Functions

Announcements

• Add/drop deadline: Today!

• Assignment 1 due Wednesday
  ▪ Check newsgroup for clarifications, corrections, etc.

Order of evaluation

• *Operator precedence* and *associativity* rules define the order in which operators are evaluated

  ▪ Some examples:

   ♦ 5 + 3 / 2 ≡ 5 + (3/2)

   ♦ 1 - 1 - 1 ≡ (1 - 1) - 1

   ♦ 3 < 5 + 2 ≡ 3 < (5 + 2)

Class	Associativity	Operators
Select	L→R	(...) [...] -> .
Unary	R→L	! ~ + - * & (*type*) sizeof ++ --
Binary arithmetical	L→R	* / %
Binary arithmetical	L→R	+ -
Shift	L→R	<< >>
Comparison	L→R	< <= > >=
Comparison	L→R	== !=
Binary bitwise	L→R	&
Binary bitwise	L→R	^
Binary bitwise	L→R		
Binary boolean	L→R	&&
Binary boolean	L→R	||
Ternary	R→L	?...:
Assignments	R→L	= += -= *= /= &= != ^= <<= >>=
Sequence	L→R	,

Math functions

• Warning: ^ is the XOR operator, not exponentiation!
  ▪ e.g. In C, `2 ^ 3 != 8` (instead, `2 ^ 3 == 1`)

• Many math functions available in math.h :
  ▪ `pow(a, b)` : computes a^b
  ▪ `exp(a)` : computes e^a
  ▪ `log(a)` : natural logarithm
  ▪ `cos, sin, tan`
  ▪ `acos, asin, atan`
  ▪ etc.

Functions

• Purpose of functions
  ▪ Breaks a program into pieces that are easier to understand
  ▪ Makes *recursive algorithms* possible to implement
  ▪ Promotes *code reuse*

• Disadvantage of functions
  ▪ Function calls add some memory and time overhead

• Functions in C
  ▪ Similar to methods in Java
  ▪ But C functions do not belong to a class. Every function is visible everywhere in the program.

A simple function

```
int power( int base, int exp )
{
  int i, p = 1;
  for( i = 1; i <= exp; i++ )
    p *= base;
  return p;
}
```

  ▪ This function takes 2 integers as arguments, returns an int
  ▪ Variables declared inside power (base, exp, p) are local variables and not visible outside the function
  ▪ `return` statement is used to specify return value

Simple function in context

function prototype
function call

```
int power( int base, int exp );

void main() {
  int i = 3, j = 4;
  printf( "%d^%d is %d.\n", i, j, power( i, j ));
}

int power( int base, int exp )
{
  int i, p = 1;
  for( i = 1; i <= exp; i++ )
    p *= base;
  return p;
}
```

function definitions

actual parameters

formal parameters

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Function return values

- If a function returns type **void**, then no **return** statement is needed
- If a function returns another type, then a **return** statement is required along all possible execution paths
  - What does this code do?

```
int foo( int arg );

int foo( int arg )
{
  if(arg == 1) return 0;
}

void main() {
  printf( "%d\n", foo(0) );
}
```

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Call by value

- Function arguments in C are passed *by value*
  - The *value* of the argument is passed, not a reference
  - Functions are given a new copy of their arguments
  - So a function can't modify the value of a variable in the calling function (unless you use pointers)

```
int F( int a )
{
  a=0;
  return a;
}

void main() {
  int A = 1, B;
  B = F(A);
  printf( "%d %d\n", A, B );  // prints "1 0"
}
```

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Call by value

- Example

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

void main() {
  int A = 1, B = 2;
  swap(A, B);
  printf( "%d %d\n", A, B );
}
```

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Call by value

- Call by value has advantages and disadvantages
  - Advantage: some functions are easier to write

```
int power(int base, int exp)
{
  int result = 1;

  for( ; exp >= 1 ; exp--)
    result *= base;
  return base;
}
```

  - Disadvantage: sometimes you'd like to modify an argument (e.g. a **swap**() function)
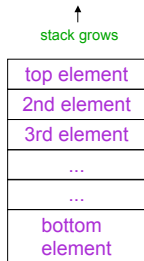   - We'll see how to do this using pointers later

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Activation records

- When a function calls occurs, the function needs:
  - Its own copy of the actual parameters
  - Memory to store its local variables
  - An address to resume executing once the program returns

- C uses *activation records* to manage this information
  - The activation records are stored on the *execution stack*
  - Whenever a function is called, an activation record is created and *pushed* onto the stack
  - Whenever a function returns, its activation record is *popped* from the stack
  - The AR for main is always at the bottom of the stack

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Stacks

↑
stack grows

top element	← top-of-stack pointer
2nd element	
3rd element	
...	
...	
bottom element	

- Like a stack of plates
- You can push data on top or pop data off the top in a LIFO (last-in-first-out) fashion
- A queue is similar, except it is FIFO (first-in-first-out)

Recursion

- *Recursion* is a powerful technique for specifying sets, functions, and programs
  - A *recursive function* is a function that refers to itself
  - Many algorithms can be written more compactly, easily, elegantly using recursion

- Early languages (e.g. Fortran) did not support recursion
  - C and most other modern languages do
  - Recursion is possible because of the execution stack

Recursion example

- Example: computing positive integral powers
  - $a^n = a \cdot a \cdot a \cdots a$ (n times)
  - Recursive definition:
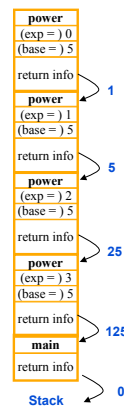   - $a^0 = 1$
    - $a^{n+1} = a \cdot a^n$

