Functions

Introduction

- Function
  - A self-contained program segment that carries out some specific, well-defined task.
- Some properties:
  - Every C program consists of one or more functions.
    - One of these functions must be called “main”.
    - Execution of the program always begins by carrying out the instructions in “main”.
  - A function will carry out its intended action whenever it is *called* or *invoked*.

- In general, a function will process information that is passed to it from the calling portion of the program, and returns a single value.
  - Information is passed to the function via special identifiers called arguments or parameters.
  - The value is returned by the “return” statement.
- Some function may not return anything.
  - Return data type specified as “void”.

```
#include  <stdio.h>

int  factorial (int m)
{
     int i, temp=1;
     for (i=1; i<=m; i++)
               temp = temp * i;
     return (temp);
}
```

```
main()
{
     int  n;
     for  (n=1; n<=10; n++)
               printf (“%d! = %d \n”,
                n, factorial (n) );
}
```

Functions: Why?

- Functions
  - Modularize a program
  - All variables declared inside functions are local variables
    - Known only in function defined
  - Parameters
    - Communicate information between functions
    - They also become local variables.
- Benefits
  - Divide and conquer
    - Manageable program development
  - Software reusability
    - Use existing functions as building blocks for new programs
    - Abstraction - hide internal details (library functions)
  - Avoids code repetition

Defining a Function

- A function definition has two parts:
  - The first line.
  - The body of the function.

return-value-type function-name (*parameter-list*)
{
declarations and statements
}

- The first line contains the return-value-type, the function name, and optionally a set of comma-separated arguments enclosed in parentheses.
  - Each argument has an associated type declaration.
  - The arguments are called formal arguments or formal parameters.
- Example:

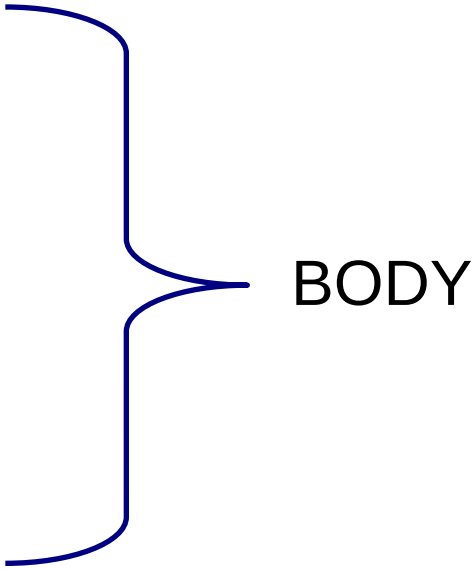
```
int  gcd  (int  A,  int  B)
```

- The argument data types can also be declared on the next line:

```
int  gcd  (A, B)
int  A, B;
```

- The body of the function is actually a compound statement that defines the action to be taken by the function.

```
int  gcd  (int A, int B)
{
    int  temp;
    while ((B % A) != 0)  {
      temp = B % A;
      B = A;
      A = temp;
    }
    return (A);
}
```



- When a function is called from some other function, the corresponding arguments in the function call are called actual arguments or actual parameters.
  - The formal and actual arguments must match in their data types.
- Point to note:
  - The identifiers used as formal arguments are “local”.
    - Not recognized outside the function.
    - Names of formal and actual arguments may differ.

```
#include  <stdio.h>
/* Compute the GCD of four numbers */

main()
{
    int  n1, n2, n3, n4, result;
    scanf ("%d %d %d %d", &n1, &n2, &n3, &n4);
    result  =  gcd ( gcd (n1, n2), gcd (n3, n4) );
    printf ("The GCD of %d, %d, %d and %d is %d \n",
              n1, n2, n3, n4, result);
}
```

Function Not Returning Any Value

- Example: A function which only prints if a number if divisible by 7 or not.

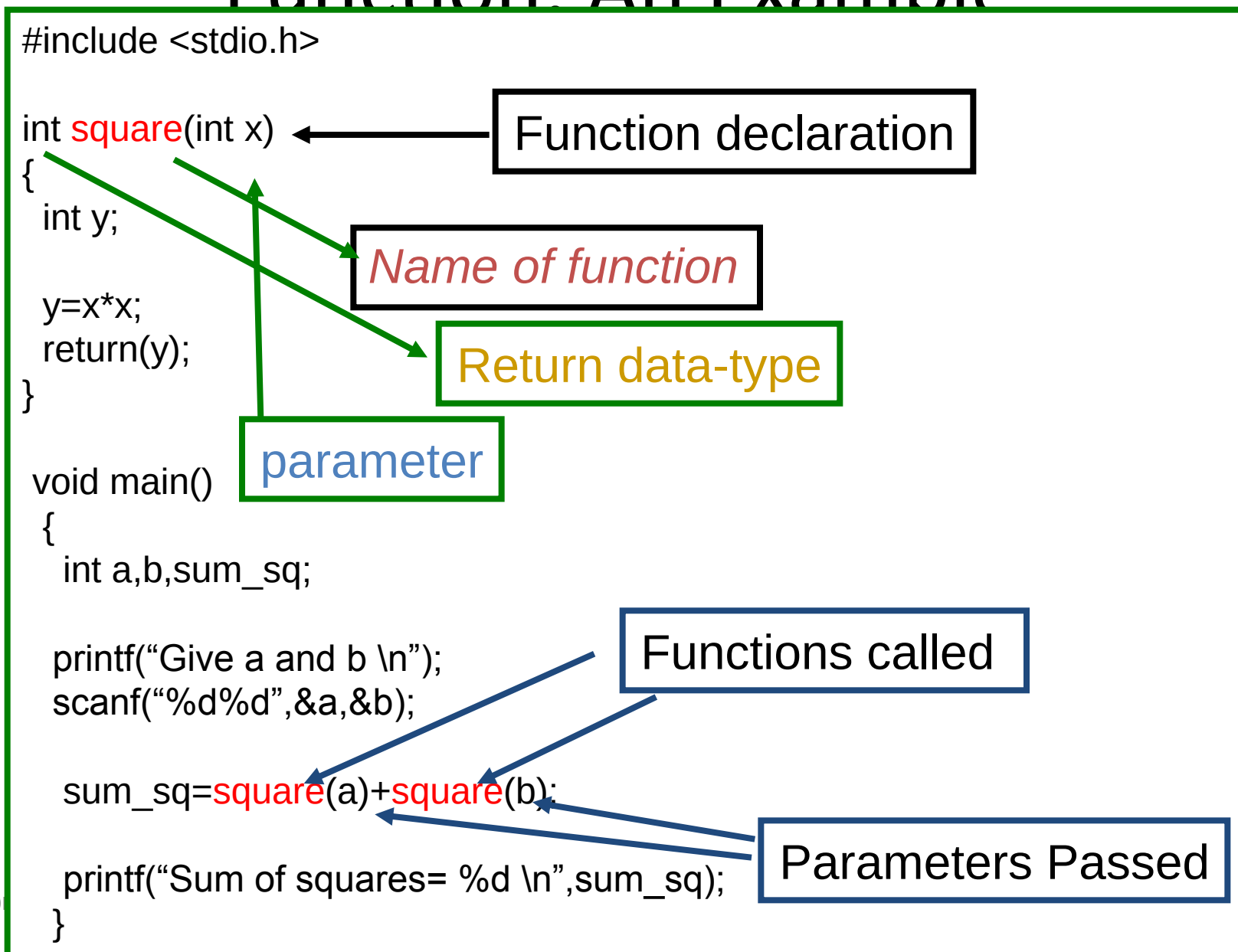
```
void  div7 (int n)
{
    if  ((n % 7) == 0)
        printf (“%d is divisible by 7”, n);
    else
        printf (“%d is not divisible by 7”, n);
    return;
}
```

