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- Labtest this Wed and next Mon. Come to your session.
- No pointers, no recursions … See “Labtests” page
- Lab 4 solutions posted tomorrow morning. Review lab 1-4

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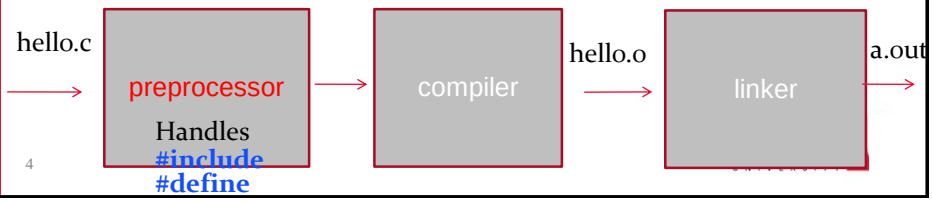
The previous lecture

- Scope, life time, initialization of local/global variables (ch4)
  - static
- Pre-processing (ch4)
- Recursion (ch4)
- Other C materials before pointer
  - Common library functions [Appendix of K&R]
  - 2D array, table of strings
- Pointer basics (ch5)

How C Programs are Compiled

- C programs go through three stages to be compiled:
  - Preprocessor - handles #include and #define etc
  - Compiler - converts C code into binary processor instructions ("object code")
  - Linker - puts multiple files together, load necessary library functions (e.g., printf), and creates an executable program



"manual". Get used to it for help!

```
indigo 307 % man gcc

NAME
       gcc - GNU project C and C++ compiler

SYNOPSIS
       gcc [-c|-S|-E] [-std=standard]
           [-g] [-pg] [-Olevel]
           [-Wwarn...] [-pedantic]
           [-Idir...] [-Ldir...]
           [-Dmacro[=defn]...] [-Umacro]
           [-foption...] [-mmachine-option...]
           [-o outfile] infile...

       Only the most useful options are listed here; see below for the
       remainder.  g++ accepts mostly the same options as gcc.

DESCRIPTION
       When you invoke GCC, it normally does preprocessing, compilation,
       assembly and linking.
```

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The c preprocessor

- Pre-process c files before compiling it
  - Handles #define and #include
    - also #undefine, #if, #ifdef, #ifndef …

  called macros

  - Removes comments
  - Output c code (to compiler)

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Pre-processing #include

- #include <file> -- include <stdio.h> which is library header file
- #include "file" -- include "file.h" which is programmer defined

- includes another file in the current file as if contents were part of the current file
  - Textual replace/copy. Nothing fancy

- file. **.header** file, which is just c code, usually contains
  - Function Declarations
  - External variable declaration
  - Macro definitions **#define**

Header file

- file. **.header** file, which is just c code, usually contains
  - Function Declarations
  - External variable declaration
  - Macro definitions **#define**

Textual replace/copy

```
#include <stdio.h>
main()
{
    int i=2;

    printf("%d\n",i);
}
```

```
extern int printf ()
extern int scanf()
extern int getchar()
extern int putchar()

#define EOF -1
….
```

Header file

cal.c

```
int x;
int y;

void func1 (void)
{
  x--;
  y++;
}
```

main.c

```
#include <stdio.h>
extern int x
extern int y;
void func1(void);

int main(){
 y = 10; x = 5;
 func1()
 printf("%d %d\n", x,y);
}
```

9 **gcc cal.c main.c**

What are printed? 4 11

9

Header file

Better way

put declarations in a .h file shared by all user files

file.h

```
extern int x
extern int y;
void func1(void);
```

cal.c

```
int x;
int y;

void func1 (void)
{
  x--;
  y++;
}
```

main.c

```
#include <stdio.h>
#include "file.h"

int main(){
 y = 10; x = 5;
 func1()
 printf("%d %d\n", x,y);

}
```

10 **gcc cal.c main.c** // gcc only .c files

10

Header file

Better way

put declarations in a .h file shared by all user files

file.h

```
extern int x
extern int y;
void func1(void);
```

cal.c

```
int x;
int y;

void func1 (void)
{
  x--;
  y++;
}
```

main.c

```
#include "file.h"
….
```

abc.c

```
#include "file.h"
..
```

def.c

```
#include "file.h"
….
```


#define

- **#define** defines macros
- Macros substitute one value for another

e.g.

```
#define IN  1
```

```
#define IN = 1 // IN -> = 1
```

```
state = IN;
```

becomes

```
state = 1;
```

#define

- Syntax `#define name value`
  - `name` called symbolic constant, conventionally written in upper case
  - `value` can be any sequence of characters

```
#define  Pi  3.1415
main() {
  int  i  = 10 + Pi;
}
```



```
main() {
   int  i = 10 + 3.1415;
}
```

```
#define SIZE 10
main() {
  int k [SIZE];
}
```

```
main() {
   int k[10];
}
```

Java: `final int SIZE = 10;`

#define -- parameterized

- Macros can also have arguments

e.g.

```
#define SQUARE(x)  x*x

y = SQUARE(4);
```

becomes

```
y = 4*4;
```

e.g., `#define MY_PRINT(x,y) printf("%d %d\n", x,y)`

```
MY_PRINT(3,5);
```

becomes

```
printf("%d %d\n", 3,5);
```

#define – Be careful with operators

```
#define TWO_PI  2*3.14
    double overpi = 1/ TWO_PI;
```

becomes

```
    double overpi = 1/2*3.14;        // 0
```

Fix: Use parentheses defensively, e.g.

```
#define TWO_PI (2*3.14)
    double overpi = 1/ TWO_PI;
```

becomes

```
    double overpi = 1/(2*3.14);      // 0.123..
```

Rule1: if replacement list contains operator, use () around whole replacement list

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#define – parameterized. Be careful with arguments

```
#define TRIPLE(x)  x * 3
    y= TRIPLE(5+2);
```

becomes

```
    y= 5+2 * 3;       // 11
```

Fix: Use parentheses defensively, e.g.

```
#define TRIPLE(x)   ((x) * 3 )
    y= TRIPLE(5+2);
```

becomes

```
    y= ((5+2) * 3);   // 21
```

Rule2: for parameterized, put () around each parameter occurrence in the replacement list

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#define – parameterized. Be careful with arguments

```
#define SQUARE(x)  x*x

      y = SQUARE(5+2);
```

becomes

```
      y = 5+2*5+2;          // 17
```

Fix: Use parentheses defensively, e.g.

```
#define SQUARE(x) ( (x)*(x) )
      y = SQUARE(5+2);
```

becomes

```
      y = ((5+2)*(5+2));    // 49
```

Rule2: for parameterized, put () around each parameter occurrence in the replacement list

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C preprocessor
predefined macro names

```
__LINE__
__FILE__
__DATE__
__TIME__
```

```
#include <stdio.h>
main(){
  printf("%s %s\n", __TIME__, __DATE__);
  printf("File: %s Line: %d\n", __FILE__,__LINE__);
}
```

```
21:45:54  May 18 2019
File: macro.c  Line:4
```

- Useful for debugging

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Playing with the C Preprocessor

- Try:

```
gcc -E hello.c
gcc -E hello.c > output.txt
```

- `-E` means “just run the preprocessor”
- Also `cpp file.c`

The previous lecture

- Pre-processing (ch4)
- Recursion (ch4)
- Other C materials before pointer
  - Common library functions [Appendix of K&R]
  - 2D array, table of strings manipulations
- Pointer basics (ch5)

Common library functions [Appendix of K+R]

<stdio.h>

```
printf()
scanf()
getchar()
putchar()

sscanf()
sprintf()

gets()  puts()
fgets()  fputs()

fprintf()
fscanf()
```

<string.h>

```
strlen(s)
strcpy(s,s)
strcat(s,s)
strcmp(s,s)
```

<math.h>

```
sin()  cos()
exp()
log()
pow()
sqrt()
ceil()
floor()
```

<stdlib.h>

```
double  atof(s)
int     atoi(s)
long    atol(s)
void    rand()
void    system()
void    exit()
int     abs(int)
```

<assert.h>

```
assert()
```

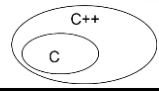
<ctype.h>

```
int islower(int)
int isupper(int)
int isdigit(int)
int isxdigit(int)
int isalpha(int)

int tolower(int)
int toupper(int)
```

<signal.h>

Included in C++ e.g., cstring.h cmath.h



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strcpy Compensate for the fact that cannot use = to copy strings

To get from another string (literal) <string.h>

```
char message[10];
strcpy(message, "This G")
```

0	1	2	3	4	5	6	7	8	9
.	.	.	.	.	.	.	.	.	.

