Plan of the day

Inheritance is last major feature of the language that we need to learn

- used to expressed common implementation
- used to expressed common behavior
- used to expressed common structure

Will divert from the text book in order to introduce HEP **specific classes**

- Examples from CLHEP
- Examples from Gismo (next session)

Recall ThreeVector

CLHEP**'s ThreeVector class (simplified)**

```
class Hep3Vector {
public:
  Hep3Vector();
  Hep3Vector(double x, double y, double z);
  Hep3Vector(const Hep3Vector &v);
  inline double x();
  inline double y();
  inline double z();
  inline double phi();
  inline double cosTheta();
  inline double mag();
  // much more not shown
private:
  double dx, dy, dz;
};
```

and some of the implementation

```
inline double Hep3Vector::x() {
  return dx;
}
inline double Hep3Vector::mag() {
  return sqrt(dx*dx + dy*dy + dz*dz);
}
```

Recall our test program

The object does the work

```
#include <iostream>
#include <CLHEP/ThreeVector.h>
using namespace std;

int main() {
  double x, y, z;

  while ( cin >> x >> y >> z ) {
    Hep3Vector aVec(x, y, z);

    cout << "r: " << aVec.mag();
    cout << "  phi: " << aVec.phi();
    cout << "  cos(theta): " << aVec.cosTheta() << endl;
  }
  return 0;
}
```

including algebraic operators

```
Hep3Vector p, q, r;
double z;
// …
z = p*q;
r = p + q;
```

Possible 4-Vector Class

Might look like…

```
class HepLorentzVector {
public:
  HepLorentzVector();
  HepLorentzVector(double x, double y, double z, double t);
  HepLorentzVector(const HepLorentzVector &v);
  inline double x();
  inline double y();
  inline double z();
  inline double t();
  inline double phi();
  inline double cosTheta();
  inline double mag();
  // much more not shown
private:
  double dx, dy, dz, dt;
};
```

Compare with 3-Vector class

- some member functions must be exactly the same
- some member functions are added
- some member functions must be re-implemented
- some data is the same
- one new data item

Another Possible 4-Vector Class

Might look like…

```
class HepLorentzVector {
public:
  HepLorentzVector();
  HepLorentzVector(double x, double y, double z, double t);
  HepLorentzVector(const HepLorentzVector &v);
  inline double x();
  inline double y();
  inline double z();
  inline double t();
  inline double mag();
  // much more not shown
private:
  Hep3Vector vec3;
  double dt;
};
```

- `HepLorentzVector` *has-a* `Hep3Vector`
- could also say `HepLorentzVector` is built by aggregation
- or with containment

Possible implementation

Constructors

```
HepLorentzVector::HepLorentzVecor() :
  vec3(), dt(0.0){}

HepLorentzVector::
HepLorentzVector(double x, double y, double z, double t) :
  vec3(x, y, z), dt(t) {}

HepLorentzVector::
HepLorentzVector(const HepLorentzVector &v ) :
  vec3(v.vec3), dt(v.dt) {}
```

- note use of initializers
- must construct data members when constructing class object

Let 3-vector component do part of the work

```
double HepLorentzVector::mag() {
    return sqrt(dt*dt - vec3.mag2() );
}
```

must still implement functions like

```
double HepLorentzVector::x() {
    return vec3.x();
}
```

YAPI

Constructors

```
class HepLorentzVector {
public:
  HepLorentzVector();
  HepLorentzVector(double x, double y, double z, double t);
  HepLorentzVector(const HepLorentzVector &v);
  inline double x();
  inline double y();
  inline double z();
  inline double t();
  inline double mag();
  // much more not shown
private:
  Hep3Vector *vec3;
  double dt;
};
```

- still have containment, but use a pointer
- makes sense in some situations (probably not here)

YAPI implementation

Constructors might be

```
HepLorentzVector::HepLorentzVector() : dt(0.0)
{
  vec3 = new Hep3Vector(0, 0, 0);
}

HepLorentzVector::
HepLorentzVector(double x, double y, double z, double t) :
  dt(t)
{
  vec3 = new Hep3Vector(x, y, z);
}

HepLorentzVector(const HepLorentzVector &v ) : dt(v.dt)
{
  vec3 = new Hep3Vector( *v.vec3); // copy constructor
}
```

- using `new` operator to create one object
- will need to implement destructor!

