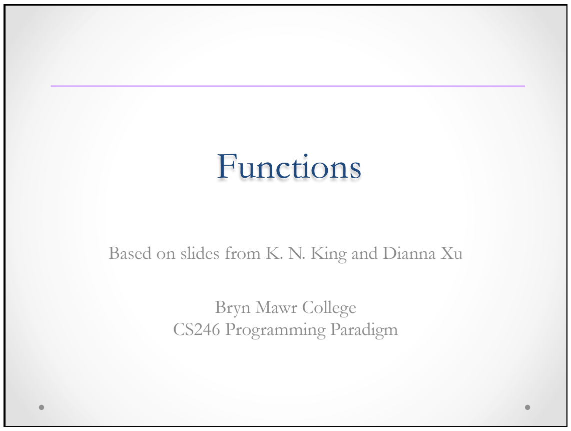
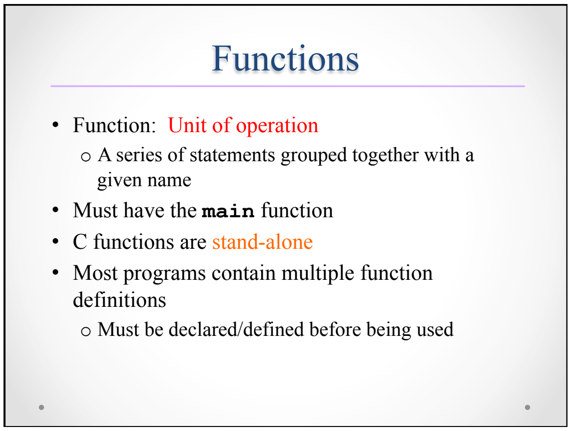


Functions

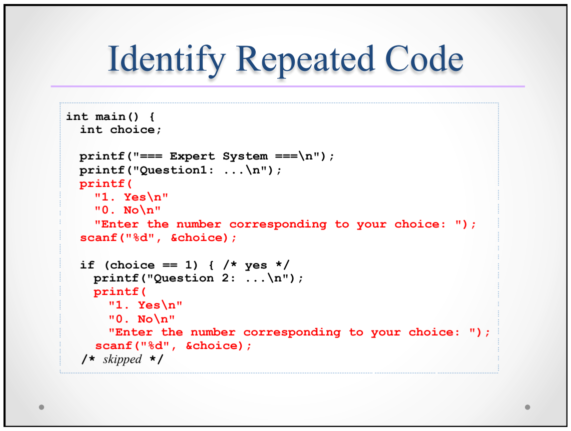
Based on slides from K. N. King and Dianna Xu

Bryn Mawr College
CS246 Programming Paradigm



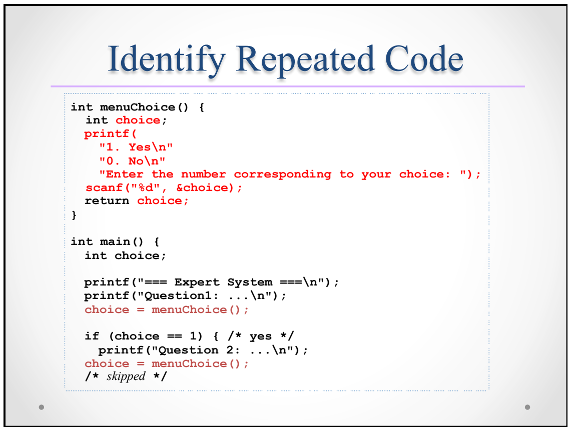
Functions

- Function: Unit of operation
  - A series of statements grouped together with a given name
- Must have the **`main`** function
- C functions are stand-alone
- Most programs contain multiple function definitions
  - Must be declared/defined before being used



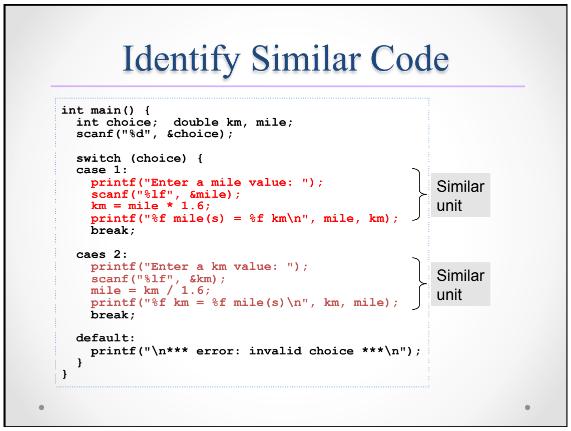
Identify Repeated Code

```
int main() {
  int choice;

  printf("=== Expert System ===\n");
  printf("Question1: ...\n");
  printf(
    "1. Yes\n"
    "0. No\n"
    "Enter the number corresponding to your choice: ");
  scanf("%d", &choice);

  if (choice == 1) { /* yes */
    printf("Question 2: ...\n");
    printf(
      "1. Yes\n"
      "0. No\n"
      "Enter the number corresponding to your choice: ");
    scanf("%d", &choice);
  /* skipped */
```



Identify Repeated Code

```
int menuChoice() {
  int choice;
  printf(
    "1. Yes\n"
    "0. No\n"
    "Enter the number corresponding to your choice: ");
  scanf("%d", &choice);
  return choice;
}

int main() {
  int choice;

  printf("=== Expert System ===\n");
  printf("Question1: ...\n");
  choice = menuChoice();

  if (choice == 1) { /* yes */
    printf("Question 2: ...\n");
  choice = menuChoice();
  /* skipped */
```