OPTIONAL

- Returning control
  - If nothing returned
    - `return;`
    - or, until reaches right brace
  - If something returned
    - `return` *expression*`;`

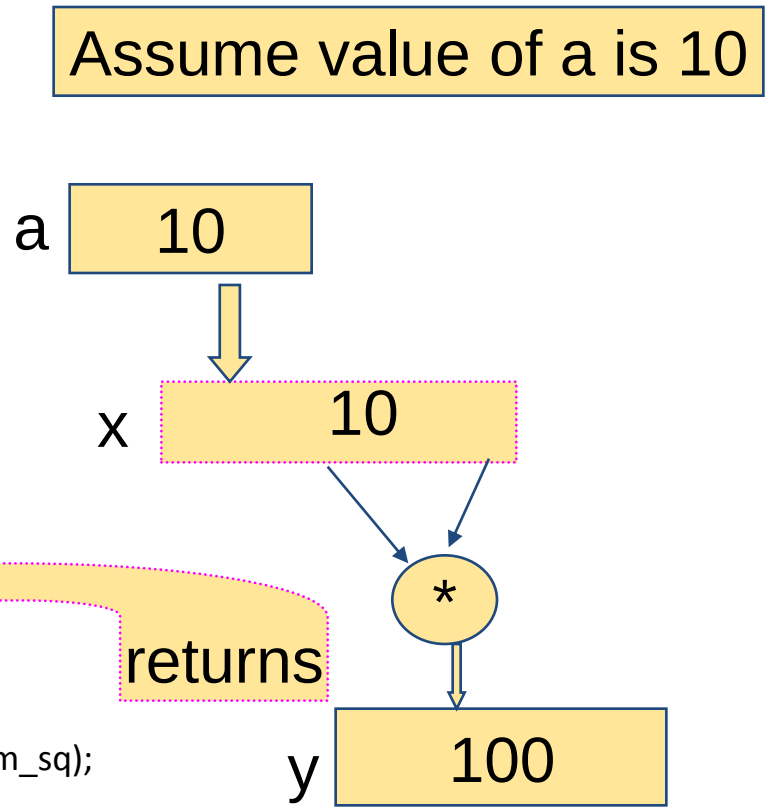
Function: An Example

```
#include <stdio.h>

int square(int x)
{
  int y;

  y=x*x;
  return(y);
}

 void main()
  {
    int a,b,sum_sq;

   printf("Give a and b \n");
   scanf("%d%d",&a,&b);

    sum_sq=square(a)+square(b);

    printf("Sum of squares= %d \n",sum_sq);
   }
```



Invoking a function call : An Example

```
#include <stdio.h>

int square(int x)
{
  int y;

  y=x*x;
  return(y);
}

 void main()
 {
   int a,b,sum_sq;

   printf("Give a and b \n");
   scanf("%d%d",&a,&b);

   sum_sq=square(a)+square(b);

   printf("Sum of squares= %d \n",sum_sq);
  }
```



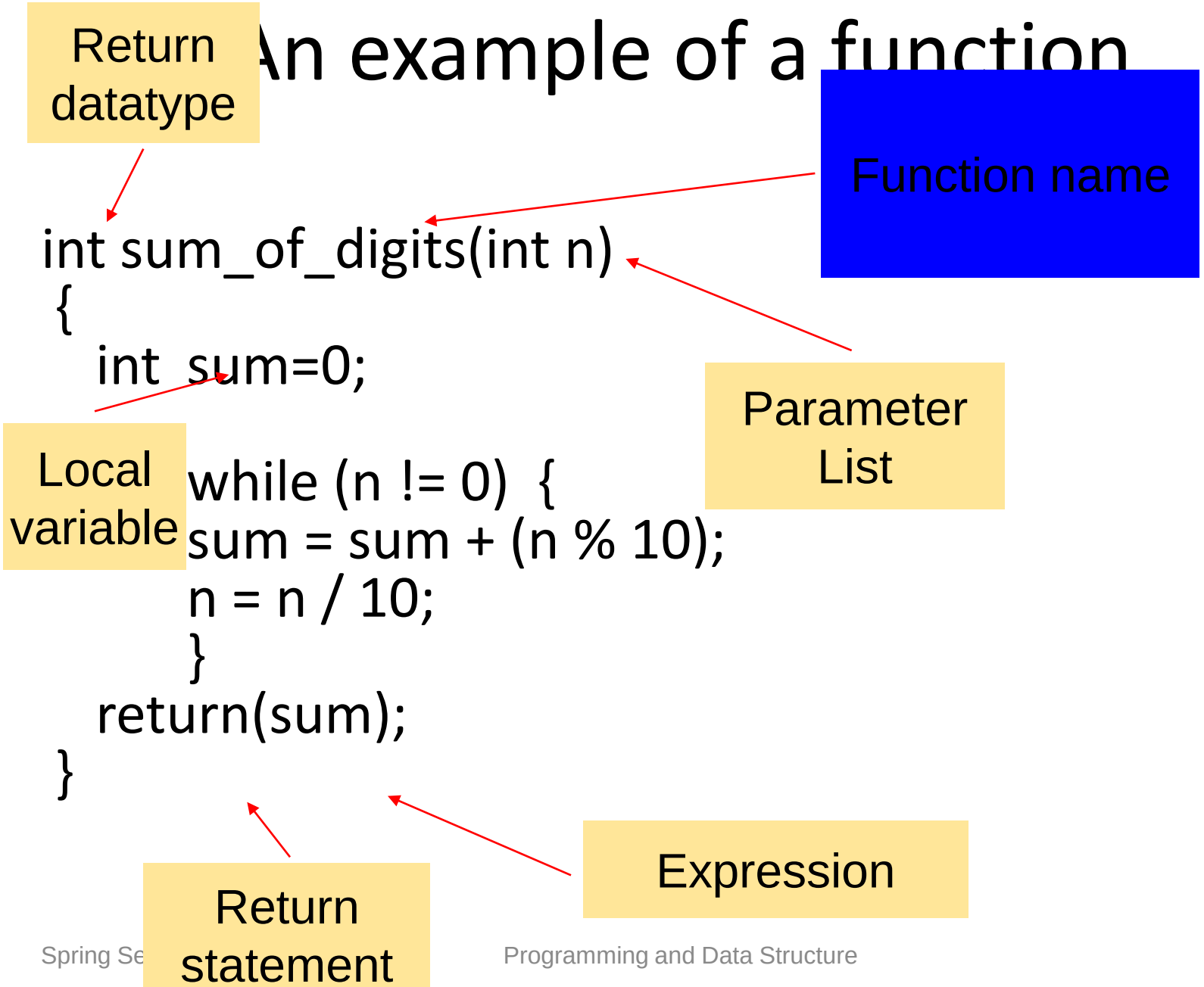
Function Definitions

- Function definition format (continued)

  return-value-type function-name (*parameter-list*)
  {
  declarations and statements
  }

  – Declarations and statements: function body (block)
    - Variables can be declared inside blocks (can be nested)
    - Function can not be defined inside another function
  – Returning control
    - If nothing returned
      – `return;`
      – or, until reaches right brace
    - If something returned
      – `return` *expression;*