Inheritance

Part of the header file

```
class HepLorentzVector : public Hep3Vector {
public:
  HepLorentzVector();
  HepLorentzVector(double x = 0., double y = 0.,
                   double z = 0., double t = 0.);
  HepLorentzVector(const HepLorentzVector &v);
  HepLorentzVector(const Hep3Vector &p, double t);
  double t();
  double mag();
  // much more not shown
private:
  double dt;
};
```

- `HepLorentzVector` *is-a* `Hep3Vector`
- All public members of `Hep3Vector` are also public members of `HepLorentzVector` by use of keyword `public` in class declaration.
- member function `t()` is added
- member function `mag()` overrides function of same name in `Hep3Vector`
- constructors take different arguments
- one new data member: `dt`

Use of Lorentz Vector

Consider

```
int main() {
  double x, y, z, t;
  while ( cin >> x >> y >> z >> t ) {
    Hep3Vector a3Vec(x, y, z);
    HepLorentzVector a4Vec(x, y, z, t);

    cout << "3-vector x and mag: "
         << a3Vec.x() << " " << a3Vec.mag() << endl;
    cout << "4-vector x and mag: "
         << a4Vec.x() << " " << a4Vec.mag() << endl;
  }
  return 0;
}
```

- `HepLorentzVector` behaves like any other class
- how does `a4Vect.x()` work since no member function has been defined?… by inheritance
- `a4Vec.mag()`, however, is completely different from `a3Vect.mag()`
- output of program

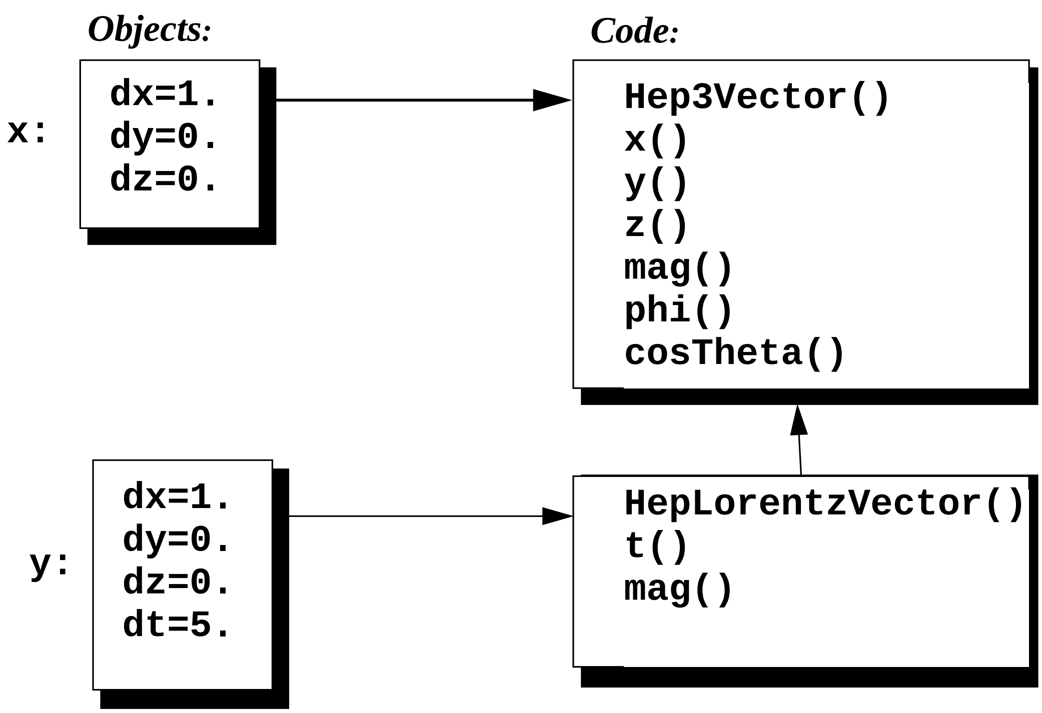
```
hpkaon> a.out
1 1 1 2
3-vector x and mag: 1 1.73205
4-vector x and mag: 1 1
```