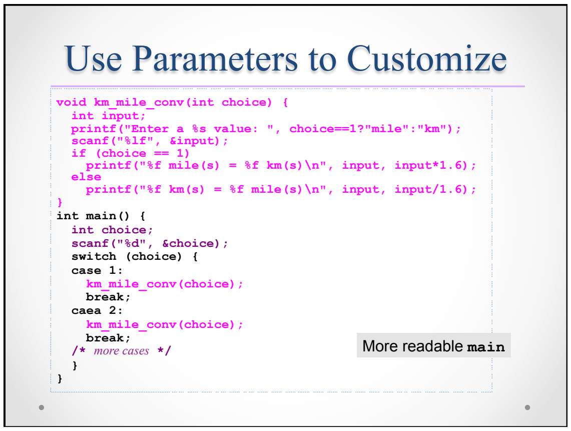


Identify Similar Code

```
int main() {
  int choice;  double km, mile;
  scanf("%d", &choice);

  switch (choice) {
  case 1:
    printf("Enter a mile value: ");
    scanf("%lf", &mile);
    km = mile * 1.6;
    printf("%f mile(s) = %f km\n", mile, km);
    break;

  caes 2:
    printf("Enter a km value: ");
    scanf("%lf", &km);
    mile = km / 1.6;
    printf("%f km = %f mile(s)\n", km, mile);
    break;

  default:
    printf("\n*** error: invalid choice ***\n");
  }
}
```

Similar unit

Similar unit



Use Parameters to Customize

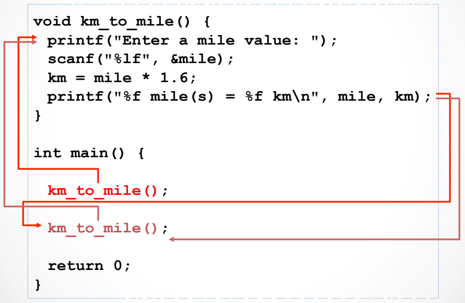
```
void km_mile_conv(int choice) {
  int input;
  printf("Enter a %s value: ", choice==1?"mile":"km");
  scanf("%lf", &input);
  if (choice == 1)
    printf("%f mile(s) = %f km(s)\n", input, input*1.6);
  else
    printf("%f km(s) = %f mile(s)\n", input, input/1.6);
}
int main() {
  int choice;
  scanf("%d", &choice);
  switch (choice) {
  case 1:
    km_mile_conv(choice);
    break;
  caea 2:
    km_mile_conv(choice);
    break;
  /* more cases */
  }
}
```

More readable **`main`**

Function-oriented

- C came before OO concept
- C program resemble java programs with a single giant class
- C is procedural
  - o Program organization and modularization is achieved through function design
  - o Carefully plan your function return type and parameter list
  - o Write small functions!

Function Call



```
void km_to_mile() {
  printf("Enter a mile value: ");
  scanf("%lf", &mile);
  km = mile * 1.6;
  printf("%f mile(s) = %f km\n", mile, km);
}

int main() {

  km_to_mile();

  km_to_mile();

  return 0;
}
```

Function Return and Parameters

- The syntax for C functions is the same as Java methods
- **void** keyword can be omitted

```
void km_to_mile(void) {

}
mile_to_km() {

}

int main() {
  int choice;
}
```

Use of **return** in **void** Functions

- Exit from the function

```
void getinput() {
  int choice;

  while (1) {
    scanf("%d", &choice);

    switch (choice) {
    case 1:
      /* some action */
      break;
    case 0:
      return; /* exit from getinput */
    }
  }
}
```

The **exit** Function

- Executing a `return` statement in `main` is one way to terminate a program.
- Another is calling the `exit` function, which belongs to `<stdlib.h>`.
- The statement

  `return` *expression*`;`

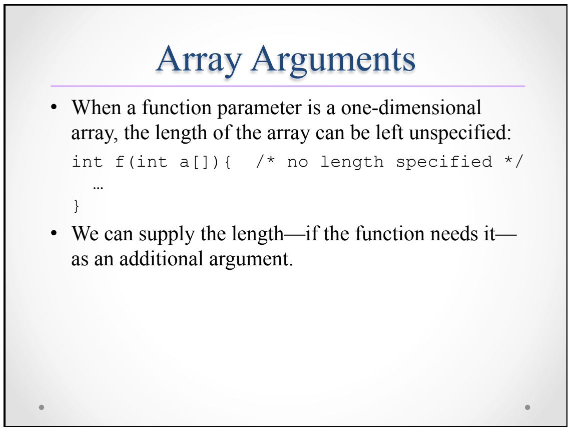
  in `main` is equivalent to

  `exit(`*expression*`);`
- To indicate normal termination, we'd pass 0:
- `exit(0);   /* normal termination */`The difference between `return` and `exit` is that `exit` causes program termination regardless of which function calls it.
- The `return` statement causes program termination only when it appears in the `main` function.

Function Prototype

- A prototype is a function declaration which includes the return type and a list of parameters
- A way to move function definitions after **main**
- Need not name formal parameters

```
/* function prototypes */
double km2mile(double);
double mile2km(double);
int main() {
}
/* actual function definitions */
double km2mile(double k) {

}
double mile2km(double m) {

}
```

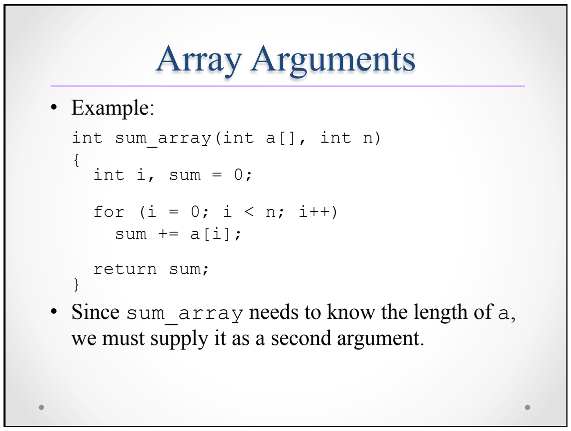


Array Arguments

- When a function parameter is a one-dimensional array, the length of the array can be left unspecified:

```
int f(int a[]){  /* no length specified */
  …
}
```

- We can supply the length—if the function needs it—as an additional argument.

