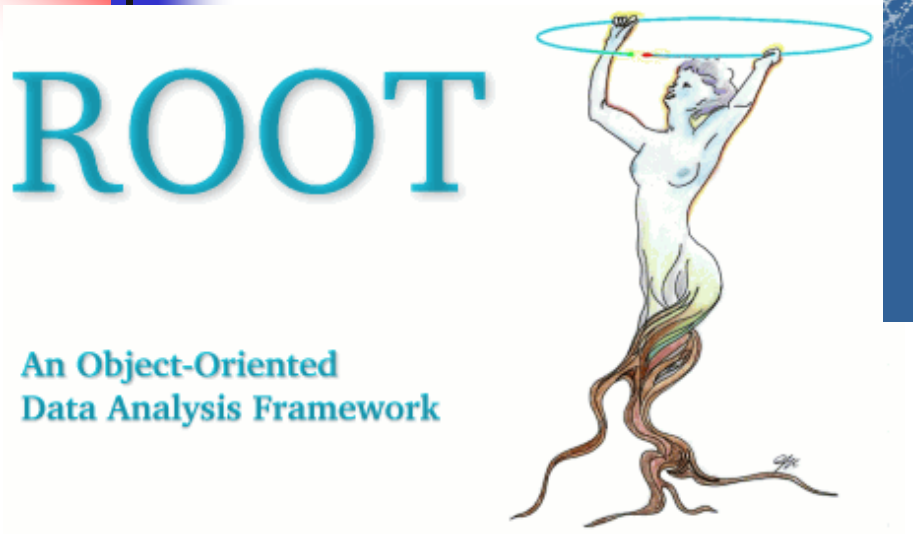
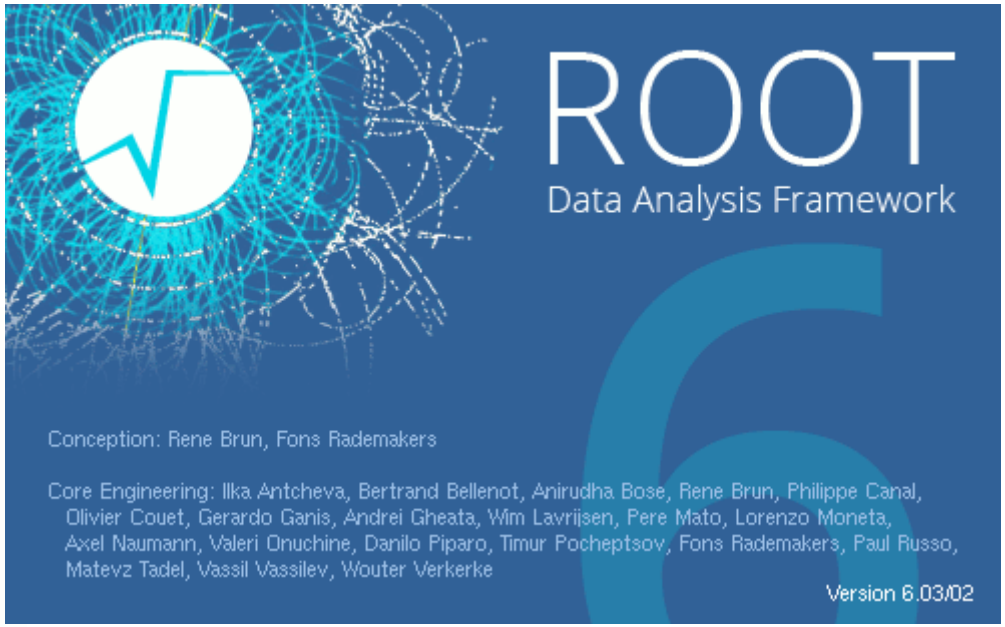