Memory model

Consider

```
Hep3Vector x(1.0, 0.0, 0.0);
HepLorentzVector y(1.0, 0.0, 0.0, 5.0);
```

In computer's memory we have



- inheritance of data members
- inheritance of member functions

Constructor Implementations

Constructors

```
HepLorentzVector::
HepLorentzVector(double x, double y, double z, double t) :
  Hep3Vector(x, y, z), dt(t) {}

HepLorentzVector::
HepLorentzVector(const Hep3Vector &v, double t) :
  Hep3Vector(v), dt(t) {}

HepLorentzVector::
HepLorentzVector(const HepLorentzVector &v) :
  Hep3Vector(v), dt(v.dt) {}
```

- super class will be constructed before subclass
- use initializers to direct how to construct superclass

More of Implementation

As you might expect

```
inline double HepLorentzVector::t() const {
  return dt;
}
```

- the `t()` member function is like we’ve seen before

This doesn’t work

```
inline double HepLorentzVector::mag2() const {
  return dt*dt - (dx*dx + dy*dy + dz*dz);
}
```

- `dx`, `dy`, and `dz` were declared `private`
- `private` means access to objects of the same class and `HepLorentzVector` is a different class
- could modify `Hep3Vector` to

```
class Hep3Vector {
public:
// same as before
protected:
double dx, dy, dz;
}
```

- `protected:` means access to members of the same class and all subclasses

More on Implementation

Keep the base class data members private

```
inline double HepLorentzVector::mag2() const {
  return dt*dt - Hep3Vector::mag2();
}
```

- use scope operator `::` to access function of same name in super class
- now we can re-write `Hep3Vector` to use `r`, `costheta` and `phi` without needing to re-write `HepLorentzVector`
- less dependencies between classes is good

Finally, we have

```
inline double HepLorentzVector::mag() const {
  double pp = mag2();
  return pp >= 0.0 ? sqrt(pp) : -sqrt(-pp);
}
```

- did you remember that 4-vector can have negative magnitude?

Even more of Implementation

The dot product

```
inline double
HepLorentzVector::dot(const HepLorentzVector & p) const {
  return dt*p.t() - z()*p.z() - y()*p.y() - x()*p.x();
}
```

- use of accessor functions `x()`, `y()`, and `z()` because data members are private in the super class
- scope operator `::` not needed because these functions are unique to the base class

The `+=` operator

```
inline HepLorentzVector &
HepLorentzVector::operator += (const HepLorentzVector& p) {
  Hep3Vector::operator += (p);
  dt += p.t();
  return *this;
}
```

- example of directly calling operator function

Many other functions will not be shown

They implement the vector algebra for Lorentz vectors

What’s new?

A Lorentz boost function

```
void HepLorentzVector::boost(double bx, double by, double bz){
  double b2 = bx*bx + by*by + bz*bz;
  register double gamma = 1.0 / sqrt(1.0 - b2);
  register double bp = bx*x() + by*y() + bz*z();
  register double gamma2 = b2 > 0 ? (gamma - 1.0)/b2 : 0.0;

  setX(x() + gamma2*bp*bx + gamma*bx*dt);
  setY(y() + gamma2*bp*by + gamma*by*dt);
  setZ(z() + gamma2*bp*bz + gamma*bz*dt);
  dt = gamma*(dt + bp);
}
```

