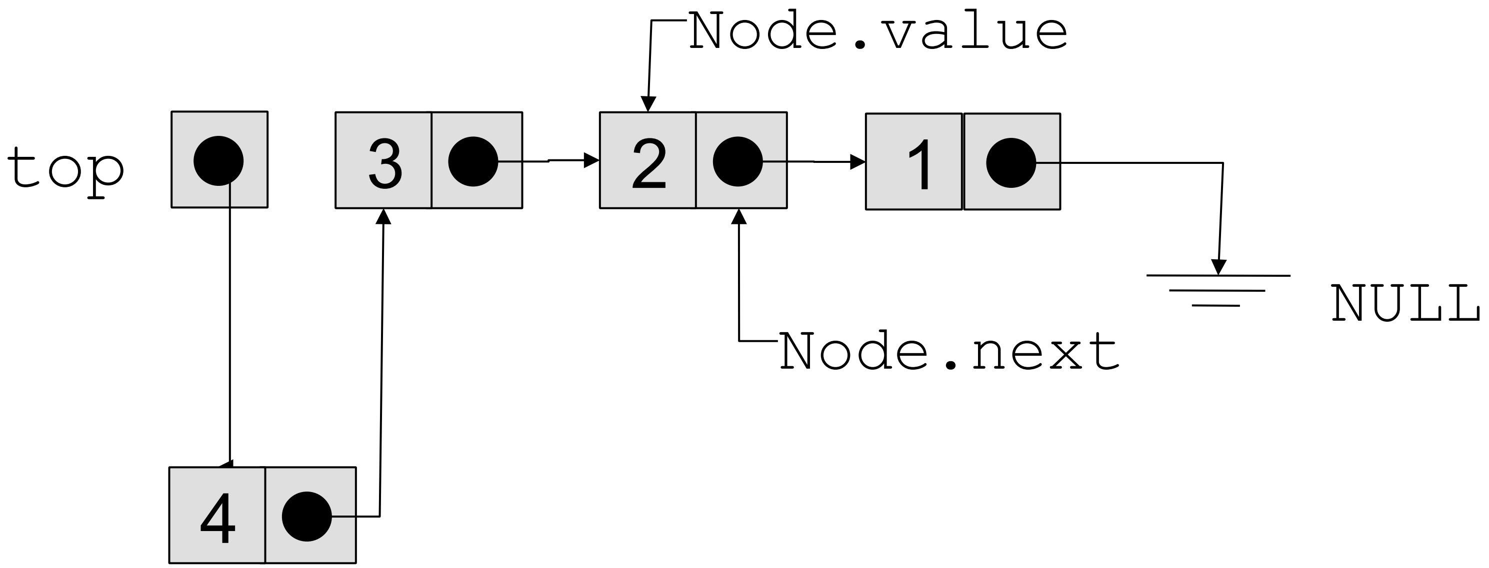
`Node.value`

`Node.next`

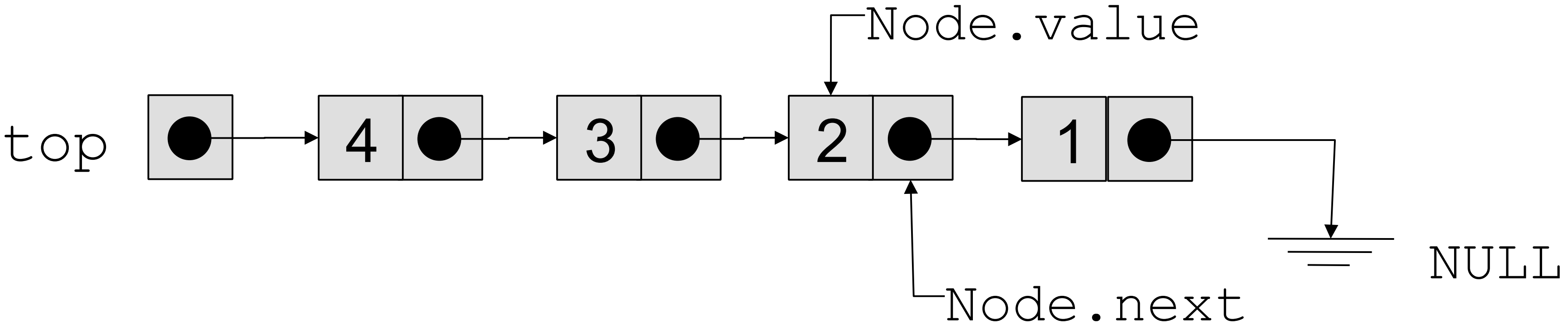
`NULL`

One `Node`
structure

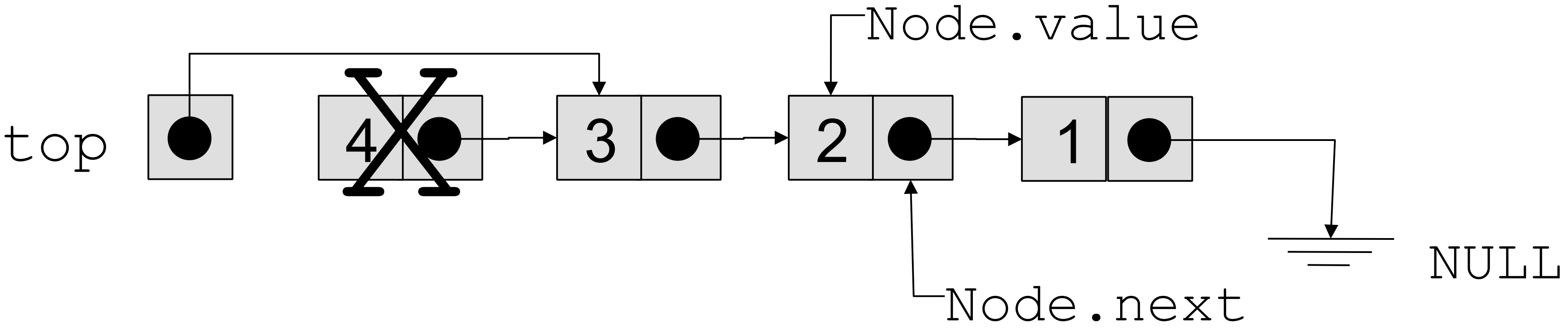
Push an Element onto the Stack



Push an Element onto the Stack



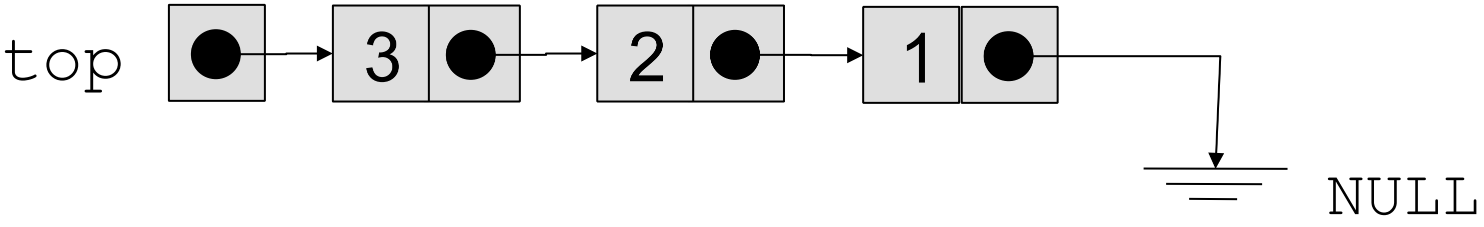
Pop an Element from the Stack



Writing the Stack Module

- Now that we know how a stack works, let's take a look at the corresponding C code

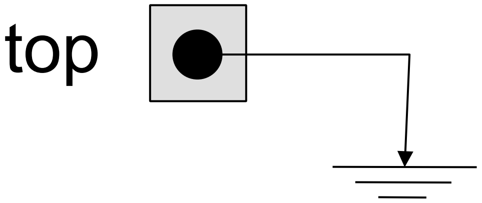
Print the Content of a Stack



```
void print(Node *top) {
  Node *current = top;
  while ( current != NULL ) {
    printf("%d\n",current->value);
    current = current->next;
  }
}
```

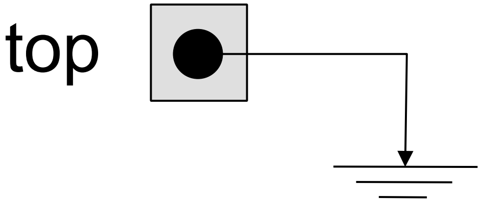
Create a New Stack

- Initializing stack: `Node *top = NULL;`



Push Data Onto Stack

```
// Client code
Node *top = NULL;
int i = 3;
push(&top, i);
```

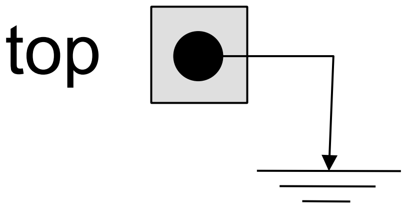


Empty stack

How should we implement the `push` function?