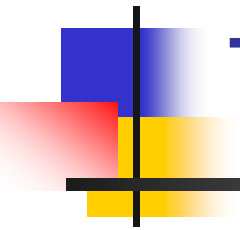


Part 3

Luciano Pandola

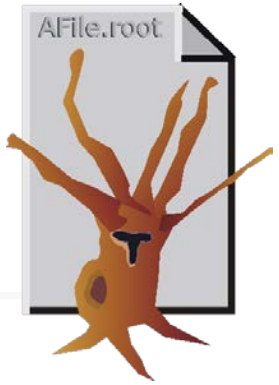
INFN, LNS

Thanks to: N. Di Marco, S. Panacek and A. Tramontana



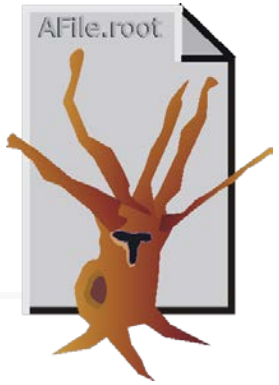
The TTree (finally!)

The ROOT trees (TTree)



- A TTree is the ROOT implementation of a old-dear ntuple
  - Table of correlated values/objects
    - E.g. energy, time and rise time of the same event
- The objects are **not necessarily numbers**
  - It can be an array or any ROOT object
    - This includes **user-custom** ROOT objects
  - The arrays can be also of variable size for each row
    - The actual size of the array is stored in an other column of the tree
- Optimized to save and manage efficiently a large number of entries
  - It is a real option for storage (e.g. raw data)

The ROOT trees (TTree)



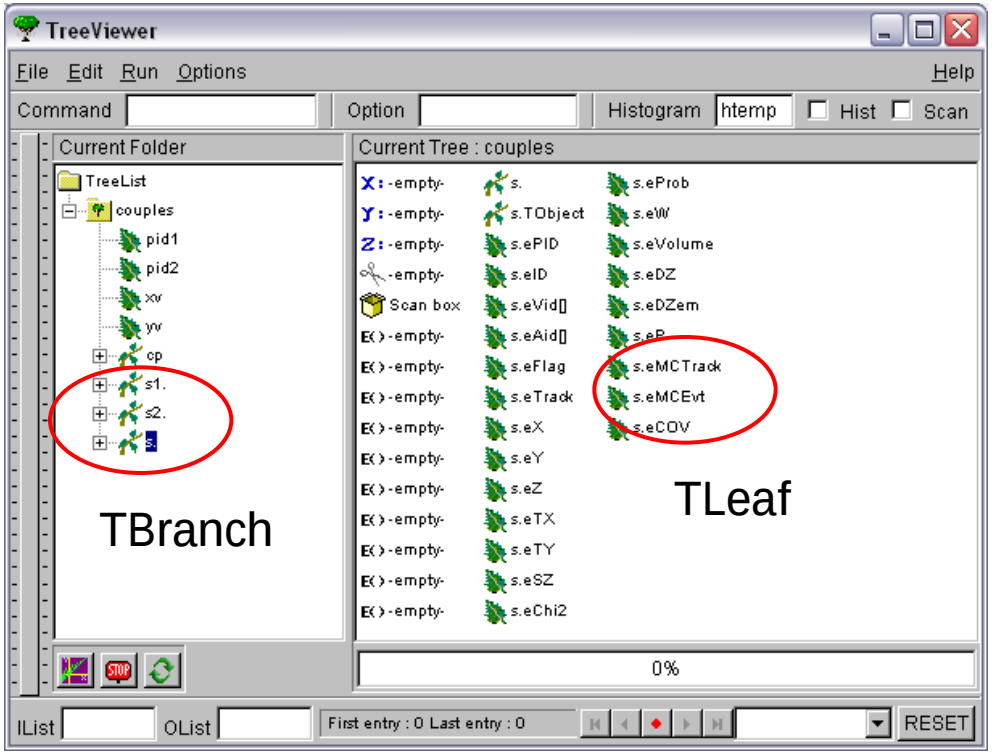
- The TTree is organized in a hierarchical structure of branches (TBranch) and leaves (TLeaf)
  - It is possible to read selectively from one branch or leaf only → no need to load the entire tree
  - In principle, branches can be written to different files
- Additional branches can be added at a later stage
  - E.g. as a result of some kind of analysis
- Surely the most powerful and flexible ROOT object

