

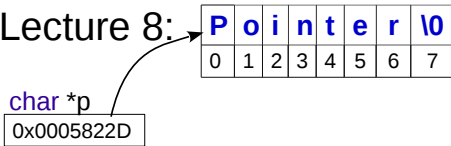
C Programming

Lecture 8:

P	o	i	n	t	e	r	\0
0	1	2	3	4	5	6	7

`char *p`

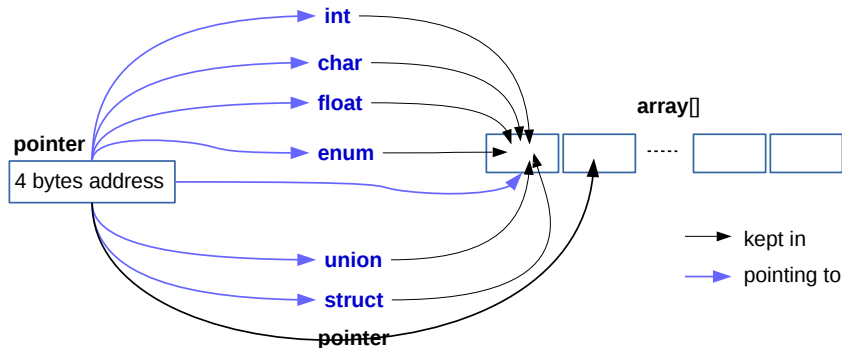
0x0005822D

A diagram illustrating a pointer variable. A box containing the text 'char *p' is positioned to the left of a box containing the memory address '0x0005822D'. An arrow originates from the 'p' in the first box and points to the first cell of a string array. The string array is a table with two rows: the top row contains the characters 'P', 'o', 'i', 'n', 't', 'e', 'r', and '\0'; the bottom row contains the indices '0', '1', '2', '3', '4', '5', '6', and '7'.

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Autumn Semester 2022

- 1 Pointer to Primitive Type Variables
- 2 Pointer to Array
- 3 Pointer to struct Variables
- 4 Dynamic Memory Allocation
- 5 List Structure
- 6 Pointer to Function



- Pointer essentially is the address of a variable
- Any types of variable has an address
- Array has address too
- It is allowed to have pointer array (array of addresses)

dataType *pointVariableName

- Pointer is a variable too
- A variable keeps address of other variable(s)
- “*” followed by variable name of the pointer

```
1 int main()  
2 {  
3     int *pt; //pointer points to an integer variable  
4 }
```

Pointer initialization

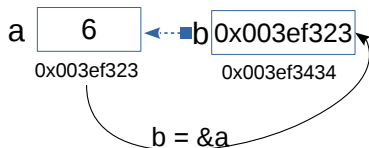
- Pointer is a variable too
- A variable keeps address of other variable(s)
- “*” followed by variable name of the pointer

```
1 #include <string.h>
2 #include <stdio.h>
3 int main()
4 {
5     short *pt = NULL; //points to an integer variable
6     float a = 3.1;
7     float *fpt = &a;
8     printf("Size-of-pt: -%d\n", sizeof(pt));
9     printf("Size-of-fpt: -%d\n", sizeof(fpt));
10    printf("Size-of-short: -%d\n", sizeof(short));
11 }
```

- “&” is an operator (something new!)
- “&a” extracts the address of variable **a**
- Address of variable **a** (4 bytes number) is then assigned to “fpt”

Pointer in its nature

```
1 #include <string.h>
2 #include <stdio.h>
3 int main()
4 {
5     int a = 6;
6     int *b = &a;
7     ....
```



- “&a” extracts the address of variable **a**
- Address of variable **a** (4 bytes number) is then assigned to “fpt”

Visit variable by its pointer (1)

```
1 #include <string.h>
2 #include <stdio.h>
3 int main()
4 {
5     short a = 4;
6     short *pa = &a;
7     float b = 3.1;
8     float *pb = &b;
9     printf("a == %d\n", a);
10    printf("b == %f\n", b);
11    printf("*pa == %d\n", *pa);
12    printf("*pb == %f\n", *pb);
13    printf("pa == %ld\n", pa);
14    printf("pb == %ld\n", pb);
15    return 0;
16 }
```

[Output:]

```
1 ??
2 ??
3 ??
4 ??
5 ??
6 ??
```

- “*pa” takes the value from the address kept by pa

Visit variable by its pointer (2)

```
1 #include <string.h>
2 #include <stdio.h>
3 int main()
4 {
5     short a = 4;
6     short *pa = &a;
7     float b = 3.1;
8     float *pb = &b;
9     printf("a=-%d\n", a);
10    printf("b=-%f\n", b);
11    printf("*pa=-%d\n", *pa);
12    printf("*pb=-%f\n", *pb);
13    printf("pa=-%ld\n", pa);
14    printf("pb=-%ld\n", pb);
15    return 0;
16 }
```

[Output:]

```
1 4
2 3.1
3 4
4 3.1
5 0439082323
6 0439082336
```

- “*pa” takes the value from the address kept by pa

Visit variable by its pointer (3)

```
1 #include <string.h>
2 #include <stdio.h>
3 int main()
4 {
5     float a = 4.5;
6     float b = 3.1;
7     float *p = &a;
8     printf("p=-%0x\n", p);
9     p = &b;
10    printf("*p=-%f\n", *p);
11    printf("p=-%0x\n", p);
12    *p = 7.2;
13    p = &a;
14    *p = 5.3;
15    printf("a=-%f\n", a);
16    printf("b=-%f\n", b);
17    return 0;
18 }
```