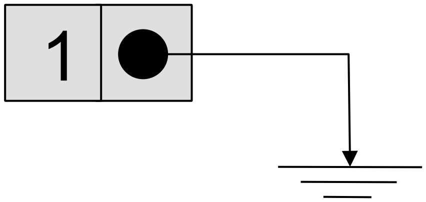
Push First Data Item Onto Stack

- Step 0: Initial state



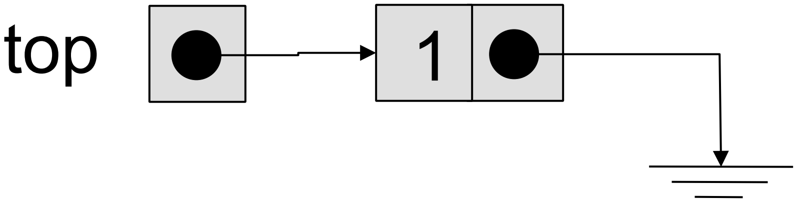
Empty stack

- Step 1: Allocate space for a new element



New element

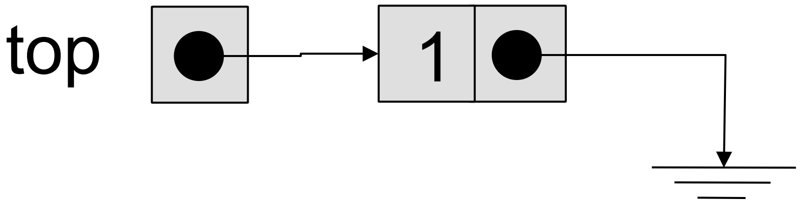
- Step 2: Update pointers to add element to stack



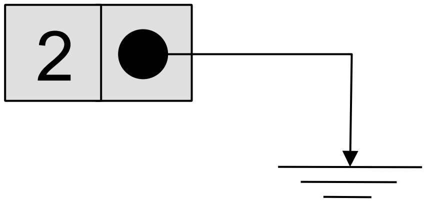
New stack

Push Subsequent Data Item Onto Stack

- Step 0: Initial state

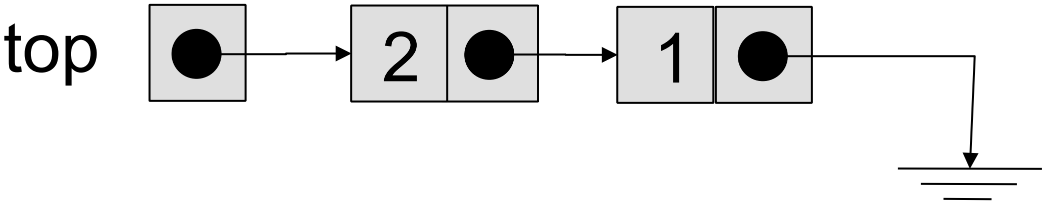


- Step 1: Allocate space for a new element



New element

- Step 2: Update pointers to add element to stack



New stack

The “push” Function

```
void push(Node **top, int value) {
  Node *e = (Node*)malloc(sizeof(Node));
  if ( !e) {
    fprintf(stderr,"Out of memory\n");
    return;
  }
  e->value = value;
  e->next = *top;
  *top = e;
}
```

