Lecture P1: Introduction to C

```
#include <stdio.h>
int main(void) {
  printf("This is a C program.\n");
  return 0;
}
```

Learning to Program

Programming is learned with practice and patience.

- **Don’t expect to learn solely from these lectures.**
- **Do exercises.**
- **Experiment and write lots of code.**

Do reading.

- **Finish King Chapters 1-6 today!**

Aspects of learning to program.

- **Language syntax.**
- **Algorithms.**
- **Libraries.**
- **These are different skills and learning processes.**

C Background

Born along with Unix in the early 1970's.

- **One of most popular languages today.**

C Features.

- **Concise.**
- **Widespread usage.**
- **Exposes low-level details of machine.**

Consequences.

- **Positive: you can do whatever you want.**

- **Negative: you can do whatever you want.**

An Example

Print a table of values of function $f(x) = 2 - x^3$. A first attempt:

```
x    f(x)
0.0  2.000
0.1  1.999
0.2  1.992
0.3  1.973
0.4  1.936
0.5  1.875
0.6  1.784
0.7  1.657
0.8  1.488
0.9  1.271
1.0  1.000
1.1  0.669
1.2  0.272
1.3 -0.197
1.4 -0.744
1.5 -1.375
1.6 -2.096
1.7 -2.913
1.8 -3.832
1.9 -4.859
```

table1.c

```
#include <stdio.h>

int main(void) {
  double x, y;

  printf(" x    f(x)\n");
  x = 0.0;
  y = 2.0 - x*x*x;
  printf("%4.1f %6.3f\n", x, y);
  x = 0.1;
  y = 2.0 - x*x*x;
  printf("%4.1f %6.3f\n", x, y);
  . . .
  x = 1.9;
  y = 2.0 - x*x*x;
  printf("%4.1f %6.3f\n", x, y);
  return 0;
}
```

Printf Library Function

Contact between your C program and outside world.

- Puts characters on "standard output."
- By default, stdout is the "terminal" that you're typing at.

Internally, all numbers represented in BINARY (0's and 1's).

- `printf()` displays more useful representation (`int`, `double`).

Formatted output.

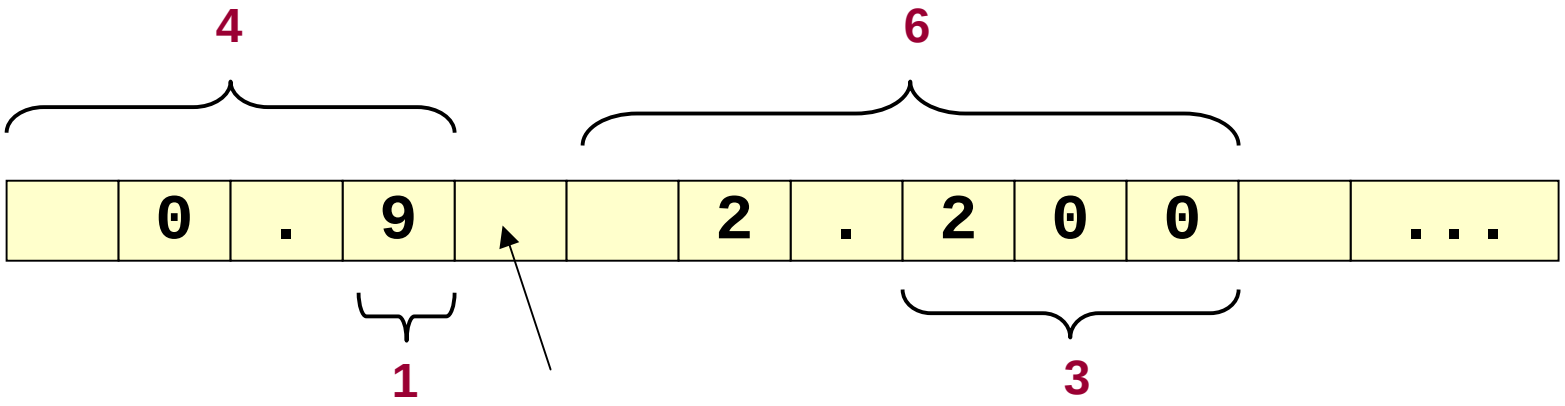
- How do you want the numbers to look?
  - integers, how many digits?
  - real numbers, how many digits after decimal place?
- Very flexible.

Anatomy of Printf

%f to print double

```
double x, y;
x = 0.927;
y = 2.2;
printf("%4.1f %6.3f\n", x, y);
```

'\n' is newline character



Running a Program in Unix

When you type commands, you are controlling an abstract machine called the "Unix shell."

- **Compile: convert the program from human's language (C) to machine's language.**
  - **1st try: syntax errors in C program**
  - **eventually, a file named a.out**

- **Execute: start the machine. (at first instruction in `main`)**
  - **1st try: semantic errors in C program**
  - **eventually, desired "printf" output**

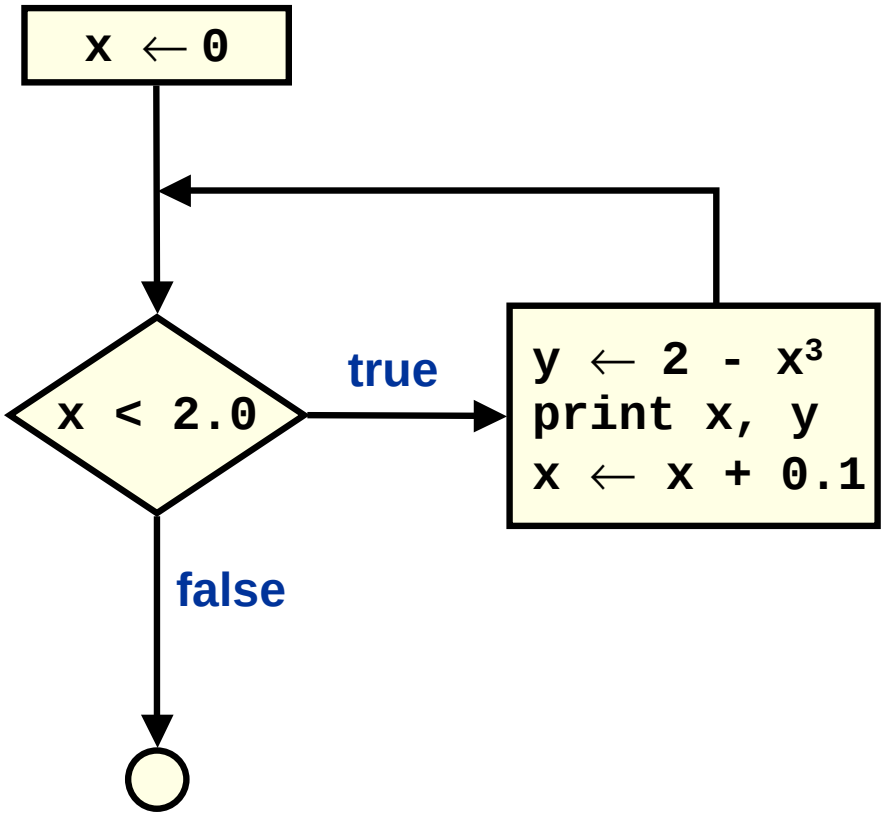
Unix

```
% gcc table.c
% a.out

x    f(x)
0.0  2.000
0.1  1.999
0.2  1.992
0.3  1.973
0.4  1.936
0.5  1.875
0.6  1.784
0.7  1.657
0.8  1.488
0.9  1.271
1.0  1.000
1.1  0.669
1.2  0.272
1.3 -0.197
1.4 -0.744
1.5 -1.375
1.6 -2.096
1.7 -2.913
1.8 -3.832
1.9 -4.859
```

Anatomy of a While Loop

Previous program repeats the same code over and over.

