Programming in C
Quick Start!

Biostatistics 615/815

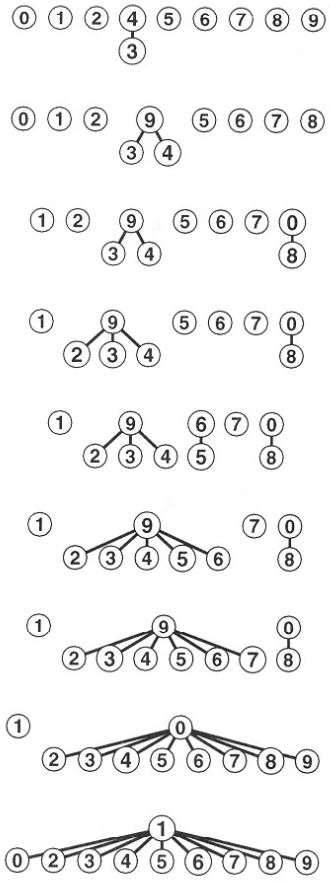
Lecture 2

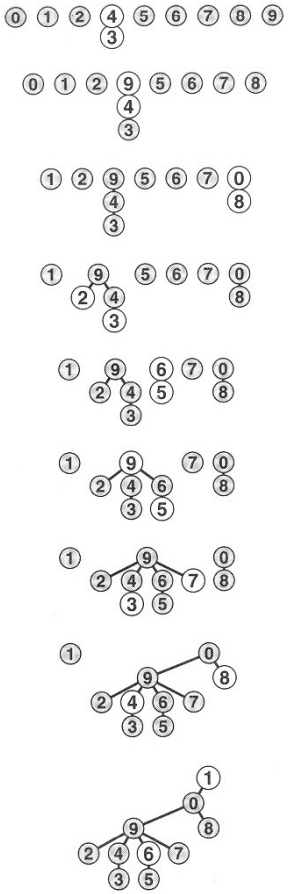
Last Lecture

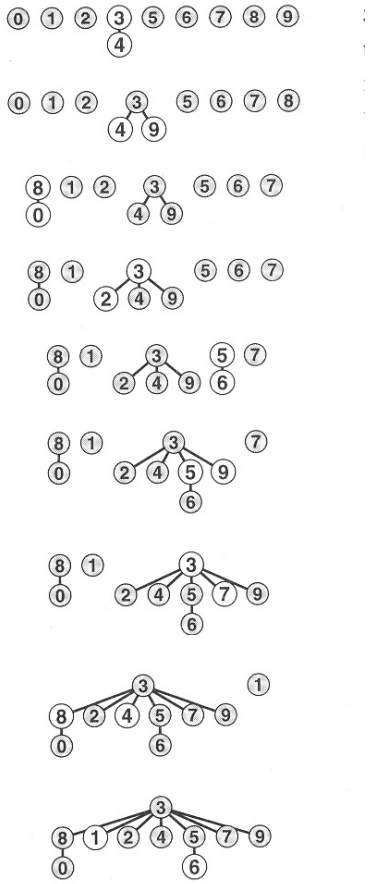
- Describe 3 algorithms for tackling the connectivity problem
  - Quick Find
  - Quick Union
  - Weighted Quick Union

Pictorial Comparison

Quick Find Quick Union Weighted







Quick Find in C

```
// Data Initialization
for (i = 0; i < N; i++)
      a[i] = i;

// Loop through connections
while (read_connection(p, q))
      {
      // Check that input is within bounds
      if (p < 0 || p >= N || q < 0 || q >= N) continue;

      if (a[p] == a[q]) continue; // FIND operation

      set = a[p];                    // UNION operation
      for (i = 0; i < N; i++)
         if (a[i] == set)
            a[i] = a[q];

      print_connection(p, q);
      unique_connections++;
      }
```

