Lecture **8**

Functions

Fundamentals of Computer and Programming

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What We Will Learn

- Introduction
- Passing input parameters
- Producing output
- Scope of variables
- Storage Class of variables
- Function usage example
- Recursion

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Introduction

- Until now, we learned to develop simple algorithms
  - Interactions, Mathematics, Decisions, and Loops
- Real problems: very complex
  - Compressing a file
  - Calculator
  - Games, MS Word, Firefox, …
- Cannot be developed at once
  - Divide the problem into smaller sub-problems
  - Solve the sub-problems
  - Put the solutions altogether to get the final solution
- **Modular** programming

Modular programming

- Solving a large and complex problem
- Design the overall algorithm
- Some portions are **black-box**
  - We know what each box does
  - But we do not worry how
  - Later, we think about the **black-boxes** and develop them
- Black-boxes are implemented by **functions**

Modular programming: Advantages

- Easy to develop and understand
- Reusability
  - Something is used frequently
    - Mathematatic: Square, Power, Sin, …
    - Programming: Printing, Reading
  - Develop it one time, use it many times
- Multiple developers can work on different parts
- Each module can be tested and debugged separately

Functions in C

- Functions in mathematics
  - *z = f(x, y)*
- Functions in C
  - Queries: Return a value
    - **`sin(), fabs()`**
  - Commands: do some tasks, do not return any value
    - **`printf_my_info(...)`**

Functions in C

- Three steps to use functions in C
- Function prototype (declaration) (اعلان تابع) (معرفی الگوی تابع)
  - Introduce the function to the compiler
- Function definition (تعریف تابع)
  - What the function does
- Function call (فراخوانی تابع)
  - Use the function

Function prototype

```
<output type> <function name>(<input
  parameter types>);
```

- <output type>
  - Queries: `int, float,…`
  - Command: `void`
- <function name> is an identifier
- <input parameter list>
  - <type>, <type>, …
    - `int, float, …`
  - `void`

Function definition

```
<output type> <function name>(<input parameters>)
{
   <statements>
}
```

- <output type>
  - Queries: `int, float,…`
  - Command: `void`
- <function name> is an identifier
- <input parameters>
  - <type> <identifier>, <type> <identifier>, …
    - `int in, float f, …`
  - `void`
- Function definition should be out of other functions
  - Function in function is not allowed

Function call

- Command function

```
<function name> (inputs);
```

- Query function

```
<variable> = <function name>(inputs);
```

- Inputs should match by function definition
- Functions are called by *another* function
  - Function call comes inside in a function

Example

```c
/* Function declaration */
void my_info(void);

int main(void){
  printf("This is my info");
  my_info(); /* Function call */
  printf("=============");
  return 0;
}

/* Function definition */
void my_info(void){
  printf("Student name is Dennis Ritchie\n");
  printf("Student number: 9822222\n");
}
```

Function declaration is optional if program is developed in a single file

```
void my_info(void){
  printf("My name is Dennis Ritchie\n");
  printf("My student number: 98222222\n");
}

int main(void){
  my_info();
  printf("---------------\n");
  my_info();
  return 0;
}
```

Function Declaration?!!!!

- Is function declaration needed?
- Is there any useful application of function declaration?
- **Yes!**
- Libraries are implemented using it
  - .h files contains the function declarations
    - and also other definitions
  - .so, .a, .dll, … are the compiled function definitions

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Input Parameters

- Inputs of function
  - No input: `void`
  - One or multiple inputs
- Each input should have a type
- Input parameters are split by " , "

```
void f(void)
void f(int a)
void f(int a, float b)
void f(int a, b) //compile error
```

Example: print_sub function

```
#include <stdio.h>

void print_sub(double a, double b){
   double res;
   res = a - b;
   printf("Sub of %f and %f is %f\n", a, b, res);
}

int main(void){
   double d1 = 10, d2 = 20;
   print_sub(56.0, 6.0);    //What is the output?
   print_sub(d1, d2);       //output?
   print_sub(d1, d2 + d2);  //output?
   return 0;
}
```

تابعی که دو عدد را بگیرد
و تفاضل آنها را چاپ کند.

How Does Function Call Work?

