Week 5 - Lecture 3
Variable Scope and Recursion
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Overview

- **Header file**
- Recursive function
- Scope of variables

Header File

Each standard library has a corresponding header containing the function prototypes for all the functions in that library and definitions of various data types and constants needed by those functions.

Header	Explanation
`<assert.h>`	Contains information for adding diagnostics that aid program debugging.
`<ctype.h>`	Contains function prototypes for functions that test characters for certain properties, and function prototypes for functions that can be used to convert lowercase letters to uppercase letters and vice versa.
`<errno.h>`	Defines macros that are useful for reporting error conditions.
`<float.h>`	Contains the floating-point size limits of the system.
`<limits.h>`	Contains the integral size limits of the system.
`<locale.h>`	Contains function prototypes and other information that enables a program to be modified for the current locale on which it's running. The notion of locale enables the computer system to handle different conventions for expressing data such as dates, times, currency amounts and large numbers throughout the world.
`<math.h>`	Contains function prototypes for math library functions.
`<setjmp.h>`	Contains function prototypes for functions that allow bypassing of the usual function call and return sequence.

Header File (2)

- Standard libraries e.g. #include <stdio.h>
- Your own libraries e.g. #include "add.h"

```c
#include <stdio.h>

// Instruction: correct the program so that it would print the the sum of 1 and 2

int add(int i, int y);

int main(void)
{
    printf("%d\n", add(1, 2));

    return 0;
}

int add(int i, int y)
{
    return (i + y);
}
```

```c
#include <stdio.h>
#include "add.h"


int main(void)
{
    printf("%d\n", add(1, 2));

    return 0;
}
```

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Example: Int Calculator

- Increase reusability of your code.

- Encapsulate (hide) unnecessary information from the user.

```c
#include <stdio.h>

int addInt(int a, int b);
int subtractInt(int a, int b);
int multiplyInt(int a, int b);
int divideInt(int a, int b);

int main(void)
{
    printf("1 + 2 = %2d\n", addInt(1, 2));
    printf("1 - 2 = %2d\n", subtractInt(1, 2));
    printf("1 * 2 = %2d\n", multiplyInt(1, 2));
    printf("1 / 2 = %2d\n", divideInt(1, 2));

    return 0;
}

int addInt(int a, int b)
{
    return (a + b);
}

int subtractInt(int a, int b)
{
    return (a - b);
}

int multiplyInt(int a, int b)
{
    return (a * b);
}

int divideInt(int a, int b)
{
    return (a / b);
}
```

```c
#include <stdio.h>
#include "calculator.h"

int main(void)
{
    printf("1 + 2 = %2d\n", addInt(1, 2));
    printf("1 - 2 = %2d\n", subtractInt(1, 2));
    printf("1 * 2 = %2d\n", multiplyInt(1, 2));
    printf("1 / 2 = %2d\n", divideInt(1, 2));

    return 0;
}
```

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Example: Int Calculator (2)

- #include <mark>"calculator.h" NOT <calculator.h></mark>
- #ifndef protects you from including the same .h files multiple times.

```
1   #ifndef CALCULATOR_H
2   #define CALCULATOR_H
3
4   int addInt(int a, int b);
5   int subtractInt(int a, int b);
6   int multiplyInt(int a, int b);
7   int divideInt(int a, int b);
8
9   #endif
```

File Name: math_func.h

```c
int add (int x, int y)
{
    return x+y;
}


int subtract (int x, int y)
{
    return x-y;
}
```

File Name: my_math.h

```
#ifndef MY_MATH_H
#define MY_MATH_H

int add (int, int);
int subtract (int, int);

#include "math_func.h"
#endif
```

File Name: my_prog.c

```c
#include <stdio.h>
#include "my_math.h"

int main (void)
{
    printf("%d\n", add(2, 1));
    printf("%d\n", subtract(2, 1));
    return 0;
}
```

#ifndef ... #endif

```c
#include <stdio.h>

#define YEARS_OLD 12
#ifndef YEARS_OLD
#define YEARS_OLD 10
#endif

int main()
{
  printf("this is older than %d ", YEARS_OLD);

  return 0;
}
```

