Recap: Anatomy of a Typical C Program

```
#preprocessor directives

declarations
  variables
  functions

int main (void){
   declarations;
   statements;
   return value;
}
```

Your First C Program

hello.c

```
/* Welcome to BBM 101 */

#include <stdio.h>


int main(void)
{
     printf(“Hello world!\n”);
     return 0;
}
```

```
Hello world!
```

Your First C Program

hello.c

```
/* Welcome to BBM 101 */

#include <stdio.h>


int main(void)
{
     printf(“Hello world!\n”);
     return 0;
}
```

/* comments */

global declarations
#include external files

main function

```
Hello world!
```

Your First C Program

hello.c

```
/* Welcome to BBM 101 */

#include <stdio.h>

int main(void)
{
     printf(“Hello world!\n”);
     return 0;
}
```

```
Hello world!
```

Text surrounded by **/*** and ***/** is ignored by computer

/* comments */

global declarations
#include external files

main function

Your First C Program

hello.c

```
/* Welcome to BBM 101 */

#include <stdio.h>

int main(void)
{
     printf("Hello world!\n");
     return 0;
}
```

```
Hello world!
```

/* comments */

global declarations

#include external files

"stdio.h" allows standard input/output operations

main function

Your First C Program

hello.c

```
/* Welcome to BBM 101 */

#include <stdio.h>

int main(void)
{
    printf(“Hello world!\n”);
    return 0;
}
```

/* comments */

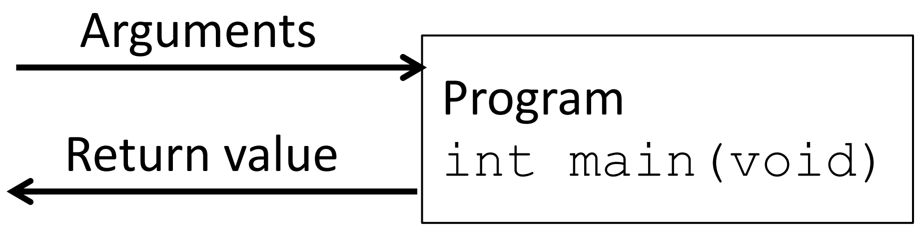
global declarations
\#include external files

main function

C programs contain one or more functions, exactly one of which must be **main**

```
Hello world!
```

The `main(void)` of `hello.c`

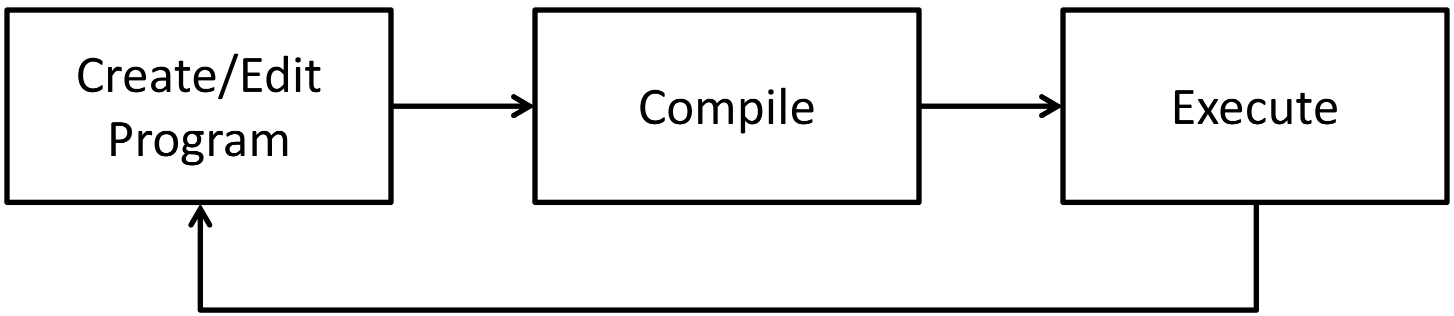



```
int main(void)
        {
                printf("Hello world!\n");
                return 0;
        }
```

return "0" to OS:
"everything is OK"

- No **arguments**.
- Returns an integer **variable**.

The Programming Process



"The cycle ends once the programmer is satisfied with the program, e.g., performance and correctness-wise."

C Statements

- One-line commands
- Always end in semicolon **;**
- Examples:
  - call function: `printf("hello"); /* from stdio */`
  - declare **variable**: `int x;`
  - assign variable value: `x = 123+456;`

Identifiers

- A sequence of letters, digits, and the underscore character ‘_’ satisfying
  - identifier = c { c | d }*
  - with c = {‘A’,…, ‘Z’, ‘a’,…, ‘z’, ‘_’ }, d = {0,…,9}, and asterisk “*” means “0 or more”
- Case-sensitive
  - e.g., *first**N**ame* and *first**n**ame* are two different identifiers.
- Identifiers are used for
  - Variable names
  - Function names
  - Macro names

Identifier Examples

- Valid identifiers
  - X
  - a1
  - _xyz_33
  - integer1
  - Double
- Invalid identifiers
  - xyz.1
  - gx^2
  - 114West
  - int ← This is a keyword
  - pi*r*r

Basic Data Types

- Integer (**int**)
- Character (**char**)
- Floating Point (**float**)
- Double Precision Floating Point (**double**)

- Data Type Modifiers
  - **signed** / **unsigned**
  - **short** / **long**

This week

- **Pointers**
  - Pointer Variable Declarations and Initialization
  - Pointer Operators
  - Pointers to void
  - Calling Functions by Reference
  - Passing parameters by reference
  - `sizeof` function
  - Dynamic Memory Management
  - Pointer Arithmetic
  - Pointers and Arrays
  - Pointers to Functions

Variables Revisited

- What actually happens when we declare variables?

```
char a;
```

- C reserves a byte in memory to store **`a`**.
- Where is that memory? At an **address**.
- Under the hood, C has been keeping track of variables and their addresses.

Slide credit: B. Huang

Pointers

- We can work with memory addresses too. We can use variables called **pointers**.
- A **pointer** is a variable that contains the address of a variable.
- Pointers provide a powerful and flexible method for manipulating data in your programs; but they are difficult to master.

