Introduction to C++

Classes, inheritance, virtual methods, smart pointers,
C from C++, examples (with cfitsio, Eigen)

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Classes

- A **class** type is a mechanism to:
  - **combine** related **data values** into a data structure, in order to treat it as a single entity
  - **hide implementation** details to the class user and
  - only **expose an interface**, i.e. a set of member functions and operators, to access objects of the class

vec3.h

```
class Vec3 {
public:
  double& at(size_t i) { return elems[i];}
  const double& at(size_t i) const { return elems[i];}

private:
  double elems[3];
};
```

Methods implemented in the class definition

- Member functions (methods) are part of the class definition and must be called using the dot operator on an instance of the class
- Methods defined inside the class definition ask the compiler to expand calls to them **inline**

Class members

- In general, a class is composed by a set of entities called members; we can identify the following type of members:
  - **Data attributes**: variables, constants, class variables or constants
    - Class variables are associated to the class and not to a single instance
  - **Member functions**: functions, class functions
    - Class functions do not depend on the state of a specific class instance
  - **Types**: type aliases, nested classes, etc.

Protection labels

- In the previous example, we use the keyword **`class`** instead of **`struct`**.
- After that keyword, a **protection label** is used: **`public`**. It defines the two overloaded member functions '`at`' as public, i.e. accessible by all users of the type
- Another protection label, **`private`**, defines the members that follow it (in this case just `elems`) as private, hence not accessible by the user:

```
Vec3 p;
p.elems[0] = 1; // compilation error, elems is private
```

- Protection labels can occur in any order within the class and can occur multiple times
- Every member declared between the { and the first protection label is private by default (while for **`struct`**, the default is public)

Const member functions

ex25

- Since an object of type Vec3 could be passed as a const reference, it is necessary to declare which member functions don't change the object state
- One of the at member functions just reads the Vec3 elements hence it is declared as a **const member function** by using the keyword **`const`** immediately after the parameter list
  - Such **`const`** is part of the method signature
- With the class Vec3 we can perform the following operations:

```
Vec3 p;
// setting the three elements of p using the non-const at
p.at(0) = 1.0;
p.at(1) = -3.0;
p.at(2) =  4.0;

// printing p
cout << "x: " << p.at(0) << ", y: " << p.at(1) << ", z: "
     << p.at(2) << endl;
```

Constructors

- One problem of the Vec3 class is that we cannot initialize an object of type Vec3
- Initialization can be defined for a class by special member functions called **Constructors**
- Constructors have the same name as the name of the class itself and have no return type

```
class Vec3 {
public:
  Vec3();
  Vec3(double x, double, y, double z);
  ...
```

- In the class definition above we are now declaring two constructors
  - The one with an empty paramter list is called default constructor
  - The second constructor let us specify an initial value for the 3 elements of Vec3

Constructor definition

ex25

- Class member functions defined outside a class definition must use the class name as scope:

vec3.cpp

```
Vec3::Vec3()
{
  elems[0] = elems[1] = elems[2] = 0;
}

Vec3::Vec3(double x, double y, double z)
{
  elems[0] = x; elems[1] = y; elems[2] = z;
}
```

main()

```
Vec3 p;  // default-constructor is called
Vec3 q{0, 1.5, -2.4};  // the second constructor is called
Vec3 r(q); // implicit copy-constructor used
```

- The third initialization initializes r as a copy of q by using an implicit constructor that performs a copy element-by-element
- The two constructors are defined in file vec3.cpp

Additional member functions

ex25

```
class Vec3 {
public:
  // computing the norm
  double norm() const;
...
}
```

- inline member functions must be defined in the header file (vec3.h)

```
inline double Vec3::norm() const
{
  return sqrt( elems[0]*elems[0] + elems[1]*elems[1] +
               elems[2]*elems[2]);
}
```

- The const keyword must be used both in the declaration and definition since it is part of the method signature

Overloading operators

ex25

- If we want to be able to add two Vec3 objects using the following notation: p += q and r = p + q. We need to overload two operators, += and +
- I could define the operation p + q as p.operator+(q) or as operator+(p, q)
- The += modifies the left operand. Hence, it must be defined as a member function
- The + doesn't modify the two operands, so it should be implemented as a non-member function

