CS-202

Dynamic Memory (Pt.2)

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Course Week

Course , Projects , Labs:

Monday	Tuesday	Wednesday	Thursday	Friday
			Lab (8:00-12:00)	
	CLASS		CLASS	
PASS Session	PASS Session	Project DEADLINE	NEW Project	

Your 7th Project will be announced today Thursday 10/26.

6th Project Deadline was this Wednesday 10/25.

- NO Project accepted past the 24-hrs delayed extension (@ 20% grade penalty).
- Send what you have in time!

Today's Topics

Memory Storage

- Automatic
- Static
- Dynamic

Program Memory

- Stack
- Heap

Program Memory Management

- Expression `new [ ]`
- Expression `delete [ ]`

Dynamic Memory Allocation

Remember: **The Basics**

There is no named Object / Variable : All work is done on a Pointer-basis.

- Allocation reserves memory space.
- Address of reserved space is returned.
- Marked as "containing a specific data type" (int, double, struct, class, arrays, etc.)

Operator **`new`** dynamically allocates memory space.

```
void* operator new (std::size_t count);
void* operator new [] (std::size_t count);
```

Operator **`delete`** can free-up this space (deallocate memory) later on.

```
void operator delete (void* ptr);
void operator delete [] (void* ptr);
```

Dynamic Memory Allocation

The `new ( [ ] )` Expression

Uses **`operator new`** (`[ ]`) to allocate memory space for the requested object / array type and size, and **`return`**s a Pointer-to (Address-of) the memory allocated.

- Pointer type as per requested type, marks what the memory contains.
- If sufficient memory is not available, the new operator returns **`NULL`**.
- The dynamically allocated object/array will persist through the program lifetime (memory will be reserved by it) until explicitly deallocated (i.e. by a **`delete`** expression).

Dynamic Memory Allocation

The new ([ ]) Expression

Allocation of a single variable / object or an array of variables / objects.

Syntax:

<type_id>* new <type_id_ctor> ([SIZE] : optional)

Examples:

```
char *myChar_Pt = new char;
int *myIntArr_Pt = new int [20];
MyClass *myClass_Pt = new MyClass("mine",1,true);
MyClass *myClassArr_Pt = new MyClass [100];
```

- Simple-type variable.
- Simple-type variable array.
- Class-type instantiation in allocated memory.

```
MyClass *myClassArr_Pt = new MyClass [100]("mine",1,true);
```

NO. Not allowed.

Notes:

Before the assignment, the Pointer may or may not point to a "legitimate" memory.

After the assignment, the pointer points to a "legitimate" memory.

Dynamic Memory Allocation

The `delete []` Expression

Uses `operator delete []` to deallocate the object / array pointed-to by a pointer, which was the run-time result of a previous `new` Expression.

- Memory is free'd and returned to the Heap.
- Pointer is considered unassigned.
- If the value of the pointer is `NULL`, then `delete` has no effect.

Dynamic Memory Allocation

The `delete` (`[ ]`) Expression

Uses **`operator delete`** (`[ ]`) to deallocate the object / array pointed-to by a pointer, which was the run-time result of a previous **`new`** Expression.

- After **`delete`** is called on a memory region, it should no longer be accessed by the program.

  Note: Otherwise, the result will be a Segmentation Fault.
- Convention is to set (/"mark") pointer to delete'd memory to **`NULL`**.
- Every **`new`** must have a corresponding **`delete`**.

  Note: Otherwise, the program has memory leak.
- **`new`** and **`delete`** may not be in the same routine.

  Note: But have to be properly sequenced during program execution.

Dynamic Memory Allocation

The `delete []` Expression

Uses **`operator delete []`** to deallocate the object / array pointed-to by a pointer, which was the run-time result of a previous **`new`** Expression.

- Called on a Pointer to dynamically allocated memory when it is no longer needed (only **`new`**'ed objects / variables can be **`delete`**'d).

```
int globInt, globIntArr[5];
int main(){
  int locInt, locIntArr[5];
  int* int_Pt;
  int_Pt = &locInt;
  int_Pt = &locIntArr;
  int_Pt = &globInt;
  int_Pt = &globIntArr;
  return 0;
}
```

```
delete intPt;
delete [] intPt;
```

- Segmentation Fault
  Freeing non-dynamic (local variable, auto storage).

```
delete intPt;
delete [] intPt;
```

- Invalid Pointer Free
  Memory address of global.