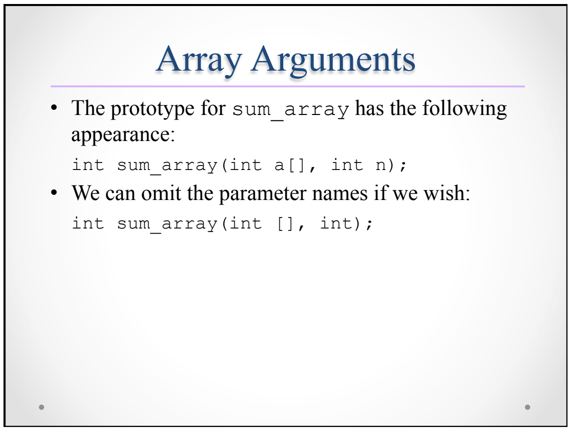


Array Arguments

- Example:

```
int sum_array(int a[], int n)
{
  int i, sum = 0;

  for (i = 0; i < n; i++)
    sum += a[i];

  return sum;
}
```

- Since `sum_array` needs to know the length of `a`, we must supply it as a second argument.



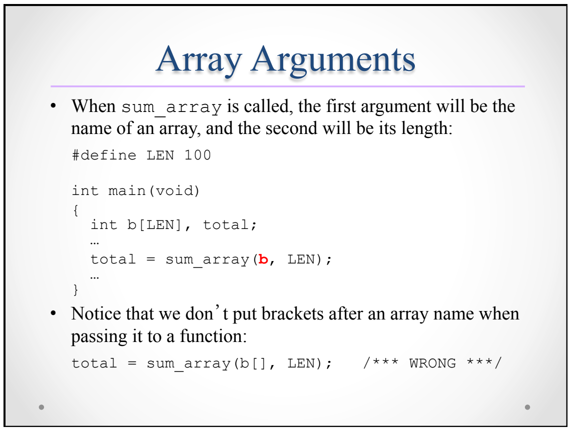
Array Arguments

- The prototype for `sum_array` has the following appearance:

```
int sum_array(int a[], int n);
```

- We can omit the parameter names if we wish:

```
int sum_array(int [], int);
```



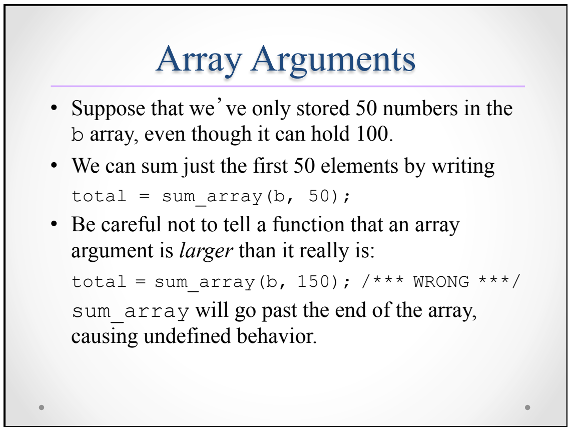
Array Arguments

- When `sum_array` is called, the first argument will be the name of an array, and the second will be its length:

```
#define LEN 100

int main(void)
{
  int b[LEN], total;
  …
  total = sum_array(b, LEN);
  …
}
```

- Notice that we don't put brackets after an array name when passing it to a function:

```
total = sum_array(b[], LEN);   /*** WRONG ***/
```



Array Arguments

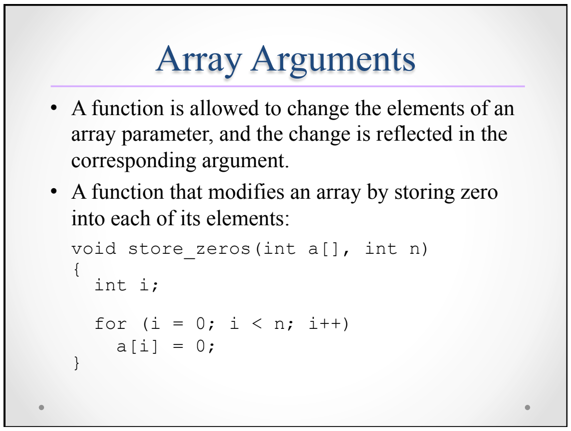
- Suppose that we've only stored 50 numbers in the `b` array, even though it can hold 100.
- We can sum just the first 50 elements by writing

```
total = sum_array(b, 50);
```

- Be careful not to tell a function that an array argument is *larger* than it really is:

```
total = sum_array(b, 150); /*** WRONG ***/
```

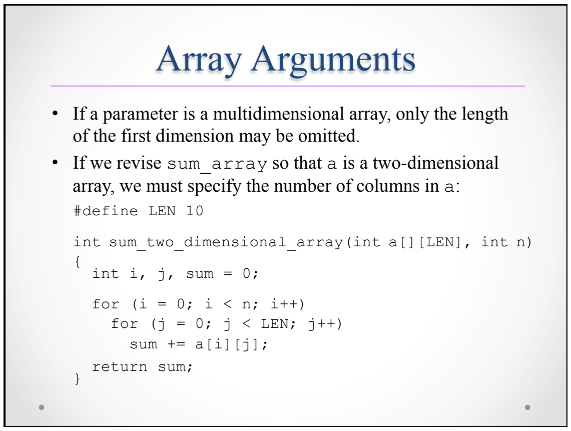
`sum_array` will go past the end of the array, causing undefined behavior.