[Output:]

```
1 ?
2 ?
3 ?
4 ?
5 ?
```

- “*pa” takes the value from the address kept by pa

Revisit: swap values of a and b (1)

```
1 #include <stdio.h>
2 void swap(int a, int b)
3 {
4     int tmp = a;
5     a = b;
6     b = tmp;
7     return ;
8 }
9 int main()
10 {
11     int a = 3;
12     int b = 5;
13     printf("a=%d, b=%d\n", a, b);
14     swap(a, b);
15     printf("a=%d, b=%d\n", a, b);
16     return 0;
17 }
```

```
1 #include <stdio.h>
2 int a, b;
3 void swap()
4 {
5     int tmp = a;
6     a = b;
7     b = tmp;
8     return ;
9 }
10 int main()
11 {
12     a = 3;
13     b = 5;
14     printf("a=%d, b=%d\n", a, b);
15     swap(a, b);
16     printf("a=%d, b=%d\n", a, b);
17     return 0;
18 }
```

Revisit: swap values of a and b (2)

```
1 #include <stdio.h>
2 void swap(int a, int b)
3 {
4     int tmp = a;
5     a = b;
6     b = tmp;
7     return ;
8 }
9 int main()
10 {
11     int a = 3;
12     int b = 5;
13     printf("a=%d, b=%d\n", a, b);
14     swap(a, b);
15     printf("a=%d, b=%d\n", a, b);
16     return 0;
17 }
```

```
1 #include <stdio.h>
2 void swap(int *a, int *b)
3 {
4     int tmp = *a;
5     *a = *b;
6     *b = tmp;
7     return ;
8 }
9 int main()
10 {
11     int a = 3;
12     int b = 5;
13     printf("a=%d, b=%d\n", a, b);
14     swap(&a, &b);
15     printf("a=%d, b=%d\n", a, b);
16     return 0;
17 }
```

Revisit: swap values of a and b (3)

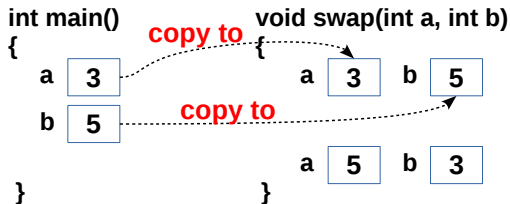


Figure: What happens for `swap(int a, int b)`.

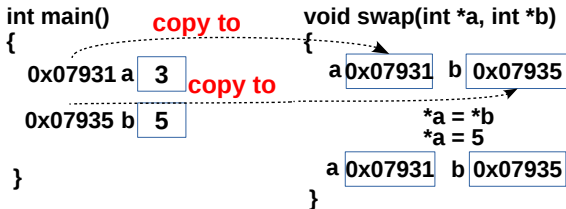


Figure: What happens for `swap(int *a, int *b)`.

Revisit: swap values of a and b (4)

```
1 #include <stdio.h>
2 void swap(int *a, int *b)
3 {
4     int tmp = *a;
5     *a = *b;
6     *b = tmp;
7     return ;
8 }
9 int main()
10 {
11     int a = 3;
12     int b = 5;
13     printf("a=%d, b=%d\n", a, b);
14     swap(&a, &b);
15     printf("a=%d, b=%d\n", a, b);
16     return 0;
17 }
```

```
1 #include <stdio.h>
2 void swap(adr a, adr b)
3 {
4     int tmp = *a;
5     *a = *b;
6     *b = tmp;
7     return ;
8 }
9 int main()
10 {
11     int a = 3;
12     int b = 5;
13     printf("a=%d, b=%d\n", a, b);
14     swap(&a, &b);
15     printf("a=%d, b=%d\n", a, b);
16     return 0;
17 }
```

- Given `adr` is an address type

Summary over Pointer to Variables (1)

- Pointer is a variable or constant
- It keeps the address of a variable
- One is allowed to do operation on a variable by its address

```
1 #include <stdio.h>
2 int main()
3 {
4     int a = 3, *p;
5     int b = 1;
6     p = &a;
7     printf("a=%d\n", *p);
8     p = &b;
9     printf("b=%d\n", *p);
10 }
```

```
1 void incr(int *a)
2 {
3     *a = *a + 1;
4 }
5 int main()
6 {
7     int a = 4, *b = &a;
8     printf("%d\n", *b);
9     incr(&a);
10    printf("%d\n", a);
11    printf("%d\n", *b);
12    return 0;
13 }
```

Summary over Pointer to Variables (2)

- Pointer is a variable or constant
- It keeps the address of a variable
- One is allowed to do operation on a variable by its address

```
1 #include <stdio.h>
2 int main()
3 {
4     int a = 3, *p;
5     int b = 1;
6     *p = a;
7     p = b;
8     p = &c;
9 }
```

```
1 #include <stdio.h>
2 int main()
3 {
4     int a = 3, *p;
5     int b = 1;
6     float c = 2.2;
7     p = &a;
8     printf("%d", *p);
9     *p = b;
10    printf("%d", *p);
11    printf("%d", a);
12 }
```

Summary over Pointer to Variables (3)

```
1 void incr(int *a)
2 {
3     *a = *a + 1;
4 }
5 int main()
6 {
7     int a = 4, *b = &a;
8     printf("%d\n", *b);
9     incr(&a);
10    printf("%d\n", a);
11    printf("%d\n", *b);
12    return 0;
13 }
```

```
1 void incr(int *a)
2 {
3     a = a + 4;
4 }
5 int main()
6 {
7     int a = 4, *b = &a;
8     printf("%d\n", *b);
9     incr(&a);
10    printf("%d\n", a);
11    printf("%d\n", *b);
12    return 0;
13 }
```