Dynamic Memory Allocation

The `delete ( [ ] )` Expression

Can delete a single object/variable or an array of objects/variables.

Syntax:

`delete <ptr_name> ( [ ] : optional)`

Examples:

```
int *myInt_Pt = new int;
delete myInt_Pt;
char *myChar_Pt = new char [255];
delete [] myChar_Pt;
MyClass *myClass_Pt = new MyClass("mine", 1, true);
delete myClass_Pt;
MyClass *myClassArr_Pt = new MyClass [100];
delete [] myClassArr_Pt;
```

Dynamic Arrays

Dynamically Allocated Array

The `[IntExp]` variant of the `new` Expression can be used to allocate arrays of objects/variables in Dynamic Memory.

```
char *myString = new char [255];
Car *myInventory = new Car [100];
```

Then `[IntExp]` variant of the `delete` Expression can be used to indicate that an array of objects is to be deallocated.

```
delete [] myString;
delete [] myInventory;
```

Note: Use array or simple variant properly (on an array).
Otherwise the C++ Standard gives Undefined Behavior.

Dynamic Arrays

Dynamically Allocated Array

By-Example:

```
int* grades = NULL;
int numberOfGrades;

cout << "Enter the number of grades: ";
cin >> numberOfGrades;

grades = new int[numberOfGrades];

for (int i = 0; i < numberOfGrades; i++)
{  cin >> grades[i];  }

for (int j = 0; j < numberOfGrades; j++)
{  cout << grades[j] << " ";  }

delete [] grades;
grades = NULL;
```

Array size is determined during run-time!

See any problem here ?

Dynamic Arrays

Dynamically Allocated Array

By-Example:

```
int* grades = NULL;
int numberOfGrades;

cout << "Enter the number of grades: ";
cin >> numberOfGrades;

grades = new int[numberOfGrades];

if (grades){
   for (int i = 0; i < numberOfGrades; i++)
   {  cin >> grades[i];  }

   for (int j = 0; j < numberOfGrades; j++)
   {  cout << grades[j] << " ";  }

   delete [] grades;
   grades = NULL;
}
```

Array size is determined during run-time!

Have to check for **new** allocation success!

Dynamic Memory Allocation

The new ([ ]) Expression

Actually, operator new ([ ]) throws !

Remember: Exceptions

If allocation fails, Expression new ([ ]) will throw a std::bad_alloc exception.

Proper syntax is:

```
try{
    char *myChar_Pt = new char [MAX_SIZE];
}
catch(std::bad_alloc& ex){
    /* handle exception ex … */
}
```

Note:
There is still however a non-throwing variant (has noexcept specification in C++11).

Dynamically Allocated Array

By-Example (the proper way):

```
int* grades = NULL;
int numberOfGrades;

cin >> numberOfGrades;

try{
  grades = new int[numberOfGrades];
  for (int i = 0; i < numberOfGrades; i++)
  {  cin >> grades[i];  }
  for (int j = 0; j < numberOfGrades; j++)
  {  cout << grades[j] << " ";  }
  delete [] grades;
  grades = NULL;
}
catch(std::bad_alloc& ex){
  /* handle exception ex … */
}
```

Exception handling.

Dynamic Arrays

Dynamically Allocated 2D Array

A two-dimensional array is an array of arrays (e.g. rows).

To dynamically allocate a 2D array, a double pointer is used.

- A pointer to a pointer.

```
<type_id> **myMatrix;
```

Example: For a 2D integer array:

```
int **intMatrix;
```

Dynamic Arrays

Dynamically Allocated 2D Array

Memory allocation the 2D array with **`rows`** rows and **`cols`** columns:

- Allocate of an array of pointers:
  (these will be used to point to the sub-arrays – i.e. the rows)

```
int **intMatrix = new int* [rows];
```

  This creates space for **`rows`** number of Addresses (each element is an **`int*`**).