0	1	2	3	4	5	6	7	8	9
T	h	i	s		G	\0	.	.	.

```
strlen(message)? 6   sizeof message? 10   message[3]? 's'
```

```
strcpy(message , "OK");    ?
```

0	1	2	3	4	5	6	7	8	9
O	K	\0	s		G	\0	.	.	.

```
strlen(message)? 2   sizeof message? 10   message[3]? 's'
printf("%s", message)?   OK
```

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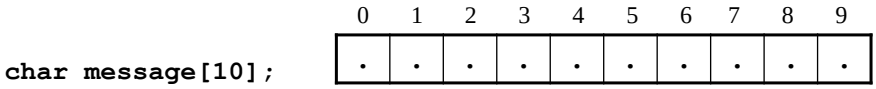
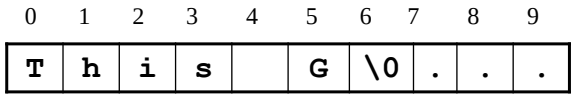
strcpy Compensate for the fact that cannot use = to copy strings
To get from another string (literal) <string.h>

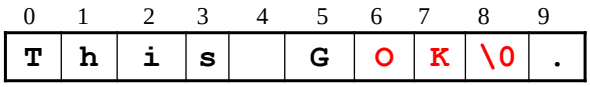



```
char message[10];
strcpy(message, "This G")
```




```
strlen(message)? 6   sizeof message? 10   message[3]? 's'
```

```
strcat(message , "OK");   ?
```




```
strlen(message)? 8   sizeof message? 10   message[3]? 's'
printf("%s", message)?   This GOK
```

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stdio library functions

- Defined in standard library, prototype in <stdio.h>

- **getchar, putchar**
- **scanf, printf**

- **gets, fgets, puts, fputs** /*read write line */

/* print to read from a string */
- **sscanf, sprintf**

- **fscanf, fprintf** (later)

- .....

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Basic I/O functions <stdio.h>

- **int printf (char *format, arg1, ….);**
  - Formats and prints arguments on standard output (screen or > outputFile)
  - **printf("This is a test %d \n", x)**
- **int scanf (char *format, arg1, ….);**
  - Formatted input from standard input (keyboard or < inputFile)
  - **scanf("%x %d", &x, &y)**

- **int sprintf (char * str, char *format, arg1,…..);**
  - Formats and prints arguments to str
  - **sprintf(str, "This is a test %d \n", x)**
- **int sscanf (char * str, char *format, arg1, ….);**
  - Formatted input from str
  - **sscanf(str, "%x %d", &x, &y)** // tokenize string str

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Char arrays: set /get in general

other ways of generating a string

- Some very import functions you might want to know

```
char message[12];  int age = 12; float wage =2.34;
```

- Defined in standard library, prototype <stdio.h>
  - `sprintf(message, "%s %d-%.1f", "Sue",age,wage);`

S	u	e		1	2	-	2	.	3	\0	

  - `sscanf(message, "%s %d-%f", name, &age, &wage);`

tokenizing the string

  - `fgets(message, 10, stdin)`
  - `fputs(message, stdout)`

`FILE * stream`

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set on the fly

```
char message[20];
```

- To get a line (with spaces) at a time:
  - `scanf(" %[^\n]s", message);`
  - `gets(message)` `fgets(message, 10, stdin)`

No &

Depreciated
Removed in C11

Read in '\n' at the end.
'H' 'e' 'l' 'l' 'o' '\n' '\0' ….

- To print a string
  - `puts(message)` `fputs(message, stdout)`

Print with '\n' at the end

Be careful the '\n'

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```
int main()
{   char str[40];
    fgets (str, 40, stdin);
    while (strcmp(str, "quit\n"))
    {
        fputs(str, stdout);
        // printf("%s",str);

        // read again
        fgets (str, 40, stdin);
     }
}
```

```
red 199 % a.out
hello the world!
hello the world!
This is good
This is good
quit
red 200 %
```

```
int main()
{
    char str[40];
    while (1)
    {
        fgets (str, 40, stdin);
        if (! strcmp(str, "quit\n"))
            break;
        fputs(str, stdout);
    }
}
```

str contains '\n'

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28

```
int main()
{   char str[40];
    scanf(" %[^\n]s", str);
    while (strcmp(str, "quit"))
    {
      puts(str);  //  \n printed
      // printf("%s\n",str);

     // read again
       scanf(" %[^\n]s", str);
     }
}
```

```
red 199 % a.out
hello the world!
hello the world!
This is good
This is good
quit
red 200 %
```

str does not contain '\n'

```
int main()
{
    char str[40];
    while (1)
    {
       scanf(" %[^\n]s", str);
       if (! strcmp(str, "quit"))
          break;
       puts(str);
    }
}
```

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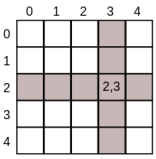

Multidimension array, array of strings

- `char messages[3][7] ={"Hello", "Hi", "There"};`
- Array of "strings"

	0	1	2	3	4	5
0	H	e	l	l	o	\0
1	H	i	\0	\0	\0	\0
2	T	h	e	r	e	\0

- Each row (e.g., message[0]) is a char array (string)
  - messages [0] "Hello"
  - messages [1] "Hi"
  - messages [2] "There"

```
printf("%s", messages[0]);
printf("%c", messages[2][1]);
scanf("%s", messages[1]);
```

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arrays: set /get in general

	0	1	2	3	4	5	6
0	H	e	l	l	o	\0	
1	H	i	\0				
2	T	h	e	r	e	\0	

- `char message[3][7];`
- `strcpy(message[0],"hello")`

Write to the first row

- `sprintf(message[1], "%s %d %.0f", "j", 1, 2.3);`

Write to the 2nd row

- `sscanf(message[1], "%s %d %f", name, &age, &wage )`

tokenizing the 2nd row

- `fgets(message[2], 7, stdin)`
- `fputs(messge[2], stdout)`

Simplified lab4D

```
printf("Enter name, age and wage: ");
scanf("%s %d %f", name, &age, &wage);

while (strcmp(name,"xxx"))
{
   sprintf(input_table[count], "%s %d %f", name, age, wage);

   age += 10;
   wage = wage *1.5;
   for(i=0; i< strlen(name); i++){
     name[i] = toupper(name[i]);  // toupper(name[i]); ✘
   }

   sprintf(input_table[count+1], "%s %d %.2f", name,age,wage);