- 'incr(int* a)' on the right, increases the address number of **a**
- It points to **another memory cell**
- **a** inside 'incr(int *a)' is a local variable
- It has no effect on input variable

Explained

```
1 void incr(addr a)
2 {
3     *a = *a + 1;
4 }
5 int main()
6 {
7     int a = 4, *b = &a;
8     printf("%d\n", *b);
9     incr(&a);
10    printf("%d\n", a);
11    printf("%d\n", *b);
12    return 0;
13 }
```

```
1 void incr(addr a)
2 {
3     a = a + 4;
4 }
5 int main()
6 {
7     int a = 4, *b = &a;
8     printf("%d\n", *b);
9     incr(&a);
10    printf("%d\n", a);
11    printf("%d\n", *b);
12    return 0;
13 }
```

- Given `addr` is an address type
- Keep the principle that parameter “**transfer by value**” in C
- `a` inside ‘`incr(addr a)`’ is a local variable
- It has no effect on input variable

A Revisit about “scanf(·,·)”

```
1 int main()  
2 {  
3     int a = 0;  
4     printf("Input-value-for-a:-");  
5     scanf("%d", &a); //<— pay attention to here  
6     return 0;  
7 }
```

- Now we should be clear why we put “&” before **a**
- By this way, we tell **scanf(·)** to put the user input value to which memory address
- Is it possible if we do something as following?

```
1 int main()  
2 {  
3     int a = 0;  
4     printf("Input-value-for-a:-");  
5     scanf("%d", a); //<—ask yourself whether this is valid??  
6     return 0;  
7 }
```

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An Overview: Pointer to Array (1)

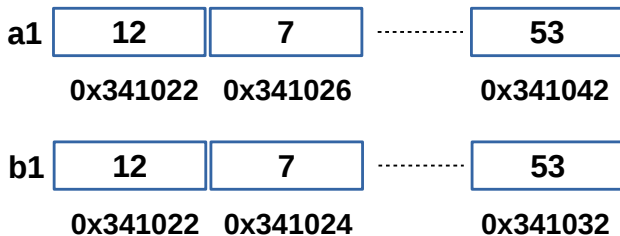


Figure: Two typical arrays of `int` type.

- Array is a continuous memory block
- It has a starting address
- It has a length
- It has a name

An Overview: Pointer to Array (2)

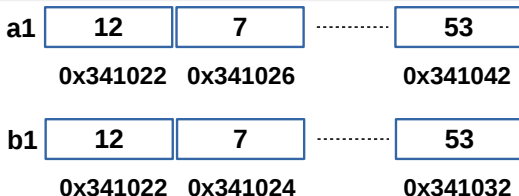


Figure: Two typical arrays of `int` type

- Unlike primitive type variable
- The name of an array is also the starting address of an array

```
1 int main()  
2 {  
3     int a[5]={4, 5, 7, 11, 13, 17};  
4     int *p = a;  
5     p = &a[0];  
6     return 0;  
7 }
```

Definition and initialization (1)

```
int *p;  
int a1[10];  
p = a1;  
p = &a1[0];
```

- Definition of array pointer is the same as variable pointer
- Above two ways are valid
- '**p**' keeps the address of starting address of **a1**
- Now think about what "**p = p+2**" means here??

Definition and initialization (2)

```
1 #include <stdio.h>
2 int main()
3 {
4     int a1[4] = {31, 1, 11, 4};
5     int i = 0, *p = a1;
6     for(i=0; i<4; i++,p++)
7     {
8         printf("%d-", *p);
9     }
10    return 0;
11 }
```

- 'p' visits element in array a1 one by one
- '*p' takes the value according to the address in 'p'

Definition and initialization (3)

```
1 #include <stdio.h>
2 int main()
3 {
4     int a1[4]={31, 1, 11, 4};
5     int i = 0, *p = a1;
6     for(i=0;i<4; i++,p++)
7     {
8         printf("%d-", *p);
9     }
10    return 0;
11 }
```

```
1 #include <stdio.h>
2 int main()
3 {
4     int a1[4]={31, 1, 11, 4};
5     int i = 0, *p = a1;
6     for(i = 0; i < 4; i++)
7     {
8         printf("%d-", a1[i]);
9     }
10    return 0;
11 }
```

- '**p**' visits element in array a1 one by one
- '***p**' takes the value according to the address in '**p**'

Definition and initialization (3)

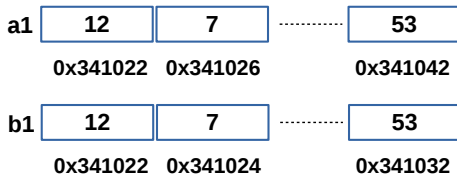


Figure: Two typical arrays of `int` type

```
1 int main()  
2 {  
3     int a1[6] = {12, 7, 7, 11, 13, 53};  
4     short b1[6] = {12, 7, 7, 11, 13, 53};  
5     int *pa = &a1;  
6     short *pb = &b1;  
7     return 0;  
8 }
```

- Like pointer to variable, different types of array need different types of pointer

Operations on Pointer of Array (1)

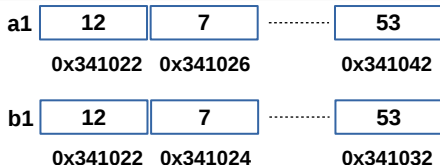


Figure: Two typical arrays of `int` type

```
1 int main()  
2 {  
3     int a1[6]={12, 7, 17, 11, 13, 53};  
4     short b1[6]={12, 7, 17, 11, 13, 53};  
5     int *pa = &a1;  
6     short *pb = &b1;  
7     pa++; pb++;  
8     printf("%d\n", *pa);  
9     printf("%d\n", *pb);  
10    return 0;  
11 }
```

[Output]

?

