How about them A's!! Go Oaktown!!

CS61C - Machine Structures

Lecture 4
C Structures
Memory Management

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Overview

- Review
- C Strings (finishing up)
- Pointers to pointers
- C Structures
- Dynamic Memory Allocation
- C Memory Management

Review

- Pointers and arrays are virtually same
  - Array names are pointers to 1st element.
- C knows how to increment pointers
- C is an efficient language, with little protection
  - Array bounds not checked
  - Variables not automatically initialized

C String Headaches

- One common mistake is to forget to allocate an extra byte for the null terminator.
- More generally, C requires the programmer to manage memory manually (unlike Java or C++).
  - When creating a long string by concatenating several smaller strings, the programmer must insure there is enough space to store the full string!
  - What if you don't know ahead of time how big your string will be?

C String Standard Functions

- `int strlen(char *string);`
  - compute the length of `string`
- `int strcmp(char *str1, char *str2);`
  - return 0 if `str1` and `str2` are identical (how is this different from `str1 == str2`?)
- `int strcpy(char *dst, char *src);`
  - copy the contents of string `src` to the memory at `dst`. The caller must ensure that `dst` has enough memory to hold the data to be copied.

Pointers to pointers (1/4) …review…

- Sometimes you want to have a procedure increment a variable?
- What gets printed?

```
void AddOne(int  x)
{     x =  x + 1;   }

int y = 5;
AddOne( y);
printf("y = %d\n", y);
```

y = 5

Pointers to pointers (2/4) …review…

- Solved by passing in a pointer to our subroutine.
- Now what gets printed?

```
void AddOne(int *p)
{    *p = *p + 1;   }

int y = 5;
AddOne(&y);
printf("y = %d\n", y);
```

y = 6

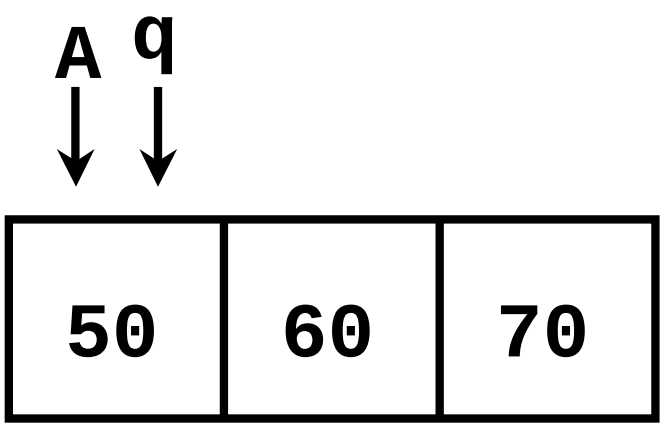
Pointers to pointers (3/4)

- But what if what you want changed is a pointer?
- What gets printed?

```
void IncrementPtr(int  *p)
{    p =  p + 1;   }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( q);
printf("*q = %d\n", *q);
```

*q = 50



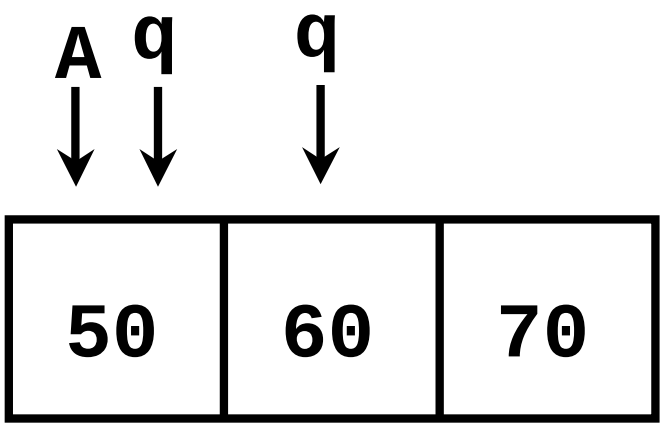
Pointers to pointers (4/4)

