Computer Programming C++

Howest, Fall 2012

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About Me

- PhD at The University of Texas at Austin in August 2010
- Currently: post-doctoral researcher at Ghent University with Dr. Lieven Eeckhout
- I research how to make memory more efficiently managed, from the application on top of a Java virtual machine, to the operating system, then to hardware caches.

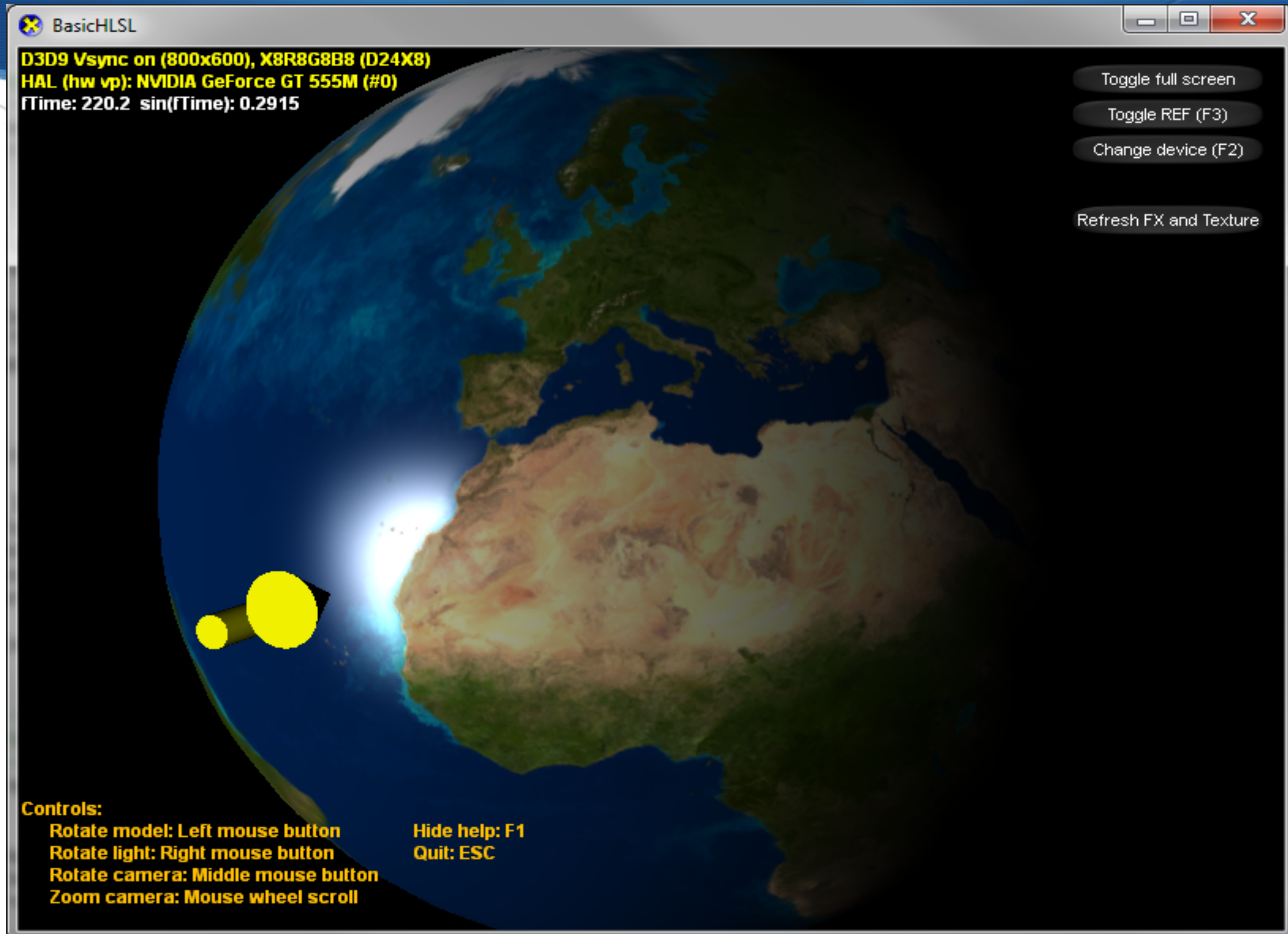
Whole Course

- Intro to C++ programming with me (6 classes)
  - Jennifer.sartor@elis.ugent.be
- Intro to Graphics programming with Bart Pieters (6 classes)
  - Bart.pieters@elis.ugent.be
  - C/C++-like language is used to program the GPU (like CUDA or OpenCL)
  - You will use C++AMP
  - Final project in graphics

