CSE 31
Computer Organization

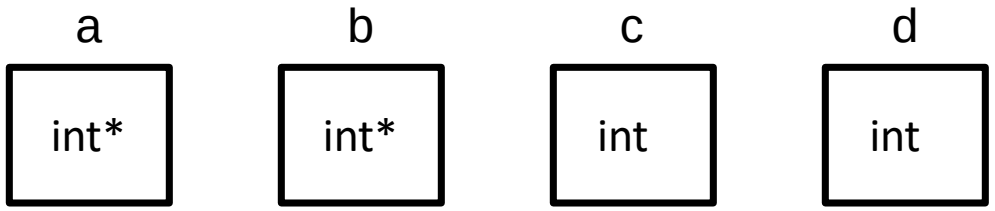
Lecture 3 – C Programming (3)

Announcement

- Lab #1 this week
  - Due at 11:59pm on the same day of your next lab
  - You must demo your submission to your TA within 14 days
- Reading assignment
  - Chapter 4-6 of K&R (C book) to review on C/C++ programming

Pointers recap

```
int *a, *b, c, d;
```



- How many variables?
- How many pointers?
- How many int?
- What do a and b store?
- What do c and d store?

Pointer Arithmetic to Copy Memory

- We can use pointer arithmetic to "walk" through memory:

```
void copy(int *from, int *to, int n) {
     int i;
     for (i=0; i<n; i++) {
          *to++ = *from++;
     }
}
```

- Note we had to pass size (`n`) to `copy`

Pointer Arithmetic Summary

- `x = *(p+1)` ?
  - `x = *(p+1) ;`
- `x = *p+1` ?
  - `x = (*p) + 1 ;`
- `x = (*p)++` ?
  - `x = *p ; *p = *p + 1;`
- `x = *p++` ? `(*p++)` ? `*(p)++` ? `*(p++)` ?
  - `x = *p ; p = p + 1;`
- `x = *++p` ?
  - `p = p + 1 ; x = *p ;`
- Lesson?
  - Using nothing but the standard `*p++`, `(*p)++` causes more problems than it solves!

Pointers (1/4)

- 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 (2/4)

