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Chapter 1

The C Programming Language

(Advanced Features)

10

MACRO Definitions

#define *identifier* *token-sequence*

#define *identifier* (*parameter-list*) *token-sequence*

- No space is allowed between the identifier and the parentheses.
- Every appearance of <*identifier*> in the code is replaced by the <*token-sequence*> prior to compilation. If *arguments* are involved, they replace the *parameters*.

- **Common Practice**: MACRO identifiers are all CAPITAL letters
- **A Useful Rule**: Constants present in software, with the possible exception of 0, 1, will backfire. USE MACROs.

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MACRO examples

```
#define MAX_STR_LEN  20
#define IS_UPPER(c)  ((c) >= 'A' && (c) <= 'Z')
#define TO_LOWER(c)  (IS_UPPER(c)? (c) - 'A' + 'a' : (c))
                . . .

    char arr[MAX_STR_LEN + 1],  *str;
                . . .
        for (str = arr; *str != '\0'; str++) {
          *str = TO_LOWER(*str);
        }
                . . .
```

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MACRO *PITFALLS*

Several problems may arise while calling the MACRO

```
#define  SQR(x)     x * x
```

- **Operator Precedence ERROR**
  - **External**

    `(int)SQR(a)` *is expanded to*
    `(int)a * a` *which casts the left operand only*

    solution: Put parentheses (or braces) around MACRO.
  - **Internal**

    `SQR(a + b)` *is expanded to*
    `a + b * a + b` *which is definitely*
    not `(a + b)*(a + b)`

    solution: Put parentheses around MACRO arguments.

```
#define  SQR(x) ((x) * (x))  /* is SAFE  */
```


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MACRO *PITFALLS* (Cont.)

- **Side Effects ERROR**

```
SQR(++i)          is expanded to
((++i) * (++i))   which may increments i twice
                  (and the result is undefined)
```

- **Unnecessary Function Calls (actually, this is *side-effect* too)**

```
SQR(very_difficult_func(a,z,t))
```

will evaluate the function twice, before multiplication.

NO General Solutions for the above two problems:

> Be ***wise*** while defining a MACRO
> and ***cautious*** while calling a MACRO

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Calling a **Function** vs. Calling a **MACRO**

* Is always an **expression**
* Will not change arguments and side-effects are fully controlled
* Can always return a newly created object
* Limited to **fixed type arguments**
* Saves executable code Easier maintenance
* **May** be passed as an argument to functions
* Function call overhead (for *stack* handling)
* May be a **statement** (e.g, one that requires *automatic* variables).
* May have unexpected side-effects
* May require an argument to carry a newly created object
* May operate unchangeably on arguments of varying types
* Code is **duplicated** though maintenance is easy
* **Cannot** be passed as an argument
* No calling overhead

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When is a **MACRO** better than a **Function** ?

Rules of Thumb:

- Operation required is **short**, **simple**, and (maybe) used in **different locations**.
- Operation required is **short**, **simple**, and is used **intensively**.
- Operation required is performed on variety of **different types**.

Examples for last case:

```
#define MAX(a, b)          ((a) > (b) ? (a) : (b))
#define SWAP(type, a, b) { type t = a; a = b; b = t;}
```

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C99: Inline functions

- **The new C standard (ANSI+ISO+IEC+9899-1999) allows `inline` functions** (this feature was taken from C++)
- **A function is *inlined* when its code is expanded at the point of the call to the function instead of creating a function-call.**
- **In that respect, inlining a function has the same effect as using a MACRO except one major difference**

  Inlining is a job done by the compiler
- **Consequently, it behaves like a function with all other respects, except code duplication and calling overhead**

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Inline Functions (cont.)

```
inline int max(int a, int b)
{return (a) > (b) ? (a) : (b)}
```

- The function definition should be in a header (if it is used across several files)
- The function is restricted to a single set of types (as denoted in its definition)
  - Arguments of other types will be converted (if permissible)
  - If you need it for different types (without conversion), use MACRO
- Since the function must be defined before use it subverts top-down presentation
- The compiler may refuse to inline a function (either completely or in selected cases)

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Enumerable Types

- **Types** that consist of certain **integral values**, which are carried by **symbolic names**.
  The names are more important than the actual values.
- Enum definitions

```
enum bool   { FALSE,TRUE };
enum month  { JAN = 1,FEB, /* … */,DEC };
enum colors { WHITE = 1,BLACK,GREEN = 8,RED };
```

- Using enum types

```
enum  bool  b[SIZE], t = FALSE;
```

- **enum** vs. **#define** (enum is superior)
  - It obeys C's scoping rules.
  - The compiler **may** check for type mismatch.
  - The debugger **may** recognize the symbolic names.

