CS 101:
Computer Programming and Utilization

Jul-Nov 2017

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Lecture 4: Variables, Data Types, and Expressions

Recap

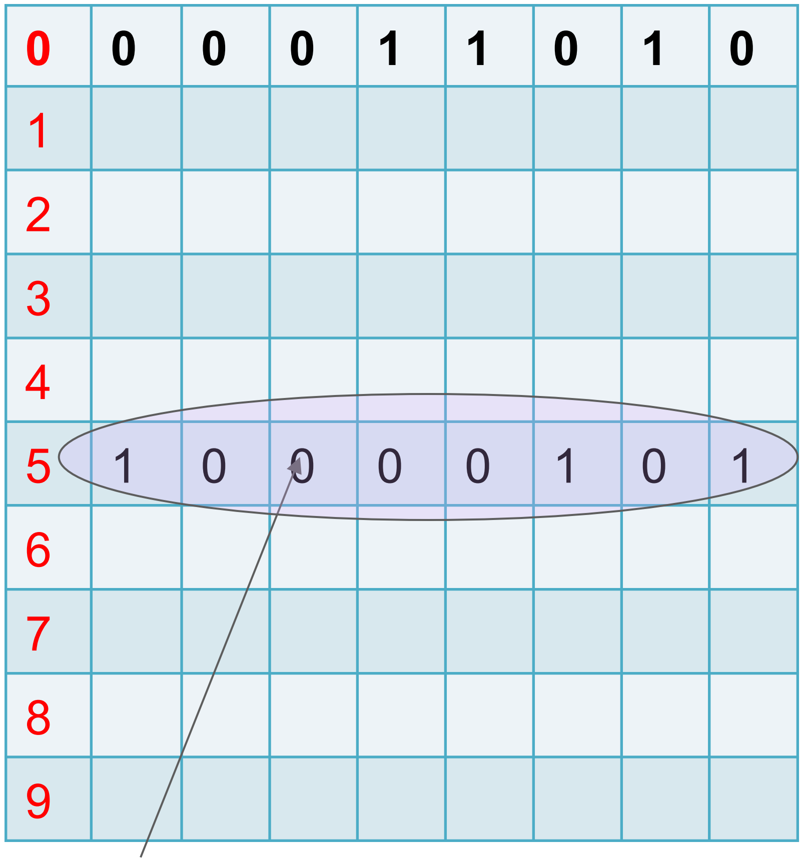
- In the previous class, we learnt that computers essentially do arithmetic operations on numbers stored in the memory
- We also looked into various number representations – decimal, binary, hex.
- AND how to store fractions in binary, negative or signed numbers in binary (sign magnitude and twos complement) and store very large and very small numbers using the IEEE FP representation on the machine.
- Now we will learn details of how different types of numbers are represented, stored and referred to ***in a program***

Outline

- Variables and their types
- Assignments and other expression types
- How to read numbers into the memory from the keyboard
- How to print numbers on the screen
- Many programs based on all this

Reserving Memory For Storing Numbers

- Before you store numbers in the computer's memory, you must explicitly reserve space for storing them in the memory
- This is done by a variable declaration statement.
- variable: ***name*** given to the space you reserved.
- You must also state what ***kind of values*** will be stored in the variable: data type of the variable.



Byte#5 reserved for some variable named, ***characterVar***, say.