- Solution! Pass a pointer to a pointer, called a handle, declared as **h
- Now what gets printed?

```
void IncrementPtr(int **h)
{   *h = *h + 1;   }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr(&q);
printf("*q = %d\n", *q);
```

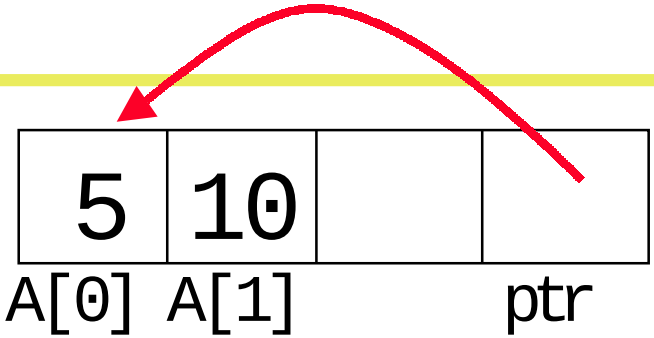
*q = 60



Peer Instruction

```
int main(void){
  int A[] = {5,10};
  int *ptr = A;

  printf("%u  %d  %d  %d\n",ptr,*ptr,A[0],A[1]);
  ptr = ptr + 1;
  printf("%u  %d  %d  %d\n",ptr,*ptr,A[0],A[1]);
  *ptr = *ptr + 1;
  printf("%u  %d  %d  %d\n",ptr,*ptr,A[0],A[1]);
  }
```



If the first printf outputs <u>100 5 5 10</u>, what will the other two printf output?

A: 101 10 5 10 then 101 11 5 11
B: 104 10 5 10 then 104 11 5 11
C: 101 <other> 5 10 then 101 <3-others>
D: 104 <other> 5 10 then 104 <3-others>
E: One of the two printfs causes an ERROR
F: I surrender!

Buffer Page "A's refuse to lose!"

- Oakland As win 20th straight!

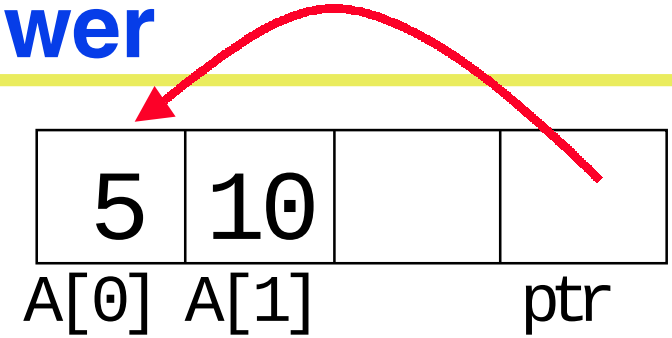
A's blow 11-run lead and win on bottom of ninth homer!

- The longest win streak in AL history!
- Largest regular-season crowd in coliseum history!

Peer Instruction Answer

```
int main(void){
  int A[] = {5,10};
  int *ptr = A;

  printf("%u  %d  %d  %d\n",ptr,*ptr,A[0],A[1]);
  ptr = ptr + 1;
  printf("%u  %d  %d  %d\n",ptr,*ptr,A[0],A[1]);
  *ptr = *ptr + 1;
  printf("%u  %d  %d  %d\n",ptr,*ptr,A[0],A[1]);
  }
```



If the first printf outputs <u>100 5 5 10</u>, what will the other two printf output?

B: 104 10 5 10 then 104 11 5 11

...because ints in this system are 4-bytes long and the actual address increments by 4 even though it appears to only incrememt 1.