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MACRO and Enum – a Comparison

```
enum day {SUN = 1,MON,TUE,WED,THR,FRI,SAT};
void f(void)
{ enum day  d = TUE,   /* o.k. */
            e = 3;     /* syntax error */
  enum bool {FALSE, TRUE};
  enum bool b = FALSE, /* o.k. */
            c = 1;     /* syntax error */
  #define   RED 3;
  int   color = 3;     /* o.k. */
}
void g(void)
{ enum day  d = TUE;   /* o.k. */
  enum bool b = FALSE; /* syntax error */
  int  color  = RED;   /* o.k. */
}
```

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const type qualifier

```
const int fixed = expression ; /* No changes after initialization */
```

- When is `const` preferred over `enum` or a **MACRO** ?
  - Its value is decided at run time (and is of **any** type).
  - It obeys C's scoping rules.
  - It is used where its address (& operator) is required.
  - It must be recognized by the compiler / debugger.
  - In *trying* to force a function not to modify an array argument, or any argument that is passed by its address.

Example: **If a function is *defined* as**

```
int scalar_product(const int vec1[], const int vec2[]);
```

the compiler *may* check that no assignment of the form

`vec1[i] = exp` is evaluated in the function body.

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typedef Declarations

C provides a facility for creating new data type **names**.

```
typedef  int  Length;        /*  Defining   */
Length   l, lvec[SIZE];      /*  Using      */
```

will make `l` *of type* **`int`**, *and* `lvec` *of type* array of int.

```
typedef  enum bool bool;     /*  Shortening */
```

- **Typedefs** are far from being MACROs.

```
typedef  char   Buf[BUF_SIZ];
Buf     buffer, buf_array[SIZE];
```

will make `buffer` - *an array* (of size BUF_SIZ),
and `buf_array` - *an array* (of size SIZE)
of arrays (of size BUF_SIZ),
i.e, ***equivalent*** *to* **`char`** `buf_array[SIZE][BUF_SIZ];`

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Why typedef ?

- **Easy modification of data types**
  Example: Certain **int** variables are used for carrying flags.
  Later, the software became more complicated, and we want to change these variables into type **long**.
  Had these variables been declared being of type **Flag** (with "**`typedef int`** `Flag`;"), all can be done by modifying the **typedef** statement.

- **Meaningful names for data types**
  In the example above, wherever we see the declaration "Flag var;" we understand that 'var' is going to be used as a "flag carrier".

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Casting

Is a way to force an expression
to be evaluated to a certain type

Example:

```
int    i = 6;
double d = 2.9;
```

– The following three expressions are evaluated to three different values :

```
i/d ( == 2.0689)   (int)(i/d) ( == 2)   i/(int)d ( == 3)
```

– Here we force an argument of a function to be of the correct type:

```
d = sqrt((double)i);   /* a documentation benefit too */
```

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Casting (Cont.)

- There are cases where we have to declare pointers without prior knowledge about the type they will point to.
- The type **void *** (i.e. a pointer to void) is used as a **generic** pointer type. In a mixed type **pointer expression**, conversion is automatic.
  -- However, **casting** is necessary when pointers are dereferenced.

Example:

```
int     i;
double  d, e;
void    *gpt0 = &i, *gpt1 = &d;        /* Causes no problem */
e = *gpt0 + *gpt1;                     /* Is impossible     */
e = *(int *)gpt0 + *(double *)gpt1;    /* Is the solution   */
```