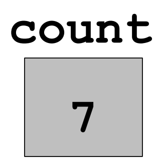
– Close relationship with arrays and strings

Benefits of Pointers

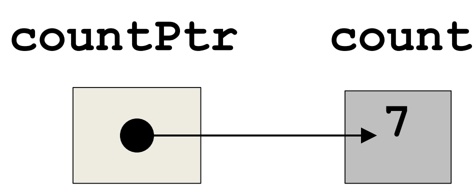
- Pointers allow you to reference a large data structure in a compact way.
- Pointers facilitate sharing data between different parts of a program.
  - Call-by-Reference
- **Dynamic memory allocation:** Pointers make it possible to reserve new memory during program execution.

Pointer Variable Declarations and Initialization

- Pointer variables
  - Contain memory addresses as their values
  - Normal variables contain a specific value (direct reference)



  - Pointers contain address of a variable that has a specific value (indirect reference)
  - Indirection – referencing a pointer value



Pointer Variable Declarations and Initialization

- Pointer declarations
  - The syntax for pointer declaration is as follows:
    *type *identifier;*
    e.g. `int *myPtr;`
  - Declares a pointer to an **`int`** (pointer of type **`int *`**)
  - Multiple pointers require using a ***** before each variable declaration

```
int *myPtr1, *myPtr2;
```

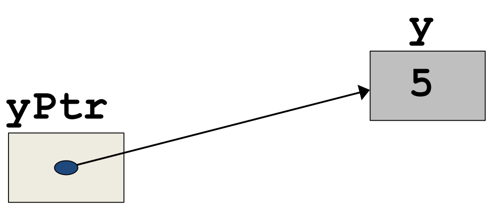
  - Can declare pointers to any data type
  - Initialize pointers to **`0`**, **`NULL`**, or an address
    - **`0`** or **`NULL`** – points to nothing (**`NULL`** preferred)

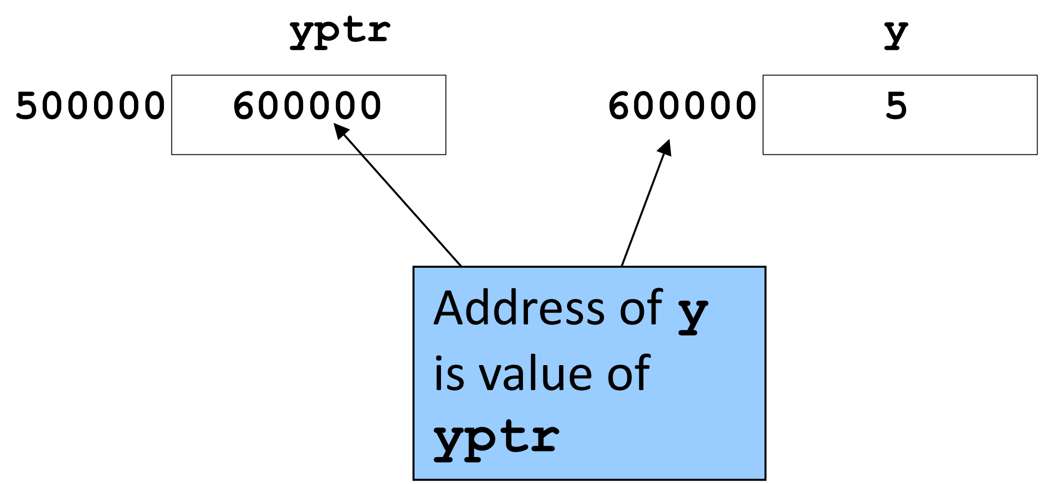
Pointer Operators

- **`&`** (address operator)
  - Returns the address of operand

```
int y = 5;
int *yPtr;
yPtr = &y;        // yPtr gets address of y
```

  - **`yPtr` “points to” `y`**





Pointer Operators

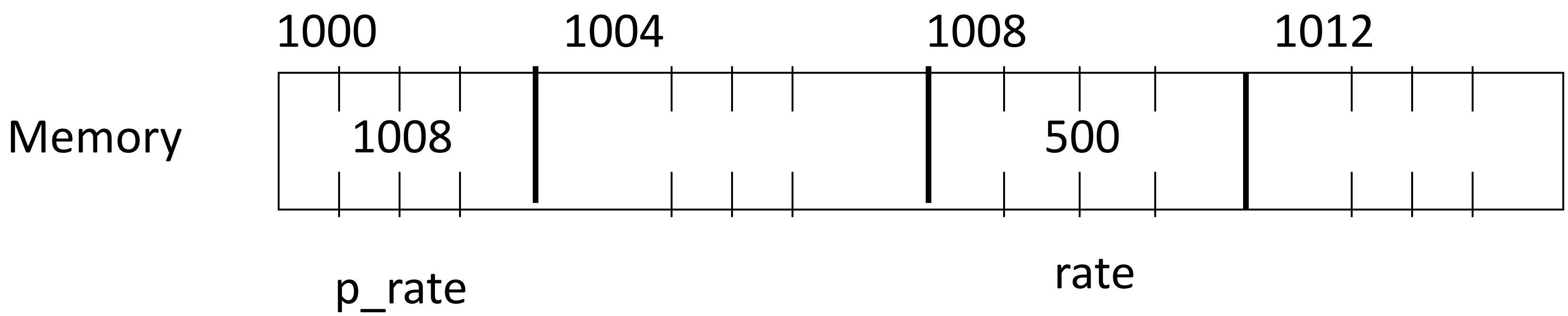
- `*` (indirection/dereferencing operator)
  - Returns a synonym/alias of what its operand points to
  - `*yptr` returns `y` (because `yptr` points to `y`)
  - `*` can be used for assignment
    - Returns alias to an object

```
*yptr = 7;  // changes y to 7
```

  - Dereferenced pointer (operand of *) must be an *lvalue* (no constants)

- `*` and `&` are inverses
  - They cancel each other out

```
int rate;
int *p_rate;

rate = 500;
p_rate = &rate;
```




```
/* Print the values */
printf("rate = %d\n", rate);    /* direct access */
printf("rate = %d\n", *p_rate); /* indirect access */
```

```c
/* Using the & and * operators */

#include <stdio.h>

int main()
{
   int a;          /* a is an integer */
   int *aPtr;      /* aPtr is a pointer to an integer */

   a = 7;
   aPtr = &a;      /* aPtr set to address of a */

   printf( "The address of a is %p\nThe value of aPtr is %p", &a, aPtr );


   printf( "\n\nThe value of a is %d\nThe value of *aPtr is %d", a, *aPtr );


   printf( "\n\nShowing that * and & are inverses of
           each other.\n&*aPtr = %p\n*&aPtr = %p\n", &*aPtr, *&aPtr );



   return 0;
}
```

The address of **a** is the value of **aPtr.**

The ***** operator returns an alias to what its operand points to. **aPtr** points to **a**, so ***aPtr** returns **a**.

