CS601: Software Development for Scientific Computing

Autumn 2021

Week4:

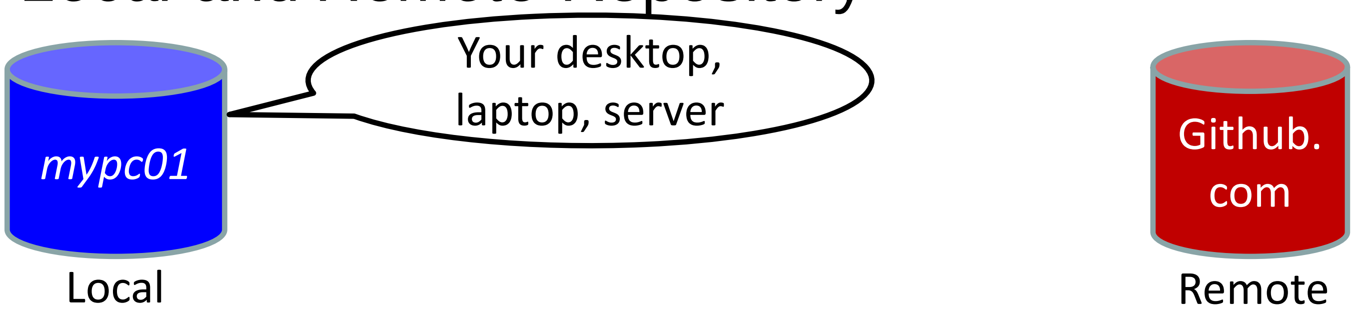
- Tools - Version Control System (Git and GitHub), Build tool (GNU make)
- Intermediate C++ (OO concepts)

Last Week..

- Intermediate C++
  - Preprocessor directives, streams, and namespaces
- Structured Grids
  - PDEs and categories, the mathematical model, approximation, algebraic equations. Case study: 1D heat equation.
  - Program Representation???

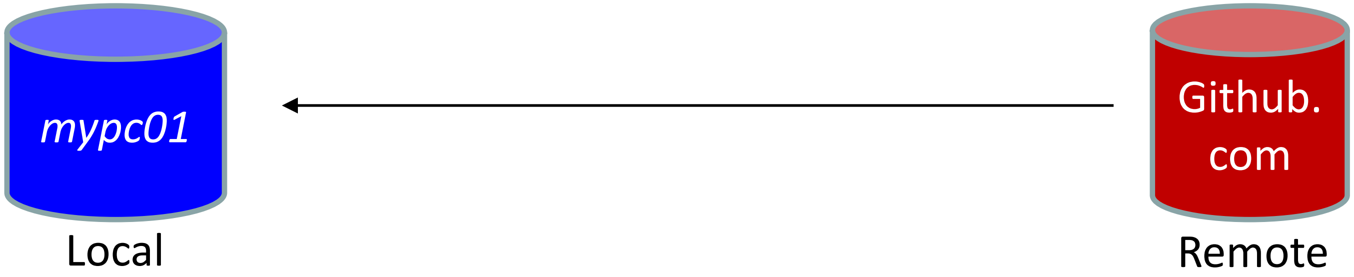
Git

- Example of a Version Control System
  - Manage versions of your code – access to different versions when needed
  - Lets you collaborate
- ‘Repository’ – term used to represent storage
  - *Local* and *Remote* Repository



Git – Creating Repositories

- Two methods:
    1. ‘Clone’ / Download an *existing* repository from GitHub



Git – Creating Repositories

- Two methods:

  2. Create local repository first and then make it available on GitHub

Method 1: `git clone` for creating local working copy

- 'Clone' / Download an existing repository from GitHub – get your own copy of source code
  - `git clone` (when a remote repository on GitHub.com exists)

```
nikhilh@ndhpc01:~$ git clone git@github.com:IITDhCSE/dem0.git
Cloning into 'dem0'...
remote: Enumerating objects: 3, done.
remote: Counting objects: 100% (3/3), done.
remote: Compressing objects: 100% (2/2), done.
remote: Total 3 (delta 0), reused 0 (delta 0), pack-reused 0
Receiving objects: 100% (3/3), done.
nikhilh@ndhpc01:~$
```

Method 2: `git init` for initializing local repository

- Create local repository first and then make it available on GitHub

  1. `git init`

  converts a directory to Git local repo

```
nikhilh@ndhpc01:~$ mkdir dem0
nikhilh@ndhpc01:~$ cd dem0/
nikhilh@ndhpc01:~/dem0$ git init
Initialized empty Git repository in /home/nikhilh/dem0/.git/
nikhilh@ndhpc01:~/dem0$ ls -a
.  ..  .git
```

`git` add for staging files

2. `git add`

‘stage’ a file i.e. prepare for saving the file on local repository

```
nikhilh@ndhpc01:~$ ls -a dem0/
.   ..   README
nikhilh@ndhpc01:~$ cd dem0/
nikhilh@ndhpc01:~/dem0$ git init
Initialized empty Git repository in /home/nikhilh/dem0/.git/
nikhilh@ndhpc01:~/dem0$ git add README
```

Note that creating a file, say, README2 in dem0 directory does not *automatically* make it part of the local repository

`git commit` for saving changes in local repository

3. `git commit`

'commit' changes i.e. save all the changes (adding a new file in this example) in the local repository

```
nikhilh@ndhpc01:~/dem0$ git commit -m "Saving the README file in local repo."
[master (root-commit) 99d0a63] Saving the README file in local repo.
 1 file changed, 1 insertion(+)
 create mode 100644 README
```

How to save changes done when you must overwrite an existing file?