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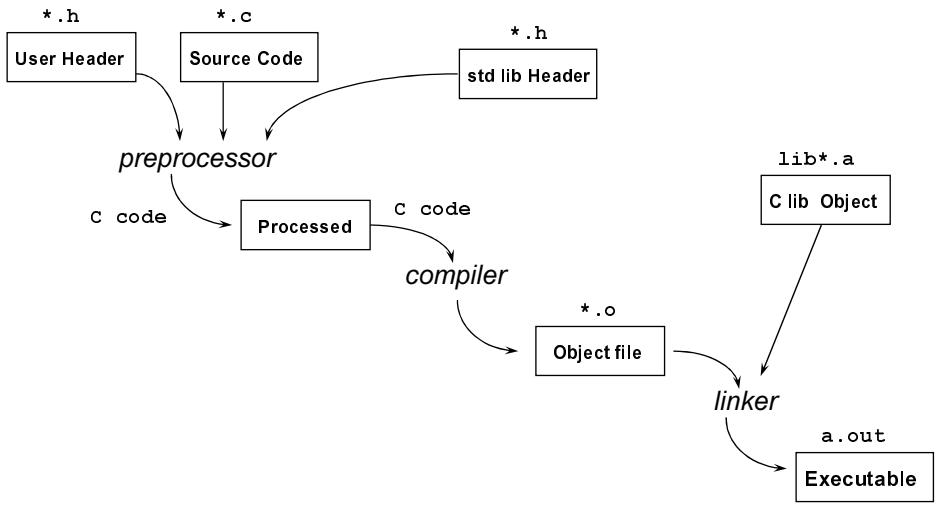
From **Source** to **Executable**



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The C Preprocessor

- **MACRO definitions**

```
#define   a macro definition
#undef    identifier
```

- **File Inclusion**

```
#include   < file-name >
#include    " file-name "
```

- **Conditional Compilation**

```
#if          constant-expression
#ifdef   identifier      /* #if  defined(identifier) */
#ifndef  identifier      /* #if !defined(identifier) */

#elif    constant--expression
#else
#endif
```

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The C Preprocessor (Cont.)

A common use of the **#ifndef** command is in **header files.**
It is, usually, harmful to include a header file more than once.
Since file inclusion is transitive, a file may inadvertently
be included more than once, through inclusion of other files.
A strong mechanism that prevents multiple inclusion, is that each file
defines a unique MACRO-identifier once included, and "refuses"
inclusion if this identifier is #defined.

Example: *(a header file named* "**list.h**"*)*

```
#ifndef  LIST_H
#define  LIST_H     /* Prevents entering here in
                       future inclusions  */
        (Here comes the content of the header file)
#endif   /* LIST_H */
```

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Structures

Syntax: ***struct*** [***name***] {**fields-list**}

- Define *new types* that are built from several, simpler types.
- Allow access to each component.
- Almost everything that can be done with built-in types (***int, double***), is legal for structures.
  - Legal: Arrays of structures, functions that return structure values, etc.
  - Illegal: Overloading predefined *arithmetical / logical* operations.
- Structures can be ***nested***.

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Structures (Cont.)

Example: Complex Numbers

```
struct complex {
  double r, i;
};
typedef struct complex complex;

#define CMPLX_ADD(x,y,z) {(z).r = (x).r + (y).r; \
                          (z).i = (x).i + (y).i; \
                         }
complex ComplexAdd(complex x, complex y)
{  complex z;
   z.r = x.r + y.r;
   z.i = x.i + y.i;
   return z;
}
```

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Structures (Cont.)

Example:

```
struct person  {
  unsigned long   id;
  char            *name;
  short           gender;
  struct {
    char     *str_n_num,
             *city;
    unsigned zip;
  } address;
  struct person  *father;
/* The above is legal because 'father' is only a pointer */
};
```


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Structures (Cont.)

Usage:

```
unsigned long id, zip;
char     *name1, *name2;
struct person  per_var, *per_ptr;
          . . .
per_var.id            = id;
(*per_ptr).id         = ++id;
per_ptr->name         = name1;
per_var.address.zip   = per_ptr->address.zip;
per_ptr->father->name = per_var.father->name;
```

- **Note:** The field operators (`->`, `.`) have the same precedence (the highest among all operators), and are associated *left* to *right*.

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Structures (Cont.)

- **Structures may be initialized:**

```
complex z = {2.3, -.4};
```

- **Structures returned by functions, may be used as such:**

```
double x = ComplexAdd(z1, z2).r;
```

- **Structure declarations do not constitute executable code:**
  They merely describe a template (a blueprint)
  to be used in building objects of a specific type.
  This blueprint describes the memory layout of these objects.