Explore the content of a TTree

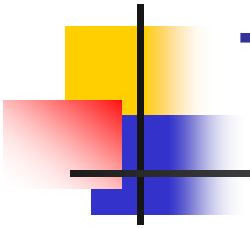
- A TTree can be loaded from a TFile exactly like a histogram, i.e. via **->Get()**

```
[] TTree* myTree =
  (TTree*) f.Get("name");
[] myTree->StartViewer();
```

The tree viewer allows the **interactive access** to the tree and to all branches and leaves → double click to plot



Command-line handling of TTrees - 1



List of all variables (leaves and branches):

```
[ ]> tree->Print()
```

One-dimensional plot of a variable

```
[ ]> tree->Draw("varname")
```

Scatter plot of two variables

```
[ ]> tree->Draw("varname1:varname2")
```

Add a graphical option (lego2)

```
[ ]> tree->Draw("varname1:varname2", "", "lego2")
```

Add a **cut** based on an other variable

```
[ ]> tree->Draw("varname1:varname2", "varname3>0", "lego")
```

Scatter plot of three variables

```
[ ]> tree->Draw("varname1:varname2:varname3")
```

Command-line handling of TTrees - 2

Show completely the content of one event (all leaves)

```
[ ]> tree->Show(eventNumber);
```

Fit of the 1-dim distribution of one variable

```
[ ]> tree->Fit("func", "varname")
```

Fit adding a cut

```
[ ]> tree->Fit("func", "varname", "varname > 10")
```

Class **TCut** to define specific cuts

```
[ ]> TCut cut1="varname1>0.3"
[ ]> tree->Draw("varname1:varname2",cut1)
[ ]> TCut cut2="varname2<0.3*varname1+89"
[ ]> tree->Draw("varname1:varname2",cut1 && cut2)
```

Create and fill a TTree

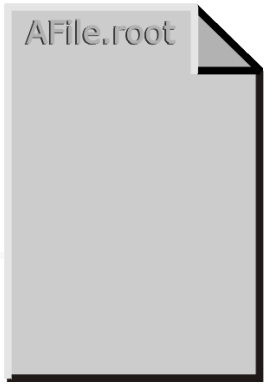
- It is a bit worksome: 5 steps required
  1. Create the TFile
  2. Create the TTree
  3. Register TBranch to TTree
  4. Fill the TTree
  5. Write the output file
- Easy situation: load branches (only numbers!) from an existing ASCII file

```
TTree* tree = new TTree("tree","My Tree Title");
tree->ReadFile("myfile.dat","energy/D:time/D:id/I");
```

filename

Branches and types (D, I)

Building a TTree - 1



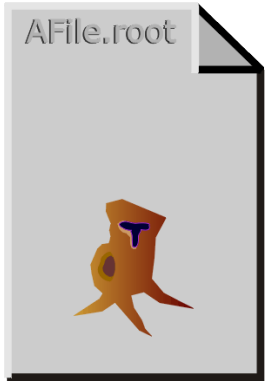
- Step 1: Create a new TFile

```
TFile *myfile = new TFile(“test.root","RECREATE");
```

The constructor of TFile has arguments:

- ✓ file name (i.e. “test.root ")
- ✓ options: NEW, CREATE, RECREATE, UPDATE, or READ

- Step 2: Create a TTree object

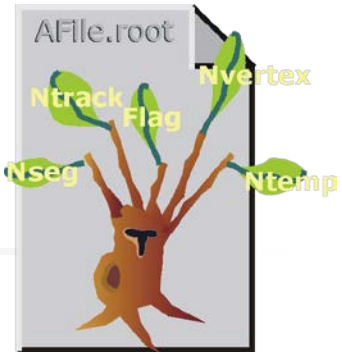



```
TTree *tree = new TTree("myTree","A ROOT tree");
```

The constructor of TTree has arguments:

- ✓ Tree Name (e.g. "myTree")
- ✓ Title (choose a descriptive one, possibly!)