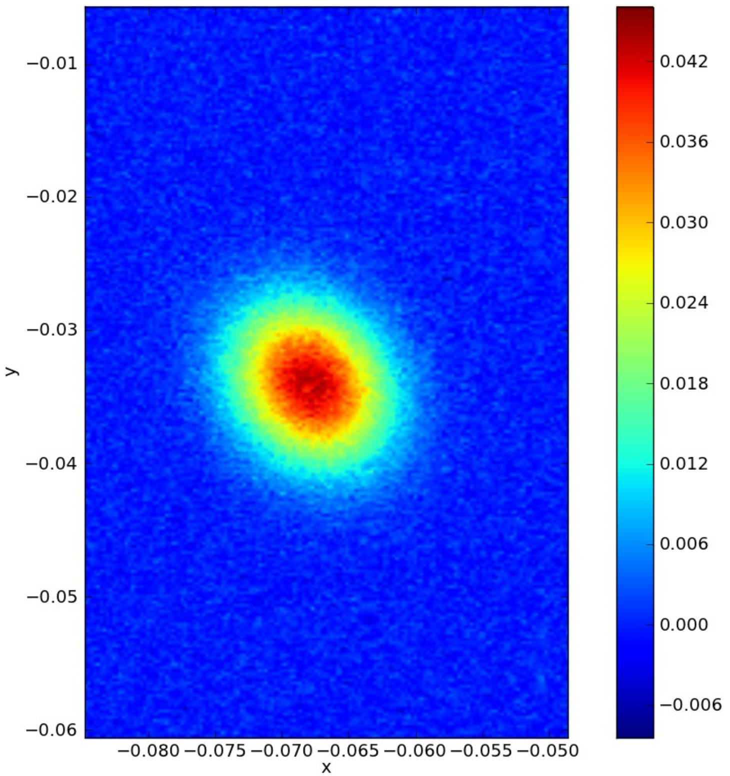
```
Vec3& Vec3::operator+=(const Vec3& s) {
  elems[0] += s.elems[0];
  elems[1] += s.elems[1];
  elems[2] += s.elems[2];
  return *this;
}

Vec3 operator+(const Vec3& lhs, const Vec3& rhs) {
  Vec3 r = lhs;   // implicit copy constructor used
  r += rhs;
  return r;
}
```

- The **this** keyword is valid only inside a member function, where it denotes a pointer to the object on which the member function is operating

Call operator

- The call operator () can be overloaded in the same way as other operators can
- One use of the operator () is to provide the usual function call syntax for objects that in some way behave like functions. They are called functors or function objects
- Example: Jupiter is used by the Planck-LFI mission for the in-flight reconstruction of the antenna beam shape.
- The elliptical beam can be defined as a bivariate Gaussian:

$$beam(x,y) = A \cdot e^{-\frac{1}{2}\left(\frac{(\Delta x \cos\alpha + \Delta y \sin\alpha)^2}{\sigma_x^2} + \frac{(\Delta y \cos\alpha - \Delta x \sin\alpha)^2}{\sigma_y^2}\right)}$$



Bivariate Gaussian functor

ex26

beam.h

```cpp
class GaussianBeam
{
 public:
  // Constructor
  GaussianBeam(double center_x, double center_y, double sigma_x, double sigma_y,
               double amplitude, double orientation):
      x0(center_x), y0(center_y), sigmax(sigma_x),
      sigmay(sigma_y),amp(amplitude),alpha(orientation) {}

  // Call operator
  double operator() (double xpos, double ypos);

 private:
  GaussianBeam(); // prevent use of default constructor

  // Beam center
  double x0, y0;
  // Beam dispersions
  double sigmax, sigmay;
  // Beam amplitude (kelvin)
  double amp;
  // Beam orientation (radians)
  double alpha;
};
```

beam.cpp

```cpp
double GaussianBeam::operator() (double xpos, double ypos)
{
  double sinalpha = sin(alpha);
  double cosalpha = cos(alpha);
  double dx = xpos - x0;
  double dy = ypos - y0;
  double partx = (dx*cosalpha + dy*sinalpha)/sigmax;
  double party = (-dx*sinalpha + dy*cosalpha)/sigmay;

  return amp*exp(-0.5*(partx*partx + party*party));
}
```

main()

```cpp
GaussianBeam beam =  {-0.0678,-0.034,0.0036,0.00446,0.044,0.70};

double x = -0.070, y =  -0.035;
double measure = beam(x, y);
```