- Function call is implemented by "stack"
- Stack is a logical part of the main memory
- Variables of function and its input variables are in stack
- When a function calls
  - Its variables including the inputs are allocated in stack
  - The value of input parameters from caller function is pushed to stack of called function
    - They are *copied* in to the variables of function
- When function finished, its stack is freed.

print_sub: What happen?

```
print_sub(56.0, 6.0);
```

- 56.0 is copied the memory location **a**
- 6.0 is copied to memory location **b**

```
double a = 56.0;
double b = 6.0;
double res;
res = a - b;
```

print_sub: What happen?

```
print_sub(d1, d2);
```

- Value of **d1** is copied to memory location **a**
- Value of **d2** is copied to memory location **b**

```
double a = 10.1;
double b = 20.2;
double res;
res = a - b;
```

Call by Value

Call by value

- In call by value mechanism
  - The values are copied to the function
- If we change values in the function
  - The copied version is changed
  - The original value does not affected
- Call by value inputs cannot be used to produce output

add function (wrong version)

```
void add(double a, double b, double res){
  res = a + b;
  return;
}

int main(void){
  double d1 = 10.1, d2 = 20.2;
  double result = 0;
  add(56.0, 6.7, result);
  printf("result = %f\n", result);   // result = 0
  add(d1, d2, result);
  printf("result = %f\n", result);   // result = 0
}
```

Stack in C/C++

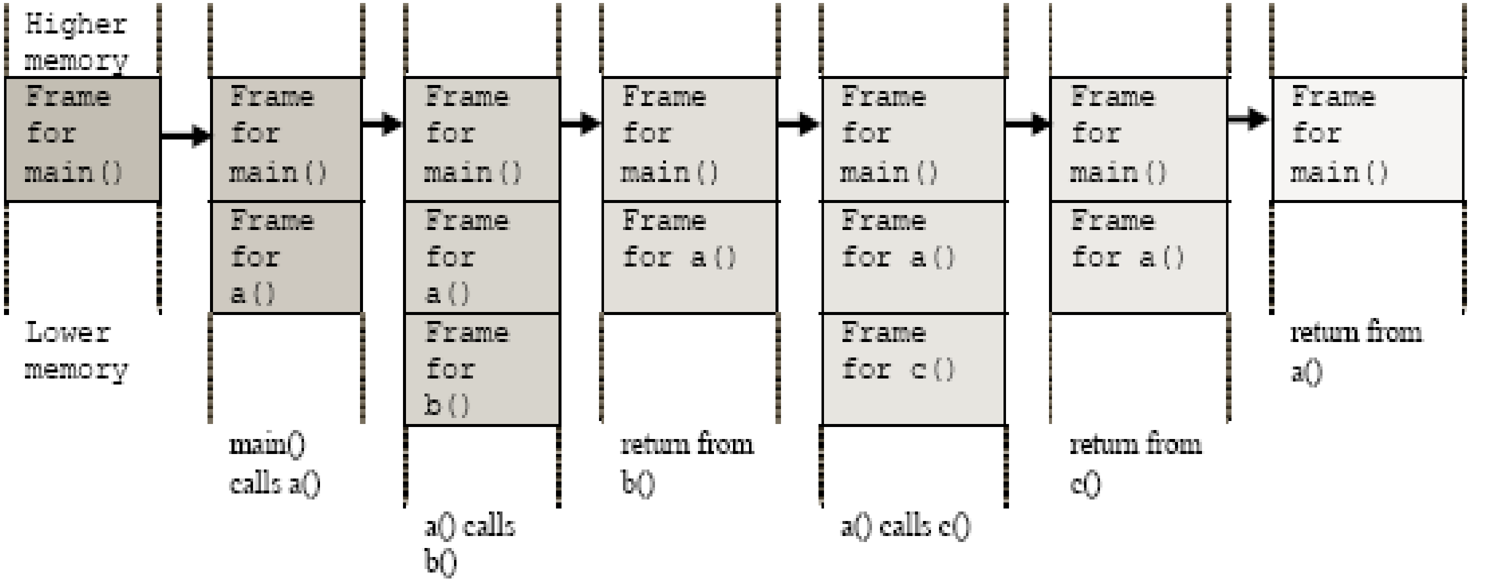
```
#include <stdio.h>

int b(int i){ return i; }

int c(int j){
   return j; }

int a(int i, int j){
  b(i);
  c(j);
  return 0;
}

int main(){
  a(3, 5);
  return 0;
}
```



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Producing output

- What we have seen are the "Command"
- Query functions
  - Produce output
  - Output cannot be produced by the "call by value" parameters
- To produce an output
  - Declare output type
  - Generate the output by `return`

The `return` command

- To generate a result by a function

```
return <value>;
```

- Only one value can be returned
- **`return`** finishes the running function
- Function can have multiple return
  - Only one of them runs each time
- The type of the returned value = the result type
  - Otherwise, cast