- `register` keyword advises compiler that variable should be optimized in machine registers

Also have

```
inline Hep3Vector HepLorentzVector::boostVector() const {
  Hep3Vector p(x()/dt, y()/dt, z()/dt);
  return p;
}
inline void HepLorentzVector::boost(const Hep3Vector & p){
  boost(p.x(), p.y(), p.z());
}
```

Diagrams

The old ones

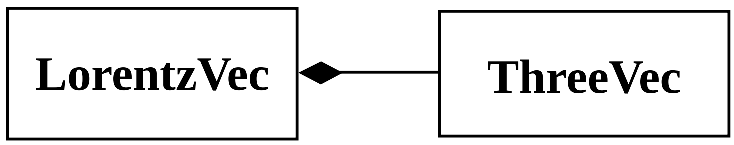
- Booch's "clouds", supported by Rational/Rose
- Rumburgh's OMT

The new one

- UML: Unified Modeling Language
- Booch and Rumburgh working together
- later joined by Jacobsen
- the "three amigos"
- submitted for standardization

Aggration

If we have a *has-a* relationship we draw it thus



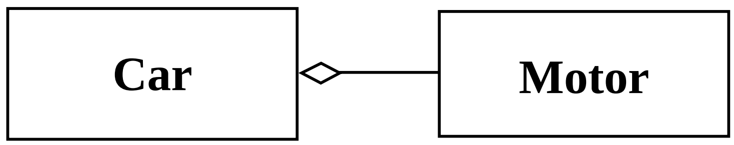
- corresponding code…

```
class LorentzVec {
  // much more not shown
private:
  ThreeVec vec3;
  double dt;
};
```

- `LorenzVec` contains `ThreeVec`
- contained object will be destroyed with the containing object is destroyed

Association

If we have *a association* relationship we draw it thus



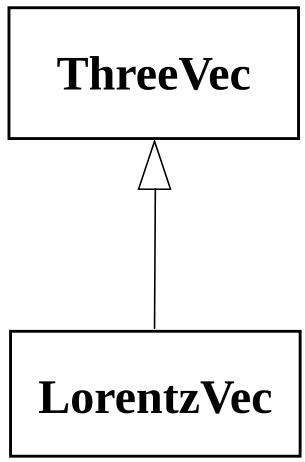
- corresponding code…

```
class Car {
  // much more not shown
private:
  Motor *m;
  };
```

- `not 100% sure just because we have pointer`
- only association if motor is replaceable
- depends on what kind of application this `Car` class is being used for.

Inheritance

If we have *is-a* relationship we draw it thus



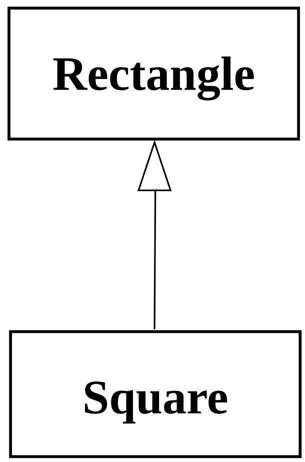
- corresponding code

```
class LorentzVec : public ThreeVec {
  // much more not shown
private:
  double dt;
};
```

- this is class relationship, not object relationship
- don't be confused with our memory model diagrams
- we say `ThreeVec` is base class and `LorentzVec` is derived class

Bad inheritance

When a square is a rectangle and when it isn't



- corresponding code

```
class Rectangle {
  // much more not shown
  void setLength(float);
  void setHeight(float);
//...
  float length, height;
};
```

- now what's the `Square` going to do about these member functions?
- in math, a square is a subset of all rectangles, but in C++ a `Square` is not a subclass of `Rectangle`