?

Operations on Pointer of Array (2)

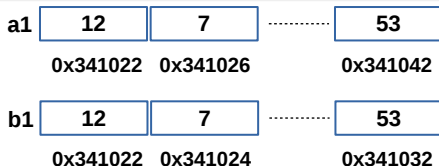


Figure: Two typical arrays of `int` type

```
1 int main()  
2 {  
3     int a1[5] = {12, 7, 17, 11, 13, 53};  
4     short b1[5] = {12, 7, 17, 11, 13, 53};  
5     int *pa = &a1;  
6     short *pb = &b1;  
7     pa++; pb++;  
8     printf("%d\n", *pa);  
9     printf("%d\n", *pb);  
10    return 0;  
11 }
```

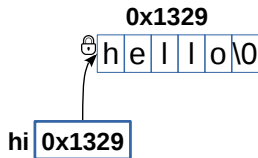
[Output]

7

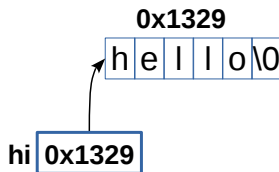
7

Pointer to String

- Think about following example
- We saw it many times
- Now we give a full explanation over it



```
1 #include <stdio.h>
2 int main()
3 {
4     char *hi = "hello";
5     hi[1] = 'a'; //<—
6     printf("%s\n", hi);
7     return 0;
8 }
```



```
1 #include <stdio.h>
2 int main()
3 {
4     char hi[] = "hello";
5     hi[1] = 'a'; //<—legal
6     printf("%s\n", hi);
7     return 0;
8 }
```

Array of chars, String and Pointer of String

- Since pointer points to the first address of an array
- “str1” is defined as **constant** array of chars, and pointed by pointer str
- Definitions about “str2” and “str3” are **equivalent**
- Definition about “str4” is **different** from above three

```
1 #include <stdio.h>
2 #include <string.h>
3 void main()
4 {
5     char *str1 = "hello"; //<—str1[0] = 'a' will be illegal
6     char str2[10] = "hello";
7     char str3[10] = {'h', 'e', 'l', 'l', 'o', '\0'};
8     char str4[10] = {'h', 'e', 'l', 'l', 'o'}; //<—it is
        different
9     printf("%s\n", str1);
10    printf("%s\n", str2);
11    printf("%s\n", str3);
12    printf("%s\n", str4);
13 }
```

Example of Pointer to Array (1)

- Given **str1**="abserds" and **str2**="xxxxx"
- You are required to copy the contents of one string to another

Example of Pointer to Array (2)

- Given **str1**="abserds" and **str2**="xxxxx"
- You are required to copy the contents of one string to another
 - 1 Define pointers (p1 and p2) for **str1** and **str2**
 - 2 Pointing to the start of each
 - 3 Assign value of p1 to p2
 - 4 Repeat **Step 3** until the end of **str1**
 - 5 Assign '\0' to the end of **str2**

Example of Pointer to Array (3)

```
1 #include <stdio.h>
2 int main()
3 {
4     char *str1="hello-world!";
5     char str2[16];
6     char *p1 = str1;
7     char *p2 = str2;
8     while(p1 != '\0')
9     {
10         *p2 = *p1;
11         p1++; p2++;
12     }
13     printf("%s\n", str1);
14     printf("%s\n", str2);
15     return 0;
16 }
```

- There is a **bug**, please tell me:)

Example of Pointer to Array (4)

```
1 #include <stdio.h>
2 void main()
3 {
4     char *str1="hello-world!";
5     char str2[16];
6     char *p1 = str1;
7     char *p2 = str2;
8     while(*p1 != '\0')
9     {
10         *p2 = *p1;
11         p1++; p2++;
12     }
13     *p2='\0'; //<—indicate the end of the string
14     printf("%s\n", str1);
15     printf("%s\n", str2);
16 }
```

- Be careful all the time

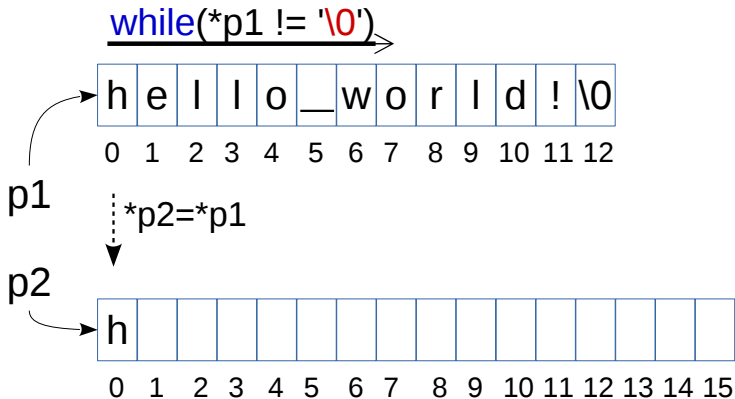
Example of Pointer to Array (5)

```
1 #include <stdio.h>
2 void strCopy(char *p1, char *p2)
3 {
4     while(*p1 != '\0')
5     {
6         *p2 = *p1;
7         p1++; p2++;
8     }
9     *p2 = '\0';
10 }
11
12 int main()
13 {
14     char *str1 = "hello-world!";
15     char str2[16];
16     strCopy(str1, str2);
17     printf("%s\n", str1);
18     printf("%s\n", str2);
19     return 0;
20 }
```