An example of a function



Variable Scope

```
int A;
void main()
{       A = 1;
        myProc();
        printf ( "A = %d\n", A);
}

void myProc()
{   int A = 2;
    while( A==2 )
        {
            int A = 3;
            printf ( "A = %d\n", A);
            break;
        }
        printf ( "A = %d\n", A);
}
. . .
```

Printout:

A = 3

A = 2

A = 1

Function: Summary

```
#include  <stdio.h>

int  factorial (int m)
{
    int i, temp=1;
    for (i=1; i<=m; i++)
        temp = temp * i;
    return (temp);
}
```

Returned data-type

parameter

Function name

Local vars

Return statement

Self contained programme

```
main()
{
    int  n;
    for  (n=1; n<=10; n++)
    printf ("%d! = %d \n", n,
    factorial (n) );
}
```

main()
is a function

Calling a function

Some Points

- A function cannot be defined within another function.
  - All function definitions must be disjoint.
- Nested function calls are allowed.
  - A calls B, B calls C, C calls D, etc.
  - The function called last will be the first to return.
- A function can also call itself, either directly or in a cycle.
  - A calls B, B calls C, C calls back A.
  - Called recursive call or recursion.

Math Library Functions

- Math library functions
  - perform common mathematical calculations
  - `#include <math.h>`
  - `cc <prog.c> -lm`

- Format for calling functions

  ```
  FunctionName (argument);
  ```

    - If multiple arguments, use comma-separated list
  - `printf( "%.2f", sqrt( 900.0 ) );`
    - Calls function `sqrt`, which returns the square root of its argument
    - All math functions return data type `double`
  - Arguments may be constants, variables, or expressions

Math Library Functions

- double acos(double x) -- Compute arc cosine of x.
- double asin(double x) -- Compute arc sine of x.
- double atan(double x) -- Compute arc tangent of x.
- double atan2(double y, double x) -- Compute arc tangent of y/x.
- double ceil(double x) -- Get smallest integral value that exceeds x.

  double floor(double x) -- Get largest integral value less than x.
- double cos(double x) -- Compute cosine of angle in radians.
  double cosh(double x) -- Compute the hyperbolic cosine of x.

  double sin(double x) -- Compute sine of angle in radians.
  double sinh(double x) - Compute the hyperbolic sine of x.

  double tan(double x) -- Compute tangent of angle in radians.
  double tanh(double x) -- Compute the hyperbolic tangent of x.
- double exp(double x -- Compute exponential of x
  double fabs (double x) -- Compute absolute value of x.
  double log(double x) -- Compute log(x).
  double log10 (double x) -- Compute log to the base 10 of x.
  double pow (double x, double y) -- Compute x raised to the power y.
  double sqrt(double x) -- Compute the square root of x.

More about scanf and printf

Entering input data :: scanf function

- General syntax:

  scanf (control string, arg1, arg2, …, argn);

  – "control string refers to a string typically containing data types of the arguments to be read in;

  – the arguments arg1, arg2, … represent pointers to data items in memory.

  Example: scanf (%d %f %c", &a, &average, &type);

- The control string consists of individual groups of characters, with one character group for each input data item.

  – '%' sign, followed by a conversion character.

– Commonly used conversion characters:

c	single character
d	decimal integer
f	floating-point number
s	string terminated by null character
X	hexadecimal integer

– We can also specify the maximum field-width of a data item, by specifying a number indicating the field width before the conversion character.

Example: scanf (“%3d %5d”, &a, &b);

Writing output data :: printf function

- General syntax:

  printf (control string, arg1, arg2, …, argn);

  – “control string refers to a string containing formatting information and data types of the arguments to be output;

  – the arguments arg1, arg2, … represent the individual output data items.

- The conversion characters are the same as in scanf.

- Examples:

```
printf  (“The average of %d and %d is %f”, a, b, avg);
printf  (“Hello \nGood \nMorning \n”);
printf (“%3d %3d %5d”, a, b, a*b+2);
printf (“%7.2f  %5.1f”, x, y);
```

- Many more options are available:
  - Read from the book.
  - Practice them in the lab.
- String I/O:
  - Will be covered later in the class.

Function Prototypes

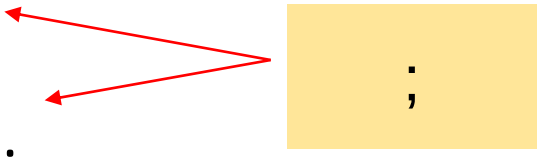
- Usually, a function is defined before it is called.
  - main() is the last function in the program.
  - Easy for the compiler to identify function definitions in a single scan through the file.
- However, many programmers prefer a top-down approach, where the functions follow main().
  - Must be some way to tell the compiler.
  - Function prototypes are used for this purpose.
    - Only needed if function definition comes after use.

Function Prototype (Contd.)

– Function prototypes are usually written at the beginning of a program, ahead of any functions (including main()).

– Examples:

```
int  gcd (int A, int B);
void div7 (int number);
```



- Note the semicolon at the end of the line.
- The argument names can be different; but it is a good practice to use the same names as in the function definition.

Function Prototype: Examples

```
#include  <stdio.h>

int ncr (int n, int r);
int fact (int n);

main()
{
     int i, m, n, sum=0;
     printf("Input m and n \n");
    scanf ("%d %d", &m, &n);

     for (i=1; i<=m; i+=2)
        sum = sum + ncr (n, i);

     printf ("Result: %d \n", sum);
}
```

Prototype declaration

```
int  ncr (int n, int r)
{
     return (fact(n) / fact(r) / fact(n-r));
}

int  fact (int n)
{
     int  i, temp=1;
     for (i=1; i<=n; i++)
        temp *= I;
     return (temp);
}
```

Function definition

Header Files

- Header files
  - contain function prototypes for library functions
  - `<stdlib.h>`, `<math.h>`, etc
  - Load with

```
#include <filename>
```

  - `#include <math.h>`

- Custom header files
  - Create file with functions
  - Save as `filename.h`
  - Load in other files with `#include "filename.h"`
  - Reuse functions

```c
/* Finding the maximum of three integers */
#include <stdio.h>

int maximum( int, int, int );   /* function prototype */

int main()
{
   int a, b, c;

   printf( "Enter three integers: " );
   scanf( "%d%d%d", &a, &b, &c );
   printf( "Maximum is: %d\n", maximum( a, b, c ) );

   return 0;
}

/* Function maximum definition */
int maximum( int x, int y, int z )
{
   int max = x;

   if ( y > max )
      max = y;

   if ( z > max )
      max = z;

   return max;
}
```

Prototype Declaration

Function Calling

Function Definition

Calling Functions: Call by Value and Call by Reference

- Used when invoking functions
- Call by value
  - Copy of argument passed to function
  - Changes in function do not effect original
  - Use when function does not need to modify argument
    - Avoids accidental changes
- Call by reference
  - Passes original argument
  - Changes in function effect original
  - Only used with trusted functions
- For now, we focus on call by value

An Example: Random Number Generation

- `rand` function
  - Prototype defined in `<stdlib.h>`
  - Returns "random" number between `0` and `RAND_MAX` (at least 32767)

    ```
    i = rand();
    ```
  - Pseudorandom
    - Preset sequence of "random" numbers
    - Same sequence for every function call
- Scaling
  - To get a random number between `1` and `n`

    ```
    1 + ( rand() % n )
    ```
    - `rand % n` returns a number between `0` and `n-1`
    - Add `1` to make random number between `1` and `n`

      ```
      1 + ( rand() % 6)   // number between 1 and 6
      ```

Random Number Generation: Contd.