C structures : Overview

- A `struct` is a data structure composed for simpler data types.
  - Like a class in Java/C++ but without methods or inheritance.

```
struct point {
    int x;
    int y;
}
void PrintPoint(point p)
{
    printf("(%d,%d)", p.x, p.y);
}
```

C structures: Pointers to them

- The C arrow operator (`->`) dereferences and extracts a structure field with a single operator.
- The following are equivalent:

```
struct point *p;

printf("x is %d\n", (*p).x);
printf("x is %d\n", p->x);
```

Dynamic Memory Allocation (1/3)

- C has operator `sizeof()` which gives size in bytes (of type or variable)
- Assume size of objects can be misleading, so use `sizeof(type)`
  - Many years ago an `int` was 16 bits, and programs assumed it was 2 bytes
- How big is `sizeof(p)`?

```
struct p {
            char x;
            int y;
        };
```

  - 5 bytes? 8 bytes?
  - Compiler may word align integer `y`

Dynamic Memory Allocation (2/3)

- To allocate room for something new to point to, use `malloc()` (with the help of a typecast and `sizeof`):

```
ptr = (int *) malloc (sizeof(int));
```

  - Now, `ptr` points to a space somewhere in memory of size `(sizeof(int))` in bytes.
  - `(int *)` simply tells the compiler what will go into that space (called a typecast).

Dynamic Memory Allocation (3/3)

- Once `malloc()` is called, the memory location might contain anything, so don't use it until you've set its value.
- After dynamically allocating space, we must dynamically free it:

```
free(ptr);
```

- Use this command to clean up.

Linked List Example

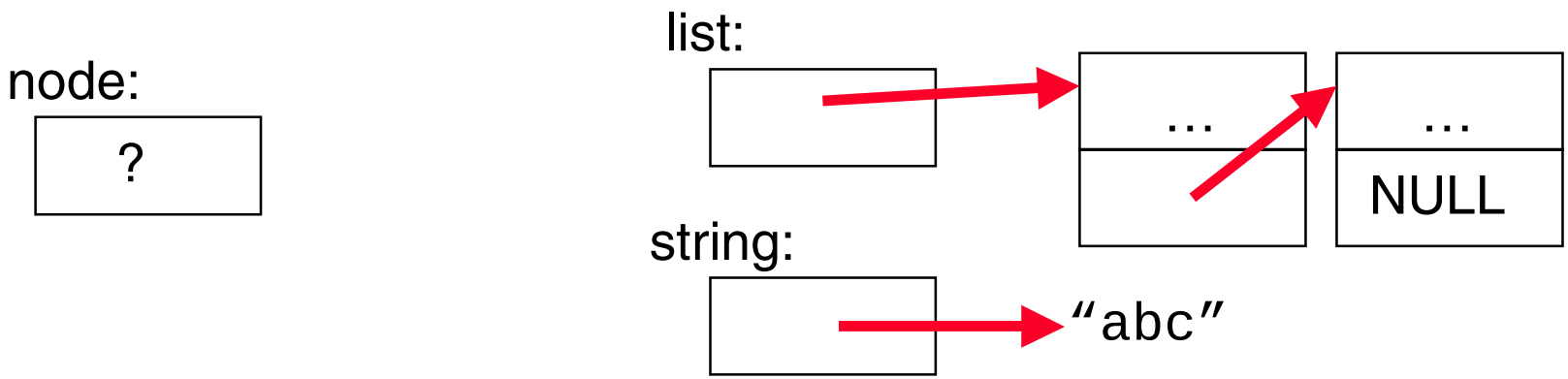
- Let's look at an example of using structures, pointers, `malloc()`, and `free()` to implement a linked list of strings.

```
struct Node {
    char *value;
    struct Node *next;
};
typedef Node *List;

/* Create a new (empty) list */
List ListNew(void)
{ return NULL; }
```