GPU Final Project

- Textures used in video games are becoming larger and larger with sizes of up to 16k x 16k pixels. These textures are typically compressed to save disk space, e.g., using JPEG compression. Yet the GPU requires these textures to be in a compressed format called DXT. As a result, the game textures need to be transcoded from JPEG to DXT on the fly. The main goal of the project is to build a texture encoder which uses the massively parallel GPU to accelerate the DXT encoding steps.

Application for Final Project



Course Overview

- Intro to C++
- Good to have previous knowledge of object-oriented and procedural programming
- Website: http://users.elis.ugent.be/~jsartor/howest/c++.htm
- All communication will be through Minerva

Additional Info

- Books:
  - Aan de slag met C++, Gertjan Laan, Academic Service 2012, ISBN 9789039526576
  - C++ Primer, Stanley B. Lippman, ISBN: 0321714113 DDC: 5 Edition: Paperback, 2012-08-13
- Another good book: C++: How to Program, 8th Edition by Deitel & Deitel
- Grades will be based on programming assignments (80%) and one final test (20%)

Programming Assignments

- 4-5 programming assignments
  - Individual programming
  - In order to pass the class, you must submit all assignments, and they must compile and run (with provided test programs)
  - Programming style worth 15% of each assignment
  - 1 emergency late day (mulligan)
- The first programming assignment will give you extra points to make up missing following assignment points.

Microsoft Visual Studio

- General IDE (integrated development environment) to write, compile, debug, and run code
- You will use it for both C++ and C++AMP
- Download from Howest webpage
- Only runs on Windows platform

C++

- Extension of C, created by Bjarne Stroustrup in 1980s
- We will try to cover:
  - basic syntax, I/O, functions and argument passing,
  - arrays, references, pointers, classes, dynamic memory management,
  - classes and inheritance,
  - generic programming with templates
  - polymorphism with virtual functions and dynamic binding,

Similarities & Differences

- Look at basic.cpp for example C++ program
  - Operators, if/else, loops, commenting are the same as Java
- Variables are not by default zero-initialized!
- You need a main function:

```
int main() {
   …
   return 0; //success
}
```

Some I/O Basics

- At the top of a program
  - #include <iostream>   //library you intend to use
  - Using declaration (which parts of library you will use), use either:
    - using namespace std;   //common (standard) parts of library
    - using std::cin; using std::cout; //only these parts of library
- Input: int foo; cin >> foo;
- Output: cout << "bar " << foo;
- If you put "using std::endl" above, can use newline:
  cout << 5 << endl;

Functions

- Example:

```
int boxVolume(int side) {
    return side * side * side;
}
```

- Need to declare a function before it is used. If a function is defined later than it is used, provide **function prototype** at top:
  - int boxVolume(int);
  - int boxVolume(int side = 1); //can specify default parameters

C++ Compilation

- Compilation
  - 1) Preprocessor (expand things like #include <iostream>)
  - 2) Compiler – creates object (machine-language) code
  - 3) Linker – links object code with libraries, creates executable file myProgram.o + library.o = program.exe
- Preprocessor goes and finds library header file (iostream.h) with function prototypes for things you will use (cin, cout).
- Actual functions are defined in .cpp file (and .o object file) that linker will fetch.

C++ Compilation

- Usually include files are called header files, are *.h and define function prototypes.
  - C++ libraries are usually in < >: #include <iostream> (compiler looks in standard library paths)
  - Header files you define are in " ": #include "myHeader.h" (compiler looks in current directory)
- Using declaration says exactly which function prototypes to include, or "namespace std" includes all common/standard ones.

How to Cast Safely?