- `srand` function
  - `Prototype defined in <stdlib.h>`
  - Takes an integer seed - jumps to location in "random" sequence

```
srand( seed );
```

```
1  /* A programming example
2     Randomizing die-rolling program */
3  #include <stdlib.h>
4  #include <stdio.h>
5
6  int main()
7  {
8     int i;
9     unsigned seed;
10
11    printf( "Enter seed: " );
12    scanf( "%u", &seed );
13    srand( seed );
14
15    for ( i = 1; i <= 10; i++ ) {
16       printf( "%10d ", 1 + ( rand() % 6 ) );
17
18       if ( i % 5 == 0 )
19          printf( "\n" );
20    }
21
22    return 0;
23 }
```

Algorithm

1. Initialize seed
2. Input value for seed
   2.1 Use `srand` to change random sequence
   2.2 Define Loop
3. Generate and output random numbers

Program Output

```
Enter seed: 67
        6       1       4       6       2
        1       6       1       6       4
```

```
Enter seed: 867
        2       4       6       1       6
        1       1       3       6       2
```

```
Enter seed: 67
        6       1       4       6       2
        1       6       1       6       4
```

#include: Revisited

- Preprocessor statement in the following form

  #include “filename”

- Filename could be specified with complete path.

  #include “/usr/home/rajan/myfile.h”

- The content of the corresponding file will be included in the present file before compilation and the compiler will compile thereafter considering the content as it is.

#include: Contd.

```
#include <stdio.h>
int x;

main()
{
  printf("Give value of x \n)";
 scanf("%d",&x);
  printf("Square of x=%d \n",x*x);
}
```

```
#include <stdio.h>

int x;
```

myfile.h

prog.c

#include <filename.h>

/usr/include/filename.h

It includes the file "filename.h" from a specific directory known as include directory.

#define: Macro definition

```
#include <stdio.h>
#define PI 3.14
main()
{
  float r=4.0,area;
  area=PI*r*r;
}
```

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```
#include <stdio.h>
main()
{
  float r=4.0,area;
  area=3.14*r*r;
}
```

#define with argument

- #define statement may be used with argument e.g.

```
#include <stdio.h>

main()
{
  int y=5;
  printf("value=%d \n", ((y)*(y))+3);
}
```

Which one is faster to execute?

sqr(x) written as macro definition?

sqr(x) written as an ordinary function?

#define with arguments: A Caution

- #define sqr(x) x*x
  - How macro substitution will be carried out?

    r = sqr(a) + sqr(30); ➔ r = a*a + 30*30;

    r = sqr(a+b); ➔ r = a+b*a+b;

    WRONG?

  - The macro definition should have been written as:

    #define sqr(x) (x)*(x)

    r = (a+b)*(a+b);

Recursion

- A process by which a function calls itself repeatedly.
  - Either directly.
    - X calls X.
  - Or cyclically in a chain.
    - X calls Y, and Y calls X.
- Used for repetitive computations in which each action is stated in terms of a previous result.
  - fact(n) = n * fact (n-1)

Contd.

- For a problem to be written in recursive form, two conditions are to be satisfied:
  - It should be possible to express the problem in recursive form.
  - The problem statement must include a stopping condition

fact(n) = 1, if n = 0

= n * fact(n-1), if n > 0

- Examples:
  - Factorial:

    fact(0) = 1

    fact(n) = n * fact(n-1), if n > 0
  - GCD:

    gcd (m, m) = m

    gcd (m, n) = gcd (m-n, n), if m > n

    gcd (m, n) = gcd (n, n-m), if m < n
  - Fibonacci series (1,1,2,3,5,8,13,21,….)

    fib (0) = 1

    fib (1) = 1

    fib (n) = fib (n-1) + fib (n-2), if n > 1

Example 1 :: Factorial

```
long  int  fact (n)
int  n;
{
   if   (n = = 0)
      return (1);
   else
      return  (n * fact(n-1));
}
```

Mechanism of Execution

- When a recursive program is executed, the recursive function calls are not executed immediately.
  - They are kept aside (on a stack) until the stopping condition is encountered.
  - The function calls are then executed in reverse order.

Example :: Calculating fact(4)

– First, the function calls will be processed:

fact(4) = 4 * fact(3)

fact(3) = 3 * fact(2)

fact(2) = 2 * fact(1)

fact(1) = 1 * fact(0)

– The actual values return in the reverse order:

fact(0) = 1

fact(1) = 1 * 1 = 1

fact(2) = 2 * 1 = 2

fact(3) = 3 * 2 = 6

fact(4) = 4 * 6 = 24

Another Example :: Fibonacci number

- Fibonacci number f(n) can be defined as:

  f(0) = 0

  f(1) = 1

  f(n) = f(n-1) + f(n-2), if n > 1

  – The successive Fibonacci numbers are:

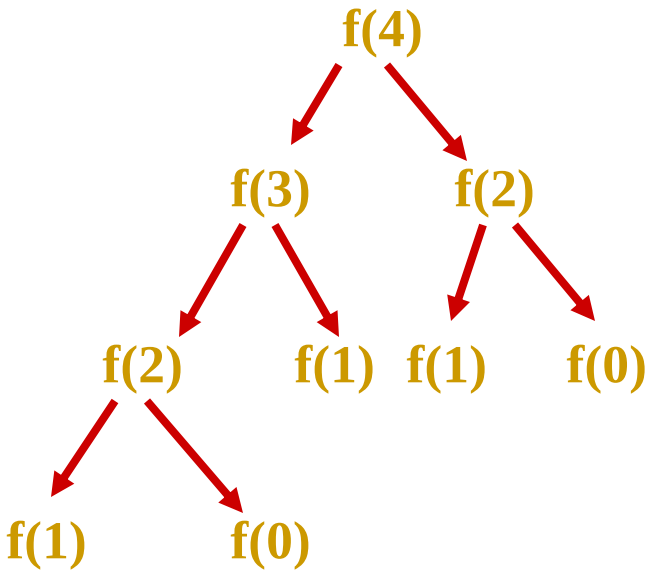
  0, 1, 1, 2, 3, 5, 8, 13, 21, ...

- Function