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

```
void AddOne(int *p)                    y = 6
{     *p = *p + 1;    }

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

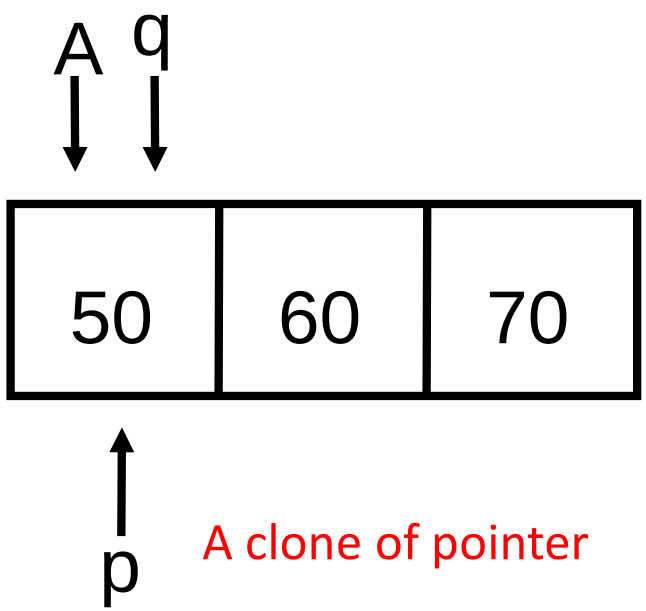
Pointers (3/4)

- 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

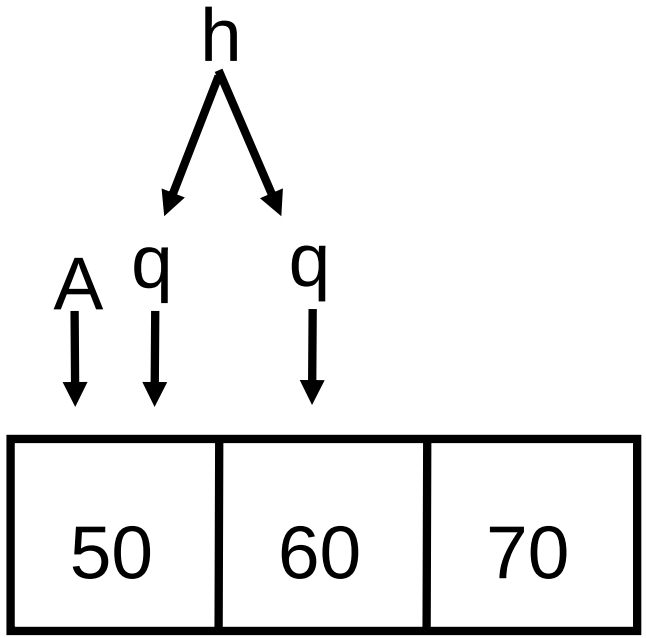


Pointers (4/4)

- Solution! Pass a pointer to a pointer, 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

Quiz:

How many of the following are invalid?

I. pointer + integer
II. integer + pointer
III. pointer + pointer
IV. pointer – integer
V. integer – pointer
VI. pointer – pointer
VII. compare pointer to pointer
VIII. compare pointer to integer
IX. compare pointer to 0
X. compare pointer to `NULL`

#invalid
a) 1
b) 2
c) 3
d) 4
e) 5

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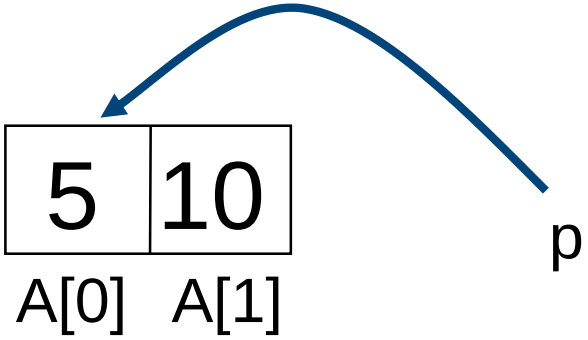
Quiz:



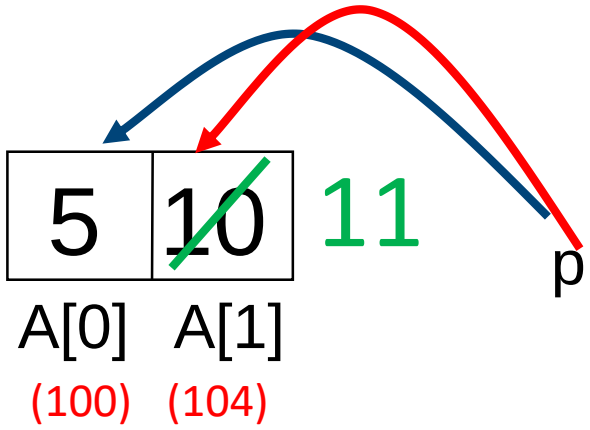
- int main(void){
  int A[] = {5,10};
  int *p = A;

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

- If the first printf outputs 100 5 5 10, 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

Quiz:



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  p = p + 1;
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Summary

- Pointers and arrays are virtually same
- C knows how to increment pointers
- C is an efficient language, with little protection
  - Array bounds not checked
  - Variables not automatically initialized
- (Beware) The cost of efficiency is more overhead for the programmer.
  - “C gives you a lot of extra rope but be careful not to hang yourself with it!”

C Strings

- A string in C is just an array of characters.

```
char string[] = "abc";
```

- How do you tell how long a string is?
  - Last character is followed by a 0 byte (null terminator)

```
int strlen(char s[])
{
    int n = 0;
    while (s[n] != 0)
    n++;
    return n;
}
```

C Strings 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?
    - Buffer overrun security holes!

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`?
- `char *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.

Dynamic Memory Allocation (1/4)

- C has operator **`sizeof()`** which gives size in bytes (of type or variable)
- Assume size of objects can be misleading and is bad style, so use **`sizeof(type)`**
  - Many years ago an `int` was 16 bits, and programs were written with this assumption.
  - What is the size of integers now?
- "**`sizeof`**" knows the size of arrays:

```
int ar[3]; // Or:   int ar[] = {54, 47, 99}
sizeof(ar) → 12
```

  - …as well for arrays whose size is determined at run-time:

```
int n = 3;
int ar[n]; // Or: int ar[fun_that_returns_3()];
sizeof(ar) → 12
```

Dynamic Memory Allocation (2/4)

- 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).
- `malloc` is almost never used for 1 value

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

  - This allocates an array of `n` integers.

Dynamic Memory Allocation (3/4)

- Once `malloc()` is called, the memory location contains garbage, so don't use it until you've initialized it.
- After dynamically allocating space, we must dynamically free it:

```
free(ptr);
```

- Use this command to clean up.
  - Even though the program `frees` all memory on `exit` (or when `main` returns), don't be lazy!
  - You never know when your `main` will get transformed into a subroutine!

Dynamic Memory Allocation (4/4)

- The following two things will cause your program to crash or behave strangely later on, and cause VERY VERY hard to figure out bugs:
  - `free()`ing the same piece of memory twice
  - calling `free()` on something you didn't get back from `malloc()`
- The runtime **does not** check for these mistakes
  - Memory allocation is so performance-critical that there just isn't time to do this
  - The usual result is that you corrupt the memory allocator's internal structure
  - You won't find out until much later on, in a totally unrelated part of your code!

C structures : Overview

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

```
struct point {  /* type definition */
     int x;
     int y;
};
```

As always in C, the argument is passed by "value" – a copy is made.

```
void PrintPoint(struct point p){

     printf("(%d,%d)", p.x, p.y);
}

struct point p1 = {0,10}; /* x=0, y=10 */

PrintPoint(p1);
```

C structures: Pointers to them

- Usually, more efficient to pass a pointer to the struct.
- The C arrow operator (->) dereferences and extracts a structure field (member) with a single operator.
- The following are equivalent:

```
struct point *p;
/* code to assign to pointer */
printf("x is %d\n", (*p).x);
printf("x is %d\n", p->x);
```

How big are structs?

- Recall C operator `sizeof()` which gives size in bytes (of type or variable)
- How big is `sizeof(p)`?

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

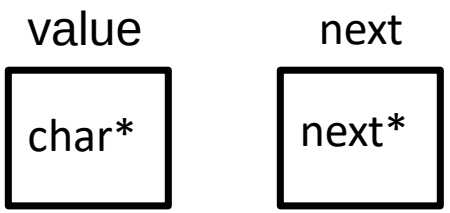
  - 5 bytes? 8 bytes?
  - Compiler may word align integer `y`
  - More on this later lectures

Linked List Example

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

```
/* node structure for linked list */
struct Node {
    char *value;
    struct Node *next;
};
```

String value;



Recursive definition!

typedef simplifies the code

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

/* "typedef" means define a new type */
typedef struct Node NodeStruct;
```

... OR ...

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

... THEN

```
 typedef NodeStruct *List;
 typedef char *String;
```

```
/* Note similarity!  */
/* To define 2 nodes */

struct Node {
    char *value;
    struct Node *next;
} node1, node2;
```

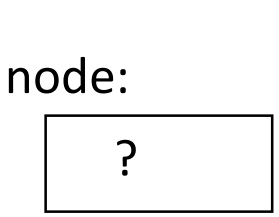
Linked List Example

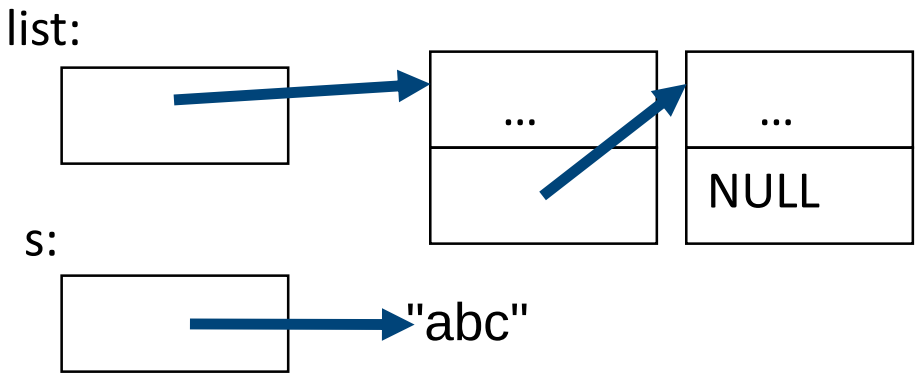
```
/* Add a string to an existing list */
List cons(String s, List list)
{
  List node = (List) malloc(sizeof(NodeStruct));

  node->value = (String) malloc (strlen(s) + 1);
  strcpy(node->value, s);
  node->next = list;
  return node;
}
```

```
String s1 = "abc", s2 = "cde";
List theList = NULL;
theList = cons(s2, theList);
theList = cons(s1, theList);
    /* or embedded */
theList = cons(s1, cons(s2, NULL));
```