Constructor initializers

ex27

- Let's consider the following template class definition, for image data manipulation:

```
template <class PixelT>
class Image {
public:
  using size_type = std::size_t;

  Image(size_type width, size_type height)
    : _width(width), _height(height) {_pix_array = new PixelT[_width * _height];}

  PixelT& operator()(size_type i, size_type j) {return _pix_array[i*_width + j];}
  const PixelT& operator()(size_type i, size_type j) const
        {return _pix_array[i*_width + j];}

private:
  size_type _width, _height;
  PixelT* _pix_array;
};
```

- It defines a Image data structure, with dynamic allocation on the heap memory
- The constructor uses some new syntax: between the : and the { we can have a list of constructor initializers
  - the given members are **initialized** by the compiler with the values appearing between parenthesis, before entering the constructor body

Copy constructor

ex27

- With the previous Image class definition, if we write:

```
Image<double> a(15, 10);
Image<double> b(a);
```

  a default copy constructor is created by the compiler to copy a in b
  - It copies each data element from an existing object into the new object
  - AND, when copying a pointer data element, it just copies the memory address it contains. So, a and b point to the same pixel buffer
- To avoid this behavior we should define our own **copy constructor**:

```
template<class PixelT>
Image<PixelT>::Image(const Image& img)
  : _width(img._width), _height(img._height)
{
  size_type size = _width*_height;
  _pix_array = new PixelT[size];
  std::copy(img._pix_array, img._pix_array + size, _pix_array);
}
```

Improving the Image class definition 1/2

ex27

- We need to extend the Image class interface and improve its modularity

image.h

```
template <class PixelT>
class Image {
public:
  // Definition of type aliases used by the class
  using size_type = std::size_t;
  using const_iterator = const PixelT*;
  using iterator = PixelT*;

  // Default constructor
  Image(): _width(0), _height(0), _pix_array(nullptr) {}
  // Constructor requiring the number of rows and columns
  Image(size_type width, size_type height)
    : _width(width), _height(height) {_pix_array = new PixelT[_width * _height];}
  // Copy constructor
  Image(const Image& img)
    : _width(img._width), _height(img._height) {create(img.begin(), img.end());}

  // Destructor
  ~Image() {uncreate();}

  // Call operator, to access each pixel
  PixelT& operator()(size_type i, size_type j) {return _pix_array[i*_width + j];}
  const PixelT& operator()(size_type i, size_type j) const
        {return _pix_array[i*_width + j];}

  // Total number of pixels and image dimensions
  size_type size() const {return _width*_height;}
  size_type width() const {return _width;}
  size_type height() const {return _height;}
```

Improving the Image class definition 2/2

ex27

image.h

```
  // Iterators
  iterator begin() {return _pix_array;}
  const_iterator begin() const {return _pix_array;}

  iterator end() {return _pix_array + size();}
  const_iterator end() const {return _pix_array + size();}

protected:
  // Helper functions to create and destroy class instances
  void create(const_iterator istart, const_iterator iend);
  void uncreate();

private:
  // Private attributes
  size_type _width, _height;
  PixelT* _pix_array;
};
```

image.cpp

```
template <class PixelT>
void Image<PixelT>::create(const_iterator istart, const_iterator iend)
{
  _pix_array = new PixelT[iend - istart];
  std::copy(istart, iend, _pix_array);
}

template <class PixelT>
void Image<PixelT>::uncreate()
{
  delete[] _pix_array;
  _pix_array = nullptr;
  _width = _height = 0;
}
```

Assignment operator

ex27

- The class definition also controls the behavior of the assignment operator (=)
  - Several overloaded assignment operators can be defined
  - However, the version that takes a const reference to the class itself is special and is considered “the assignment operator”

image.cpp

```
template <class PixelT>
Image<PixelT>& Image<PixelT>::operator=(const Image& rhs)
{
  // check for self-assignment
  if (&rhs != this) {
    // free the array in the left-hand side
    uncreate();
    // copy pixels from rhs
    create(rhs.begin(), rhs.end());
    // copy dimensions
    _width = rhs._width;
    _height = rhs._height;
  }
  return *this;
}
```