Variable Declaration

- A general statement of the form:

  ```
  data_type    variable_name;
  ```

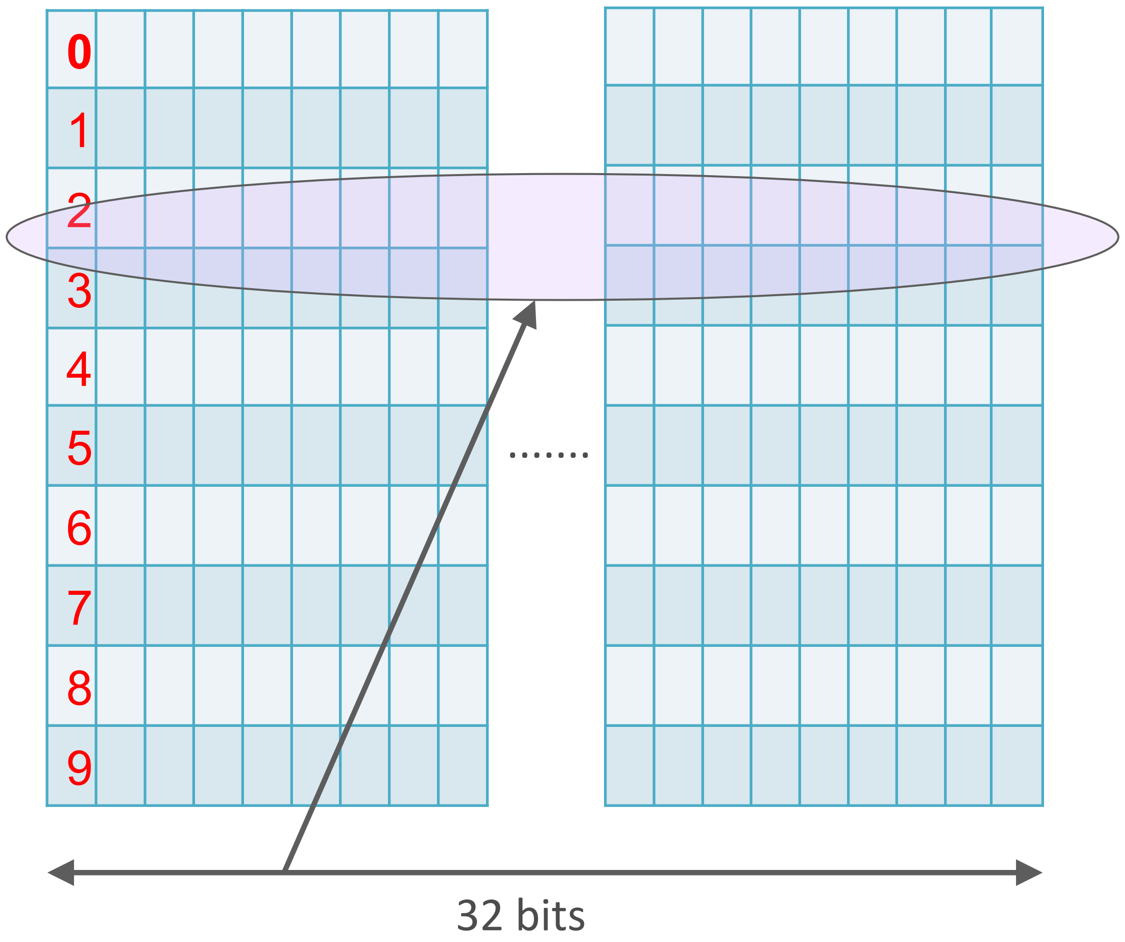
  Creates and declares variables

- Example from polygon program:

  ```
  int sides;
  ```

  - `int` : name of the data type. Short form for integer. Says
    - reserve space for storing integer values, positive or negative, of a standard size
    - Standard size = 32 bits on most computers
  - `sides` : name given to the reserved space, or the variable created

Variable Declaration



```
int sides;
```

Results in memory of size 32 bits being reserved for this variable. The program will refer to it by the name `sides`. ***Sides*** therefore refers to where the integer is stored.

Variable Names: *Identifiers*

- Sequence of one or more letters, digits and the underscore "_" character
- Should **NOT** begin with a digit
- Some words such as int cannot be used as variable names. Reserved by C/C++ for its own use
- **Case Matter:** ABC and abc are distinct identifiers

- **Valid Identifiers**: sides, telephone_number, x, x123, third_cousin

- **Invalid identifiers:** #sides, 3rd_cousin, third cousin
- Recommendation: use meaningful names, describing the purpose for which the variable will be used

Some Other Data Types Of C++

- unsigned int : Used for storing integers which will always be positive
  - 1 word (32 bits) will be allocated
  - Ordinary binary representation will be used
- char : Used for storing characters or small integers
  - 1 byte will be allocated
  - ASCII code of characters is stored
- float : Used for storing real numbers
  - 1 word will be allocated
  - IEEE FP representation, 8 bits exponent, 23 bits significand
- double : Used for storing real numbers
  - 2 words will be allocated
  - IEEE FP representation, 11 bits exponent, 52 bits significand