Exmaple: my_fabs (Version 1)

```
double my_fabs(double x){
   double res;
   if(x >= 0)
      res = x;
   else
      res = -1 * x;
   return res;
}

void main(void){
   double d = -10;
   double b;
   b = my_fabs(d);
   printf("%lf\n", b);                          // 10
   printf("%lf\n", my_fabs(-2 * b));            // 20
}
```

Exmaple: my_fabs (Version 2)

```
double my_fabs(double x){
   if(x >= 0)
      return x;
   return (-1 * x);
}

void main(void){
   double d = -10;
   double b;
   b = my_fabs(d);
   printf("b  = %lf\n", b);
   b = my_fabs(-2 * d);
   printf("b  = %lf\n", b);
}
```

Output of functions

- A function can produce at most one output

- Output of functions can be **dropped**

```
double f;
sin(f);         //we drop the output of sin
gcd(10, 20); //we drop the output of gcd
```

Casting in functions

- Cast for input
  - Prototype: `void f(int a, double b);`
  - Call: `f(10.1, 20.2);`
- Cast for output
  - Prototype: `int f(int a);`
  - Call: `double d = f(10);`
  - Cast in return

```
int f(int a){
    ...
    return 10.20
}
```

Be careful: empty input/output type

- If output or input type is not specified → int
  - Casting may not work

```
f1(a){
     printf("a = %d\n", a);  return a / 2;
}
f2(int a){
     printf("a = %d\n", a);  return a / 2;
}
f3(float a){
     printf("a = %f\n", a);  return a / 2;
}
int main(){
     printf("%d\n", f1(10.5));
     printf("%d\n", f2(10.5));
     printf("%d\n", f3(10.5));
     return 0;
}
```

```
// a = 1
// 0
// a = 10
// 5
// a = 10.500000
// 5
```

Inline Functions & Macro

- Function call using stack has its overhead
  - 2 approaches to reduce the overhead
- **`inline`** function
  - To ask from compiler to compile it as inline, but no guarantee

```
inline int f(float x)
```

- Macros

```
#define PRINT_INT(X) printf("%d\n", X)
```

Example: GCD (بزرگترین مقسوم علیه مشترک)

```
# define PRINT_INT(x) printf("%d\n",x); \
                      printf("==================\n");
inline int gcd(int a, int b){ /* return gcd of a and b */
   int temp;
   while(b != 0){
       temp = a % b;
       a = b;
       b = temp;
   }
   return a;
}

void main(void){
   int i = 20, j = 35, g;
   g = gcd(i, j);
   printf("GCD of %d and %d = ", i , j);
   PRINT_INT(g);
   g = gcd(j, i);
   printf("GCD of %d and %d = ", j , i);
   PRINT_INT(g);}
```

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Scope of Variables

- Variables
  - Are declared in the start of functions
  - Are used any where in the function after declaration
  - Cannot be used outside of function
  - Cannot be used in other functions
- Scope of variable
  - A range of code that the variable can be used
- Variable cannot not be used outside of its scope
  - Compile error

Scopes and Blocks

- Scopes are determined by Blocks
  - Start with { and finished by }
  - Example: statements of a function, statement of a **`if`** or **`while`**, …
- Variables
  - Can be declared in a block
  - Can be used in the declared block
  - Cannot be used outside the declared block
- The declared block is the scope of the variable

Variables in Blocks

```
#include <stdio.h>
int main(void){
   int i;
   for(i = 1; i <= 10; i++){
      int number;
      printf("Enter %d-th number: ", i);
      scanf("%d", &number);
      if((number % 2) == 0)
         printf("Your number is even\n");
      else
          printf("Your number is odd\n");
   }
   /* compile error
    printf("The last number is %d\n", number); */
   return 0;
}
```

Nested Scopes/Blocks

- Scopes can be nested
  - Example: Nested **`if`**, nested **`for`**, …

```
void main(){ // block 1
  int i;
  { // block 2
    int j;
    { // block 3
      int k;
    }
    int m;
  }
}
```

Variables in Nested Blocks

- All variables from outer block can be used in inner blocks
  - Scope of outer block contains the inner block

- Variables in inner block cannot be used in outer block
  - Scope of the inner block does not contains the outer block

Variables in Nested Blocks: Example

```
int k = 0;
for(int i = 0; i < 10; i++){
    /* block 1 */
    if(i > 5){
        /* block 2 */
        int j = i;
        ...
    }
    while(k > 10){
        /* block 3 */
        int l = i;
        /* int m = j; compile error */
        ...
    }
    /* k = l; compile error */
}
```

Same Variables in Nested Block

- If a variable in inner block has the same identifier of a variable in outer block
  - The inner variable hides the outer variable
  - Changing inner variables does not change outer variable

```
int j = 20, i = 10;
printf("outer i = %d, %d\n", i, j);
while(…){
   int i = 100;
   j = 200;
   printf("inner i = %d, %d\n", i, j);
   ...
}
printf("outer i = %d, %d\n", i, j);
```

Do NOT Use It!!!

