# *Programming in C*
# *Quick Start!*

Biostatistics 615/815

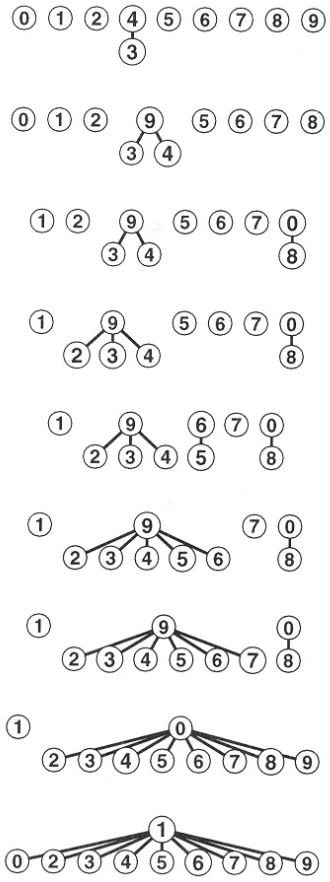
Lecture 2

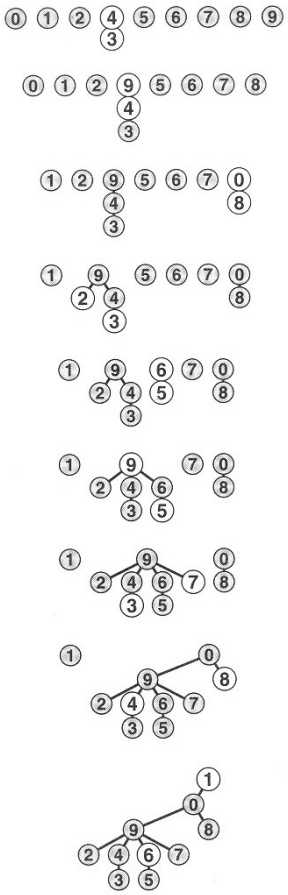
# Last Lecture

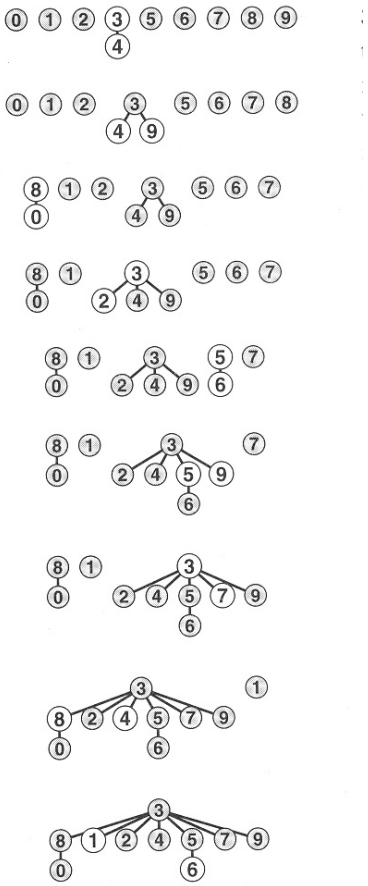
- Describe 3 algorithms for tackling the connectivity problem
  - Quick Find
  - Quick Union
  - Weighted Quick Union

# 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 (scanf(" %d %d", &p, &q) == 2)
    {
    // Check that input is within bounds
    if (p < 0 || p >= N || q < 0 || q >= N) continue;

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

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

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

# Quick Union in C

```
// To start, place each element in its own group
for (i = 0; i < N; i++)
   a[i] = i;

// Loop through connections
while (scanf(" %d %d", &p, &q) == 2)
   {
   // Check that input is within bounds
   if (p < 0 || p >= N || q < 0 || q >= N) continue;

   // 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
   a[i] = j;

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

# Weighted Quick Union in C

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

// Loop through connections
while (scanf(" %d %d", &p, &q) == 2)
   {
   // Check that input is within bounds
   if (p < 0 || p >= N || q < 0 || q >= N) continue;

   // 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);
   }
```