Types of variables

```
int a;       // Signed Integer 4 bytes
long int b;     // Signed integer 4 or 8 bytes
short int s;    // Signed integer 2 bytes
char c;      // Signed integer 1 byte
unsigned int d;    // Unsigned int 4 bytes
unsigned long e;   // Unsigned int 4 or 8 bytes
unsigned short f; // Unsigned int 2 bytes
unsigned char g;   // Unsigned int 1 byte
float f;     // Note that floats cannot be unsigned.
double dd;      // double cannot be unsigned, 8 bytes
long long int; // 16 bytes but may not be available
long double ddd;   // double precFloating Point 16 bytes,
```

Boolean and Int

- There is **no** Boolean type
- 0 is False and anything other than 0 is True.

```
 if(5){
          //always executed
   }
   if(0){
          //never executed
   }
```

Variable Declarations

- Okay to define several variables in same statement
  - `float mass, accel;`
- The keyword `long` says, I need to store bigger numbers, so give me more than the usual space.
  - `long unsigned int crypto_password;`
    - long unsigned int: Likely 64 bits will be allocated
  - `Long double more_precise_value;`
    - long double: likely 96 bits will be allocated

Variable *Initialization*

- Initialization – an INITIAL value is assigned to the variable

  the value stored in the variable at the time of its creation

- Variables `i, vx, vy` are declared AND are initialized
  - 2.0e5 is how we write $2.0*10^5$
  - 'f' is a character constant representing the ASCII value of the quoted character
  - result and weight are declared but not initialized

```
int i=0, result;

float vx=1.0,
      vy=2.0e5,
      weight;

char value = 'f';
```

`const` Keyword

```
const double pi = 3.14;
```

The keyword const means : *value assigned once cannot be changed in the program.*

Useful in readability AND uniformity of a program

```
    area = pi * radius * radius;
```

reads better than

```
    area = 3.14 * radius * radius;
```

Reading Values Into Variables from cin

- `>>` is a reading operator defined on `cin`
- Can read into several variables one after another
- If you read into a char type variable, the ASCII code of the typed character gets stored
  - If you input the character 'f' , the ASCII value of 'f' will get stored

```
cin >> no_of_sides;

cin >> vx >> vy;

char command;

cin >> command;
```

Reading Values Into Variables (2)

- User expected to type in values consistent with the type of the variable into which it is to be read

- Whitespaces (i.e. space characters, tabs, newlines) typed by the user are ignored.

- **newline/enter key must be pressed after values are typed**

Printing Variables On The Screen

- Output stream `cout` defines a operator `<<`
- General form: `cout << variable;`
- Many values can be printed one after another
- To print newline, use `endl`
- Verbatim text can be printed by enclosing it in quotes. This one prints the text Position: , then x and y with a comma between them and a newline after them
- If you print a char variable, then the content is interpreted as an ASCII code, and the corresponding character is printed.
  G will be printed.

```
cout << x;

cout << x << y;

cout << “Position:”
<< x << “, “ <<
y  << endl;

char var = ‘G’;
cout << var;
```

Statements

An *Assignment* Statement

Used to assign a value to a variable or store results of computation into a variable. Form: ***variable_name = expression;***

```
    name = “myname”;
    s = u*t + 0.5 * a * t * t ;
   n = (3/x)*y + (45 * z);
```

Expression : can specify a formula involving constants or variables, almost as in algebra

- If variables are specified, their ***values*** are used.
- operators must be written explicitly
- multiplication, division have higher precedence than addition, subtraction
- multiplication, division have same precedence
- addition, subtraction have same precedence
- operators of same precedence will be evaluated left to right.
- Parentheses can be used with usual meaning

More Examples

```
int x=2, y=3, p=4, q=5, r, s, t;
x = r*s;                    // disaster. r, s undefined
r = x*y + p*q;
                         // r becomes 2*3 + 4*5 = 26
s = x*(y+p)*q;
                         // s becomes 2*(3+4)*5 = 70
t = x – y + p – q;
                         // equal precedence,
                         // so evaluated left to right,
                         // t becomes (((2-3)+4)-5 = -2
```

