Functions in C

C Programming and Software Tools

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Functions in C

- Functions are also called *subroutines* or *procedures*
- One part of a program *calls* (or invokes the execution of) the function

Example: **`printf()`**

```
int main(void) {
    …
    (void) printf (…);
    …
}
```

caller

passes control

returns control

```
int printf(…) {
    …code for printf…
}
```

callee

Similar to Java methods, but not associated with a class

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Are Functions Necessary?

Alternative: just copy the source code of **`printf()`** into the caller, everywhere it is called

– this is called *inlining* the function code

Ex.:

```
int main(void) {
    …
    …code for printing something…
    …
    …code for printing something else…
    …
    …code for printing something else…
    …
}
```

Reasons to Inline

- There is overhead in each function call
  1. *saving return address and register values*
  2. *allocating space on the stack for local variables and copying their values*
  3. *jumping to new instruction*
  4. *reversing all of the above when returning control to caller*
- inlined code can be stripped down for the particular inputs expected

Reasons to Use Functions

- Functions improve modularity
  - reduce duplication, inconsistency
  - improve readability, easier to understand
  - simplifies debugging
    - test parts – unit testing
    - then the whole – system/functional testing
- Allows creation of libraries of useful "building blocks" for common processing tasks

Function Return Values

- The simplest possible function has no return value and no input parameters, ex.:
- Useful?

```
void abort (void)
```

The next simplest case: value returned, but no input parameters, ex.:

```
char getchar (void)
int rand (void)
clock_t clock (void)
```

What Values Can a Function Return?

- The datatype of a function can be any of:
  - integer or floating point number
  - structs and unions
  - enumerated constants
  - **`void`**
  - pointers to any of the above
- Each function's type should be declared before use

Values… (cont'd)

- Functions cannot return arrays, nor can they return functions
  - (although they can return pointers to both)

```
int main(void) {
   char s[100];
   …
   s[] = readstring();
   …
}

char readstring() [100]  {
    …
}
```

Illegal – do not try!

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How Many Values Returned?

- A function can return at most one value
- What if you need a function to return multiple results?
- Example: you provide the radius and height of a cylinder to a function, and want to get back…

1. surface area

and

2. volume of the cylinder

How Many … (cont'd)

- Choice #1: make the return type a ***struct***

```
typedef struct { //similar to an object
      int area;  // first field
      int vol;   // second field
} mystruct;

mystruct ans;
mystruct cyl (int , int );

int main(void) {
   …
   ans = cyl (r, h);
}
```

How Many … (cont'd)

- Choice #2: use *global* variables
  - global variables are *visible* to (and can be updated by) all functions

```
double area, vol;
void cyl (int , int );

int main(void) {
  …
  cyl (r, h);
}
```

☠ *common source of bugs* ☠
use of global variables

```
void cyl (int r, int h)
{
  area = h * (2 * PI * r);
  vol = h * (r * r * PI);
}
```

How Many … (cont'd)

- Choice #3: pass parameters by reference (using pointers), instead of by value
  - allows them to be updated by the function
- Ex.: *later, when we talk about pointers…*

Function Side Effects

- Besides the value returned, these are things that *may be* changed by the execution of the function
- Examples
  - input to or output by the computer
  - changes to the state of the computer system
  - changes to global variables
  - changes to input parameters (using pointers)
- There are problems with side effects; *we'll come back to this...*

☠ *common source of bugs* ☠

side effects in functions and expressions

Input Parameters of a Function

- Often called *arguments* of the function
- Two types
  - *formal* or *abstract* – parameter declarations in the function definition
  - *actual* or *concrete* – the actual values passed to the function at run time
- If no input parameters to the function, leave empty, or use the **`void`** keyword

Input Parameters of a Function (cont'd)

- The number and value of actual parameters should match the number and type of formal parameters

function prototype

```
int a, v;

void cyl (int , int );

int main(void) {
    float r;
    …
    (void) cyl (r);
}
```

Oops!