Building a TTree - 2



- Step 3: Add the branches
- Simplest option: **TBranch = TLeaf**
  - Each branch contains only one variable
- Map each branch into a memory address (i.e. a pointer)

Memory address where read the value from

Variable type

```
Int_t ntrack;
Double_t energy;
Double_t myArray[10];
myTree->Branch("NTrack",&ntrack,"ntrack/I");
myTree->Branch("Energy",&energy,"energy/D");
myTree->Branch("MyArray",myArray,"myArray[10]/D");
```

Notice: an array is already a pointer

Building a TTree - 3

- Many possible types

```
- C : a character string terminated by the 0 character
- B : an 8 bit signed integer (Char_t)
- b : an 8 bit unsigned integer (UChar_t)
- S : a 16 bit signed integer (Short_t)
- s : a 16 bit unsigned integer (UShort_t)
- I : a 32 bit signed integer (Int_t)
- i : a 32 bit unsigned integer (UInt_t)
- F : a 32 bit floating point (Float_t)
- D : a 64 bit floating point (Double_t)
- L : a 64 bit signed integer (Long64_t)
- l : a 64 bit unsigned integer (ULong64_t)
- O : [the letter 'o', not a zero] a boolean (Bool_t)
```

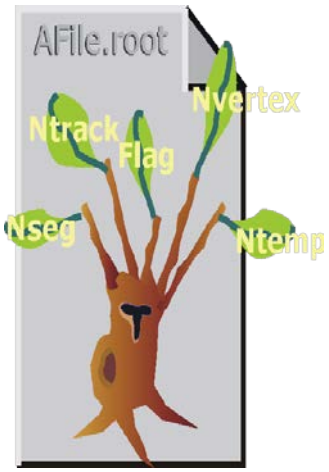
- But one can also use user-custom classes as TBranch
  - Typical case: the class already "packs" in itself all the relevant information (e.g. MyEvent)
  - So, have a TTree of MyEvents

Building a TTree - 4

- Step 3 (alternative): Add the Branches from user-defined classes

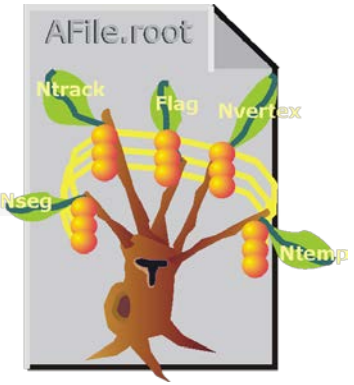
User custom class

```
MyEvent *event = new MyEvent();
myTree->Branch("EventBranch","Event",&event);
(or) myTree->Branch("EventBranch",&event);
```



- ✓ Branch Name
- ✓ Class name (optional)
- ✓ Memory address (pointer) of the object to be stored (MyEvent, in this case)
  - ✓ The class MyEvent may contain several data members (e.g., Ntrack, Flag)
  - ✓ Each of them becomes a TLeaf

Building a TTree - 5



- Step 4: Fill the TTree

✓ Set the proper values to all variable/objects that have been registered as branches or leaves and **`Fill()`**

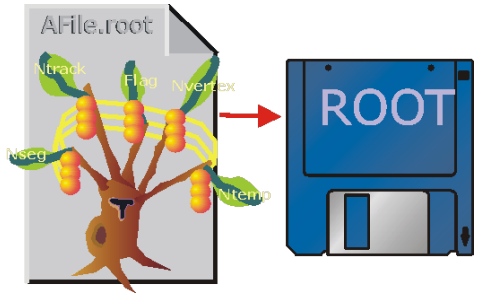
```
nTrack = 5;
energy = 12.5;
myTree->Fill();
```

✓ The operation can be repeated within a **`for()`** loop

- Step 5: Save the TTree on the TFile

The method **`Write()`** of TFile **writes automatically** all TTrees and all histograms

```
myFile->Write();
```



One extra filling option

- There is the possibility to have arrays of variable size as leaves of a TTree
  - Typical case: suppose you have 1000 detectors and only one or two have a signal in each event
    - Would you store two numbers and 998 zeroes?
    - Store only the two numbers (and the detector ID!)
- The number of elements (event-per-event) is stored in an other leaf of the TTree

```
Int_t nDetectors;
Double_t energy[NMAX];
fTree = new TTree("tree","Global results");
fTree->Branch("NDetectors",&nDetectors,"NDetectors/I");
fTree->Branch("Energy",energy,"energy[NDetectors]/D");
```