Notice how ***** and **&** are inverses

Program Output

```
The address of a is 0012FF88
The value of aPtr is 0012FF88

The value of a is 7
The value of *aPtr is 7
Showing that * and & are inverses of each other.
&*aPtr = 0012FF88
*&aPtr = 0012FF88
```

Operator Precedences – Revisited

Operators								Associativity	Type
()	[]							left to right	highest
+	-	++	--	!	*	&	(type)	right to left	unary
*	/	%						left to right	multiplicative
+	-							left to right	additive
<	<=	>	>=					left to right	relational
==	!=							left to right	equality
&&								left to right	logical and
||								left to right	logical or
?:								right to left	conditional
=	+=	-=	*=	/=	%=			right to left	assignment
,								left to right	comma

Addressing and Dereferencing

```
int a, b, *p;

a = b = 7;
p = &a;
printf("*p = %d\n",*p);

*p = 3;
printf("a = %d\n",a);

p = &b;
*p = 2 * *p - a;
printf("b = %d \n", b);
```

Program Output

```
*p = 7
a = 3
b = 11
```

Addressing and Dereferencing

```
float x, y, *p;

x = 5;
y = 7;
p = &x;
y = *p;
```

Thus,

```
y = *p;
y = *&x;
y = x;
```

All equivalent

Addressing and Dereferencing

Declarations and initializations		
`int k=3, j=5, *p = &k, *q = &j, *r;`		
`double x;`		
Expression	**Equivalent Expression**	**Value**
`p == &k`	`p == (&k)`	1
`p = k + 7`	`p = (k + 7)`	illegal
`* * &p`	`* ( * (&p))`	3
`r = &x`	`r = (& x)`	illegal
`7 * * p/ *q +7`	`(( (7 * (*p) )) / (*q)) + 7`	11
`* (r = &j) *= *p`	`( * (r = (&j))) *= (*p)`	15

Pointers to `void`

- `void *identifier;`
- In C, **`void`** represents the absence of type.
- **`void`** pointers are pointers that point to a value that has no specific type.
- This allows void pointers to point to any data type.
- The data pointed by void pointers cannot be directly dereferenced.
- We have to use explicit type casting before dereferencing it.

Pointers to `void`

```
int x = 4;
void *q = &x;
int *p = q;
int i = *p;
int j = *(int*)q;
```

Declarations	
`int *p;`	
`float *q;`	
`void *v;`	
Legal assignments	**Illegal assignments**
`p = 0;`	`p = 1;`
`p = (int *) 1;`	`v = 1;`
`p = v = q;`	`p = q;`
`p = (int *) q;`	

Calling Functions by Reference

- Call by reference with pointer arguments
  - Pass address of argument using **&** operator
  - Allows you to change actual location in memory
  - Arrays are not passed with & because the array name is already a pointer
- * operator
  - Used as alias/nickname for variable inside of function

```
void double_it( int *number )
 {
    *number = 2 * ( *number );
 }
```

  - **`*number`** used as nickname for the variable passed

Passing parameters by reference

```
void SetToZero (int var)
{
   var = 0;
}
```

- You would make the following call:

```
SetToZero(x);
```

- This function has no effect whatever. Instead, pass a pointer:

```
void SetToZero (int *ip)
{
   *ip = 0;
}
```

You would make the following call:

```
SetToZero(&x);
```

This is referred to as ***call-by-reference*.**

```c
/* An example using call-by-reference */
#include <stdio.h>

void change_arg(int *y);

int main (void)
{
     int x = 5;

     change_arg(&x);
     printf("%d \n", x);
     return 0;
}

void change_arg(int *y)
{
     *y = *y + 2;
}
```

```c
/* Cube a variable using call-by-reference
   with a pointer argument */

#include <stdio.h>

void cubeByReference( int * );    /* prototype */

 int main()
 {
    int number = 5;

    printf( "The original value of number is %d", number );
    cubeByReference( &number );
    printf( "\nThe new value of number is %d\n", number );

    return 0;
 }

 void cubeByReference( int *nPtr )
 {
 *nPtr = *nPtr * *nPtr * *nPtr;  /* cube number in main */
 }
```

Notice that the function prototype takes a pointer to an integer (**`int *`**).

Notice how the address of **`number`** is given - **`cubeByReference`** expects a pointer (an address of a variable).

Inside **`cubeByReference`**, **`*nPtr`** is used (**`*nPtr`** is **`number`**).

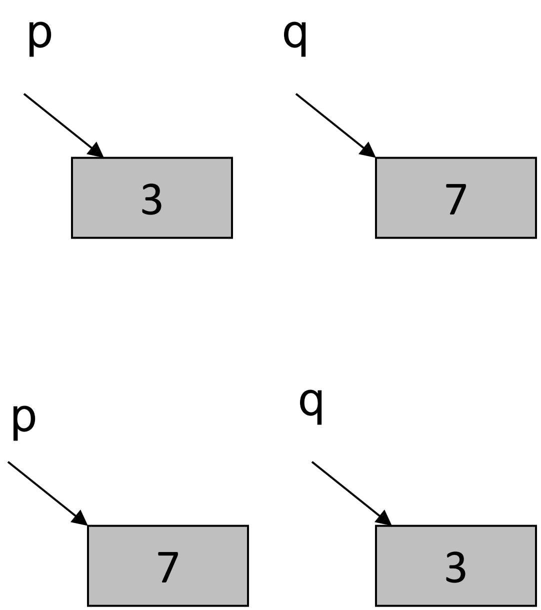
Program Output

```
The original value of number is 5
The new value of number is 125
```

```c
/* Cube a variable using call by value */
#include <stdio.h>

int CubeByValue (int n);

int main(void)
{
     int number = 5;
     printf("The original value of number is %d\n", number);
     number = CubeByValue(number);
     printf("The new value of number is %d\n",number);
     return 0;
}

int CubeByValue (int n)
{
     return (n*n*n);
}
```

```c
/* Swapping arguments (incorrect version) */
#include <stdio.h>

void swap (int p, int q);
int main (void)
{
      int a = 3;
      int b = 7;
      printf("%d  %d\n", a,b);
      swap(a,b);
      printf("%d  %d\n", a, b);
      return 0;
}

void swap (int p, int q)
{
      int tmp;

      tmp = p;
      p = q;
      q = tmp;
}
```

```c
/* Swapping arguments (correct version) */
#include <stdio.h>

void swap (int *p, int *q);
int main (void)
{
      int a = 3;
      int b = 7;
      printf("%d  %d\n", a,b);
      swap(&a, &b);
      printf("%d  %d\n", a, b);
      return 0;
}

void swap (int *p, int *q)
{
      int tmp;

      tmp = *p;
      *p = *q;
      *q = tmp;
}
```



```c
/*
 * This function separates a number into three parts: a sign (+, -,
 * or blank), a whole number magnitude and a fraction part.
 * Preconditions: num is defined; signp, wholep and fracp contain
 *                addresses of memory cells where results are to be
stored
 * Postconditions: function results are stored in cells pointed to by
 *                 signp, wholep, and fracp
 */

void separate(double num, char *signp, int *wholep, double *fracp)
{
        double magnitude;

        if (num < 0)
                *signp = '-';
        else if (num == 0)
                *signp = ' ';
        else
                *signp = '+';

        magnitude = fabs(num);
        *wholep = floor(magnitude);
        *fracp = magnitude - *wholep;
}
```