Method 2 only: `git branch` for branch management

4. `git branch –M master`

rename the current as ‘`master`’ (-M for force rename even if a branch by that name already exists)

```
nikhilh@ndhpc01:~/dem0$ git branch -M master
```

Method 2 only: `git remote add`

5. `git remote add origin git@github.com:IITDhCSE/dem0.git` – prepare the local repository to be managed as a tracked repository

```
nikhilh@ndhpc01:~/dem0$ git remote add origin git@github.com:IITDhCSE/dem0.git
```

command to manage remote repo.

associates a name 'origin' with the remote repo's URL

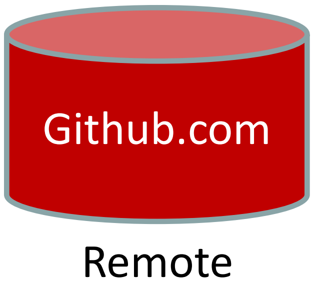
The URL of the repository on GitHub.com.

- This URL can be that of any other user's or server's address.
- uses SSH protocol
  - HTTP protocol is an alternative. Looks like: https://github.com/IITDhCSE/dem0.git

Method 2 only: GitHub Repository Creation

5.a) Create an empty repository on GitHub.com

(name must be same as the one mentioned previously – `dem0`)



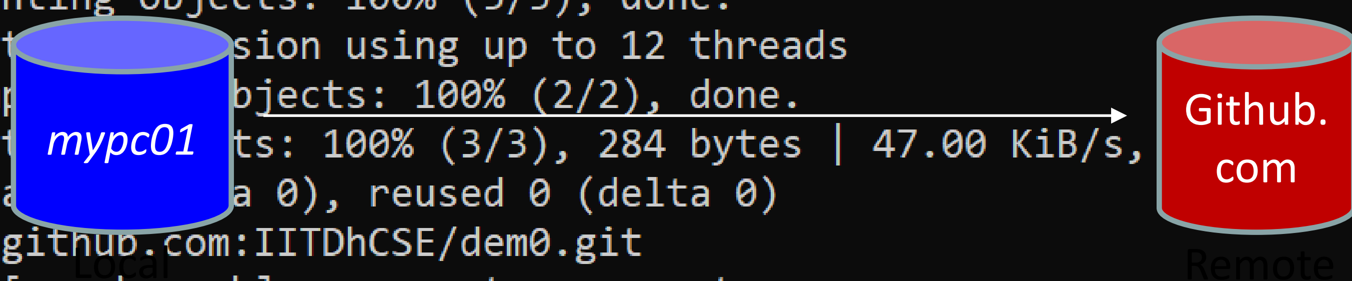
`git push` for saving changes in remote repo

`6. git push –u origin master`

‘push’ or save all the changes done to the ‘master’ branch in local repo to remote repo. *(necessary for guarding against deletes to local repository)*

`syntax: git push <remotename> <branchname>`

```
nikhilh@ndhpc01:~/dem0$ git push -u origin master
Enumerating objects: 3, done.
Counting objects: 100% (3/3), done.
Delt[illegible]sion using up to 12 threads
Comp[illegible]bjects: 100% (2/2), done.
Writ[illegible]ts: 100% (3/3), 284 bytes | 47.00 KiB/s,
Tota[illegible]a 0), reused 0 (delta 0)
To github.com:IITDhCSE/dem0.git
 * [new branch]      master -> master
Branch 'master' set up to track remote branch 'master' from 'origin'.
```



what does the –u option do?

Git – Releasing Code

- Tagging
  1. Check for unsaved changes in local repository.

```
nikhilh@ndhpc01:~/dem0$ git status .
On branch master
Your branch is up to date with 'origin/master'.

nothing to commit, working tree clean
```

  1. Create a tag and associate a comment with that tag

```
nikhilh@ndhpc01:~/dem0$ git tag -a VERSION1 -m "Release version 1 implements feature XYZ"
```

  2. Save tags in remote repository

```
nikhilh@ndhpc01:~/dem0$ git push --tags
Enumerating objects: 1, done.
Counting objects: 100% (1/1), done.
Writing objects: 100% (1/1), 191 bytes | 95.00 KiB/s, done.
Total 1 (delta 0), reused 0 (delta 0)
To github.com:IITDhCSE/dem0.git
 * [new tag]         VERSION1 -> VERSION1
```

Git – Recap..

```
1. git clone (creating a local working copy)
2. git add (staging the modified local copy)
3. git commit (saving local working copy)
4. git push (saving to remote repository)
5. git tag (Naming the release with a label)
6. git push --tags (saving the label to remote)
```

- Note that commands 2, 3, and 4 are common to Method 1 and Method 2.
- Please read https://git-scm.com/book/en/v2 for details

For git download on Windows: https://git-scm.com/download/win

`Makefile` or `makefile`

- Is a file, contains instructions for the `make` program to generate a target (executable).
- Generating a target involves:
  1. Preprocessing (e.g. strips comments, conditional compilation etc.)
  2. Compiling (.c -> .s files, .s -> .o files)
  3. Linking (e.g. making printf available)
- A `Makefile` typically contains directives on how to do steps 1, 2, and 3.

`Makefile` - Format

1. Contains series of ‘rules’-

```
target: dependencies
[TAB]  system command(s)
```

Note that it is important that there be a TAB character before the system command (not spaces).