- Then allocate the space for the 1D arrays (i.e. the rows) themselves, each with a size of **`cols`**.

```
for (int i=0; i<rows; i++)
  intMatrix[i] = new int [cols];
```

Dynamic Arrays

Dynamically Allocated 2D Array

The elements of the 2D array can be accessed by the notation:

```
intMatrix[i][j];
```

Note: The entire array is not (guaranteed to be) in contiguous space.
Unlike a statically allocated 2D array!

- Each row sub-array is contiguous in memory.
- But the sequence of rows is not.

`intMatrix[i][j+1]` is after `intMatrix[i][j]` in memory.

`intMatrix[i+1][0]` may be before or after `intMatrix[i][0]` in memory.

Dynamically Allocated 2D Array

By-Example:

```
int rows, cols;
int **intMatrix;

cin >> rows >> cols;
```

a) `intMatrix = new int* [rows];`

b)
```
for (int i=0; i<rows; i++)
  intMatrix[i] = new int [cols];
```

Allocation:
a) Rows array of pointers first.
b) Each row sub-array then.

c)
```
for (int i=0; i<rows; i++)
  delete [] intMatrix[i];
```

d) `delete [] intMatrix;`

Deallocation:
c) Each row sub-array first.
d) Rows array of pointers last.

Dynamic Arrays

Dynamically Allocated 2D Array

By-Example (the proper way):

```
try{
  intMatrix = new int* [rows];
  for (int i=0; i<rows; ++i)
    intMatrix[i] = NULL;
  for (int i=0; i<rows; ++i){
    try
    { intMatrix[i] = new int [cols]; }
    catch(std::bad_alloc& ex){
      for (; i>=0; --i)
        delete [] intMatrix[i];
      throw;
    }
  }
}
catch(std::bad_alloc& ex)
{  delete [] intMatrix; }
…
```

Initialize: Set to **NULL**
(exception handling might need so).

Deallocate all previously allocated row sub-arrays on exception (allocation failure for one)

Deallocate rows array of pointers on exception (allocation failure).

Memory Handling

Memory Leaks

When creating objects with Dynamic Memory allocation, access is provided through the **`prvalue`** of the Expression **`new`** (**`[]`**).

- I.e. the pointer (of requested type) to the newly allocated memory.
- To keep track and access in the future, this is stored to a pointer variable.

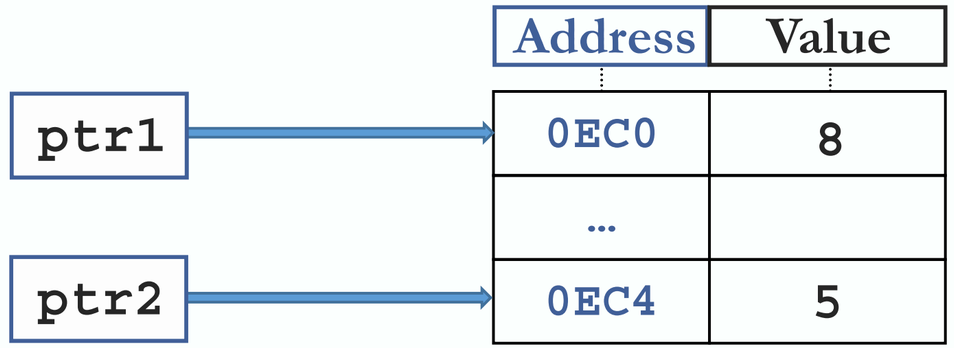
Reassigning that pointer, letting it go out of scope without maintaining its value, etc. without first **`delete`**ing the memory it used to pointed to, is called a Memory Leak.

- Unless explicitly instructed to be deallocated (by a **`delete`** (**`[]`**) Expression), that memory part will remain reserved.
- Memory leaks result in loss of available memory space.

