From Selection to Repetition

- The `if` statement and `if/else` statement allow a *block* of statements to be executed selectively: based on a guard/test

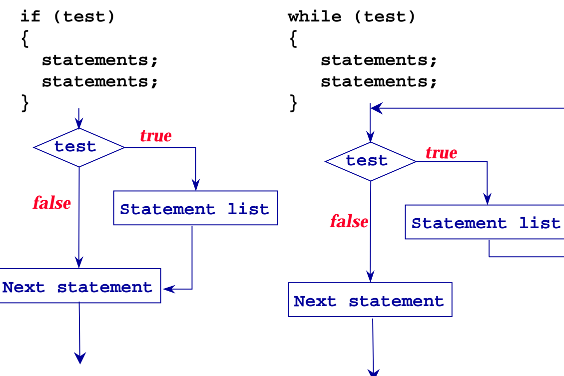
```
if (area > 20.0)
{
   cout << area << " is large" << endl;
}
```

- The `while` statement repeatedly executes a block of statements while the guard/test is true

```
int month = 0;
while (month < 12)
{
   PrintCalendar(month, 1999);
   month += 1;     // month = month + 1;
}
```


Semantics of while loop

```
if (test)                 while (test)
{                         {
   statements;               statements;
   statements;               statements;
}                         }
```



Print a string backwards

- Determine # characters in string, access each character
  - What string functions do we have ?
  - How many times should the loop iterate ?

```
cout << "enter string: ";
cin >> s;
cout << s << " reversed is ";

k = s.length() - 1; // index of last character in s
while (k >= 0)
{   cout << s.substr(k,1);
    k -= 1;
}
cout << endl;
```

- Modify to create a new string that's the reverse of a string.

ReverseString as a function

- First step, what is the prototype?

```
string Reverse(string s)
// pre: s = c0c1c2…cn-1
// post: return cn-1…c2c1c0
```

(pre: $s = c_0c_1c_2 \ldots c_{n-1}$; post: return $c_{n-1} \ldots c_2c_1c_0$)

- Second step, how do we build a new string?
  - Start with an empty string, `""`
  - Add one character at a time using concatenation, +

```
rev = rev + s.substr(k,0);
```

- Use `Reverse` to determine if a string is a palindrome

Anatomy of a loop

- Initialize variables used in loop/loop test (before loop)
  - Loop test affected by initial values of variables
- The loop test or guard is evaluated before each loop iteration
  - NOT evaluated after each statement in loop
- The loop body must update some variable/expression used in the loop test so that the loop eventually terminates
  - If loop test is always true, loop is infinite

```
k = s.length() - 1;
string rev = "";
while (k >= 0)
{   rev = rev + s.substr(k,1);
    k -= 1;
}
return rev;
```


Infinite loops

- Sometimes your program will be “stuck”, control-C to stop
  - What’s the problem in the loop below? Fixable?

```
cin >> num;
int start = 0;
while (start != 0)
{   start += 2;
    cout << start << endl;
}
```

- It’s impossible to write one program that detects all infinite loops (the compiler doesn’t do the job, for example)
  - This can be proven mathematically, Halting Problem
  - Some detection possible, but not universally

Developing Loops

- Some loops are easy to develop code for, others are not
  - Sometimes the proper loop test/body are hard to design
  - Techniques from formal reasoning/logic can help
- Practice helps, but remember
  - Good design comes from experience, experience comes from bad design
- There are other looping statements in addition to `while`, but they don’t offer anything more powerful, just some syntactic convenience
  - `for` loop
  - `do-while` loop

Factorial

- `N! = 1x2x…xN` is “N factorial”, used in math, statistics

```
int factorial(int n)
// pre: 0 <= n
// post: returns n! (1 x 2 x … x n)
```

- We’ll return the value of a variable `product`, we’ll need to accumulate the answer in `product`
  - The loop will iterate n times, mutiplying by 1, 2, …, n
  - Alternatives: how many multiplications are needed?
  - If `product` holds the answer, then `product == n!` when the loop terminates
    - Use this to help develop the loop

Factorial continued

- If `product` holds the answer, then `product == n!` when the loop terminates, replace `n` with `count`, the looping variable
  - Invariant: `product == count!`

```
long Factorial(int num)
// precondition: num >= 0
// postcondition returns num!
{
    long product = 1;
    int count = 0;
    while (count < num)
    {
        count += 1;
        product *= count;
    }
    return product;
}
```


