Arrays and Vectors

Victor Eijkhout, Harika Gurram, Je'aime Powell, Charley Dey

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Vectors



Vector definition

Definition, mostly without initialization.

```
#include <vector>
using std::vector;

vector<type> name;
vector<type> name(size);
```

where

- vector is a keyword,
- type (in angle brackets) is any elementary type or class name,
- name is up to you, and
- size is the (initial size of the array). This is an integer, or more precisely, a size_t parameter.



Accessing vector elements

You have already seen the square bracket notation:

```
vector<double> x(5, 0.1 );
x[1] = 3.14;
cout << x[2];

Alteratively:

x.at(1) = 3.14;
cout << x.at(2);</pre>
```

Safer, slower.



Indexing the elements

You can write an *indexed for* loop, which uses an index variable that ranges from the first to the last element.

```
for (int i= /* from first to last index */ )
  // statement about index i
```

Example: find the maximum element and where it occurs.

Code:

Output [array] idxmax:

```
int tmp_idx = 0;
int tmp_max = numbers[tmp_idx];
for (int i=0; i<5; i++) {
  int v = numbers[i];
  if (v>tmp_max) {
    tmp_max = v; tmp_idx = i;
  }
}
cout << "Max: " << tmp_max
  << " at index: " << tmp_idx << endl;</pre>
```



Indexing with pre/post increment

Array indexing in while loop and such:

```
x = a[i++]; /* is */ x = a[i]; i++;
y = b[++i]; /* is */ i++; y = b[i];
```



Range over elements

You can write a *range-based for* loop, which considers the elements as a collection.

```
for ( float e : array )
  // statement about element with value e
for ( auto e : array )
  // same, with type deduced by compiler
```

Code:

Output



Ranging over a vector

```
for ( auto e : my_vector)
  cout << e;</pre>
```

Note that e is a copy of the vector element:



Ranging over a vector by reference

To set array elements, make e a reference:

```
for ( auto &e : my_vector)
    e = ....

Code:

vector<float> myvector
    = {1.1, 2.2, 3.3};
```

Output [array] vectorrangeref:

6.6



Vector initialization

You can initialize a vector as a whole:

```
vector<int> odd_array{1,3,5,7,9};
vector<int> even_array = {0,2,4,6,8};
```

(This syntax requires compilation with the -std=c++11 option.)



Vector initialization'

There is a syntax for initializing a vector with a constant:

```
vector<float> x(25,3.15);
```

which gives a vector of size 25, with all elements initialized to 3.15.



Vector indexing

Your choice: fast but unsafe, or slower but safe

```
vector<double> x(5);
x[5] = 1.; // will probably work
x.at(5) = 1.; // runtime error!
```



Vector copy

Vectors can be copied just like other datatypes:

```
vector<float> v(5,0), vcopy;
```

```
v[2] = 3.5;
vcopy = v;
cout << vcopy[2] << endl;</pre>
```

```
Output
[array] vectorcopy:
```

```
./vectorcopy
3.5
```



Code:

Find the element with maximum absolute value in an array. Use:

```
vector<int> numbers = \{1,-4,2,-6,5\};
```

Which mechanism do you use for traversing the array?

Hint:

```
#include <cmath>
...
absx = abs(x);
```



Find the location of the first negative element in an array.

Which mechanism do you use?



Create a vector x of float elements, and set them to random values.

Now normalize the vector in L_2 norm and check the correctness of your calculation, that is,

1. Compute the L_2 norm of the vector:

$$||v|| \equiv \sqrt{\sum_{i} v_{i}^{2}}$$

- 2. Divide each element by that norm;
- 3. The norm of the scaled vector should now by 1. Check this.

What type of loop are you using?



Vector methods

- Get elements with ar [3] (zero-based indexing).
- Get elements, including bound checking, with ar.at(3).
- Size: ar.size().
- Other functions: front, back.
- vector is a 'templated class'



Dynamic extension

```
Extend with push_back:

Code:

Output
[array] vectorend:

vector<int> array(5,2);
array.push_back(35);
cout << array.size() << endl;
cout << array[array.size()-1] << endl;

also pop_back, insert, erase.
```

Flexibility comes with a price.



Multi-dimensional vectors

Multi-dimensional is harder with vectors:

```
vector<float> row(20);
vector<vector<float>> rows(10,row);
```

Vector of vectors.



Static arrays



Array creation

```
{
  int numbers[] = {5,4,3,2,1};
  cout << numbers[3] << endl;
}
{
  int numbers[5]{5,4,3,2,1};
  numbers[3] = 21;
  cout << numbers[3] << endl;
}</pre>
```



Ranging

Same as for vector



Dynamic behaviour



Dynamic size extending

```
vector<int> iarray;

creates a vector of size zero. You can then

iarray.push_back(5);
iarray.push_back(32);
iarray.push_back(4);
```



Vector extension

You can push elements into a vector:

```
vector<int> flex;
/* ... */
for (int i=0; i<LENGTH; i++)
  flex.push_back(i);</pre>
```

If you allocate the vector statically, you can assign with at:

```
vector<int> stat(LENGTH);
/* ... */
for (int i=0; i<LENGTH; i++)
    stat.at(i) = i;</pre>
```