```
int   f (int n)
{
    if  (n  < 2)   return (n);
    else  return (f(n-1) + f(n-2));
}
```

Tracing Execution

- How many times the function is called when evaluating f(4) ?



- Inefficiency:
  - Same thing is computed several times.

9 times

Example Codes: fibonacci()

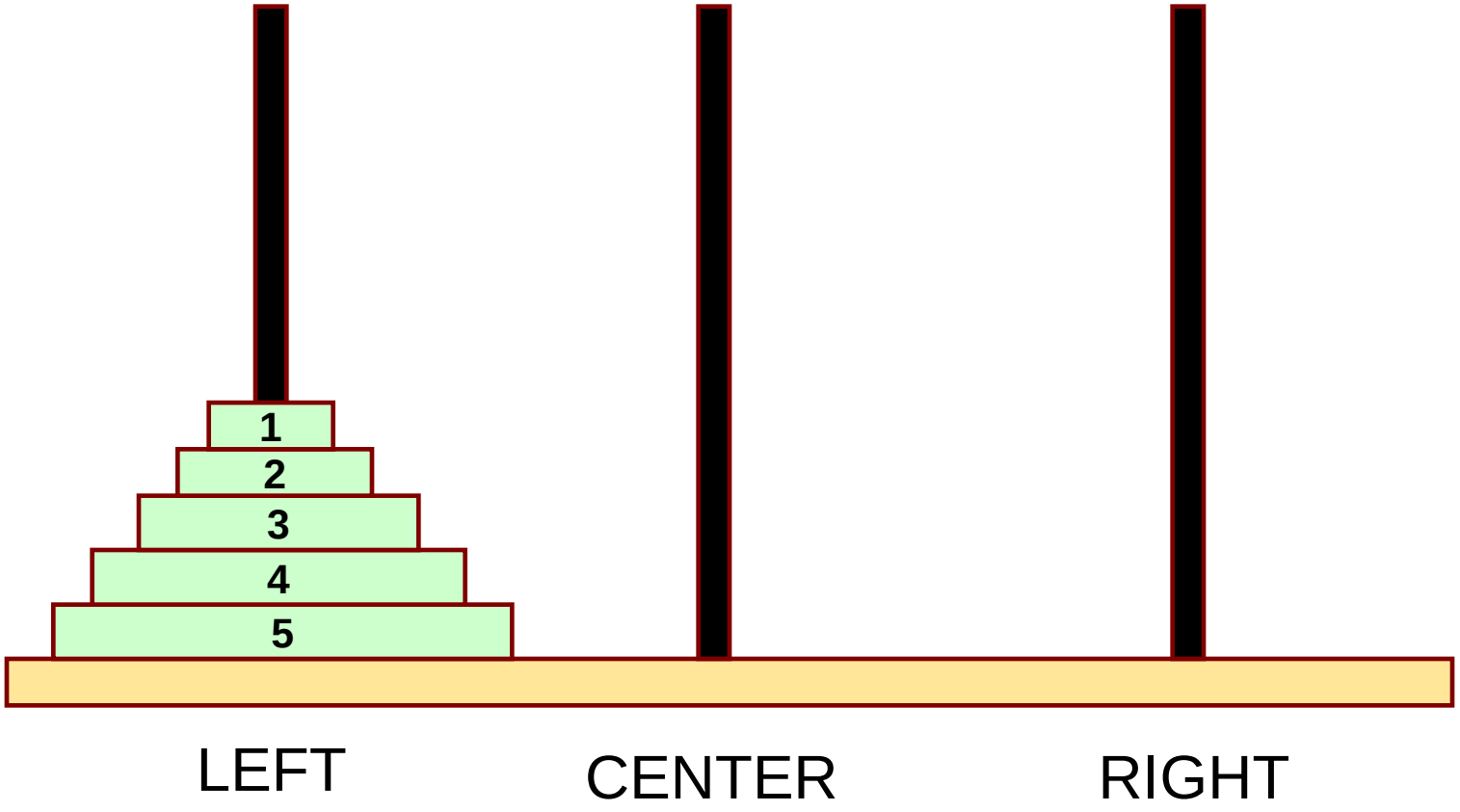
– Code for the `fibonacci` function

```
long fibonacci( long n )
{
 if (n == 0 || n == 1)  // base case
    return n;
 else
    return fibonacci( n - 1) +
      fibonacci( n – 2 );
}
```

Performance Tip

- Avoid Fibonacci-style recursive programs which result in an exponential “explosion” of calls.

Example: Towers of Hanoi Problem



- The problem statement:
  - Initially all the disks are stacked on the LEFT pole.
  - Required to transfer all the disks to the RIGHT pole.
    - Only one disk can be moved at a time.
    - A larger disk cannot be placed on a smaller disk.

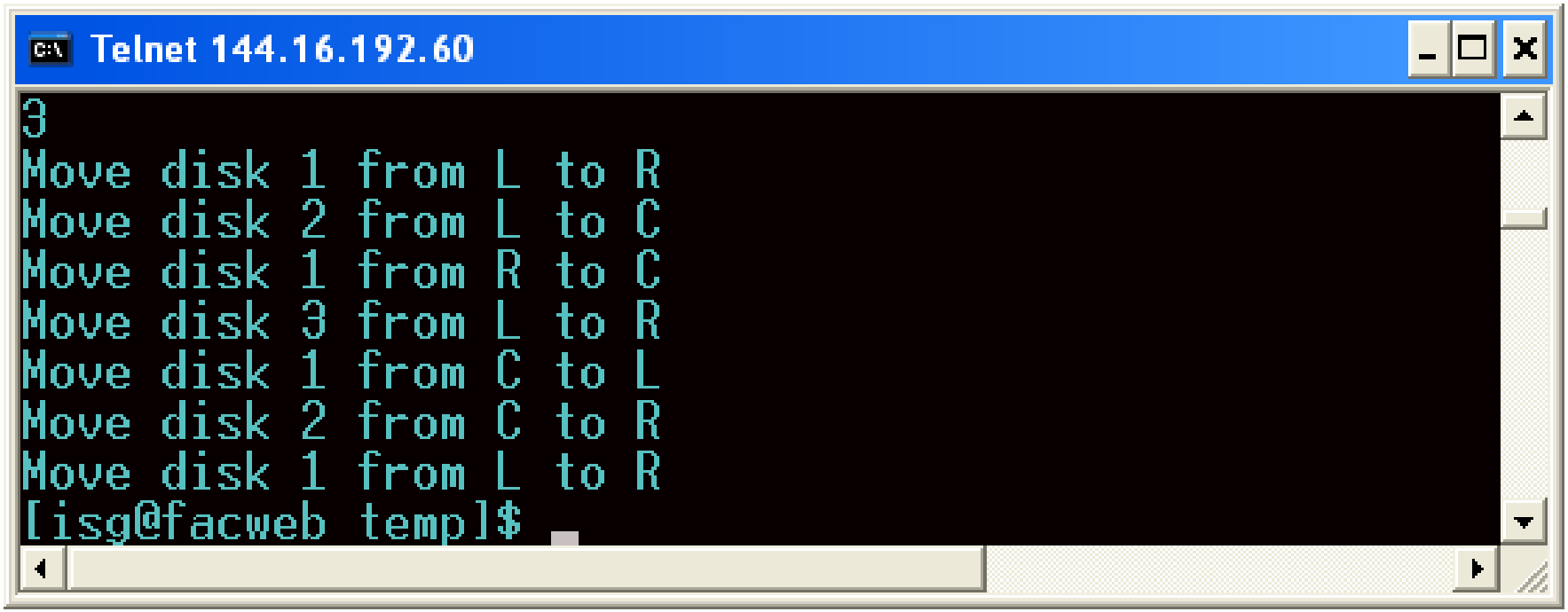
- Recursive statement of the general problem of n disks.
  - Step 1:
    - Move the top (n-1) disks from LEFT to CENTER.
  - Step 2:
    - Move the largest disk from LEFT to RIGHT.
  - Step 3:
    - Move the (n-1) disks from CENTER to RIGHT.

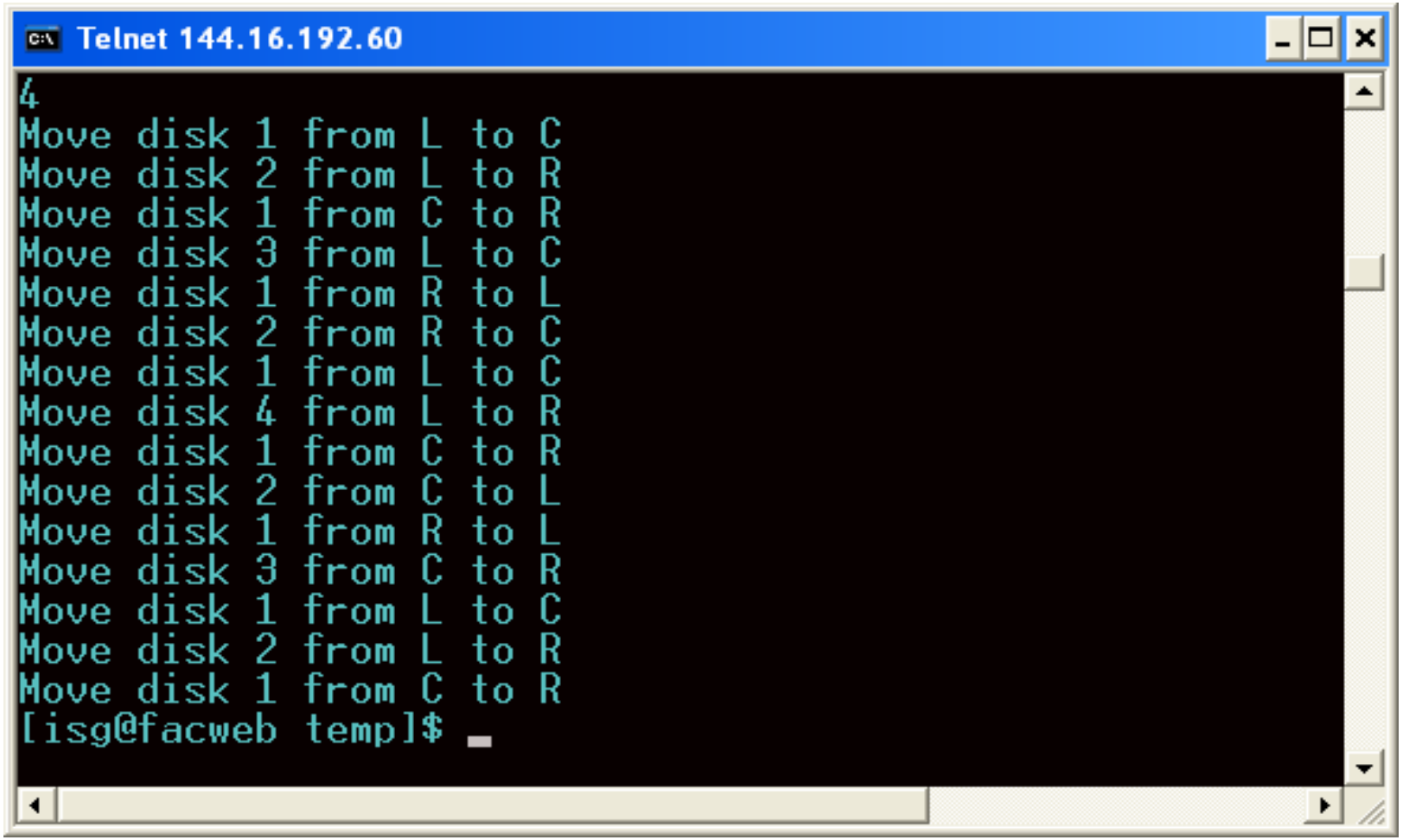
```
#include  <stdio.h>