```
int power(int base, int exp);

int power(int base, int exp)
{
  if(exp == 0) return 1;
  else return base*power(base, exp-1);
}

int main(void)
{
  printf("%d\n", power(5, 2));
  return 0;
}
```

Example: power(5, 2)

power	
(exp =) 0	
(base =) 5	
return info	1
power	
(exp =) 1	
(base =) 5	
return info	5
power	
(exp =) 2	
(base =) 5	
return info	25
power	
(exp =) 3	
(base =) 5	
return info	125
main	
return info	0

Stack

```
int power(int base, int exp);

int power(int base, int exp) {
  if(exp == 0) return 1;
  else return base*power(base, exp-1);
}

int main(void) {
  printf("%d\n", power(5, 3));
  return 0;
}
```

How Do We Keep Track?

- At any point in execution, many invocations of *power* may be in existence
  - Many stack frames (all for *power*) may be in Stack
  - Thus there may be different versions of the variables *base* and *exp*

- How does processor know which location is relevant at a given point in the computation?
  - Frame Base Register
    - When a method is invoked, a frame is created for that method invocation, and FBR is set to point to that frame
    - When the invocation returns, FBR is restored to what it was before the invocation

- How does machine know what value to restore in the FBR?
  - This is part of the return info in the stack frame

An aside: Loops in C

- So far we've seen 4 ways of writing loops:
  - while statements
  - do-while statements
  - for statements
  - recursion

- There's one more way…

goto statements

- A `goto` statement explicitly forces execution to jump from one part of the program to another
  - Syntax: `goto label`
  - One application is looping, e.g.:

```c
int main(void)
{
  int j=0;

begin_loop:
  printf("%d\n", j);
  j++;
  if(j < 10) goto begin_loop;

  return 0;
}
```

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A common use of goto

- `goto` statements are often used to handle errors
  - like a rudimentary form of exception handling in Java or C++

```c
int function(void)
{
  int j=0;

  for( . . . )
   for( . . . )
    while( . . . ) {
       /*lots of complex code */
       if(error) goto abort;
       /* more code */
    }

abort:
  printf("error detected!\n")
  return 0;
}
```

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Use of goto

"GOTO is a four letter word." -- Edsger Dijkstra

- gotos should almost always be avoided
  - goto statements make code harder to understand
  - It's always possible to rewrite code without a goto

- goto statements have become nearly extinct
  - They were common in older languages like Fortran
  - Modern programming constructs (`for` loops, etc.) render them unnecessary
  - Many newer languages (e.g. Java) don't support them at all

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Multiple source files

- C lets you break up a program into several source files
  - Unlike Java or Matlab, it doesn't *require* you to do this
  - How you break up the program is up to you

- To do this,
  - Put the code for a function in exactly one file
  - Put a function prototype in any file that uses the function

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Example: multiple source files

main.c
```c
#include <stdio.h>

int power(int base, int exp);
int cube(int base);

int main(void)
{
  printf("%d\n", power(5, 3));
  printf("%d\n", cube(10));
  return 0;
}
```

power.c
```c
int power( int base, int exp )
{
  int i, p = 1;
  for( i = 1; i <= exp; i++ )
    p *= base;
  return p;
}
```

cube.c
```c
int power(int base, int exp);

int cube(intbase)
{
  return power(base, 3);
}
```

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Create header files to store prototypes

mymath.h
```c
int power(int base, int exp);
int cube(int base);
```

main.c
```c
#include "mymath.h"

int main(void)
{
  printf("%d\n", power(5, 3));
  printf("%d\n", cube(10));
  return 0;
}
```

power.c
```c
#include "mymath.h"

int power( int base, int exp )
{
  int i, p = 1;
  for( i = 1; i <= exp; i++ )
    p *= base;
  return p;
}
```

cube.c
```c
#include "mymath.h"

int cube(intbase)
{
  return power(base, 3);
}
```