Program Output

```
Enter a value to analyze:13.3
Parts of 13.3000
 sign: +
whole number magnitude: 13
fractional part : 0.3000
```

```
Enter a value to analyze:-24.3
Parts of -24.3000
 sign: -
whole number magnitude: 24
fractional part : 0.3000
```

```
int main()
{
        double value;
        char sn;
        int whl;
        double fr;

        /* Gets data */
        printf("Enter a value to analyze:");
        scanf("%lf", &value);

        /* Separates data value in three parts */
        separate(value, &sn, &whl, &fr);

        /* Prints results */
        printf("Parts of %.4f\n sign: %c\n", value, sn);
        printf("whole number magnitude: %d\n", whl);
        printf("fractional part : %.4f\n", fr);

        return 0;
}
```

Bubble Sort Using Call-by-reference

- Implement bubblesort using pointers
  - Swap two elements
  - swap function must receive address (using &) of array elements
    - Array elements have call-by-value default
  - Using pointers and the * operator, swap can switch array elements
- Psuedocode

    Initialize array

      print data in original order

    Call function bubblesort

      print sorted array

    Define bubblesort

Example

```c
/* This program puts values into an array, sorts the values into
ascending order, and prints the resulting array. */

#include <stdio.h>
#define SIZE 10

void bubbleSort( int *array, const int size );
void swap( int *element1Ptr, int *element2Ptr );
int main() {
    /* initialize array a */
    int a[ SIZE ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
    int i;
    printf( "Data items in original order\n" );

    for ( i = 0; i < SIZE; i++ )
        printf( "%4d", a[ i ] );

    bubbleSort( a, SIZE ); /* sort the array */
    printf( "\nData items in ascending order\n" );
```

Example

```
/* loop through array a */
    for ( i = 0; i < SIZE; i++ )
        printf( "%4d", a[ i ] );
    printf( "\n" );
    return 0; /* indicates successful termination */
} /* end main */

/* sort an array of integers using bubble sort algorithm */
   void bubbleSort( int *array, const int size )
   {
        int pass,j;
      for ( pass = 0; pass < size - 1; pass++ )
           for ( j = 0; j < size - 1; j++ )
           /* swap adjacent elements if they are out of order */
               if ( array[ j ] > array[ j + 1 ] )
                   swap( &array[ j ], &array[ j + 1 ] );
   } /* end function bubbleSort */
```

Example

```
/* swap values at memory locations to which element1Ptr and
   element2Ptr point */
void swap( int *element1Ptr, int *element2Ptr )
{
   int hold = *element1Ptr;
   *element1Ptr = *element2Ptr;
   *element2Ptr = hold;
} /* end function swap */
```

Program Output

```
Data items in original order
   2   6   4   8  10  12  89  68  45  37
Data items in ascending order
   2   4   6   8  10  12  37  45  68  89
```

`sizeof` function

- **`sizeof`**
  - Returns size of operand in bytes
  - For arrays: size of 1 element * number of elements
  - if **`sizeof( int )`** equals 4 bytes, then

```
int myArray[ 10 ];
printf( "%d", sizeof( myArray ) );
```

    - will print 40
- **`sizeof`** can be used with
  - Variable names
  - Type name
  - Constant values

Example

```c
/* sizeof operator when used on an array name returns the number of
   bytes in the array. */
#include <stdio.h>
size_t getSize( float *ptr ); /* prototype */

int main(){
  float array[ 20 ]; /* create array */

  printf( "The number of bytes in the array is %d"
          "\nThe number of bytes returned by getSize is %d\n",
          sizeof( array ), getSize( array ) );

  return 0;
}

size_t getSize( float *ptr ) {
  return sizeof( ptr );
}
```

Program Output

```
The number of bytes in the array is 80
The number of bytes returned by getSize is 4
```

Example

```
/* Demonstrating the sizeof operator */
#include <stdio.h>

int main()
{
   char c;              /* define c */
   short s;             /* define s */
   int i;               /* define i */
   long l;              /* define l */
   float f;             /* define f */
   double d;            /* define d */
   long double ld;      /* define ld */
   int array[ 20 ];     /* initialize array */
   int *ptr = array;    /* create pointer to array */
```

Example

```
  printf( "       sizeof c = %d\tsizeof(char)  = %d"
          "\n     sizeof s = %d\tsizeof(short) = %d"
          "\n     sizeof i = %d\tsizeof(int) = %d"
          "\n     sizeof l = %d\tsizeof(long) = %d"
          "\n     sizeof f = %d\tsizeof(float) = %d"
          "\n     sizeof d = %d\tsizeof(double) = %d"
          "\n    sizeof ld = %d\tsizeof(long double) = %d"
          "\n sizeof array = %d"
          "\n   sizeof ptr = %d\n",
         sizeof c, sizeof( char ), sizeof s,
         sizeof( short ), sizeof i, sizeof( int ),
         sizeof l, sizeof( long ), sizeof f,
         sizeof( float ), sizeof d, sizeof( double ),
         sizeof ld, sizeof( long double ),
         sizeof array, sizeof ptr );

  return 0;
}
```