Local Variables

- All variables defined in a function are the local variable of the function
- Can ONLY be used in the function, not other functions

```
void func(void){
   int i, j;
   float f;
   /* These are local variables */
}
int main(void){
   i = 10; /* compile error, why? */
   f = 0;  /* compile error, why? */
}
```

Global/External Variables

- Global variables are defined outside of all functions
- Global variables are *initialized* to zero
- Global variables are available to all **subsequent** functions

```
void f(){
  i = 0; // compile error
}
int i;
void g(){
  int j = i; // g can use i
}
```

Global/External Variables: Example

```
int i, j;
float f;
void func(void){
   printf("i = %d \n", i);       // i = 0
   printf("f = %f \n", f);       // f = 1000
   i = 20;
}
void f1(){
   printf("%d", i);
}
int main(void){
   f = 1000;
   func();
   f1();
   return 0;
}
```

Parameter Passing by Global Variables: my_fabs (V.3)

```
double x;

void my_fabs(void){
   x = (x > 0) ? x : -1 * x;
}

void main(void){
   double b, d = -10;
   x = d;
   my_fabs();
   b = x;
   printf("b  = %f\n", b);
}
```

Do not use this method. Parameters should be passed by input parameter list.

Global variable are used to define (large) variables that are used in many functions

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Storage Classes

- Storage class
  - How memory is allocated for the variable
  - Until when the variable exists
  - How it is initialized
- Storage classes in C
  - Automatic (اتوماتیک)
  - External (خارجی)
  - Static (ایستا)
  - Register (ثبات)

Storage Classes: Automatic

- All local variables are automatic by default
  - Input parameters of a function
  - Variables defined inside a function/block
  - Keyword "**`auto`**" is optional before them
- Generated at the start of each run of the block
- Destroyed at the end of each run of the block
- Are not initialized

Storage Classes: External

- All global variables are external by default
  - Are initialized by 0
  - Are generated when program starts
  - Are destroyed when program finishes
- Usage of keyword "**`extern`**"
  - To use global variables in other files
  - To use global variables before definition
  - To emphasize that variable is global
    - This usage is optional
  - Access to a global variable with the same name

extern Example

```
#include <stdio.h>
int x=50;
int main()
{
   int x=100;
   {
       extern int x;
       printf("x= %d\n",x);
   }
   printf("x= %d\n",x);
   return 0;
}
// x = 50
// x = 100
```

Use a global variable in another file in C

To use a global variable in another file in C using extern, you need to do the following steps:

- Declare the global variable in one source file (for example, **file1.c**) and initialize it with a value. For example: `int global_var = 42;`
- Declare the same global variable in a header file (for example, **file1.h**) using the extern keyword. This tells the compiler that the variable is defined elsewhere and it should not allocate storage for it. For example: `extern int global_var;`
- Include the header file in any other source file (for example, file2.c) that needs to access the global variable. For example: **#include "file1.h"**

Use a global variable in another file in C

- Use the global variable in any function in the other source file as you would normally do. For example: `printf("Global variable: %d\n", global_var);`
- This way, you can share the same global variable across multiple source files without redefining it or causing conflicts.
- You can also modify the value of the global variable in any source file and the changes will be reflected in all the other source files that use it.

Storage Classes: Static

- Keyword "`static`" comes before them
- For local variables:
  - 1) Generated in the first run of the block
  - 2) Destroyed when program finishes
  - 3) Initialized
    - If no value → initialized by 0
  - **Only initialized in the first run of the block**

Storage Classes: Static

- Keyword "`static`" comes before them
- For global variables:
  - 1) Generated when program starts
  - 2) Destroyed when program finishes
  - 3) Always initialized
    - If no value → initialized by 0
- *4) Is not accessible for other files*

Storage Classes: Register

- Keyword "**`register`**" comes before them
- Can be used for local variables
- Compiler tries to allocated the variable in registers of CPU
  - But does not guaranteed
  - Registers are very fast and small memories
- Improve performance