   //read again
   count += 2;
   printf("Enter name age and wage: ");
   scanf("%s %d %f", name, &age, &wage );
}  /* end of while */
```

lab4D

```
printf("Enter name age and wage: ");
scanf("%s %s %s", name, ageS, wageS);
while(strcmp(name,"xxx")){

  /* strcat(name," "); strcat(name, ageS); strcat(name," ");
     strcat(name, wageS);  strcpy(inputs[count], name); *//

   sprintf(input_table[count], "%s %s %s", name, ageS,wageS);

   int age = atoi(ageS) + 10;
   float wage = atof(wageS) *1.5;
   for(i=0; i< strlen(name); i++){
      name[i] = toupper(name[i]);
   }

   sprintf(input_table[count+1], "%s %d %.2f", name,age,wage);

   count += 2;
   printf("Enter name age and wage: ");
   scanf("%s %s %s", name,  ageS, wageS ); // read again
}  /* end of while */
```

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lab4D2

```
name2[SIZE];

while(1)
{
  printf("Enter name age and wage: ");
  fgets(input_table[count], 50, stdin); /* read in directly.
                                           add a \n */

  sscanf(input_table[count],"%s %d %f", name, &age, &wage);

  if (strcmp(name, "xxx") == 0)  break;

  age += 10;  wage *= 1.5;
  for(i=0; i< strlen(name); i++)
     name2[i] = toupper(name[i]);
  name2[i]= '\0';  // needed!

  sprintf(input_table[count+1],"%s %d %.2f\n",name2,age,wage

  count =+ 2;

}
```

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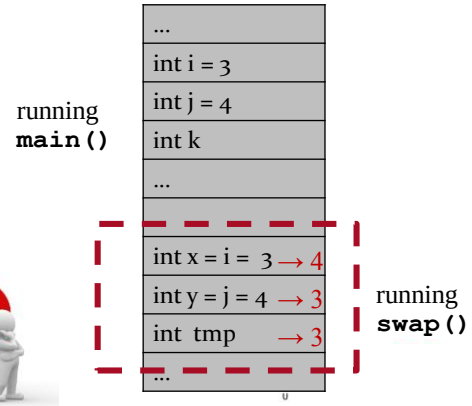
The previous lecture

- Pre-processing (ch4)
- Recursion (ch4)
- Other C materials before pointer
  - Common library functions [Appendix of K&R]
  - 2D array, table of strings manipulations
- Pointer basics (ch5)

Motivations: Calling-by-Value

- In C, all functions are **called by value**
  - Value of the arguments are passed to functions, but not the arguments themselves (i.e., not "~~call by reference~~")

```
int swap (int x, int y)
{ int tmp;
  tmp = x;
  x = y;
  y = tmp;
}
main(){
  int i=3, j=4;
  swap(i,j)
}
```



```
char [] fromStr = "Hello!";
char [20] toStr;

strcpy(toStr, fromStr);

fgets(toStr, 10, stdin);
```

- Given an array as an argument, a function can modify the contents of the array -- Arrays are passed *as if* "call-by-reference"
  - also `scanf ("%d %s", &a,  arr);`
- But isn't C "call-by-value"? -- pass single numerical value
  1) How to pass strings to `strcpy()`?
  2) How does `strcpy(),scanf(),fgets()` modify argument?

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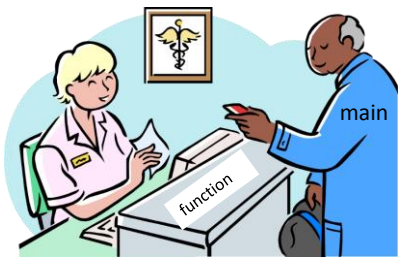

Mr. Main

Hi, function, I have some manuscripts, stored in lockers (memory), and I want you to repaint them so their color changeded.

Ms function

Hi, Mr Main, here is how we function work: We don't take your original manuscript over the counter (not pass by reference). We always photocopy things (pass by value) passed here, and work on copies.

Mr. Main

Then, is there a way to have my original manuscripts' color changed by you?

Ms function

Don't worry. Of course there is a way. Here is the way it works ….

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* & operators specifically for pointers

int * p ;

- p is a pointer variable capable of pointing to variable of type int – storing the address of a int variable

```
int * p, *q;
int  j, a[10],  * p, *q;
```

&x

- address of a variable, array element. No expression

```
p = &x;
int *p = &x;
```

```
scanf("%d %d",  &a, &b);
```

```
p = &arr[0];
```

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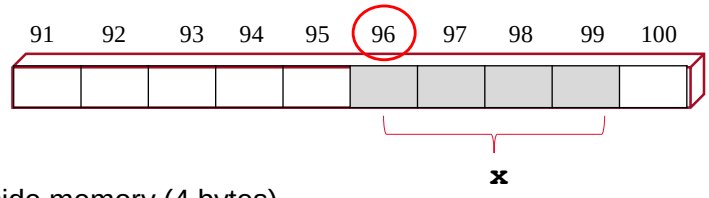
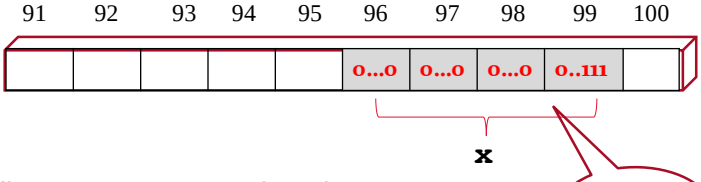


- **int x;**
  - set aside memory (4 bytes)
  - associates 96 (starting address) with **x**;



- **x = 7;**
  - Complier access memory location 96
  - Store value 7 (00….00000111 using h/l voltages)
  - Hidden from you

7

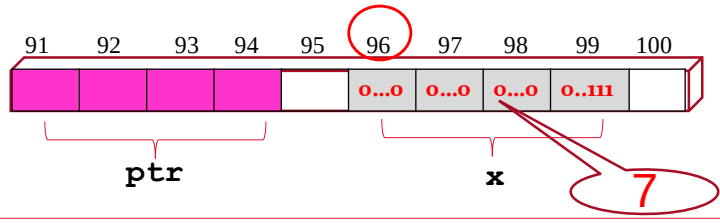
40

40

Declare and initialize pointer

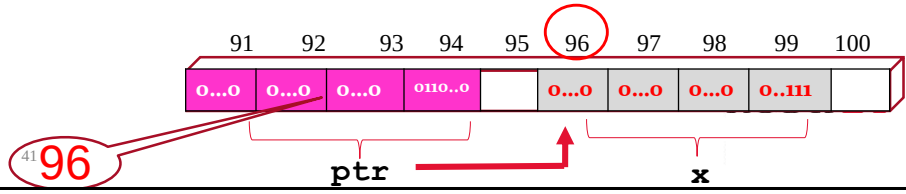
```
int * ptr;  /* declare a pointer to int  */
```

- Create a special variable that stores the address of other variable




```
ptr = &x  /* assigning address of x  */
```

- Store address of x in ptr (ptr's value is x's (starting) address 96)
- ptr now 'points to' x



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```
int * ptr;      /* I'm a pointer to an int */
```

mnemonic: "expression *ptr is an int"

```
ptr= &x;  /*I got the address of rate */
```


```
*ptr;   /* dereferencing. Indirect access. Alias of x.
           Get value of the pointee x  */
```

```
 ptr    &x   address of x
*ptr    x    content (value) of x

   printf("%d",  x );     // 7      direct access
   printf("%d", *ptr);    // 7      indirect access
```