Ok, now we want to read the TTree back

- Already described how to open, read and plot a TTree from command line (interactively)
  - Print(), Draw(), Show(), ...
  - Scatter plots, cuts on variables,...
- But what about retrieving the content of each TLeaf for each event from a macro or from a C++ code?
  - This is surely necessary for any real-life analysis with a fair amount of data
- ROOT tutorial available in

  `$ROOTSYS/tutorials/tree1.C`

How to read a TTree - 1

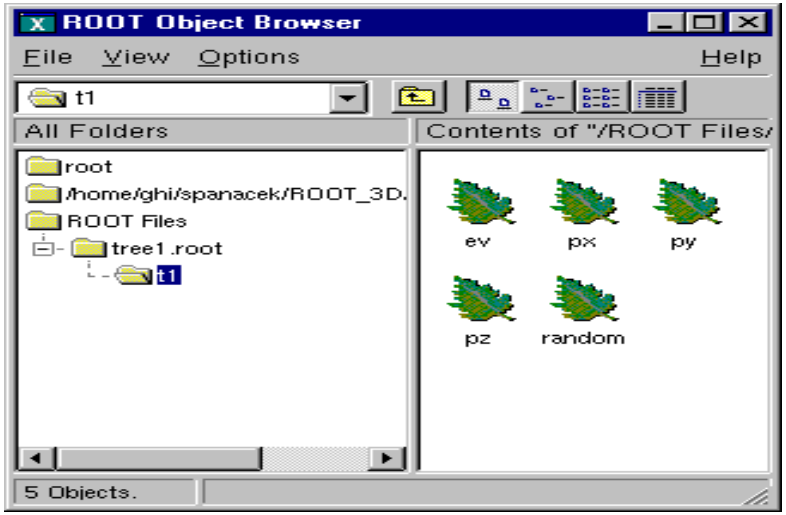
- Open the TFile which contains the TTree

```
TFile* file = new TFile ("tree1.root")
file->ls();
```

- Retrieve the TTree (via the name)

```
TTree * t1 =
(TTree*)file.Get("t1")
t1->Print();
(or) t1->StartViewer()
```

The TTree here has 5 leaves, named ev, px, py, pz and random



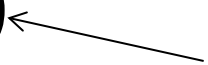
How to read a TTree - 2

- Create the appropriate variables to store the data in the leaves

```
Float_t px, py;
```

- Map the branches/leaves that you want to read into your local variables (better, into the memory address of them)
  - You do not have to read all branches, but only some of them, if you wish

```
t1->SetBranchAddress("px",&px)
t1->SetBranchAddress("py",&py)
```



Branch name Memory address

How to read a TTree - 3

- Read each row of the TTree using GetEvent(ID);

```
t1->GetEvent(0); //read first event
```

- After *each call* of GetEvent() , the variables that are mapped to a branch **get their actual values**
- One can loop over entries and read the entire tree

```
for (Int_t i=0;i<t1->GetEntries(); i++)
 {
  t1->GetEvent(i);
  //do what you need with the tree content
 }
```

Load many TTrees: the TChain

- Sometimes, you want to merge/load trees **split in many files**
  - Same tree name, same branches
- May happen e.g. because
  - The tree is too big and it is split in many files
  - There is one file per each run of your experiment and you want to load the entire dataset

```
TChain *ch = new TChain("tree");
ch->Add("run1.root");
ch->Add("run2.root");
ch->Print()
ch->GetEntries() …
```

Add files

Use TChain **as a TTree**

Common name of all trees

Adding a branch to an existing TTree

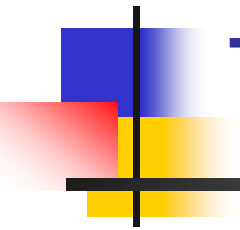
- It is possible to add a new TBranch to a TTree which already exists
  - Typical case: you want to add some extra variable calculated from the others

```
TFile f("tree3.root", "update");
Float_t new_v; //variable for the new branch
TTree *t3 = (TTree*)f->Get("t3");
TBranch *newBranch = t3->Branch("new_v", &new_v,
"new_v/F");
for (Int_t i = 0; i < t3->GetEntries(); i++){
     new_v= gRandom->Gaus(0, 1);
     newBranch->Fill();
   }
t3->Write("", TObject::kOverwrite);
```