Image.cpp

```
template <class PixelT>
Image<PixelT>& Image<PixelT>::operator=(const PixelT val)
{
  std::fill(begin(), end(), val);
  return *this;
}
```

Using the Image class

- A quick example showing the usage of the Image class:

```
int main(int argc, char* argv[])
{
  // Creates an image of double values
  // with 15 rows and 10 columns
  Image<double> a(15, 10);
  // All pixels are set to 5.0
  a = 5;
  // Setting pixel (4,5) to 10
  a(4, 5) = 10;
  // b is a copy of a
  Image<double> b(a);
  // Retrieving image dimensions and size
  auto size = b.size();
  auto width = b.width();
  auto height = b.height();
  // Resetting all pixels in a range-for loop
  for (auto& x : a)
    x = 0;
}
```

Destructor

- Like constructors, which say how to create objects, there is a special member function, called a **destructor**, that controls what happens when objects of the type are destroyed
- An object is destroyed when it goes out of scope or, for dynamically allocated objects, when calling **`delete`** on the object
- For the Image class defined in the previous example, it is necessary to define a destructor, in order to correctly free the memory allocated for the `_pix_array` member
- Destructors have the same name as the name of the class prefixed by a tilde (~)

```
// Destructor
~Image() { uncreate();}
```

The rule of three

- Classes that **allocate resources** (in the heap) in their constructors, require that every copy deal correctly with those resources
  - Such classes almost surely need a **destructor** to free the resources
  - If a class needs a destructor, it almost surely need a **copy constructor** to control how the dynamically allocated resources are copied
  - If a class needs a copy constructor, it also needs an **assignment operator** since copying or assigning allocates those resources in the same way
- To control how every object of class T deals with its resources, you need:

```
T::T()                  // one or more constructors, perhaps with arguments
T::~T()                 // the destructor
T::T(const T&)          // The copy constructor
T::operator=(const T&)  // the assignment operator
```

Reuse inheritance

- Together with an image, we also need to define a mask, i.e. an array of bitsets that provides information on the quality of each pixel in the image (e.g. Bad, Saturated, Cosmic-ray hit, etc.)
- We would like to reuse the Image definition, since its basic interface is also suitable for a Mask data structure
- We can define a Mask class as a class **derived** from the Image class
  - then Image is a **base class** of Mask
  - Mask inherits from Image “all” its attributes and its member functions, with the exception of:
    - Constructors
    - Assignment operators
    - Destructor

The Mask derived class

ex27

```
template<class MaskPixT>
class Mask: public Image<MaskPixT> {
public:
  using Super = Image<MaskPixT>;
  using typename Super::size_type;

  // Default constructor
  Mask() {}
  // Constructor requiring image dimensions and maximum bit plane
  Mask(size_type width, size_type height,
       size_type maxBitPlane = std::numeric_limits<MaskPixT>::digits)
    : Super(width, height), _maxBitPlane(maxBitPlane)  {}
  // Copy constructor
  Mask(const Mask& rhs): Super(rhs), _maxBitPlane(rhs._maxBitPlane) {}

  // Assignment operators
  Mask& operator=(const Mask& rhs);
  Mask& operator=(const MaskPixT val);

  // Method to get a specific bit of the mask
  bool getBitAt(size_type i, size_type j, size_type bitPlane)
    {return this->operator()(i,j) & getBitMask(bitPlane);}
  // Operator performing a bitwise-or with another mask
  Mask& operator|=(const Mask& rhs);

private:
  // Helper function to compute bit plane mask
  MaskPixT getBitMask(size_type bitPlane)
    {return (bitPlane >= 0 && bitPlane < _maxBitPlane) ? 1 << bitPlane : 0; }

  size_type _maxBitPlane;
};
```

Public methods in Image are also public in Mask

Helper type aliases

typename tells the compiler that size_type is the name of a type even if MaskPixT is not yet instantiated

