Dynamic memory, dynamic arrays, memory leaks, classes with pointer members, constructors and destructors

Comp Sci 1575 Data Structures

OOPs...

From back when Object wriented Programming and data hiding were new:

"In C++ it's harder to shoot yourself in the foot, but when you do, you blow off your whole leg." Bjarne Stroustrup (the original author of C++).

Outline

Dynamic memory
Dynamic variables
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delete
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delete[ ]
Multidimensional arrays
Problems
Memory leaks
Invalid and dangling pointers
Dynamic user-defined types
this
Structs and classes with dynamic memory
Constructors and destructors
Requirements of dynamic members

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Dynamic variables

- **Operator:** new
- **General syntax:** pointer = new type
- **Example:**
  int *p1;
  p1 = new int;
  *p1 = 42;
- **Example 2:**
  double *p2 = new double;
  *p2 = 42

Name of variable	Storage address	Value
	0x7ffcb158c140	
	0x7ffcb158c144	42
	0x7ffcb158c148	
p1	0x7ffcb158c14c	0x7ffcb158c144
	0x7ffcb158c150	

Address and value pointed to by p1 have no named alias

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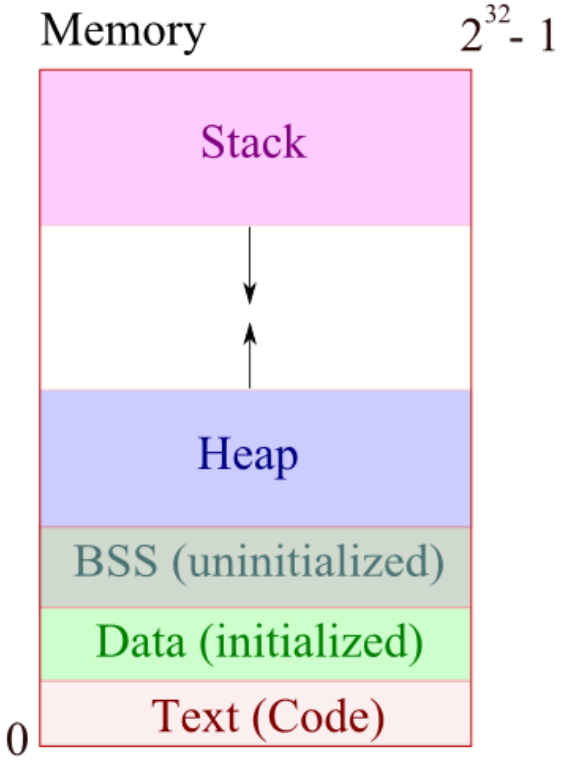
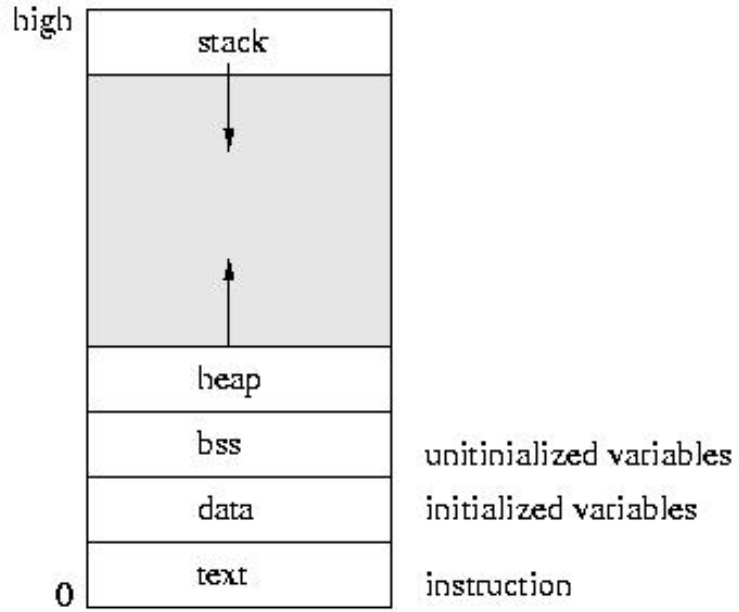
Dynamic memory

