```
int studentId00 = 9000; int studentId20 = 9020;  int studentId40 = 9040;  int studentId60 = 9060;
int studentId01 = 9001; int studentId21 = 9021;  int studentId41 = 9041;  int studentId61 = 9061;
int studentId02 = 9002; int studentId22 = 9022;  int studentId42 = 9042;  int studentId62 = 9062;
int studentId03 = 9003; int studentId23 = 9023;  int studentId43 = 9043;  int studentId63 = 9063;
int studentId04 = 9004; int studentId24 = 9024;  int studentId44 = 9044;  int studentId64 = 9064;
int studentId05 = 9005; int studentId25 = 9025;  int studentId45 = 9045;  int studentId65 = 9065;
int studentId06 = 9006; int studentId26 = 9026;  int studentId46 = 9046;  int studentId66 = 9066;
int studentId07 = 9007; int studentId27 = 9027;  int studentId47 = 9047;  int studentId67 = 9067;
int studentId08 = 9008; int studentId28 = 9028;  int studentId48 = 9048;  int studentId68 = 9068;
int studentId09 = 9009; int studentId29 = 9029;  int studentId49 = 9049;  int studentId68 = 9069;
int studentId10 = 9010; int studentId30 = 9030;  int studentId50 = 9050;  int studentId70 = 9070;
int studentId11 = 9011;  int studentId31 = 9031;  int studentId51 = 9051;  int studentId71 = 9071;
int studentId12 = 9012; int studentId32 = 9032;  int studentId52 = 9052;  int studentId72 = 9072;
int studentId13 = 9013; int studentId33 = 9033;  int studentId53 = 9053;  int studentId73 = 9073;
int studentId14 = 9014; int studentId34 = 9034;  int studentId54 = 9054;  int studentId74 = 9074;
int studentId15 = 9015; int studentId35 = 9035;  int studentId55 = 9055;  int studentId75 = 9075;
int studentId16 = 9016; int studentId36 = 9036;  int studentId56 = 9056;  int studentId76 = 9076;
int studentId17 = 9017; int studentId37 = 9037;  int studentId57 = 9057;  int studentId77 = 9077;
int studentId18 = 9018; int studentId38 = 9038;  int studentId58 = 9058;  int studentId78 = 9078;
int studentId19 = 9019; int studentId39 = 9039;  int studentId59 = 9059;  int studentId79 = 9079;
```

I figured out how to store 80 student numbers!!!!

Vectors

Slides #13 – Chapter 8.3

Topics

1) How can we store many values at once?
2) How can we pass vectors to functions?
3) How can we copy/compare vectors?

Vectors
Part 1

How to store many values?

Vector

- Vector Object:
  -
  - Can dynamically grow and shrink, and report its size.

Vector example

```
#include <iostream>
#include <vector>
using namespace std;

int main() {
    // Create a vector of double
    vector<double> myFavNums;

    // Insert my favourite numbers
    myFavNums.push_back(42);
    myFavNums.push_back(-2.5);
    myFavNums.push_back(3.141590000);

    // Print out the three numbers
    cout << "Num 1: " << myFavNums.at(0) << endl;
    cout << "Num 2: " << myFavNums.at(1) << endl;
    cout << "Num 3: " << myFavNums.at(2) << endl;

    return 0;
}
```

Must include <vector> and name-space std.

When created, must specify type of values it will hold:..

Add an element to the vector with:..