- **The #ifndef directive of the C Programming Language helps in allowing the conditional compilation.**
- **The #ifndef preprocessor only checks If the specific macro is not at all defined with the help of the #define directive.**
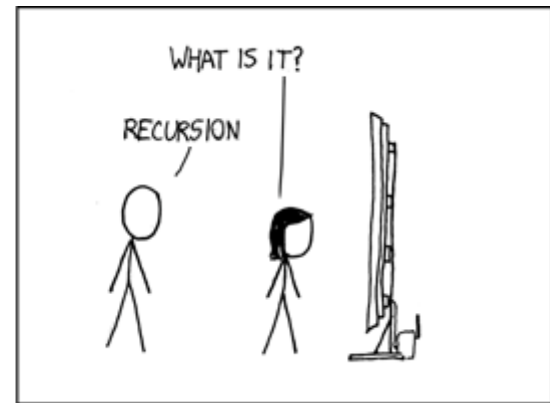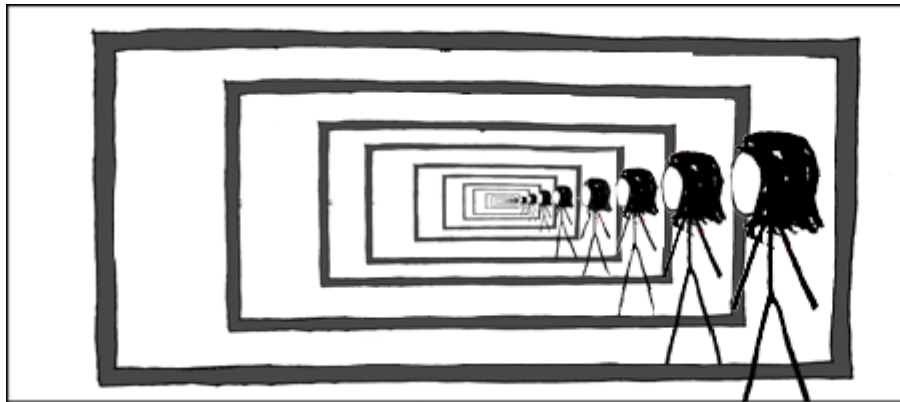
Overview

- Header file

- **Recursive function**

- Scope of variables

Recursion

- Functions that call themselves either directly or indirectly through another function.

- Base case – stopping condition for recursive function, to avoid infinite loop.

Source: http://vaidehijoshi.github.io/blog/2014/12/14/to-understand-recursion-you-must-first-understand-recursion/

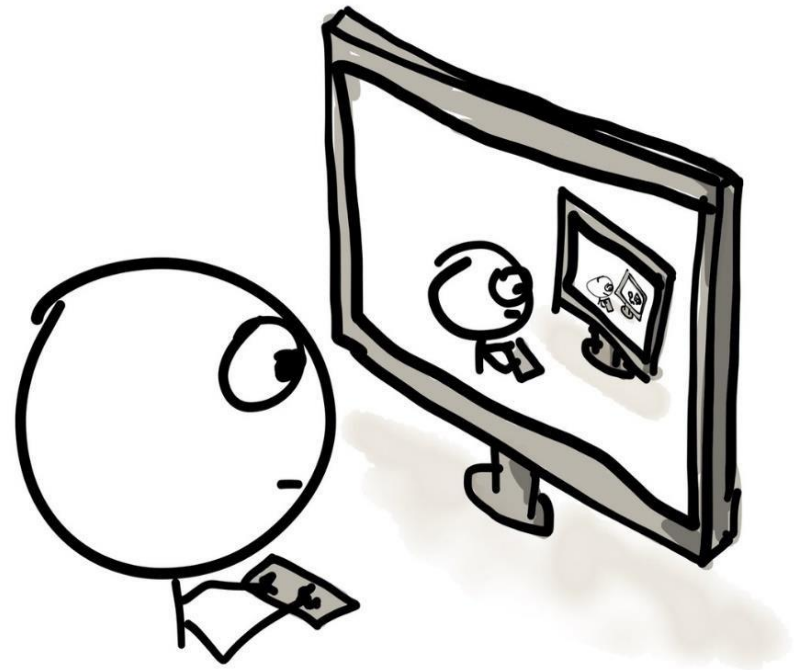# Example: Factorials

- A factorial of a number *n* is the product of all integers between *n* and 1.