Linked List Example

```
/* Add a string to an existing list, 2nd call */
List cons(String s, List list)
{
  List node = (List) malloc(sizeof(NodeStruct));

  node->value = (String) malloc (strlen(s) + 1);
  strcpy(node->value, s);
  node->next = list;
  return node;
}
```





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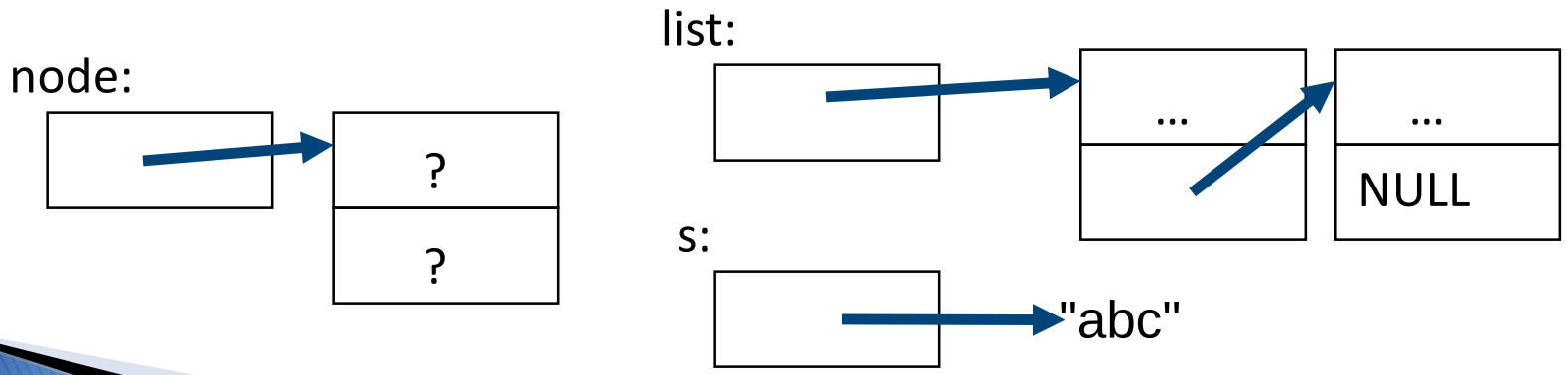

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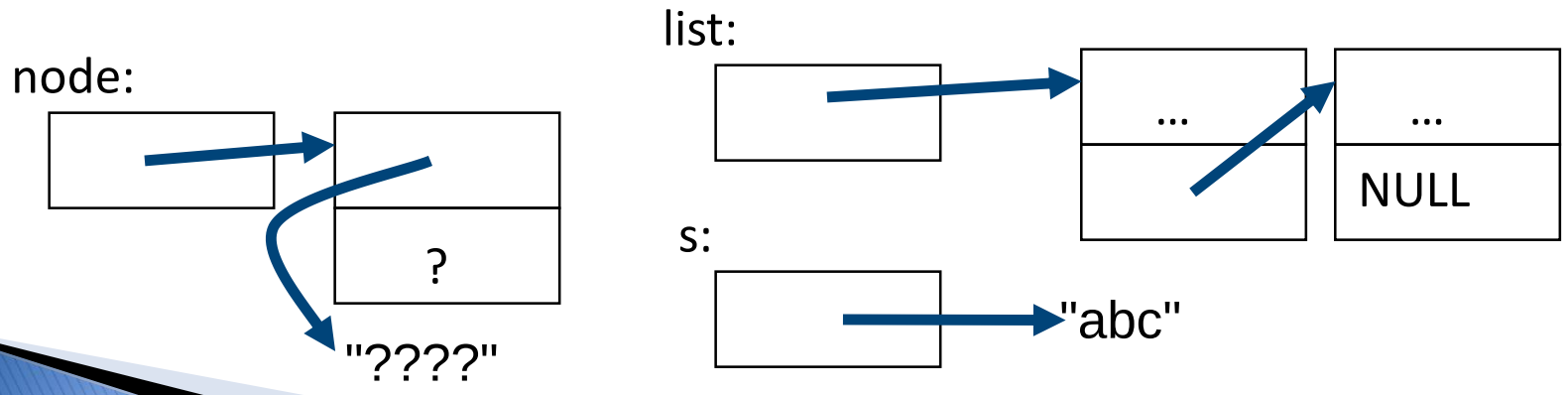