- **Repetitive code boring to write and hard to debug.**
- **Use while loop to repeat code.**




```
x = 0.0;
while (x < 2.0) {
  y = 2 - x*x*x;
  printf("%f %f\n", x, y);
  x = x + 0.1;
}
```

C code

While Loop Example

Print a table of values of function $f(x) = 2 - x^3$. A second attempt.

uses while loop

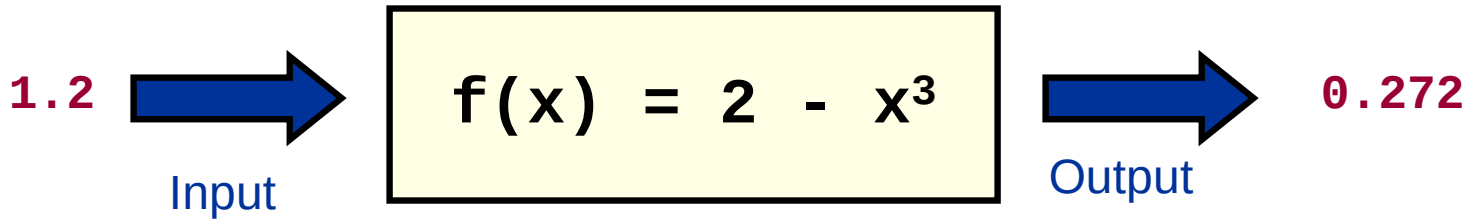
table2.c

```
#include <stdio.h>

int main(void) {
  double x, y;

  printf(" x     f(x)\n");
  x = 0.0;
  while (x < 2.0) {
    y = 2.0 - x*x*x;
    printf("%4.1f %6.3f\n", x, y);
    x = x + 0.1;
  }

  return 0;
}
```

Anatomy of a Function

Convenient to break up programs into smaller modules or functions.

- **Layers of abstraction.**
- **Makes code easier to understand.**
- **Makes code easier to debug.**
- **Makes code easier to change later on.**




```
double f(double x) {
  return 2 - x*x*x;
}
```

C function

Anatomy of a Function

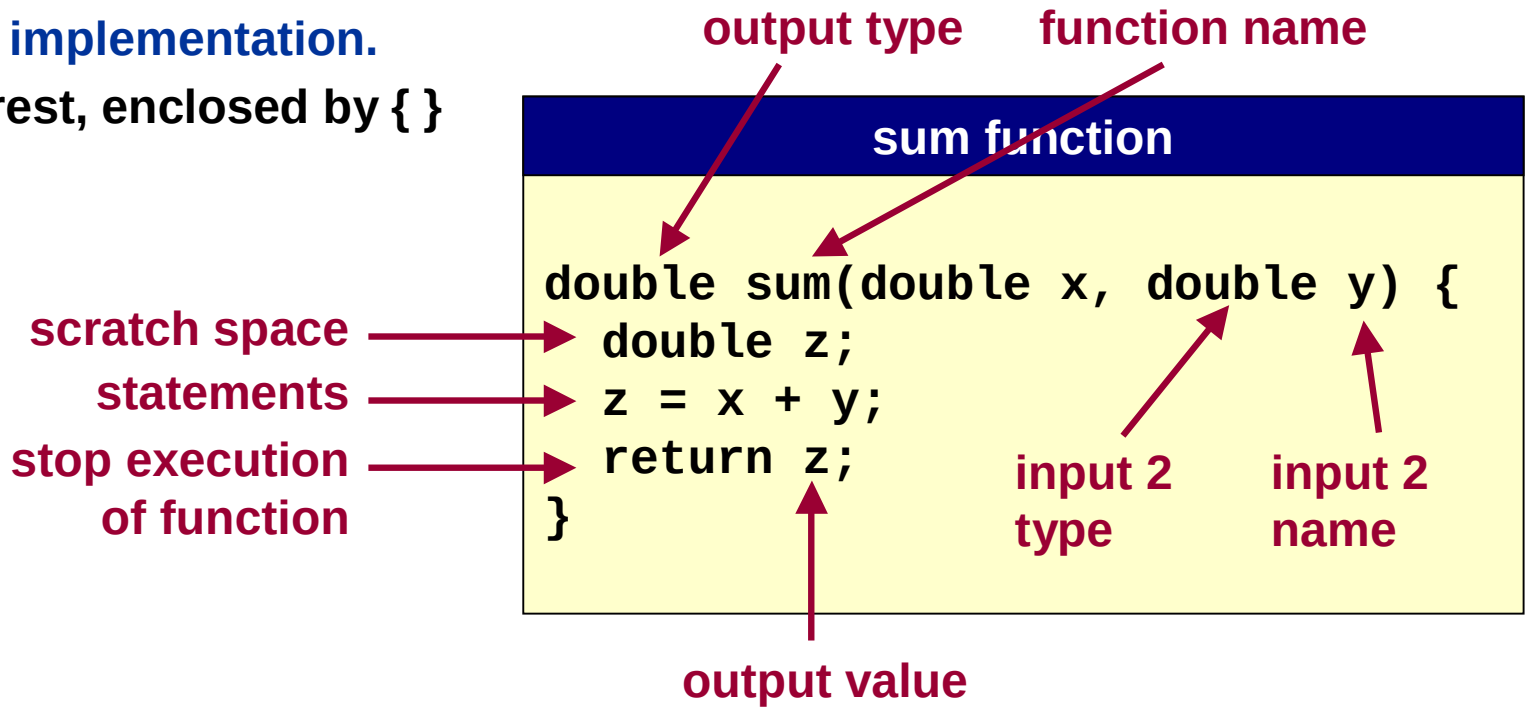
C function similar to mathematical function.

Prototype or interface is first line of C function.