- E.g. factorial of 5 is 5 * 4 * 3 * 2 * 1

- Factorial base case:
  - if i <= 1
    - return 1;

- Factorial how to:
  - return (i * fact(n – 1));

Example: Factorials (2)

- Starting from the largest i.e. *x*.

- Each loop iteration reduces x by 1.

```
92   /* Iterative implementation of factorial */
93   int factorial_iter(int x)
94   {
95       if(x < 1)
96       {
97           printf("Error, x < 1\n");
98           exit(1);
99       }
100
101      int total = 1;
102      int i = 0;
103      for(i = x; i > 1; i--)
104      {
105          total = total * i;
106      }
107      return total;
108  }
```

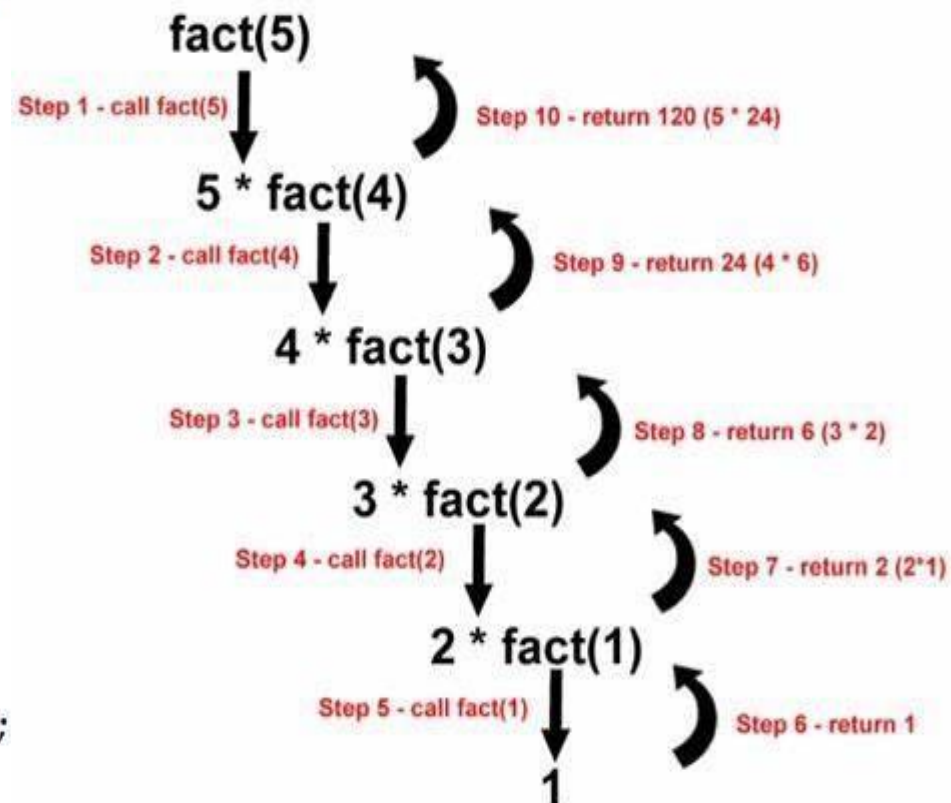Source: https://derickbailey.com/2015/01/21/hiding-recursion-with-nested-functions-in-javascript/

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Example: Factorials (3)

- Starting from the largest i.e. *x*.