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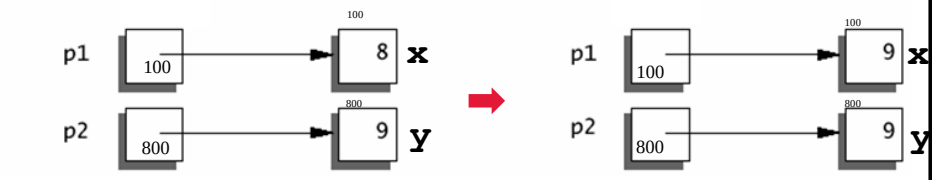
42

Some example of Pointers

```
int *p1, *p2;  int x = 8, y = 9;
p1 = &x;  p2 = &y;
*p1 = *p2;    // alias. x = y
```




```
// copy value of p2's pointee (y) into p1's pointee (x)
   *p1 is the alias of x     *p2 is the alias of y
```

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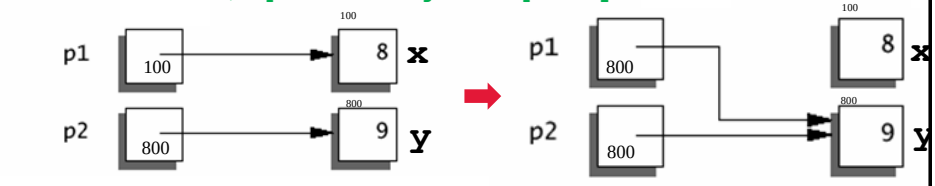
Some example of Pointers

```
int *p1, *p2;  int x = 8, y = 9;
p1 = &x;  p2 = &y;
p1 = p2;    /*copy the content of p2 (address of y) into p1 */
            /* pointer assignment. p1 = &y  */
```



Java:
```
Student s1 = new Student("John", 22);
Student s2 = s1;
```

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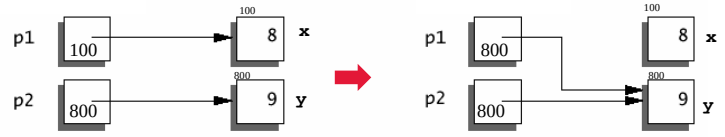
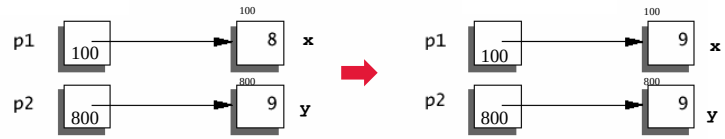
Some example of Pointers -- summary

```
int *p1, *p2, x = 8, y = 9;
p1 = &x;   p2 = &y;
```

```
p1 = p2;     // p1 = &y
```




```
*p1 = *p2;    // x = y
```



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Precedence and Associativity p53

Operator Type	Operator	
Primary Expression Operators	() [] . ->	
Unary Operators	* & + - !~ ++ -- (typecast) sizeof	
Binary Operators	* / %	arithmetic
	+ -	arithmetic
	>> <<	bitwise
	< > <= >=	relational
	== !=	relational
	&	bitwise
	^	bitwise
	|	bitwise
	&&	logical
	||	logical
Ternary Operator	?:	
Assignment Operators	= += -= *= /= %= >>= <<= &= ^= |=	
Comma	,	

```
ptr = &x;
*ptr = 5;

y= *ptr + 4

ptr= &arr[0]
```

No () needed

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++ --	Prefix increment/decrement	right-to-left
+ -	Unary plus/minus	
! ~	Logical negation/bitwise complement	
(type)	Cast (change type)	
*	Dereference	
&	Address	
sizeof	Determine size in bytes	

```
++ * ptr        * ptr;   * ptr = * ptr + 1
* ++ ptr         ptr = ptr +1;    *ptr;

(* ptr) ++     * ptr;   * ptr = * ptr + 1
* ptr ++       * ptr;   ptr = ptr +1
```

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For your information

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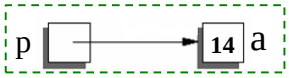
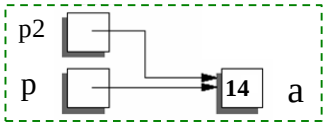
```
int main()
{
  int a = 22;
  int *p = &a;
  printf("%d %d\n", a, *p);   /* 22 22 */

  *p =  14;   // a = 14
  printf("%d %d\n", a, *p);   /* 14 14 */

  int *p2 = p; //= &a

  (*p2)--;   // *p2 = *p2 - 1;
  printf("%d %d %d\n", a, *p, *p2); // 13 13 13
  printf("%p %p %p\n", &a, p,  p2); // address
}
```





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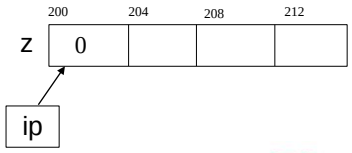
More Examples

```
int x = 1, y = 2, z[4], k;
int *ip;
ip = &x;          /* ip points to x */

y = *ip;          /* y = x   y is now 1 */
*ip = 0;          /* x is now 0, y? */

z[0] = 0;
ip = &z[0];       /* ip points to z[0] now */
for (k = 1; k < 4; k++)
   z[k] = *ip + k;

*ip += 100; // *ip = *ip + 100
            //  z[0] = z[0]+100
(*ip)++;
```



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x: 0 y: 1 z: 101 1 2 3

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Pointers K&R Ch 5

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- Pointer to structures (6.4)
- Memory allocation (extra)

today

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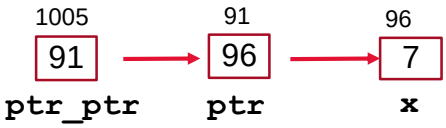
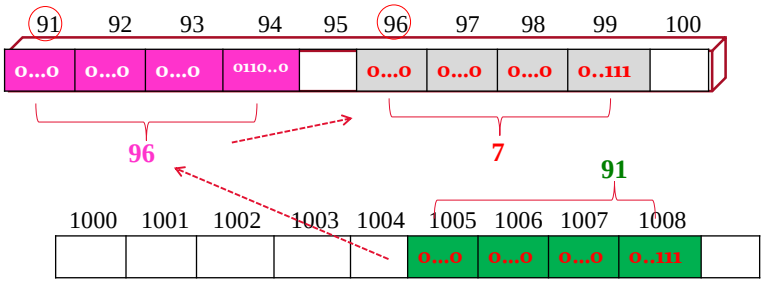
Pointer to pointers




```
int x = 7;
int * ptr = &x;
```

```
int ** ptr_ptr          // a pointer to pointer
ptr_ptr = &ptr;         // ptr_ptr value is 91
** ptr_ptr = 20;        // ** access x, set x to 20
```



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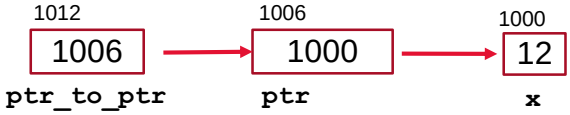
Pointer to pointers another example



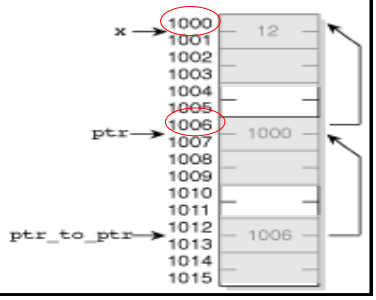

```
int x = 12;
int *ptr;
ptr = &x;
int **ptr_to_ptr          /* I am a pointer to pointer */
ptr_to_ptr = &ptr;        /* points to ptr */
**ptr_to_ptr = 20;        /* multiple indirection*/
```

valid operations

```
x, &x                *x
ptr   &ptr   *ptr    **ptr

ptr_to_ptr    &ptr_to_ptr
*ptr_to_ptr   **prt_to_ptr
```

```
**ptr_to_ptr == *ptr == x;
```