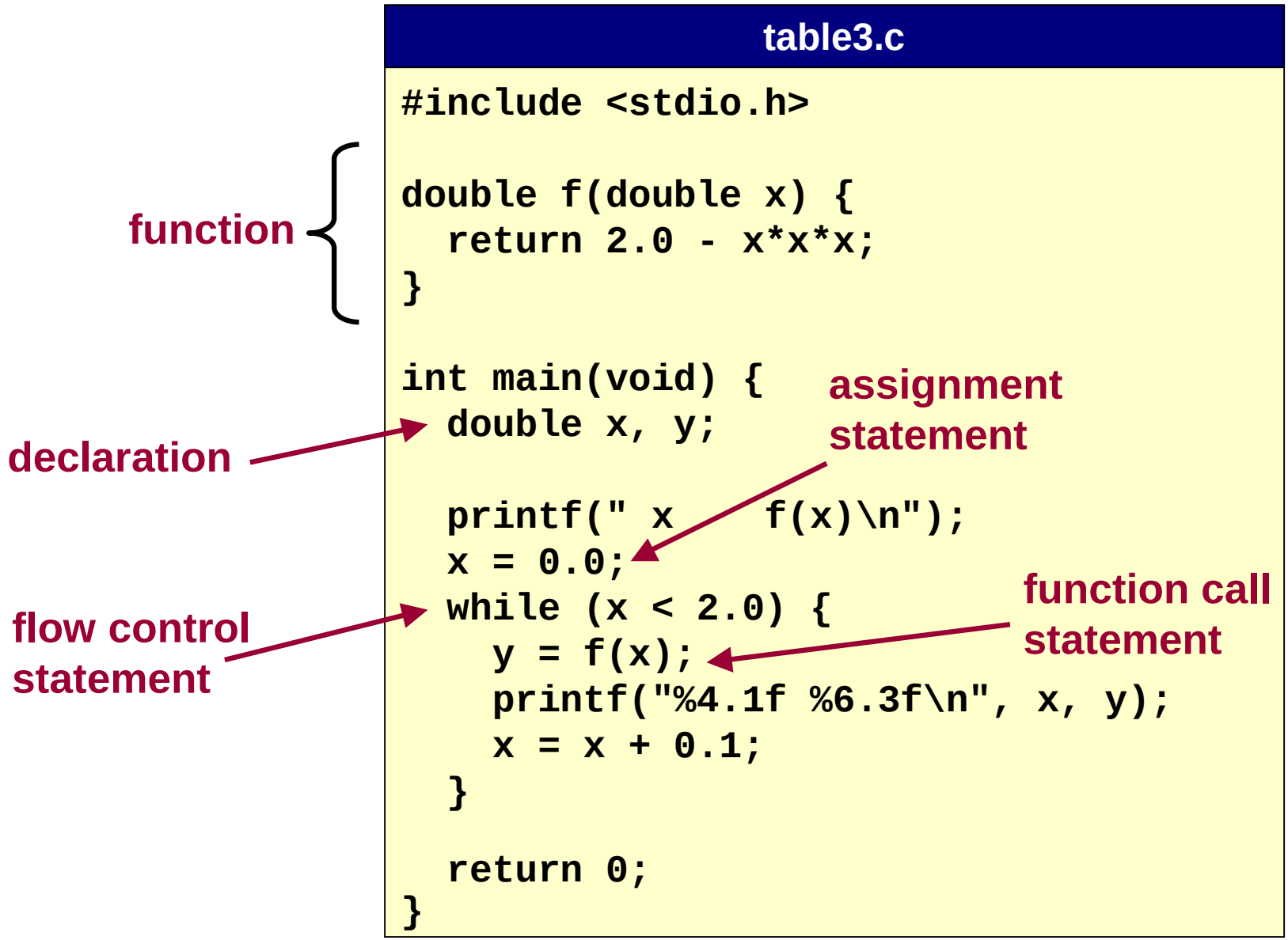
- specifies input argument(s) and their types
  - can be integers, real numbers, strings, vectors, user-defined
- specifies return value

Body or implementation.

- The rest, enclosed by { }



Anatomy of a C Program



Random Integers

Print 10 "random" integers.

- Library function `rand()` in `stdlib.h` returns integer between 0 and `RAND_MAX` (32,767 = 2^{16} - 1 on arizona).

int.c

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

int main(void) {
  int i = 0;
  while (i < 10) {
    printf("%d\n", rand());
    i = i + 1;
  }
  return 0;
}
```

i++;

Unix

```
% gcc int.c
% a.out
16838
5758
10113
17515
31051
5627
23010
7419
16212
4086
```

Random Integers

Print 10 "random" integers between 0 and 599.

- No precise match in library.
- Try to leverage what's there to accomplish what you want.

int600.c

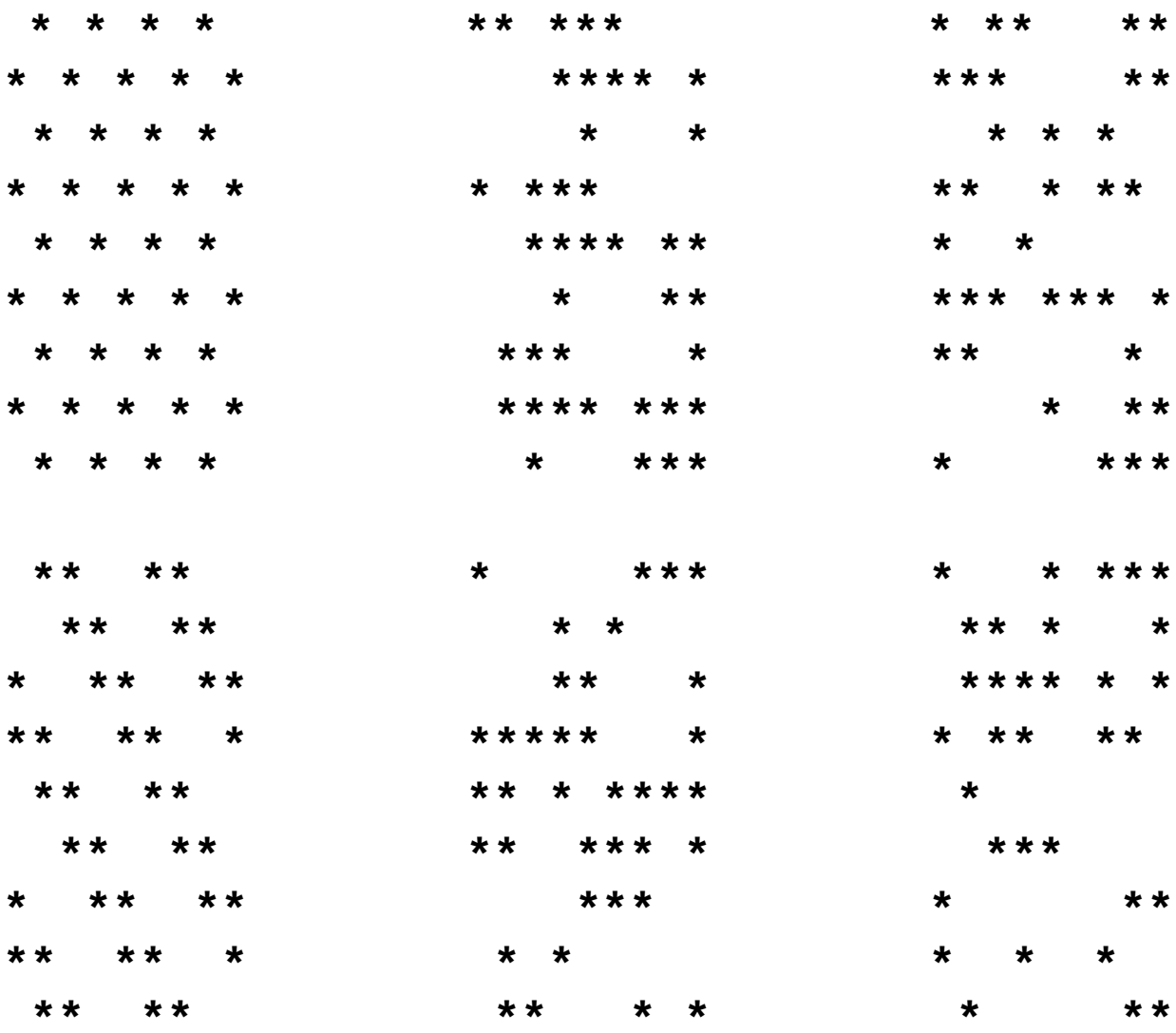
```
#include <stdio.h>
#include <stdlib.h>