void  transfer (int n, char from, char to, char temp);

main()
{
      int  n;  /* Number of disks */
      scanf (“%d”, &n);
      transfer (n, ‘L’, ‘R’, ‘C’);
}

void  transfer (int n, char from, char to, char temp)
{
      if  (n > 0)  {
                transfer  (n-1, from, temp,to);
                printf (“Move disk %d from %c to %c \n”, n, from, to);
                transfer (n-1, temp, to, from);
      }
      return;
}
```


Telnet 144.16.192.60
3
Move disk 1 from L to R
Move disk 2 from L to C
Move disk 1 from R to C
Move disk 3 from L to R
Move disk 1 from C to L
Move disk 2 from C to R
Move disk 1 from L to R
[isg@facweb temp]$


Telnet 144.16.192.60
4
Move disk 1 from L to C
Move disk 2 from L to R
Move disk 1 from C to R
Move disk 3 from L to C
Move disk 1 from R to L
Move disk 2 from R to C
Move disk 1 from L to C
Move disk 4 from L to R
Move disk 1 from C to R
Move disk 2 from C to L
Move disk 1 from R to L
Move disk 3 from C to R
Move disk 1 from L to C
Move disk 2 from L to R
Move disk 1 from C to R
[isg@facweb temp]$

Recursion vs. Iteration

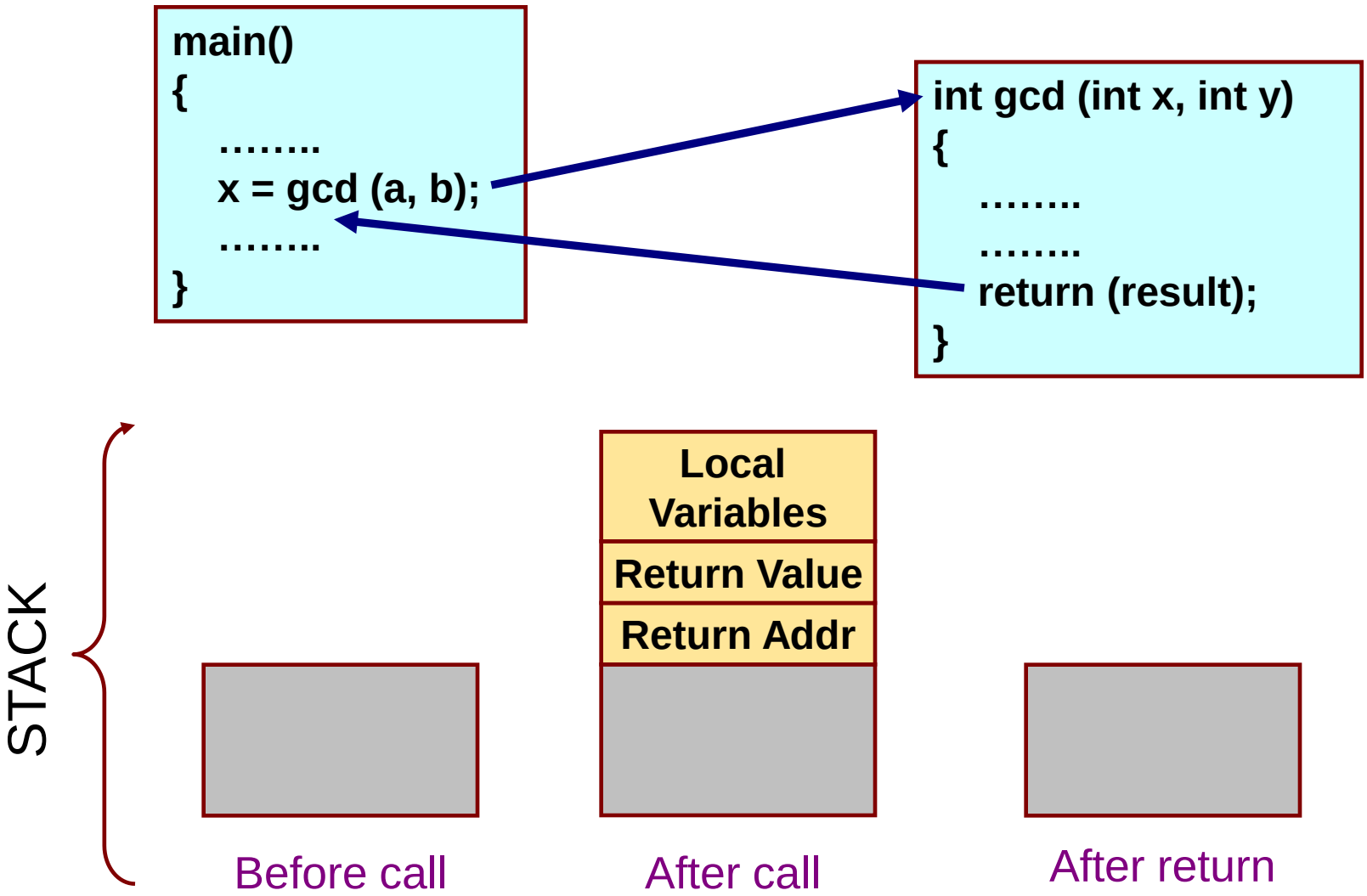
- Repetition
  - Iteration: explicit loop
  - Recursion: repeated function calls
- Termination
  - Iteration: loop condition fails
  - Recursion: base case recognized
- Both can have infinite loops
- Balance
  - Choice between performance (iteration) and good software engineering (recursion)

Performance Tip

- Avoid using recursion in performance situations. Recursive calls take time and consume additional memory.

How are function calls implemented?

- In general, during program execution
  - The system maintains a stack in memory.