Need to call base class constructor to initialize base class attributes

Mask class operators

ex27

```
template <class MaskPixT>
Mask<MaskPixT>& Mask<MaskPixT>::operator=(const Mask& rhs)
{
  Super::operator=(rhs);
  _maxBitPlane = rhs._maxBitPlane;
  return *this;
}

template <class MaskPixT>
Mask<MaskPixT>& Mask<MaskPixT>::operator=(const MaskPixT val)
{
  Super::operator=(val);
  return *this;
}

template <class MaskPixT>
Mask<MaskPixT>& Mask<MaskPixT>::operator|=(const Mask& rhs)
{
  if (Super::width() != rhs.width() || Super::height() != rhs.height())
    throw std::length_error("Images are of different size");

  std::transform(rhs.begin(), rhs.end(), Super::begin(), Super::begin(),
                 std::bit_or<MaskPixT>());
  return *this;
}
```

Calling the base class equivalent operator (reuse)

Inheritance

- When a function or method takes, as parameter, a **reference** or **pointer** to the base class, then we can pass as actual value also a reference or pointer to a derived class
  - Supposing that a function requires, as parameter, a reference or pointer to an instance of tipe Image<PixelT>
  - We can call it passing an instance of type Mask<MaskPixT>
  - BUT, due to the Image and Mask definitions, the function will take only the Image portion of the Mask instance
- A derived class can redefine methods of the base-class (same method name, parameters and returned type). In this manner it **overrides** (hides) the same methods from the base-class, i.e.:
  - If class B inherits from class A and both have a method name() defined, then:
    B x; // x instance has type B
    x.name() referes to the name() method defined in B and not in A

Abstract class

- A file in FITS standard format usually stores an image or table data together with the associated metadata.
- Metadata is provided as a set of keywords. Each keyword has a unique name and a value. The value can be a boolean, an integer, a floating point value, a string or a complex number
- When we read the set of keywords from a FITS file, it would be useful to keep them in a std::map, associating the keyword name with the corresponding value
- But a std::map requires all values to have the same type
- Then, we need to group all possible keyword types under a common, **abstract**, parent type, that defines a set of **virtual** common operations for each keyword type
  - Virtual means that each concrete subtype will implement such set of operations, based on its own structure

Virtual methods example: the Property class

ex28

- Let's define a class, named Property, that represents all keyword types we can read from a FITS file (simplified version)

```
class Property {
public:
  Property(const std::string& name): _name(name) {}
  const std::string& name() const {return _name;}

  virtual ~Property() {}  // virtual destructor

  virtual double getValueAsDouble() const = 0;
  virtual int getValueAsInt() const = 0;
  virtual std::string getValueAsString() const = 0;
private:
  std::string _name;
};
```

- The Property class has only the name (keyword name) attribute, while the concrete value will be provided by derived classes
- It defines the common set of operations expected in each derived class, declared as virtual, but it does not provide an implementation that will depend on the concrete value provided by the derived classes
- We cannot instantiate objects of type Propety, since it is a pure abstract class, i.e. some virtual methods are not defined (= 0)

ex28

Virtual methods example: two concrete derived classes

property.h

```
class DoubleProperty: public Property  {
public:
  DoubleProperty(const std::string& name, double value)
    : Property(name), _value(value) {}

  double getValueAsDouble() const {return _value;}
  int getValueAsInt() const {return static_cast<int>(_value);}
  std::string getValueAsString() const;

private:
  double _value;
};
```

property.h

```
class IntProperty: public Property  {
public:
  IntProperty(const std::string& name, int value)
    : Property(name), _value(value) {}

  double getValueAsDouble() const {return _value;}
  int getValueAsInt() const {return _value;}
  std::string getValueAsString() const;

private:
  int _value;
};
```

Different implementations of the same virtual methods

property.cpp

```
std::string DoubleProperty::getValueAsString() const
{
  std::ostringstream os;
  os << _value;
  return os.str();
}
```

property.cpp

```
std::string IntProperty::getValueAsString() const
{
  std::ostringstream os;
  os << _value;
  return os.str();
}
```

Virtual methods example: dynamic binding

ex28

property.cpp

```
Property* createProperty(const std::string& name, double value)
{
  return new DoubleProperty(name, value);
}

Property* createProperty(const std::string& name, int value)
{
  return new IntProperty(name, value);
}

Property* createProperty(const std::string& name, const std::string& value)
{
  return new StringProperty(name, value);
}
```

```
int main(int argc, char* argv[])
{
  std::map<string, Property*> pmap;

  pmap["APID"] = createProperty("APID", 1536);
  pmap["TELESCOP"] = createProperty("TELESCOP", "PLANCK");
  pmap["MEAN_VAL"] = createProperty("MEAN_VAL", 4.434234);

  for (const auto& x : pmap){
    cout << x.first << ": " << x.second->getValueAsString() << endl;
  }
}
```