# This Week

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

# 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 Language

- Portable language
  - C compilers are available for desktop computers, mainframes and mobile phones
- Very efficient
- C++ is the successor to C
  - Simplifies grouping of functions and related data

# 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

# C libraries

- Most programs are not built from scratch
- Rely on pre-existing collections of functions
  - e.g. the Standard C library
- Header (.h) files describe functions in these collections
  - e.g. accessed through **#include** statements

# 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

# A simple C program

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

#include <stdio.h>

int main()
  {
  printf("Hello, I am a program\n");

  return 0;
  }
```

# 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;
    }
```

# Basic Data Types in C

- Integer data types
  - `int, long`
- Floating point data types
  - `float, double`
- Character types
  - `Char`
- Pointers and user-defined types are also available

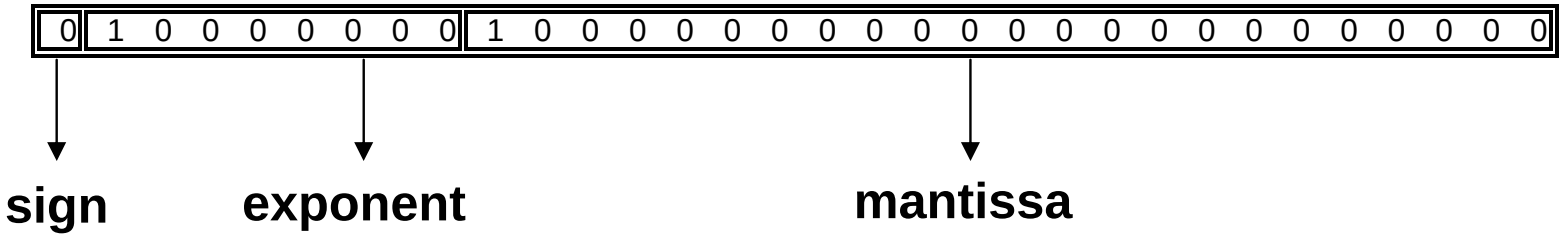
# Integers

- 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)

# 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

# Programming Constructs in C

- Function definitions and calls
- Compound statements
- Flow-control
  - **`if … else`** …
  - **`do`** … **`while …`**
  - **`while`** …
  - **`for`** …

# Compound Statements

- C statements can be grouped with **{}**
- Optionally, each compound statement starts with local variable declarations
- Individual statements separated by “**;**”

## 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

```
/* 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

```
/* Calculate maximum integer */
double maximum_integer()
   {
   int a = 2, b = 1, bits = 1;

   while (a > b)
        {
        b = a;
        a = a + a;
        bits++;
        }

   printf("Looks like a %d-bit computer\n", bits);

   return b;
   }
```

# for

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

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

# Example

```
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 square(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, square(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

# Thursday: Executing C Code

- C is a high level language
  - Relatively easy to understand
- Computer CPUs execute much more detailed, "lower-level" instructions
- A compiler performs the necessary translation…