Example

Program Output

```
sizeof c = 1          sizeof(char)  = 1
sizeof s = 2          sizeof(short) = 2
sizeof i = 4          sizeof(int) = 4
sizeof l = 4          sizeof(long) = 4
sizeof f = 4          sizeof(float) = 4
sizeof d = 8          sizeof(double) = 8
sizeof ld = 8         sizeof(long double) = 8
sizeof array = 80
sizeof ptr = 4
```

Dynamic Memory Management

- **Static memory allocation:** space for the object is provided in the binary at <u>compile-time</u>
- **Dynamic memory allocation:** blocks of memory of arbitrary size can be requested at <u>run-time</u>

- The four dynamic memory management functions are **`malloc`**, **`calloc`**, **`realloc`**, and **`free`**.
- These functions are included in the header file **`<stdlib.h>`**.

Dynamic Memory Management

- **`void *malloc(size_t size);`**

- allocates storage for an object whose size is specified by **`size`**:
  - It returns a pointer to the allocated storage,
  - **`NULL`** if it is not possible to allocate the storage requested.
  - The allocated storage is not initialized in any way.

- e.g. **`float *fp, fa[10];`**
  `fp = (float *) malloc(sizeof(fa));`
  allocates the storage to hold an array of 10 floating-point elements, and assigns the pointer to this storage to fp.

Dynamic Memory Management

- `void *calloc(size_t nobj, size_t size);`

- allocates the storage for an array of nobj objects, each of size **`size`**.
  - It returns a pointer to the allocated storage,
  - **`NULL`** if it is not possible to allocate the storage requested.
  - The allocated storage is initialized to zeros.

- e.g. **`double *dp, da[10];`**
  `dp=(double *) calloc(10,sizeof(double));`
  allocates the storage to hold an array of 10 **`double`** values, and assigns the pointer to this storage to dp.

Dynamic Memory Management

- `void *realloc(void *p, size_t size);`

- changes the size of the object pointed to by **`p`** to **`size`**.
  - It returns a pointer to the new storage,
  - **`NULL`** if it is not possible to resize the object, in which case the object (`*p`) remains unchanged.
  - The new size may be larger (the original contents are preserved and the remaining space is unitialized) or smaller (the contents are unchanged upto the new size) than the original size.

Dynamic Memory Management

- e.g. `char *cp;`

  ```
  cp =(char *) malloc(sizeof("computer"));
  strcpy(cp, "computer");
  ```

  `cp` points to an array of 9 characters containing the null-terminated string **`computer`**.

  ```
  cp = (char *) realloc(cp, sizeof("compute"));
  ```

  discards the trailing '\0' and makes cp point to an array if 8 characters containing the characters in **`computer`**

  ```
  cp=(char *)realloc(cp,sizeof("computerization"));
  ```

  `cp` points to an array of 16 characters, the first 9 of which contain the null-terminated string **`computer`** and the remaining 7 are uninitialized.

Dynamic Memory Management

- `void *free(void *p);`

- deallocates the storage pointed to by p, where p is a pointer to the storage previously allocated by **`malloc`**, **`calloc`**, or **`realloc`**.

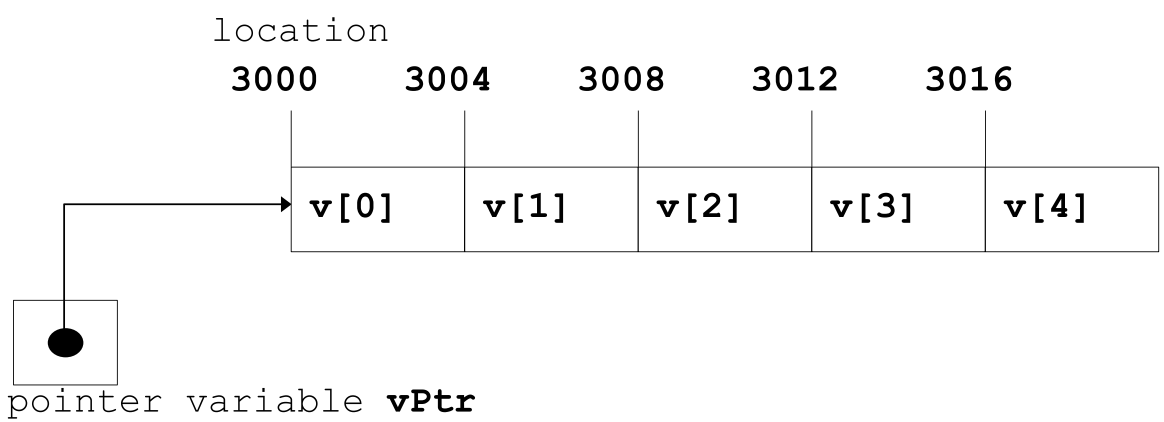
- e.g.
```
free(fp);
free(dp);
free(cp);
```

Pointer Arithmetic

- Arithmetic operations can be performed on pointers
  - Increment/decrement pointer (**++** or **--**)
  - Add an integer to a pointer(**+** or **+=** , **-** or **-=**)
  - Pointers may be subtracted from each other
  - Operations meaningless unless performed on an array

Pointer Expressions and Pointer Arithmetic

- 5 element **`int`** array on machine with 4 byte **`int`**s
  - **`vPtr`** points to first element **`v[ 0 ]`**
    - i.e. location **3000** (**`vPtr = 3000`**)
  - **`vPtr += 2;`** sets **`vPtr`** to **3008**
    - **`vPtr`** points to **`v[ 2 ]`** (incremented by 2), but the machine has 4 byte **`int`**s, so it points to address **3008**



Pointer Expressions and Pointer Arithmetic

- Subtracting pointers
  - Returns number of elements from one to the other. If

```
vPtr = &v[ 0 ];
vPtr2 = &v[ 2 ];  //vPtr2 = vPtr + 2;
```

