Biostatistics 615 - Statistical Computing

Lecture 2
Computer Arithmetic & Basic Syntax

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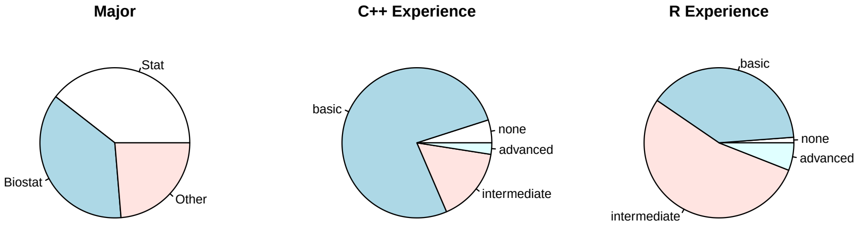
Summary of the previous lecture

- ✓ Syllabus
- ✓ Introduction to statistical computing
- ✓ Introduction to computer representation of data
  - ✓ Binary representation
  - ✓ Storage unit (Bit, Byte, KB, MB, GB, TB, PB)
- ✓ Class survey



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Storage in C++

- How the ideas about number representation are implemented in C++?
- While investigating this issue, we will also introduce some of language features that will allow us to begin to write, compile and execute C++ programs
- The amount of storage that is allocated to different data types can be determined using the sizeof operator
- Example 2.1: demonstrates the use of sizeof to determine information about storage space, in bytes

```
//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
int main(){
  cout << "The storage allocated for a char is "
  << sizeof(char) << " byte" << endl;
  cout << "The storage allocated for an unsigned short integer is "
  << sizeof(unsigned short int) << " bytes" << endl;
  cout << "The storage allocated for an integer is "
  << sizeof(int) << " bytes" << endl;
  cout << "The storage allocated for a long integer is "
  << sizeof(long int) << " bytes" << endl;
  cout << "The storage allocated for an unsigned long integer is "
  << sizeof(unsigned long int) << " bytes" << endl;
  cout << "The storage allocated for a float is "
  << sizeof(float) << " bytes" << endl;
  cout << "The storage allocated for a double is "
  << sizeof(double) << " bytes" << endl;
  cout << "The storage allocated for a long double is "
  << sizeof(long double) << " bytes" << endl;
  return 0;
}
```

Basic syntax – comment statement

```
//Example 2.1: storageSize.cpp
... ...
```

- Use "//" at the start of each line
- Bracket the comment encompassing possibly multiple lines by "/*" and "*/"

Basic syntax – header files

```
//Example 2.1: storageSize.cpp
#include <iostream>
... ...
```

- #include<...>: directive to the preprocessor to include functions and classes in the C++ Standard Library, where the code has been compiled and will be automatically linked with the developed program
- iostream: input/output operator classes
- Many other tools are available: e.g.
  - cmath: many the standard math functions
  - array: container class template for a fixed size array

Basic syntax – statement "using"

```
//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
... ...
```

- This ensures that there will be no ambiguity in referring to functions and classes in the C++ Standard Library

Basic syntax – statement "using"

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//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
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- This ensures that there will be no ambiguity in referring to functions and classes in the C++ Standard Library
- A *namespace* is a collection of definitions of variables, functions and other key components associated with a library or program

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- A *namespace* is a collection of definitions of variables, functions and other key components associated with a library or program
- Example 2.1 uses a cout object and the output manipulator endl that are declared in the iostream header file.

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- Example 2.1 uses a cout object and the output manipulator endl that are declared in the iostream header file.

```
cout << "The storage allocated for a char is " << ... << endl;
```

Basic syntax – statement "using"

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//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
... ...
```

- This ensures that there will be no ambiguity in referring to functions and classes in the C++ Standard Library
- A *namespace* is a collection of definitions of variables, functions and other key components associated with a library or program
- Example 2.1 uses a cout object and the output manipulator endl that are declared in the iostream header file.