Attach the branch to the tree

← Fill only the new branch

← Save only new version

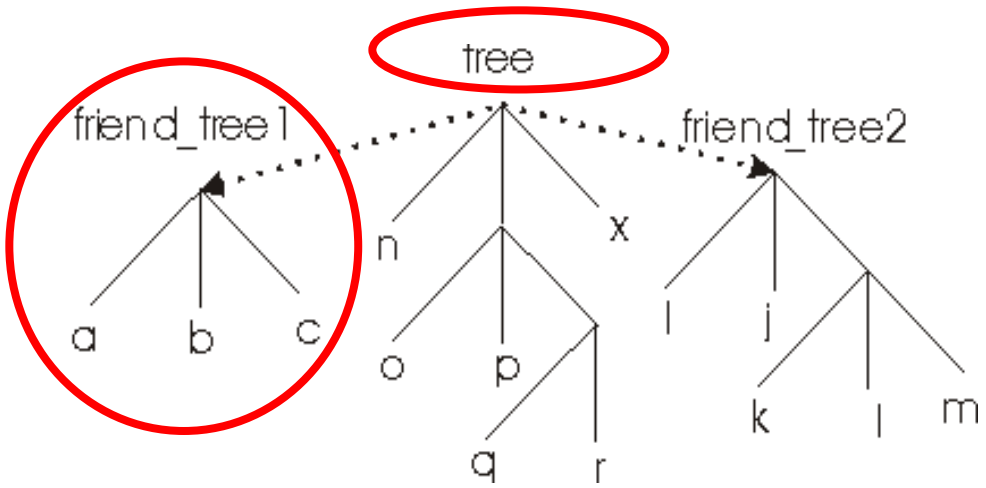


The TTree friendship

TTree friends

- In some cases, it is not possible/advisable to add a new branch to an existing tree
  - The parent tree might be readonly (raw data!)
  - Risk of losing the original tree with an unsuccessful attempt to save the modification
- Solution: add a **TTree friend**
  - Each TTree has unrestricted access to **all** fields/data of its own friends

To all practical purposes, this is equivalent to a **single TTree** which contains tree, friend_tree1 and friend_tree2



Add friends to a TTree

- **`AddFriend("treeName","fileName")`**

  `mytree->AddFriend("ft1","ff.root")`

  - If no file name is given, the friend tree is looked for in the same TFile as the starting tree

- If the TTree's have the same name, it is mandatory that the friend gets an "alias" so that the trees **can be distinguished**

  `mytree->AddFriend("tree1 = tree", "ff.root")`

Access to the friends

- Access:

  `treeName.branchName.leafName`

  - The leafName only is sufficient if it unambiguosly identifies the leaf

- Example:

```
mytree->Draw("t2.px")
mytree->Draw(“t2.pz”,”t1.px>0”)
mytree->SetBranchAddress("t2.px",&p)
```

- List of all branches

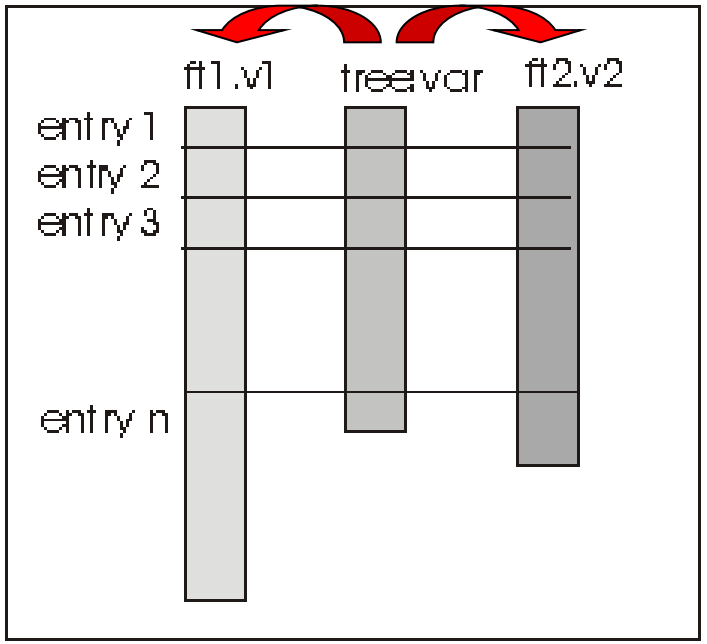
```
mytree->Print("all");
```

Access to all variables of all TTrees

The friend list

- The number of entries of the friends tree must be equal or larger than the "main" tree