- In Java:
  - double pi = 3.1415;
  - int num = (int) pi;
- C++ uses a **static cast**:
  - int num = **static_cast** <int> (pi);
  - Keyword = built into language

Storage Classes

- Storage-class specifiers
  - auto
  - register
  - extern
  - mutable
  - static
- Determine the period during which identifier exists in memory

Storage Classes

- Storage-class specifiers
  - auto
  - register
  - extern
  - mutable
  - static

automatic storage class (auto, register)

static storage class (extern, mutable, static)

- Determine the period during which identifier exists in memory

Storage Classes

- Storage-class specifiers
  - Automatic storage class
    - Active during block of program
    - Local variables (automatically auto)
    - register – suggestion to compiler, only with local variables and function parameters
  - Static storage class
    - Exist from program begin to end
    - Can be global or local
    - Static local variables retain their value when function returns.

Fun with Static Variables

- What does this print?

```
void func() {
    static int x = 0;
    x++;
    cout << x << endl;

}
```

```
int main() {
    func();
    func();
    func();
    return 0;

}
```

Stacks

- Function call stack
- Stack frame or activation record
  - Holds function parameters, return address of caller function, and local variables
- Do not want stack overflow! (often as result of recursion)
- Static and global variables are stored separately
- Later – dynamic memory and the heap

Scope

```
1.  int x = 1;
2.  void useStaticLocal();
3.  void useGlobal();
4.  int main() {
5.     int x = 5;
6.     { int x = 7;}
7.     useStaticLocal ();
8.     useGlobal();
9.  }
```

```
1.  void useStaticLocal () {
2.     static int x = 83;  //where?
3.     x++;
4.  }
5.  void useGlobal() {
6.     x *= 10;
7.  }
```

Statics and globals
x: global
x: useStaticLocal

Return: main
Parameters: (none)
Locals: (none)
useGlobal

Parameters: (none)
Locals: x, inner x
main

Parameter passing

- 2 types
  - Pass-by-value
  - Pass-by-reference

Parameter passing

- 2 types
  - Pass-by-value
    - Argument copied
    - Caller and callee each have own copy
  - Pass-by-reference
    - Only 1 copy! Caller and callee share it
    - Beware – it can be modified by everyone

Pass-by-value

```
int squareByValue(int number) {
    return number *= number;
}
int main() {
    int x = 3;
    int x_squared = squareByValue(x);
    //what is x and what is x_squared?
}
```

Pass-by-reference

```
void squareByReference(int &number) {
    number *= number;
}
int main() {
    int x = 3;
    squareByReference(x);
    //what is x?
}
```

Pass-by-reference

- void myFunction(int &x);
  - x is a reference to an int.
- Be careful – you are giving callee method power to change your variable
- To save copying space, but protect your variable, use **const**
  - void myFunction(const int &x);
  - Now myFunction cannot modify x.

References as Aliases

```
int count = 1;

int &cRef = count;

cRef++;

//count is ?
```

- Reference variables must be initialized in their declaration and cannot be reassigned later.

Returning References

- Returning references from a function is dangerous
- Variable declared on stack cannot be returned
- Can return static variable, but might not be what you want
- Dangling reference = reference to undefined variable

Inputting from a File

```
#include <fstream>
#include <stdio>
#include <stdlib>
using namespace std;
int main() {
     ifstream inputFile(”file.in", ios::in);
     if (!inputFile) {
       cerr << "File could not be opened" << endl;
       exit(1);  //or return -1
    }
    int numPpl;
    inputFile >> numPpl;
    cout << "Num people is " << numPpl << endl;
    return 0;
}
```

Arrays!

- Indexed data structure
  - Starts at zero!
- How do we declare an array?

Arrays!