- If x is not one, repeatedly call itself with x – 1.

```
73  /* Recursive implementation of factorial */
74  int factorial_rec(int x)
75  {
76      if(x < 1)
77      {
78          printf("Error, x < 1\n");
79          exit(1);
80      }
81
82      if(x == 1)
83      {
84          return 1;
85      }
86      else
87      {
88          return factorial_rec(x - 1) * x;
89      }
90  }
```


fact(5)

Step 1 - call fact(5)   Step 10 - return 120 (5 * 24)

5 * fact(4)

Step 2 - call fact(4)   Step 9 - return 24 (4 * 6)

4 * fact(3)

Step 3 - call fact(3)   Step 8 - return 6 (3 * 2)

3 * fact(2)

Step 4 - call fact(2)   Step 7 - return 2 (2*1)

2 * fact(1)

Step 5 - call fact(1)   Step 6 - return 1

1

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Recursion vs. iteration

- Recursion is a very important tool in developing algorithms. However, careless use of recursion in programming has many negatives.

- It repeatedly invokes the mechanism---and consequently the overhead---of function calls.

- This can be expensive in both processor time and memory space.

Recursion vs. iteration (2)

- Each recursive call causes another copy of the function (actually only the function's variables) to be created; this can consume considerable memory.

- Iteration normally occurs within a function, so the overhead of repeated function calls and extra memory assignment is omitted.

- So why choose recursion?
  - It makes the code easier to underhand and debug.

Example: Searching an Array

- Given an array of integers.

- Return the array index of the first element of the array which is equal to *x*

```
121     #include <stdio.h>
122     #include <stdlib.h>
123
124     // Iterative implementation of search.
125     int search_iter(const int *ns, int len, int target)
126     {
127         int i = 0;
128         for(i = 0; i < len; i++)
129         {
130             if(ns[i] == target)
131             {
132                 return i;
133             }
134         }
135         return -1;
136     }
```
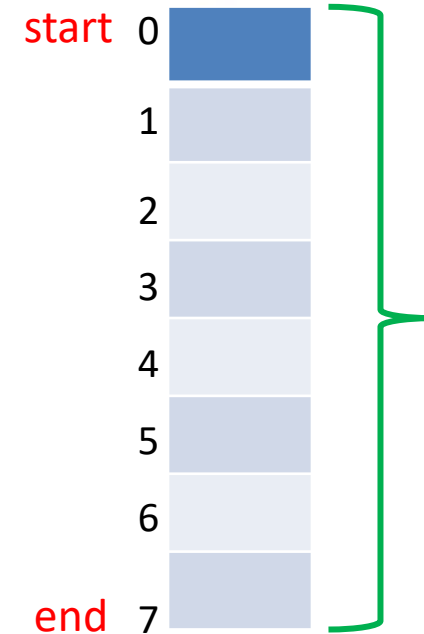
Iterative

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Example: Search an Array (2)

- Start from array[0].

- Increase the index by 1 each time.

```
139    int search_rec_a(const int *ns, int start, int end, int target)
140    {
141        if(start == end)
142        {
143            return -1;
144        }
145
146        if(ns[start] == target)
147        {
148            return start;
149        }
150        else
151        {
152            return search_rec_a(ns, start + 1, end, target);
153        }
154    }
```

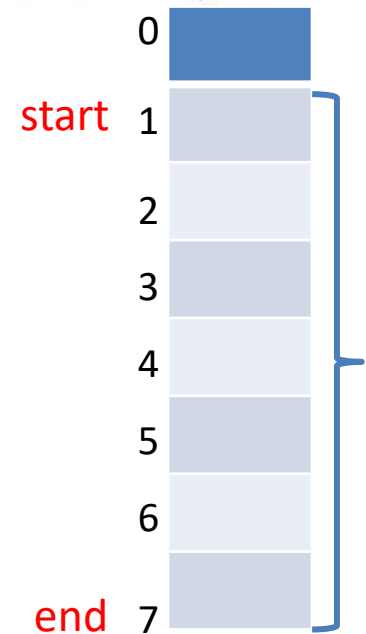start 0
1
2
3
Recursive 4
5
6
end 7

Example: Search an Array (2)

- Start from array[0].