Storage Classes, Auto: Examples

```
void f(int i, double d){
  int i2;
  auto int i3;
  double d2;
  auto double d3;
}
```

All variables (i, d, i2, i3, d2, d3) are auto variables

Storage Classes, Extern: Examples

```
int i = 10, j = 20;

void print(void){
  printf("i = %d, j = %d\n", i, j);
}

int main(void){
  extern int i;  // i refers the global i
  int j;         // j is new variable

  print();       // i = 10, j = 20
  i = 1000;
  j = 2000;
  print();       // i = 1000, j = 20
  return 0;
}
```

Storage Classes: Examples

```
int i;
void func(void){
  int j;
  printf("i = %d \n", i);
  printf("j = %d \n", j);
  i = 20;
}
int main(void){
  func();
  func();
  i = 30;
  func();
  return 0;
}
```

```
// i = 0
// j = ???
// i = 20
// j = ??
// i = 30
// j = ??
```

Storage Classes, Static: Examples

```
void func(void){
  int j;
  static int i;
  printf("i = %d \n", i);
  printf("j = %d \n", j);
  i = 20;
}
int main(void){
  func();                                            // i = 0
  func();                                            // j = ???
  /* i = 30;  compile error, why? */                 // i = 20
  func();                                            // j = ???
  return 0;                                          // i = 20
}                                                    // j = ???
```

Storage Classes, Static: Examples

```
void func(void){
  int j;
  static int i = 10;
  printf("i = %d \n", i);
  printf("j = %d \n", j);
  i = 20;
}

int main(void){
  func();                     // i = 10
                              // j = ???
  func();                     // i = 20
                              // j = ???
  return 0;
}
```

Storage Classes, Register: Examples

```
register int i;

for(i = 0; i < 100; i++)
   …
```

Be careful: loops & automatic variables

- According to standard:

"For such an object that does not have a variable length array type, its lifetime extends from entry into the block with which it is associated until execution of that block ends in any way."

- Variable is defined in a block of a loop
- 1) the variable retains its value between iterations of the loop if it is NOT variable length array
- 2) the variable does NOT retain its value between iterations of the loop if it is a variable length array

Loops & automatic variables

```
int main(){
    int i;
    for(i = 0; i < 5; i++){
        int j;
        if(i){
            printf("&j = %p, j = %d\n"
                    , &j, j);
            j++;
        }
        else
            j = i;
    }
}
```

```
&j = 0xffffcc38, j = 0
&j = 0xffffcc38, j = 1
&j = 0xffffcc38, j = 2
&j = 0xffffcc38, j = 3
```

Loops & automatic variables

```
int main(){
    int i;
    for(i = 0; i < 5; i++){
        int j[5 * i + 1];
        if(i){
            printf("&j[0] = %p, j[0] = %d\n"
                    , &(j[0]), j[0]);
            j[0]++;
        }
        else
            j[0] = i;
    }
}
```

```
&j[0] = 0xffffcbd0, j[0] = 12291
&j[0] = 0xffffcbc0, j[0] = 230944
&j[0] = 0xffffcbb0, j[0] = 230944
&j[0] = 0xffffcb90, j[0] = -2148
```

Loops & automatic variables

```
int main(){
    int i;
    for(i = 0; i < 5; i++){
        int j[5 * 3 + 1];
        if(i){
            printf("&j[0] = %p, j[0] = %d\n"
                   , &(j[0]), j[0]);
            j[0]++;
        }
        else
            j[0] = i;
    }
}
```

```
&j[0] = 0xffffcbf0, j[0] = 0
&j[0] = 0xffffcbf0, j[0] = 1
&j[0] = 0xffffcbf0, j[0] = 2
&j[0] = 0xffffcbf0, j[0] = 3
```

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How to use functions: Example

- An Example
  - Goldbach's Conjecture (حدس گلدباخ)
  - Any even number larger than 2 can be expressed as sum of two prime numbers.
- It is not proved yet!
  - A prize of 1,000,000$ to proof ;-)
- Write a program that takes a set numbers which ends by 0 and checks correctness of the conjecture.