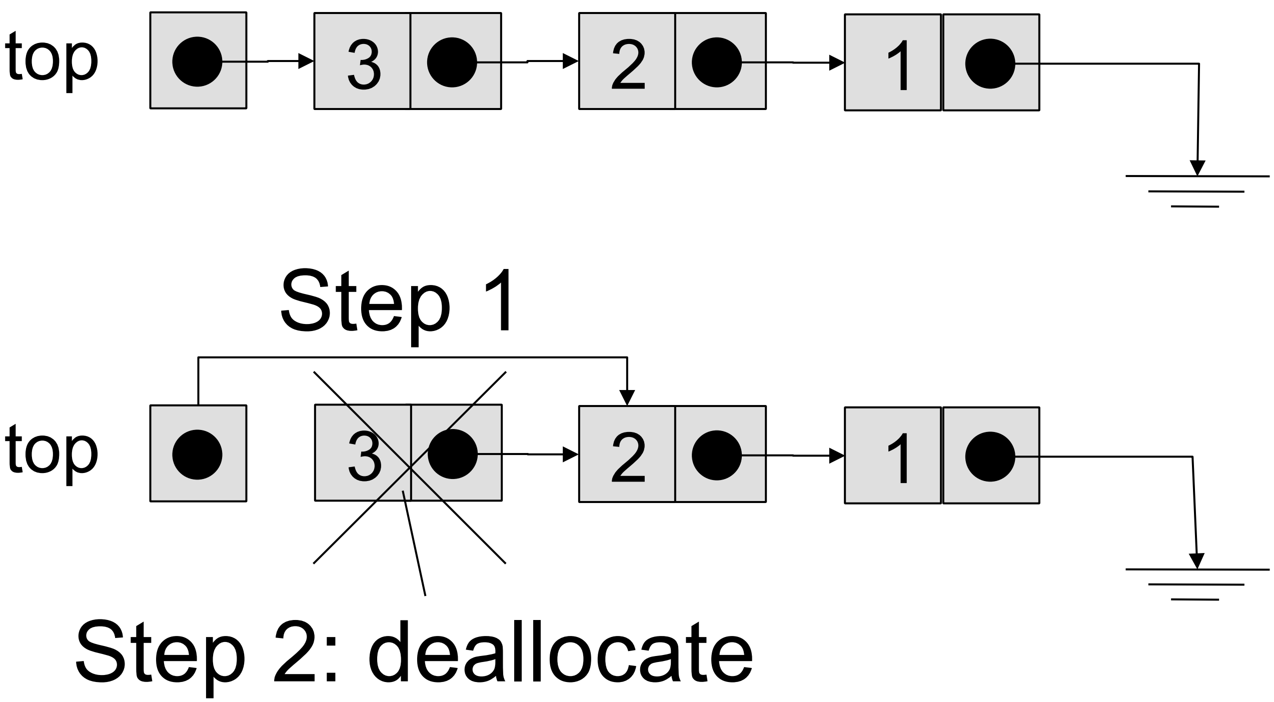
Popping Data From Stack

```
// Client code
Node *top = NULL;
push(&top, 1);
push(&top, 2);
push(&top, 3);
...
int value = pop(&top)
```

How should we implement the `pop` function?

Popping Data From Stack

- Pop an element from stack



top

Step 1

top

Step 2: deallocate

Popping Data From Stack

```
int pop(Node **top) {
  if ( ! is_empty(*top) ) {
    Node *removed = *top;
    int value = removed->value;
    *top = removed->next;
    free(removed);
    return value;
  }
  return -1;
}
```

Other Data Structures

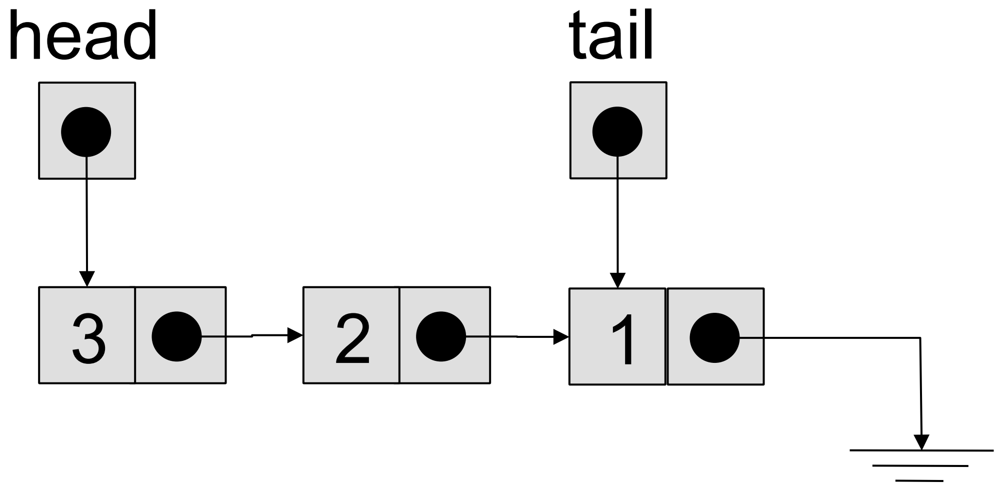
- Other data structures in C can be implemented in a similar manner
- Self-referential structures form the basic elements
- When inserting
  - Allocate space for new element (malloc)
  - Initialize its fields
  - Update pointers
- When removing
  - Update pointers
  - Reclame space used by deleted element (free)