Quick Union in C

```
// Loop through connections
while (read_connection(p, q))
   {
   // Check that input is within bounds
   if (p < 0 || p >= N || q < 0 || q >= N) continue;

   // FIND operation
   i = a[p];
   while (a[i] != i)
      i = a[i];

   j = a[q];
   while (a[j] != j)
      j = a[j];

   if (i == j) continue;

   // UNION operation
   a[i] = j;

   print_connection(p, q);
   unique_connections++;
   }
```

Weighted Quick Union in C

```
for (i = 0; i < N; i++)          // Initialize weights
   weight[i] = 1;                //

while (read_connection(p, q))    // Loop through connections
   {
   // Check that input is within bounds
   if (p < 0 || p >= N || q < 0 || q >= N) continue;

   i = a[p];                     // FIND operation
   while (a[i] != i)             //
      i = a[i];                  //  Identify group to which items p and q
                                 //  belong, by tracing up their respective
   j = a[q];                     // chains
   while (a[j] != j)             //
      j = a[j];                  //
                                 //
   if (i == j) continue;         //

   if (weight[i] < weight[j])                    // UNION operation
      { a[i] = j; weight[j] += weight[i]; }      //
   else                                          // Link smaller group to
      { a[j] = i; weight[i] += weight[j]; }      // the larger one …

   print_connection(p, q);
   unique_connections++;
   }
```

Today

- How to compile and debug C programs
  - On Windows, with Visual Studio
  - On Unix (and Macs!), with GCC / GDB
- Basics of Programming in C
  - General organization of C programs
  - C function libraries

Brief History of C

- C was developed by Dennis Ritchie at Bell Labs (1969 – 72)
  - Support the new UNIX operating system
  - Successor to B and BCPL
- Strongly typed language
- Dynamic memory allocation
- User defined data structures

The Modern C/C++ Languages

- High level languages
  - Relatively easy to understand
- Portable language
  - Work on desktop computers, mainframes and mobile phones
- Computers execute much more detailed, "lower-level" instructions …
- … compilers perform the necessary translation.

Anatomy of C Program

- A collection of functions
  - Receive a set of parameters
  - Declare local variables
  - Carry out processing
  - Return a value
- `main()` function
  - Called to start the program

A C function definition

```
type function(argument_list)
  {
  variable_declarations;

  statements;
  }
```

- Each function has a type
- Each function argument has a type
- Each local variable has a type

C libraries

- Most programs are not built from scratch
- Rely on pre-existing collections of functions
  - Standard C Library, C++ Templates, KDE/Qt, GNU Scientific Library…
- Header (.h) files describe functions in these collections
  - Accessed through **#include** statements

Very Basic C Program

```
/* C code is stored in .c or .cpp files */

#include <stdio.h>

int main()
  {
  printf("Hello, I am a program ...\n");
  printf("... And I don't do much.\n");

  return 0;
  }
```

Now I have a program ...
... how do I run it?

In a UNIX Environment...

- Many of you will end up running your programs in a Unix or Linux server
- GNU tools are widely available and quite popular
  - Start with a text editor, type in your code, then use …
  - GCC / G++ to compile code
  - GDB to debug and test code
  - GPROF to collect performance metrics
- … this approach has seriously steep learning curve.
- I recommend a more friendly setting …
- … write and debug code in a Windows PC or a Mac.