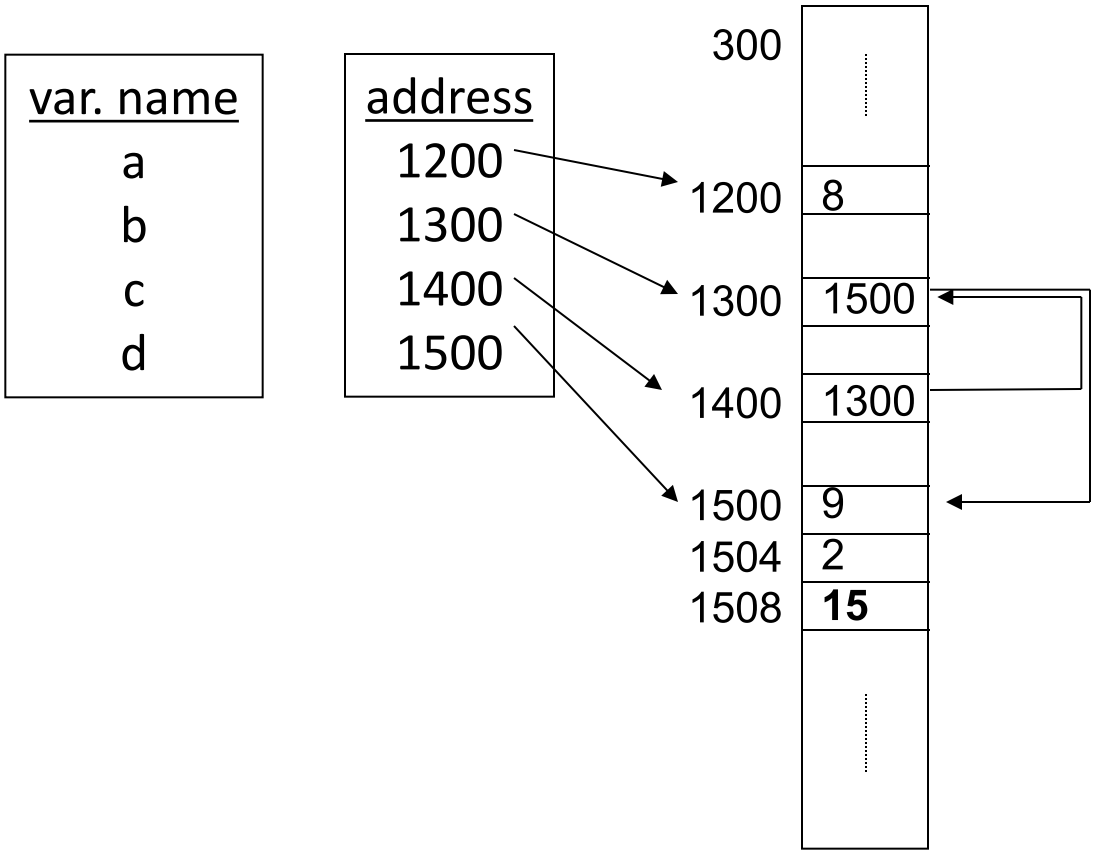
  - `vPtr2 - vPtr` would produce 2
- Pointer comparison (**<**, **==** , **>**)
  - See which pointer points to the higher numbered array element
  - Also, see if a pointer points to **0**

Pointer Expressions and Pointer Arithmetic

- Pointers of the same type can be assigned to each other
  - If not the same type, a cast operator must be used
  - Exception: pointer to **`void`** (type **`void *`**)
    - Generic pointer, represents any type
    - No casting needed to convert a pointer to **`void`** pointer
    - **`void`** pointers cannot be dereferenced

Pointers

```
int a=10;
int *b;
int **c;
int d[3]={1,2,3};

b=&a;
*b=5;
c=&b;
*(*c)=8;
b=d;
*(*c)=9;
*(*c+2)=15;
```



Example

```
int SumIntegerArray(int *ip, int n)
{
    int i, sum;
    sum = 0;
    for (i=0; i < n; i++) {
        sum += *ip++;
    }
    return sum;
}
```

Assume

```
 int sum, list[5];
```

are declared in the main function. We can make the following function call:

```
sum = SumIntegerArray(list, 5);
```

Example

```
#include<stdio.h>
#include<stdlib.h>

int main(void) {
  int *array, *p;
  int i,no_elements;
  printf("Enter number of elements: ");
  scanf("%d",&no_elements);

  printf("Enter the elements: ");
  array = ( int* )malloc( no_elements*sizeof( int ) );
  for(p=array,i=0; i<no_elements; i++, p++)
       scanf("%d",p);

  printf("Elements: ");
  for(p=array,i=0; i<no_elements; i++, p++)
       printf("%d ",*p);
  printf("\n");
```

Example

```
  array = ( int* )realloc(array, (no_elements+2)*sizeof( int ) );

  printf("Enter two new elements: ");
  for(p=array,i=0; i<no_elements; i++, p++) ;
  for(; i<no_elements+2; i++, p++)
       scanf("%d",p);

  printf("Elements: ");
  for(p=array,i=0; i<no_elements+2; i++, p++)
       printf("%d ",*p);
  printf("\n");

  free(array);
  return 0;
}
```

Program Output

```
Enter number of elements: 4
Enter the elements: 2 3 4 5
Elements: 2 3 4 5
Enter two new elements: 6 7
Elements: 2 3 4 5 6 7
```

Using the `const` Qualifier with Pointers**

- **`const`** qualifier
  - Variable cannot be changed
  - Use **`const`** if function does not need to change a variable
  - Attempting to change a **`const`** variable produces an error
- **`const`** pointers
  - Point to a constant memory location
  - Must be initialized when defined
  - **`int *const myPtr = &x;`**
    - Type **`int *const`** – constant pointer to an **`int`**
  - **`const int *myPtr = &x;`**
    - Regular pointer to a **`const int`**
  - **`const int *const Ptr = &x;`**
    - **`const`** pointer to a **`const int`**
    - x can be changed, but not **`*Ptr`**

Example

```
/* Converting lowercase letters to uppercase letters using a non-constant
   pointer to non-constant data */

#include <stdio.h>
#include <ctype.h>

void convertToUppercase( char *sPtr );

int main()
{
   char string[] = "characters and $32.98"; /* initialize char array */

   printf( "The string before conversion is: %s", string );
   convertToUppercase( string );
   printf( "\nThe string after conversion is: %s\n", string );

   return 0; /* indicates successful termination */

}
```