A Possible Particle class

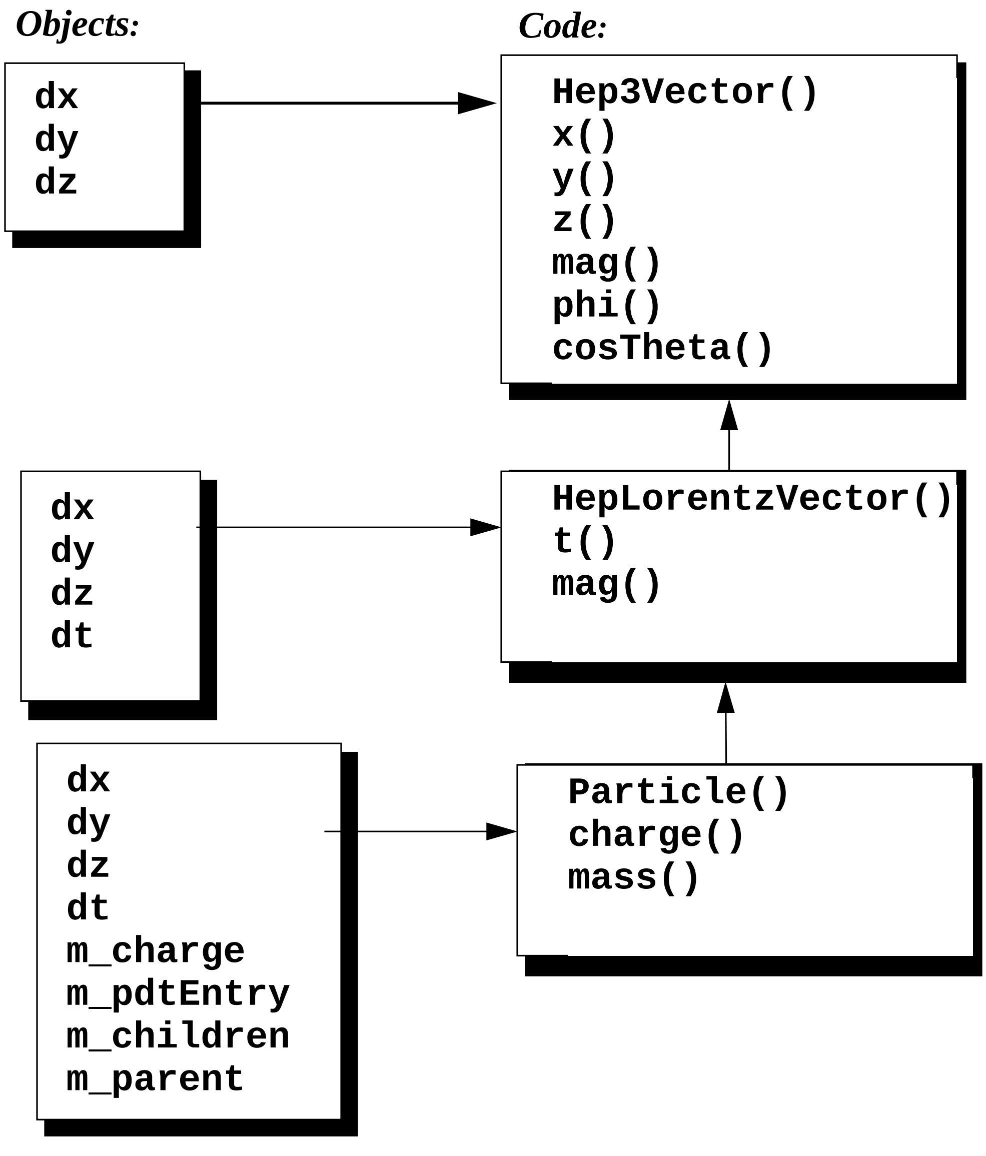
Take Lorentz vector and add to it

```
class Particle : public HepLorentzVector
{
public:
     Particle();
     Particle(HepLorentzVector &, PDTEntry *);
     Particle(const Particle &);
     ~Particle() {}
     float charge() const;
     float mass() const;
  // more methods not shown
protected:
     float m_charge;  // units of e
     PDTEntry * m_pdtEntry;
     std::list<Particle *> m_children;
     Particle * m_parent;
};
```