```
cout << "The storage allocated for a char is " << ... << endl;
```

- *scope resolution operator* "::" to bypass the using directive

```
std::cout << "The storage allocated for a char is " << ... <<  std::endl;
```

Basic syntax – main function

```
//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
int main(){...}
```

- Every C++ program has one and only one main function.

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- Return type: int.
- Parameters
  - must be enclosed by a pair of parentheses “(” and “)”
  - can be void, two-parameter form or multi-parameter form

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- Body
  - must be enclosed by the matching curly braces "{" and "}"
- In Example 2.1, the main is just a collection of explanatory text to be printed with values that are returned by the sizeof operator.

Basic syntax – output operator

```
//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
int main(){
  cout << "The storage allocated for a char is "
  << sizeof(char) << " byte" << endl;
  ...
  return 0;
}
```

- Output insertion operator: "`<<`" for standard output object `cout`
- Output manipulator: ``endl"
  - appears at the end of each output line
  - produces a carriage return (starts a new line)
  - flushes (cleans out) the output buffer

Basic syntax – statement “return”

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//Example 2.1: storageSize.cpp
#include <iostream>
using namespace std;
int main(){
  cout << "The storage allocated for a char is "
  << sizeof(char) << " byte" << endl;
  ...
  return 0;
}
```

- In general, it returns control back to a calling function

Basic syntax – statement “return”

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  << sizeof(char) << " byte" << endl;
  ...
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```

- In general, it returns control back to a calling function
- In main function, it transfers control back to the operating system

Basic syntax – statement “return”

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#include <iostream>
using namespace std;
int main(){
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  << sizeof(char) << " byte" << endl;
  ...
  return 0;
}
```

- In general, it returns control back to a calling function
- In main function, it transfers control back to the operating system
- The main function may not have the return statement, in which case “return 0;” will be executed

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- The “storage size” source code was saved as “storageSize.cpp”

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- To run the program, we first compile it using

```
$  g++ -Wall storageSize.cpp -o storageSize
```

- It transforms the input file storageSize.cpp into machine language
  - "g++" invokes the GNU compiler
  - "-Wall" turns on all of the most commonly used compiler warnings
  - "-o" specifies the name of the executable program

Run

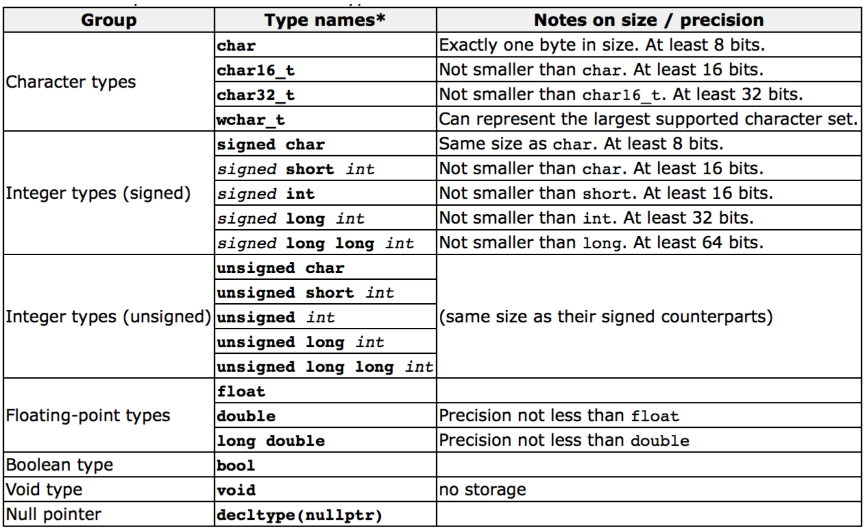
- To load and run the compiled program, the name of the executable program (i.e., storageSize) is entered on the command line prefaced by the "./" modifier that informs the shell where to look for the executable.

Run

- To load and run the compiled program, the name of the executable program (i.e., storageSize) is entered on the command line prefaced by the "./" modifier that informs the shell where to look for the executable.

```
$ ./storageSize
The storage allocated for a char is 1 byte
The storage allocated for an unsigned short integer is 2 bytes
The storage allocated for an integer is 4 bytes
The storage allocated for a long integer is 8 bytes
The storage allocated for an unsigned long integer is 8 bytes
The storage allocated for a float is 4 bytes
The storage allocated for a double is 8 bytes
The storage allocated for a long double is 16 bytes
```

Complete list of fundamental types



Group	Type names*	Notes on size / precision
Character types	**char**	Exactly one byte in size. At least 8 bits.
	char16_t	Not smaller than `char`. At least 16 bits.
	char32_t	Not smaller than `char16_t`. At least 32 bits.
	wchar_t	Can represent the largest supported character set.
Integer types (signed)	**signed char**	Same size as `char`. At least 8 bits.
	signed **short** *int*	Not smaller than `char`. At least 16 bits.
	signed **int**	Not smaller than `short`. At least 16 bits.
	signed **long** *int*	Not smaller than `int`. At least 32 bits.
	signed **long long** *int*	Not smaller than `long`. At least 64 bits.
Integer types (unsigned)	**unsigned char**	(same size as their signed counterparts)
	unsigned short *int*	
	unsigned *int*	
	unsigned long *int*	
	unsigned long long *int*	
Floating-point types	**float**	
	double	Precision not less than `float`
	long double	Precision not less than `double`
Boolean type	**bool**	
Void type	**void**	no storage
Null pointer	**decltype(nullptr)**	

http://www.cplusplus.com/doc/tutorial/variables/

Nonnegative integer storage in C++

- Take unsigned short data type as an example.
- How many bytes of storage?
- What is the range?
- How to write a C++ program to obtain the binary representation of an unsigned short integer?
  - The number can be viewed as having ___ possible slots corresponding to 2^0 all the way to ___ .
  - The program can step through each of these slots

Binary representation of nonnegative integer

