Managing 2D Arrays

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Simple Dynamic Allocation

A 2-dimensional int array of any fixed size can be allocated and initialized as follows:

```c++
cons int Col = 4;
int Row = 2;
int (*A)[Col];
A = new int[Row][Col];
for (int i = 0; i < Row; i++)
for (int j = 0; j < Col; j++)
A[i][j] = i;
```

The primary shortcoming of the approach above is that the column dimension MUST be a constant.

Passing a 2D array to a function also involves a requirement...

Example: 2D Array Parameter

```c++
#include <iostream>
#include <iomanip>
using namespace std;
const int Col = 4;
void init2D(int A[][Col], int nRows, int nCols) {
for (int i = 0; i < nRows; i++)
for (int j = 0; j < nCols; j++)
A[i][j] = i;
}
```

The reason relates to the manner in which the elements of the array A will be laid out in memory...

Passing a 2D Array to a Function

A 2-dimensional array parameter requires that the column dimension of the array be specified in the function prototype:

```c++
void init2D(int A[][Col], int nRows, int nCols) {
  for (int i = 0; i < Row; i++)
    for (int j = 0; j < Col; j++)
      A[i][j] = i;
}
```

Example: 2D Array Parameter

```c++
#include <iostream>
#include <iomanip>
using namespace std;
const int Col = 4;
void init2D(int A[][Col], int nRows, int nCols) {
  for (int i = 0; i < nRows; i++)
    for (int j = 0; j < nCols; j++)
      A[i][j] = i;
}
```
Memory Layout for 2D Arrays

First, physical memory is simply a one-dimensional array of bytes, indexed by addresses. C++ (like most languages) specifies that 2D arrays are to be mapped into this one-dimensional environment by storing the array cells row-by-row (known as row-major order). Assuming that the array has R rows and C columns, that results in a layout something like:

```
0.0 0.1 0.2 ... 0.C-1 1.0 1.1 ... 1.C-1 2.0 2.1 ... 2.R-1
```

Then the address of the 0-th cell of the second row depends on the number of elements in the first row (which is the number of columns in the matrix) and the size of each array element in bytes.

When you make an array reference, like `A[4][3]`, the compiler must generate code to calculate the address of the specified cell at runtime. The formula will necessarily involve the column dimension C of the matrix A.

There MUST be a Better Way

Well... of course... but as usual, it’s a matter of picking which type of pain you wish to endure.

One approach is to allocate an array of pointers, viewed say as pointers to the columns in a 2D matrix, and then use each pointer to dynamically allocate a column of the desired size. That’s syntactically (and conceptually) ugly but it WILL work.

Another approach is to simply allocate a one-dimensional array, say `A1D`, of the correct total size and then treat it as a 2D array. How? By taking on the management of the array indexing arithmetic yourself. (See the previous memory layout again.)

```
0.0 0.1 0.2 ... 0.C-1 1.0 1.1 ... 1.C-1 2.0 2.1 ... 2.R-1
```

This is cell 0 of a 1D array.

This would be cell C of a 1D array.

Now, if you want to logically refer to `A[i][j]`, you just have to do some simple arithmetic to calculate the correct index k and refer to `A1D[k]` instead.

2D Array Encapsulation

Of course, if you’re going to do that, there’s an advantage to be gained by wrapping the one-dimensional array inside a class and hiding all the messy translation details inside its member functions:

```cpp
class Array2D {
private:
  int *Data;
  int nRows; // (logical) number of rows
  int nCols; // (logical) number of columns
public:
  Array2D();
  Array2D(int R, int C); // allocate array of R*C cells
  Array2D(const Array2D& Source); // copy constructor and assignment
  Array2D operator=(const Array2D& Source); // assignment operator
  bool Set(int R, int C, int Value); // store Value at A[R][C] (logically)
  int Get(int R, int C) const; // get Value at A[R][C] (logically)
};
```

The idea is to allow the user to act as if there’s really a normal 2D array under the hood, while supporting pure dynamic allocation (no requirements that any dimension be a constant). Of course, we also provide protection against array bounds errors as well.

Array2D Construction and Destruction

The constructor will provide a (logical) 2D array with any dimensions:

```cpp
Array2D::Array2D(int R, int C) {
  nRows = R;
  nCols = C;
  Data = new int[nRows * nCols];
  if (Data == NULL) {
    nRows = nCols = 0;
  }
}
```

And destruction poses no new issues since `Data` is a simple one-dimensional array:

```cpp
Array2D::~Array2D() {
  delete [] Data;
}
```
Array2D Implementation

The remainder of the implementation is left to the reader. A few notes...

The copy constructor is necessary in order to pass Array2D objects as parameters or use them as return values. The assignment overload is not used in the following example, but it’s cheap to provide since a copy constructor must be written anyway.

The function Map() that provides the translation from 2D to 1D indices is simple. Draw a few pictures and play around with indices and you’ll see the correct formula.

The ValidRC() function does not use Map() (or any other translation code).

It’s fairly trivial to turn Array2D into a template.

Array2D Use

#include <iostream>
#include <iomanip>
using namespace std;
#include "Array2D.h"

void init2D(Array2D A, int Rows, int Cols);
void print2D(const Array2D A, int Rows, int Cols, ostream &Out);

void main() {
  int R = 3, C = 5;
  Array2D myArray(R, C);
  init2D(myArray, R, C);
  print2D(myArray, R, C, cout);
}

void init2D(Array2D A, int Rows, int Cols) {
  int row, col;
  for (row = 0; row < Rows; row++)
    for (col = 0; col < Cols; col++)
      A.Set(row, col, row);
}

//...continues...

void print2D(const Array2D A, int Rows, int Cols, ostream &Out) {
  int row, col;
  for (row = 0; row < Rows; row++)
    for (col = 0; col < Cols; col++)
      cout << setw(5) << A.Get(row, col);
  cout << endl;
}

//...continued...

void print2D(const Array2D A, int Rows, int Cols, ostream &Out) {
  int row, col;
  for (row = 0; row < Rows; row++)
    for (col = 0; col < Cols; col++)
      cout << setw(5) << A.Get(row, col);
  cout << endl;
}