- note one can inherit from a class which is derived class
- added features are charge, pointer to entry in particle data table, list of children, and pointer to parent
- owns list of children
- `m_pdtEntry` and `m_parent` are pointers because of shared objects
- not very useful class

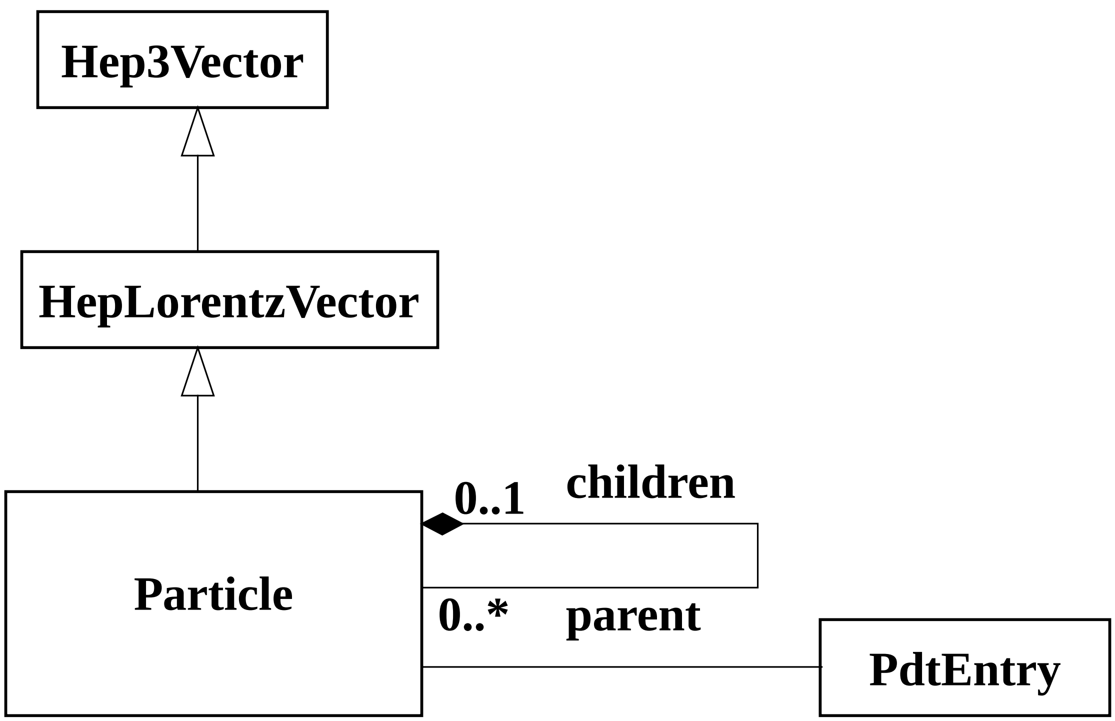
Data Model

In computer's memory we have



Class Diagram

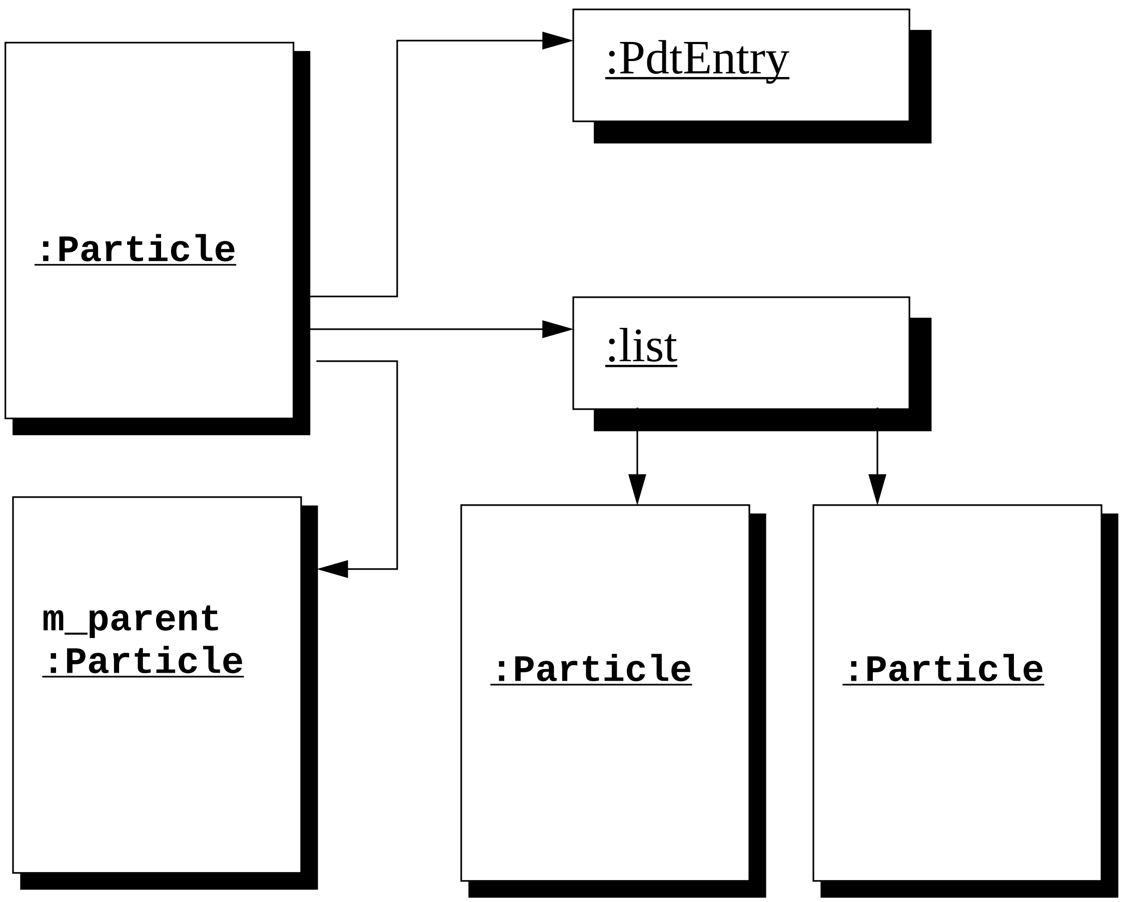
Inheritance and relationships



- `Particle` has 0 to n children and 0 or 1 parents