Array Arguments

- A function is allowed to change the elements of an array parameter, and the change is reflected in the corresponding argument.
- A function that modifies an array by storing zero into each of its elements:

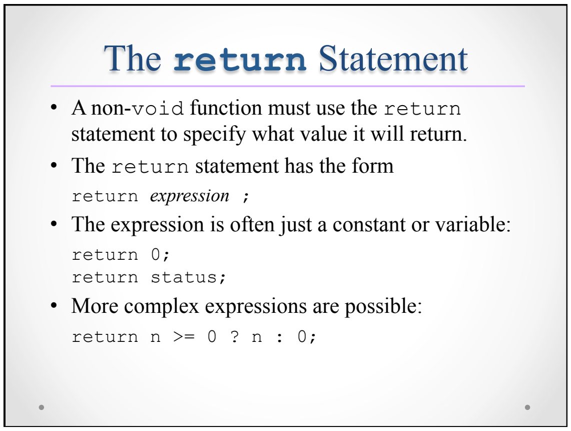
```
void store_zeros(int a[], int n)
{
  int i;

  for (i = 0; i < n; i++)
    a[i] = 0;
}
```



Array Arguments

- If a parameter is a multidimensional array, only the length of the first dimension may be omitted.
- If we revise `sum_array` so that `a` is a two-dimensional array, we must specify the number of columns in `a`:

```
#define LEN 10

int sum_two_dimensional_array(int a[][LEN], int n)
{
  int i, j, sum = 0;

  for (i = 0; i < n; i++)
    for (j = 0; j < LEN; j++)
      sum += a[i][j];
  return sum;
}
```



The `return` Statement

- A non-`void` function must use the `return` statement to specify what value it will return.
- The `return` statement has the form

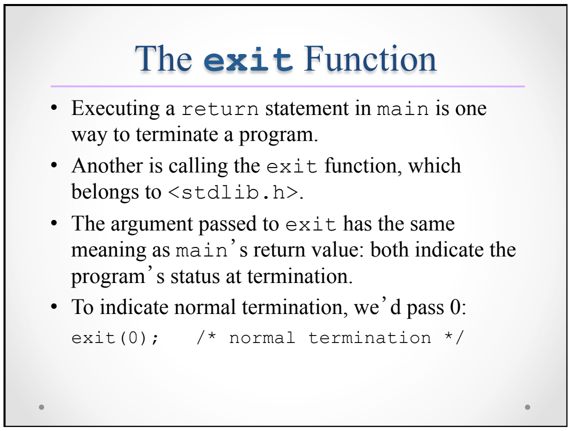
`return` *expression* `;`

- The expression is often just a constant or variable:

```
return 0;
return status;
```

- More complex expressions are possible:

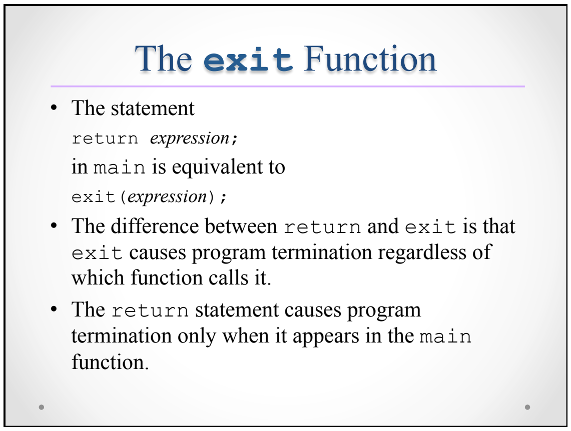
```
return n >= 0 ? n : 0;
```



The `exit` Function

- Executing a `return` statement in `main` is one way to terminate a program.
- Another is calling the `exit` function, which belongs to `<stdlib.h>`.
- The argument passed to `exit` has the same meaning as `main`'s return value: both indicate the program's status at termination.
- To indicate normal termination, we'd pass 0:

```
exit(0);    /* normal termination */
```



The `exit` Function

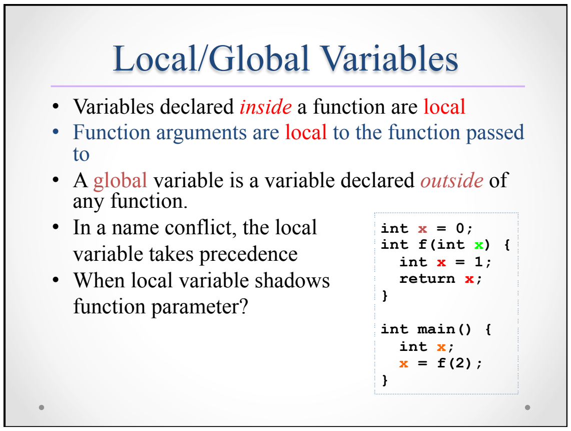
- The statement

`return` *expression*`;`

in `main` is equivalent to

`exit(`*expression*`);`

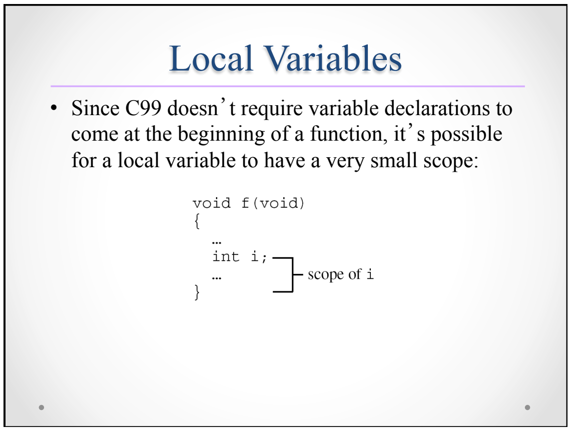
- The difference between `return` and `exit` is that `exit` causes program termination regardless of which function calls it.
- The `return` statement causes program termination only when it appears in the `main` function.



Local/Global Variables

- Variables declared *inside* a function are local
- Function arguments are local to the function passed to
- A global variable is a variable declared *outside* of any function.
- In a name conflict, the local variable takes precedence
- When local variable shadows function parameter?