Arithmetic Between Different Types Allowed

```
int x=2, y=3, z, w;
float q=3.14, r, s;
r = x;          // representation changed
               // 2 stored as a float in r   "2.0"

z = q;            // store with truncation
                  // z takes integer value 3

s = x*q;           // convert to same type,
                   // then multiply
                  // Which type?
                  HIGHER PRECISION.
```

Evaluating varA op varB
e.g. x*q

- if varA, varB have the same data type: the result will have same data type
- if varA, varB have different data types: the result will have more expressive data type
- int/short/unsigned int are less expressive than float/double
  - shorter types are less expressive than longer types

Storing numbers of one type into variable of another type

C++ does the “best possible”.

```
int x; float y;
x = 2.5;
y = 123456789;
```

x will become 2, since it can hold only integers. Fractional part is dropped.

123456789 is stored as 1.234567E8 (May have loss of precision!)

Integer Division

```
int x=2, y=3, p=4, q=5, u;

u = x/y + p/q;

Cout << u << endl;

cout << p/y << endl;
```

- x/y :   both are int. So truncation. Hence 0
- p/q : similarly 0 => u = 0;
- p/y : 4/3 after truncation will be 1
- So the output is 0 followed by 1

More Examples of Division

```
int no_of_sides=100, i_angle1, i_angle2;
i_angle1 = 360/no_of_sides + 0.45;            // 3
i_angle2 = 360.0/no_of_sides + 0.45;          // 4



float f_angle1, f_angle2;
f_angle1 = 360/no_of_sides + 0.1;              // 3.1
f_angle2 = 360.0/no_of_sides + 0.1         // 3.7
```

An Example Limited Precision

```
float w, y=1.5, avogadro=6.022E23;
w = y + avogadro;
```

- Actual sum : 602200000000000000000001.5
- y + avogadro will have type float, i.e. about 7 digits of precision.
- With 7 digits of precision (2^{23}), all digits after the 7th will get truncated and the value of avogadro will be the same as the value of y + avogadro
- w will be equal to avogadro
- No effect of addition!

Program Example

```
main_program{
  double centigrade, fahrenheit;
  ~~cout <<“Give temperature in Centigrade: ”;~~
  cin >>centigrade;
  fahrenheit = centigrade * 9 / 5 + 32;
  cout << “In Fahrenheit: ” << fahrenheit
       << endl;  // newline
}
```

Prompting for input is meaningless in Prutor because it is non-interactive

Re-Assignment

- Same variable can be assigned a value again
- When a variable appears in a statement, its value at the time of the execution of the statement gets used

```
int p=3, q=4, r;
r = p + q;                 // 7 stored into r
cout << r << endl;   // 7 printed as the value of r
r = p * q;               // 12 stored into r
cout << r << endl;   // 12 printed as the value of r
```

In C++ "=" is assignment not "equal"

```
int p=12;
p = p+1;
```

See it as: $p \longleftarrow p+1;$ // Let p *become* p+1

Rule for evaluation:

- FIRST evaluate the RHS and THEN store the result into the LHS variable
- So 1 is added to 12, the value of p
- The result, 13, is then stored in p
- Thus p finally becomes 13

p = p + 1 is nonsensical in mathematics

“=” in C++ is different from “=” in mathematics

Repeat And Reassignment

```
main_program{
   int i=1;
      repeat(10){
           cout << i << endl;
           i = i + 1;
      }
}
```

This program will print 1, 2,…, 10 on separate lines

Another Idiom: Accumulation

```
main_program{
   int term, s = 0;
      repeat(10){
            cin >> term;
            s = s + term;
      }
      cout << s << endl;
}
```

- Values read are ***accumulated*** into ***s***
- Accumulation happens here using +
- We could use other operators too

Fundamental idiom

Sequence generation

- Can you make i take values 1, 3, 5, 7, …?
- Can you make i take values 1, 2, 4, 8, 16, …?

```
int i=1;
repeat(10){
      cout << i << endl;
      i = i + 2;
}
```

```
int output=0; i = 0;
repeat(10){
   output = pow(2,i);
   cout << output << endl;
   i = i + 1;
}
```