Vector extension

With subscript:

```
vector<int> stat(LENGTH);
/* ... */
for (int i=0; i<LENGTH; i++)
   stat[i] = i;</pre>
```

You can also use new to allocate (see section ??):

```
int *stat = new int[LENGTH];
/* ... */
for (int i=0; i<LENGTH; i++)
   stat[i] = i;</pre>
```



Timing

Flexible time: 2.445 Static at time: 1.177

Static assign time: 0.334

Static assign time to new: 0.467



Write code to take a vector of integers, and construct two vectors, one containing all the odd inputs, and one containing all the even inputs. So:

```
input:
    5,6,2,4,5
output:
    5,5
    6,2,4
```



Vectors and functions



Vector as function return

You can have a vector as return type of a function:



Vector as function argument

You can pass a vector to a function:

```
void print0( vector<double> v ) {
  cout << v[0] << endl;
};</pre>
```

Vectors, like any argument, are passed by value, so the vector is actually copied into the function.



Vector pass by value example

Code:

```
void set0
  ( vector<float> v,float x )
{
   v[0] = x;
}
  /* ... */
   vector<float> v(1);
   v[0] = 3.5;
   set0(v,4.6);
   cout << v[0] << endl;</pre>
```

Output [array] vectorpassnot:

```
./vectorpassnot
3.5
```



Vector pass by reference

If you want to alter the vector, you have to pass by reference:

Code:

```
void set0
  ( vector<float> &v,float x )
{
  v[0] = x;
}
  /* ... */
  vector<float> v(1);
  v[0] = 3.5;
  set0(v,4.6);
  cout << v[0] << endl;</pre>
```

Output [array] vectorpassref:

```
./vectorpassref
4.6
```



Revisit exercise 16 and introduce a function for computing the L_2 norm.



Revisit exercise 28.

Can you write a function that accepts a vector and returns two vectors with the above functionality?



(hints for the next exercise)

```
// high up in your code:
#include <random>
using std::rand;

// in your main or function:
float r = 1.*rand()/RAND_MAX;
// gives random between 0 and 1
```



Write functions random_vector and sort to make the following main program work:

```
int length = 10;
vector<float> values = random_vector(length);
sort(values);
```

(This creates a vector of random values of a specified length, and then sorts it.)

See section ?? for the random fuction.



Vectors in classes



Can you make a class around a vector?

Vector needs to be created with the object, so you can not have the size in the class definition

```
class witharray {
private:
  vector<int> the_array( ???? );
public:
  witharray( int n ) {
    thearray( ???? n ???? );
  }
}
```



Create and assign

The following mechanism works:

```
class witharray {
private:
  vector<int> the_array;
public:
  witharray( int n )
    : the_array(vector<int>(n)) {
  };
};
Better than
  witharray( int n ) {
    the_array = vector<int>(n);
  };
```



Matrix class

```
class matrix {
private:
  int rows, cols;
 vector<vector<double>> elements;
public:
 matrix(int m,int n) {
   rows = m; cols = n;
    elements =
      vector<vector<double>>(m,vector<double>(n));
 void set(int i,int j,double v) {
    elements.at(i).at(j) = v;
 };
 double get(int i,int j) {
    return elements.at(i).at(j);
 };
};
```



Matrix class'

Better idea:

```
elements = vector<double>(rows*cols);
...
void get(int i,int j) {
  return elements.at(i*cols+j);
}
```

(Even more efficient: use cpp macro)



Add methods such as transpose, scale to your matrix class. Implement matrix-matrix multiplication.



Pascal's triangle

Pascal's triangle contains binomial coefficients:

```
R.ow
R.ow
     2:
Row
Row
    4:
   5:
R.ow
   6:
R.ow
       1 6 15 20 15 6 1
   7:
R.ow
   8: 1 7 21 35 35 21 7 1
R.ow
Row
     9:
          1 8 28 56 70 56 28 8 1
R.ow
    10:
         1 9 36 84 126 126 84 36 9 1
```

where

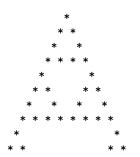
$$p_{rc} = \binom{r}{c} = \frac{r!}{c!(r-c)!}.$$

The coefficients can easily be computed from the recurrence

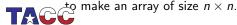
$$\underline{p_{rc}} = \begin{cases} 1 & c \equiv 1 \lor c \equiv r \\ \underline{p_{r-1,c-1} + p_{r-1,c}} \end{cases}$$



- Write a class pascal so that pascal(n) is the object containing n rows of the above coefficients. Write a method get(i,j) that returns the (i,j) coefficient.
- Write a method print that prints the above display.
- Write a method print(int m) that prints a star if the coefficient modulo m is nonzero, and a space otherwise.



• The object needs to have an array internally. The easiest solution is



Extend the Pascal exercise:

Optimize your code to use precisely enough space for the coefficients.



Turn it in!

- Write a program that accepts two integers: the height of the triangle, and the modulo with which to print it. The tester will search for stars in your output and test that you have the right number in each line.
- If you have compiled your program, do: sdstestpascal yourprogram.cc
 where 'yourprogram.cc' stands for the name of your source file.
- Is it reporting that your program is correct? If so, do: sdstestpascal -s yourprogram.cc where the -s flag stands for 'submit'.
- If you don't manage to get your code working correctly, you can submit as incomplete with sdstestpascal -i yourprogram.cc