Additional Example

- The following slides show another data structure: the queue
- You can find the code for that example in `queue.c, queue.h, main-queue.c`

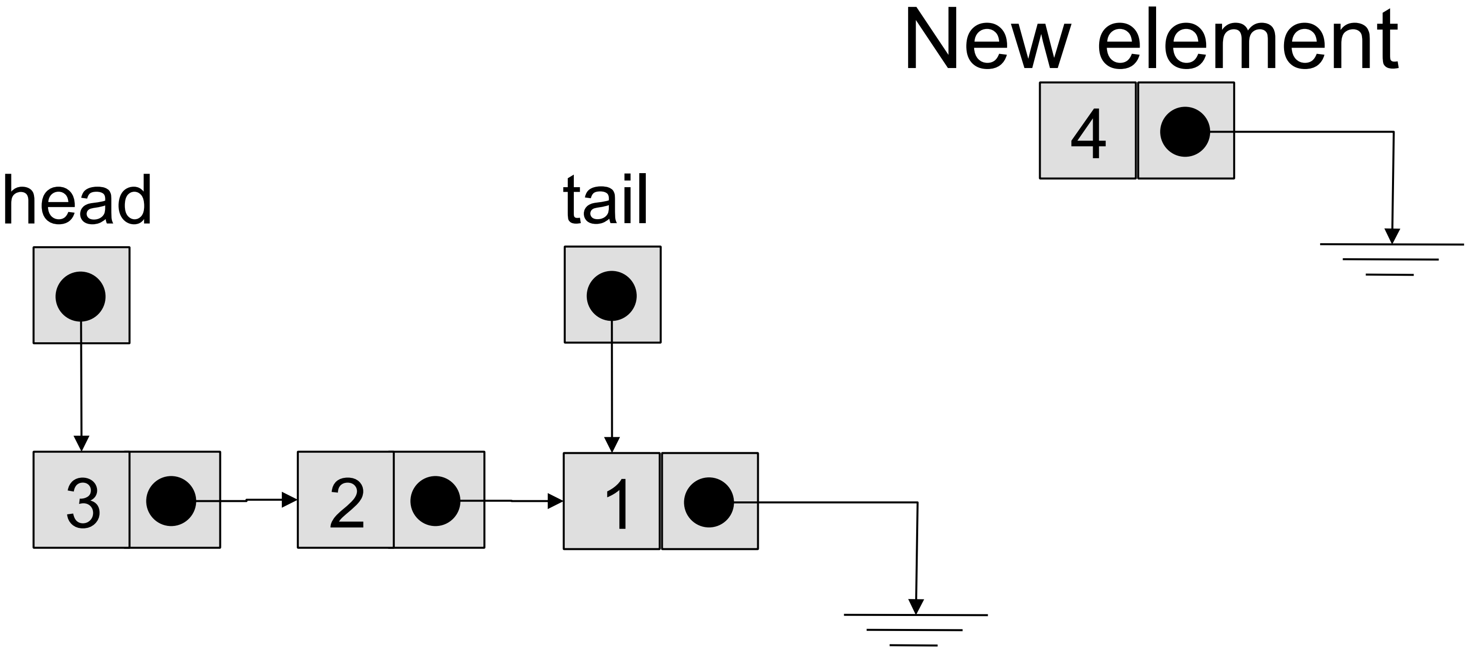
Second Example: Queue

- This time we need to keep around two pointers
  - head: pointer to the head of the queue
  - tail: pointer to the end of the queue