- **Stack:** Declared variables will reside in stack memory
- **Heap:** Can be used to allocate memory dynamically when program runs
- When finished running, stack memory is automatically de-allocated, but the data referenced by new pointers on the heap is not
- Operator "delete" should be used to de-allocate the data pointed to
- **delete p;** de-allocateds item being pointed to on the heap
- What is de-allocation? It is not actually deleting, but marking the memory as available for use

Memory organization





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Delete example


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

int main(){
   double *pvalue  = NULL; // Why?
   pvalue  = new double; // Request memory
   *pvalue = 29494.99; // ??

   cout << *pvalue << endl; // ??

   delete pvalue; // free up the memory.

   return 0;
}
```

- What happens if your program repeats without delete?
- What is it called when you forget delete?
  Microsoft Windows...

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Dynamic array operator: new [ ]

Dynamic array creation: pointer = new type[numElements]

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

int main(){
  int userDefinedSize;
  int *pUserSizedArray;

  cout << ``How large of an array?" << endl;
  cin >> userDefinedSize;

  pUserSizedArray = new int[userDefinedSize];
  pUserSizedArray[1] = 23;
  cout << *(pUserSizedArray+1) << endl; // 23
  return 0;
}
```

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Deleting array values


```
int *pArray;
pArray = new int[500];

// assign and manipulate here...

delete pArray;
```

What will happen if you execute this many times?

Dynamic array operator: delete [ ]

To avoid the memory leak caused by the previous slide's mistake, use:

```
int *pArray = NULL;
pArray = new int[500];

// assign and manipulate here...

delete[ ] pArray;
```

Arrays created with new require: "delete[ ] pArray;" or it will only delete the first element, leaving the rest as garbage

Kahoot

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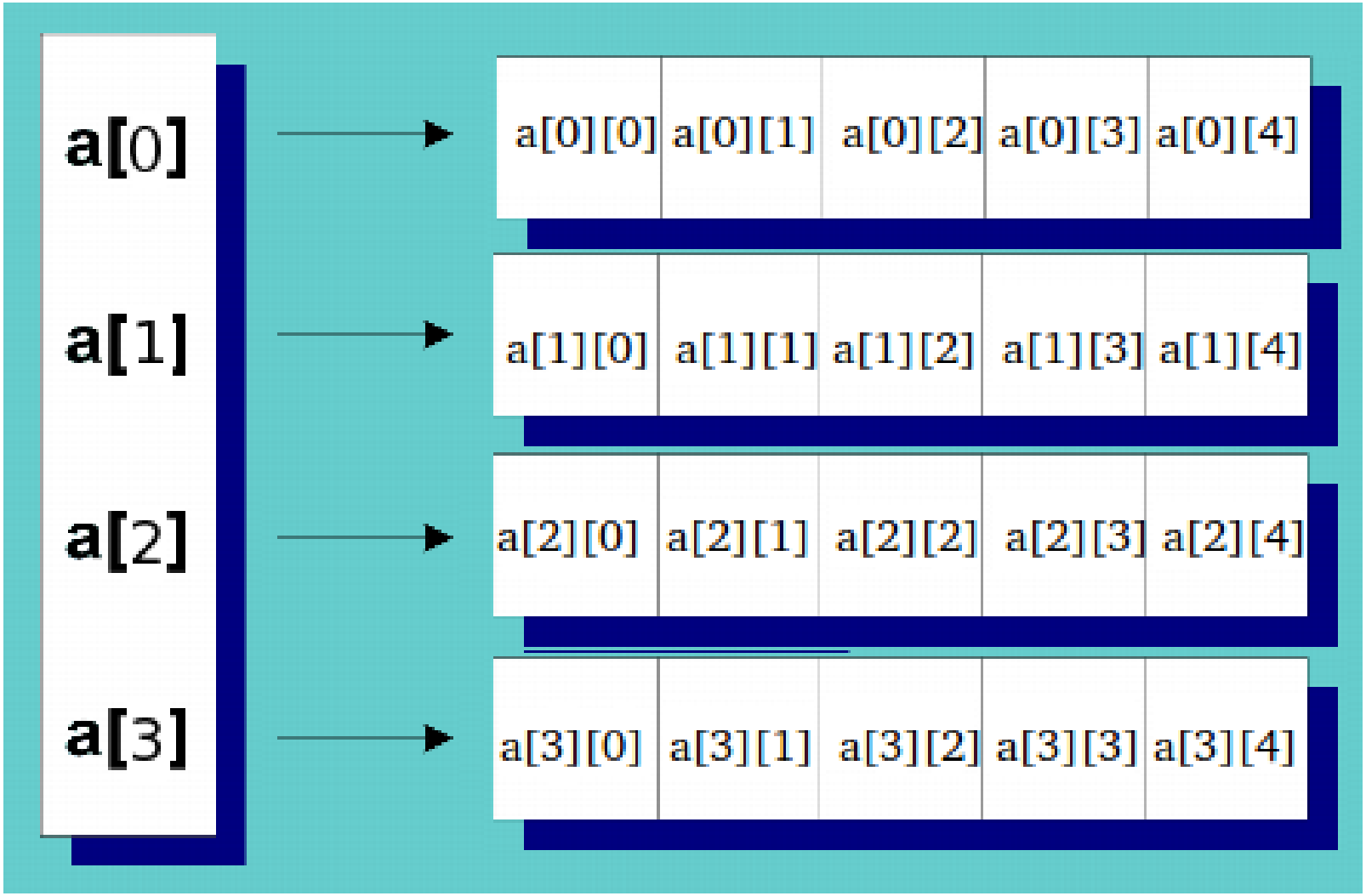
Dynamic multidimensional arrays


```
cin >> numRows;
cin >> numCols;

// Allocate memory for rows (left column next)
double **a  = new double *[numRows];

// Allocate memory for columns
for(int i = 0; i < numRows; i++) {
  a[i] = new double[numCols];
}

a[1][2] = 32; // array[row][col]

// deallocate
for(int i = 0; i < numRows; i++) {
  delete[] a[i];
}
delete[] a;
a = nullptr;
```