# Working in a UNIX Environment

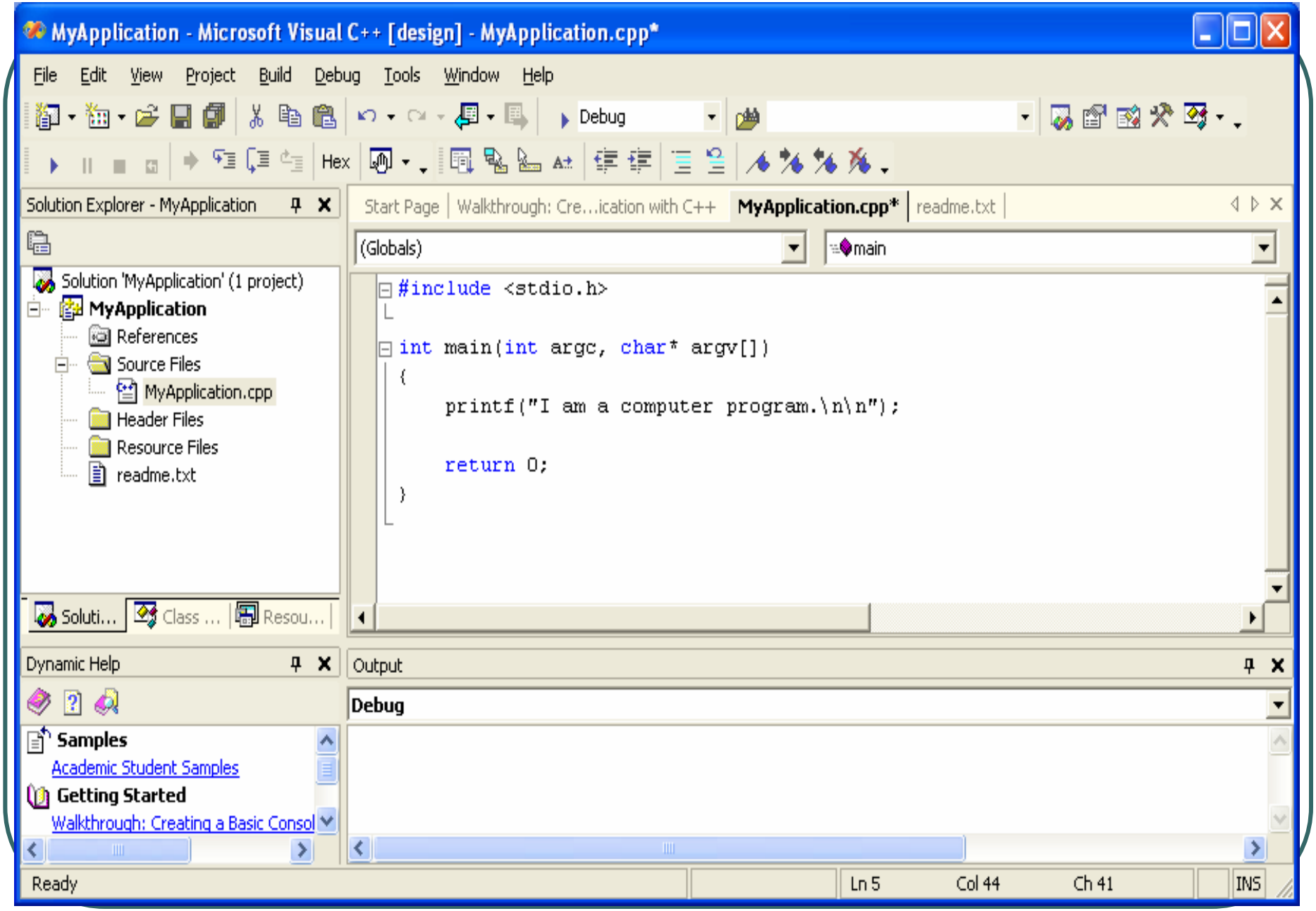
- GCC / G++
  - Compile code
- GDB
  - Debug and test code
- GPROF
  - Collect performance metrics

# GCC

- GCC is a free C compiler
  - GNU C Compiler
- Versions available for
  - Linux
  - Unix
  - Mac
  - Windows
- Developed by Free Software Foundation

# Working in a Windows Environment

- Good integrated toolsets exist
- Good options include:
  - Microsoft Visual Studio / Visual C++
    - Discounted version available through the University
  - Turbo C++ Explorer
    - Free C/C++ compiler, www.turboexplorer.com


MyApplication - Microsoft Visual C++ [design] - MyApplication.cpp*
File Edit View Project Build Debug Tools Window Help
Debug
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References
Source Files
MyApplication.cpp
Header Files
Resource Files
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MyApplication.cpp*
readme.txt
(Globals)
main
#include <stdio.h>
int main(int argc, char* argv[])
{
printf("I am a computer program.\n\n");
return 0;
}
Dynamic Help
Samples
Academic Student Samples
Getting Started
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