- Increase the index by 1 each time.

```
139    int search_rec_a(const int *ns, int start, int end, int target)
140    {
141        if(start == end)
142        {
143            return -1;
144        }
145
146        if(ns[start] == target)
147        {
148            return start;
149        }
150        else
151        {
152            return search_rec_a(ns, start + 1, end, target);
153        }
154    }
```

0

start 1
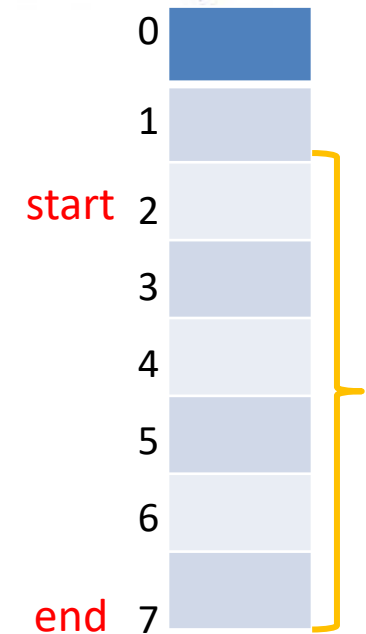
2

3

Recursive 4

5

6

end 7

Example: Search an Array (2)

- Start from array[0].

- Increase the index by 1 each time.

```
139    int search_rec_a(const int *ns, int start, int end, int target)
140    {
141        if(start == end)
142        {
143            return -1;
144        }
145
146        if(ns[start] == target)
147        {
148            return start;
149        }
150        else
151        {
152            return search_rec_a(ns, start + 1, end, target);
153        }
154    }
```

Recursive

0
1
start 2
3
4
5
6
end 7

Be Careful … Stack Overflow

- Computers have limited memory.
- Each function call uses a part of your computer's memory.

Source: https://www.codewithc.com/c-program-for-tower-of-hanoi-recursion/
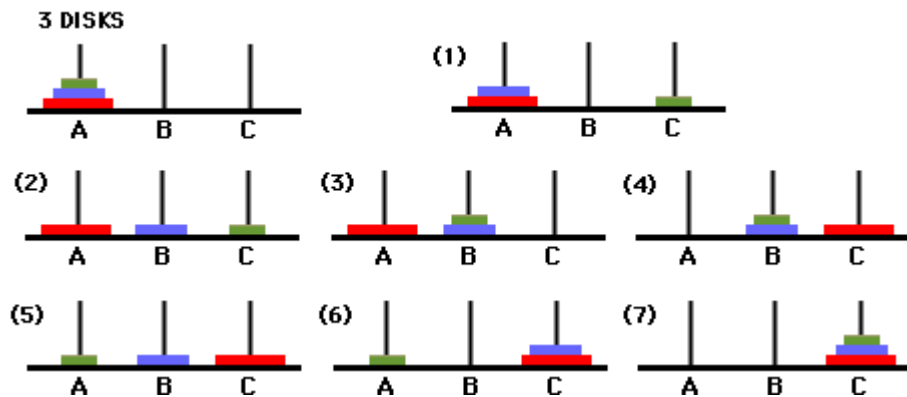
Stack Overflows

results from too much data being pushed onto the stack. The memory/capacity of the stack is exceeded.

Source: https://www.freecodecamp.org/news/recursion-is-not-hard-858a48830d83/

Learn to Debug!!

- Print something … anything to see when your program breaks!!