Caller

actual parameters

formal parameters

```
void cyl (int r, int h)
{
    a = h * (2 * PI * r);
    v = h * (r * r * PI);
}
```

Callee

Parameter Passing

- Parameters are passed using *call by value* (same as Java primitives)
  - i.e., a copy of the parameter value is made and provided to the function
- Any changes the function makes to this (copied) value have no effect on the caller's variables

Input Parameters (cont'd)

- Ex.:

```
float a, v;
void main ( )
{
    int r, h;
    ...
    (void) cylbigger (r, h);
    ...
```

```
void cylbigger (int r, int h)
{
    r = 2 * r;
    h = 2 * h;
    a = h * (2 * PI * r);
    v = h * (r * r * PI);
}
```

does not change caller's variables r and h

Arrays as Local Variables?

- Arrays can be declared as local variables of functions, e.g.:

```
int main() {
   double smallarray[20];

   int i, ...
   for (i < 0; i < 20; i++)
      smallarray[i] = ...
```

- Space for local variables is allocated on the stack
  - means: large arrays must be declared as static or global variables – otherwise segmentation fault

```
double bigarray[10000000];

int main() {
   int i, ...
   for (i = 0; i < 10000000; i++)
      bigarray[i] = ...
```

Types for Function Arguments

- In C, an implicit type conversion occurs if actual argument type disagrees with formal argument type

formal

```
void u ( char c );
...
double g = 12345678.0;
...
u (g);
```

actual

```
g = 12345678.0
c = 78
```

no compiler warnings!

☠ *common source of bugs* ☠

overlooking type differences in parameters

Advice: more predictable if you cast it yourself

Must Declare Function Before Use

Program with compilation errors

```
#include <stdio.h>

int main (void)
{
    float w, x, y;
    …
    w = f(x, y);
    …
}

float f (float x, float y)
{
    …
}
```

Program without compilation errors

```
#include <stdio.h>

float f (float x, float y)
{
    …
}

int main (void)
{
    float w, x, y;
    …
    w = f(x, y);
    …
}
```

why should this make a difference?

Declare Before... (cont'd)

- Approaches
  1. (unusual) locate the function definition at the beginning of the source code file, or…
  2. (usual) put a *function prototype* at the beginning of the source code (actual function definition can appear anywhere)

Declare Before... (cont'd)

Program without compilation errors

```
#include <stdio.h>

float f (float , float );

int main (void)
{
    float w, x, y;
    …
    w = f(x, y);
    …
}

float f (float x, float y)
{
    …
}
```

← function prototype

```
float f (float x, float y);
```

Also a valid prototype

(you can include variable names; they do nothing)

Arrays as Function Arguments

- An array can be passed as an input argument
- You can specify the array length explicitly in the function declaration
- Ex.:

```
void getdays (int months[12])
{
    …
}
```

```
void getdays (int years[10][12])
{
    …
}
```

Arrays as Arguments (cont'd)

- Make sure actual argument lengths agree with formal argument lengths!
  - will generate compiler errors otherwise
- Ex.:

```
int years[5][12];
…
result = getdays (years);
```

why not **years[5][12]** here?

Omitting Array Sizes

- Implicit length for the first dimension of a formal parameter is allowed
- However, you cannot omit the length of other dimensions

OK

```
void days (int years[][12])
{
    …
}
```

NOT OK

```
void days (int years[10][])
{
    …
}
```

Dynamic Array Size Declaration

- Q: How can you tell how big the array is if its size is implicit?
- A: You provide array size as an input parameter to the function
- Ex.:

```
void days (int nm, int months[])
{ … }
```

OR

```
void days (int nm, int months[nm])
{ … }
```

Note: make sure the size parameter comes before the array parameter

Dynamic Array Size… (cont'd)

```
void days(int ny, int nm, int years[ny][nm])
{   …
    for ( i = 0 ; i < ny ; i++)
        for ( j = 0; j < nm ; j++)
            dcnt += years[i][j];

    …
}
```

- Just make sure sizes are consistent with array declaration

```
int years[10][12];
…
(void) days(20,12, years);
```

problem here!