Long, int, and BigInt

- On some systems the type `long int` (`long`) provides a greater range than `int`
  - With 32-bit (modern) compilers/operating systems `int` is roughly –2 billion to 2 billion, but on 16-bit machines the range is usually –32,768 to 32,767 [how many values?]
  - 13! Is 1,932,053,504, so what happens with 14!
- The type `BigInt`, accessible via `#include "bigint.h"` can be used like an `int`, but gets as big as you want it to be
  - Really arbitrarily large?
  - Disadvantages of using `BigInt` compared to `int`?

Determining if a number is prime

- Cryptographic protocols depend on prime numbers
  - Determining if a number is prime must be "easy"
  - Actually factoring a number must be "hard"
  - What does hard mean? What factors affect difficulty?
- PGP (pretty good privacy) and e-commerce depend on secure/encrypted transactions
  - What are government restrictions on exporting PGP?
  - Different versions of Netscape in US and other countries?
- Sophisticated mathematics used for easy prime-testing, we'll do basic prime testing that's reasonably fast, but not good enough for encryption (why not?)

Determining Primality (continued)

- 2 is prime, 3 is prime, 5 is prime, 17 is prime, … 137, 193?
  - To check 137, divide it by 3, 5, 7, 9, 11, 13
  - To check 193, divide it by 3 ,5, 7, 9, 11, 13
    - Note that 14x14 = 196, why is 13 largest potential factor?
    - How do we determine if a number is divisible by another?
- We'll check odd numbers as potential divisors
  - Treat even numbers as special case, avoid lengthy testing
  - Watch out for 2, special case of even number
  - Instead of odd numbers, what would be better as tests?
  - How many times will our testing loop iterate to determine if n is prime?
  - See `primes.cpp` for code

Details of `IsPrime` in *primes.cpp*

- Several different return statements are written, only one is executed when function executes
  - The `return` statement immediately tops, return to call
  - Some people think functions should have one return
    - Potentially easier to debug and reason about,
    - Often introduces extraneous variables/tests
- To assign a `double` value to an `int`, a *typecast* is used, tell the compiler that the loss of precision is ok
  - Fix all compiler warnings whenever possible
  - Make casts explicit, tell the compiler you know what you are doing
- What about complexity/efficiency of `IsPrime`?

C++ details: syntax and shorthand

- With while loops and variables we can write a program to do anything a program can be written for
  - Other language features make programs easier to develop and maintain: functions, if statements, other statements
  - Yet, we want to avoid needing to understand many, many language features if we don't have to
  - You'll read code written by others who may use features
- Loops are statements, can be combined with other loops, with if statements, in functions, etc.
- Other kinds of looping statements can make programming simpler to develop and maintain
- Similar shorthand for other language features: `x = x + 1;`

The `for` loop

- In many coding problems a definite loop is needed
  - Number of iterations known before loop begins and simple to calculate and use in loop (counting loop)
    - Example: length of string: print a string vertically

```
void Vertical(string s)
// post: chars of s printed vertically

int len = s.length();        // for loop alternative
int k = 0;                   for(k=0; k < len; k+= 1)
while (k < len)              {  cout << s.substr(k,0);
{ cout << s.substr(k,0);     }
  k += 1;
}
```

- Initialization, test, update are localized into one place, harder to leave update out, for example

Example: add up digits of a number

- If we have a number like 27 or 1,618 what expression yields the number of digits in the number (hint, think log)
  - Which digit is easiest to get, how can we access it?
  - How can we chop off one digit at-a-time?

```
int digitSum(int n)
// post: returns sum of digits in n
{
                                  // what's needed here?
   while (n > 0)                  // for loop alternative?
   {  sum += n % 10;
                                  // what's needed here?
   }
   return sum;
}
```

Shorthand for increment/decrement

- Lots of code requires incrementing a variable by one
  - Three methods, using +, using +=, and using ++

```
num = num + 1;
num += 1;
num++;
```

- We use postincrement ++, also possible to write ++num
  - These differ on when the increment is performed, but this difference doesn't matter when used as abbreviation for the statement `n += 1;` in a single statement
- Similarly there are postdecrement (and predecrement)

```
num = num - 1;        num -= 1;            num--;
```


The `do-while` loop

- The while loop may never execute, some loops should execute at least once
  - Prompt for a number between 0 and 100, loop until entered

```
do
{   cout << "num in range [0..100] ";
    cin >> num;
} while (num < 0 || 100 < num);
```

  - Execute while the test/guard is true, in example above what must be true when loop terminates (de Morgan) ?