Linked List Example

```
/* add a string to an existing list */
List list_add(List list, char *string)
{
  struct Node *node =
    (struct Node*) malloc(sizeof(struct Node));
  node->value =
    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



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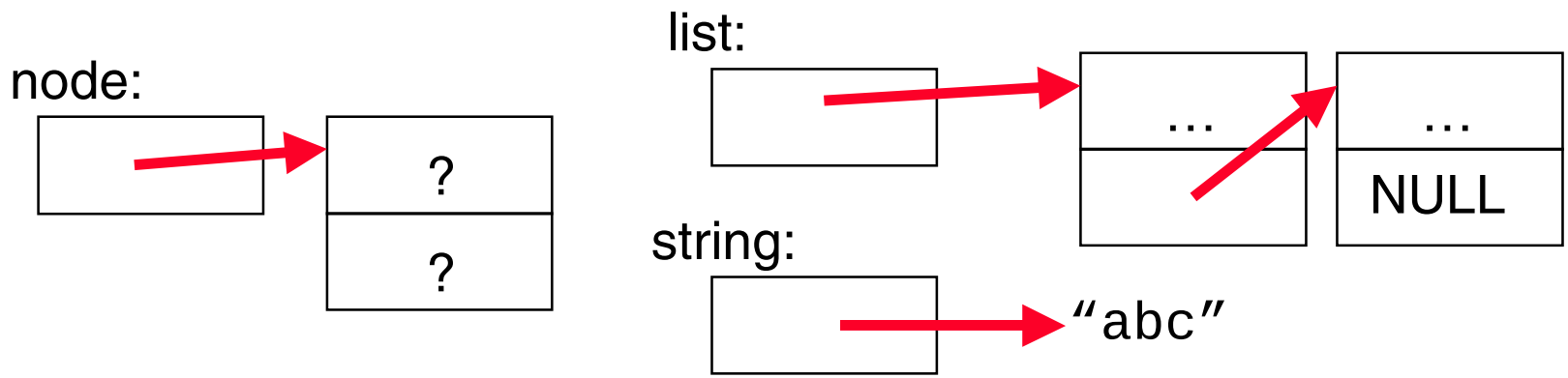
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



Linked List Example

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  strcpy(node->value, string);
  node->next = list;
  return node;
}
```