Main Overall Algorithm

While(number is not zero)

    if(number >= 2 and even)

        Check Goldbach's Conjecture

    else

        Print some message

    read next number

This is a module

It is a black-box in this step

Check Goldbach's Conjecture Algorithm

Algorithm: Goldbach
Input: n
Output: 0 if conjecture is incorrect else 1

```
i = 2
while (i <= n/2)
    j = n – i
    if(is_prime(j))
        conjecture is correct
        return
    i = next_prime_number(i)

Conjecture is incorrect
```

This is a module

It is a black-box in this step

is_prime algorithm

Algorithm: is_prime

Input: n

Output: 1 if n is prime else 0

```
for(i from 2 to sqrt(n))
    if(n % i == 0)
        n is not prime
n is prime
```

next_prime_number algorithm

Algorithm: next_prime_number

Input: n

Output: prime number

```
if n is 2
    output is 3
else
    do
        n = n + 2
    while(is_prime(n) == 0)
    output is n
```

Putting them altogether

```
int is_prime(int n){
   …
}

int next_prime_number(int n){
   …
}

int check_Goldbach(int n){
   …
}

int main(void){
   …
}
```

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Introduction

- Iteration *vs.* Recursion
  - The Recursion and Iteration both **repeatedly** execute the set of instructions.

- Factorial
  - n! = n x n-1 x … x 2 x 1
  - n! = n x (n-1) !

- Greatest common divisor (GCD)
  - GCD(a, b) = Euclidean Algorithm
  - GCD(a, b) = GCD(b, a mod b)

Introduction

- Original problem can be solved by
  - Solving a similar but simpler problem (recursion)
    - (n-1)! in factorial, GCD(b, a mod b)
- There is a simple (basic) problem which we can solve it directly (without recursion)
  - Factorial: 1! = 1
  - GCD: a mode b == 0 → a

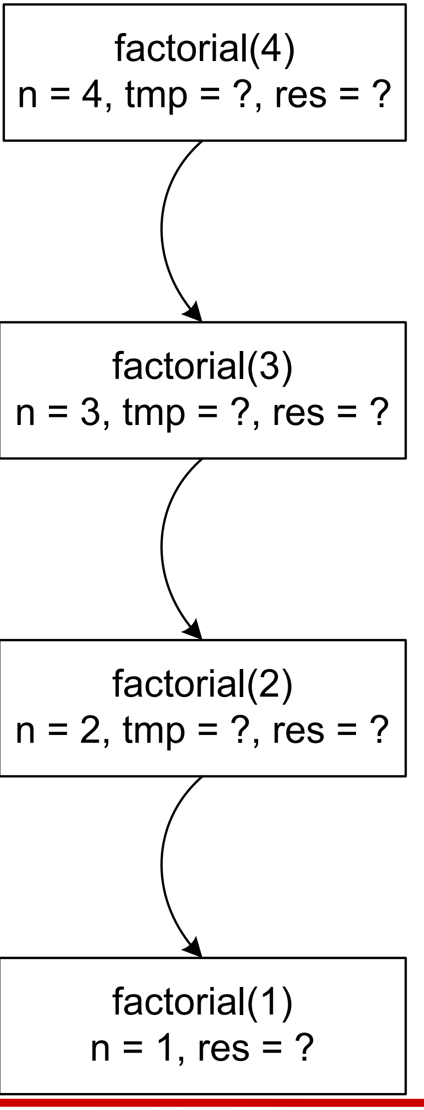
Recursion in C

- Recursive Algorithm
  - An algorithm uses itself to solve the problem
  - There is a basic problem with known solution
- Recursive Algorithms are implemented by recursive functions
- Recursive function
  - A function which calls itself
  - There is a condition that it does not call itself

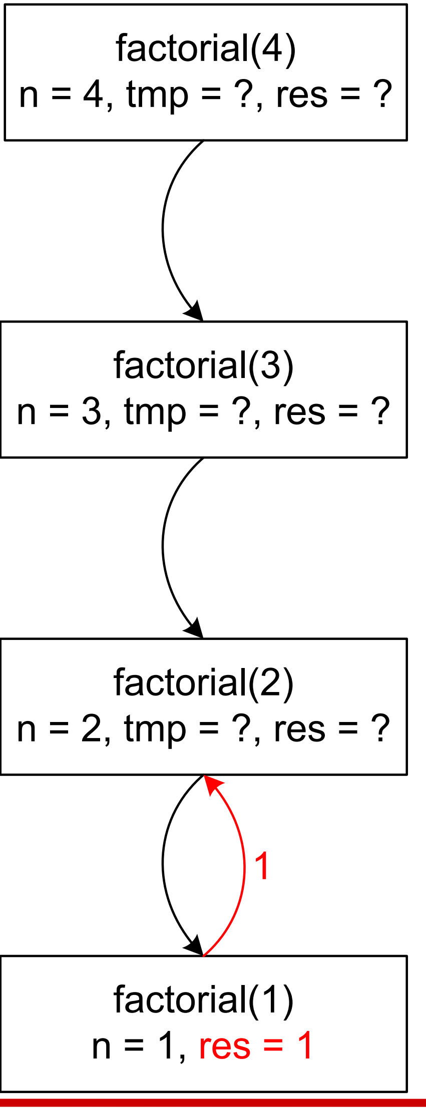
Recursive function to calculate Factorial

```
#include <stdio.h>
int factorial(int n){
    int res, tmp;
    if(n == 1)
     /* The basic problem */
     res = 1;
    else{ /* The recursive call */
     tmp = factorial(n - 1);
     res = n * tmp;
    }
    return res;
}
void main(void){
    int i = 4;
    int fac = factorial(i);
    printf("%d! = %d\n", i, fac);
}
```