- Indexed data structure
  - Starts at zero!
- How do we declare an array?
  - *type arrayName[arraySize];*
  - Ex: int array[5];

Array Initialization

- Loop
- Initializer list
- Use **const** array size

Array Initialization

- Loop

```
int array[5];
for (int i = 0; i < 5; i++) {
    array[i] = i;
}
```

- Initializer list
- Use **const** array size

Array Initialization

- Loop
- Initializer list
  - int array[5] = {99, 88, 77, 66, 55};
  - int array2[5] = {}; //what does this do?
  - int array[] = {44, 33, 22, 11};
- Use **const** array size

Array Initialization

- Loop
- Initializer list
- Use **const** array size

  const int arraySize = 10;

  int array[arraySize];

  - const variables must be initialized when declared, are constant
  - Only constants can be used to declare size of automatic and static arrays

Differences from Java

- No automatic ".length" for arrays
- No guaranteed compiler array bounds checks – if you go outside [0 through (arraySize-1)], undefined behavior
- Arrays are always contiguous in memory

Character Arrays

- char string1[] = “hello”;
- What is the size of the array above?

Character Arrays

- char string1[] = “hello”;
- What size is the above array? **6**
- Char arrays are terminated with null character!
- char string1[] = {‘h’, ‘e’, ‘l’, ‘l’, ‘o’, ‘\0’};

Strings

- C++ does have string type
  - #include <string>
  - string hello = “hello”;
- Some useful string functions:
  - char chArray[] = hello.data( ); //get string’s character array
  - hello.length();   //get length
  - char oneChar = hello[1]; //can index strings
  - string wstr = “world”;   hello.append(wstr, 0, wstr.length());   //append wstr onto hello to get “helloworld”
  - wstr.copy(chArray, wstr.length(), 0); //copy wstr string into char array

Character Arrays

- char string2[20];
- cin >> string2;
  - cin reads in a string (until whitespace) and appends null character to end
  - Make sure input from user <= 19 characters, otherwise error
- For a line at a time:
  - cin.getline(string2, 20);
  - string myStr; getline(cin, myStr);

```
for (int i = 0; string2[i] != '\0'; i++) {
    cout << string2[i] << ' ';
}
```

Passing Arrays to Functions

```
void modifyArray(int [], int);

int main() {
    const int arraySize = 5;
    int a[arraySize] = {0, 1, 2, 3, 4};
    modifyArray(a, arraySize);
    return 0;
}
```

```
void modifyArray(int b[],
    int arrSize) {
    for (int i = 0; i < arrSize; i++) {
        b[i] *= 2;
    }
}
```

Passing Arrays to Functions

- Arrays are passed by reference
- Name of array is the address in memory of the 1st element
- Need to pass size too – unlike Java
- Use const to make sure function can't change array
  - void cannotModifyArray(const int b[]);

Static Local Arrays

```
void staticArrayInit();

int main() {
    staticArrayInit();
    staticArrayInit();
    return 0;

}
```

```
void staticArrayInit( void ) {
    static int array1[3];
    for (int i = 0; i < 3; i++) {
        arrays1[i] += 5;
    }

} //what if array is not static?
```

Multidimensional Arrays

- int array[2][3] = {{1, 2, 3}, {4, 5, 6}};
- int array[2][3] = {1, 2, 3, 4};
- int array[2][3] = {{1, 2}, {4}};
- Different from Java – contiguous in memory
- 2nd dimension needs to be known when passing to a function

Multidimensional Arrays

- int array[2][3] = {{1, 2}, {4}};
- Different from Java – contiguous in memory
  - Conceptually:

[0][0] = 1	[0][1] = 2	[0][2] = 0
[1][0] = 4	[1][1] = 0	[1][2] = 0

  - Actual layout:

[0][0] = 1	[0][1] = 2	[0][2] = 0	[1][0] = 4	[1][1] = 0	[1][2] = 0

Passing Multi-D Arrays

```
void printArray( const int[][3],
                 int numRows );

int main() {
    int array1[2][3] = {1, 2, 3, 4};
    printArray(array1, 2);
    return 0;
}
```

```
void printArray( const int[][3],  //why?
                 int numRows) {
    for (int i = 0; i < numRows; i++) {
        for (int j = 0; j < 3; j++) {
            cout << a[i][j] << ' ';
        } cout << endl;
    }
}
```

2D as 1D array

- int array1[2][3] = {};