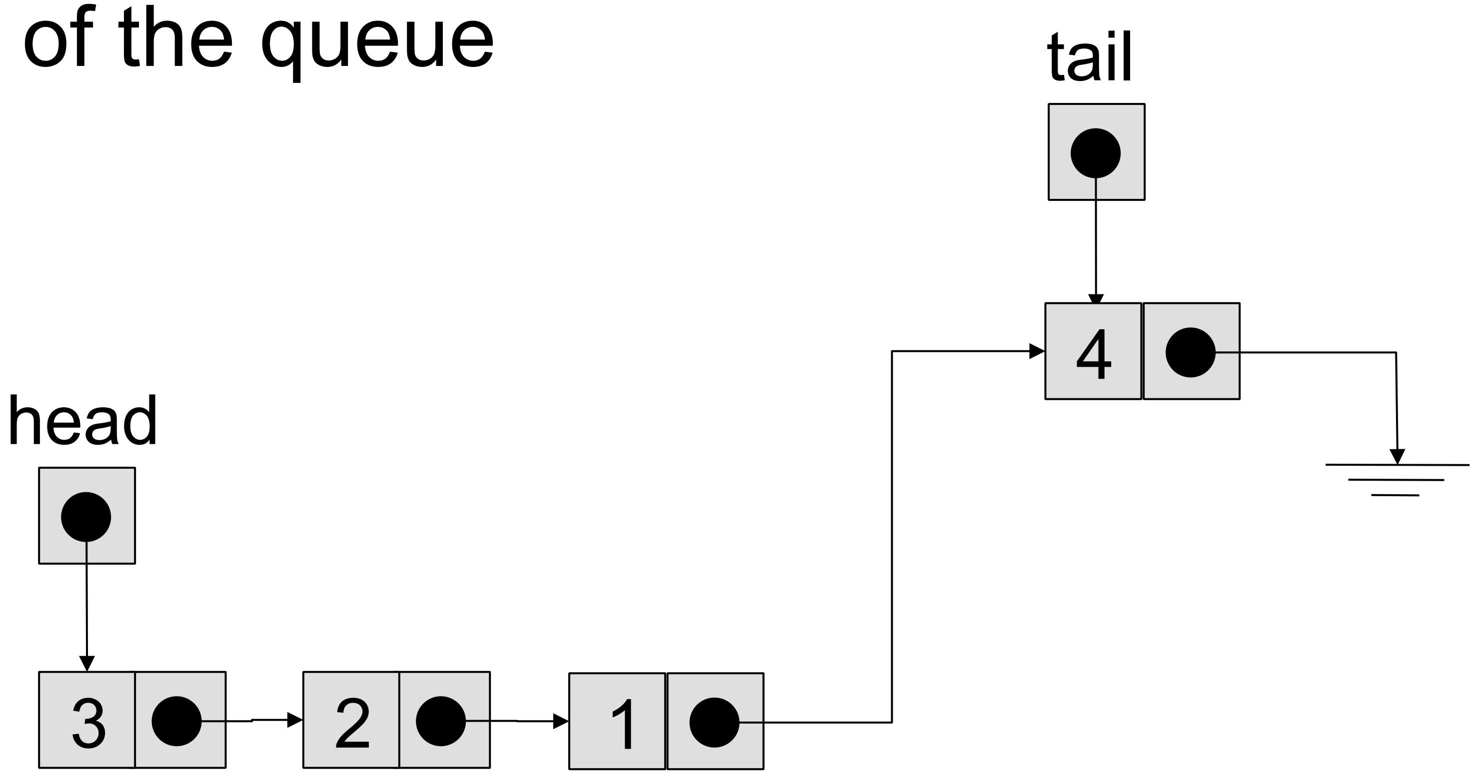
Enqueue Operation

- Enqueue a value: value = 4
- Step 1: Allocate memory for new element and initialize fields