- Print the values of the parameters to see if your program does what it suppose to do!
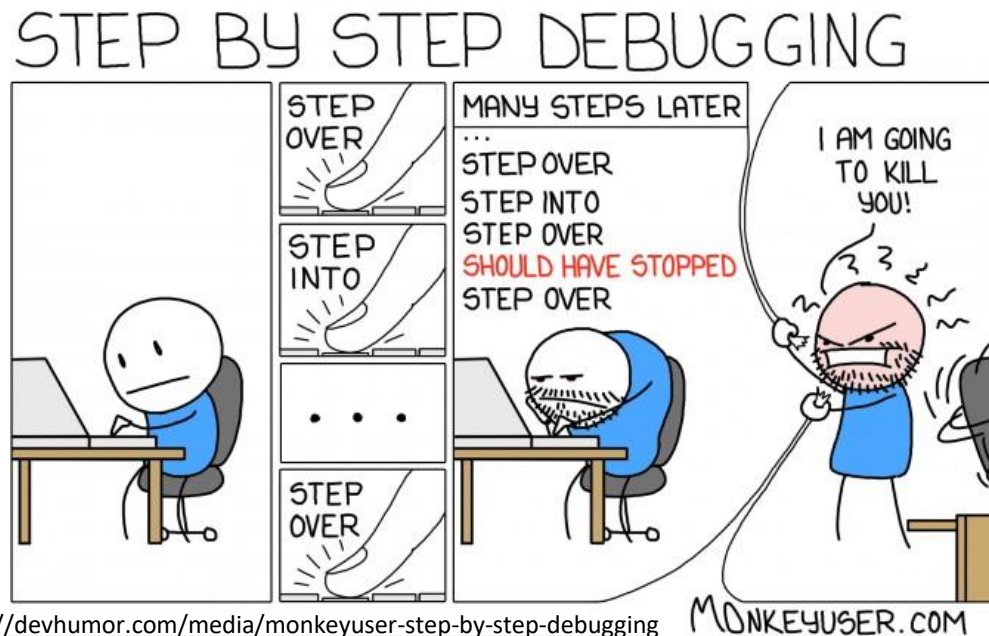
Source: http://devhumor.com/media/monkeyuser-step-by-step-debugging
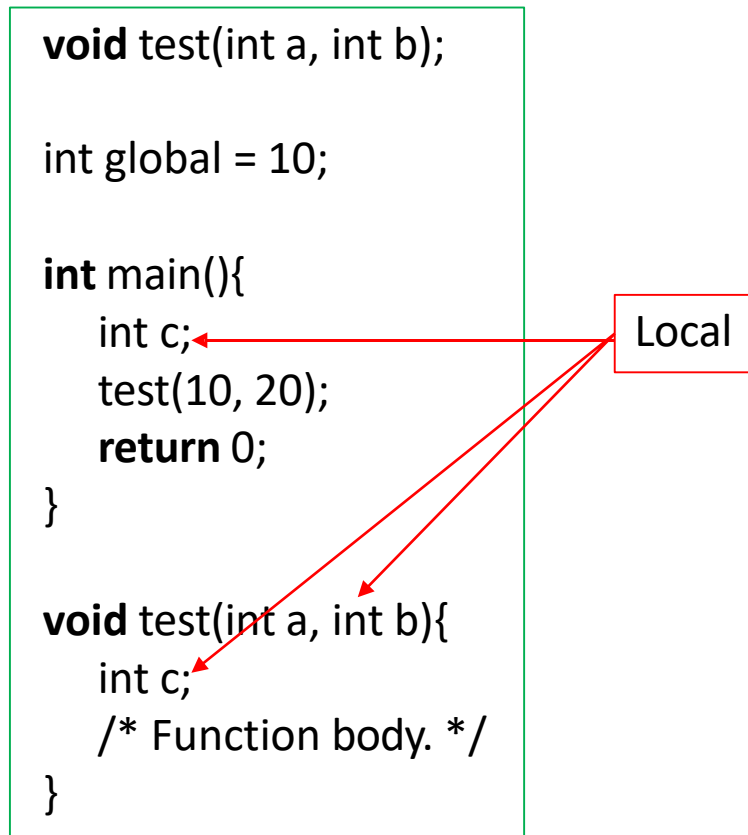
Overview