Example of Pointer to Array (6)

```
1 #include <stdio.h>
2 void strCopy(char *p1, char *p2)
3 {
4     while(*p1 != '\0')
5     {
6         *p2 = *p1;
7         p1++; p2++;
8     }
9     *p2 = '\0';
10 }
11
12 int main()
13 {
14     char *str1="hello-world!";
15     char str2[16];
16     strCopy(str1, str2);
17     printf("%s\n", str1);
18     printf("%s\n", str2);
19     return 0;
20 }
```

Example of Pointer to Array (7)



- The while loop stop at '\0'
- '\0' will not be copied in the loop

Popular functions for string operation (1)

1. **strlen**(str1); length of str1, '\0' is not counted
2. **strcpy**(str1, str2); copy str2 to str1
3. **strcmp**(str1, str2); compare two strings
4. **strcat**(str1, str2); concatenate two strings
5. **strncpy**(str1, str2, n); copy first n chars of str2 to str1

Popular functions for string operation (2)

- 2. **strcpy**(str1, str2); copy str2 to str1
- 4. **strcat**(str1, str2); concatenate two strings

```
1 #include <stdio.h>
2 #include <string.h>
3 int main()
4 {
5     char *str1="hello", *str2 = "world";
6     char hi[32];
7     strcpy(hi, str1);
8     strcat(hi, " -");
9     strcat(hi, str2);
10    printf("%s\n", hi);
11    return 0;
12 }
```

3. **strcmp**(str1, str2); compare two strings

```
1 #include <stdio.h>
2 #include <string.h>
3 void main()
4 {
5     char *str1="hello", *str2 = "hi", *str3="hello";
6     if(strcmp(str1, str2) == -1)
7     {
8         printf("str1 <- str2!\n");
9     } else if(strcmp(str1, str2) == 1) {
10         printf("str1 >- str2!\n");
11     }
12     if(strcmp(str1, str3) == 0)
13     {
14         printf("They are equal!\n");
15     } else {
16         printf("They are unequal!\n");
17     }
18 }
```

- 1 Pointer to Primitive Type Variables
- 2 Pointer to Array
- 3 Pointer to struct Variables**
- 4 Dynamic Memory Allocation
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Pointer to struct Type Variable (1)

- The declaration of pointer to **struct** type is similar as pointer to primitive type and array

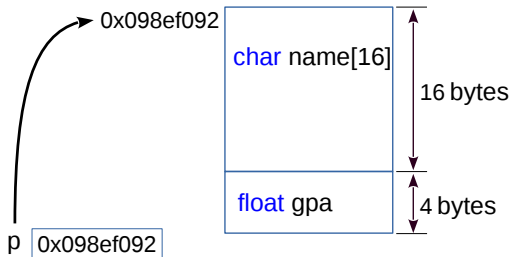
```
1 struct STD {  
2     char name[16];  
3     float gpa;  
4 };  
5 int main()  
6 {  
7     struct STD std1 = {"Peter", 3.8};  
8     struct STD *p = &std1;  
9     printf("Name: -%s\n", (*p).name);  
10    printf("GPA: -%f\n", (*p).gpa);  
11    return 0;  
12 }
```

Pointer to struct Type Variable (1)

- The declaration of pointer to **struct** type is similar as pointer to primitive type and array

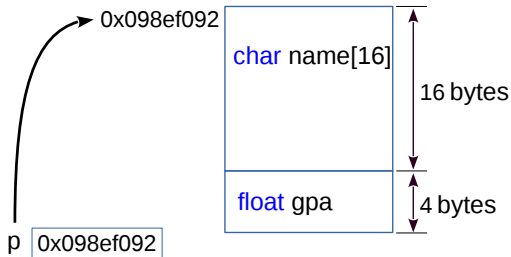
```
1 struct STD {  
2     char name[16];  
3     float gpa;  
4 };  
5 int main()  
6 {  
7     struct STD std1 = {"Peter", 3.8};  
8     struct STD *p = &std1;  
9     printf("Name: -%s\n", (*p).name);  
10    printf("GPA: -%f\n", (*p).gpa);  
11    return 0;  
12 }
```

Pointer to struct Type Variable (2): explained



- Pointer keeps the starting address of the struct type variable
- `sizeof(p) = ?`

Pointer to struct Type Variable (3): explained



- Pointer keeps the starting address of the struct type variable
- `sizeof(p) = ?`
- Notice that the address is only 4 bytes (32 bits system)

Pointer to struct Type Variable

```
1 struct STD {
2     char name[16];
3     float gpa;
4 };
5 typedef struct STD STDT;
6 void main()
7 {
8     STDT std1 = {"Peter", 3.8};
9     struct STD *p = &std1;
10    printf("%s\n", (*p).name);
11    printf("%f\n", (*p).gpa);
12 }
```

```
1 struct STD {
2     char name[16];
3     float gpa;
4 };
5 typedef struct STD STDT;
6 void main()
7 {
8     STDT std1 = {"Peter", 3.8};
9     struct STD *p = &std1;
10    printf("%s\n", p->name);
11    printf("%f\n", p->gpa);
12 }
```

- `typedef` denotes “`struct STD`” as “`STDT`”
- “`p->`” is equivalent to “`(*p).`”

Comparison Study over Pointers

```
1 #include <stdio.h>
2 struct STD {
3     char name[16];
4     float gpa;
5 };
6 void main()
7 {
8     struct STD std1 = {"Peter", 3.8};
9     struct STD *p = &std1;
10    int *q;
11    char *r;
12    printf("size-of-STD: %d\n", sizeof(struct STD));
13    printf("size-of-p: %d\n", sizeof(p));
14    printf("size-of-q: %d\n", sizeof(q));
15    printf("size-of-r: %d\n", sizeof(r));
16 }
```

- The size is the same for different kinds of pointers
- Why??