Use .at(*n*) to access element *n*. Ex:
double k = data.at(i);

```
Num 1: 42
Num 2: -2.5
Num 3: 3.14159
```

Vectors

- Vector is in the Standard Template Library (STL):
  - STL is programmer-created data types and algorithms (not part of 'core' C++).
  - It is a template class:
    It can be used to hold...
- Specify type of data to hold when creating vector:

```
vector<int>          ages;
vector<double>       heights;
vector<string>       names;
vector<char>         firstInitials;
```

Initializing a Vector

```
#include <iostream>
#include <vector>
using namespace std;
int main()  {
    // Option #1:..


    vector<int> prices;
    prices.push_back(20);
    prices.push_back(5);

    // Option #2:..


    vector<int> daysPerMonth {31, 28, 31, 30, 31, 30, 31,
                              31, 30, 31, 30, 31};

    // Display all values (explanation coming on next slide!)
    for (int i = 0; i < daysPerMonth.size(); i++) {
        cout << i << ": " << daysPerMonth.at(i) << endl;
    }
}
```

For Loop Generates a Warning:

"Comparison between signed and unsigned"

Explanation: myVector.size() is unsigned.

Fix: for (unsigned int i = 0; i < myVector.size; i++) {...}

Vector Element Access

- Direct access to any element:
  - For N elements...

    daysPerMonth.at(0) = 31; // January

    Pronounced...

- Ex:

```
daysPerMonth.at(11) = 31;              // December
int a = daysPerMonth.at(1);            // February
int guess = daysPerMonth.at(i + 1);    // Depends on i.
cout << daysPerMonth.at(1);            // Outputs 28
cin >> daysPerMonth.at(9);             // Read in oct.
```

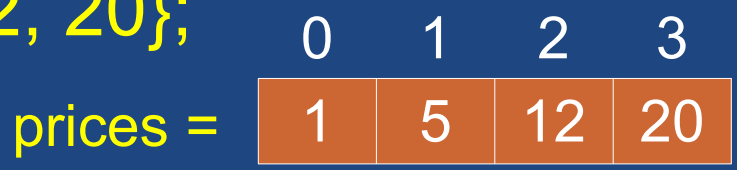
Vector object daysPerMonth

	Idx	Val
Jan	0	31
Feb	1	28
Mar	2	31
Apr	3	30
May	4	31
Jun	5	30
Jul	6	31
Aug	7	31
Sep	8	30
Oct	9	31
Nov	10	30
Dec	11	31

Vector Indices vs Values

- An element's value and its index are different:

```
vector<int> prices {1, 5, 12, 20};
```



  - Add 2 elements:

```
int a = prices.at(1) + prices.at(2);//
```

  - Add 2 indices:

```
int b =prices.at(1 + 2);                    //
```

Vector methods

Function	Description
myVect.at(i) or use: myVect[i]	Access the i'th element of myVect (where i is an integer) Ex: int val = myVect.at(i); Ex: myVect.at(i) = 77;
myVect.clear()	Removes all elements from the vector.
myVect.empty()	Returns true if the vector is empty, false otherwise.
myVect.pop_back()	Removes the last element from the vector.
myVect.push_back(42)	Adds the number 42 to the end of the vector. The value must match vector type.
myVect.size()	

.at(i) vs [i] are similar; however .at(i) is safer (more later).

See text or online documentation for more vector methods and constructors.

Vector example: Hours worked

```
int main() {
    const int DAYS_PER_WEEK = 7;
    // Create the vector for hours per day.
    vector<float> hoursWorked;

    // Ask user for time worked.
    for (int i = 0; i < DAYS_PER_WEEK; i++) {
        cout << "Hrs worked on day #" << i << ": ";
        float hours = 0;
        cin >> hours;
        hoursWorked.push_back(hours);
    }

    // Calculate total hours
    cout << "Week summary:\n";
    float totalHours = 0;
    for (int i = 0; i < DAYS_PER_WEEK; i++) {
        cout << fixed << setprecision(2);
        cout << "\t " << i << " = " << setw(5) << hoursWorked.at(i) << " hours\n";
        totalHours += hoursWorked.at(i);
    }
    cout << "Total hours: " << totalHours << endl;
}
```

```
Hrs worked on day #0: 0
Hrs worked on day #1: 1.5
Hrs worked on day #2: 26.9
Hrs worked on day #3: 8.2
Hrs worked on day #4: 1.6
Hrs worked on day #5: 0
Hrs worked on day #6: 0
Week summary:
         0 =  0.00 hours
         1 =  1.50 hours
         2 = 26.90 hours
         3 =  8.20 hours
         4 =  1.60 hours
         5 =  0.00 hours
         6 =  0.00 hours
Total hours: 38.20
```