Array creation and access

double **a = new double *[numRows]; // left column



a[i]=new double[numCols]; // each right row

Multidimensional array templated


```
template <typename T>
T ** AllocateDynamicArray(int nRows, int nCols){
  T **dynamicArray;
  dynamicArray = new T *[nRows];
  for(int i = 0 ; i < nRows ; i++){
    dynamicArray[i] = new T [nCols];
  }
  return dynamicArray;
}
template <typename T>
void FreeDynamicArray(T **dArray, nRows){
  for(int i = 0; i < numRows; i++){delete[] dArray[i];}
  delete[] dArray;
}
int main(){
  int **my2dArr = AllocateDynamicArray<int>(4,4);
  my2dArr[2][2] = 8;
  FreeDynamicArray<int>(my2dArr, 4);
  return 0;
}
```

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Memory leaks

- Memory leaks occur when new memory is allocated dynamically and never deallocated.
- In C++, new memory is usually allocated by the new and new [ ] operators and deallocated by the delete or the delete [ ] operators.
- One of the most common mistakes leading to memory leaks is applying the wrong delete operator.
- Deallocating multi-dimensional arrays can also lead to problems

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Invalid and dangling pointers


```
int *p; // uninitialized pointer

p = new int;
*p = 5;
delete p;
int *q = p; // ?? What if delete p; was last?

int *pArr;
int myarray[10];
pArr = myarray + 20; // ??

int *dynArr;
dynArr = new int[10];
delete dynArr; // correct?
cout << *dynArr << endl; // ??
cout << *(dynArr + 2) << endl; // ??
```

Set dangling pointers to nullptr

Dangling pointer should be assigned to nullprt (old: NULL or 0)

```
int *q = nullptr; // C++ 11; recommended
int *p = 0;
int *r = NULL;

if(q)      // succeeds if p is not null
if(q)     // succeeds if p is null
```

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Dynamic user-defined types


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

class Box{
  private:
    int w, h, d;
  public:
    void setDim(int x, int y, int z) {w=x; h=y; d=z;}
    int volume(){return w*h*d;}
};

int main(){
  Box *myBox = new Box;
  myBox->setDim(4, 5, 2);
  cout << myBox->volume(); // 40
  delete myBox;
  Box *myBoxArray = new Box[4];
  myBoxArray[2].setDim(4, 1, 2);
  delete[ ] myBoxArray; // Delete array
  return 0;
}
```

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Review: objects and this

- Inside every non-static member function, the variable: **T *const this** holds the address of the class object from which the member function was invoked
- **this** represents a pointer to the object whose member function is being executed
- **this** is a hidden parameter accessible in a class's function to refer to the object of which the function is a member:

How many variables are in the two functions below?