    - Stack is a last-in first-out structure.
    - Two operations on stack, push and pop.
  - Whenever there is a function call, the activation record gets pushed into the stack.
    - Activation record consists of the return address in the calling program, the return value from the function, and the local variables inside the function.
    - At the end of function call, the corresponding activation record gets popped out of the stack.

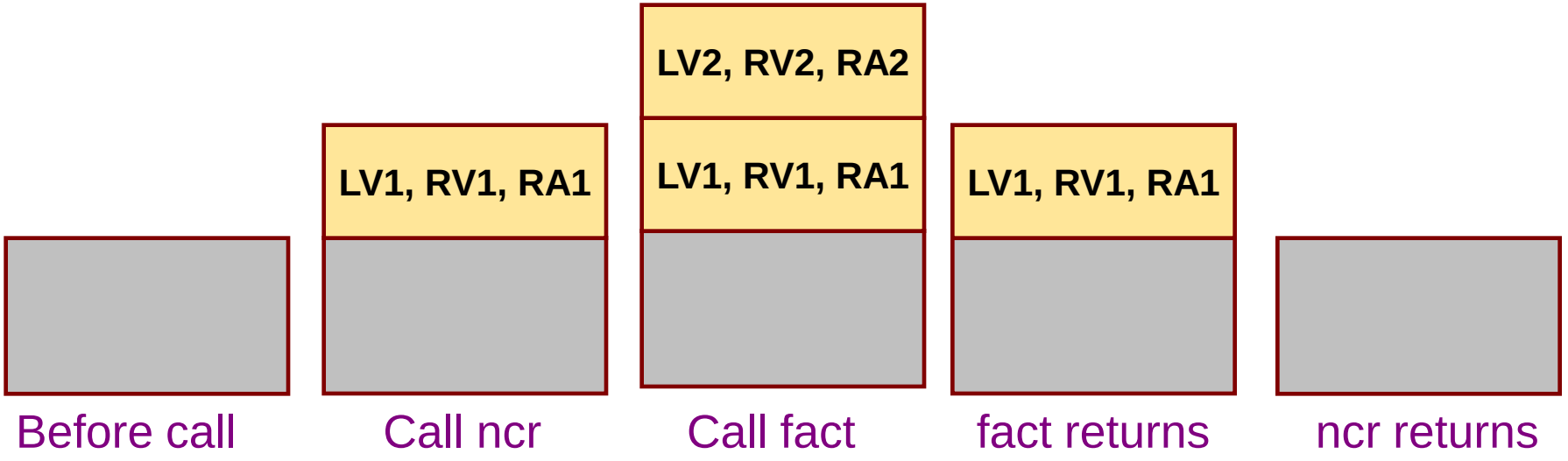

main()
{
……..
x = gcd (a, b);
……..
}
int gcd (int x, int y)
{
……..
……..
return (result);
}
STACK
Local Variables
Return Value
Return Addr
Before call
After call
After return

```
main()
{
    ……..
    x = ncr (a, b);
    ……..
}
```

```
int ncr (int n, int r)
{
    return (fact(n)/
        fact(r)/fact(n-r));
}
```

3 times

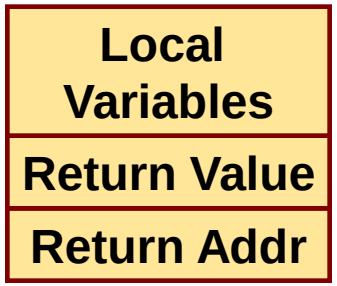
```
int fact (int n)
{
    ……..
    return (result);
}
```



What happens for recursive calls?

- What we have seen ….
  - Activation record gets pushed into the stack when a function call is made.
  - Activation record is popped off the stack when the function returns.
- In recursion, a function calls itself.
  - Several function calls going on, with none of the function calls returning back.
    - Activation records are pushed onto the stack continuously.
    - Large stack space required.
    - Activation records keep popping off, when the termination condition of recursion is reached.

- We shall illustrate the process by an example of computing factorial.
  - Activation record looks like:

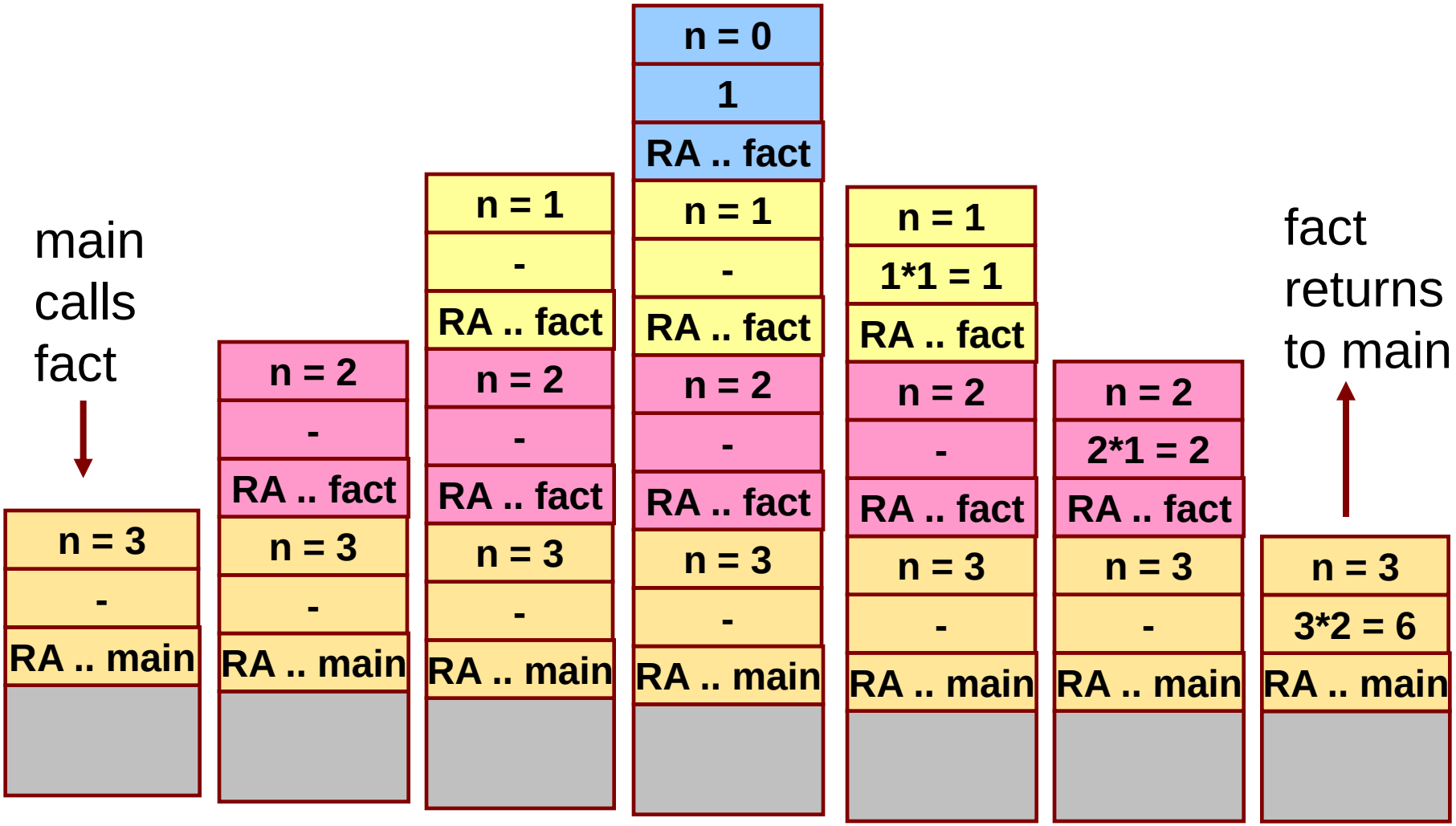


Example:: main() calls fact(3)