Example

```
/* convert string to uppercase letters */
void convertToUppercase( char *sPtr )
{
     while ( *sPtr != '\0' ) {
          if ( islower( *sPtr ) ) {     /* if character is lowercase, */
              *sPtr = toupper( *sPtr ); /* convert to uppercase */
           }
         ++sPtr;  /* move sPtr to the next character */
     }
} /* end function convertToUppercase */
```

Program Output

```
The string before conversion is: characters and $32.98
The string after conversion is: CHARACTERS AND $32.98
```

Example

```c
/* Printing a string one character at a time using a non-constant pointer
   to constant data */

#include <stdio.h>

void printCharacters( const char *sPtr );

int main()
{
   /* initialize char array */
   char string[] = "print characters of a string";

   printf( "The string is:\n" );
   printCharacters( string );
   printf( "\n" );

   return 0;
}
```

Example

```c
/* sPtr cannot modify the character to which it points, i.e.,
   sPtr is a "read-only" pointer */

void printCharacters( const char *sPtr )
{
   /* loop through entire string */
   for ( ; *sPtr != '\0'; sPtr++ )
       printf( "%c", *sPtr );
} /* end function printCharacters */
```

Program Output

```
The string is:
print characters of a string
```

Example

```
/*Attempting to modify data through a non-constant pointer to constant data.*/
#include <stdio.h>

void f( const int *xPtr ); /* prototype */

int main()
{
    int y;        /* define y */
    f( &y );      /* f attempts illegal modification */
    return 0;     /* indicates successful termination */
} /* end main */

/* xPtr cannot be used to modify the value of the variable to which it
   points */
void f( const int *xPtr )
{
   *xPtr = 100;  /* error: cannot modify a const object */
} /* end function f */
```

```
Syntax error: l-value specifies const object
```

Example

```c
/* Attempting to modify a constant pointer to non-constant data */
#include <stdio.h>

int main()
{
  int x; /* define x */
  int y; /* define y */

  /* ptr is a constant pointer to an                               ed
     through ptr, but ptr always points to the same memory location */
  int * const ptr = &x;

  *ptr = 7; /* allowed: *ptr is not const */
   ptr = &y; /* error: ptr is const; cannot assign new address */

   return 0;
} /* end main */
```

Changing **`*ptr`** is allowed – **`x`** is not a constant.

Changing **`ptr`** is an error – **`ptr`** is a constant pointer.

```
Syntax error: l-value specifies const object
```

Example

```c
/* Attempting to modify a constant pointer to constant data. */
#include <stdio.h>

int main() {
   int x = 5; /* initialize x */
   int y;     /* define y */

   /* ptr is a constant pointer to a constant integer. ptr always points to
      the same location; the integer at that location cannot be modified */
   const int *const ptr = &x;
   printf( "%d\n", *ptr );

   *ptr = 7; /* error: *ptr is const; cannot assign new value */
    ptr = &y; /* error: ptr is const; cannot assign new address */

   return 0; /* indicates successful termination */
} /* end main */
```

```
Syntax error: assignment of read-only location
syntax error: assignment of read-only variable 'ptr'
```

Pointers and Arrays

- Arrays are implemented as pointers.
- Consider:

  `double list[3];`

  `&list[1] :` is the address of the second element

  `&list[i] :` the address of **`list[i]`** which is calculated by the formula

  base address of the array + i ** 8*

The Relationship between Pointers and Arrays

- Arrays and pointers are closely related
  - Array name is like a constant pointer
  - Pointers can do array subscripting operations
- Declare an array **`b[5]`** and a pointer **`bPtr`**
  - To set them equal to one another use:

    `bPtr = b;`

    - The array name (**`b`**) is actually the address of first element of the array **`b[5]`**

    `bPtr = &b[0]`

    - Explicitly assigns **`bPtr`** to address of first element of **`b`**

The Relationship between Pointers and Arrays

- Element **`b[3]`**
  - Can be accessed by **`*(bPtr+3)`**
    - Where **`n`** is the offset. Called pointer/offset notation
  - Can be accessed by **`bptr[3]`**
    - Called pointer/subscript notation
    - **`bPtr[3]`** same as **`b[3]`**
  - Can be accessed by performing pointer arithmetic on the array itself

    `*(b+3)`

Example (cont.)

```
/* Using subscripting and pointer notations with arrays */
#include <stdio.h>
int main(void)
{
   int i, offset, b[4]={10,20,30,40};
   int *bPtr = b;

/* Array is printed with array subscript notation */

   for (i=0; i < 4; i++)
      printf("b[%d] = %d\n", i, b[i]);
```

Example (cont.)

```
/* Pointer/offset notation where the pointer is
   the array name */

  for (offset=0; offset < 4; offset++)
    printf("*(b + %d) = %d\n",offset,*(b + offset));

/* Pointer subscript notation */
  for (i=0; i < 4; i++)
     printf("bPtr[%d] = %d\n", i, bPtr[i]);

/* Pointer offset notation */
  for (offset = 0; offset < 4; offset++)
     printf("*(bPtr + %d) = %d\n", offset"
                                   "*(bPtr + offset)");

  return 0;
}
```

Example (cont.)

```
b[ 0 ] = 10
b[ 1 ] = 20
b[ 2 ] = 30
b[ 3 ] = 40

*( b + 0 ) = 10
*( b + 1 ) = 20
*( b + 2 ) = 30
*( b + 3 ) = 40

bPtr[ 0 ] = 10
bPtr[ 1 ] = 20
bPtr[ 2 ] = 30
bPtr[ 3 ] = 40

*( bPtr + 0 ) = 10
*( bPtr + 1 ) = 20
*( bPtr + 2 ) = 30
*( bPtr + 3 ) = 40
```

Example

```c
/* Copying a string using array notation and pointer notation. */
#include <stdio.h>
void copy1( char *s1, const char *s2 );
void copy2( char *s1, const char *s2 );

int main()
{
  char string1[ 10 ];           /* create array string1 */
  char *string2 = "Hello";      /* create a pointer to a string */
  char string3[ 10 ];           /* create array string3 */
  char string4[] = "Good Bye"; /* create a pointer to a string */

  copy1( string1, string2 );
  printf( "string1 = %s\n", string1 );
  copy2( string3, string4 );
  printf( "string3 = %s\n", string3 );

  return 0;
}
```