int randomInteger(int n) {
  return rand() % n;
}

int main(void) {
  int i = 0;
  while (I < 10) {
    printf("%d\n", randomInteger(600));
    i++;
  }
  return 0;
}
```

p % q gives remainder of p divided by q

Unix

```
% gcc int600.c
% a.out
168
5
1
175
310
562
230
341
16
386
```

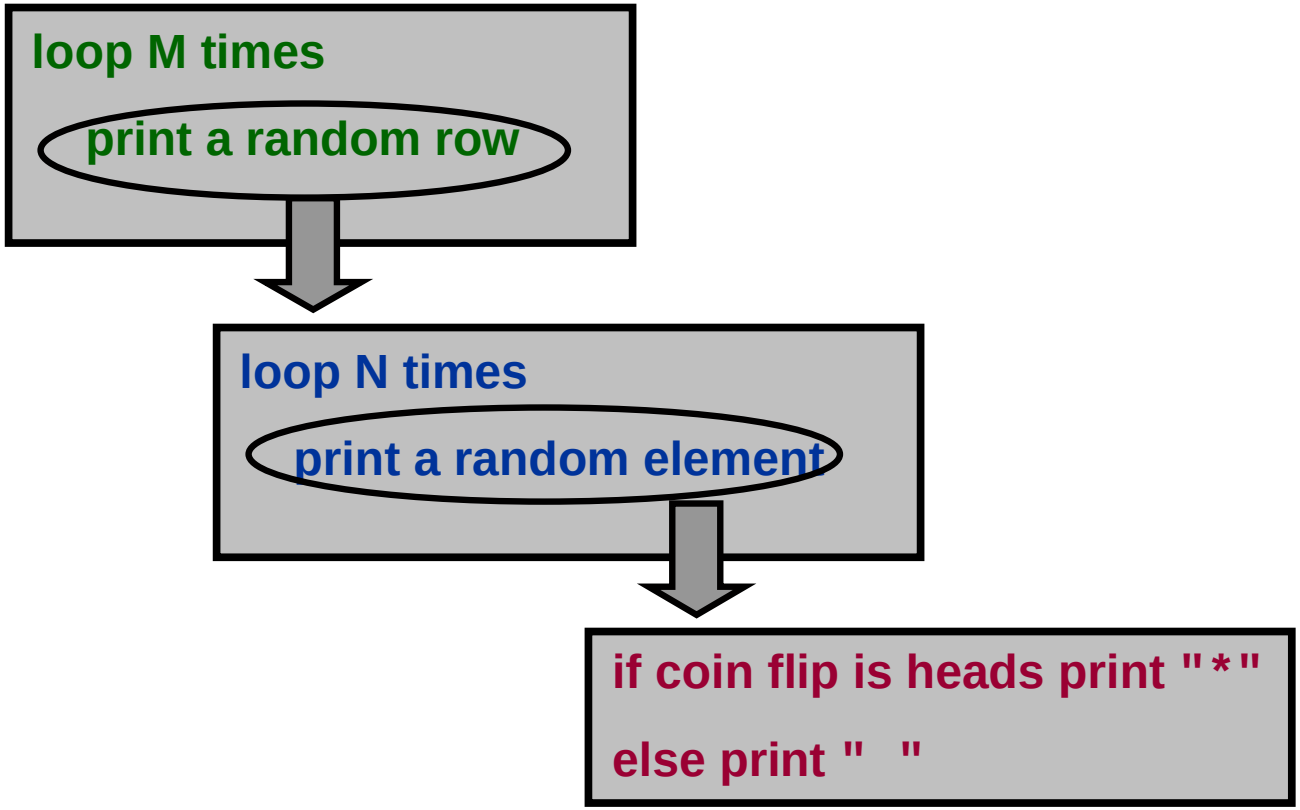
Random M x N Pattern



Random M x N Pattern

Top-down design.

- **Break a big problem into smaller subproblems.**
- **Break down subproblems into sub-subproblems.**
- **Repeat until all details filled in.**



randpattern.c

```
#include <stdio.h>
#define M 9
#define N 9
int randomInteger(int n) {...}

int main(void) {
  int i, j;