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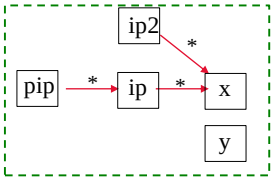
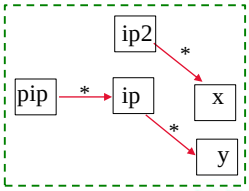
More Examples




```
int x = 1, y = 2;
int *ip, *ip2;

ip = &x;

int **pip;      // I am a pointer to pointer
pip = &ip;      // pip points to pointer ip

y = **pip;     // y=x  y is 1 now
(**pip)--;    // x is 0

ip2 = ip;
*ip2 += 10;  // *ip2=*ip2+10  x=x+10=10

ip = &y;
(**pip)--;  // y = y-1       y is 0 */

printf("%d %d\n", x,  y);    10  0

ip2 = pip; ???  Not valid! Type must match
pip = ip2; ???  Not valid! Type must match
```



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Pointers K&R Ch 5

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today

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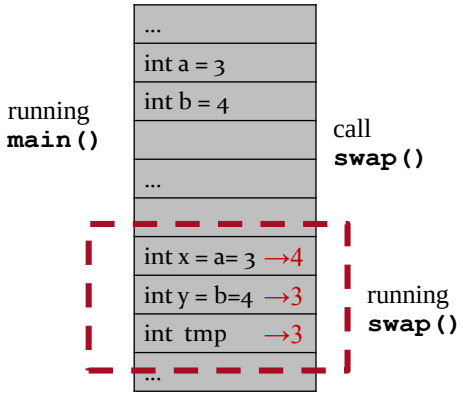
Calling by Value

- In C, all functions are **called by value**
  - Value of the arguments are passed to functions, but not the arguments themselves (i.e., not ~~call by reference~~)

```
int swap (int x, int y)
{
  int tmp;
  tmp = x;
  x = y;
  y = tmp;
}
main(){
  int a=3, b=4;
  swap(a,b);
}
```



Pointers and function arguments

- In C, all functions are **called by value**
  - Value of the arguments are passed to functions, but not the arguments themselves (i.e., not ~~call by reference~~)
  - How to modify the arguments? increment() swap()
  - How to pass a structure such as array?

- Modify an actual argument by passing its address/pointer
  - Possibly modify passed arguments via their address
  - Efficient.

Mr. Main

Hi, function, I have some manuscripts, stored in lockers (memory), and I want you to repaint them so their color changed.

Ms function

Hi, Mr Main, here is how we function work:
We don't take your original manuscript over the counter (not pass by reference). We always photocopy things (pass by value) passed here, and work on copies.

Mr. Main

Then, is there a way to have my original manuscripts' color swapped?

Ms function

Write down the locker number (address) on a paper, bring that paper to us (pass pointer/address) .
We photocopy the paper (still pass by value),
Then, based on the locker number on the copy, we go to your locker, fetch your original manuscripts there and work on them!

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An example. Not working.

```
void increment(int x, int y)
{

  x ++;
  y += 10;
}

void main( ) {
  int a=2, b=40;

  increment( a, b);
  printf("%d %d", a, b);
}
```

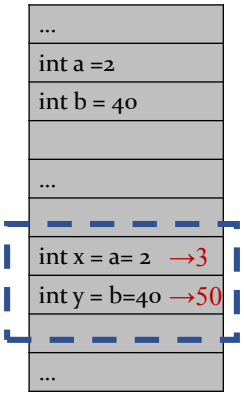
Pass by value !!!

x = a

y = b

2 40

running **main()**



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The Correct Version

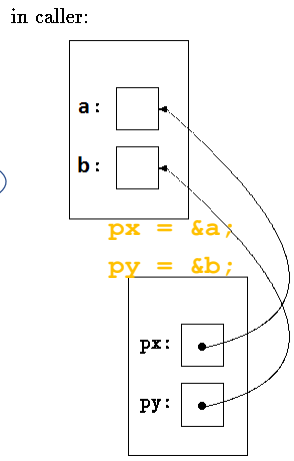
I am expecting int pointers

```
void increment(int *px, int *py)
{
   (*px) ++;  // *px is a

   *py += 10; // *py is b
}

void main( ) {
   int a=2, b=40;

   increment(&a, &b);
   printf("%d %d", a, b);
}
```

px = &a

py = &b

Pass by value !!!



3 50

59

The Correct Version

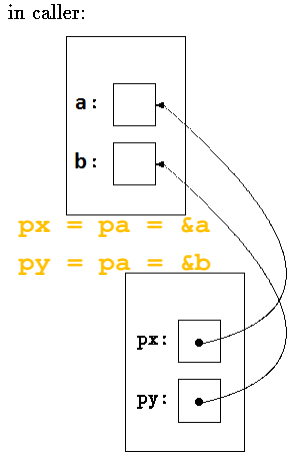
I am expecting int pointers

```
void increment(int *px, int *py)
{
   (*px) ++;

   *py += 10;
}

void main( ) {
   int a=2, b=40;
   int *pa=&a;  int *pb=&b;
   increment(pa, pb);
   printf("%d %d", a, b);
}
```

px = pa = &a

py = pa = &b

Pass by value !!!



3 50

60

The Correct Version

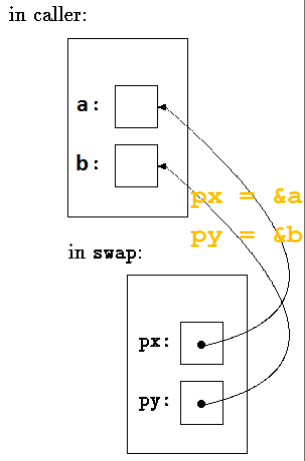
I am expecting int pointers

```
void swap(int *px, int *py)
{
   int tmp;
   tmp = *px;
   *px = *py;
   *py = tmp;
}

void main( ) {
    int a=2, b=40;

    swap(&a, &b);

    printf("%d %d", a, b);
}
```

Pass by value !!!

```
px = &a;
py = &b
```

Pass address/pointer



The Correct Version

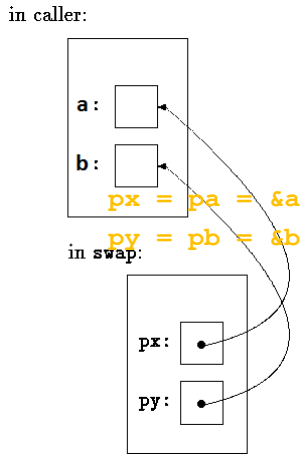
I am expecting int pointers

```
void swap(int *px, int *py)
{
   int tmp;
   tmp = *px;
   *px = *py;
   *py = tmp;
}

void main( ) {
    int a=2, b=40;
    int *pa = &a;
    int *pb = &b;
    swap(pa,pb);

}
```