Example: “Dependencies or Prerequisite files” “Recipe”

```
testgen: testgen.cpp
        g++ testgen.cpp –o testgen
```

“target file name”

2. And Macro/Variable definitions -

```
CFLAGS = -std=c++11 -g -Wall -Wshadow --pedantic -Wvla –Werror

GCC = g++
```

Makefile - Usage

– The ‘make’ command (Assumes that a file by name ‘makefile’ or ‘Makefile’. exists)

```
n2021/slides/week4_codesamples$ cat makefile
vectorprod: vectorprod.cpp scprod.cpp scprod.h
        g++ vectorprod.cpp scprod.cpp -o vectorprod
```

- Run the ‘make’ command

```
n2021/slides/week4_codesamples$ make
g++ vectorprod.cpp scprod.cpp -o vectorprod
```

`Makefile` - Benefits

- Systematic dependency tracking and building for projects
  - Minimal rebuilding of project
  - Rule adding is ‘declarative’ in nature (i.e. more intuitive to read *caveat: make also lets you write equivalent rules that are very concise and non-intuitive.*)
- To know more, please read: https://www.gnu.org/software/make/manual/html_node/index.html#Top

`make` - Demo

- Minimal build
  - What if only `scprod.cpp` changes?
- Special targets (`.phony`)
  - E.g. explicit request to `clean` executes the associated recipe. What if there is a file named `clean`?
- Organizing into folders
  - Use of variables (built-in (`CXX, CFLAGS`) and automatic (`$@, $^, $<`))

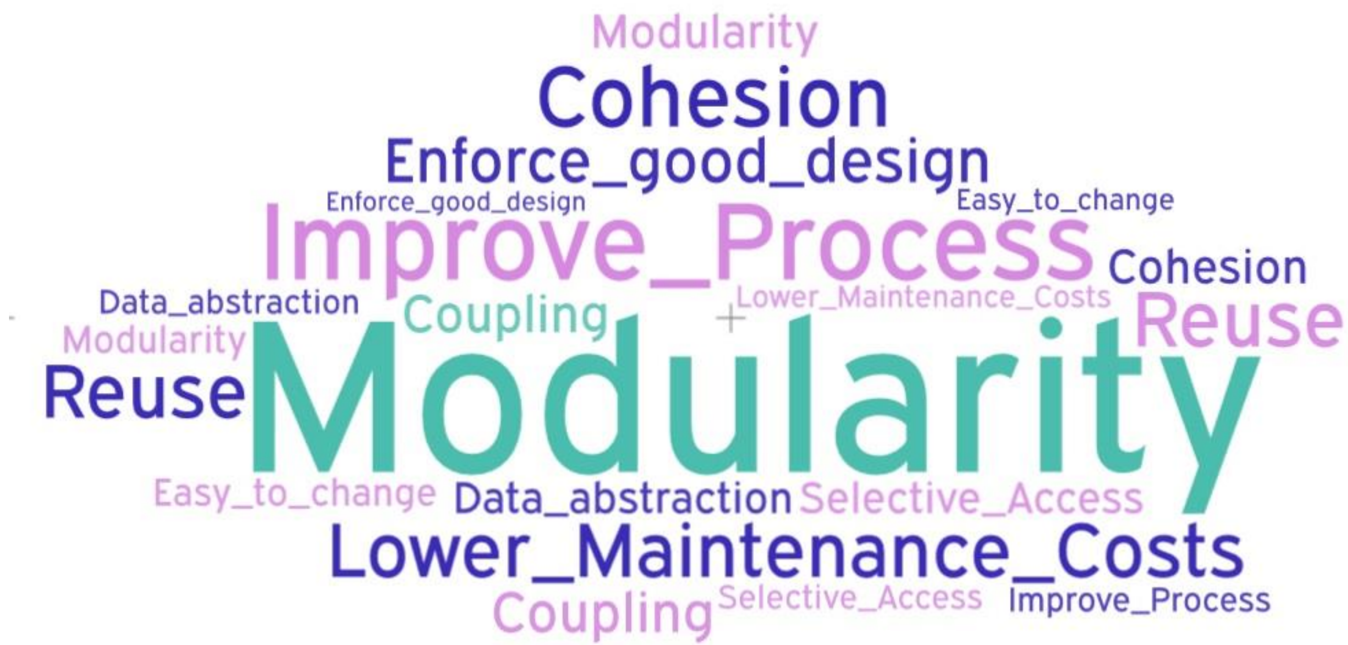
refer to week4_codesamples

Object Orientation

- What does it mean to think in terms of object orientation?
    1. Give precedence to data over functions *(think: objects, attributes, methods)*
    2. Hide information under well-defined and stable interfaces *(think: encapsulation)*
    3. Enable incremental refinement and (re)use *(think: inheritance and polymorphism)*

Object Orientation: Why?

- Improve costs
- Improve development process and
- Enforce good design



Objects and Instances

- Object is a computational unit
  - Has a state and operations that operate on the state.
  - The state consists of a collection of *instance* variables or attributes.
  - Send a “message” to an object to invoke/execute an operation (*message-passing metaphor* in traditional OO thinking)
- An instance is a *specific version* of the object

Classes

- Template or blueprint for creating objects. Defines the shape of objects
  - Has *features* = attributes + operations
  - New objects created are *instances of the class*
  - E.g.

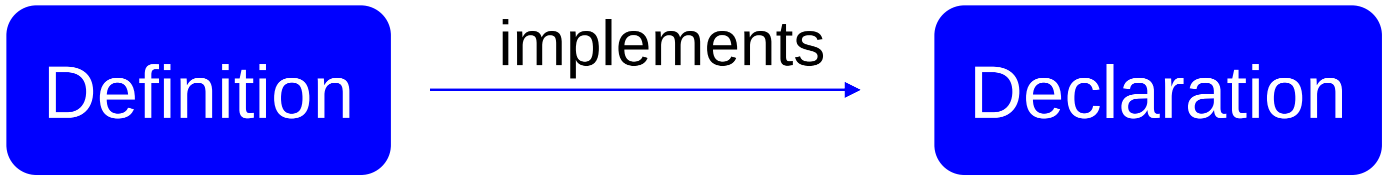
Class - lollypop mould

Objects - lollypops

Classes continued..