[0][0] = 0	[0][1] = 0	[0][2] = 0	[1][0] = 0	[1][1] = 0	[1][2] = 0

- // to access array1[1][0] – we need to skip over 1st row then go over to element 0 in second row
- //number of entries per row = number of columns
- array1[3 * 1 + 0] == array1[1][0];
- //formula: numColumns * 1stIndex + 2ndIndex

typedef

- **typedef** is a keyword that declares synonyms (aliases) for previously defined data types
- Does not create a data type, it creates a type name (usually shorter, simpler) that maybe be used in the program
- **typedef** unsigned long int ulint;
- ulint myNum;
- size_t is a typedef for unsigned int (used for string's length())

sizeof Operator

- **sizeof** does exactly what you'd expect – give it a variable or type, it will return the size of it in bytes.
- return type: not int, size_t (unsigned int)

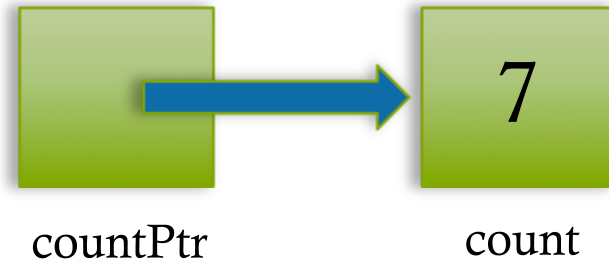
```
int x = 5;

cout << sizeof x << endl;  //can omit parens with variable

cout << sizeof( int ) << endl;
```

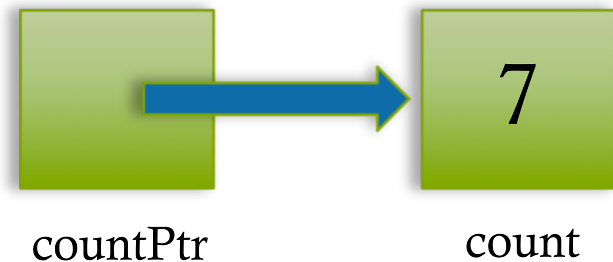
Pointers

- Mysterious, but very useful.
- int *countPtr, count; //what are types of each variable?
- count = 7;
- countPtr = &count;
- *countPtr == count == 7;
- countPtr indirectly references count



Pointer Operators

- Similar to references
- & means "obtain memory address" (countPtr = &count)
- * is indirection or dereferencing operator. * returns synonym for object to which operand points.
- & and * are inverses

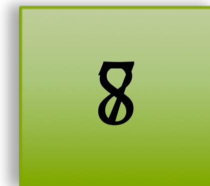


Pointers

- int *countPtr, count;
- count = 7;
- countPtr = &count;
- *countPtr++;
- countPtr indirectly references count, *countPtr is called "deferencing a pointer"

location: x5000 x6000

countPtr



count

Pointer Operators

- * in indirection or dereferencing operator.
- Pointer is undefined when created – can be set to 0 or NULL
- Dereferencing an uninitialized or NULL pointer is BAD!
  - What if we did (*count)?
  - Or int *countPtr; then (*countPtr) ?

count

Pointers vs. References

- **Differences**
  - In reference declaration (int &cRef = count;), "&" is part of type, it is not an operation (as with pointers)
  - References have to be initialized at declaration time
- void func_ptr(int *pi) {*pi = 5;}
- void func_ref(int &ri) {ri = 6;}
- int num; int *p = # int &r = num;
- func_ptr(&num);
- func_ref(num); //We are passing parameters by… what?

Pointer Example

```
void cubeByReferenceWithPointer(int *nPtr) {
    *nPtr = *nPtr  *  *nPtr  *  *nPtr;

}

int main() {
    int number = 5;
    cubeByReferenceWithPointer(&number);
    cout << number;
    return 0;

}
```

Arrays are Just Pointers

int arrayName[5] = {};

- "arrayName" is constant pointer to start of array
- arrayName == &arrayName[0];
- void modifyArray(int [], int) == void modifyArray(int*, int);
- Array parameter translated by the compiler to be int *. So 2nd function above has to know whether it receives array or int pointer.

sizeof Array vs. Pointer

```
size_t getSize(double *);

int main() {
    double array[20];
    cout << sizeof(array) << endl;
    cout << getSize(array) << endl;
    cout << (sizeof(array) / sizeof(double)) << endl;  //array length
    return 0;
}
```

```
size_t getSize (double *ptr) {
    return sizeof(ptr);
}
```

Parameter Arithmetic & Arrays

- int v[5]; int *vPtr = v; (or = &v[0];)

	like 5012	like 5016

location: x5000 x5004 x5008 x500c x5010

- vPtr += 2; //goes from x5000 to ?