In a Windows PC or Mac

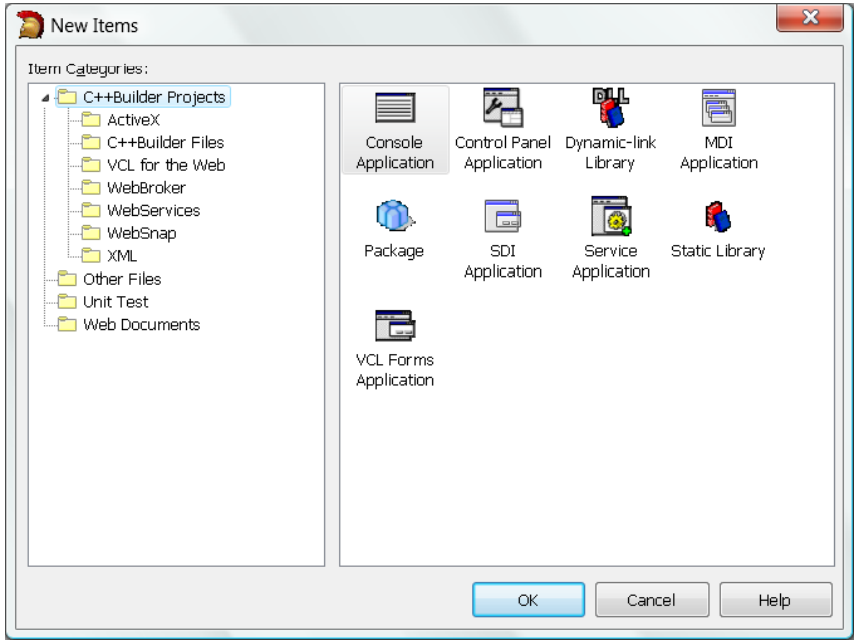
- Integrated toolsets exist combine editing, compiling, debugging and extensive documentation
- Microsoft Visual Studio / Visual C++
  - Discounted versions available through the University
- Turbo C++ Explorer
  - Free version of Borland C++ Builder
  - Available from www.turboexplorer.com
- Xcode
  - Included in Mac OS X (may have to find original DVD)

Getting Started: Create a New Project

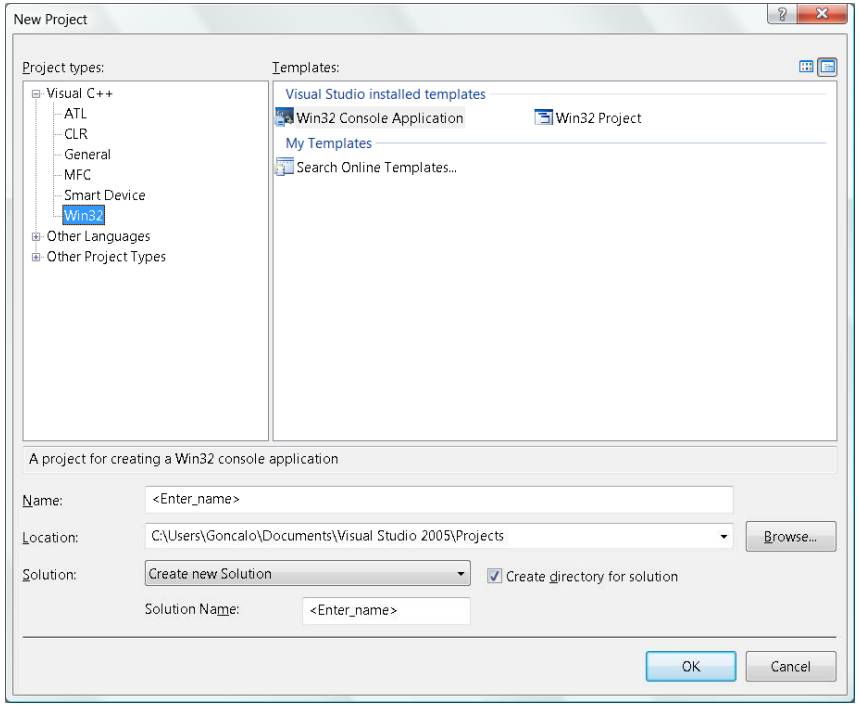
- The first step is to create a new project.
- Throughout the course, we will be focus on data manipulation and analysis using ***console applications***
- So, we'll use a "Console Application" template for our projects…

File | New ...