- Operations defined in a class are a prescription or service provided by the class to access the state of an object
- Why do we need classes?
  - To define user-defined types / invent new types and extend the language
  - Built-in or Primitive types of a language – int, char, float, string, bool etc. have implicitly defined operations:
    - E.g. cannot execute a *shift* operator on a negative integer
  - Composite types *(read: classes)* have operations that are implicit as well as those that are explicitly defined.

Classes declaration vs. definition



Implementation of functions in a .cpp file

listing of functions and attributes in a .h file

Classes: declaration

- *file* `Fruit.h`

```
#include<string>

class Fruit {
      string commonName;

public:
      Fruit(string name);
      string GetName();
};
```

Class Name

Attribute

Constructor

Method

Trivia: *Python doesn't support data hiding*

Classes: access control

- `Public / Private / Protected`

```
class Fruit {
        string commonName; // private by default

public:
        Fruit(string name);
        string GetName();
};
```

- `Private:` methods-only (self) access
- `Public:` all access
- `Protected:` methods (self and *sub-class*) access

Classes: definition

- *file* `Fruit.cpp`

```
#include<Fruit.h>

//constructor definition: initialize all attributes
Fruit::Fruit(string name) {
      commonName = name;
}
//constructor definition can also be written as:
Fruit::Fruit(string name): commonName(name) { }

string Fruit::GetName() {
      return commonName;
}
```

Objects: creation and usage

- *file* `Fruit.cpp`

```
#include<Fruit.h>

Fruit::Fruit(string name): commonName(name) { }
string Fruit::GetName() { return commonName; }

int main() {
      Fruit obj1("Mango"); //calls constructor
      //following line prints "Mango"
      cout<<obj1.GetName()<<endl; //calls GetName method
}
```

- *How is `obj1` destroyed?* – by calling *destructor*

Objects: Destructor

```
Fruit::~Fruit(){ } //default destructor implicitly
defined

int main() {
      Fruit obj1("Mango"); //statically allocated
object
      Fruit* obj2 = new Fruit("Apple"); //dynamic
object
      delete obj2; //calls obj2->~Fruit();
      //calls obj1.~Fruit()
}
```

- Statically allocated objects: Automatic
- Dynamically allocated objects: Explicit

Post-class Exercise - Encapsulation

- The earlier quiz at the beginning of the class was a Pre-class Exercise.
- Re-attempt the same Quiz.

Inheritance

- Create a brand-new class based on existing class

```
file Mango.h
#include<Fruit.h>
class Mango : public Fruit {
        string variety;
public:
        Mango(string name, string var) : Fruit(name),
variety(var){}
};
```

calling base-class constructor

- Fruit is a base type, Mango is a sub-type
- Sub-type inherits attributes and methods of its base type

Inheritance

```
file Fruit.h
#include<string>

class Fruit {
        string commonName;
public:
        Fruit(string name);
        string GetName();
};
```

```
file Mango.h
#include<Fruit.h>
class Mango : public Fruit {
        string variety;
public:
        Mango(string name, string var) :
Fruit(name), variety(var){}
};
```

```
file Fruit.cpp
...
int main() {
        Mango item1("Mango", "Alphonso"); //create sub-class object
        cout<<item1.GetName()<<endl; //only commonName is printed!
                                     (variety is not included).
                                     Refer slide 41.
}
```

commonName variety

Method overriding

- Customizing methods of derived / sub- class

file Fruit.h

```
#include<string>

class Fruit {
        string
commonName;
public:
        Fruit(string
name);
        string GetName();
};
```

file Mango.h

```
#include<Fruit.h>
class Mango : public Fruit {
        string variety;
public:
        Mango(string name, string var) :
Fruit(name), variety(var){}
    string GetName();
};
```

method with the same
name as in base class

Method overriding

file Fruit.h

```
#include<string>

class Fruit {
protected:
        string commonName;
public:
        Fruit(string name);
        string GetName();
};
```

file Mango.h

```
#include<Fruit.h>
class Mango : public Fruit {
        string variety;
public:
        Mango(string name, string var) :
Fruit(name), variety(var){}
        string GetName() {      return
commonName + "_" + variety; }
};
```

accessing base class attribute

Method overriding

file Fruit.h
```
#include<string>

class Fruit {
protected:
	string commonName;
public:
	Fruit(string name);
	string GetName();
};
```

file Mango.h
```
#include<Fruit.h>
class Mango : public Fruit {
	string variety;
public:
	Mango(string name, string var) : 
Fruit(name), variety(var){}
	string GetName() {	return 
commonName + “_” + variety; }
};
```

file Fruit.cpp
```
...
int main() {
	Mango item1(“Mango”, “Alphonso”); //create sub-class object
	cout<<item1.GetName()<<endl;  //prints “Mango_Alphonso”
}
```

Polymorphism

- Ability of one type to appear and be used as another type
- E.g. type `Mango` used as type `Fruit`

```
file Fruit.cpp
...
int main() {
//create a sub-class object and initialize it to a pointer of
//type base-class
       Fruit* item1 = new Mango("Mango", "Alphonso");
       cout<<item1->GetName()<<endl;  //prints "Mango" !
       ...
}
```

Trivia: Java treats all functions as virtual

Polymorphism

- Declare overridden functions as `virtual` in base class
- Invoke those functions using pointers

file Fruit.h

```
#include<string>

class Fruit {
protected:
        string commonName;
public:
        Fruit(string name);
        virtual string GetName();
};
```

file Mango.h

```
#include<Fruit.h>
class Mango : public Fruit {
        string variety;
public:
        Mango(string name, string
var) : Fruit(name), variety(var){}
string GetName() {    return
commonName + "_" + variety; }
};
```

```
Fruit* item1 = new Mango("Mango", "Alphonso");
cout<<item1->GetName()<<endl; //prints "Mango_Alphonso"
```

Polymorphism and Destructors

- declare base class destructors as `virtual` if using base class in a polymorphic way

```
file Fruit.h
#include<string>

class Fruit {
protected:
        string commonName;
public:
        Fruit(string name);
        virtual string GetName();
        virtual ~Fruit();
};
```

```
...
Fruit* item1 = new Mango(“Mango”,
“Alphonso”);
...
delete item1; //calls Mango::~Mango()
first and then Fruit::~Fruit()
```

Post-class Exercise - Inheritence

- The earlier quiz at the beginning of the class was a Pre-class Exercise.
- Re-attempt the same Quiz.