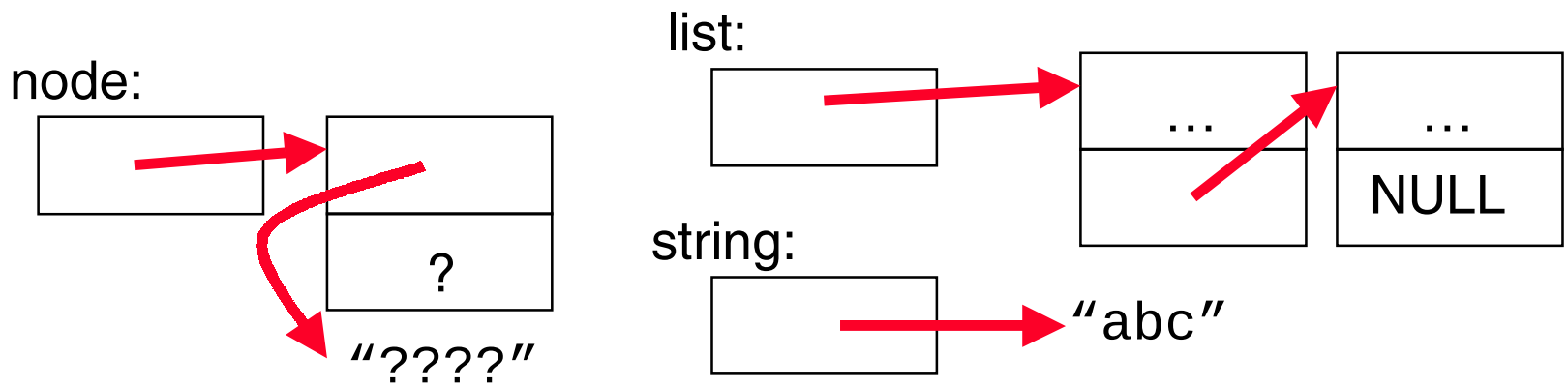

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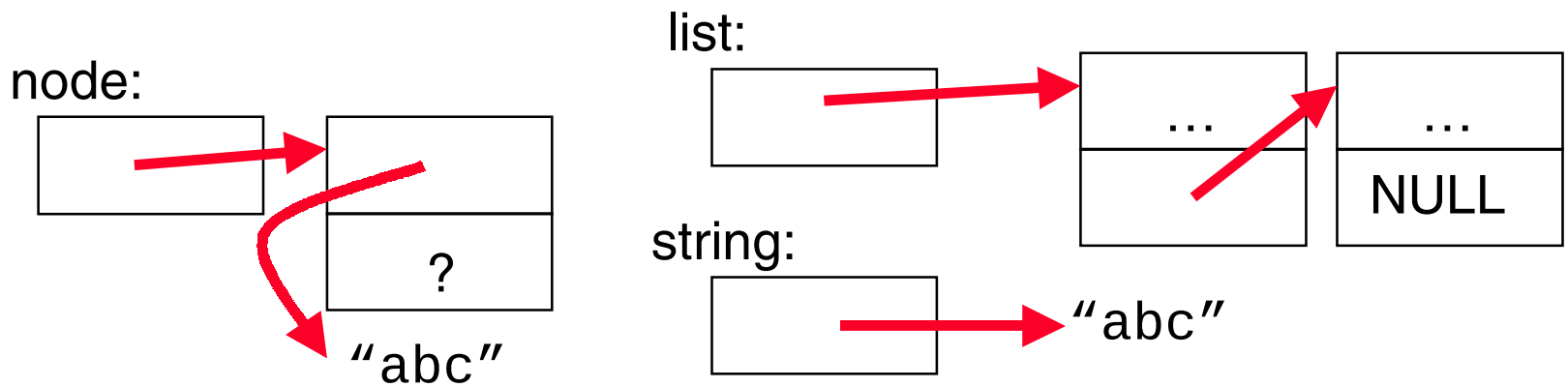
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```



Linked List Example

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    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```

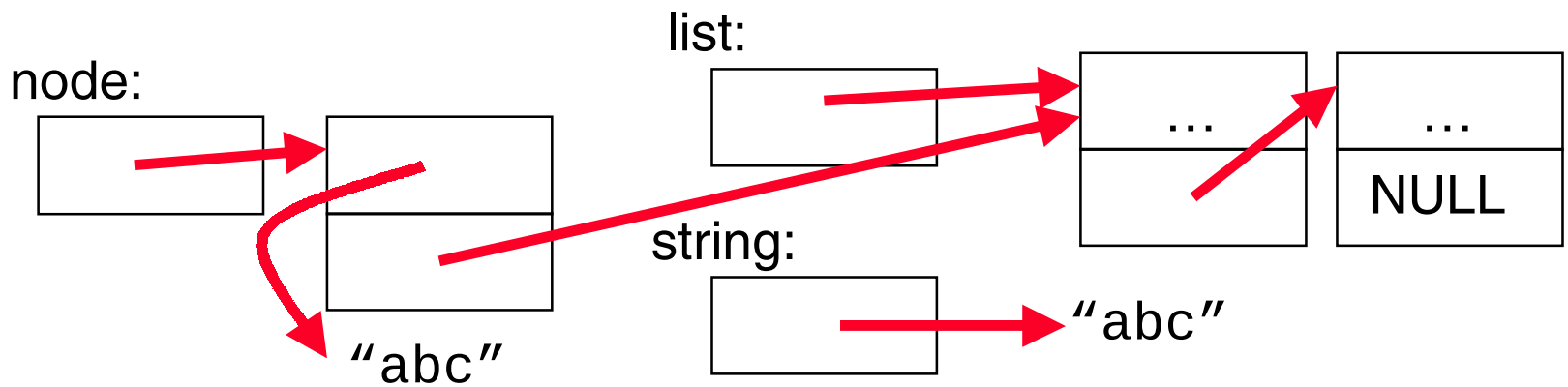

Linked List Example

```
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List list_add(List list, char *string)
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    (struct Node*) malloc(sizeof(struct Node));
  node->value =
    (char*) malloc(strlen(string) + 1);
  strcpy(node->value, string);
  node->next = list;
  return node;
}
```