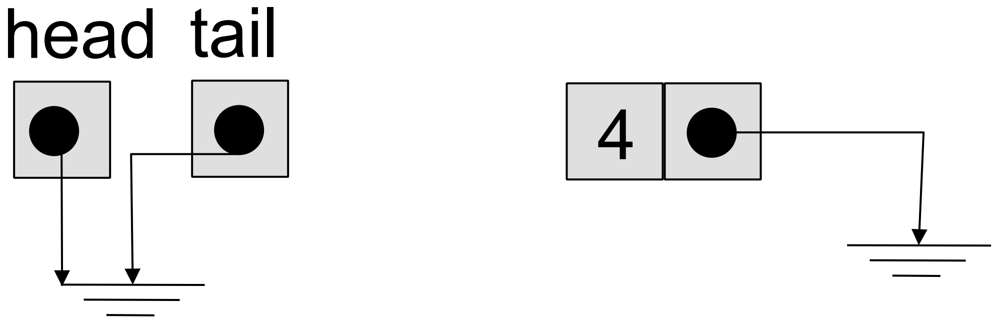
Enqueue Operation

- Step 2: Update links to add element to the end of the queue



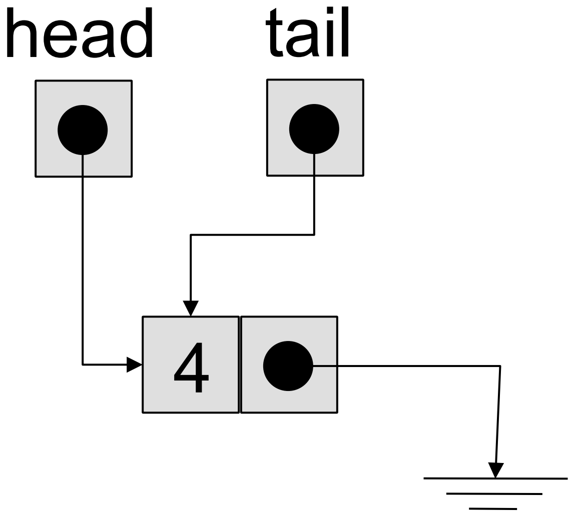
Enqueue Operation

- Special case: adding first element to an empty queue



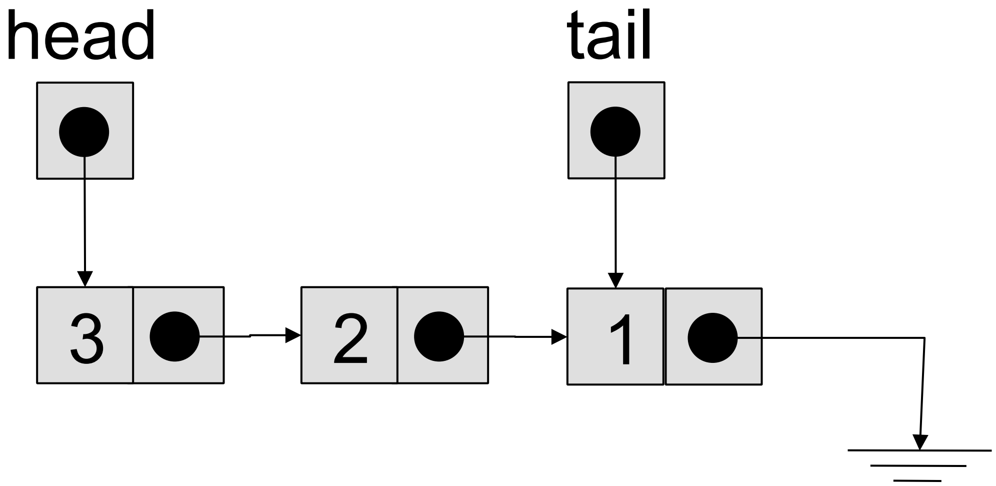
Enqueue Operation

- Special case: adding first element to an empty queue



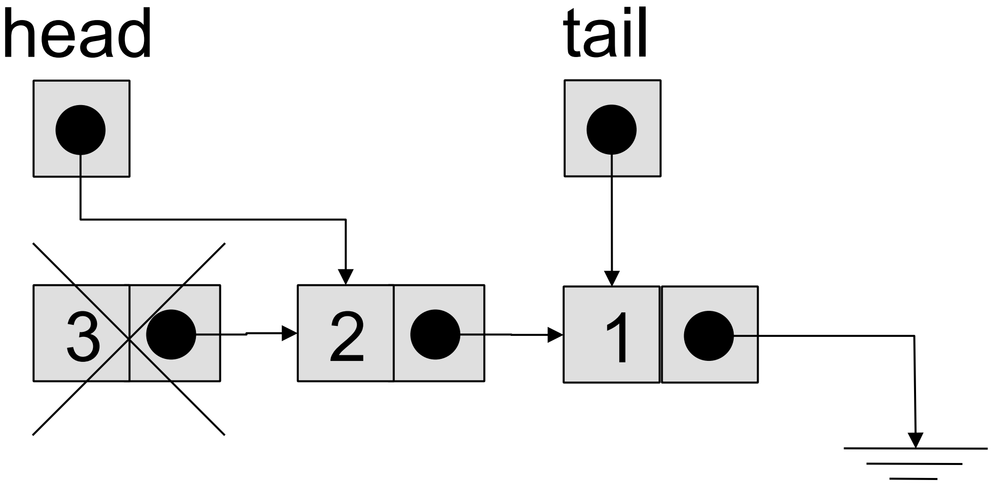
Dequeue Operation

- Elements are removed from the head of the queue



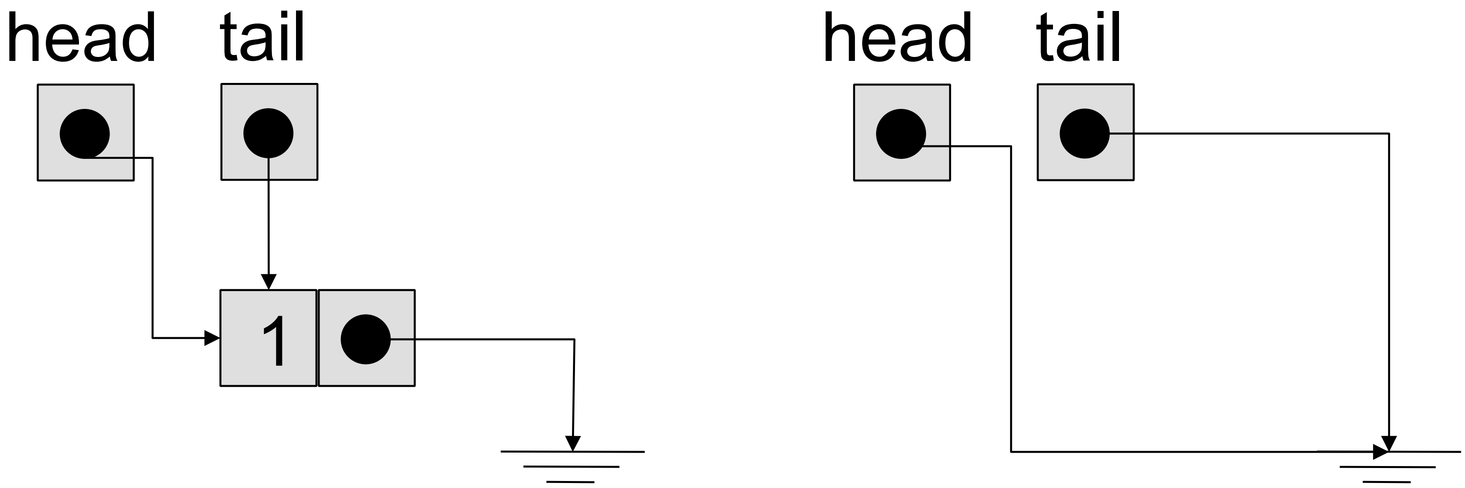
Dequeue Operation

- Step 1: Update links
- Step 2: Deallocate element



Dequeue Operation

- Special case: removing the last element from a queue



- Source code is in:
  - `queue.h queue.c, main-queue.c`

Summary

- Quite easy to build useful structures
- Be systematic
  - One method allocates new elements
    - Example: enqueue, push
  - One method deallocates elements
    - Example: dequeue, pop
- Be careful
  - Watch-out for corner cases (ex: empty queue)

Frequent Bugs

- Memory leak: forgetting to free memory
  - Example: remove element from list, forget to free it, and lose all pointers to that element
- Dangling pointers
  - Can cause crash
  - Can cause you to overwrite other data
- Good news: tools exist to help you catch these bugs: dmalloc, *valgrind* (we will not have time to cover these tools in class)

Readings

- No additional readings for this class
- Examine the examples carefully
  - Pay attention to the parameters
  - Either Node * (pointer to a Node)
  - Or Node** (pointer to a pointer to a Node)