Pass by value !!!

```
px = pa = &a;
py = pb  = &b
```

Pass address/pointer, another way

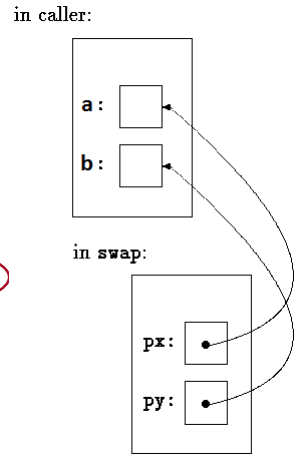


Another example

```
void increment(int *px2, int *py2)
{
      (*px2) ++;
      (*py2) += 10;
}
```

```
void swapIncre(int *px, int *py)
{
   int tmp;
   tmp = *px;
   *px = *py;
   *py = tmp;
   increment(?, ?);
}

void main( ) {
    int a=2, b=40;

    swapIncre(&a, &b);
    printf("%d %d", a, b);
}
```

increment(px, py)



63 41 12

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Now understand scanf() -- more or less

```
int x=1;  int y = 2;
swap(&x,&y);  increment(&x,&y);
```

```
int x;
scanf ("%d", &x);
printf("%d", x);

int x;
int *px = &x;
scanf("%d", px);
printf("%d",*px);
```

But why array name is used directly

```
scanf ("%d %s", &x, arrName)
fgets (arrName, 5,stdin);
```

explain shortly

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Pointers K&R Ch 5

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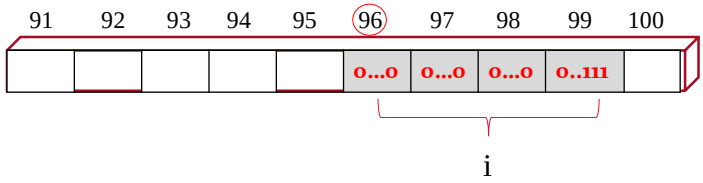
Pointers and variable type base type is important!

```
int i = 7, y; int *pi;
pi = &i;  // ip store 96, pointing to i
y = *pi;  // how many bytes to transfer? y = 7
```



- Each pointer stores the address of the first byte of its pointee
- How many bytes to transfer? -- Base type is important!

```
int i; char c; short sh;
int* pi; char *pc; short *psh;
```

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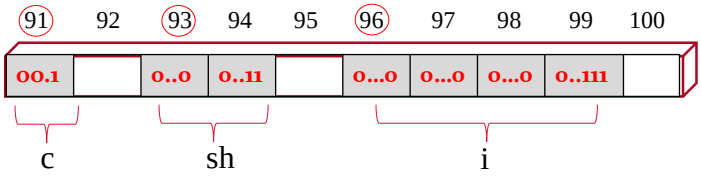
Pointers and variable type
base type is important!




```
char *pc=&c;//91   short *psh=&sh;//93    int* pi = &i;//96
```

- Each pointer store the address of the first byte of its pointee
- How many bytes to transfer?
- Base type is important! Allowing proper read/write.

```
c = *pc;   *pc='d';      r/w 1 byte  from 91
s = *psh;  *psh=2;       r/w 2 bytes from 93 [93, 94]
y = *pi;   *pi = 100;    r/w 4 bytes from 96 [96,97,98,99]
```

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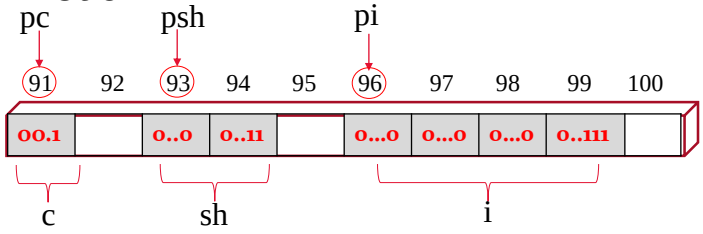
Pointer arithmetic



- Limited math on a pointer
- Four arithmetic operators that can be applied

  + - ++ --

  Result is a pointer (address)

```
int* pi=&i;//96 char* pc=&c;//91   short* psh=&sh;//93

pi + 1?   97?
psh + 2?  95?
pi++?  pc++?  psh++?
```

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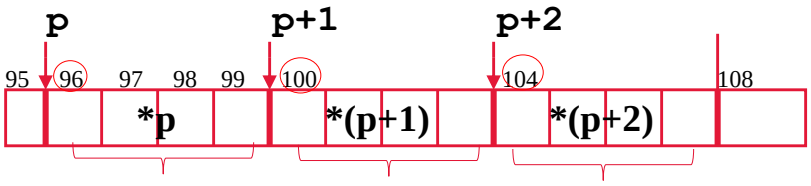
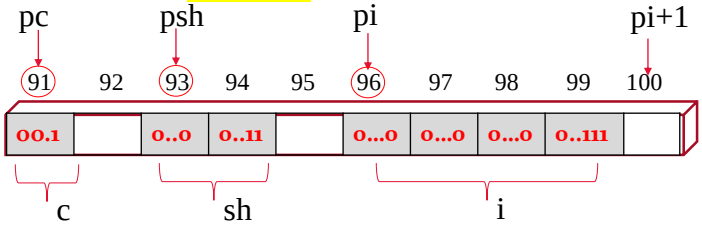
Pointer arithmetic – scaled

- Incrementing / decrementing a pointer by *n* moves it *n* units bytes p ± *n* ➔ p ± *n* × unit byte
  - value of a "unit" is based upon the size of the type
  - If p points to an integer (4 bytes), value of unit is 4
    p + n advances by n*4 bytes:
    p + 1 = 96 + 1*4 = 100 p + 2 = 96 + 2*4 = 104



- Why would we need to move pointer? p+1; p++
- Why designed this way? *"p+1 is p+4"*

Pointer arithmetic -- scaled




```
int* pi=&i;//96 char *pc=&c;//91 short* psh=&sh;//93
```

`pi + 1?` address 96+ 1*4 =100

`pi + 2?` address 96+ 2*4 =104

`psh +1?` address 93+ 1*2 =95

`psh +2?` address 93+ 2*2 =97

`pi` ++? `pc`++? `psh`++?

`pi = 96 + 4` `pc = 91 + 1` `psh = 93 + 2`

arithmetic2019.c

```
main(){
int a; short b; char c; double d;
int * pInt   = &a;
short * pShort = &b;
char * pChar = &c;
double * pDouble = &d;

printf("char  short  int  double\n");
printf("p:%p  %p  %p  %p\n", pChar, pShort,pInt, pDouble);

pInt++; pShort++; pChar ++; pDouble++;
printf("p++:%p  %p  %p  %p\n", pChar, pShort,pInt, pDouble);

pInt++; pShort++; pChar ++; pDouble++;
printf("p++:%p  %p  %p  %p\n", pChar, pShort,pInt, pDouble);

pInt += 4;  pShort += 4; pChar += 4; pDouble +=4;
printf("p+=4:%p  %p  %p  %p\n", pChar, pShort,pInt, pDouble);
```

```
indigo 305 % a.out
        char *          short *         int *           double *
p:      0x7ffe58856389  0x7ffe5885638a  0x7ffe5885638c  0x7ffe58856380
p++:    0x7ffe5885638a  0x7ffe5885638c  0x7ffe58856390  0x7ffe58856388
p++:    0x7ffe5885638b  0x7ffe5885638e  0x7ffe58856394  0x7ffe58856390
p+=4:   0x7ffe5885638f  0x7ffe58856396  0x7ffe588563a4  0x7ffe588563b0
p-=2:   0x7ffe5885638d  0x7ffe58856392  0x7ffe5885639c  0x7ffe588563a0
indigo 306 %
```

+1n +2n +4n +8n

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- Pointer to functions (5.11)
- Pointer to structures (6.4)
- Memory allocation (extra)

today

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Pointers K&R Ch 5

- Basics: Declaration and assignment (5.1)
- Pointer to Pointer (5.6)
- Pointer and functions (5.2) -- pass pointer by value
- Pointer arithmetic (5.4) + - ++ -- "*p+1 is p+4*"