- 1 Pointer to Primitive Type Variables
- 2 Pointer to Array
- 3 Pointer to struct Variables
- 4 Dynamic Memory Allocation**
- 5 List Structure
- 6 Pointer to Function

Static and Dynamic Memory Allocation (1)

- Recall what the variables we learned so far

- 1 Primitive type variables
- 2 Primitive type arrays
- 3 Composite type variables
- 4 Composite type arrays

```
1 struct STD {  
2     char name[16];  
3     float gpa;  
4 };  
5 typedef STD STDT;  
6 void main()  
7 {  
8     int a, a1[10];  
9     STDT b, b1[10];  
10 }
```

- The memory cells for a, a1, b and b1 are allocated when your code is loaded into memory
- It is done **before the code is executed**

Static and Dynamic Memory Allocation (2)

- In some cases, we are not sure how long is the array we need before run it
- We have two options for this case
 - ① Apply for a very long array, i.e., 65,536
 - ② Apply the memory cells in the **runtime**
- The second way is called dynamic memory allocation

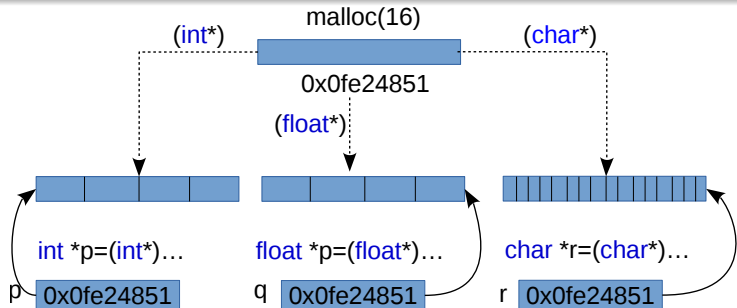
```
int *p = (int*)malloc(sizeof(int)*10);
```

- 1 Apply a block of memory sized of $10 * \text{sizeof}(\text{int}) = ??$
- 2 Function “**malloc**(.)” returns the starting address of this memory
- 3 Convert this starting address to an `int` type pointer
- 4 Assign this starting address to **p**

```
int *p = (int*)malloc(sizeof(int)*10);
```

- 1 Function “**malloc**(.)” sends the applicaiton to OS
- 2 When the application is approved, a block of memory is returned
- 3 OS extracts memory from **Heap**
- 4 Once it is allocated, you can operate it as an array

Dynamic Memory Allocation: explained



```
1 #include <stdlib.h>
2 void main()
3 {
4     void *x = malloc(16);
5     int *p = (int*)x;
6     float *q = (float*)x;
7     char *r = (char*)x;
8 }
```

- We just show it is possible
- It is NOT suggested in practice

Dynamic Memory Allocation: example

```
1 #include <stdlib.h>
2 void main()
3 {
4     int i = 0, *a1 = (int*) malloc(5* sizeof(int));
5     for(i = 0; i < 5; i++)
6     {
7         a1[i] = i+1;
8     }
9     free(a1); //<—release the memory pointing by a1
10 }
```

- 1 Function “**malloc**(.)” returns the starting address of this block of memory
- 2 Once it is allocated, you can operate it as an array
- 3 Always remember to **release** it by calling **free**(.)

Dynamic Memory Allocation: memory leakage (1)

- Different from static memory allocation
- You are required to release the dynamically allocated memory on your own
- If you fail to do that, memory leakage occurs (90%) C bugs arise from this

```
1 #include <stdlib.h>
2 int main()
3 {
4     int i = 0, *a1 = (int*) malloc(5* sizeof(int));
5     for(i = 0; i < 5; i++)
6     {
7         a1[i] = i+1;
8     }
9     free(a1); //<— very important here
10    return 0;
11 }
```

Dynamic Memory Allocation: memory leakage (2)

```
1 #include <stdlib.h>
2 int main()
3 {
4     int i = 0, *a1 = (int*)malloc(5*sizeof(int));
5     for(i = 0; i < 5; i++)
6     {
7         a1[i] = i+1;
8     }
9     free(a1);
10    a1[2] = 3; //<— illegal memory access
11    return 0;
12 }
```

- You are not allowed to use memory that has been released
- Above code (line 10) causes **illegal memory access exception**

Dynamic Memory Allocation: memory leakage (3)

```
1 #include <stdlib.h>
2 void main()
3 {
4     int i = 0, *a1 = (int*) malloc(5* sizeof(int));
5     for(i = 0; i < 5; i++)
6     {
7         a1[i] = i+1;
8     }
9     a1 = (int*) malloc(15* sizeof(int)); //<—something wrong here
10    free(a1);
11 }
```