Parameter Arithmetic & Arrays

- int v[5]; int *vPtr = v; (or = &v[0];)

like 5012 like 5016

location: x5000 x5004 x5008 x500c x5010

- vPtr += 2; //goes from x5000 to x5008
- Pointer arithmetic depends on type of pointer
- cout << (vPtr – v) << endl; //what is this?

Parameter Arithmetic & Arrays

- int v[5]; int *vPtr = v; (or = &v[0];)
- v[3] == * (vPtr + 3) == * (v + 3) == vPtr[3]
- vPtr + 3 is the same as &v[3]
- Array names cannot be modified in arithmetic expressions because they are constant.

Void*

- void* voidPtr;
- void* is generic pointer, it can point to any type, but can't be dereferenced.
  - Cannot do (*voidPtr) (even if initialized) – why?
- All pointer types can be assigned to a pointer of type void* without casting. void* pointer **cannot** be assigned to pointer of other type without casting.
  - void* voidPtr = whateverPtr; //assigning specific to general
  - int* intPtr = (int*) voidPtr;//assigning general to specific – need cast

Arrays and Pointers

```
void copy1(char*, const char *);

int main() {
    char phrase1[10];
    char *phrase2 = “Hello”;
    copy1(phrase1, phrase2);
    cout << phrase1 <<  endl;
    return 0;

}
```

```
void copy1(char * s1,

              const char * s2) {
    for(int i =0;
        (s1[i] = s2[i]) != ‘\0’; i++) {
            ;
    }

}
```

Arrays and Pointers

```
void copy2(char*, const char *);

int main() {
    char phrase3[10];
    char *phrase4 = “GBye”;
    copy2(phrase3, phrase4);
    cout << phrase3 << endl;
    return 0;
}
```

```
void copy2(char * s1,
               const char * s2) {
   for(; (*s1 = *s2) != ‘\0’;
         s1++, s2++) {
         ;
   }
}
```

Vector

```
#include <vector>

using std::vector;

vector<int> integers1(5);  //already initialized to zero

cout << integers1.size() << endl;  //type is actually size_t

integers1[3] = 89;   //will NOT check bounds, but at(#) will

vector<int> integers2(integers1);  //copies 1 into 2
```

Vector and Iterators

```
#include <vector>

using std::vector;

vector<int> integers1(5);  //already initialized to zero

vector<int>::iterator iter_i;  //pointer into vector

for(iter_i = integers1.begin(); iter_i != integers1.end(); iter_i++) {
    cout << (*iter_i) << " ";

} cout << endl;
```

Vector and Iterators

iter_i

```
#include <vector>

using std::vector;

vector<int> integers1(5);  //already initialized to zero

vector<int>::iterator iter_i;  //pointer into vector

for(iter_i = integers1.begin(); iter_i != integers1.end(); iter_i++) {
    cout << ++(*iter_i) << " "; //you can use iterator to modify elements!

} cout << endl;
```

Dynamic Memory Management

- Like Java, puts things on the heap instead of the stack (so can be returned from functions!)
- Unlike Java, you manage memory yourself – no garbage collection
- Helps create dynamic structures, arrays of correct size
- Use **new** and **delete**
- **new** finds memory of correct size, returns pointer to it

Dynamic Allocation

```
double *pi = new double(3.14159);

int *num = new int();   *num = 9;

int *grades = new int[40];
```

- Finds space for 40 integers, returns address of first element to int pointer grades
- Memory allocated for array NOT initialized (unknown)
- Remember array name is a constant pointer to 0th element of array

Dynamic Deallocation

```
double *pi = new double(3.14159);

int *num = new int();      *num = 9;

int *grades = new int[40];  //finds space for 40 integers, returns
    address of first element to int pointer grades

delete pi;

delete num;

delete [] grades;  //NEED [] when deleting an array!
```

Dynamic Deallocation

int *grades = **new** int[40]; //finds space for 40 integers, returns address of first element to int pointer grades

delete [] grades; //NEED [] when deleting an array!

grades = NULL; //good to null so no dangling pointers

- You MUST pair every **new** with a **delete**
- Not releasing dynamically allocated memory back to the heap can cause memory leaks. This is BAD.