☠ *common source of bugs* ☠

mismatches in array size declarations

Arrays as Parameters

- Arrays are passed BY REFERENCE, not by value
  - i.e., the callee function can modify the caller's array values
- Therefore, if you update values in an array passed to a function, you are updating the caller's array

```
int years[10][12];
…
(void) changedays(years);
…
void changedays (int inyears[10][12])
{ …   inyears[1][7] = 29;    … }
```

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confusion about call by reference vs. call by value

Checking Input Parameters for Errors

- Who should check for errors: caller or callee?
  - advantages of caller checking for errors?
  - advantages of callee checking for errors?

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failure to check inputs for errors

```
a = 26;
b = 0;
c = divide (a, b);
```

Caller

```
int
divide (int x, int y) {
    return (x / y) ;
}
```

Callee

Variable Number of Arguments?

- Q: If a function takes a variable number of arguments (ex.: **`printf()`**), how do you specify that in a function prototype?
- A: Use ellipses to indicate unknown number of (additional) input parameters
  - **`int printf(…)`**, or **`int printf(*s, …)`**
- How do you specify a variable number of arguments in the function definition?
  - *to be discussed later…*

Side Effects, Again

- Q: If a variable is referenced multiple times in a single statement, and modified (by side effects) one of those times, do the other references see the side effect?
- Ex.:

```
x = 1;
b = --x && x;
```

```
a = 2;
b = ++a;
c = a + a;
```

```
a = 2;
if (a++)
    b = a;
```

```
a = 2;
b = ++a + a;
```

```
a = 2;
b = f( ++a, a);
```

```
a = 2;
b = ++a, c = a;
```

```
a = 2;
x = (++a > 2) ? a : 5;
```

Side Effects… (cont'd)

- Complete set of *sequence points* for C
  - statement termination **;**
  - closing parent in a condition evaluation **)**
  - the following operators:
    a**&&**b a**||**b a**?**b:c a**,**b
  - after evaluation of all arguments to a function call
  - after returning a value from a function
- Advice: avoid having multiple references to a variable in a single statement if one of those references has side effects

Functions Calling Functions

- **`f()`** calls **`g()`** calls **`h()`** calls **`i()`** calls **`j()`** calls …
- Is there such a thing as having too many layers, or too deep a calling stack? Disadvantages?

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Recursion

- What about **`f()`** calling **`f()`**???
- A powerful and flexible way to iteratively compute a value
  - *although this idea seems modest, recursion is one of the most important concepts in computer science*
- Each iteration must temporarily store some input or intermediate values while waiting for the results of recursion to be returned