C++ Builder



Visual Studio

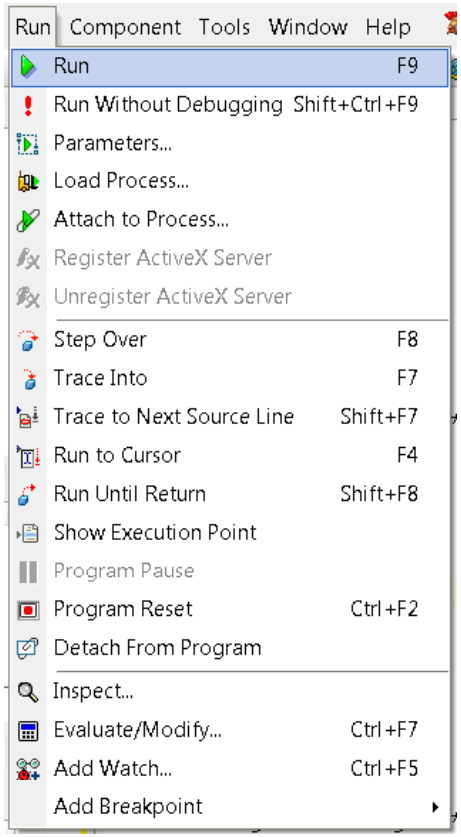


Very Basic C Program

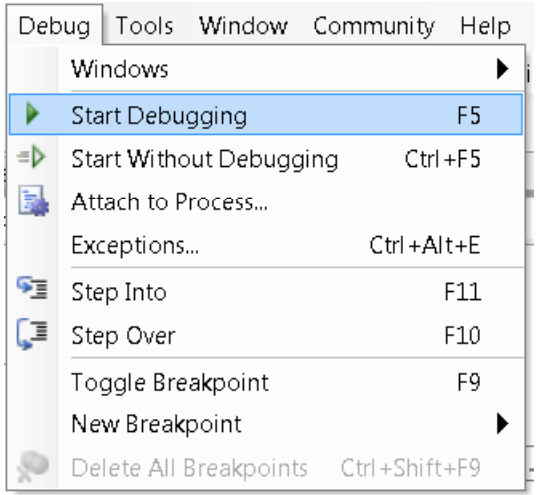
```
/* C code is stored in .c or .cpp files */

#include <stdio.h>

int main()
  {
  printf("Hello, I am a program ...\n");
  printf("... And I don't do much.\n");

  return 0;
  }
```

Running the Program ...

C++ Builder



Visual Studio



Errors?

- Compiler will list problems in your code and you should be able to click on each error message to identify problem …
- … sometimes a single problem can lead to many error messages.

Making our program more...
"Useful"...
"Complicated"...

Variables in C

- Must be declared before use
- Each variable has a specific type
  - integer
  - floating point
  - character
- Names are case-sensitive

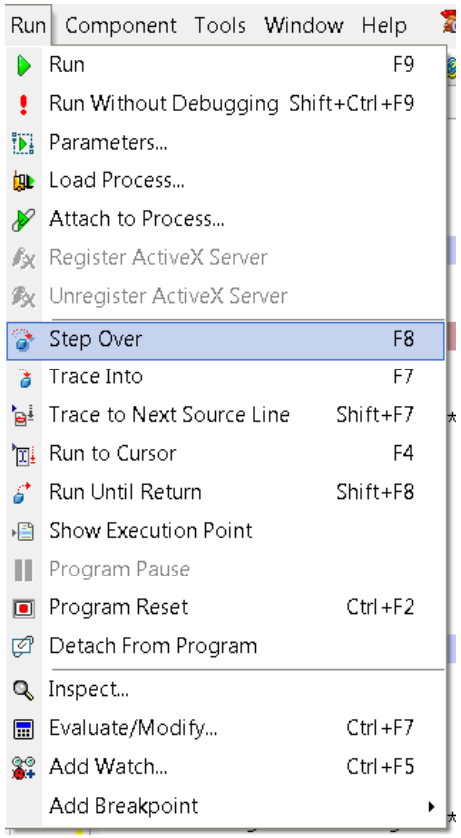
Another C Program

```
#include <stdio.h>

int Multiply(int x, int y)
    {
    int product = x * y;

    return product;
    }

int main()
    {
    int x = 2;

    printf("%d * %d = %d\n", x, x, Multiply(x, x));

    return 0;
    }
```