Priming, loop-and-half problems

- Problem: enter numbers, add them up, stop when 0 entered
  - What should loop test be?

```
int sum = 0;
int num;
cin >> num;             // prime the loop
while (num != 0)
{   sum += num;
    cin >> num;
}
cout << "total = " << sum << end;
```

  - Code duplication problem: input (and perhaps prompt) code is repeated before loop and in loop
    - Why is duplicated code a bad thing? Alternatives?

Loop and a half: quasi infinite solution

- To avoid repeating code, include it in the body of the loop only, use a test to break out of the loop
  - `break` statement exits (inner-most) loop

```
int sum = 0;
int num;
while (true)
{   cin >> num;
    if (num == 0)     // get out of loop
    {  break;
    }
    sum += num;
}
cout << "total = " << sum << end;
```

Alternative priming solution

- Force loop to execute once by giving tested variable a value
  - What's wrong with the solution below?

```
int sum = 0;
int num=-1;
while (num != 0)
{    cin >> num;
     if (num != 0)
     {    sum += num;
     }
}
cout << "total = " << sum << end;
```


Nested loops

- Sometimes one loop occurs in another
  - Generating tabular data
  - Sorting vectors (which is studied much later)
- Often code is simpler to reason about if inner loop is moved to another function

```
int j,k;
for(j=1; j <= 6; j++)
{    cout << j;
     for(k=0; k < j; k++)
     {    cout << "\t" << j*k;
     }
     cout << endl;
}
```

- What's printed? What's the purpose of the inner loop?

Using classes

- Using only strings, ints, and doubles limits the kinds of programs we can write
  - What about graphics?
  - What about calendars, address books?
  - What about web-servers, games, …?
- Using object-oriented techniques means we develop new types that correspond to the real-world artifact we're writing code for
  - What about an online roulette game?
  - What about appointment book that synchs with PalmV?
- New types are called classes, variables are called objects and objects are instances of a class, e.g., 3 for int, "hello" for string

The class `Date`

- The class `Date` is accessible to client programmers by
  - `#include "date.h"` to get access to the class
    - The compiler needs this information, it may contain documentation for the programmer
  - Link the implementation in *`date.cpp`*, which has been compiled to *`date.o`* (and maybe stored in a library)
- The class `Date` models a calendar date:
  - Month, day, and year make up the *state* of a `Date` object
  - `Dates` can be printed, compared to each other, day-of-week determined, # days in month determined, many other *behaviors*
    - Behaviors are called methods or member functions

Constructing `Date` objects

- See *usedate.cpp*

```
int main()
{
  Date today;
  Date birthDay(7,4,1776);
  Date million(1000000L);
  Date badDate(3,38,1999);
  Date y2k(1,1,2000);

  cout << "today   \t: "  << today    << endl;
  cout << "US bday \t: "  << birthDay << endl;
  cout << "million \t: "  << million  << endl;
  cout << "bad date \t: " << badDate  << endl;
  cout << y2k << " is a " << y2k.DayName() << endl;
```


Constructing/defining an object

- `Date` objects (like `string` objects) are constructed when they're first defined
  - Three ways to construct a `Date`, what are they?
  - How have we constructed `string` objects?
- Constructors for `Date` objects look like function calls
  - We'll see that constructor is special member function
  - Different parameter lists means different constructors
- Once constructed many ways to manipulate a `Date`
  - Increment it, subtract an int from it, print it, …
  - `MonthName()`, `DayName()`, `DaysIn()`, …

Finding Thanksgiving in the US

- Thanksgiving occurs on fourth Thursday in November

```
Date Thanksgiving(int year)
// post: return date for Thanksgiving in year


cout << "what year ";
cin >> year;
cout << "bird day is " << Thanksgiving(year) << endl;
```

- How do we write the function?
  - How is it similar to Labor Day, Mother's Day, Flag Day?
  - Can we generalize the function?