Recap-Classes

Header file (`myvec.h`)

```
#ifndef MYVEC_H
#define MYVEC_H



#endif
```

Header file (`myvec.h`)

- Declare the class

Class *declaration* opening scope

Keyword

Class name

Class *declaration* closing scope

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{



};
#endif
```

Header file (`myvec.h`)

Declaring attributes

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;




};
#endif
```

Header file (`myvec.h`)

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;
public:
        MyVec(int len); //constructor
        ~MyVec(); //destructor


};
#endif
```

Specifying access control

Declaring operations

Defining the class (`myvec.h` and `myvec.cpp`)

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;
public:
        MyVec(int len); //constructor decl.
        ~MyVec(); //destructor decl.

};
#endif
```

```
#include"myvec.h"
//defining the constructor
MyVec::MyVec(int len) {
        vecLen=len;
        data=new double[vecLen];
}

//defining the destructor
MyVec::~MyVec() {
        delete [] data;
}
```

Scope resolution operator
Constructor: no return type.
Destructor: no parameters, no return type.

Defining the class (`myvec.h` and `myvec.cpp`)

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;
public:
        MyVec(int len); //constructor decl.
        ~MyVec(); //destructor decl.
        int GetVecLen(); //member function


};
#endif
~
~
```

```
#include"myvec.h"
//defining the constructor
MyVec::MyVec(int len) {
        vecLen=len;
        data=new double[vecLen];
}

//defining the destructor
MyVec::~MyVec() {
        delete [] data;
}

//defining GetVecLen member function
int MyVec::GetVecLen() {
        return vecLen;
}
```

Using an object

```
#include<iostream>
#include"myvec.h"
using namespace std;
int main() {
        MyVec v(10); //calls the constructor and passes the argument 10
        int size=v.GetVecLen(); //calls the member function
        cout<<"size of MyVec is: "<<size<<" elements"<<endl;
}
```

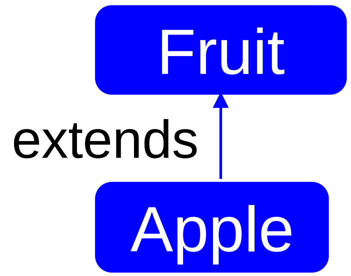
Abstract base classes

- A class can have a `virtual` method without a definition – *pure virtual functions*
- E.g

```
class Fruit {
protected:
        string commonName;
        float weight;
        float energyPerUnitWeight; //in kCals / 100g
public:
        Fruit(string name, float weight);
        virtual string GetName();
        virtual ~Fruit();
        virtual void Energy() = 0;
};
```

Energy is 'pure' – no implementation

Defining pure virtual function

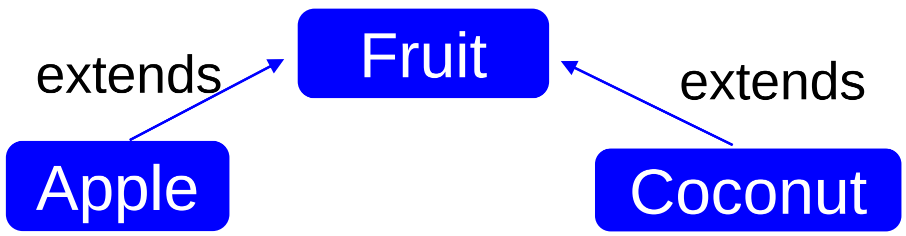



```
class Apple : public Fruit {
        vector<pair<string, float> > constituents;
public:
        Apple(string name, float weight);
        virtual ~Apple();
        . . .
        void Energy() {
        energyPerUnitWeight = ComputeEnergy(weight, constituents);
        }
};
```

Pure virtual method defined in derived class.

Base class attribute

Defining pure virtual function




```
class Coconut : public Fruit {
        vector<pair<string, float> > constituents;
public:
        Coconut(string name, float weight);
        virtual ~Coconut();
        . . .
        void Energy() {
        float effWeight = GetEdibleContentWeight();
        energyPerUnitWeight = ComputeEnergy(effWeight, constituents);
        }
};
```

Computation is different from that of Apple's method

Abstract base classes..

- Cannot create objects from abstract base classes. But may need constructors. Why?

```
Fruit item1; //not allowed. Fruit::Energy() is pure virtual
```

- Can create pointers to abstract base classes and use them in polymorphic way

```
Fruit* item1 = new Apple("Apple", 0.24);
cout<<item1->Energy()<<"Kcals per 100 g"<<endl;
```

- Often used to create *interfaces*

Friend functions

- Can access `private` and `protected` members

```
class Coconut {
        vector<pair<string, float> > constituents;
public:
        ...
        friend float ComputeEnergy(float wt, Coconut* c);
};

float ComputeEnergy(float weight, Coconut* c) {
//get a set of items, for each item, get its weight and
//energy_per_g. multiply both. Sum the product of all items...
//read from c->constituents to get the set of items.
}
```

The non-member function `ComputeEnergy` can access private attribute `constituent` of `Coconut` class

Operator overloading

- How can we assign one object to another?