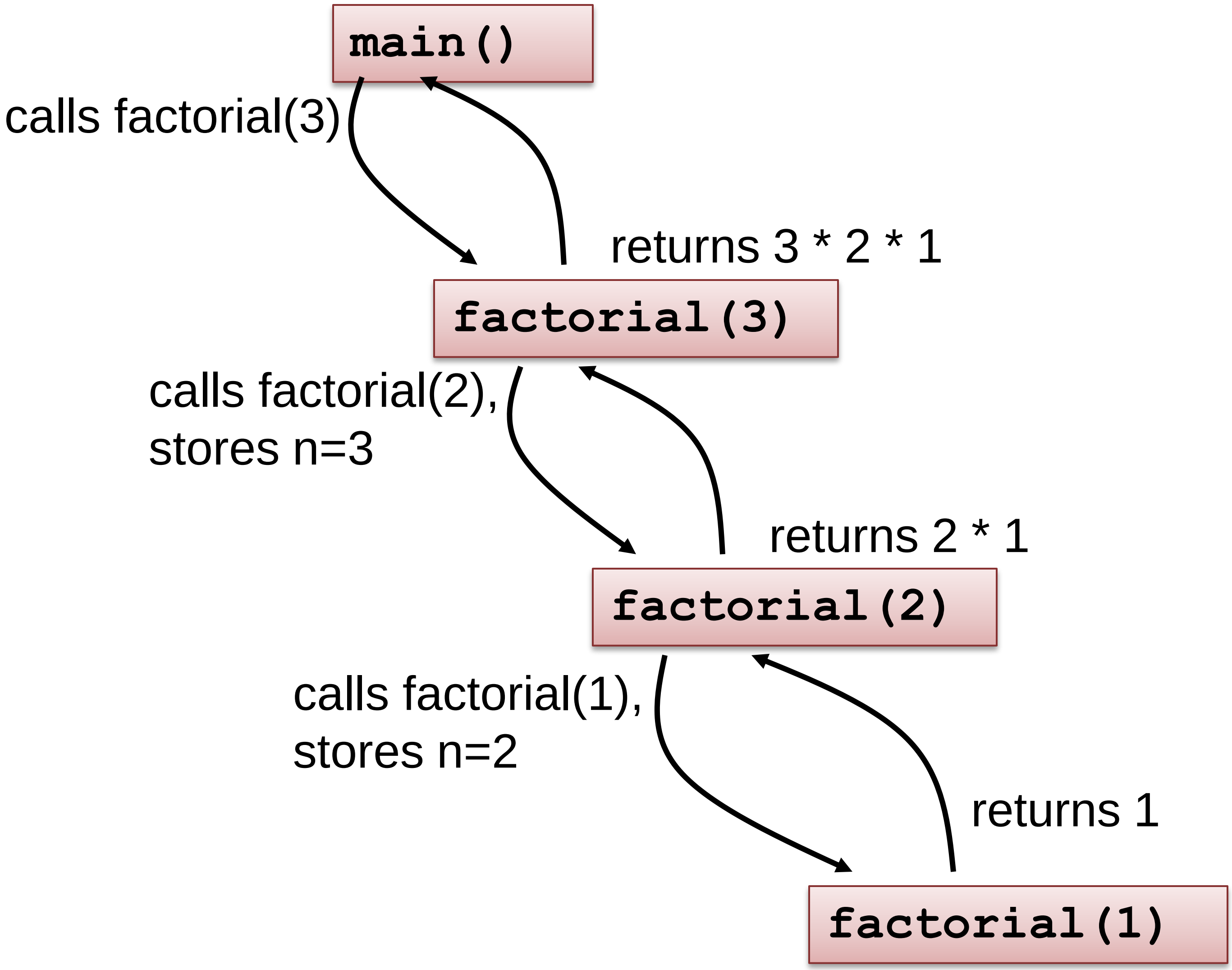
☠ common source of bugs ☠
misunderstanding of recursion

Recursion Example

```
...
int main (void)
{ …
  int n = 3;
  w = factorial ( n );
…
}

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

Example… (cont'd)



Recursion … (etc)

- What does the function $f(n) = f(n\text{-}1) + f(n\text{-}2)$ (and $f(1) == f(0) == 1$) return for n = 5?

```
long long int f (long long int n)
{
  if ((n == 1) || (n == 0))
    return 1;
  else
    return (f(n-1) + f(n-2));
}
```

what function is this? any problems if n = 50?
code it and try!

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Recursion or Iteration?

- Every recursion can be rewritten as a combination of
  1. a loop (iteration), plus…
  2. storage (a stack) for intermediate values

Iterative Version of f()

