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

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

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

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

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

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

A Computer Science Tapestry
Print a number backwards

- Given 12345, print 54321
  - How can we get just one digit from a number?
  - How can we remove the digit from the number?

```c
void ReversePrint(int num)
// post: print num backwards

int Reverse(int num)
// post: return reverse of num
```

- What to return for 123? For 100?, what about printing?

- We need a loop: what’s the loop test? What’s the loop body?
Print a string backwards

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

```cpp
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 = c_0c_1c_2...c_{n-1}
  // post: return c_{n-1}...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

```java
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?

```cpp
    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

- \( N! = 1 \times 2 \times \ldots \times N \) is “N factorial”, used in math, statistics

```c
int factorial(int n)
// pre: 0 <= n
// post: returns n! (1 \times 2 \times \ldots \times 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, multiplying 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 \( \text{product} \) holds the answer, then \( \text{product} == n! \) when the loop terminates, replace \( n \) with \( \text{count} \), the looping variable
  - Invariant: \( \text{product} == \text{count}! \)

```java
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?
  - Versions of IE/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 $14 \times 14 = 196$, 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 \texttt{IsPrime} in \texttt{primes.cpp}

- Several different return statements are written, only one is executed when function executes
  - The \texttt{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 \texttt{double} value to an \texttt{int}, a \texttt{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 \texttt{IsPrime}?
Typical loop problem: fencepost

- Print numbers 1,2,3,4,5 comma-separated
  - Generalize to print 1,2,3,...,n comma-separated

```cpp
int num = 1;
while (num <= 5) {
  cout << num << ",";
  num += 1;
}
```

- What’s the problem here? How can we fix it?

- Fence-post problem: one more post than cross bar
  - One more number than comma
  - Print once before loop, or once after, or guard print with if
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

```cpp
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)
    {
        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?

```c
int digitSum(int n)
// post: returns sum of digits in n
{
    sum = 0; // 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 `num += 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

```cpp
    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)?
Primming, loop-and-half problems

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

```cpp
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

```cpp
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?

```cpp
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

```cpp
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

```cpp
int main()
{
    Date today;
    Date birthDay(7,4,1776);
    Date million(1000000L);
    Date badDate(3,38,2001);
    Date y2k2(1,1,2002);
    cout << "today \t: " << today << endl;
    cout << "US bday \t: " << birthDay << endl;
    cout << "million \t: " << million << endl;
    cout << "bad date \t: " << badDate << endl;
    cout << y2k2 << " is a " << y2k2.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

```cpp
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

```cpp
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
Loop development, three-of-a-kind

- Roll three dice, determine how many rolls needed until three of a kind show
  - How can we solve this problem with mathematics?
  - How can we simulate/experiment to answer the question?

```c
int rollThreeOfAKind()
  // post: return # rolls to get 3 of a kind
{
  Dice a(6), b(6), c(6);
  int count = 0;
  while(              ) {
    count += 1;
  }
  return count;
}
```
Solve a simpler problem, does it help?

```cpp
int rollTwoOfAKind()
// post: return # rolls to get 2 of a kind
{
    Dice a(6), b(6);
    int count = 0;
    while( a.Roll() != b.Roll() ) {
        count += 1;
    }
    return count;
}
```

- **How is this similar to rolling three? Different?**
  - Can we easily add a `cout <<` statement to print the different rolls? When two of a kind come up?
  - Should we modify this code or Dice class?
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 $a \times a \times \ldots \times a$, $n$ times?

- **Using 1,024 multiplications to calculate** $6^{1024}$ **probably ok**, but what about **BigInt** values raised to powers?
  - $3 \times 3 = 9$  
  - $9 \times 9 = 81$  
  - $81 \times 81 = 6561$  
  - $6561 \times 6561 = 43,046,721$
  - 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?
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
   }
   // 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 \times base^{expo} = (result \times base) \times base^{expo/2} \times 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?