Through the base class ponter (Property*), the specific getValueAsString() implementation is is selected at run-time, based on the type of the object the pointer is **bound** to

Virtual methods summary

- We can use a derived type where a pointer or reference to the base class is expected
- **Polymorphism** refers to the ability of one type to stand in for many types
- C++ supports polymorphism through the **dynamic binding** properties of the virtual methods
  - When we call a **virtual method** through a pointer or reference to a base class, we can potentially call one of many functions, as many as the number of derived types
- In the previous example, the base class Property also defines a virtual destructor
  - A **virtual destructor** is needed any time it is possible that an object of the derived type is destroyed through a pointer to base
  - The derived class inherits the virtual property of its base-class destructor

Class methods and static attributes

- The C++ keyword static can be used in several contexts
- For classes, we can use the static keyword both when defining data attributes and member functions

```
class Exposure {
public:
  // Read an exposure from a fits file
  static Exposure readFits(std::string const & filename);

private:
  // next id to use
  static int _id;

  Image<unsigned short> ccd_array;
  Mask<unsigned short> mask;
}
```

- A static attribute is shared by all class instances
  - If an object of the class changes the static attribute value, all the other class instances can read the updated value
- A static method can only access class static attributes and call other class methods
- Usually, class methods are called using the class scope and not through a class instance

```
Exposure e = Exposure::readFits("sample.fits");
```

Unique and shared pointers

- Smart pointers manage the memory held by a built-in pointer
- They provide the operator "->" to access the object and the operator "*" to retrieve the pointed object
- **`unique_ptr`** allows only a single instance to hold the built-in pointer
  - When the unique_ptr is deleted, if is still holding a built-in pointer, it deletes it as well
  - Using unique_ptr instead of built-in pointer does not causes overhead neither in the execution time nor in memory consumption
- **`shared_ptr`** allows the built-in pointer to be shared between multiple copies
  - When all the shared_ptr holding the same built-in pointer are deleted, the built-in pointer is deleted as well
  - They keep a reference counting of all the shared_pointers wrapping the same built-in pointer. Increments and decrements of the counter are thread safe
  - A shared_ptr is at least twice the size of a built-in pointer

Using shared pointers: vector or galaxies revisited

ex29

```
#include "../ex14/galaxy.h"
#include <vector>
#include <algorithm>
#include <iostream>
#include <memory>
using namespace std;

int main()
{
  // filling a vector of galaxy pointers with dynamically allocated instances
  vector<shared_ptr<Galaxy>> vg;
  vg.push_back(shared_ptr<Galaxy>(new Galaxy{1, {349.18372, -0.070794291}, 0.527313}));
  vg.push_back(shared_ptr<Galaxy>(new Galaxy{2, {348.3452, 0.0653423}, 0.5135289}));
  vg.push_back(shared_ptr<Galaxy>(new Galaxy{3, {346.29340, 0.034823}, 0.5126848}));

  // lambda expression to sort galaxy shared pointers by RA
  auto sort_by_ra = [] (shared_ptr<const Galaxy> x, shared_ptr<const Galaxy> y)
                       {return x->coord.ra < y->coord.ra;};

  sort(vg.begin(), vg.end(), sort_by_ra);

  cout << "galaxies ordering by RA: ";
  for (const auto x : vg)
    cout << x->id << " ";
  cout << endl;


// deleting all the dynamically allocated galaxies within the vector
//  for (auto x : vg) {
//    delete x;
//    x = nullptr;
//  }
  return 0;
}
```