Pointers to Pointers

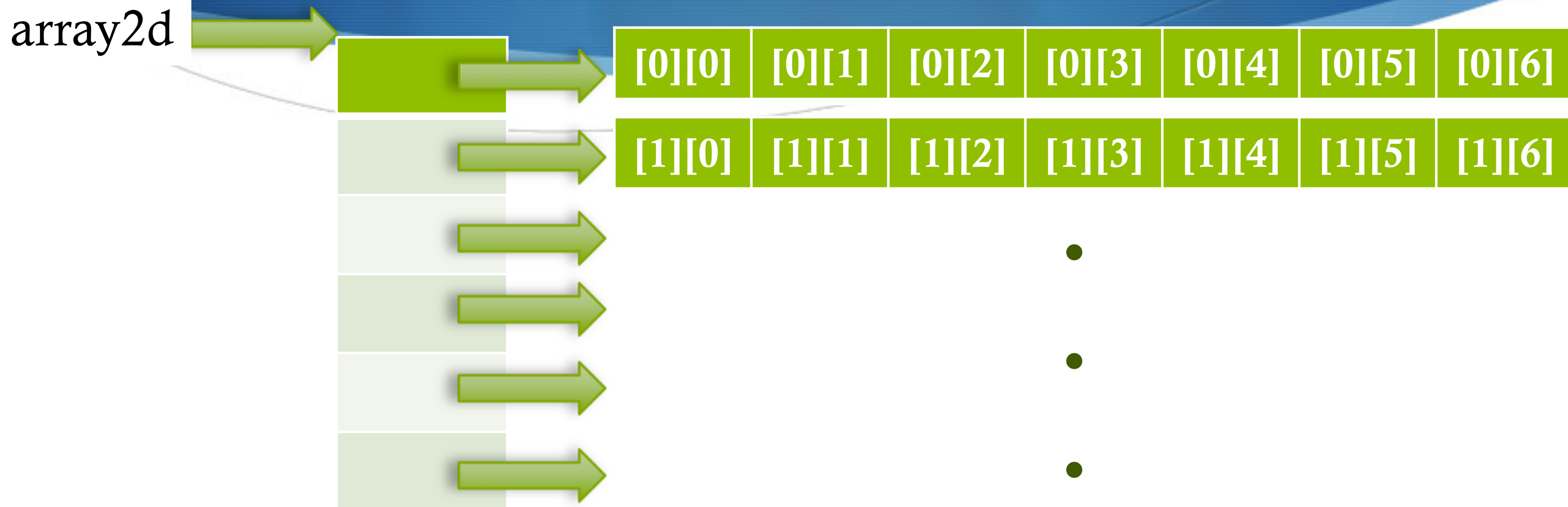
```
int **array2d = new int*[6];
```

- array2d is a pointer to a pointer, or a pointer to an array of pointers

```
for (int i = 0; i < 6; i++) {
    array2d[i] = new int[7];  //initialize each row to array of ints
}  array2d[0][0] = 8;
```

- Dynamically allocated 2d arrays are NOT contiguous in memory

Pointers to Pointers




```
int **array2d = new int*[6];

for (int i = 0; i < 6; i++) {
    array2d[i] = new int[7];
} //Dynamically allocated 2d arrays NOT contiguous in
    memory (each new is contiguous)
```

Dealloc Pointers to Pointers

```
int **array2d = new int*[6];

for (int i = 0; i < 6; i++) {
    array2d[i] = new int[7];  //initialize each row to array of ints

}  array2d[0][0] = 8;

 for (int i = 0; i < 6; i++) {
    delete [] array2d[i];

}

delete [] array2d;
```

const with Pointers and Data

- 4 types
  - nonconstant pointer to nonconstant data
  - nonconstant pointer to constant data
  - constant pointer to nonconstant data
  - constant pointer to constant data