```
Apple a1("Apple", 1.2); //constructor Apple::Apple(string, float)
                        //is invoked
Apple a2; //constructor Apple::Apple() is invoked.
a2  = a1 //object a1 is assigned to a2. assignment operator invoked
```

```
Apple& Apple::operator=(const Apple& rhs) {
commonName = rhs.commonName;
weight = rhs.weight;
energyPerUnitWeight = rhs.energyPerUnitWeight;
constituents = rhs.constituents;
return *this;
}
```

Called Copy Assignment Operator

Operator overloading []

```cpp
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;
public:
        MyVec(int len); //constructor decl.
        ~MyVec(); //destructor decl.
        int GetVecLen(); //member function
        double& operator[](int index);


};

#endif
```

```cpp
        delete [] data;
}

//defining GetVecLen member function
int MyVec::GetVecLen() {
        return vecLen;
}

double& MyVec::operator[](int index) {
        return data[index];
}
```

Operator overloading - usage

```cpp
#include<iostream>
#include"myvec.h"
using namespace std;
int main() {
        MyVec v(10); //calls the constructor MyVec::MyVec(int) and passes the argument 10
        int size=v.GetVecLen(); //calls the member function
        cout<<"size of MyVec is: "<<size<<" elements"<<endl;
        cout<<"Setting first element to 100"<<endl;
        v[0]=100;
        cout<<"Fetching first element value: "<< v[0] << endl;
}
```

Copying Objects

```
Apple a1(“Apple_red”, 0.2);
Apple a2 = a1; //calls copy constructor

    Apple::Apple(const Apple& rhs) {
            commonName = rhs.commonName;
            weight = rhs.weight;
            energyPerUnitWeight = rhs.energyPerUnitWeight;
    }
```

Copy constructor - usage

```
#include<iostream>
#include"myvec.h"
using namespace std;
int main() {
        MyVec v(10); //calls the constructor MyVec::MyVec(int) and passes the argument 1
        int size=v.GetVecLen(); //calls the member function
        cout<<"size of MyVec is: "<<size<<" elements"<<endl;
        cout<<"Setting first element to 100"<<endl;
        v[0]=100;
        cout<<"Fetching first element value: "<< v[0] << endl;
        MyVec v2=v; //calls the copy constructor
        cout<<"v2's first element: "<<v2[0]<<endl;
}
```

- Not necessary to define the copy constructor. Compiler defines one for us.

```cpp
#include<iostream>
#include"myvec.h"
using namespace std;
int main() {
	MyVec v(10); //calls the constructor MyVec::MyVec(int) and passes the argument 10
	int size=v.GetVecLen(); //calls the member function
	cout<<"size of MyVec is: "<<size<<" elements"<<endl;
	cout<<"Setting first element to 100"<<endl;
	v[0]=100;
	cout<<"Fetching first element value: "<< v[0] << endl;
	MyVec v2=v; //calls the copy constructor
	cout<<"v2's first element: "<<v2[0]<<endl;
}
```

```
size of MyVec is: 10 elements
Setting first element to 100
Fetching first element value: 100
v2's first element: 100
free(): double free detected in tcache 2
Aborted
```

```cpp
#include<iostream>
#include"myvec.h"
using namespace std;
int main() {
        MyVec v(10); //calls the constructor MyVec::MyVec(int) and passes the argument 10
        int size=v.GetVecLen(); //calls the member function
        cout<<"size of MyVec is: "<<size<<" elements"<<endl;
        cout<<"Setting first element to 100"<<endl;
        v[0]=100;
        cout<<"Fetching first element value: "<< v[0] << endl;
        MyVec v2=v; //calls the copy constructor
        cout<<"v2's first element: "<<v2[0]<<endl;
}
```

```
size of MyVec is: 10 elements
Setting first element to 100
v2's first element: 100
free(): double free detected in tcache 2
Aborted
```

If you don't define a copy constructor, in some cases, e.g., for class MyVec, the program aborts. *Why in this case?*

const and references

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;
public:
        MyVec(int len); //constructor decl.
        MyVec(const MyVec& rhs); //copy cons
tructor
        int GetVecLen() const; //member func
tion
        double& operator[](int index) const;
        ~MyVec(); //destructor decl.


};
```

```
}

MyVec::MyVec(const MyVec& rhs) {
        vecLen=rhs.GetVecLen();
        data=new double[vecLen];
        for(int i=0;i<vecLen;i++) {
                data[i] = rhs[i];
        }
}

//defining GetVecLen member function
int MyVec::GetVecLen() const {
        return vecLen;
}

double& MyVec::operator[](int index) const {
        return data[index];
}
```

```
#ifndef MYVEC_H
#define MYVEC_H
class MyVec{
        //private attributes
        double* data;
        int vecLen;
public:
        MyVec(int len); //constructor decl.
        MyVec(const MyVec& rhs); //copy constructor
        int GetVecLen() const; //member function
        double& operator[](int index) const;
        ~MyVec(); //destructor decl.


};
```

```
}

MyVec::MyVec(const MyVec& rhs) {
        vecLen=rhs.GetVecLen();
        data=new double[vecLen];
        for(int i=0;i<vecLen;i++) {
                data[i] = rhs[i];
        }
}

//defining GetVecLen member function
int MyVec::GetVecLen() const {
        return vecLen;
}

double& MyVec::operator[](int index) const {
        return data[index];
```

Define the copy constructor. Now you need to make changes to other methods (const) as well.

```
Setting first element to 100
Fetching first element value: 100
v2's first element: 100
```

Detour: References and Const

- We saw reference variables earlier (slides 83 and 84, Week2)
- Closely related to pointers:
  – Directly name another object of the *same* type.
  – A pointer is defined using the * (dereference operator) symbol. A reference is defined using the & (address of operator) symbol. Furthermore, unlike in pointer definitions, a reference must be defined/initialized with the object that it names *(cannot be changed later)*.