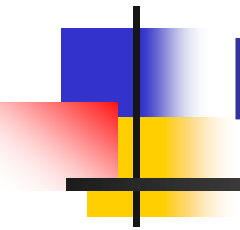
- The "main" tree must be the shortest one (→ "tree", here)
- **`ft1`** can be friend of **`tree`**, but **`tree`** cannot be friend di **`ft1`**



Access to the friend list:

`TTree::GetListOfFriends()`

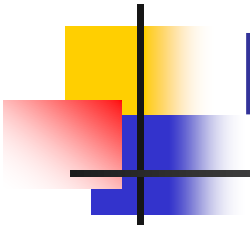
Definition of user-custom ROOT classes



One more step ahead: "ROOTify" your own class

- It is possible to **ROOTify user-classes**, so that they are handled as ROOT classes:
  - instantiated by command line
  - written in ROOT files
  - used as branches in a Tree
- Typical case: customized "containers" (e.g. **`MyEvent`**) and new objects (e.g. **`MyTRun`**)
  - Encapsulate and "pack" the information of an event: a "run = TTree of MyEvent objects"
- Can be done as:
  - Command line (but **no I/O**)
  - Via **ACLiC** (= compiled code)

Define your own class in ROOT



- Step 1: the user class must inherit from **`TObject`** (or from the derived class **`TNamed`**)
  - The user class inherits all characteristics of the ROOT objects, as the name (string) and all methods for I/O and management (e.g. **`Write()`**)
- Step 2: add to the source code the lines

  `ClassDef(ClassName,ClassVersionID)`

  At the end of the *header* (.h)

  Takes a version number ID

  `ClassImp(ClassName)`

  At the beginning of the *implementation* (.c)

ClassDef() and ClassImp()

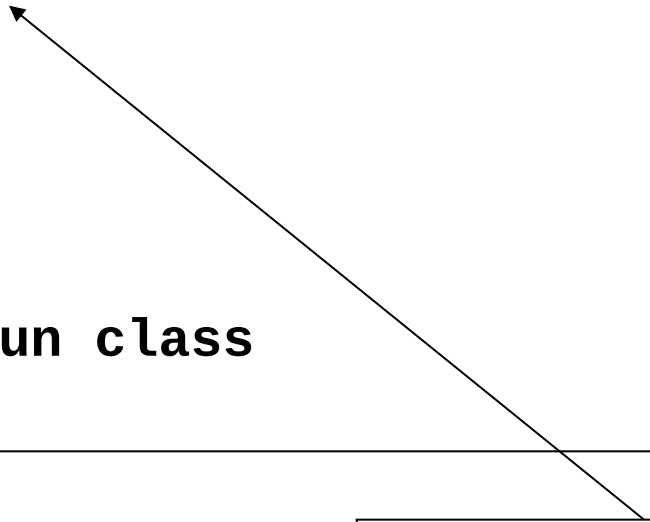
- **`ClassDef()`** and **`ClassImp()`** are **macros** defined in ROOT
- They are required to manage the I/O of the object
- They actually yield:
  - The streamer methods to write the objects in a **ROOT file** or as **branches of a TTree**.
  - Method **`ShowMembers()`** to list public class members
  - Overload of the input operator >>
- User must provide a default constructor for his/her class

A concrete example

```
class MyTRun : public TNamed
{
public:
  MyTRun() {;};
  virtual ~MyTRun(){;};

  ClassDef(MyTRun, 1) // Run class
};
```

.h



ROOT inheritance

```
#include "MyTRun.hh"

ClassImp(MyTRun);
```

.c

That's not enough...