- Header file
- Recursive function
- **Scope of variables**

Local vs. Global Variables

- Variable's **scope** is the part of the program in which the variable can be accessed.

```
void test(int a, int b);

int global = 10;

int main(){
    int c;
    test(10, 20);
    return 0;
}

void test(int a, int b){
    int c;
    /* Function body. */
}
```
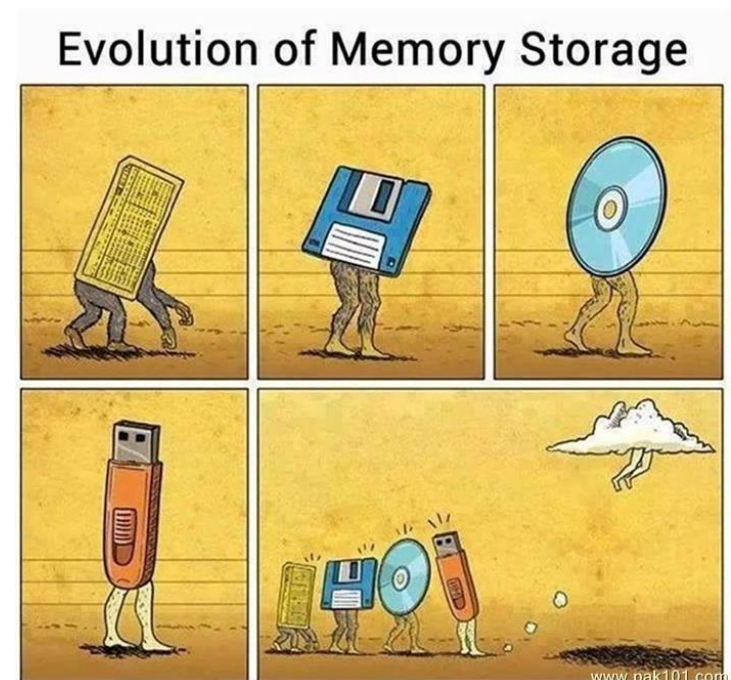
Local

Global Variables

- SHOULD be avoided, unless application performance is critical.

- Global variables allow unintended side effects e.g. a function does not need to access a variable but access and modify it accidentally or maliciously.

Storage Classes in C

- Storage class specifiers in C are auto, register, extern and static.

- They specify the period during which the identifier exists in memory, e.g. briefly, repeatedly created and destroyed, or entire execution of the program.

Evolution of Memory Storage

Automatic Storage Duration

- Use keyword auto.
- Local variables have automatic storage duration by default so the keyword itself is rarely used.

```
221     int main(void)
222   {
223         auto int myInt =  1;
224
225         return 0;
226   }
```
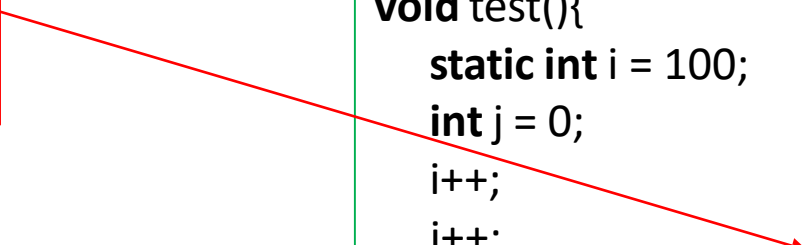
- This conserves memory because automatic variables are created and destroyed when needed e.g. when a function is entered and exited.

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static Variables

- The memory that is allocated to store the local variables is allocated and initialised only once, before the program begins execution.

- static variables retain their values when the function is exited.

displays
101 1
102 1

```
void test();
int main(){
    test();
    test();
    return 0;
}
void test(){
    static int i = 100;
    int j = 0;
    i++;
    j++;
    printf("%d %d\n", i, j);
}
```

```
void test();

int main(){
    test();
    test();
    return 0;
}

void test(){
    static int i = 100;
    int j = 0;
    i++;
    j++;
    printf("%d %d\n", i, j);
}
```

displays
101 1
102 1

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Scope of Arrays as Arguments

- Note that by default, arrays are **passed by reference**.