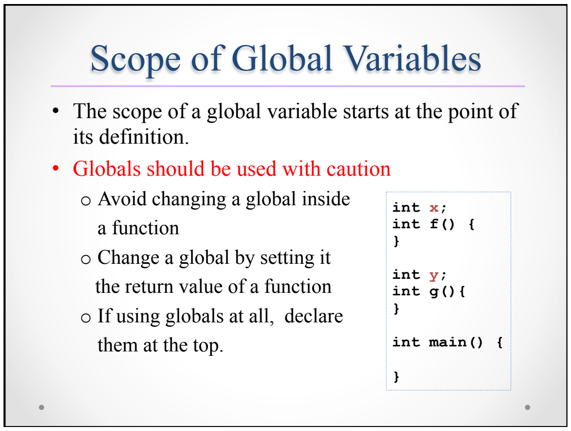
```
int x = 0;
int f(int x) {
  int x = 1;
  return x;
}

int main() {
  int x;
  x = f(2);
}
```



Local Variables

- Since C99 doesn't require variable declarations to come at the beginning of a function, it's possible for a local variable to have a very small scope:

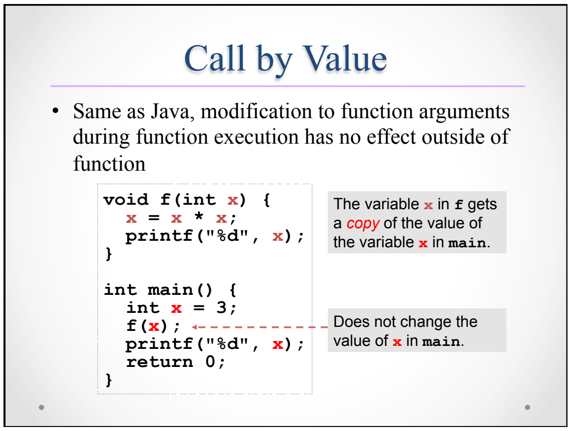
```
void f(void)
{
  …
  int i; ─┐
  …        ├ scope of i
}         ─┘
```



Scope of Global Variables

- The scope of a global variable starts at the point of its definition.
- Globals should be used with caution
  - Avoid changing a global inside a function
  - Change a global by setting it the return value of a function
  - If using globals at all, declare them at the top.

```
int x;
int f() {
}

int y;
int g(){
}

int main() {

}
```



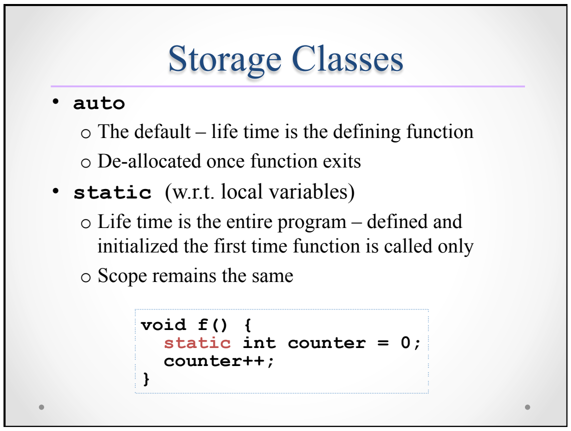
Call by Value

- Same as Java, modification to function arguments during function execution has no effect outside of function

```
void f(int x) {
  x = x * x;
  printf("%d", x);
}

int main() {
  int x = 3;
  f(x);
  printf("%d", x);
  return 0;
}
```

The variable x in f gets a *copy* of the value of the variable x in main.

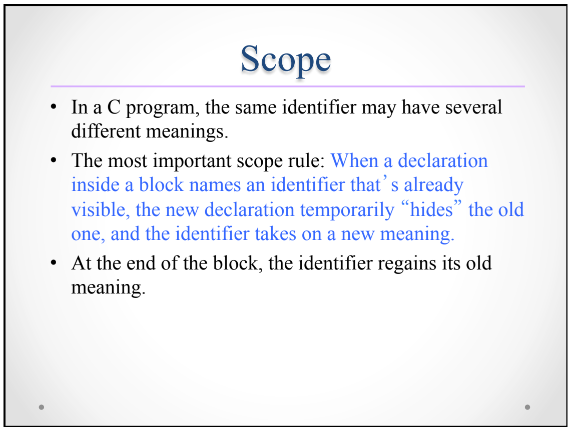
Does not change the value of x in main.



Storage Classes

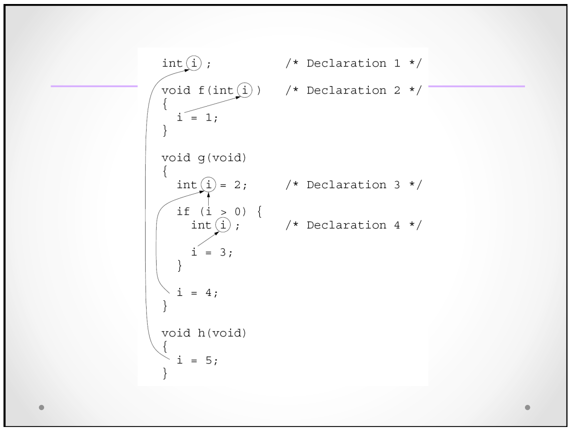
- **auto**
  - The default – life time is the defining function
  - De-allocated once function exits
- **static** (w.r.t. local variables)
  - Life time is the entire program – defined and initialized the first time function is called only
  - Scope remains the same

```
void f() {
  static int counter = 0;
  counter++;
}
```

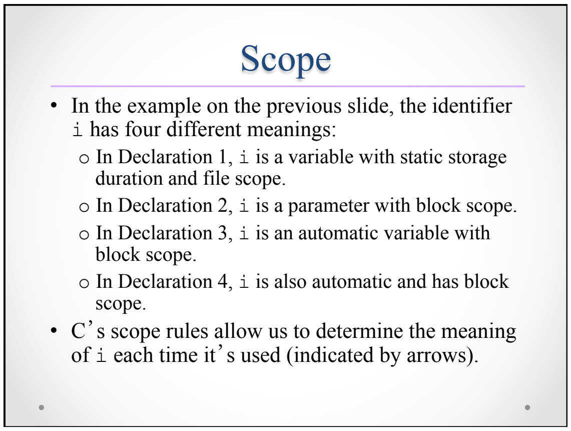


Scope

- In a C program, the same identifier may have several different meanings.
- The most important scope rule: When a declaration inside a block names an identifier that's already visible, the new declaration temporarily "hides" the old one, and the identifier takes on a new meaning.
- At the end of the block, the identifier regains its old meaning.