Composing The Two Idioms

Write a program to calculate n! given n.

```
main_program{
  int n, nfac=1, i=1;
  cin >> n;
  repeat(n){
     nfac = nfac * i;
     i = i + 1;
  }
  cout << nfac << endl;
}
```

Accummulation idiom

Sequence idiom

Finding Remainder

- x % y computes the remainder of dividing x by y
- Both x and y must be integer expressions
- Example

```
int n=12345678, d0, d1;
d0 = n % 10;
d1 = (n / 10) % 10;
```

d0 will equal 8 (the least significant digit of n)

d1 will equal 7 (the second least significant digit of n)

Some Additional Operators

- The fragment i = i + 1 is required very frequently, and so can be abbreviated as i++

  ++ : increment operator. Unary

- Similarly we may write j-- which means j = j – 1

  -- : decrement operator. Unary

Intricacies Of ++ and --

++ and –- can be written after or before the variable. Both cause the variable to increment or decrement but with subtle differences

```
int i=5, j=5, r, s;
r = ++i;
s = j++;
cout << "r= " << r << " s= " << s;
```

i,j both become 6 but r is 6 and s is 5.

++ and -– can be put inside expressions but not recommended in good programming

Compound Assignment

The fragments of the form sum = sum + expression occur frequently, and hence they can be shortened to sum += expression

Likewise you may have *=, -=, /= …

```
int x=5, y=6, z=7, w=8;
x += z;      // x becomes x+z = 12
y *= z+w; // y becomes y*(z+w) = 90
```

Arithmetic Operators

operator	meaning	examples
+	addition	x=3+2; /∗constants∗/ y+z; /∗variables∗/ x+y+2; /∗both∗/
-	subtraction	3−2; /∗constants∗/ **int** x=y−z; /∗variables∗/ y−2−z; /∗both∗/
∗	multiplication	**int** x=3∗2; /∗constants∗/ **int** x=y∗z; /∗variables∗/ x∗y∗2; /∗both∗/

operator	meaning	examples
/	division	**float** x=3/2; /∗produces x=1 (int /) ∗/ **float** x=3.0/2 /∗produces x=1.5 (float /) ∗/ **int** x=3.0/2; /∗produces x=1 (int conversion)∗/
%	modulus (remainder)	**int** x=3%2; /∗produces x=1∗/ **int** y=7;**int** x=y%4; /∗produces 3∗/ **int** y=7;**int** x=y%10; /∗produces 7∗/

Note the type conversions

Relational Operators (boolean result)

operator	meaning	examples
>	greater than	3>2; /*evaluates to 1 */ 2.99>3 /*evaluates to 0 */
>=	greater than or equal to	3>=3; /*evaluates to 1 */ 2.99>=3 /*evaluates to 0 */
<	lesser than	3<3; /*evaluates to 0 */ 'A'<'B' /*evaluates to 1*/
<=	lesser than or equal to	3<=3; /*evaluates to 1 */ 3.99<3 /*evaluates to 0 */

int x = (3 >2); is equivalent to int x = 1;
int x = (3 < 3) is equivalent to int x = 0;

Equality and Inequality

operator	meaning	examples
==	equal to	3==3; /*evaluates to 1 */ 'A'=='a'/*evaluates to 0 */
!=	not equal to	3!=3; /*evaluates to 0 */ 2.99!=3 /*evaluates to 1 */

Note that the "==" equality operator is different from the "=", assignment operator.

Note that the "==" operator on float variables is tricky because of finite precision.