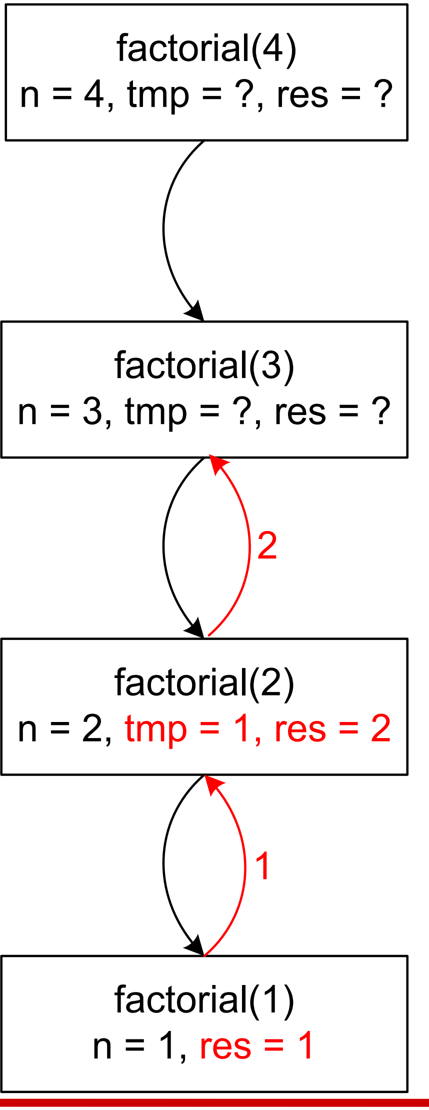
Function Call Graph + Stacks



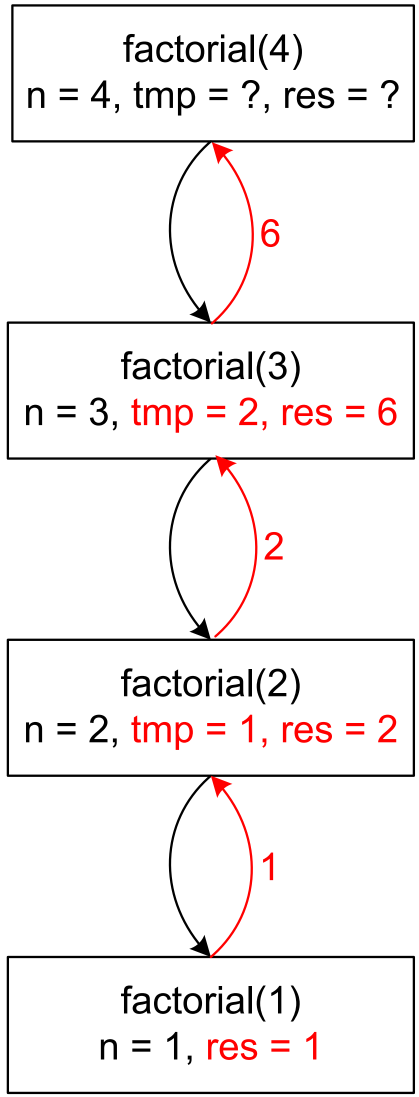
Function Call Graph + Stacks



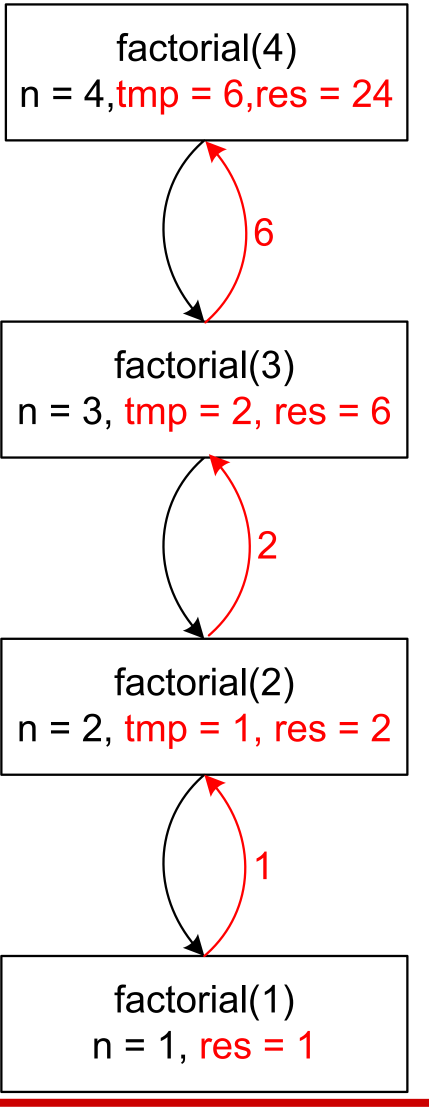
Function Call Graph + Stacks



Function Call Graph + Stacks



Function Call Graph + Stacks



Examples

- Recursive version of GCD?
- Recursive version of Fibonacci numbers
  - Fibonacci numbers
    - 1, 1, 2, 3, 5, 8, ...
- Print digits: left-to-right and right-to-left

Greatest common divisor (GCD)

```
#include <stdio.h>
int GCD(int a, int b){
    if(b == 0)
        return a;
    else
        return GCD(b, a % b);
}
int main(void){
    printf("GCD(1, 10) = %d \n", GCD(1, 10));
    printf("GCD(10, 1) = %d \n", GCD(10, 1));
    printf("GCD(15, 100) = %d \n", GCD(15, 100));
    printf("GCD(201, 27) = %d \n", GCD(201, 27));
    return 0;
}
```

Fibonacci numbers

```
#include <stdio.h>
int fibo(int n){
    if(n == 1)
        return 1;
    else if(n == 2)
        return 1;
    else
        return fibo(n - 1) + fibo(n - 2);
}
int main(void){
    printf("fibo(1) = %d\n", fibo(1));
    printf("fibo(3) = %d\n", fibo(3));
    printf("fibo(5) = %d\n", fibo(5));
    printf("fibo(8) = %d\n", fibo(8));

    return 0;
}
```

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Print digits recursive

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```
#include <stdio.h>
void print_digit_right_left(int n){
    int digit = n % 10;
    printf("%d ", digit);
    if(n >= 10)
        print_digit_right_left(n / 10);
}
int main(void){
    printf("\n print_digit_right_left(123): ");
    print_digit_right_left(123);    // 3 2 1
    printf("\n print_digit_right_left(1000): ");
    print_digit_right_left (1000);  // 0 0 0 1
   return 0;
}
```

Print digits recursive