```
main()
{
    int  n;
    n = 4;
    printf ("%d \n", fact(n) );
}
```

```
int  fact (int n)
{
    if   (n = = 0)
        return (1);
    else
        return  (n * fact(n-1));
}
```

TRACE OF THE STACK DURING EXECUTION



Do Yourself

- Trace the activation records for the following version of Fibonacci sequence.

```
#include <stdio.h>
int   f (int n)
{
      int a, b;
      if  (n  < 2)    return (n);
      else  {
        a = f(n-1);
        b = f(n-2);
        return (a+b);   }
}

main() {
    printf("Fib(4) is: %d \n", f(4));
}
```

X

Y

main

Local Variables (n, a, b)
Return Value
Return Addr (either main, or X, or Y)

Storage Class of Variables

What is Storage Class?

- It refers to the permanence of a variable, and its *scope* within a program.
- Four storage class specifications in C:
  - Automatic: `auto`
  - External: `extern`
  - Static: `static`
  - Register: `register`

Automatic Variables

- These are always declared within a function and are local to the function in which they are declared.
  - Scope is confined to that function.
- This is the default storage class specification.
  - All variables are considered as `auto` unless explicitly specified otherwise.
  - The keyword `auto` is optional.
  - An automatic variable does not retain its value once control is transferred out of its defining function.

```
#include <stdio.h>

int factorial(int m)
{
   auto int i;
   auto int temp=1;
   for (i=1; i<=m; i++)
       temp = temp * i;
   return (temp);
}
```

```
main()
{
   auto int  n;
   for (n=1; n<=10; n++)
     printf ("%d! = %d \n",
           n, factorial (n));
}
```

Static Variables

- Static variables are defined within individual functions and have the same scope as automatic variables.
- Unlike automatic variables, static variables retain their values throughout the life of the program.
  - If a function is exited and re-entered at a later time, the static variables defined within that function will retain their previous values.
  - Initial values can be included in the static variable declaration.
    - Will be initialized only once.
- An example of using static variable:
  - Count number of times a function is called.

EXAMPLE 1

```
#include <stdio.h>

int factorial (int n)
{
   static int count=0;
   count++;
   printf ("n=%d, count=%d \n", n, count);
   if (n == 0) return 1;
   else return (n * factorial(n-1));
}
```

```
main()
{
    int i=6;
    printf ("Value is: %d \n", factorial(i));
}
```

- Program output:

```
n=6, count=1
n=5, count=2
n=4, count=3
n=3, count=4
n=2, count=5
n=1, count=6
n=0, count=7
Value is: 720
```

EXAMPLE 2

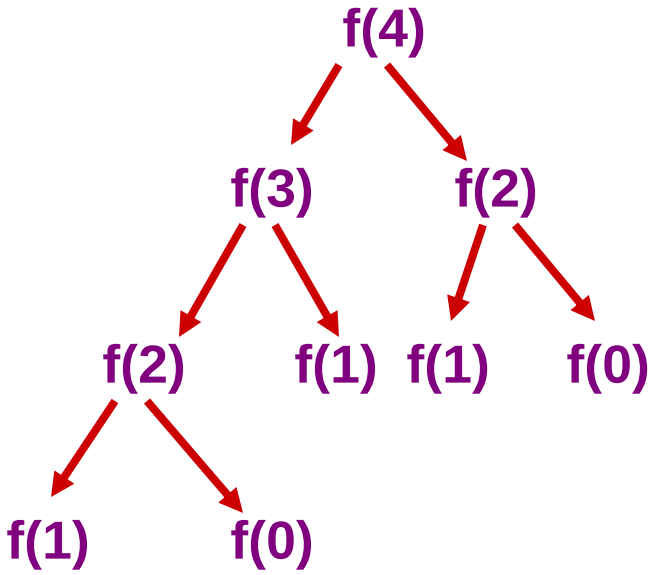
```
#include <stdio.h>

int fib (int n)
{
   static int count=0;
   count++;
   printf ("n=%d, count=%d \n", n, count);
   if (n < 2) return n;
   else return (fib(n-1) + fib(n-2));
}
```

```
main()
{
    int i=4;
    printf ("Value is: %d \n", fib(i));
}
```

- Program output:

```
n=4, count=1
n=3, count=2
n=2, count=3
n=1, count=4
n=0, count=5
n=1, count=6
n=2, count=7
n=1, count=8
n=0, count=9
Value is: 3
```



[0,1,1,2,3,5,8,….]

Register Variables

- These variables are stored in high-speed registers within the CPU.
  - Commonly used variables may be declared as register variables.
  - Results in increase in execution speed.
  - The allocation is done by the compiler.

External Variables

- They are not confined to single functions.
- Their scope extends from the point of definition through the remainder of the program.
  - They may span more than one functions.
  - Also called global variables.
- Alternate way of declaring global variables.
  - Declare them outside the function, at the beginning.

```
#include <stdio.h>

int count=0;    /** GLOBAL VARIABLE **/
int factorial (int n)
{
   count++;
  printf ("n=%d, count=%d \n", n, count);
   if (n == 0) return 1;
  else return (n * factorial(n-1));
}
```

```
main()  {
    int i=6;
    printf ("Value is: %d \n", factorial(i));
    printf ("Count is: %d \n", count);
}
```

- Program output:

```
n=6, count=1
n=5, count=2
n=4, count=3
n=3, count=4
n=2, count=5
n=1, count=6
n=0, count=7
Value is: 720
Count is: 7
```