- e.g. void test (int arr[]);
          test(arr);   ← Use the name of the array as pointer

To prevent a function from changing the values of the array elements, use the word **const** in its declaration.

void test(const int arr[]);

```
void test(int arr[]){
printf("Size = %d bytes\n", sizeof(arr));
}
```
← Return the size of pointer, not arr

Scope of Arrays as Arguments (2)

```c
314    #include <stdio.h>
315
316    void testArray(int *a, int size);
317
318    int main(void)
319    {
320        int array[3] = {1, 2, 3};
321
322        printf("Output from main()\n");
323        int i = 0;
324        for(i = 0; i < 3; i++)
325        {
326            printf("%d %d\n", i, array[i]);
327        }
328        printf("\n\n");
329
330        testArray(array, 3);
331
332        printf("Output from main()\n");
333        for(i = 0; i < 3; i++)
334        {
335            printf("%d %d\n", i, array[i]);
336        }
337
338        return 0;
339    }
340
341    void testArray(int *a, int size)
342    {
343        printf("Output from testArray()\n");
344        int i = 0;
345        for(i = 0; i < size; i++)
346        {
347            printf("%d %d\n", i, a[i]);
348        }
349        printf("\n\n");
350
351        a[0] = 333;
352
353        printf("Output from testArray() after changing the value of a[0]\n");
354        for(i = 0; i < size; i++)
355        {
356            printf("%d %d\n", i, a[i]);
357        }
358        printf("\n\n");
359    }
```

```
C:\Users\z2017233\Downloads>recursion
Output from main()
0 1
1 2
2 3


Output from testArray()
0 1
1 2
2 3


Output from testArray() after changing the value of a[0]
0 333
1 2
2 3


Output from main()
0 333
1 2
2 3

C:\Users\z2017233\Downloads>
```

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```c
314    #include <stdio.h>
315
316    void testArray(int *a, int size);
317
318    int main(void)
319    {
320        int array[3] = {1, 2, 3};
321
322        printf("Output from main()\n");
323        int i = 0;
324        for(i = 0; i < 3; i++)
325        {
326            printf("%d %d\n", i, array[i]);
327        }
328        printf("\n\n");
329
330        testArray(array, 3);
331
332        printf("Output from main()\n");
333        for(i = 0; i < 3; i++)
334        {
335            printf("%d %d\n", i, array[i]);
336        }
337
338        return 0;
339    }
340
341    void testArray(int *a, int size)
342    {
343        printf("Output from testArray()\n");
344        int i = 0;
345        for(i = 0; i < size; i++)
346        {
347            printf("%d %d\n", i, a[i]);
348        }
349        printf("\n\n");
350
351        a[0] = 333;
352
353        printf("Output from testArray() after changing the value of a[0]\n");
354        for(i = 0; i < size; i++)
355        {
356            printf("%d %d\n", i, a[i]);
357        }
358        printf("\n\n");
359    }
```

```
C:\Users\z2017233\Downloads>recursion
Output from main()
0 1
1 2
2 3


Output from testArray()
0 1
1 2
2 3


Output from testArray() after changing the value of a[0]
0 333
1 2
2 3


Output from main()
0 333
1 2
2 3

C:\Users\z2017233\Downloads>
```

Passing 2D array: dimensions are available globally

```c
#include <stdio.h>
const int M = 3;
const int N = 3;

void print(int arr[M][N])
{
   int i, j;
   for (i = 0; i < M; i++)
    for (j = 0; j < N; j++)
      printf("%d ", arr[i][j]);
}

int main()
{
   int arr[][3] = {{1, 2, 3}, {4, 5, 6}, {7, 8, 9}};
   print(arr);
   return 0;
}
```

Passing 2D array: a dimension is available globally

```c
#include <stdio.h>
const int N = 3;

void print(int arr[][N], int m)
{
   int i, j;
   for (i = 0; i < m; i++)
    for (j = 0; j < N; j++)
      printf("%d ", arr[i][j]);
}

int main()
{
   int arr[][3] = {{1, 2, 3}, {4, 5, 6}, {7, 8, 9}};
   print(arr, 3);
   return 0;
}
```

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Passing 2D array: a pointer

```c
#include <stdio.h>
void print(int *arr, int m, int n)
{
    int i, j;
    for (i = 0; i < m; i++)
      for (j = 0; j < n; j++)
        printf("%d ", *((arr+i*n) + j));
}

int main()
{
    int arr[][3] = {{1, 2, 3}, {4, 5, 6}, {7, 8, 9}};
    int m = 3, n = 3;

    print((int *)arr, m, n);
    return 0;
}
```

Summary

- Header file

- Recursive function

- Scope of variables