  i = 0;
  while (i < M) {
    j = 0;
    while (j < N) {
      if (randomInteger(2) == 1) printf("*");
      else printf(" ");
      j++;
    }
    printf("\n");
    i++;
  }
  return 0;
}
```

Print random M x N pattern.

Print a random element.

Print a random row.

Libraries

How is library function `printf()` created?

- User doesn't need to know details (see COS 217).
- User doesn't want to know details (abstraction).

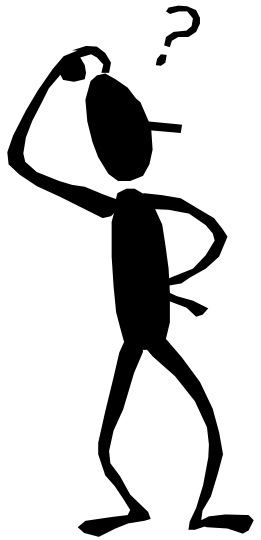
How is library function `rand()` created?

- Linear feedback shift register? Cosmic rays?
- Depends on compiler and operating system.
- Caveat 1: "random" numbers are not really random.

- Caveat 2: on many systems, our `randomInteger()` is very poor.

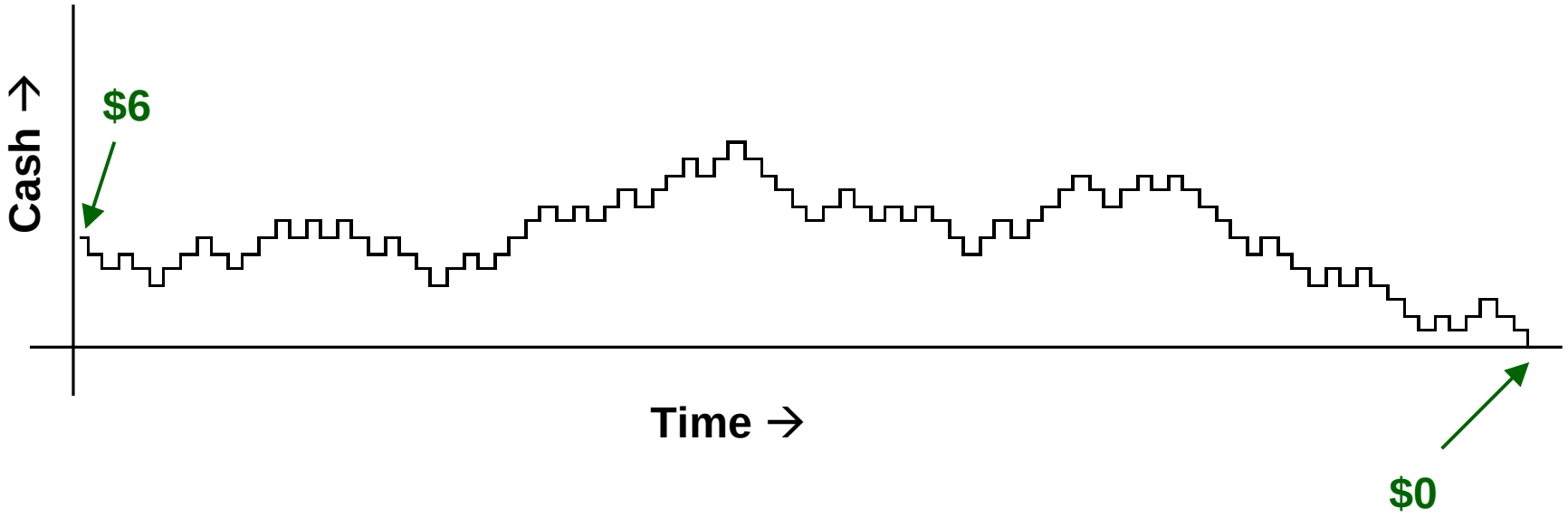
Moral: check assumptions about library function.

Gambler's Ruin



Simulate gambler placing $1 even bets.

- **Will gambler always go broke.**
- **If so, how long will it take if gambler starts with $c?**



Gambler's Ruin

gambler.c

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

int randomInteger(int n) { ... }

int main(void) {
  int cash, seed;
  scanf("%d %d", &cash, &seed);
  srand(seed);

  while (cash > 0) {
     if (randomInteger(2) == 1)
        cash++;
     else
        cash--;
     printf("%d\n", cash);
  }
  return 0;
}
```

scanf() takes input from terminal

srand() sets random seed

while I still have money left, repeat

make a bet

print money left

Gambler's Ruin

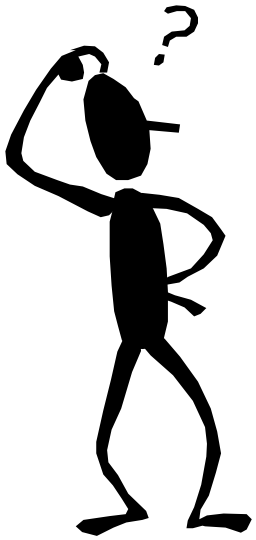
Simulate gambler placing $1 even bets.

Q. How long does the game last if we start with $c ?

Unix

```
% gcc gambler.c

% a.out          % a.out
4 543            4 1234
3                3
4                2
5                3
4                4
3                3
4                4
3                5
2                6
1                7
0                6
                 7
                 8
                 9
```

Hmmm.



Gambler's Ruin

Simulate gambler placing $1 even bets.

Q. How long does the game last if we start with $c ?

Unix

```
% gcc gambler.c

% a.out                % a.out
4 543                  4 1234
***                    ***
****                   **
*****                  ***
****                   ****
***                    ***
****                   ****
***                    *****
**                     ******
*                      *******
                       ******
                       *******
                       ********
                       *********
```

To print plot, replace:

```
printf("%d\n", cash);
```

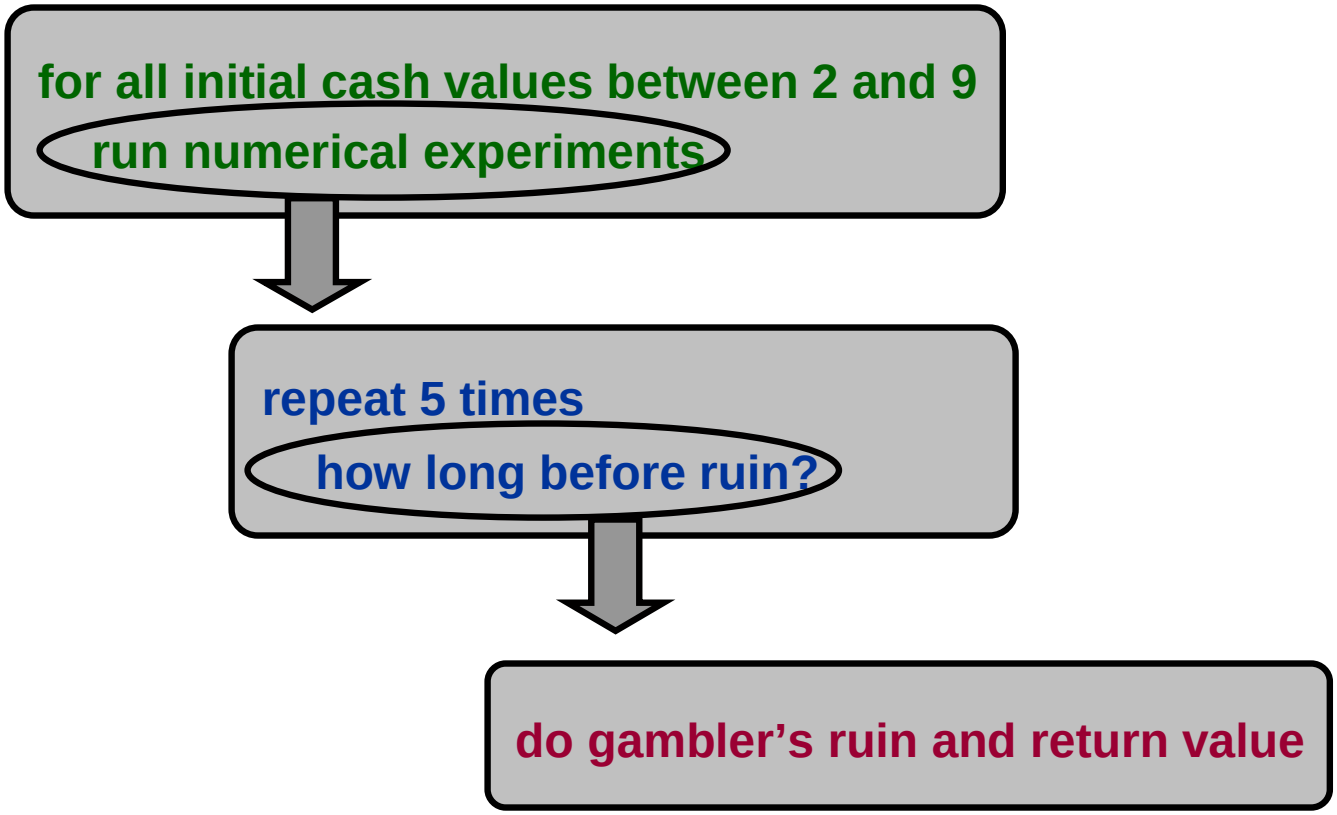
with

```
i = cash;
while (i > 0) {
   printf("*");
   i--;
}
printf("\n");
```

Top-Down Design of Numerical Experiment

Goal: run experiment to see how long it takes to go broke.