- Step 3: (optional) create a file called **LinkDef.h**. It is required to notify ROOT of the presence of a new user-custom class, to be included in the dictionary

```
#ifdef __CINT__          ROOT <= 5
#ifdef __CLING__         ROOT 6
#pragma link off all globals;
#pragma link off all classes;
#pragma link off all functions;
#pragma link C++ class MyTRun;
#endif
```

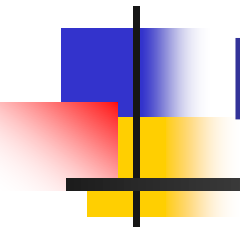
Line to add

Still, that's not enough...

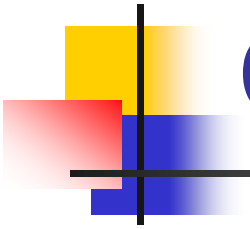
- Step 4 (and last): Create the dictionary using the command **rootcint**

```
$(ROOTSYS)/bin/rootcint
-f MyDictionary.cxx
-c MyTRun.cxx [LinkDef.h]
```

- The output are the files **MyDictionary.cxx** and **MyDictionary.h**
  - They are **compiler-ready** and can be used to produce a shared library
- **LinkDef.h** (if given) must be the last argument of the **rootcint** command line
  - The name of the LinkDef file must contain the string LinkDef.h or linkdef.h:
  - **MyNice_LinkDef.h** is ok
- Notice: for ROOT 6, use **rootcling** instead of **rootcint**



ROOT extras



Other tools available in ROOT

- In these lectures, there was only an overview of the main tools available in ROOT
- There are **many more**, e.g.
  - Linear algebra and matrix/vector calculations
  - Support for custom GUI's and interface to Qt
  - Handling of spectra (**`TSpectra`**)
    - Automatic peak finding, fitting, etc.
  - Python module (PyROOT)
- Not all tools are compiled by default when building ROOT
  - some of them have to be activated explicitly

Other tools available in ROOT

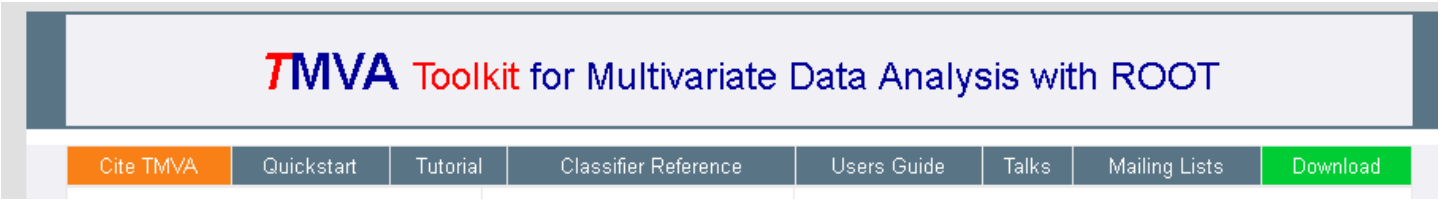
- Additional tools for (advanced) fitting
  - Minuit2
  - **RooFit**
- **RooFit** initialially developed by BaBar
  - Model the expected event distribution of events
  - Unbinned maximum likelihood fits
  - Generate "toy Monte Carlo" samples for various studies

```
gSystem->Load("libRooFit") ;
using namespace RooFit ;
```

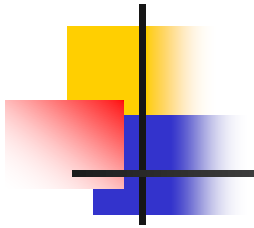
- Some modules/tools were provided by experiments or by other users

Other tools available in ROOT

- Toolkit for Multivariate Data Analysis (TVMA)
  - External package, distributed with ROOT



  - Includes advanced analysis tools like:
    - Artificial Neural Networks, Boosted/Bagged decision trees, Support Vector Machine, Multidimensional probability density estimation, Rectangular cut optimisation
- User custom modules can be built and **integrated** in the ROOT source dir
  - Makefile **`MyModules.mk`** provided



It is your turn, now:

- Try Task2 under

http://geant4.lngs.infn.it/ROOTAlghero2015/introduction/index.html