Suggested Exercise

- Change the hoursWorked:
  - When reading in hours worked, display the day name (hint Vector!)
  - Stop reading in values when the user enters -1.
- Additional
  - Calculate max # hours on a day. Or, find the day which has max hours worked.

```
Hours worked on Sunday: 0
Hours worked on Monday: 8.2
Hours worked on Tuesday: 5
Hours worked on Wednesday: -4
Hours worked on Thursday: -1
Week summary:
     Sunday =  0.00 hours
     Monday =  8.20 hours
    Tuesday =  5.00 hours
  Wednesday = -4.00 hours
Total hours: 9.20
Max hours in single day: 8.20
```

Review

- Write some code which creates a vector to hold characters and insert the first 2 letters of your name.

- Write a loop to output the contents of the above vector. Do not hardcode the size!

Vectors
Part 2

Passing vectors to functions
without making a copy!

Passing Vector to Function

```cpp
#include <iostream>
#include <vector>
using namespace std;

void printVector(vector<int> data) {
    for (unsigned int i = 0; i < data.size(); i++) {
        cout << data.at(i) << ", ";
    }
    cout << endl;
}

void doubleVector(vector<int> data) {
    for (unsigned int i = 0; i < data.size(); i++) {
        data.at(i) = 2 * data.at(i);
    }
}

int main() {
    vector<int> salaries {10'000, 20'000, 15'000};

    cout << "Initial pay:      ";
    printVector(salaries);

    // Give a big raise!
    doubleVector(salaries);

    cout << "After big raises: ";
    printVector(salaries);
}
```

Program does not (yet) work!

Output

```
Initial pay:      10000, 20000, 15000,
After big raises: 10000, 20000, 15000,
```

Can use ` to separate digit groups

Explaining pass by reference

- Reference:
  - One variable is an alias of another variable:..

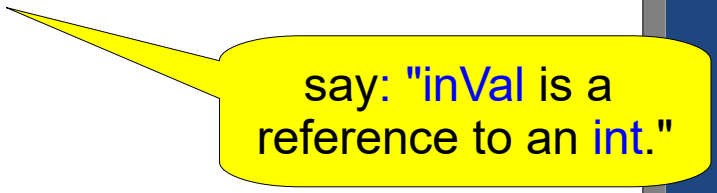
- When using Pass-by-Reference:
  function's parameter refers to the actual argument.
  - Changing the parameter's value...

Pass by reference

- To pass-by-reference, put an & between the parameter's type and name in the parameter list.
  - This makes the function's parameter an alias for the calling argument.

```
void growOlder(int &inVal) {
    inVal++;
}

int main () {
    int age = 25;
    growOlder(age);
    cout << "Age is:   " << age << endl;
}
```



Output

Passing Vector to Function (Again!)

```
#include <iostream>
#include <vector>
using namespace std;

void doubleVector(vector<int> &data) {
    for (unsigned int i = 0; i < data.size(); i++) {
        data.at(i) = 2 * data.at(i);
    }
}

void printVector(vector<int> data) {
    for (int val : data) {
        cout << val << ", ";
    }
    cout << endl;
}

int main() {
    vector<int> salaries {10'000, 20'000, 15'000};

    cout << "Initial pay:      ";
    printVector(salaries);

    // Give a big raise!
    doubleVector(salaries);

    cout << "After big raises: ";
    printVector(salaries);
}
```

Output

```
Initial pay:      10000, 20000, 15000,
After big raises: 20000, 40000, 30000,
```