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Addresses and Pointers

- Every object in the computer memory has an **address**.
- **Some** of the objects in a **C** program may be referenced through the address of their location in memory.
  - Expressions like `&var`, are evaluated to the **address** of `var`.
- The **address operator, &,** cannot be applied to objects that have a temporary location in the memory (examples are: explicit constants, compound expressions).
- Addresses can be stored in variables of type **pointer to . . .**

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Addresses and Pointers (Cont.)

- When `pvar` is a pointer variable carrying an address, the **dereferencing** (or **indirection**) **operator, *,** is used to extract the value stored in that address (via the expression `*pvar`).
- The character `*` , is also used for the **declaration** of pointer type variables.

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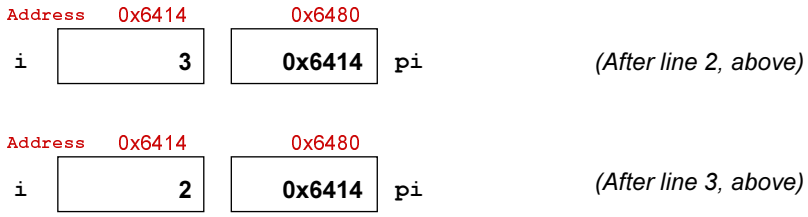
Addresses and Pointers (Cont.)

Example:

```
int i, *pi;          /* pi - a pointer to integer          */
                     /* Another words, *pi is an int       */
i = 3; pi = &i;      /* Now,   (*pi  ==  3)                */
*pi = 2;             /* Now,   (  i  == 2 )                */
```

Memory Image



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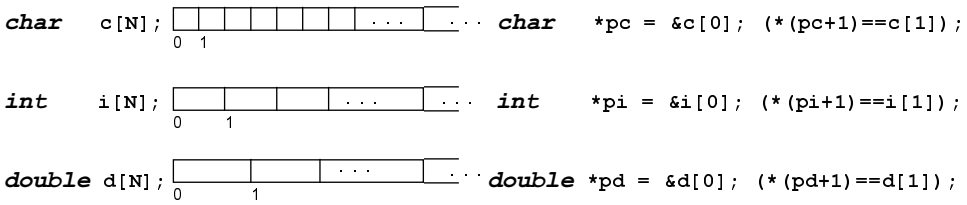
Addresses and Pointers (Cont.)

- In order to dereference a pointer, it **must be known** to which **type** it refers.
- Objects of different types may occupy spaces of **different size**, e.g, char, int, float, double.

Example: *(Showing how pointers differ from integers.)*



- It is **illegal** to compare two pointers, **unless** they are known to point to a **single object** (e.g, an array), or to be **NULL**. Illegal comparisons are many times **possible**, but the results may be **surprising**.

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Pointers and Arrays

Following a declaration like `double weight[LEN], *pw;`

we have:

- `weight[i]` is an expression of type **double** that refers to the value stored in the i'th entry of the array.
- `weight` is an expression of the type LEN-**size array of double**.
- Under most circumstances, the expression `weight` is evaluated **as if** it was of type **pointer to double** that refers to the address of the first element of the array.
  - This means that `weight == &weight[0]` is always **TRUE**.
  - However, `sizeof(weight)` will **not** evaluate to `sizeof(double*)`
- **Fact:** The **C** compiler always translates an "array expression" like `weight[i]` into its equivalent "pointer expression" `*(weight+i)`

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Pointers and Arrays (Cont.)

- However, when dealing with an object of type **array of ...** using the "array style expression" `weight[i]` is **recommended**, stressing the fact that we deal with an **actual array**.
- Assigning `pw = weight` will make the expression `pw[2]` have the value `weight[2]`
- The main **practical difference** between `pw` and `weight` is that `weight` **acts as a constant**, and `pw` **is a variable**, i.e, `weight` cannot be assigned to.

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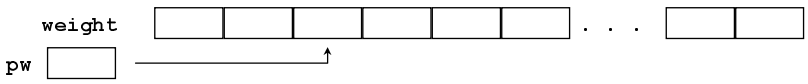
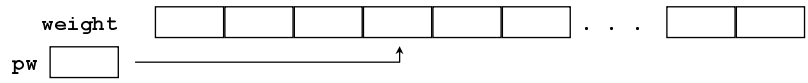
Pointers and Arrays (Cont.)

Example:

```
pw = weight + 2;
```




```
pw++;                    (now pw[1] is weight[4])
```



BUT `weight++;` ***is illegal***.