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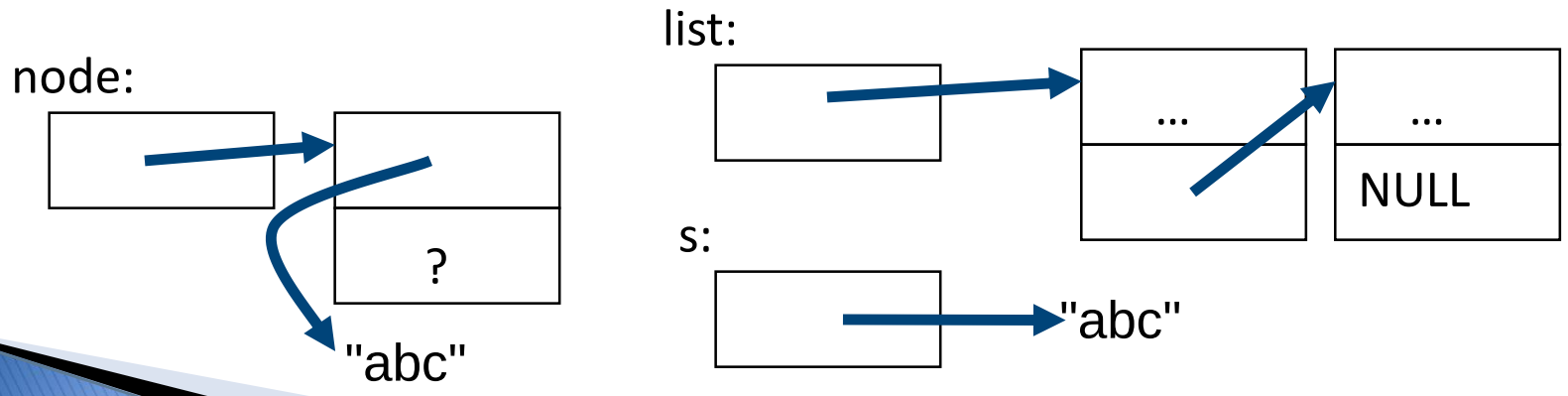

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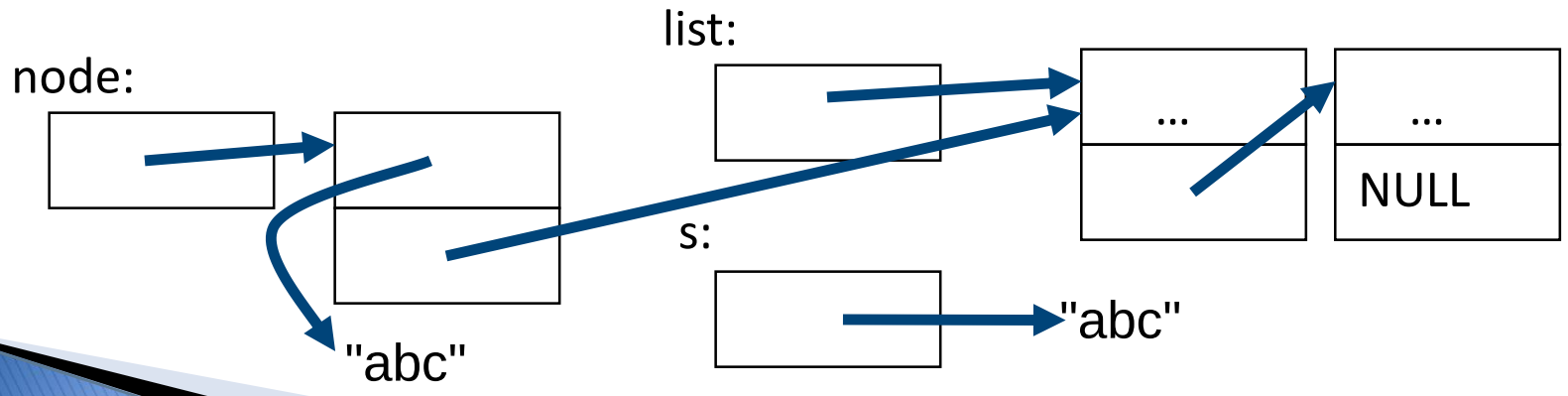