Uses for pass-by-reference

- Useful for passing back multiple values:

```
// Return true if successfully read first and last names.
// Otherwise, return false.
bool readName(string &first, string &last);
```

- Cautions on Use:
  - Use pass-by-value as much as possible!
  - Use a return value to pass back a single value.
  - Arguments for pass-by-reference...
    - Ex:

```
string a, b;
readName(a, b);                 // Good
readName("Hello", "World");     // Compile Error.
```

Passing elements

- Single elements of a vector can be passed to function...

```
void showChar(char ch) {
	cout << "Element: " << ch << endl;
}
void changeChar(char &ch) {
	char newVal = 'x';
	cout << "Changing " << ch << " to "
		<< newVal << "." << endl;
	ch = newVal;
}
```

```
int main () {
	vector<char> greeting {'H', 'i', '!'};

	// Pass an element by value.
	showChar( greeting.at(0) );

	// Pass an element by reference.
	changeChar( greeting.at(0) );
	showChar( greeting.at(0) );
	...
}
```

Passing a whole vector

- You can pass a to a function using pass by value, or pass by reference.

```
void changeA( vector<int> data ) {
	data.push_back(42);
}

void changeB( vector<int> &data) {
	data.push_back(1337);
}
```

```
int main () {
	// Create the vectors
	vector<int> ages {10};

	// Pass by value example
	changeA(ages);

	// Pass by reference example
	changeB(ages);
	...
}
```

Working with Vectors

Copy and Compare

```
#include <iostream>
#include <vector>
using namespace std;

int main() {
	vector<double> grades {95.2, 56.1, 4.0, 88.5};

	// Copy an existing vector (element by element):
	vector<double> copy = grades;

	// Check if two have identical elements:
	if (grades == copy) {
		cout << "Same!" << endl;
	} else {
		cout << "Not the same!" << endl;
	}

}
```

- Vector “overloads” = and == to do..
- Makes it easy to work with!

Sample Output:
Same!

Out of Bounds

```
#include <iostream>
#include <vector>
using namespace std;

int main() {
	vector<double> grades {95.2, 56.1, 4.0, 88.5};

	// [] lets you..
	grades[6] = 12.345;
	cout << "Testing out of bounds:" << endl;
	for (int i = 0; i < 10; i++) {
		cout << i << " = " << grades[i] << endl;
	}

	// Use grades.at(i) function instead of grades[i]
	cout << "Out of bounds execption: " << grades.at(10);
	cout << "Done!" << endl;
}
```

```
Testing out of bounds:
0 = 95.2
1 = 56.1
2 = 4
3 = 88.5
4 = 0
5 = 2.42092e-322
6 = 12.345
7 = 7.3067e-251
8 = 4.8671e-306
9 = 2.122e-314
```

```
terminate called after
throwing an instance of
'std::out_of_range'
  what():
vector::_M_range_check
```

Generates a runtime error (exception).

Why is this good?

Sample Program

- Write a complete C++ program which:
  - Reads in course percentages from the user (doubles) into a vector.
  - Has a function to compute pass/fail grades for each student (pass = 65% or more)
  - Display a table of results like:
    #1 82.5% P
    #2 59.0% F
    ...
  - *Optional:* Before displaying, call a function which clamps all percentages to between [0%, 100%] (for example, a grade of 103% becomes 100%).

Personal Review Questions

- Write a function which returns the largest value stored in a vector of integers.
  - Write a program to test it (different length vectors, positive and negative numbers).
- Write a function which returns the *index* of the largest value stored in a vector of integers.
  - Test as before.

Summary

- C++ vectors store many items of the same type.
  - Can grow & shrink.
- Passing to functions
  - Pass by value: passes in a copy.
  - Pass by reference: passes in the real variable.
  - Can pass whole vector, or just elements.
- Working with Vectors
  - Copy and compare with = and ==
  - Out of bounds