Example

```
/* copy s2 to s1 using array notation */
   void copy1( char *s1, const char *s2 )
   {
      int i;
      for ( i = 0; ( s1[ i ] = s2[ i ] ) != '\0'; i++ )
         ;
   } /* end function copy1 */

   /* copy s2 to s1 using pointer notation */
   void copy2( char *s1, const char *s2 )
   {
      /* loop through strings */
      for ( ; ( *s1 = *s2 ) != '\0'; s1++, s2++ )
         ;
   } /* end function copy2 */
```

Program Output

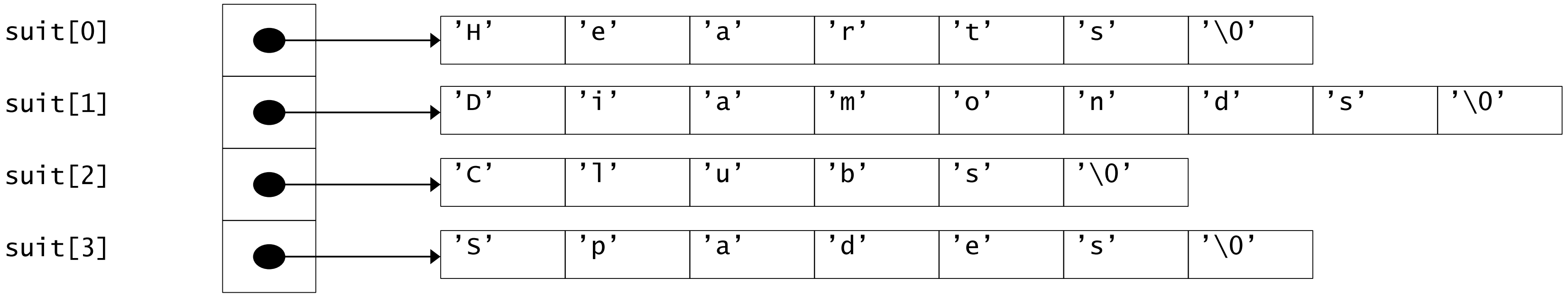
```
string1 = Hello
string3 = Good Bye
```

Arrays of Pointers

- Arrays can contain pointers
- For example: an array of strings

```
char *suit[ 4 ] = { "Hearts", "Diamonds",
   "Clubs", "Spades" };
```

  - Strings are pointers to the first character
  - `char *` – each element of **`suit`** is a pointer to a **`char`**
  - The strings are not actually stored in the array **`suit`**, only pointers to the strings are stored



  - **`suit`** array has a fixed size, but strings can be of any size

Pointers to Functions

- Pointer to function
  - Contains address of function
  - Similar to how array name is address of first element
  - Function name is starting address of code that defines function
- Function pointers can be
  - Passed to functions
  - Stored in arrays
  - Assigned to other function pointers

Pointers to Functions

- Example: **`bubblesort`**
  - Function **`bubble`** takes a function pointer
    - **`bubble`** calls this helper function
    - this determines ascending or descending sorting
  - The argument in **`bubblesort`** for the function pointer:

    ```
    int ( *compare )( int a, int b )
    ```

    tells **`bubblesort`** to expect a pointer to a function that takes two **`ints`** and returns an **`int`**
  - If the parentheses were left out:

    ```
    int *compare( int a, int b )
    ```

    - Defines a function that receives two integers and returns a pointer to a **`int`**

Example

```c
/* Multipurpose sorting program using function pointers */
#include <stdio.h>
#define SIZE 10

void bubble( int work[], const int size, int (*compare)( int a, int b ) );
int ascending( int a, int b );
int descending( int a, int b );

int main() {
     int order;   /* 1 for ascending order or 2 for descending order */
     int counter; /* counter */

     /* initialize array a */
     int a[ SIZE ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };

     printf( "Enter 1 to sort in ascending order,\n"
             "Enter 2 to sort in descending order: " );
     scanf( "%d",  &order );
     printf( "\nData items in original order\n" );
```

Example

```
/* output original array */
   for ( counter = 0; counter < SIZE; counter++ )
        printf( "%5d", a[ counter ] );
/* sort array in ascending order; pass function ascending as an argument */
   if ( order == 1 ) {
        bubble( a, SIZE, ascending );
        printf( "\nData items in ascending order\n" ); }
   else { /* pass function descending */
        bubble( a, SIZE, descending );
        printf( "\nData items in descending order\n" ); }
/* output sorted array */
   for ( counter = 0; counter < SIZE; counter++ )
        printf( "%5d", a[ counter ] );
   printf( "\n" );

   return 0;
}
```

Example

```
/* multipurpose bubble sort; parameter compare is a pointer to
   the comparison function that determines sorting order */
  void bubble( int work[], const int size, int (*compare)( int a, int b ) )
  {
    int pass;  /* pass counter */
    int count; /* comparison counter */

    void swap( int *element1Ptr, int *element2ptr );
    for ( pass = 1; pass < size; pass++ ) {
         for ( count = 0; count < size - 1; count++ ) {
          /* if adjacent elements are out of order, swap them */
          if ( (*compare)( work[ count ], work[ count + 1 ] ) ) {
              swap( &work[ count ], &work[ count + 1 ] );
           }
       }
    }
  } /* end function bubble */
```

Example

```
/*swap values at memory locations to which element1Ptr and element2Ptr point */
   void swap( int *element1Ptr, int *element2Ptr )
   {
      int hold; /* temporary holding variable */
      hold = *element1Ptr;
      *element1Ptr = *element2Ptr;
      *element2Ptr = hold;
   } /* end function swap */

/* determine whether elements are out of order for an ascending order sort */
   int ascending( int a, int b ) {
      return b < a;
   } /* end function ascending */

/* determine whether elements are out of order for a descending order sort */
   int descending( int a, int b ) {
     return b > a; /* swap if b is greater than a */
  } /* end function descending */
```

Example

```
Enter 1 to sort in ascending order,
Enter 2 to sort in descending order: 2

Data items in original order
    2    6    4    8   10   12   89   68   45   37
Data items in descending order
   89   68   45   37   12   10    8    6    4    2
```


```
Enter 1 to sort in ascending order,
Enter 2 to sort in descending order: 2

Data items in original order
    2    6    4    8   10   12   89   68   45   37
Data items in descending order
   89   68   45   37   12   10    8    6    4    2
```


Program Output