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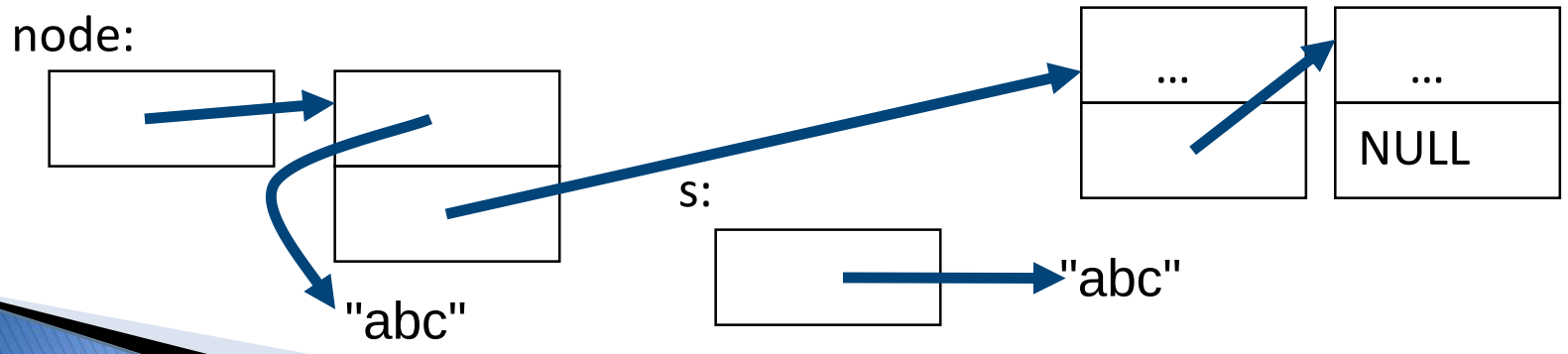
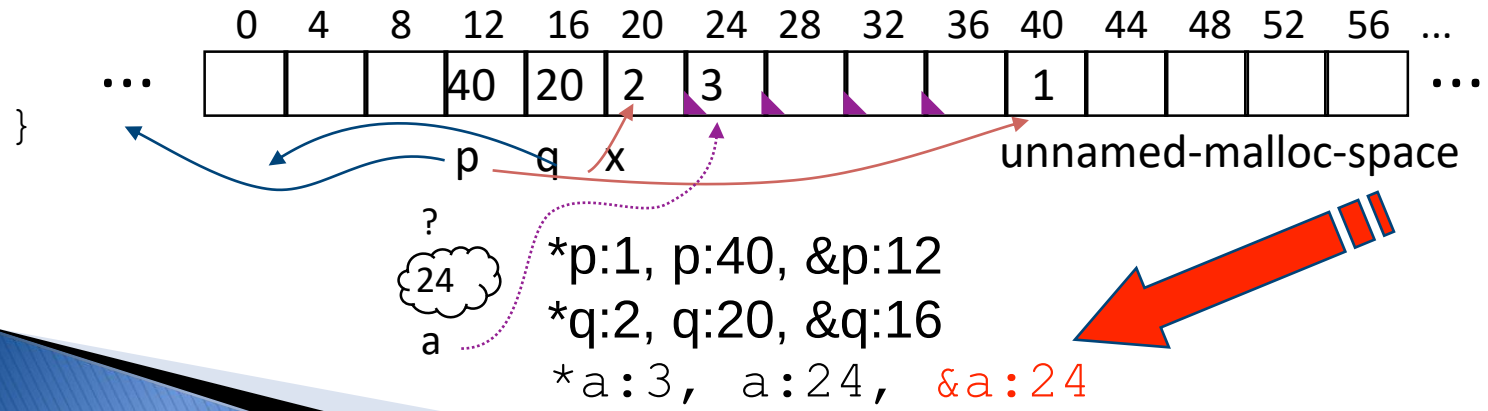


Arrays not implemented as you'd think

```
void foo() {
  int *p, *q, x;
  int a[4];
  p = (int *) malloc (sizeof(int));
  q = &x;

  *p = 1; // p[0] would also work here
  printf("*p:%u, p:%u, &p:%u\n", *p, p, &p);
  *q = 2; // q[0] would also work here
  printf("*q:%u, q:%u, &q:%u\n", *q, q, &q);
  *a = 3; // a[0] would also work here
  printf("*a:%u, a:%u, &a:%u\n", *a, a, &a);
}
```



K&R: "An array name is not a variable"

Summary

- 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.