- **Pointers and arrays (5.3)**
  - Arrays are stored consecutively
  - Pointer to array elements p + i = &a[i] *(p+i) = a[i]
  - Array name contains address of 1st element a = &a[0]
  - Pointer arithmetic on array (extension)
  - Array as function argument – "decay"
  - Pass sub_array

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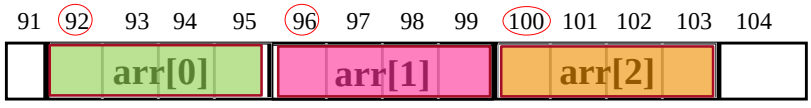
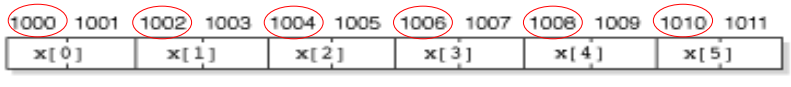
Pointers and Arrays (5.3)

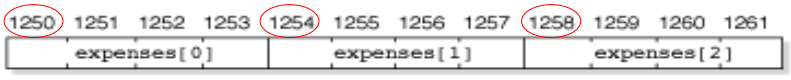
- Array members are next to each other in memory
  - `arr[0]` always occupies in the lowest address
  - e.g. `int arr[3];`



short x[6];



float expenses[3];



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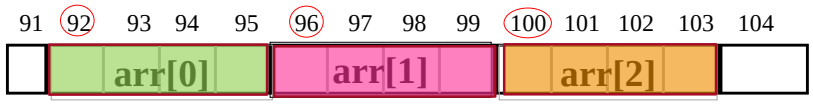

arrayElementSize2019.c

```
int i[10], x;
float f[10];
double d[10];
char c[10];

main()
{

    /* Print the addresses of each array element. */
    printf("\n================================");

    for (x = 0; x < 10; x++)
        printf("\nElement [%d]: %p  %p %p %p", x, &c[x], &i[x],&f[x], &d[x]);

    printf("\n================================");
```

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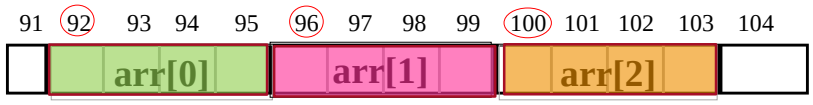
- Array members are next to each other in memory
  - **`arr[0]`** always occupies in the lowest address




```
indigo 307 % a.out
                char[]          int[]           float[]         double[]
================================================================================
Element [0]:    0x600b88        0x600ba0        0x600b60        0x600b00
Element [1]:    0x600b89        0x600ba4        0x600b64        0x600b08
Element [2]:    0x600b8a        0x600ba8        0x600b68        0x600b10
Element [3]:    0x600b8b        0x600bac        0x600b6c        0x600b18
Element [4]:    0x600b8c        0x600bb0        0x600b70        0x600b20
Element [5]:    0x600b8d        0x600bb4        0x600b74        0x600b28
Element [6]:    0x600b8e        0x600bb8        0x600b78        0x600b30
Element [7]:    0x600b8f        0x600bbc        0x600b7c        0x600b38
Element [8]:    0x600b90        0x600bc0        0x600b80        0x600b40
Element [9]:    0x600b91        0x600bc4        0x600b84        0x600b48
================================================================================
indigo 308 %
```

76 + 1 + 4 + 4 + 8

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Pointers K&R Ch 5

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- Pointer to Pointer
- Pointer and functions (pass pointer by value)
- Pointer arithmetic +- ++ --

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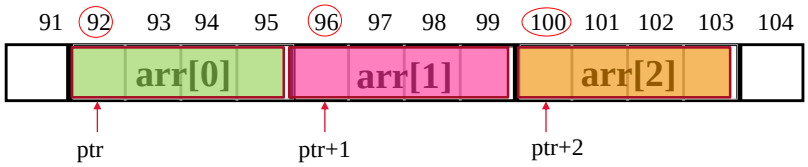
Pointers and Arrays (5.3)

- Array members are next to each other in memory
  - arr [0] always occupies in the lowest address




```
int arr[3]; int *ptr;
ptr = &arr[0];  // 92

ptr + 1 ?       // 92+1*4= 96 == &arr[1]
ptr + 2 ?       // 92+2*4= 100 == &arr[2]
*(ptr +2 ) ?    // *&arr[2] → access arr[2]
```

```
ptr + i    == & arr[i]
*(ptr + i) == arr[i]
```

Pointers K&R Ch 5

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Pointers and Arrays (5.3)

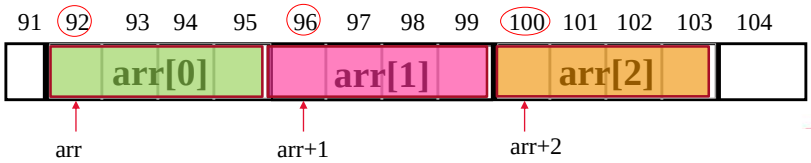
- There is special relationship between pointers and arrays
- When you use array, you are using pointers!

```
int i, arr[20], char c;
scanf("%d  %c  %s", &i, &c, arr); /* &arr is wrong */
```

- Identifier (name) of an array is equivalent to the address of its 1st element. **`arr == &arr[0]`**

```
arr + 1 == address of next element == &arr[1]

*(arr + 2) == *(&arr[2]) == arr[2]
```



80 Array name can be used as a pointer. Follow pointer arithmetic!

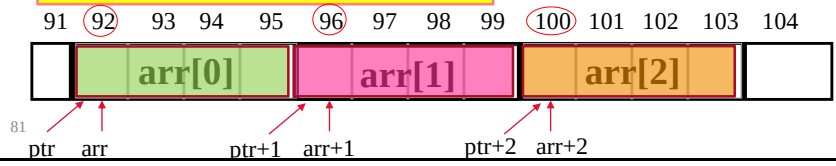
Pointers and Arrays (5.3)

- There is special relationship between pointers and arrays
- Identifier (name) of an array is equivalent to the address of its 1st element. `arr == &arr[0]`

```
*arr == *(&arr[0]) == arr[0]
arr + i == &arr[i]
*(arr + 2) == *(&arr[2]) == arr[2]
```

```
int arr[3];
int * ptr;
ptr = arr;    // ptr = &arr[0]   92
```

```
ptr + i == &arr[i]
*(ptr + i) == arr[i]
```



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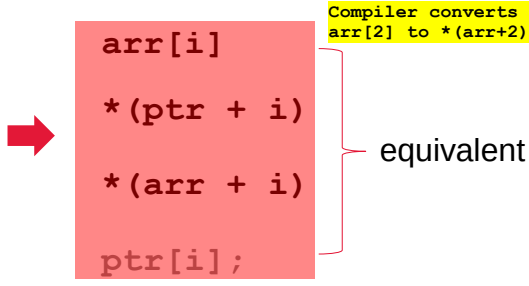
Pointers and Arrays (5.3)

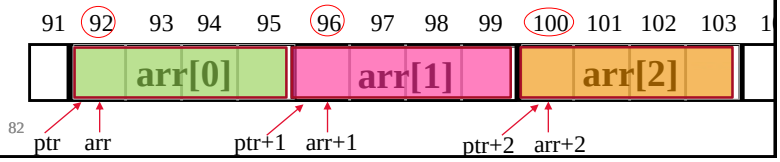
`arr` can be used as a pointer

- Identifier (name) of an array is equivalent to the address of its 1st element. `arr == &arr[0]`

```
int arr[3]; int * p;
ptr = arr;   /*   ptr = &arr[0]   */
```

```
arr+i == &arr[i]
ptr+i == &arr[i]
```