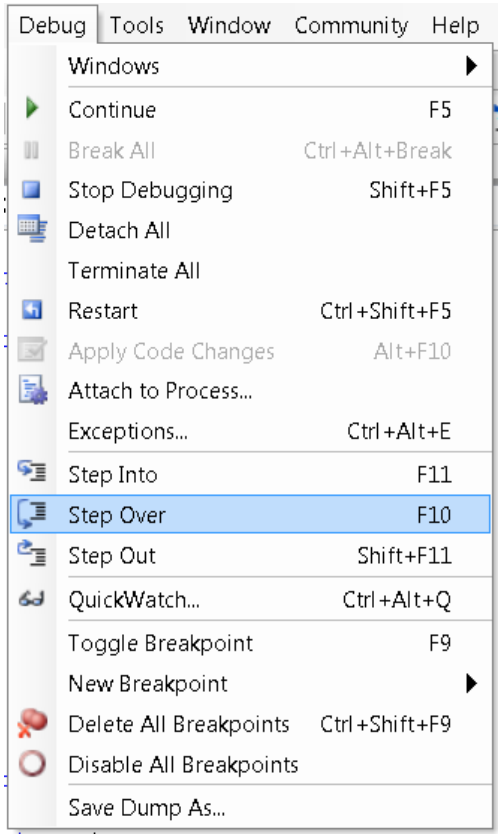
Executing Code Line by Line...

(TIP: place mouse over variables to see their contents)

C++ Builder



Visual Studio



Basic Data Types in C

- Integer data types
  - `int, short, long`
- Floating point data types
  - `float, double`
- Character types
  - `char` (which is also an integer!)
- Pointers and user-defined types are also available

Integers

- For most purposes the **`int`** type will do
  - **`unsigned int`** for strictly positive quantities
  - **`long long`** data type for storing large integers

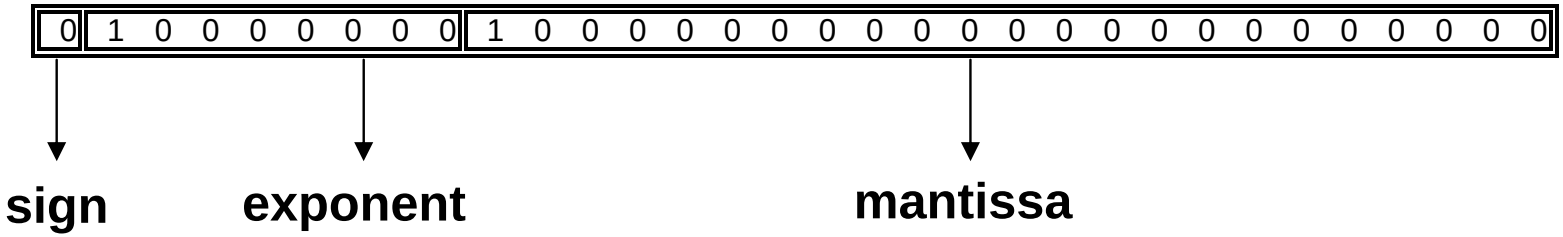
- Typically, store up to 31 or 63 digits
  - in base 2
  - plus one digit for sign
  - range is about -2.1 to 2.1 billion (32 bit)

Counting digits in an *int* ...

```
int count_integer_bits()
   {
   int bits = 0;
   int integer = 1;

   while (integer != 0)
      {
      bits++;
      integer = integer * 2;
      }

   return bits;
   }
```

Floating point numbers

- Stored as exponent, mantissa and sign
  - Representation varies between machines
- Limited range and precision