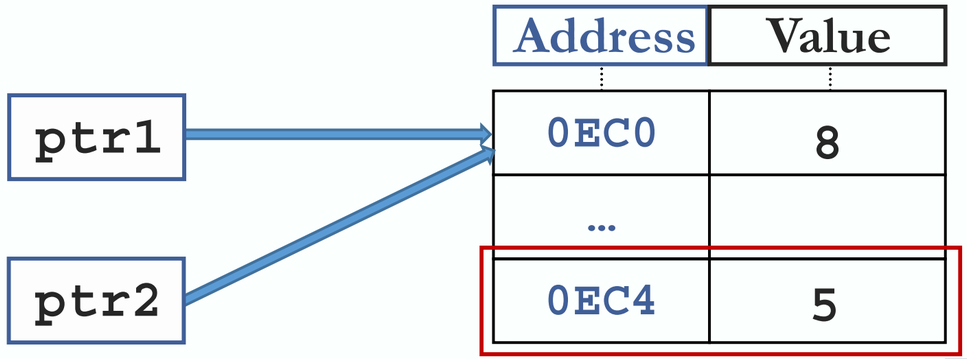
Memory Leak

A pointer that points to Dynamic Memory that has previously been deallocated.

```
int *ptr1 = new int;
int *ptr2 = new int;
*ptr1 = 8;
*ptr2 = 5;
```




```
ptr2 = ptr1;
```



Memory Handling

Inaccessible Object

An Anonymous Object that was created by Expression `new ( [] )` and which has been left with no pointer to it by the programmer

- A logical error.
- A common cause of Memory Leaks.

Memory Handling

Dangling Pointer

A pointer that points to Dynamic Memory that has previously been deallocated.

- Allocation and deallocation properly implemented, but pointer never set to `NULL` to satisfy convention.
- Could also happen with uninitialized pointer.

Note: Dereferencing a dangling pointer is undefined behavior per the C++ standard:

An **`lvalue`** of a non-function, non-array type T can be converted to an **`rvalue`** … If the object to which the **`lvalue`** refers is not an object of type T and is not an object of a type derived from T, or if the object is uninitialized, a program that necessitates this conversion has undefined behavior.

Memory Handling

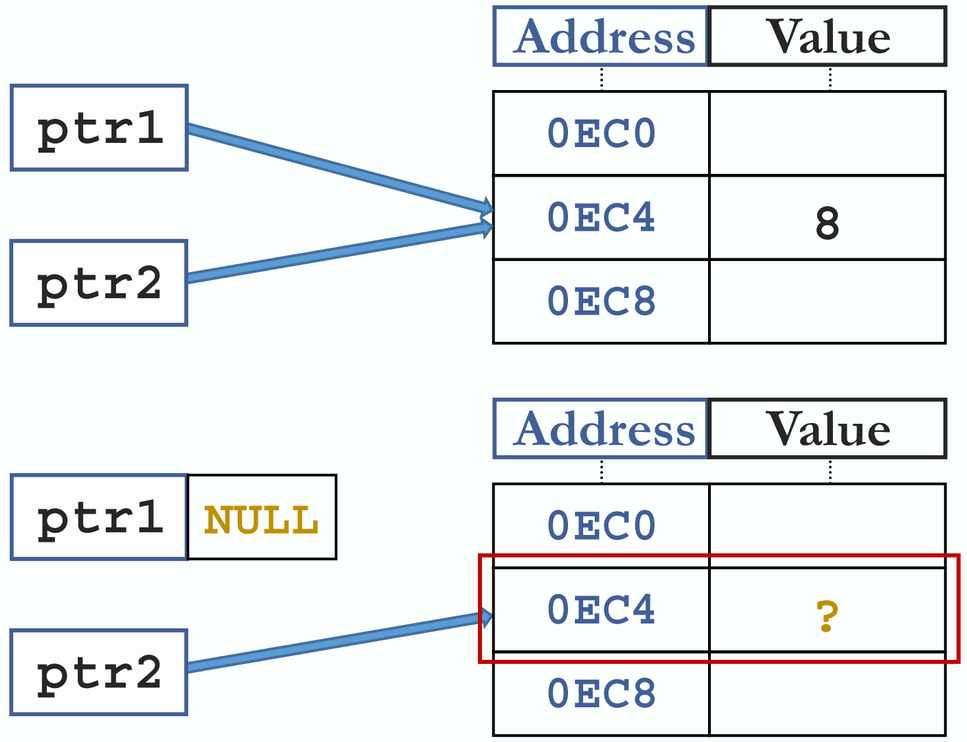
Dangling Pointer

A pointer that points to Dynamic Memory that has previously been deallocated.

```
int *ptr1 = new int;
int *ptr2;

*ptr1 = 8;
ptr2 = ptr1;


delete ptr1;
ptr1 = NULL;
```



Memory Handling

Dynamically Allocated 2D Array (By-Demonstration)