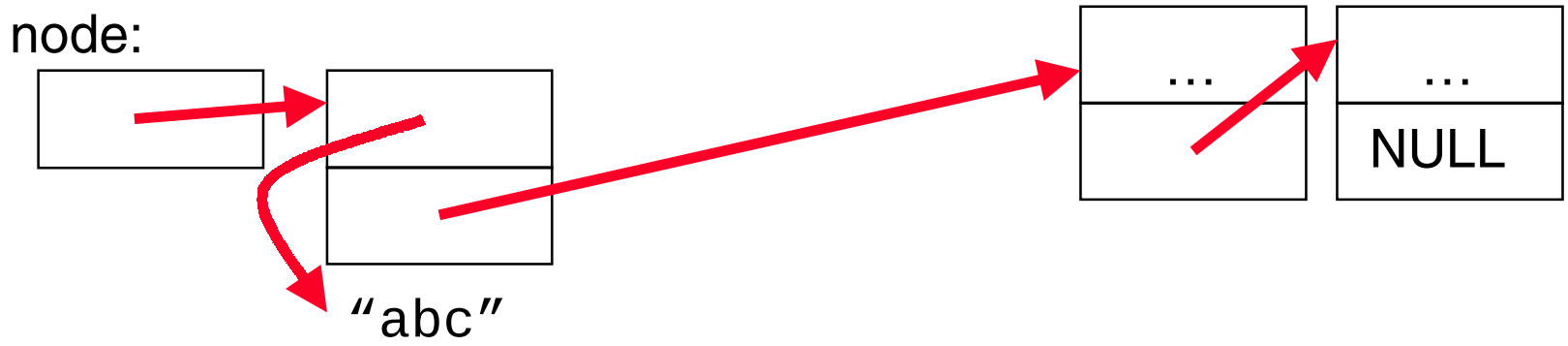

Peer Instruction

```
I:   main() {
     int *a-ptr; *a-ptr = 5; printf("%d", *a-ptr); }

II:  main() {
     int *p, a = 5;
     p = &a;
     ...   /* code, but a & p NEVER on LHS of = */
     printf("%d", a); }

III: main() {
     int *ptr;
     ptr = (int *) malloc (sizeof(int));
     *ptr = 5;
     printf("%d", *ptr); }
```

Which of these prints out 5?

A: I only
B: II only
C: III only
D: I and II
E: I and III
F: II and III
BLANK PALM: NONE

Administrivia

- HW graded on effort
- Enrollment
  - Put yourself on the waitlist of the section you want to get into
  - Section 14 still has room for 20 people!
  - It looks like we'll be able to fit ALL the people with 61B requirements! Yay!

Peer Instruction Answer

```
I:   main() {
     int *a-ptr; *a-ptr = 5; printf("%d", *a-ptr); }

II:  main() {
     int *p, a = 5;
     p = &a;
        ...   /* code, but a & p NEVER on LHS of = */
     printf("%d", a); }

III: main() {
     int *ptr;
     ptr = (int *) malloc (sizeof(int));
     *ptr = 5;
     printf("%d", *ptr); }
```

Which of these prints out 5?

C: III only

I fails for TWO reasons. You can't use "-" in names of variables and you didn't allocate int storage!

II fails because a subroutine could be called with a pointer to a (e.g., p) which changes a.

Bonus Slide: Linked List Example

```
List list_remove(List list, char *string)
{
  /* handle the first node */
  if (strcmp(list->value, string) == 0) {
    List next = list->next;
    free(list->value);
    free(list);
    return next;
  }
}
```

Bonus Slide: Linked List Example

```
List list_remove(List list, char *string)
{
  . . . first node code from above . . .
  List prev = list;
  List node = prev->next;
  while (strcmp(node->value, string) != 0) {
    prev = node;
    node = node->next;
  }

  prev->next = node->next;
  free(node->value);
  free(node);
  return list;
}
```

"And in Conclusion…"

- Use handles to change pointers
- Create abstractions with structures
- Dynamically allocated heap memory must be manually deallocated in C.
  - Use `malloc()` and `free()` to allocate and deallocate memory from heap.