- `Particle` has association with `PdtEntry`
- we leave the `list<>` out of the picture

Object Hierarchy

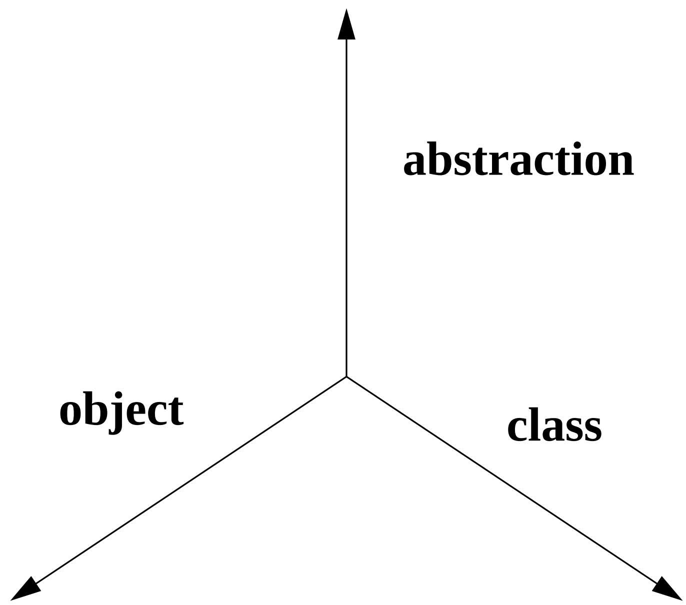
In computer memory we have



- the class and object hierarchies are different in dimensions

The 3 hierarchies of OOP

It's a three dimensional space



- Class hierarchy describes behavior
- Object hierarchy describes data structure
- hierarchy of levels of abstraction, *e.g.* float, vector, lists, arrays, particle, *etc.*