Floating point data

- Stored in exponential notation
  - In base 2
- Has limited accuracy
  - Computing two similar quantities and evaluating their difference can be especially inaccurate
- Greater range than integer data
  - Exact for small integers

Measuring accuracy of a *double*

```
/* Calculate precision of double */
double precision()
   {
   double e = 1.0, temp;

   do {
       e = e * 0.5;
       temp = 1.0 + e;
   } while (temp > 1.0);

   return e * 2.0;
   }
```

Arithmetic has limited precision

- You just saw examples where:
  - `a * 2 == 0` and `a > 0`...
  - `a + b == a` and `b > 0`...
- In some applications, these limits of arithmetic precision can make a lot of difference!
- This is a feature of most computer applications

Flow Control Statements...

- Allow programs to make choices based on input or results of previous operations
- Most interesting programs will depend on these…
- Examples …
  - **`if … else`** …
  - **`do`** … **`while …`**
  - **`while`** …
  - **`for`** …

if … else …

```
if (expression)
    statement1;
else
    statement2;
```

- When `expression` is true (or nonzero) `statement1` is executed; otherwise `statement2` is executed.

Example

```
void Compare(int a, int b)
  {
  if (a == b)
     printf(“Values Match!\n”);
  else
     printf(“Values are different!\n”);
  }
```

do ... while ...

```
do
    statement;
while (expression);
```

- `statement` is executed until `expression` evaluates to false (or zero).
- `statement` is executed is executed at least once.

Example: Measuring Precision for a *double*

```
/* Calculate precision of double */
double precision()
   {
   double e = 1.0, temp;

   do {
       e = e * 0.5;
       temp = 1.0 + e;
   } while (temp > 1.0);

   return e * 2.0;
   }
```

while ...

```
while (expression)
    statement;
```

- `statement` is executed while `expression` evaluates to true.
- `statement` may never be executed.

Example: Counting digits in an *int* ...

```
int count_integer_bits()
   {
   int bits = 0;
   int integer = 1;

   while (integer != 0)
      {
      bits++;
      integer = integer * 2;
      }

   return bits;
   }
```

for

```
for ( initialization; condition; increment)
      statement;
```

- Executes `initialization`.
- While `condition` is true:
  - Execute `statement`.
  - Evaluate `increment`.
- `statement` may never be executed.

Example: Searching for value in a list...

```
int search(int a[], int value, int start, int stop)
   {
   // Variable declarations
   int i;

   // Search through each item
   for (i = start; i <= stop; i++)
       if (value == a[i])
              return i;

   // Search failed
   return -1;
   }
```

break and continue

- `continue`
  - Re-evaluates loop condition.
  - If not finished, start a new cycle.
- `break`
  - Stop looping early.

Some Standard C Libraries

Header File	Functionality
`ctype.h`	Information about characters
`float.h`	Information about floating point
`limits.h`	Information about integers
`math.h`	Common mathematical functions
`stdio.h`	Basic input / output functions
`stdlib.h`	Kitchen Sink!
`string.h`	String manipulation functions
`time.h`	Time

`math.h`, Mathematical Functions

- double exp(double *x*);
  - exponential of *x*
- double log(double *x*);
  - natural logarithm of *x*
- double log10(double *x*);
  - base-10 logarithm of *x*
- double pow(double *x*, double *y*);
  - *x* raised to power *y*

- double sin(double *x*);
- double cos(double *x*); …
  - Standard trigonometric functions

- double sqrt(double *x*);
  - square root of *x*
- double ceil(double *x*);
  - smallest integer not less than *x*
- double floor(double *x*);
  - largest integer not greater than *x*
- double fabs(double *x*);
  - absolute value of *x*

Important Library Functions

- `<stdio.h>`
  - Input and output
- `<stdlib.h>`
  - Basic random numbers and memory allocation