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arrayAddressPPP.c

```
/* Demonstrates use of pointer arithmetic in array*/
main() {
 int arr[10] = {0,10,20,30,40,50,60,70,80,90}, i;
 int *ptr = arr;    /* = &arr[0] */

 printf("%p %p", arr, ptr);

/* Print the addresses of each array element. */
 for (i = 0; i < 10; i++)
   printf("%p %p %p", &arr[i], arr+i, ptr+i);

/* Print the content of each array element. */
 for (i = 0; i < 10; i++)
   printf("%d %d %d  %d",arr[i],*(arr+i),*(ptr+i),ptr[i]);

 return 0;
}
```

Different ways of accessing array elements


```
indigo 330 % a.out
arr: 0x600ba0     ptr:0x600ba0

                &arr[i]         arr+i           ptr+i
=====================================================
Element 0:      0x600ba0        0x600ba0        0x600ba0
Element 1:      0x600ba4        0x600ba4        0x600ba4
Element 2:      0x600ba8        0x600ba8        0x600ba8
Element 3:      0x600bac        0x600bac        0x600bac
Element 4:      0x600bb0        0x600bb0        0x600bb0
Element 5:      0x600bb4        0x600bb4        0x600bb4
Element 6:      0x600bb8        0x600bb8        0x600bb8
Element 7:      0x600bbc        0x600bbc        0x600bbc
Element 8:      0x600bc0        0x600bc0        0x600bc0
Element 9:      0x600bc4        0x600bc4        0x600bc4
=====================================================

                arr[i]          *(arr+i)        *(ptr+i)        ptr[i]
Element 0:      0               0               0               0
Element 1:      10              10              10              10
Element 2:      20              20              20              20
Element 3:      30              30              30              30
Element 4:      40              40              40              40
Element 5:      50              50              50              50
Element 6:      60              60              60              60
Element 7:      70              70              70              70
Element 8:      80              80              80              80
Element 9:      90              90              90              90
=====================================================
indigo 331 %
```

arr == &arr[0]

+ 4

Another way ++

```
/* Demonstrates use of pointer arithmetic in array */
main() {
 int arr[10] = {0,10,20,30,40,50,60,70,80,90}, i;
 int *ptr = arr;          // = &arr[0]

/* Print the addresses of each array element. */
  for (i = 0; i < 10; i++){
    printf("%p %p %p", &arr[i], arr+i, ptr);
    ptr++; // advance 4 bytes, pointing to next element
  }
  ptr = arr;  // reset to point to arr[0]

  /* Print the content of each array element. */
  for (i = 0; i < 10; i++){
    printf("%d %d %d", arr[i], *(arr+i), *ptr);
    ptr++; // advance 4 bytes, pointing to next element
  }
 return 0;
}
```

arr++ ???

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Attention: Array name can be used as a pointer, but is not a pointer variable!

```
int arr[20];
int * p = arr;
```

- **p** and **arr** are equivalent in that they have the same properties: **&arr[0]**
- Difference: **p** is a pointer variable, **arr** is a pointer constant
  - we could assign another value to the pointer **p**
  - **arr** will always point to the first of the 20 integer numbers of type int. Cannot change **arr** (point to somewhere else)

```
p = arr;   /*valid*/        arr = p;  /*invalid*/
p++;       /*valid*/        arr++;    /*invalid*/
```

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```
char arr[10] = "hello";  int i;
char * p;
p = arr;        // p=&arr[0]

arr = p;        /*invalid*/
arr = &i;       /*invalid*/      p = arr+2;      /*valid*/
arr = arr +1;   /*invalid*/      *(arr + 1)=5;   /*valid*/
arr++;          /*invalid*/      c = *(arr+2);   /*valid*/

p++;            /*valid*/
p = &i;         /*valid.  now points to others*/
```

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Pointers K&R Ch 5

- Basics: Declaration and assignment
- Pointer to Pointer
- Pointer and functions (pass pointer by value)
- Pointer arithmetic +- ++ --
- Pointers and arrays (5.3)
  - Stored consecutively
  - Pointer to array elements p + i = &a[i] *(p+i) = a[i]
  - Array name contains address of 1st element a = &a[0]
  - Pointer arithmetic on array (extension) p1-p2 p1<>!= p2
  - Array as function argument – "decay"
  - Pass sub_array
- Array of pointers
- Command line argument
- Pointer to arrays and two dimensional arrays
- Pointer to functions
- Pointer to structures
- Memory allocation

today

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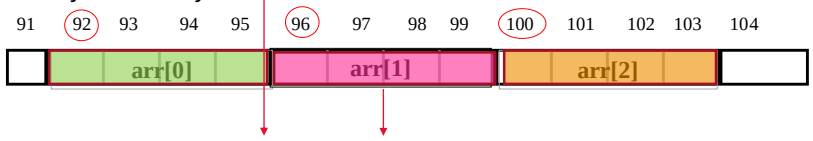
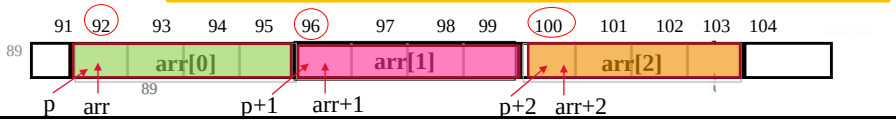
Summary

- Pointer arithmetic: If p points to an integer of 4 bytes, p + n advances by 4*n bytes: p + 1 = 96 + 1*4 = 100 p + 2 = 96 + 2*4 = 104
- Array in memory:



- Suppose `p` points to array element `k`, then `p+1` points to `k+1` (next) element. `p + i` points to `arr[k+i]`.
  - `p = &arr[k]:  p + i == &arr[k+i]  → *(p+i) == arr[k+i]`
  - `k=0: p=&arr[0]:  p + i == &arr[i]  → *(p+i) == arr[i]`
- **Array name contains pointer to 1st element** `arr==&arr[0]`
  - `arr==&arr[0]:  arr+i == &arr[i]  → *(arr+i) == arr[i]`

`p = arr:  p + i == &arr[i]  →  *(p+i) == arr[i]`



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Summary

`arr` can be used as a pointer

- Identifier (name) of an array is equivalent to the address of its 1st element. **`arr == &arr[0]`**

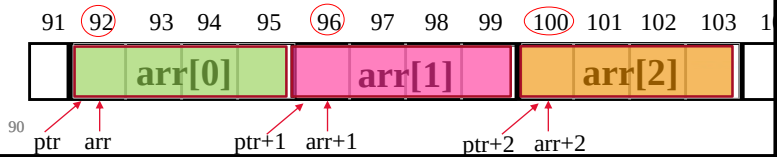
```
int arr[3]; int * p;
ptr = arr;   /*   ptr = &arr[0]   */
```

`arr+i == &arr[i]`
`ptr+i == &arr[i]`

`arr[i]`
`*(ptr + i)`
`*(arr + i)`
`ptr[i];`

equivalent

`Compiler convert arr[2] to *(arr+2)`



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Suppose flag's representation is
000 ….0011111111

- **flags = flags & (1<<3)**

What is flag's representation?

00001000. keep 3rd bit, turn off all others **000…00001000**

- **flags = flags & ~(1<< 3)**

What is flag's representation?

00001000 → 11110111. Turn 3rd bit off (set to 0), others no change **000 ….11110111**