```
#include <stdio.h>
int i;
int main (void)
{
   static int n = 50;
   long long int f[n]; //stack

   f[0] = f[1] = 1;
   for (i = 2; i < n; i++)
      f[i] = f[i-1] + f[i-2];

   printf("%lld\n", f[n]);
   return 0;
}
```

better? worse?

How Big Should A Function Be?

- Too small (100 line program, 20 functions)???
- Too large (10,000 line program with 2 functions)???
- Just right ? (Linux recommendations)
  - "Functions should ... do just one thing...[and] fit on one or two screenfuls of text"
  - "... the number of local variables [for a function] .... shouldn't exceed 5-10"

Top-Down Programming in C

- Procedural programming languages encourage a way of structuring your programs:
  - start with the basics
  - then progressively fill in the details
- Ex.: writing a web browser
  - how does one get started on a large program like this?

The C Standard Library

- Small set of useful functions, standardized on all platforms
- Definitions are captured in 24 header files
- Today: how to generate random numbers
  - needed for cryptography, games of chance, simulation, probability, etc…

`<stdlib.h>`: Random Numbers

- The `<stdlib.h>` library header defines:
  - **`int rand(void)`**
    returns pseudo-random number in range 0 to **`RAND_MAX`**
  - **`void srand(unsigned int seed)`**
    sets the random number generator seed to the given value, so that a different sequence of pseudo-random numbers can be produced
  - **`RAND_MAX`**
    Maximum value returned **`by rand()`**
- Don't forget: **`#include <stdlib.h>`**

Random Numbers... (cont'd)

- To seed the random number generator

```
srand( time(NULL) );
```

where **`time()`** is defined in **`<time.h>`**

To generate a random (real) number **`r2`** in the (real number) range **`min`**...**`max`**:

```
double min = …, max = … ;
double range = max - min;

double r1 =
   ((double) rand() / (double) RAND_MAX) * range;
double r2 = r1 + min;
```

Example

- To generate a number in the interval [0.0,1.0)

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

double getrand() {
    int r = rand();
    return ((double) r / (RAND_MAX + 1));
}

int main () {
    (void) srand( time (NULL) );
   …
    double r = getrand();
   …
```

Command line arguments

ARGument Count

ARGument Vector

```
int main(int argc, char* argv[])
{
	for (int i=0; i<argc; i++) {
		printf("Arg %d: '%s'\n",i,argv[i]);
	}
}
```

```
$ ./argtest one two three "wow it works"
Arg 0: './argtest'
Arg 1: 'one'
Arg 2: 'two'
Arg 3: 'three'
Arg 4: 'wow it works'
```

Converting string to int

```
sscanf(const char* str, const char* format, ...);
```

- **`sscanf`**: Like **`scanf`**, but for a ***s****tring*.

```
char s[] = "100";
int x;
int r = sscanf(s,"%d",&x);
if (r==1) {
      printf("got %d!\n",x);
} else {
      printf("unable to parse an integer!\n");
}
```

Parsing command line arguments

```
void usage() {
    printf("Usage: argparse [number]\n");
    exit(1);
}

int main(int argc, char* argv[])
{
    if (argc!=2) {
        usage();
    }
    int x;
    int r = sscanf(argv[1],"%d",&x);
    if (r==1) {
        printf("The square of %d is %d\n",x,x*x);
    } else {
        printf("Unable to parse an integer!\n");
        usage();
    }
}
```

```
$ ./argparse
Usage: argparse [number]
$ ./argparse 5
The square of 5 is 25
$ ./argparse bluh
Unable to parse an integer!
Usage: argparse [number]
$ ./argparse 5 blah
Usage: argparse [number]
$
```

Exercise 09a: Dice tool

Dice tool

- Write a program that will roll a number of 6-sided dice specified on the command line.

```
$ ./dice
Usage: dice [number-of-dice]
$ ./dice 1
1
$ ./dice 10
5 3 3 3 4 6 5 6 5 1
$
```

WORD BANK

```
#include <time.h>
rand()
srand( time(NULL) );
RAND_MAX
int main(int argc, char* argv[])
sscanf(str,fmt,...);
```


Reminder: Go to course web page for link to exercise form.
Paste code into ideone.com and submit the link.