- **Find out how this changes for different values of c.**



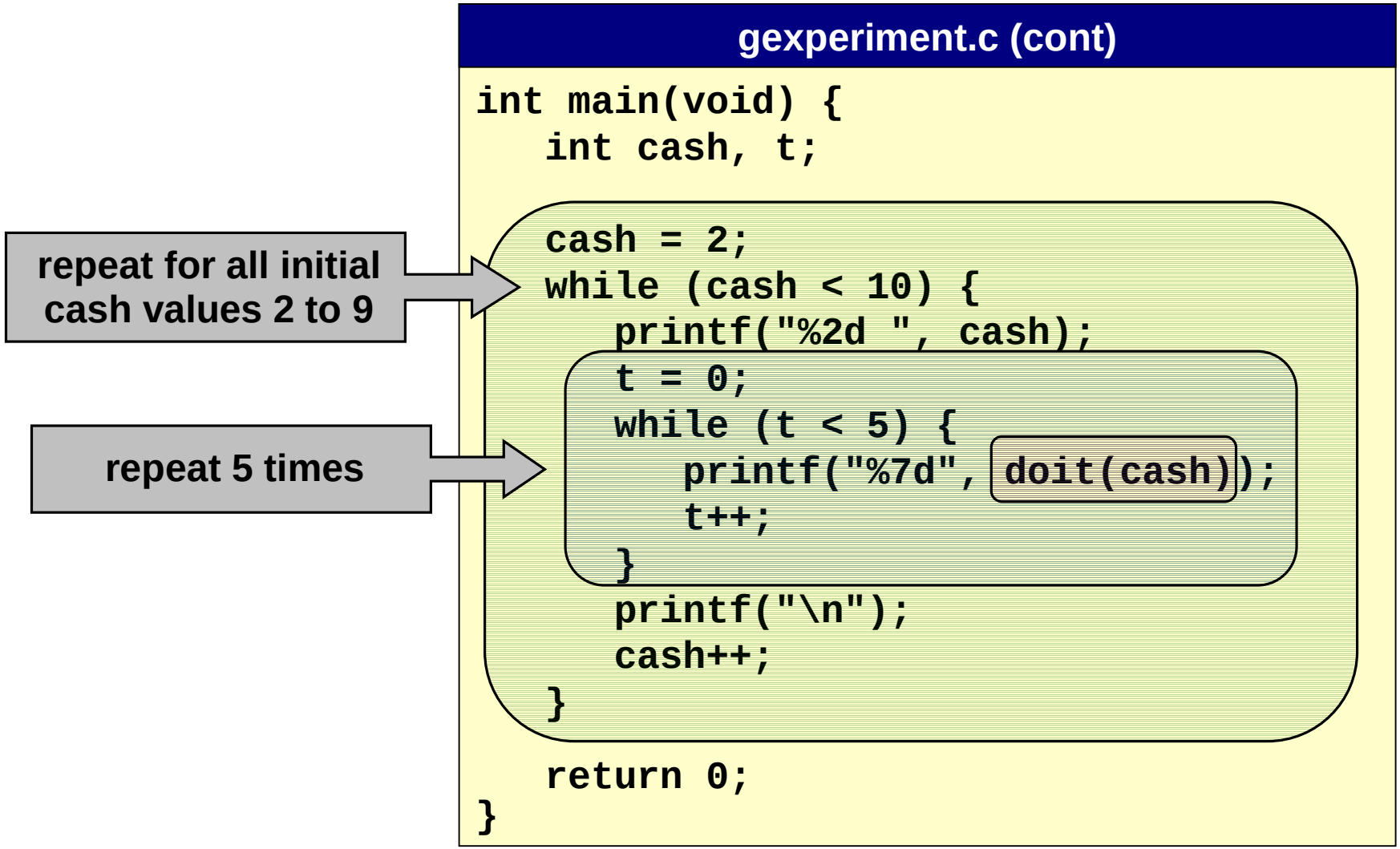
Gambler's Ruin Experiment

single experiment
(code as before)

gexperiment.c

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

int randomInteger(int n) { ... }

int doit(int cash) {
  int cnt = 0;
  while (cash > 0) {
     if (randomInteger(2) == 1)
        cash++;
     else
        cash--;
     cnt++;
  }
  return cnt;
}
```

Gambler's Ruin Experiment



Gambler's Ruin Experiment

Unix

```
% gcc gexperiment.c
% a.out
```

initial cash	# bets				
2	2	6	304	2	2
3	33	17	15	53	29
4	22	1024	7820	22	54
5	243	25	41	7	249
6	494	14	124	152	14
7	299	33	531	49	93
8	218	10650	36	42048	248
9	174090315	83579	299	759	69

How long will it take to go broke?

Layers of abstraction.

- **Random bit → gambler's ruin sequence → experiment.**

Programming Advice

Understand your program.

- **What would the machine do?**

Read, understand, and borrow from similar code.

Develop programs incrementally.

- **Test each piece separately before continuing.**
- **Plan multiple lab sessions.**

Debugging

Find the FIRST bug and fix it.

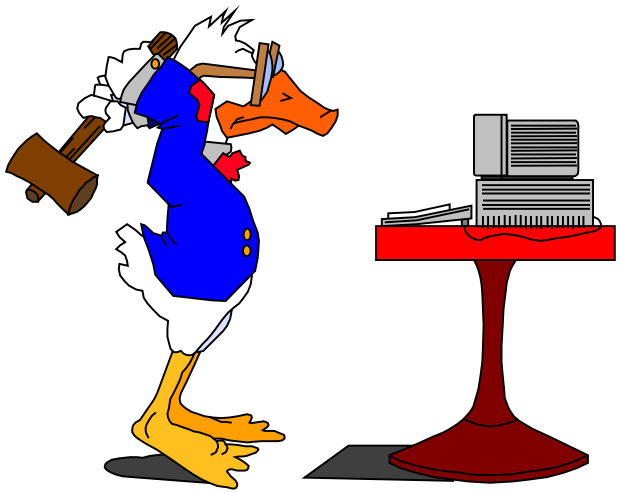
Syntax error - illegal C program.

- **Compiler error messages are good - tell you what you need to change.**

Semantic error - wrong C program.

- **Use "printf" method.**

Always a logical explanation.



Programming Style

Concise programs are the norm in C.

Your goal: write READABLE and EFFICIENT programs.

- **Use consistent indenting.**
  - **automatic indenting in emacs**
- **Choose descriptive variable names.**
- **Use comments as needed.**

"Pick a style that suits you, then use it consistently."

-Kernighan and Ritchie

Poor Indentation

fact.c