The class `Dice`

- Accessible to client programmers using `#include "dice.h"`
  - How do clients get access to implementation?
  - Why are quotes used instead of angle brackets < .. > ?
- What do we do with `Dice` outside of programs (real world)
  - What would be nice to model with the class `Dice`?
  - What would be hard?
- Dice objects will work as pseudo-random number generators
  - Not truly random in a strict mathematical sense
  - Still useful to introduce randomness into programs
  - Some random numbers are more random than others

Using the class `Dice`

```
int main()
{
  Dice cube(6);          // six-sided die
  Dice dodeca(12);       // twelve-sided die

  cout << "rolling " << cube.NumSides()
       << " sided die" << endl;
  cout << cube.Roll() << endl;
  cout << cube.Roll() << endl;
  cout << "rolled " << cube.NumRolls()
       << " times" << endl;

  // more here
```

- See *roll.cpp*, how is a Dice object constructed?

What you can and cannot do with Dice

- Cannot define a Dice object without specifying # sides

```
Dice d(1);     // ok, but what is it?
Dice cube;     // NOT ok, won't compile
```

- How random is a `Dice` object – how can we test this?
  - Roll two `Dice` 10,000 times, count how many 2's and 12's
  - How can we test every valid roll? For n-sided `Dice`?
  - How many rolls needed to get a "pure Yahtzee"? (five six-sided Dice rolled, all yield the same value)
    - What techniques help in developing this loop/program?
    - What about two Dice, three Dice

Grace Murray Hopper (1906-1992)

- One of the first programmers on one of the first computers in the US
  - "third programmer on world's first large-scale digital computer"
  - US Navy, later Admiral

"It's better to show that something can be done and apologize for not asking permission, than to try to persuade the powers that be at the beginning"

- ACM Hopper award given for contributions before 30
  1994, Bjarne Stroustrup/C++

Loop development case study

- To calculate a^n what are the options?
  - Use `pow` in `<cmath>`, when can't `pow` be used?
  - Multiply `a x a x … x a`, `n` times?

- Using 1,024 multiplications to calculate 6^{1024} probably ok, but what about `BigInt` values raised to powers?

`3x3=9     9x9=81     81x81=6561     6561x6561=43,046,721`

  - Number of multiplications needed for 3^{16}?
  - Does this matter?

- How do we calculate 4^{125} or 17^{67}?
  - Divide exponent in half

Efficient Exponentiation (continued)

```
double Power(double base, int expo)
 // precondition: expo >= 0
 // postcondition: returns base^expo (base to the power expo)
 {
    double result = 1.0;
    // invariant:  result * (base^expo) = answer
```

- Is invariant true initially? Why?
- If we use `return result;` then what should loop test be?
  - How will we make progress towards loop termination?
  - What values will change in body of loop?

Exponentiation loop development

```
double Power(double base, int expo)
// precondition: expo >= 0
// postcondition: returns base^expo (base to the power expo)
{
   double result = 1.0;
   // invariant:  result * (base^expo) = answer
   while (expo > 0)
   {    if (expo % 2 == 0)
        {   expo /= 2;          // divide by 2 how many times?
                                // how does base change?
        }
        // more here for odd exponent
   }
   return result;
 }
```

- When exponent is even we divide it by two, what about when exponent is odd?

Code for odd exponents

```
double Power(double base, int expo)
 // precondition: expo >= 0
 // postcondition: returns base^expo (base to the power expo)
 {
    double result = 1.0;
    // invariant:  result * (base^expo) = answer
    while (expo > 0)
    {    if (expo % 2 == 0)  // code here from before
         else
         {


         }
    }
    return result;
  }
```

- Use: `result x base`^{expo} `= (result x base) x base`$^{expo/2}$ `x base`$^{expo/2}$

Factor out common code

```
double Power(double base, int expo)
// precondition: expo >= 0
// postcondition: returns base^expo (base to the power expo)
{
   double result = 1.0;
   // invariant:  result * (base^expo) = answer
   while (expo > 0)
   {   if (expo % 2 != 0)       // exponent is odd
       {   result *= base;
       }
       expo /= 2;               // 4/2 == 2, 5/2 == 2
       base *= base;            // (a*a)^(b/2) == a^b
   }
   return result;
}
```

- Will this function work if `base` is a `BigInt` value? What must change?