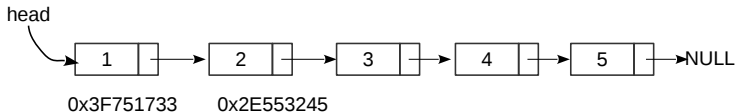
- You are not allowed to use memory that has been released
- We lose the pointer to one block of memory (at line 9)
- Memory leaks (**ghost** memory cells)

- 1 Pointer to Primitive Type Variables
- 2 Pointer to Array
- 3 Pointer to struct Variables
- 4 Dynamic Memory Allocation
- 5 List Structure**
- 6 Pointer to Function

Overview of List Structure

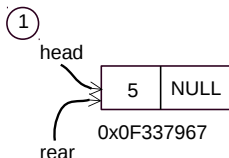
int d	struct Node *next
-------	-------------------

1	0x2E553245
---	------------



```
1 struct Node {  
2     int a;  
3     struct Node *next;  
4 };  
5 typedef Node TNode;
```

Build List—Step 1



```
1 struct Node {  
2     int a;  
3     struct Node *next;  
4 };  
5 typedef Node TNode;  
6 int main()  
7 {  
8     TNode *head = NULL, *rear = NULL;  
9     TNode *p = (TNode*) malloc( sizeof(TNode) );  
10    p->a = 5; p->next = NULL;  
11    head = p; rear = p;  
12 }
```

Build List—Step 2



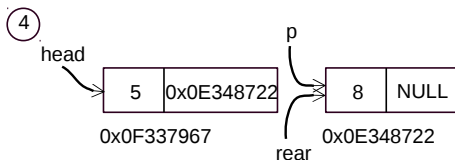
```
1 struct Node {  
2     int a;  
3     struct Node *next;  
4 };  
5 typedef Node TNode;  
6 TNode *buidList()  
7 {  
8     TNode *head = NULL, *rear = NULL;  
9     TNode *p = (TNode*) malloc( sizeof(TNode) );  
10    p->a = 5; p->next = NULL;  
11    head = p; rear = p;  
12    p = (TNode*) malloc( sizeof(TNode) );  
13    return head;  
14 }
```

Build List—Step 3



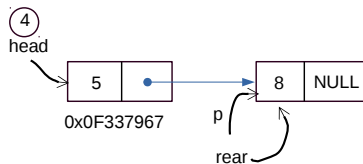
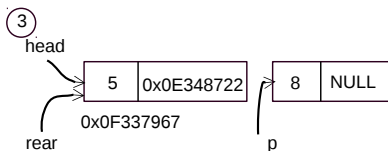
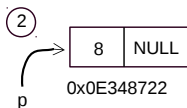
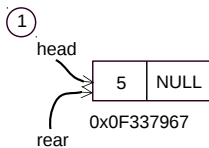
```
1 TNode *buidList()  
2 {  
3     TNode *head = NULL, *rear = NULL;  
4     TNode *p = (TNode*) malloc( sizeof(TNode));  
5     p->a = 5; p->next = NULL;  
6     head = p; rear = p;  
7     p = (TNode*) malloc( sizeof(TNode));  
8     rear->next = p;  
9     return head;  
10 }
```

Build List—Step 4

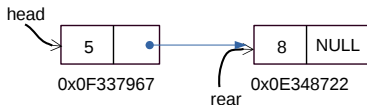


```
1 TNode *buidList()  
2 {  
3     TNode *head = NULL, *rear = NULL;  
4     TNode *p = (TNode*) malloc( sizeof( TNode ));  
5     p->a = 5; p->next = NULL;  
6     head = p; rear = p;  
7     p = (TNode*) malloc( sizeof( TNode ));  
8     rear->next = p;  
9     rear = p;  
10    return head;  
11 }
```

Build List—Summary



Print List



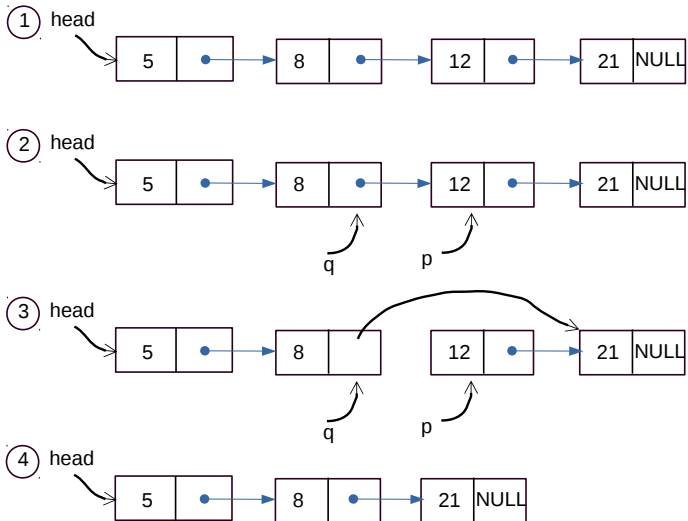
```
1 int printList(TNode *head)
2 {
3     TNode *p = head;
4     int i = 0;
5     while(p != NULL)
6     {
7         printf("%3d\n", p->a);
8         p = p->next;
9         i++;
10    }
11    return i;
12 }
```


Delete Node from List



- We want to delete the node in which **a** equals to **12**

Delete Node from List-Steps



Delete Node from List—Procedure



- We want to delete the node in which **a** equals to **12**

① Find the node, whose **a** equals to **12**

② Given it is **p**, the node before it is **q**

① $q \rightarrow \text{next} = p \rightarrow \text{next};$

② $p \rightarrow \text{next} = \text{NULL};$

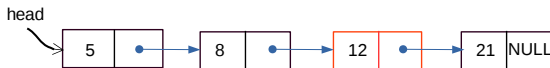
③ $\text{free}(p);$

Delete Node from List—Codes



```
1 void deleteNode(int val , TNode *head)
2 {
3     TNode *p = head , *q = head;
4     //filling the codes here
5 }
```

Delete Node from List—The answer



```
1 void deleteNode(int val , TNode *head)
2 {
3     TNode *p = head , *q = head;
4     while(p != NUL && p->a != val)
5     {
6         q = p;
7         p = p->next;
8     }
9     if(p != NULL && p->a == val)
10    {
11        q->next = p->next;
12        p->next = NULL;
13        free(p);
14    }
15 }
```

Why condition “p != NUL” first???