References

```
int n=10;
int &re=n; //re must be initialized
int* ptr; //ptr need not be initialized here
ptr=&n //ptr now initialized (now pointing to n)
int x=20;
ptr=&x; //ptr now pointing to x
re=x; //is illegal. Cannot change what re names.
printf(“%p %p\n”,&re, &n); // re and n are naming the
same box in memory. Hence, they have the same address.
```

`const`

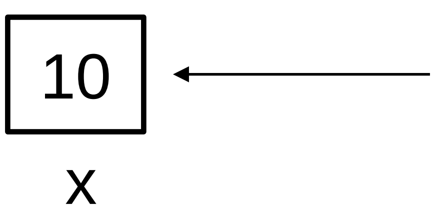
- A type qualifier
- The type is a constant (cannot be modified).
- `const` is the keyword
- Example:

```
const int x=10; //equivalent to: int const x=10;
//x is a constant integer. Hence, cannot be
//modified.
```

In what memory segment does x gets stored?

Const Properties

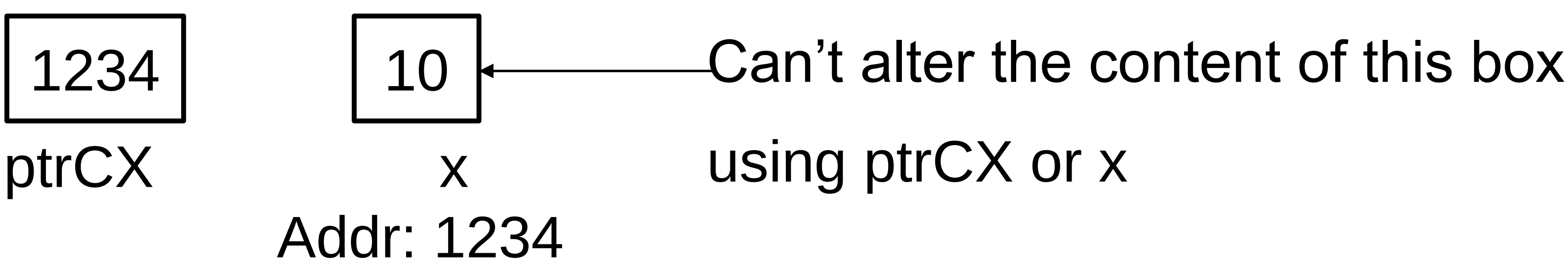
- Needs to be initialized at the time of definition
- Can’t modify after definition
- `const int x=10;`
  `x=20; //compiler would throw an error`
- `int const x=10;`
  `x=10; //can’t even assign the same value`
- `int const y; //uninitialized const variable y. Useless.`



Can’t alter the content of this box

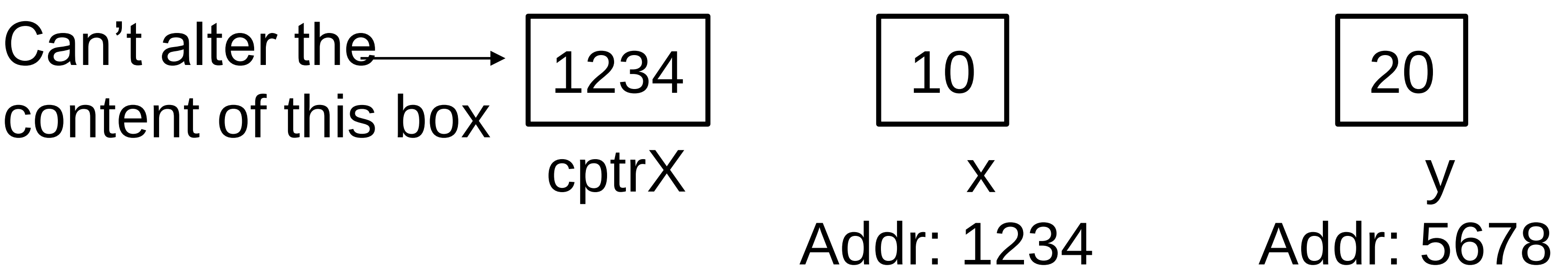
Const Example1 (error)

```
/*ptrCX is a pointer to a constant integer. So, can’t
modify what ptrCX points to.*/
const int* ptrCX; //or equivalently:
int const* ptrCX;

int const x=10;
ptrCX = &x;
*ptrCX = 20; //Error
```



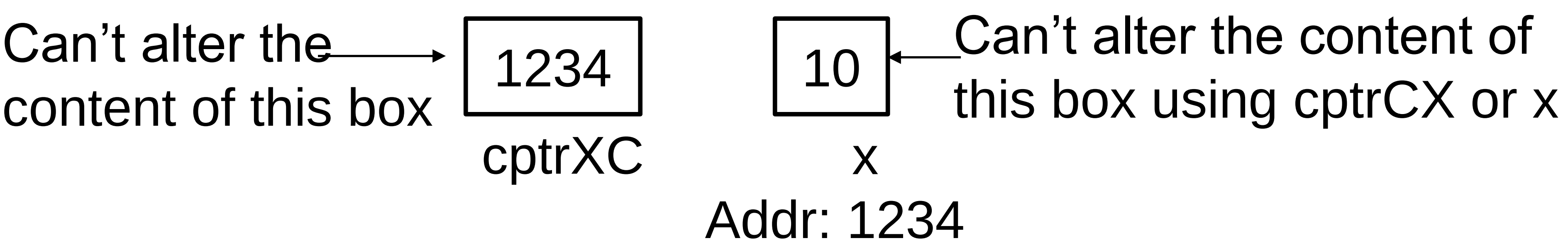
Const Example2 (error)

```
/*cptrX is a constant pointer to an integer. So, can’t
point to anything else after initialized.*/
int x=10, y=20;
int *const cptrX=&x;
cptrX = &y; //Error
```