```cpp
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){
  unsigned short inVal;
  cout << "Enter an integer between 0 and 65535: ";
  cin >> inVal;
  cout << "This integer in binary is ";
  printBinary(inVal);
  cout << endl;
  return 0;
}
void printBinary(unsigned short val){
  for (int i = 15; i >=0; i--)
      if(val & (1 << i))
        cout << "1";
      else
        cout << "0";
}
```

Basic syntax – prototype or declaration of function

```
//Example 2.2: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){...}
void printBinary(unsigned short val){...}
```

- Example 2.2 employs some elementary bit-wise operations in a function called printBinary to pick off the internal binary representations of a nonnegative integer
- The *prototype* or *declaration* of the basic form for printBinary that appears prior to the main function
- The *return type* of the function is designated as void which means it does not return a value to the calling program
- In C++, it is necessary to tell the compiler about the essential details (e.g. return type and type for arguments) in a function before it can be used

Basic syntax – Type declaration

```
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){
   unsigned short inVal;
...
}
void printBinary(unsigned short val){...}
```

- The variable inVal will hold the integer whose binary representation will be determined
- The code consists of a *type declaration* which states that inVal is of storage type unsigned short
- In C++, every variable's type must be explicitly stated when it is introduced into program

Basic syntax – Input operator and object

```cpp
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){
  unsigned short inVal;
  cout << "Enter an integer between 0 and 65535: ";
  cin >> inVal;
  printBinary(inVal);
  cout << endl;
  return 0;
}
void printBinary(unsigned short val){...}
```

- cin is the standard input object
- >> is the input operator
- The code reads a value from the shell command line into inVal

Basic syntax – The for loop

```
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){...}
void printBinary(unsigned short val){
  for (int i = 15; i >=0; i--)
      if(val & (1 << i))
        cout << "1";
      else
        cout << "0";
}
```

- int i is the type declaration of the index variable i
- Three important things in a for loop for the index variable i
  1. Starting value ($i = 15$)
  2. Logical condition (False) to stop the loop ($i >= 0$)
  3. Rule to move ($i--$ or $i = i - 1$)

Basic syntax – Bit shift operators

```
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){...}
void printBinary(unsigned short val){
  for (int i = 15; i >=0; i--)
      if(val & (1 << i))
        cout << "1";
      else
        cout << "0";
}
```

- "`<<`" is the left bit shift operator
- "`a << k`" cause the bits in `a` to be shifted left by `k` positions
  - If `a = 15 =` $(00001111)_2$, then `(a << 1) = 30 =` $(00011110)_2$
  - "`a << k`" is equal to "a*$\underbrace{2 * \ldots * 2}_{k}$"; Thus, "`1 << i`" $= 2^i$.
- Recall "`<<`" is also the output operator with `cout` (Operator overloading)

Basic syntax – Bit-wise AND operator

```
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){...}
void printBinary(unsigned short val){
  for (int i = 15; i >=0; i--)
      if(val & (1 << i))
        cout << "1";
      else
        cout << "0";
}
```

- "&" is the bit-wise AND operator
- "a & b" each bit of a to the corresponding bit of b. If both bits are 1, the corresponding result bit is set to 1. Otherwise, the corresponding result bit is set to 0.
  - If a = 15 = $(00001111)_2$ and b = 16 = $(00010000)_2$, then "(a & b) = $(00000000)_2$ = 0"

Basic syntax – Bit-wise AND operator continued

```
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){...}
void printBinary(unsigned short val){
  for (int i = 15; i >=0; i--)
      if(val & (1 << i))
        cout << "1";
      else
        cout << "0";
}
```

- If `a >=` 2^{i} and `a <` 2^{i+1}, then

  `( a &` 2^{i} `) > 0`
- If `a <` 2^{i} then

  `( a &` 2^{i} `) = 0`
- Why is this true?

Basic syntax – Statement if ... else ...