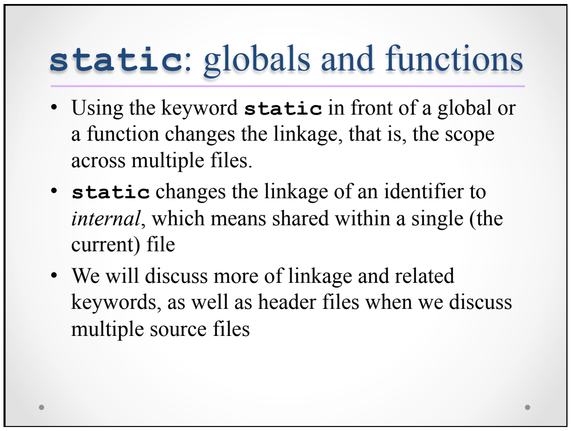


```
int i ;                 /* Declaration 1 */

void f(int i )          /* Declaration 2 */
{
  i = 1;
}

void g(void)
{
  int i = 2;            /* Declaration 3 */

  if (i > 0) {
    int i ;             /* Declaration 4 */

    i = 3;
  }

  i = 4;
}

void h(void)
{
  i = 5;
}
```



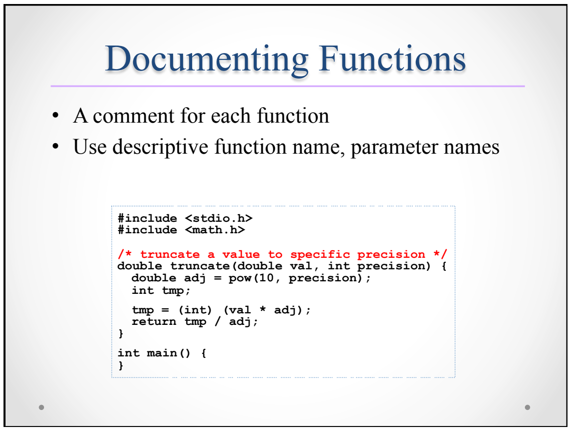
Scope

- In the example on the previous slide, the identifier i has four different meanings:
  - In Declaration 1, i is a variable with static storage duration and file scope.
  - In Declaration 2, i is a parameter with block scope.
  - In Declaration 3, i is an automatic variable with block scope.
  - In Declaration 4, i is also automatic and has block scope.
- C's scope rules allow us to determine the meaning of i each time it's used (indicated by arrows).



`static`: globals and functions

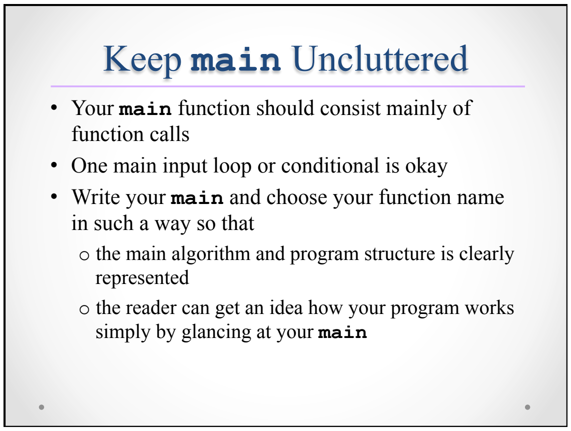
- Using the keyword **`static`** in front of a global or a function changes the linkage, that is, the scope across multiple files.
- **`static`** changes the linkage of an identifier to *internal*, which means shared within a single (the current) file
- We will discuss more of linkage and related keywords, as well as header files when we discuss multiple source files



Documenting Functions

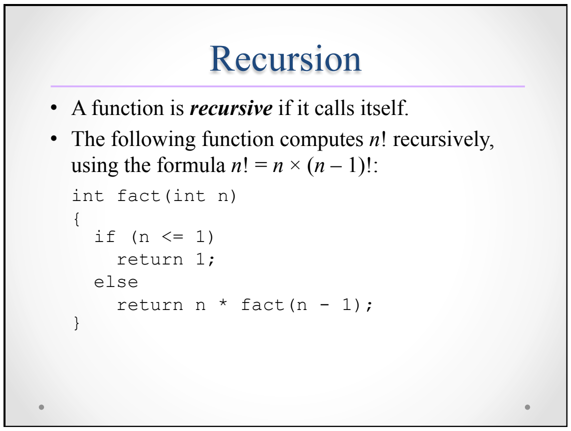
- A comment for each function
- Use descriptive function name, parameter names