Const Example3 (error)

```
/*cptrXC is a constant pointer to a constant integer. So,
can’t point to anything else after initialized. Also,
can’t modify what cptrXC points to.*/

const int x=10, y=20;
const int *const cptrXC=&x;
int const *const cptrXC2=&x; //equivalent to prev. defn.
cptrXC = &y; //Error
*cptrX = 40; //Error
```



Const Example4 (warning)

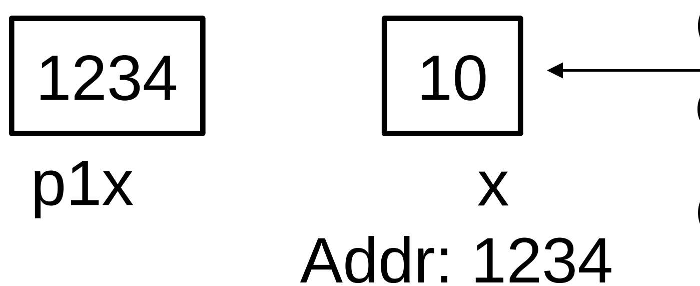
```
/*p2x is a pointer to an integer. So, we can use p2x to
alter the contents of the memory location that it points
to. However, the memory location contains read-only data -
cannot be altered. */

const int x=10;
const int *p1x=&x;
int *p2x=&x; //warning
*p2x = 20; //goes through. Might crash depending on memory
location accessed
```

1234	1234	10
p2x	p1x	x Addr: 1234

Can't alter the content of this box using p1x or x. Can alter using p2x.

Const Example5 (no warning, no error)

```
/*p1x is a pointer to a constant integer. So, we can't use
p1x to alter the content of the memory location that it
points to. However, the memory location it points to can
be altered (through some other means e.g. using x)*/

int x=10;
const int *p1x=&x;
```

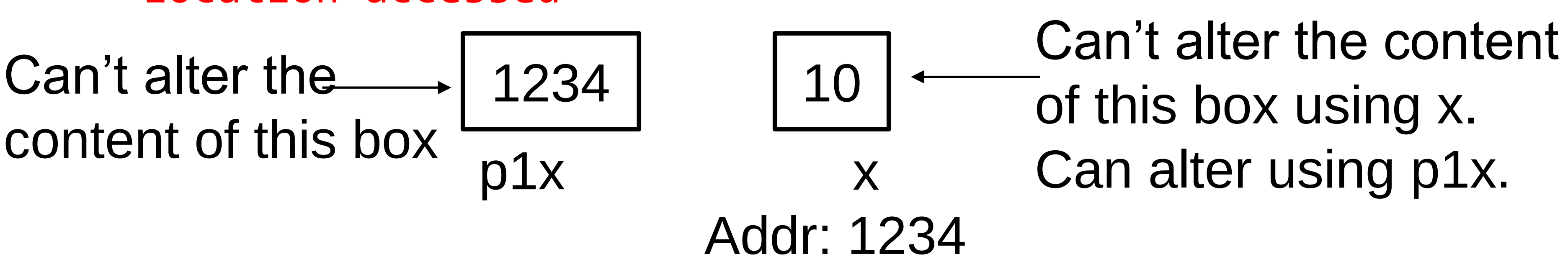


Can't alter the content of this box using p1x.

Can alter using x.

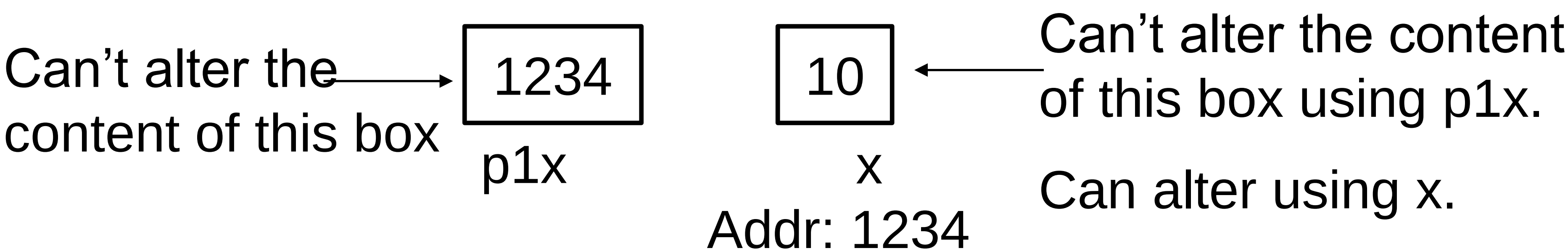
Const Example6 (warning)

```
/*p1x is a constant pointer to an integer. So, we can use
p1x to alter the contents of the memory location that it
points to (and we can’t let p1x point to something else
other than x). However, the memory location contains read-
only data - cannot be altered. */

const int x=10;
int *const p1x=&x;//warning
*p1x = 20; //goes through. Might crash depending on memory
location accessed
```



Const Example7 (no warning, no error)

```
/*p1x is a constant pointer to a constant integer. So, we
can't use p1x to alter the content of the memory location
that it points to. However, the memory location it points
to can be altered (through some other means e.g. using
x)*/

int x=10;
const int *const p1x=&x;
```



Const and References - Summary

- Allow for compiler optimizations
  - pass-by-reference: allows for passing large objects to a function call
- Tell us immediately (by looking at the interface) that a parameter is read-only

Post-class Exercise – Abstract Classes

- The earlier quiz at the beginning of the class was a Pre-class Exercise.
- Re-attempt the same Quiz.

Templating Functions

- Provide a recipe for generating multiple versions of the function based on the data type of the data on which the function operates
- Demo: refer to function_template folder in week4_codesamples