Nonconst Ptr, Nonconst Data

```
void convertToUpperCase(char *);

int main() {
    char phrase[] = “Hello world”;
    convertToUpperCase(phrase);
    cout << phrase << endl;
    return 0;

}
```

```
void convertToUpperCase(
                        char * sPtr) {
  while (*sPtr != ‘\0’) {
      if ((*sPtr) == ‘o’) {
          *sPtr = ‘O’;
      } sPtr++;
  }

}
```

Nonconst Ptr, Const Data

```
void printChars(const char *);

int main() {
    const char phrase[] = "Hello world";
    printChars(phrase);
    cout << endl;
    return 0;
}
```

```
void printChars (
        const char * sPtr) {
    for( ; *sPtr != '\0'; sPtr++) {
        cout << *sPtr;
    }
}
```

Const Ptr, Nonconst Data

```
void printChars(const char *);

int main() {
    const char phrase[] = "Hello world";
    printChars(phrase);
    cout << endl;
    return 0;

}
```

```
void printChars (

        char * const sPtr) {

    //can we change array elems?

    //can we do sPtr++?
    for( ; *sPtr != '\0'; sPtr++) {
        *sPtr = toupper(*sPtr);
        cout << *sPtr;
    }

}
```

Const Ptr, Nonconst Data

```
void printChars(const char *);

int main() {
    const char phrase[] = "Hello world";
    printChars(phrase);
    cout << endl;
    return 0;
}
```

```
void printChars (
        char * const sPtr) {
    //can we change array elems? YES
    //can we do sPtr++? NO
    for(int i =0; (sPtr[i]) != '\0'; i++) {
        sPtr[i] = toupper(sPtr[i]);
        cout << sPtr[i];
        //or *(sPtr + i)
    }
}
```

Const Ptr, Nonconst Data

```
int main() {
    int x, y;
    int * const ptr = &x;  //const pointer has to be initialized
    *ptr = 7;  //modifies x – no problem
    ptr = &y; //compiler ERROR – const ptr cannot be reassigned
    return 0;
}
```

- Arrays are constant pointers to nonconstant data

Const Ptr, Const Data

```
int main() {
    int x = 5, y;
    const int * const ptr = &x;  //const pointer has to be initialized
    cout << *ptr << endl;  //no problems – nothing modified
    *ptr = 7;  //compiler ERROR – const data cannot be changed
    ptr = &y; //compiler ERROR – const ptr cannot be reassigned
    x++; //is this ok?
    return 0;

}
```

Volatile/Mutable/const_cast

- Keyword **volatile** means variable could be modified by hardware not known to the compiler. Key to tell compiler not to optimize it.
- Cast **const_cast** adds or removes **const** and **volatile** modifiers
  - Useful when get const char* back from function, and you need to modify it.
- Keyword **mutable** is an alternative to const_cast.
  - mutable member variable is always modifiable even with const member function or const object of that class.

const_cast< T > (v)

- Adds or removes **const** or **volatile** modifiers
- Single cast removes all modifiers
- Result is an rvalue unless T is a reference
- Types cannot be defined within **const_cast**

```
const int a = 10;
const int* b = &a;
int* c = const_cast< int* > (b);
*b = 20;  //compiler error
*c = 30;  //OK
```

Function Templates

- We can do function overloading

```
int boxVolume(int side) {
    return side * side * side;
}
double boxVolume(double side) {
    return side * side * side;
}
```

- Why define 2 functions that look identical, but have different types?
- Overloading that is more compact and convenient = function templates. Only write it once!

Function Templates

- Template

```
template <class T>  //or template <typename T>
T boxVolume(T side) {
    return side * side * side;
}
```

- C++ compiler automatically generates separate function template specializations for each type the function is called with.
- T is placeholder for actual data type
- int result = boxVolume(3); double result = boxVolume(6.2);

Extra

Compiling with g++

- g++ basic.cpp (creates "a.out" executable)
- g++ -o program basic.cpp ("program" is executable)

  ./program

- Flags that are good practice
  - g++ -Wall -o program basic.cpp (print all warnings)
  - g++ **-Wall -Werror** -o program basic.cpp (treat warnings as compilation errors)