Multiple Inheritance

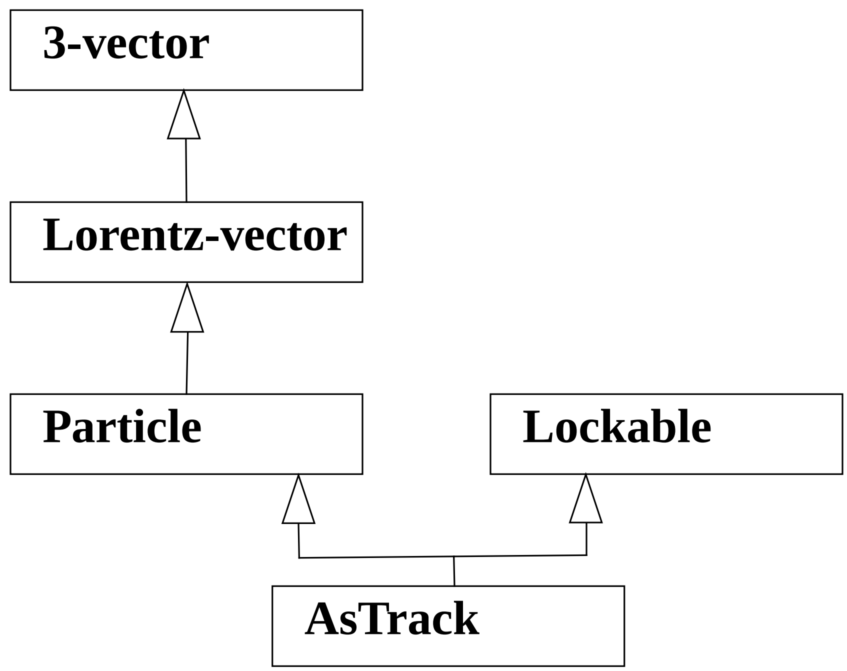
One can inherit from more than one class

```
class AsTrack : public HepLockable, public Particle
{
public:
     AsTrack();
     AsTrack(AsEvent *e, int type, int index);
     AsTrack(const AsTrack &);
     virtual ~AsTrack();
  // more member functions not shown
}
```

- `AsTrack` inherits from both `Particle` and `HepLockable`
- both data members and member functions are inherited from both classes

Class hierarchy

For both data members and functions we have



- `AsTrack` has the functions defined in itself and all of its super classes
- `AsTrack` has data members defined in itself and all of its super classes

`AsTrack`'s constructor

Beginning of constructor

```
AsTrack::AsTrack(AsEvent *e, int type, int index)
   : Lockable(), Particle()
{
     _type = type;
     _index = index;
     int ftype = type + 1;
     int find = index + 1;
     float p[20];
     trkallc(&ftype, &find, p);

     setX(p[0]);
     setY(p[1]);
     setZ(p[2]);
     setT(p[3]);
     _charge = p[10];
  // more not shown
```

- note calling the constructors of the super classes
- careful: the super class constructors are called in order of the class definition, not necessarily in the order listed in the constructor.
- `trkallc` is a Fortran subroutine that fetches data out of ASLUND's COMMON blocks

Summary

We now know enough C++ to do a physics analysis

Next session we'll look at polymorphic uses of inheritance with examples from Gismo

Then, we'll be pretty much done with learning the language

It's soon time to start some mini-projects using C++