Logical Operators

operator	meaning	examples
&&	AND	((9/3)==3) && (2*3==6); /*evaluates to 1 */
		('A'=='a') && (3==3) /*evaluates to 0 */
||	OR	2==3 || 'A'=='A'; /*evaluates to 1 */
		2.99>=3 || 0 /*evaluates to 0 */
!	NOT	!(3==3); /*evaluates to 0 */
		!(2.99>=3) /*evaluates to 1 */

Bit Operations: Left and Right Shift << >>

- x >> i
  - Shifts bits of a number x to the right i positions
- x << i
  - Shifts bits of a number x to the left i positions
- Example:

```
int i, j;
i = 5; // In binary i is 00000101
j= (5 << 3); // In binary j is 00101000
printf(“i=%d j=%d\n”); // Output: i=5 j=40
```

- `x<<i is equivalent to x*2^i`
- `x>>i is equivalent to x/2^i`

Bitwise Operations: OR |

- The “|” operator executes “OR” bit operation.

```
unsigned x = 0x05; // 00000101
unsigned y = (x | 0x2);
          // 00000101 | 00000010=00000111
```

Bitwise Operations: &

- The “&” operator executes “AND” bit operation.

```
unsigned x = 5; // 00000101
unsigned y =(x & 0x3);// 00000101 & 00000011 =00000001
```

Bitwise Operations: XOR ^

- The “^” operator executes “XOR” bit operation.
- XOR : 0^0==0, 0 ^1 == 1, 1^0==1, 1^1==0

```
unsigned x = 0x05; // 00000101
unsigned y =(x ^ 0x3);// 00000101 ^ 00000011 =00000110

Example:
// Inverting the bits of a number
unsigned x = 0x05; // 00000000 00000000 00000000 00000101
unsigned y = x ^ 0xFFFFFFFF;
//0xFFFFFFFF=11111111 11111111 1111111 11111111
        // y = 11111111 1111111 1111111 11111010
```

Bitwise Operations: NOT ~

- The “~” negates bits.

```
unsigned x = 0x05; // 0000000 0000000 0000000 00000101
unsigned y = ~x;
    // ~00000101 = 11111111 11111111 11111111 11111010
```

Blocks and Scope

- Code inside { } is called a block.
- Blocks are associated with repeats, but you may create them otherwise too.
- You may declare variables inside any block.
- New summing program:
- The variable `term` is defined close to where it is used, rather than at the beginning. This makes the program more readable.
- But the execution of this code is a bit involved.

```
// The summing program
// written differently.

main_program{
   int s = 0;
   repeat(10){
        int term;
        cin >> term;
        s = s + term;
   }
   cout << s << term << endl;
}
```

How definitions in a block execute

- Basic rules
- A variable is defined/created every time control reaches the definition.
- All variables defined in a block are destroyed every time control reaches the end of the block.
- “Creating” a variable is only notional; the compiler simply starts using that region of memory from then on.
- Likewise “destroying” a variable is notional.
- New summing program executes exactly like the old, it just reads different (better!).

Shadowing and scope

- Variables defined outside a block can be used inside the block, if no variable of the same name is defined inside the block.
- If a variable of the same name is defined, then from the point of definition to the end of the block, the newly defined variable gets used.
- The new variable is said to “shadow” the old variable.
- The region of the program where a variable defined in a particular definition can be used is said to be the scope of the definition.

Example

```
main_program{
  int x=5;
  cout << x << endl;   // prints 5
  {
    cout << x << endl; // prints 5
    int x = 10;
     x *= 2;
    cout << x << endl; // prints 20
  }
  cout << x << endl; // prints 5
}
```

Concluding Remarks

Variables are regions of memory which can store values

Variables have a type, as decided at the time of creation

Choose variable names to fit the purpose for which the variable is defined

The name of the variable may refer to the region of memory (if the name appears on the left hand side of an assignment), or its value (if the name appears on the right hand side of an assignment)

Further Remarks

Expressions in C++ are similar to those in mathematics, except that values may get converted from integer to real or vice versa and truncation might happen

Truncation may also happen when values get stored into a variable

Sequence generation and accumulation are very common idioms

Increment/decrement operators and compound assignment operators also are commonly used (they are not found in mathematics)

More Remarks

Variables can be defined inside any block

Variables defined outside a block may get shadowed by variables defined inside

SAFE quiz

- What is the result of evaluating the expression (3+2)/4?
- What is printed by this code snippet: "float f=6.022E23; float r=f+2-f; cout<<r;"?
- What is printed by this code snippet: "int t=10; repeat(2){t=t-1.2;} cout<<t;"?
- What is printed by this code: "int i=2, j=3, k=4; i=j; j=k; k=i; cout << (i*j*k)"?