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Pointers and Function-Arguments

- In the C language, function arguments are passed only by value.
- It means that a variable that is used as an argument at a function call, will always retain its value when the function returns to the caller.

Example:

```
int i = 3, j = 4;
swap(i,j);
/*  i is still  3,
 *  j is still  4.
 */
```

```
void swap(int a, int b)
{  int t = a;
   a = b;  b = t;
   return;
}
```


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Pointers and Function-Arguments
(Cont.)

- By using pointers as function arguments this restriction is overcome.

Example:

```
    int i = 3, j = 4;
    swap(&i,&j);
/*  i is now  4,
 *  j is now  3.
 */
```

```
void swap(int *a, int *b)
{  int t = *a;
   *a = *b;  *b = t;
   return;
}
```

- This makes the call to `swap()`, practically a call by reference.
- In both cases, `a`,`b`, are **local** variables, which are initialized to the values of the arguments at the function call.

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Arrays as Function-Arguments

An exception to the C "call by value" paradigm is for array parameters

- When an array is used as an argument at a function call, the entire array is not copied, but only its address is passed.
  - For a one-dimensional array of integers `vec[SZ]`, that is used as an argument at a function call, `f(vec)` and `f(&vec[0])` are synonyms.
  - In that case, at the **definition** or **declaration** of the function `f`, `f(int *arr)` and `f(int arr[])` are synonyms too.
  - If part of the array is to be transferred at the function call, then, e.g, `f(vec+2)` and `f(&vec[2])` are synonyms.
  - For multidimensional arrays, the above discussion is true for the first (leftmost) coordinate only.

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Pointers to Functions

There are cases where there is a **function call** in a command, but there is no prior knowledge **which function** is to be called.

Example:

```
void *v1, *v2;
        .   .   .
if (compare(v1,v2) == 0) {
        .   .   .
```

`v1, v2` may point to **integers** or **strings**, or other types.
An appropriate **compare** function should be called, according to the **type** of the objects pointed to by `v1, v2.`

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Pointers to Functions (Cont.)

This is how we deal with the situation:

```
void *v1, *v2;
enum {INT, STR} type;          /* coding actual type */
int  (*compare)(void*,void*); /* a pointer to function */
          . . .
switch(type) {
    case INT:  compare = int_cmpr;
               break;
    case STR:  compare = str_cmpr; /* calls strcmp() */
               break;
}         . . .
if ((*compare)(v1,v2) == 0) { /* compare(v1,v2) is legal too */
          . . .
```

```
int  int_cmpr(void *p,void *q)
{ return *(int*)p - *(int*)q;}
```


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Pointers to Functions (Cont.)

- Another case of using a pointer to function is when a function is used as an **argument**, passed to another function (in principle, this is similar to the previous case: had we known a-priori a single function that would be used, there was no need to put it as an argument).

Example:

– A definition of a function which uses a function as an argument:

```
char*
string_manipulation(char s[], int (*chr_manip)(int))
{ for (int i=0; i < strlen(s); i++)   /* C99 initialization */
    s[i] = chr_manip(s[i]);           /* A given operation on a char */
  return s;
}
```

– A call to that function:

```
char str[10] = "aBcD";
    . . .
string_manipulation(str,tolower);
```

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Dynamic Memory Allocation

- **C** allows general purpose dynamic memory allocation off the heap, restricted only by the amount of memory available at run time.

- There are three predefined functions for this: (in `<stdlib.h>`)

```
void     *ptr =  malloc(num_bytes_to_allocate);
void   *z_ptr =  calloc(num_of_obj, size_of_1_obj);
void *new_ptr = realloc(old_ptr, new_size_in_bytes);
```

- If memory allocation fails, these functions return a **NULL** pointer.

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Dynamic Memory Allocation
(Cont.)

Example:

Casting is not obligatory

```
int *vec, *new;

if ((vec = (int*)malloc(arr_lng*sizeof(int))) == NULL) {
   fprintf(stderr,"cannot allocate\n");
   exit(1);     /* a MACRO will save you from code duplication */
}
if ((new = (int*)realloc(vec,new_lng*sizeof(int))) == NULL){
   fprintf(stderr,"cannot allocate\n");
   exit(1);
}   /* Now, vec points "nowhere" */
```

- **Dynamically allocated** memory (**only**) can be returned to the system using the function `free(old_ptr)`, which returns **void**.