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

/* truncate a value to specific precision */
double truncate(double val, int precision) {
  double adj = pow(10, precision);
  int tmp;

  tmp = (int) (val * adj);
  return tmp / adj;
}

int main() {
}
```



Keep `main` Uncluttered

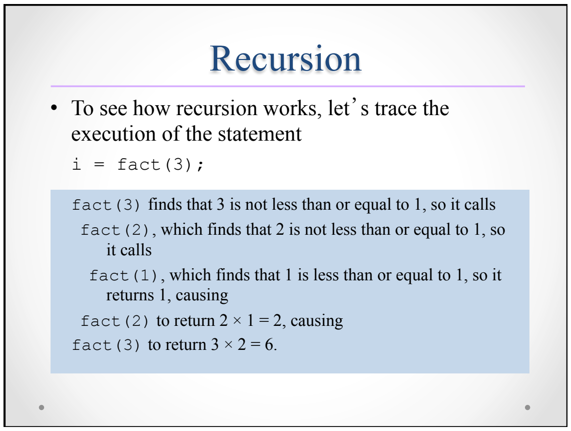
- Your **`main`** function should consist mainly of function calls
- One main input loop or conditional is okay
- Write your **`main`** and choose your function name in such a way so that
  - o the main algorithm and program structure is clearly represented
  - o the reader can get an idea how your program works simply by glancing at your **`main`**



Recursion

- A function is ***recursive*** if it calls itself.
- The following function computes $n!$ recursively, using the formula $n! = n \times (n - 1)!$:

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

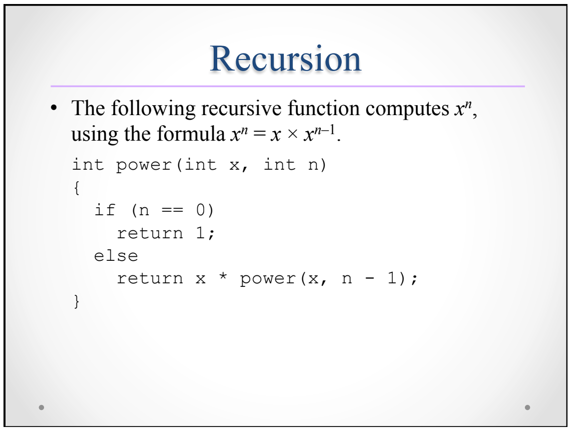


Recursion

- To see how recursion works, let's trace the execution of the statement

```
i = fact(3);
```

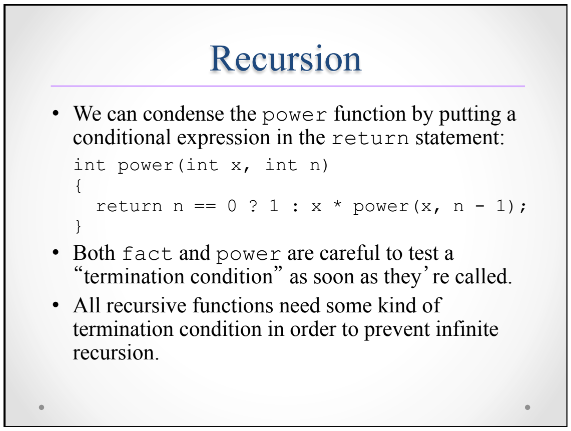
`fact(3)` finds that 3 is not less than or equal to 1, so it calls
 `fact(2)`, which finds that 2 is not less than or equal to 1, so it calls
  `fact(1)`, which finds that 1 is less than or equal to 1, so it returns 1, causing
 `fact(2)` to return 2 × 1 = 2, causing
`fact(3)` to return 3 × 2 = 6.



Recursion

- The following recursive function computes x^n, using the formula $x^n = x \times x^{n-1}$.

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

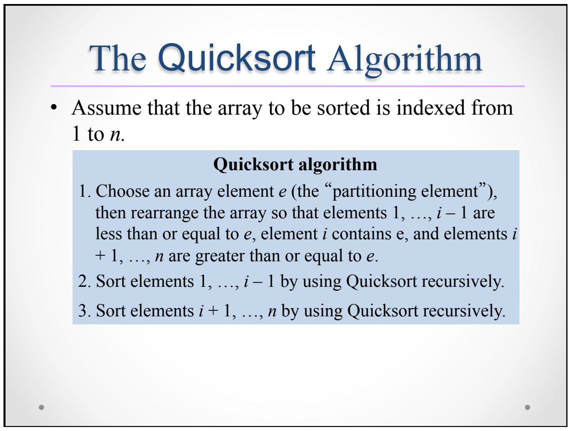


Recursion

- We can condense the `power` function by putting a conditional expression in the `return` statement:

```
int power(int x, int n)
{
  return n == 0 ? 1 : x * power(x, n - 1);
}
```

- Both `fact` and `power` are careful to test a “termination condition” as soon as they’re called.
- All recursive functions need some kind of termination condition in order to prevent infinite recursion.

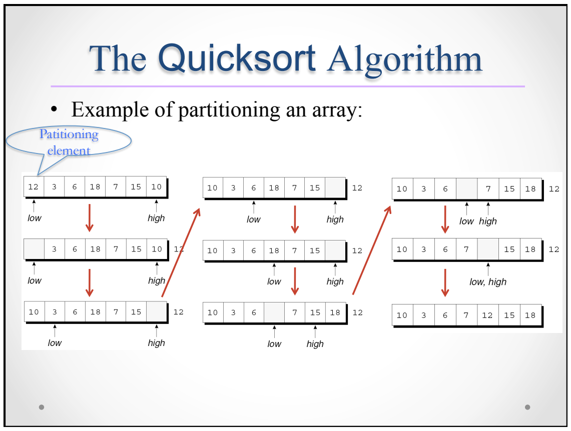


The Quicksort Algorithm

- Assume that the array to be sorted is indexed from 1 to *n*.

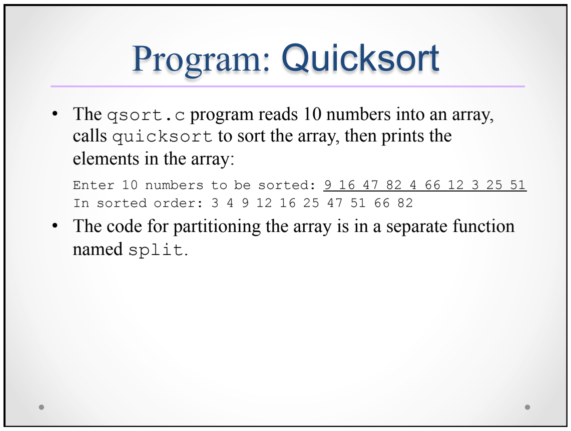
Quicksort algorithm

1. Choose an array element *e* (the “partitioning element”), then rearrange the array so that elements 1, …, *i* – 1 are less than or equal to *e*, element *i* contains e, and elements *i* + 1, …, *n* are greater than or equal to *e*.
2. Sort elements 1, …, *i* – 1 by using Quicksort recursively.
3. Sort elements *i* + 1, …, *n* by using Quicksort recursively.



The Quicksort Algorithm

- Example of partitioning an array:

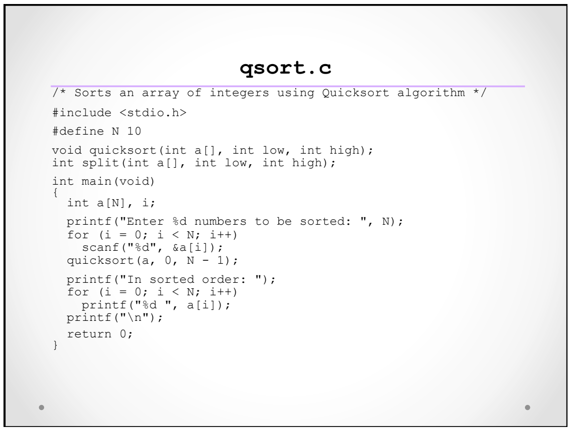


Program: Quicksort

- The `qsort.c` program reads 10 numbers into an array, calls `quicksort` to sort the array, then prints the elements in the array:

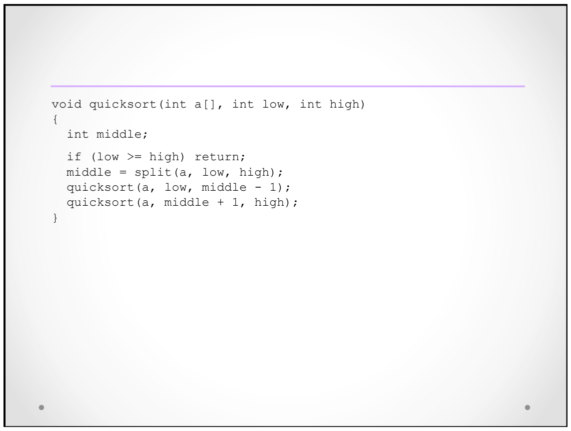
```
Enter 10 numbers to be sorted: 9 16 47 82 4 66 12 3 25 51
In sorted order: 3 4 9 12 16 25 47 51 66 82
```

- The code for partitioning the array is in a separate function named `split`.

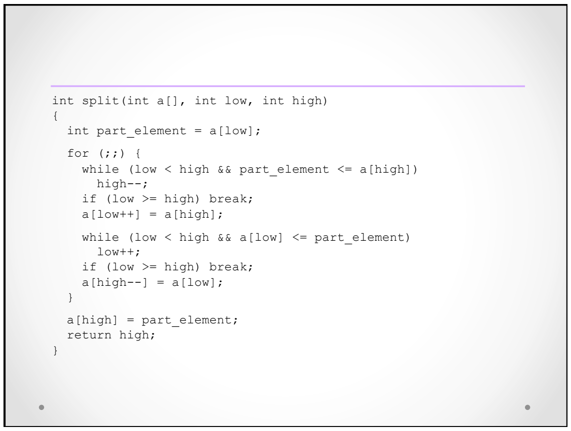


qsort.c

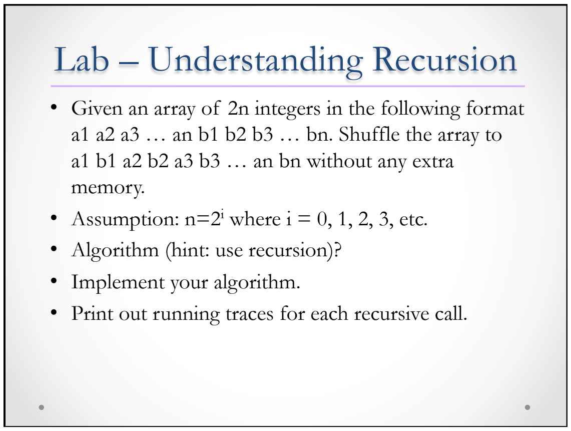
```
/* Sorts an array of integers using Quicksort algorithm */
#include <stdio.h>
#define N 10

void quicksort(int a[], int low, int high);
int split(int a[], int low, int high);

int main(void)
{
  int a[N], i;

  printf("Enter %d numbers to be sorted: ", N);
  for (i = 0; i < N; i++)
    scanf("%d", &a[i]);
  quicksort(a, 0, N - 1);

  printf("In sorted order: ");
  for (i = 0; i < N; i++)
    printf("%d ", a[i]);
  printf("\n");

  return 0;
}
```



```
void quicksort(int a[], int low, int high)
{
  int middle;

  if (low >= high) return;
  middle = split(a, low, high);
  quicksort(a, low, middle - 1);
  quicksort(a, middle + 1, high);
}
```



```
int split(int a[], int low, int high)
{
  int part_element = a[low];

  for (;;) {
    while (low < high && part_element <= a[high])
      high--;
    if (low >= high) break;
    a[low++] = a[high];

    while (low < high && a[low] <= part_element)
      low++;
    if (low >= high) break;
    a[high--] = a[low];
  }

  a[high] = part_element;
  return high;
}
```



Lab – Understanding Recursion

- Given an array of 2n integers in the following format a1 a2 a3 … an b1 b2 b3 … bn. Shuffle the array to a1 b1 a2 b2 a3 b3 … an bn without any extra memory.
- Assumption: $n=2^i$ where i = 0, 1, 2, 3, etc.
- Algorithm (hint: use recursion)?
- Implement your algorithm.
- Print out running traces for each recursive call.