What are the differences between Array and List

	Array	List
Structure	linear	linear
Memory	continous block	chain of blocks
Visit	subscript	linear scan
Insert/delete	element shifting	direct operation

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An Overview: Motivation (1)

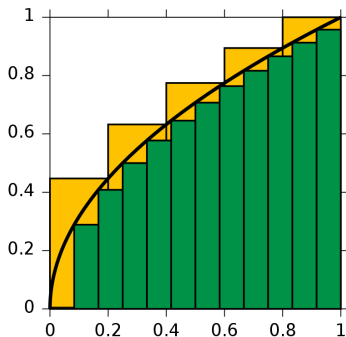


Figure: Numerical integral of \sqrt{x}

- Given two functions to perform the numerical integral
- $f(x) = \sqrt{x}$, $g(x) = \cos(x)$
- $\int_a^b f(x)dx = ?$, $\int_a^b g(x)dx = ?$

An Overview: Motivation (2)

- Define $dx=0.05$, given a and b
- We can calculate integral of \sqrt{x} when $x \in [a, b]$

```
1 #include <math.h>
2 #include <stdio.h>
3 float intSqrt(float dx, float a, float b){
4     float s = 0, x = a;
5     while(x < b){
6         s += sqrt(x)*dx;
7         x += dx;
8     }
9     return s;
10 }
11 float intCos(float dx, float a, float b){
12     float s = 0, x = a;
13     while(x < b){
14         s += cos(x)*dx;
15         x += dx;
16     }
17     return s;
18 }
```

An Overview: Motivation (3)

- Define $dx=0.05$, given a and b
- We can calculate integral of \sqrt{x} when $x \in [a, b]$

```
19 void main()  
20 {  
21     float a = 1.0, b = 5.0, dx = 0.05, s = 0;  
22     char funcName[8] = "";  
23     scanf("%s", &funcName);  
24     if(strcmp(funcName, "sqrt") == 0){  
25         s = intSqrt(dx, a, b);  
26     } else if(strcmp(funcName, "sin") == 0){  
27         s = intSin(dx, a, b);  
28     } else if(strcmp(funcName, "cos") == 0){  
29         s = intCos(dx, a, b);  
30     }  
31     printf("Integral is: -%f\n", s);  
32 }
```

An Overview: Motivation (4)

- Define $dx=0.05$, given a and b
- We can calculate integral of \sqrt{x} $x \in [a, b]$

```
19 void main()  
20 {  
21     float (*fun_ptr)(float dx, float a, float b);  
22     float a = 1.0, b = 5.0, dx = 0.05, s = 0;  
23     char funcName[8] = "";  
24     scanf("%s", &funcName);  
25     if(strcmp(funcName, "sqrt") == 0){  
26         func_ptr = &intSqrt;  
27     }else if(strcmp(funcName, "sin") == 0){  
28         func_ptr = &intSin;  
29     }else if(strcmp(funcName, "cos") == 0){  
30         func_ptr = &intCos;  
31     }  
32     s = (*fun_ptr)(dx, a, b);  
33     printf("Integral is: %f\n", s);  
34 }
```

Function Pointer: the declaration (1)

`type0 (*function_pointer_name)(type1 p1, type2 p2);`

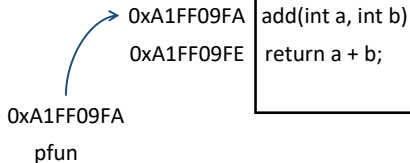
- Given a function in the same form

`type0 fun1(type1 p1, type2 p2);`

`*function_pointer_name = &fun1;`

```
1 #include <stdio.h>
2 int add(int a, int b){
3     return a+b;
4 }
5 int main(){
6     int (*pfun)(int a, int b) = NULL;
7     int a = 5, b = 8, r = 0;
8     pfun = &add;
9     r = pfun(a, b);
10    printf("r = %d\n", r);
11    return 0;
12 }
```

Function Pointer: the declaration (2)



```
1 #include <stdio.h>
2
3 int add(int a, int b){
4     return a+b;
5 }
6 int main(){
7     int (*pfun)(int a, int b) = NULL;
8     int a = 5, b = 8, r = 0;
9     pfun = &add;
10    r = pfun(a, b);
11    printf("r = %d\n", r);
12    return 0;
13 }
```

Function Pointer: the declaration (3)

```
1 #include <stdio.h>
2
3 int add(int a, int b){
4     return a+b;
5 }
6 int main()
7 {
8     int (*pfun)(int a, int b) = NULL;
9     int a = 5, b = 8, r = 0;
10    pfun = &add;
11    r = pfun(a, b);
12    printf("size of pointer: %d\n", sizeof(pfun));
13    printf("r = %d\n", r);
14    return 0;
15 }
```