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Dynamic Memory Allocation
Example

```
#include <stdio.h>
#include <stdlib.h>  /*  For  malloc(), etc.  */
#include <ctype.h>   /*  For tolower(), etc.  */
#define LNG1  (6)
#define LNG2  (7)

char*
string_manipulation(char *s, int (*chr_manip)(int))
{
   while (*s != '\0') {
      *s = chr_manip(*s);
      s++;
   }
   return s;
}
```


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Dynamic Memory Allocation
Example (Cont.)

```
int
main()
{
  char  *str, *new_str, *str1;

  str = (char *) malloc(LNG2);

  while (printf("Enter 6-char string\n")
         && fgets(str,LNG2,stdin)) {
    printf("  %s  ==>>  ",str);
    string_manipulation(str, tolower);
    printf("%s\n",str);
  }
```

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Dynamic Memory Allocation
Example (Cont.)

```
  new_str = realloc(str, LNG2+LNG1);
  printf("line %d:\tnew_str = %s\n", __LINE__, new_str); (line 33)
  printf("line %d:\t    str = %s\n", __LINE__, str);     (line 34)
  string_manipulation(str, toupper);
  printf("line %d:\tnew_str = %s\n", __LINE__, new_str); (line 36)
  printf("line %d:\t    str = %s\n", __LINE__, str);     (line 37)

  str1 = malloc(LNG2);
  printf("line %d:\t   str1 = %s\n", __LINE__, str1);    (line 40)
  string_manipulation(str, tolower);
  printf("line %d:\t   str1 = %s\n", __LINE__, str1);    (line 42)
  return 0;
}
```


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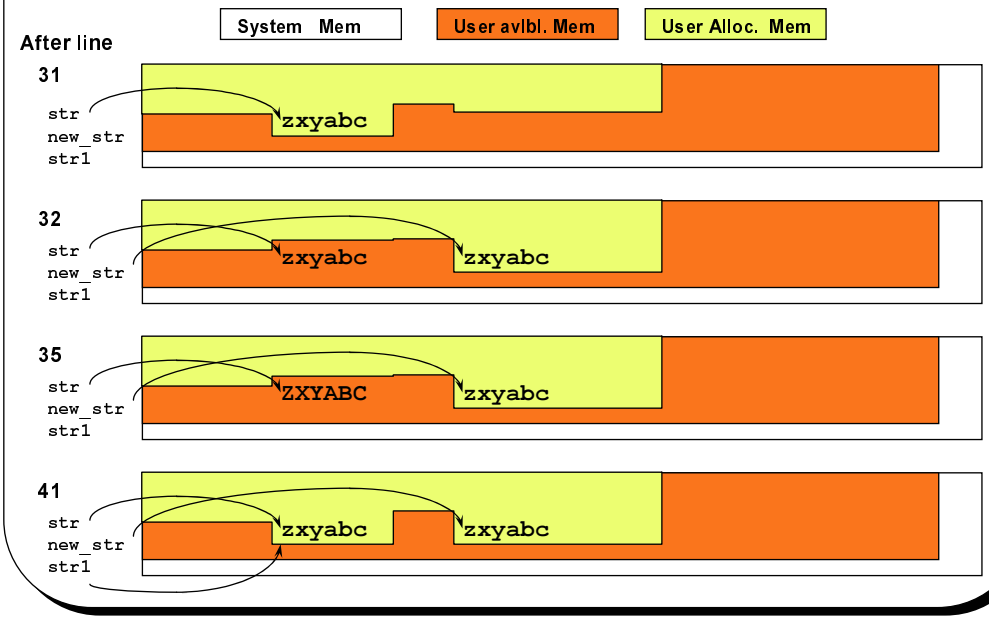
Dynamic Memory Allocation
Example (Cont.)



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Dynamic Memory Allocation
Example (Cont.)

A Sample Output

```
Enter 6-char string
  CDfsER  ==>>  cdfser
Enter 6-char string
  ZYXABC  ==>>  zyxabc
Enter 6-char string
line 33:      new_str = zyxabc
line 34:          str = zyxabc   This is a FREE memory area !!!
line 36:      new_str = zyxabc
line 37:          str = ZYXABC   A FREE memory is manipulated
line 40:         str1 = ZYXABC   This area is ALLOCATED again
line 42:         str1 = zyxabc   and manipulated by an OLD pointer
```