```
#include <stdio.h>

#define l11l 0xFFFF
#define ll1 for
#define ll111 if
#define l1l1 unsigned
#define l111 struct
#define lll11 short
#define ll11l long
#define ll1ll putchar
#define l1l1l(l) l=malloc(sizeof(l111 llll1));l->lll1l=1-1;l->ll1l1=1-1;
#define l1ll1 *llll1++=l1ll%10000;l1ll/=10000;
#define l1lll ll111(!l1->lll1l){l1l1l(l1->lll1l);l1->lll1l->ll1l1=l1;}\
llll1=(l1=l1->lll1l)->lll;ll=1-1;
#define llll 1000

                                                l111 llll1 {
                                                l111 llll1 *
     lll1l,*ll1l1       ;l1l1                   lll11 lll [
     llll];};main     (){l111 llll1             *ll11,*l1l,*
     l1, *ll1l, *    malloc ( ) ; l1l1          ll11l l1ll ;
     ll11l l11,ll  ,l;l1l1 lll11 *lll1,*        llll1; ll1(l
     =1-1 ;l< 14; ll1ll("\t\"8)>l\"9!.)>vl"     [l]^'L'),++l
     );scanf("%d",&l);l1l1l(l1l) l1l1l(ll11     ) (l1=l1l)->
     lll[l1l->lll[1-1]    =1]=l11l;ll1(l11      =1+1;l11<=l;
     ++l11){l1=ll11;       lll1 = (ll1l=(       ll11=l1l))->
     lll; llll1 =(          l1l=l1)->lll;       ll=(l1ll=1-1
     );ll1(;ll1l->           lll1l||l11l!=      *lll1;){l1ll
     +=l11**lll1++           ;l1ll1 ll111       (++ll>llll){
     l1lll lll1=(            ll1l =ll1l->       llll1)->lll;
     }}ll1(;l1ll;            ){l1ll1 ll111      (++ll>=llll)
     { l1lll} } *            llll1=l11l;}
     ll1(l=(ll=1-            1);(l<llll)&&
     (l1->lll[ l]            !=l11l);++l);      ll1 (;l1;l1=
     l1->ll1l1,l=            llll){ll1(--l      ;l>=1-1;--l,
     ++ll)printf(            (ll)?((ll%19)      ?"%04d":(ll=
     19,"\n%04d")            ):"%4d",l1->       lll[l] ) ; }
                                                ll1ll(10); }
```

Summary

Lots of material.

C is a structured programming language.

- **Functions, loops.**
- **Simple but powerful tools.**

Programming maturity comes with practice.

- **Everything seems simpler in lecture and textbooks.**
- **Always more difficult when you do it yourself!**
- **Learn main ideas from lecture, learn to program by writing code.**

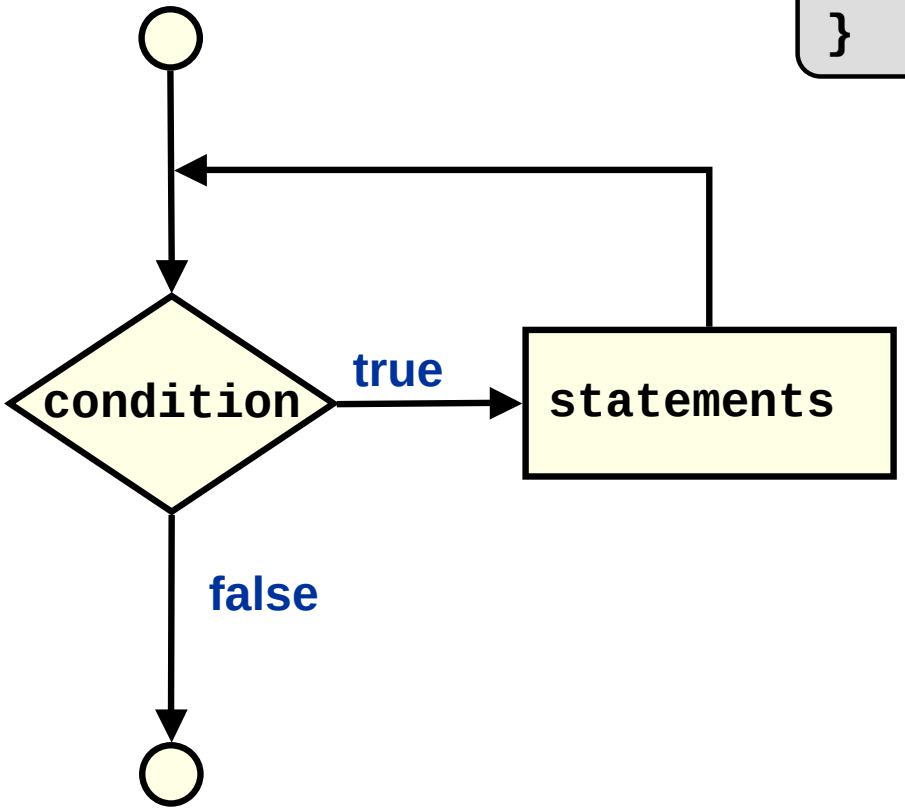
Lecture P1: Supplemental Notes

Anatomy of a While Loop

The while loop is a common repetition structure.