Input / Output Functions

- <stdio.h>
- Default
  - `int printf(char * format, …);`
  - `int scanf(char * format, …);`
- File based functions
  - `FILE * fopen(char * filename, char * mode);`
  - `int fclose(FILE * file);`
  - `int fprintf(FILE * file, char * format, …);`
  - `int fscanf(FILE * file, char * format, …);`

printf

- Writes formatted output
- Format string controls how arguments are converted to text
  - Parameters are printed as specied in % fields
    - `%[flags][width][.precision]type`
  - Otherwise, string is quoted

printf fields

- Flags:
  - “-” to left justify result
  - “+” to show sign in positive numbers
- Width
  - Minimum number of characters to print
- Precision
  - Number of digits after decimal (for floating point)
  - Maximum number of characters (for strings)
- Type
  - “s” for strings
  - “d” for integers, “x” to print hexadecimal integers
  - “f” for floating point, “e” for exponential notation, “g” for automatic

scanf

- Reads formatted input
- Format string defines input interpretation
  - Each `%[type]` field is converted and stored
- Arguments should be addresses of variables where input is to be stored

scanf fields

- Field types
  - “s” for strings
  - “d” for **`int`** variables
  - “lld” for **`long long`** variables
  - “f” for **`float`** variables
  - “lf” for **`double`** variables

Example

```
#include <stdio.h>

int square(int x)
   {
   return x * x;
   }

int main()
   {
   int number;

   printf("Type a number:");
   scanf("%d", &number);
   printf("The square of %d is %d.\n", number, square(number));

   return 0;
   }
```

Opening and closing files

- `FILE * fopen(char * filename, char * type);`
  - Opens file with *filename*
  - If type is “wt”, a text file is opened for writing
  - If type is “rt”, a text file is opened for reading
  - Types “rb” and “wb” are analogous for binary files
  - Returns NULL on failure
- `int fclose(FILE * file);`
  - Closes file
  - Returns 0 on success

Example

```
#include <stdio.h>

int sqr(int x)
   { return x * x; }

int main()
   {
   int number;
   FILE * output;

   printf("Type a number:");
   scanf("%d", &number);

   output = fopen("results.txt", "wt");
   fprintf(output, "The square of %d is %d\n“, number, sqr(number));
   fclose(output);

   return 0;
   }
```

Basic Random Numbers

- <stdlib.h>
- `int rand()`
  - Sample a uniformly distributed random integer between 0 and RAND_MAX
- `void srand(int seed)`
  - Select the sequence of random numbers specified by seed

Weighted Quick Union in C

```
// Initialize random generator
srand(1234);

// Generate M random connections
while (count++ < M)
   {
   // Pick random elements to connect
    p = rand() % N;
    q = rand() % N;

   // FIND operation
   for (i = a[p]; a[i] != i; i = a[i] )  ;
   for (j = a[q]; a[j] != j; j = a[j] )  ;
   if (i == j) continue;

   // UNION operation
   if (weight[i] < weight[j])
      { a[i] = j; weight[j] += weight[i]; }
   else
      { a[j] = i; weight[i] += weight[j]; }

   printf("%d %d is a new connection\n", p, q);
   }
```

Weighted Quick Union in C

```
// Initialize random generator
srand(1234);

// Generate M random connections
while (count++ < M)
   {
   // This method generates better randomness in many computers
    p = (int) (rand() * 1.0 * N / (RAND_MAX + 1.0));
    q = (int) (rand() * 1.0 * N / (RAND_MAX + 1.0));

   // FIND operation
   for (i = a[p]; a[i] != i; i = a[i] )  ;
   for (j = a[q]; a[j] != j; j = a[j] )  ;
   if (i == j) continue;

   // UNION operation
   if (weight[i] < weight[j])
      { a[i] = j; weight[j] += weight[i]; }
   else
      { a[j] = i; weight[i] += weight[j]; }

   printf("%d %d is a new connection\n", p, q);
   }
```

Today

- Organization of C programs
- Basic data types
- Standard libraries