```
//Example 2.1: nonNegIntBinaryRep.cpp
#include <iostream>
using namespace std;
void printBinary(unsigned short val);
int main(){...}
void printBinary(unsigned short val){
  for (int i = 15; i >=0; i--){
      if(val & (1 << i)){
        cout << "1";
      }
      else{
        cout << "0";
      }
   }
}
```

- Three parts: 1) *boolean expression*: `val & (1 << i)`; 2) *If block of code*: `cout << "1";`; 3) *else block of code*: `cout << "0";`
- If the *boolean expression* is `true`, then the *if block of code* will be executed, otherwise *else block of code* will be executed

Environment for homework : Connect to scs.itd.umich.edu

- Windows environment : Use PuTTY for command line and WinSCP for file transfer
- Mac or Linux

Command line	ssh [your-uniqname]@scs.itd.umich.edu
File transfer	scp [your-file] [your-uniqname]@scs.itd.umich.edu:[path-to-destination]

Tips :

- See http://www.itcs.umich.edu/scs/ and http://www.itcs.umich.edu/ssh/ for details
- Linux tutorial: http://ryanstutorials.net/linuxtutorial/
- Add the following line in `~/.cshrc` file for more convenient command line (which shows current working directory).

```
set prompt="`whoami`@`hostname -s`:%~$ "
```

Steps for Homework 0

1. Create a directory `Private/biostat615/hw0/` in your home directory
   - Create a directory `Private/biostat615/hw0/` using WinSCP
   - Type `mkdir -p ~/Private/biostat615/hw0/` in the command line
   - Make sure your homework is in private space. If it is accessible by someone else, your homework will be discarded.
2. Create a file (e.g. `Private/biostat615/hw0/storageSize.cpp`)
   - Directly type `vi ~/Private/biostat615/hw0/storageSize.cpp`
   - Copy a file remotely using `WinSCP` or `scp`
3. Use basic Unix commands (e.g. `cd ~/my/path/`, `pwd`) to navigate between directories.
4. Compile and run the program
5. Before submission, remove all the executable and object (.o) files, and compress your code (under Private/biostat615)

```
$ cd ~/Private/biostat615/hw0/
$ rm storageSize
$ cd ../
$ tar czvf hw0.tar.gz hw0/
```

Homework 0

- Implement the following two programs and submit to the instructor by copying the compressed source codes to `~jiankang/biostat615/[your-uniqname]/`

  `storageSize.cpp`

  `nonNegIntBinaryRep.cpp`
- This homework will not be graded, but mandatory to submit for everyone who wants to take the class for credit
- No due date, but homework 0 must be submitted prior to submitting any other homework.

Steps for homework 0

1. `ssh [your-uniqname]@scs.itd.umich.edu`
2. `mkdir -p ~/Private/biostat615/hw0/`
3. `cd ~/Private/biostat615/hw0/`
4. `vi storageSize.cpp`
5. (input the code)
6. `rm storageSize`
7. `vi nonNegIntBinaryRep.cpp`
8. (input the code)
9. `rm nonNegIntBinaryRep`
10. `cd ../`
11. `tar czvf hw0.tar.gz hw0/`
12. `cp hw0.tar.gz ~jiankang/biostat615/[your-uniqname]/`

Recourses

- C++ Tutorials: http://www.cplusplus.com/doc/tutorial/
- C++ IDE on local computers
  - Code::blocks: Windows/Linux/MacOS, http://sourceforge.net/projects/codeblocks/
  - Visual studio express: Windows, https://www.visualstudio.com/en-US/products/visual-studio-express-vs
  - Vi: Linux/Mac OS
    http://www.unix-manuals.com/tutorials/vi/vi-in-10-1.html
    http://www.thegeekstuff.com/2009/01/tutorial-make-vim-as-your-cc-ide-using-cvim-plugin/

Summary

- Datatypes in C++
- Binary representation of a nonnegative integer in C++
- Basic syntax
  - Comment statement
  - Header files (iostream)
  - Statement "using"
  - The main function (return type and return statement)
  - Output/input operators (`cin, cout, << , >>`)
  - Prototype / declaration of functions and variables
  - The "for" loop and statement "if ... else ... "
  - Bit-wise operators (shift and AND)
- Compile and run using GNU C++ complier
- Environment for homework
- Homework 0
- Resources