```
while (condition) {
  statements;
}
```

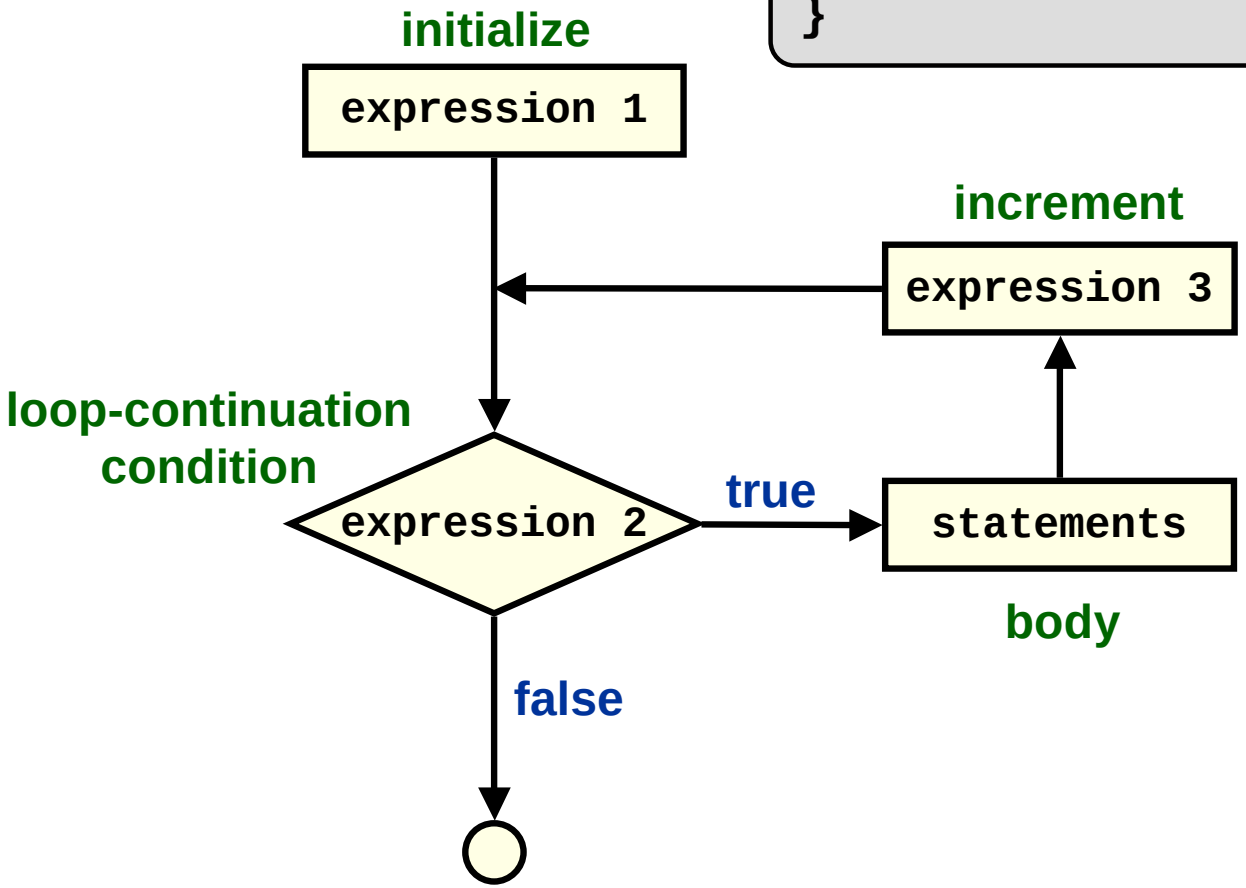
while loop



Anatomy of a For Loop

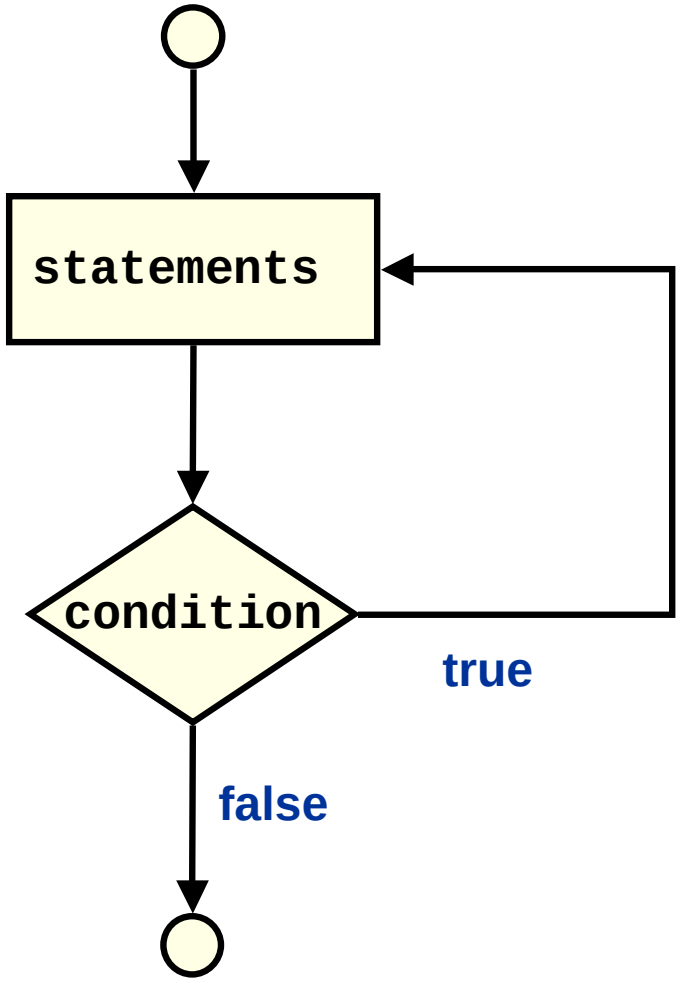
The for loop is another common repetition structure.

```
for (expr1; expr2; expr3) {
  statements;
}
```



Anatomy of a Do-While Loop

The do-while loop is not-so-common repetition structure.




```
do {
  statements;
} while (condition)
```

do-while loop

For Loop Example

Print a table of values of function f(x) = 2 - x^3. A fourth attempt.

table4.c

```
#include <stdio.h>

int main(void) {
  double x, y;

  printf(" x     f(x)\n");
  for (x = 0.0; x < 2.0; x = x + 0.1) {
    y = 2 - x*x*x;
    printf("%4.1f %6.3f\n", x, y);
  }

  return 0;
}
```

Final Attempt

Print a table of values of function $f(x) = 2 - x^3$. A fifth attempt.

table5.c

```
#include <stdio.h>

double f (double x) {
  return 2.0 - x*x*x;
}

int main(void) {
  double x;

  printf(" x     f(x)\n");
  for (x = 0.0; x < 2.0; x += 0.1)
    printf("%4.1f %6.3f\n", x, f(x));
  return 0;
}
```

x += 0.1 is shorthand in C for x = x+ 0.1

no need for { } if only one statement

What is a C Program?

C PROGRAM: a sequence of FUNCTIONS that manipulate data.

- `main()` function executed first.

A FUNCTION consists of a sequence of DECLARATIONS followed by a sequence of STATEMENTS.

- Can be built-in like `printf(...)`.
- Or user-defined like `f(x)` or `sum(x, y)`.

A DECLARATION names variables and defines type.

- double `double x;`
- integer `int i;`

A STATEMENT manipulate data or controls execution.

- assignment: `x = 0.0;`
- control: `while (x < 2.0) {...}`
- function call: `printf(...);`

Random Integers

Print 10 "random" integers.

- Library function `rand()` in `stdlib.h` returns integer between 0 and `RAND_MAX` (32,767 = 2^{16} - 1 on arizona).

int.c

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

int main(void) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%d\n", rand());
  return 0;
}
```

Unix

```
% gcc int.c
% a.out
16838
5758
10113
17515
31051
5627
23010
7419
16212
4086
```

Random Integers

Print 10 "random" integers between 0 and 599.

- **No precise match in library.**
- **Try to leverage what's there to accomplish what you want.**

int600.c

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

int randomInteger(int n) {
  return rand() % n;
}

int main(void) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%d\n", randomInteger(600));
  return 0;
}
```

p % q gives remainder of p divided by q

Unix

```
% gcc int600.c
% a.out
168
5
1
175
310
562
230
341
16
386
```

Random Real Numbers

Print 10 "random" real numbers between 0.0 and 1.0.

- **No precise match in library.**
- **Try to leverage what's there to accomplish what you want.**

real.c

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

int main(void) {
  int i;
  for (i = 0; i < 10; i++)
    printf("%f\n", 1.0 * rand() / RAND_MAX);
  return 0;
}
```

Integer division: 16838 / 32767 = 0.
C has conversions for mixed types:
1.0 * 15838 / 32767 = 0.513871.

Unix

```
% gcc real.c
% a.out
0.513871
0.175726
0.308634
0.534532
0.947630
0.171728
0.702231
0.226417
0.494766
0.124699
```