```
class Rectangle{
    int width, height;
  public:
    int getArea(){return width*height;} // #param?
    void printWidth(){
      cout << this->width << endl;
      cout << (*this).width << endl;
      cout << width << endl;
    }
}
```

More useful application of this


```
class Rectangle
{
  private:
    int width, height;
  public:
    int getArea(){return width*height;}
    int compare(Rectangle rect){ // #param?
      return this->getArea() > rect.getArea();
    }
}

//Assignment operator= overload
Rectangle & Rectangle::operator=(const Rectangle &rhs)
{
  width = rhs.width;
  height = rhs.height;

  // Allows chaining of operator= when called.
  return *this;
}
```

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Constructors and destructors

The compiler provides each Class has a default constructor, so we can declare via:

```
MyClass classObject;
```

until defining our own parameterized constructor, then we need a new default constructor (or defaulted values)

Further, C++ automatically generates some member functions methods for every class.

1. **copy constructor** used for definition with initialization:
   MyClass B = A;
   MyClass B(A);
   Also called when passing or returning by value, rather than by reference with &
2. **operator=** used for assignment between existing objects:
   A = B = C; (can be chained with multiple assignment)
3. **destructor** called automatically when a class goes out of scope, or is explicitly deallocated with delete

Constructors and destructors: main


```
int main() {
  // parameterized constructor
  Rectangle rect(3, 4, 253);

  // default constructor
  Rectangle recta;

  // copy constructor
  Rectangle rectb(rect);
  Rectangle rectc = rect;

  // operator= assignment (not constructor)
  recta = rect;

  return 0;
}
```

Constructors and destructors: declarations


```
class Rectangle{
    int width, height, *pfill;

  public:
    // parameterized constructor
    Rectangle(int, int, int);

    // new default constructor
    Rectangle();

    // copy constructor
    Rectangle(const Rectangle &);

     // assignment (overload operator, not constructor)
    const Rectangle & operator=(const Rectangle &);

    // destructor uses ~ in front of class name
    ~Rectangle();

    int printFill() {return *pFill;}
};
```

Constructors and destructors: definitions


```
Rectangle::Rectangle(int a, int b, int fillVal){
  width = a;  height = b;
  pFill = new int(fillVal);
}

Rectangle::Rectangle(){
  width = 5;  height = 5;
  pFill = new int(255);
}

Rectangle::Rectangle(const Rectangle &source){
  width = source.width;
  height = source.height;
  // pFill = source.pFill; // shallow copy pointer itself
  pFill = new int(*(source.pFill)); // deep copy contents
}

const Rectangle & Rectangle::operator=(const Rectangle &rhs){
  if (this != &rhs){
    width = rhs.width;
    height = rhs.height;
    // pFill = rhs.pFill; // shallow copy pointer itself
    *pFill = *(rhs.pFill); // deep copy contents
    return *this;
  } // what if pFill was an array?  delete[] old first for size mismatch?
}

Rectangle::~Rectangle(){
  delete pFill;
}
```

Watch out for shallow and deep copy!

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Class with dynamic members

If a your user-defined class with dynamically allocated members is to function in all typical ways, you likely need to to re-write its:

1. Default constructor
2. Parameterized constructor
3. Copy constructor
4. Assignment operator=
5. Default destructor

Guidelines for classes with dynamic memory

- Initialize pointers in the constructor! If not allocating space right away, best to initialize to **nullptr** until ready for use.
- Use **new** inside class member functions to allocate space
- Use **delete** to clean up dynamically allocated space whenever finished using it. Do so in the destructor, which is the last function that runs for an object
- Isolate memory management tasks from the functionality/algorithmic tasks wherever possible: Write a set of member functions just for dealing with memory management issues – like creation of space, deallocation, resizing, etc. Your algorithmic functions can call the memory-handling functions, when needed