Type:

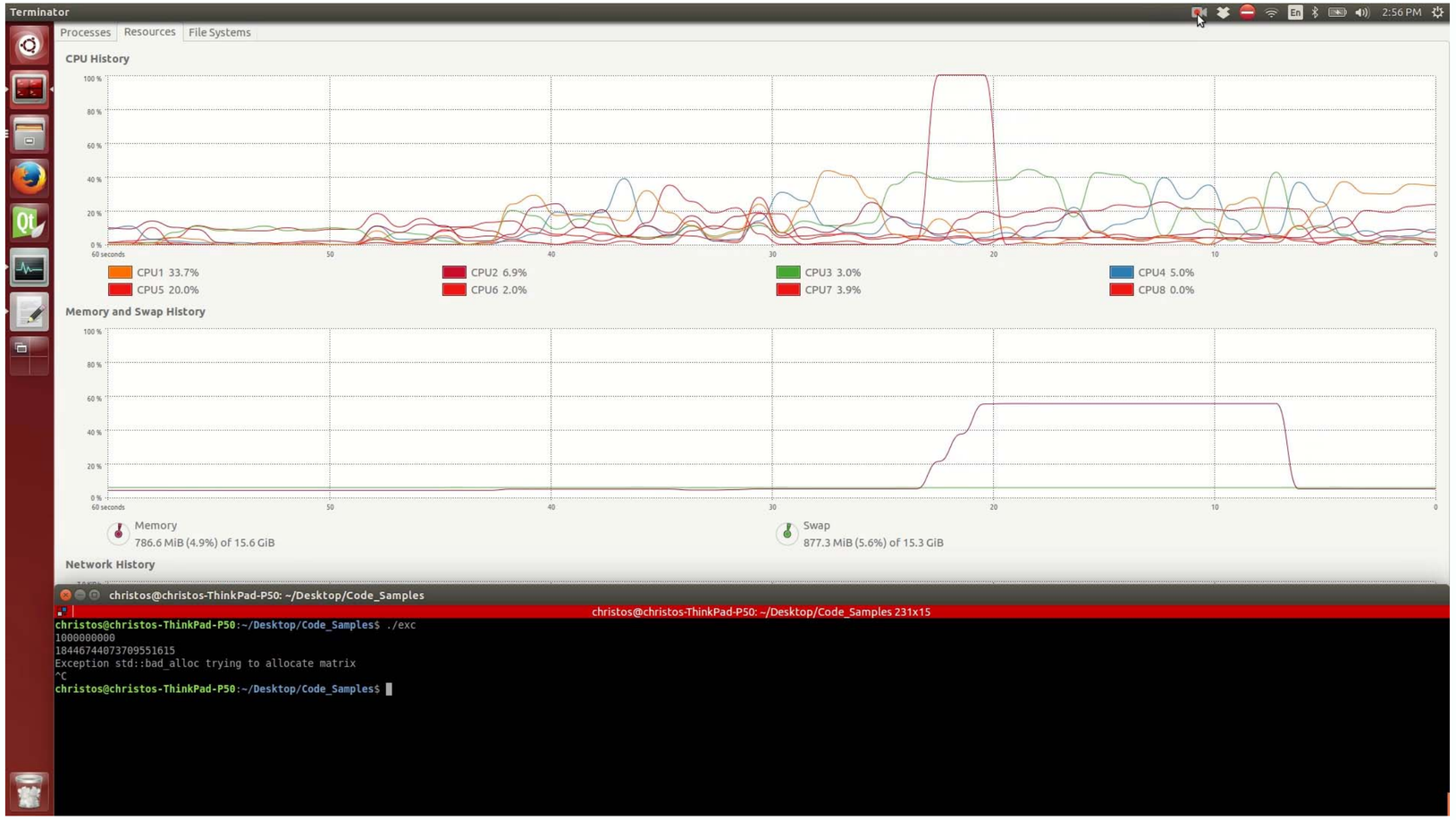
`int`

rows:

1,000,000,000

cols:

18,446,744,073,709,551,615



Memory Handling

Dynamically Allocated 2D Array (By-Demonstration)

Type:

`int`

rows:

10 * 1,000,000,000

cols:

18,446,744,073,709,551,615

CS-202

Time for Questions !