```
#include <stdio.h>
void print_digit_left_right(int n){
    if(n >= 10)
         print_digit_left_right(n / 10);
    int digit = n % 10;
    printf("%d ", digit);
}
int main(void){
    printf("\n print_digit_left_right(123): ");
    print_digit_left_right(123);   //1 2 3
    printf("\n print_digit_left_right(1000): ");
    print_digit_left_right (1000); // 1 0 0 0
  return 0;
}
```

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Indirect recursion

- What we have seen are direct recursion
  - A function calls itself directly
- Indirect recursion
  - A function calls itself using another function
  - Example:
    - Function A calls function B
    - Function B calls function A

Determine whether input is odd or even

```
#include <stdio.h>
#include <stdbool.h>
bool is_even(int n);
bool is_odd(int n);

bool is_even(int n){
    if(n == 0)
        return true;
    if(n == 1)
        return false;
    else
        return is_odd(n - 1);
}
bool is_odd(int n){
     if(n == 0)
         return false;
     if(n == 1)
         return true;
     else
        return is_even(n - 1);
}
```

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```
int main(void){
    if(is_even(20))
        printf("20 is even\n");
    else
        printf("20 is odd\n");

    printf("23 is %s\n",
is_odd(23) ? "odd" : "even");

    return 0;
}
```

Bugs & Avoiding Them

- Be careful about the order of input parameters

```
int diff(int a, int b){return a - b;}

diff(x,y) or diff(y,x)
```

- Be careful about casting in functions
- Recursion must finish, be careful a bout basic problem in the recursive functions
  - No base problem → Stack Overflow
- Static variables are useful debugging

Reference

- Reading Assignment: Chapter 5 of “C How to Program”