shared_ptr and unique_ptr are declared in the <memory> header

Defining a vector of shared_ptr to Galaxy

Galaxy built-in pointers are immediately passed to a shared_ptr constructor

Linear algebra with Eigen

ex30

- Eigen is a fast and elegant header only library for the linear algebra

```
#include <iostream>
#include <eigen3/Eigen/Dense>

using namespace std;
namespace E = Eigen;
int main()
{
  double a[] = {
    1, 2, 3,
    2, 1, 2,
    2, 5, 2};

  // create a  3x3 matrix of doubles using a built-in array as buffer
  E::Map<E::Matrix<double,3,3, E::RowMajor>> A(a);

  // create a vector and initialize using the initialization list
  E::Vector3d b {1,2,1};

  // solve the linear sistem using the LU factorization
  E::Vector3d x = A.fullPivLu().solve(b);

  // use overloaded arithmetic operators with matrices and vectors
  double relative_error = (A*x - b).norm() / b.norm(); // norm() is L2 norm

  cout << "A: \n" << A << endl;
  cout << "Solution: \n" << x << endl;
  cout << "The relative error is: " << relative_error << endl;
}
```

- For a quick-reference, see http://eigen.tuxfamily.org/dox/group__QuickRefPage.html

Example with CCfits and Eigen libraries

ex31

```
#include <CCfits/CCfits>
#include <iostream>
#include <valarray>
#define EIGEN_DEFAULT_TO_ROW_MAJOR
#include <eigen3/Eigen/Dense>

using namespace CCfits;
using namespace std;

int main(){

  bool readAllInMemory = true; //read data at Fits object construction
  unique_ptr<FITS> pInFile(new FITS("sample.fits", Read, readAllInMemory));

  ExtHDU& image = pInFile->extension(1);

  valarray<double> v;

  // copy the image in the container
  image.read(v);

  // create an Eigen array of doubles
  Eigen::ArrayXXd m(image.axis(0), image.axis(1));

  //copy the elements in the array
  size_t i = 0;
  for(auto x : v)
    m(i++) = x;

  cout << m << endl;
}
```

Using C libraries from C++

- C++ type system is more restrictive then the C one
- linkage specification allows the compiler to:
  - use C type system (only in the linkage specification scope)
  - link object files compiled with C compilers

```
#include <iostream>
#include <exception>          // C++ header
#include <memory>

extern "C" {
#include <fitsio.h>           // C header
}
```

Put C headers inclusion within the extern “C” linkage specification

Example: cfitsio and templates 1/2

ex32

```
#include <iostream>
#include <exception>
#include <memory>
#include <sstream>
#include <cstdio>
#define EIGEN_DEFAULT_TO_ROW_MAJOR
#include <Eigen/Dense>

extern "C" {
#include <fitsio.h>
}

using namespace std;
template<class T> using DMatrix = Eigen::Matrix<T,Eigen::Dynamic,Eigen::Dynamic>;

template<typename T>
class PixelType{
public:
  static const int type;
  static const int fits_type;
};

template<> const int PixelType<unsigned char>::type = BYTE_IMG;
template<> const int PixelType<unsigned char>::fits_type = TBYTE;

template<> const int PixelType<float>::type = FLOAT_IMG;
template<> const int PixelType<float>::fits_type = TFLOAT;

template<> const int PixelType<double>::type = DOUBLE_IMG;
template<> const int PixelType<double>::fits_type = TDOUBLE;
...
```

Partial template specialization provided as an alias

Template specialization

Example: cfitsio and templates 2/2

ex32

```
template<typename T>
DMatrix<T> read_image(const string& file_name, int extension=0){
  fitsfile *fptr;
  int bitpix, naxis, an;
  int status = 0;
  long naxes[2];
  stringstream ss;
  ss << file_name << "["<< extension << "]";

  fits_open_file(&fptr,ss.str().c_str() , READONLY, &status);
  if(status) throw FitsException(status);

  fits_get_img_param(fptr, 2,  &bitpix, &naxis, naxes, &status);
  if(status) close_and_throw(fptr, FitsException(status));

  if(PixelType<T>::type != bitpix) close_and_throw(fptr, domain_error("wrong pixel type"));
  if(naxis != 2) close_and_throw(fptr, domain_error("non 2D image"));

  DMatrix<T> m(naxes[0],naxes[1]);
  long fpixel[] = {1,1};
  fits_read_pix(fptr,PixelType<T>::fits_type,fpixel,naxes[0]*naxes[1],NULL,m.data(),&an,&status);

  if(status) close_and_throw(fptr, FitsException(status));

  fits_close_file(fptr, &status);
  return m;
}

int main(int argc, char *argv[]){
  DMatrix<float> m = read_image<float>("sample.fits", 1);
}
```