Andrew Savchenko
NRNU MEPhI, Moscow, Russia
24 August 2014
Outline

1. Introduction
2. ROOT Features
3. Applications
4. Summary

Disclaimer: most images are taken from official ROOT sources
Introduction

HEP (high energy physics) aside from scientific research pushes leading edge technology as its byproduct.

Main demands for data processing:
• for petabytes of data:
  • effective storage
  • fast analysis

• extensible framework

And so ROOT (ROOT Object Oriented Toolkit) was born in 1995 for NA49 experiment. PAW is its ancestor, Rene Brun is founder of both projects.
HEP (high energy physics) aside from scientific research pushes leading edge technology as its byproduct.

Main demands for data processing:
- for petabytes of data:
  - effective storage
  - fast analysis
- extensible framework

And so ROOT (ROOT Object Oriented Toolkit) was born in 1995 for NA49 experiment. PAW is its ancestor, Rene Brun is founder of both projects.
HEP (high energy physics) aside from scientific research pushes leading edge technology as its byproduct.

Main demands for data processing:
- for petabytes of data:
  - effective storage
  - fast analysis
- extensible framework

And so ROOT (ROOT Object Oriented Toolkit) was born in 1995 for NA49 experiment. PAW is its ancestor, Rene Brun is founder of both projects.
C++11 framework

Typically each experiment creates own classes and applications based on ROOT framework.
Key features

- Cross-platform: Linux, MacOS, Windows
- All major compilers: gcc, clang, icc
- LGPL-2.1 (+ other free licenses for aux components)

- C++11 framework for building applications
- Analysis tools

- Regular compilation/linking
- C++ interpreter: Cling (LLVM/Clang based)
- Automatic interface to compiler (ACLiC)
Key features

• Cross-platform: Linux, MacOS, Windows
• All major compilers: gcc, clang, icc
• LGPL-2.1 (+ other free licenses for aux components)

• C++11 framework for building applications
• Analysis tools

• Regular compilation/linking
• C++ interpreter: Cling (LLVM/Clang based)
• Automatic interface to compiler (ACLiC)
Key features

• Cross-platform: Linux, MacOS, Windows
• All major compilers: gcc, clang, icc
• LGPL-2.1 (+ other free licenses for aux components)

• C++11 framework for building applications
• Analysis tools

• Regular compilation/linking
• C++ interpreter: Cling (LLVM/Clang based)
• Automatic interface to compiler (ACLiC)
Advanced features

• ~ 2700 C++ classes
• Statistical analysis tools (fitting, minimizing)
• Multivariate analysis (MVA)
• Neural networks
• Visualisation tools (including OpenGL)
• Effective data queries in large data sets
• Client/server networking
• Parallel computing facilities (PROOF)
• Grid, AFS
• ...
Advanced features

- ~ 2700 C++ classes
- Statistical analysis tools (fitting, minimizing)
- Multivariate analysis (MVA)
- Neural networks
- Visualisation tools (including OpenGL)
- Effective data queries in large data sets
- Client/server networking
- Parallel computing facilities (PROOF)
- Grid, AFS
- ...
C++ Interpreter

```
$ root -l
root [0] TF1 f1("func","sin(x)/x",0,10);
root [1] f1.Draw();
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [2] c1->Print("sin.pdf");
Info in <TCanvas::Print>: pdf file sin.pdf has been created
root [3] .q
```
C++ Interpreter

- \( \leq \) ROOT-5.x CINT (C Ineterpreter)
- \( \geq \) ROOT-6.x Cling
- ACLiC support for fast compiling and linking
- Can be separated from ROOT!

Cling features:
- based on Clang and LLVM
- JIT
- stricter C++11 support
C++ Interpreter

- \( \leq \)ROOT-5.x CINT (C Ineterpreter)
- \( \geq \)ROOT-6.x Cling
- ACLiC support for fast compiling and linking
- Can be separated from ROOT!

Cling features:
- based on Clang and LLVM
- JIT
- stricter C++11 support
ROOT File

File Header
- `root`: Root File Identifier
- `fVersion`: File version identifier
- `fBEGIN`: Pointer to first data record
- `fEND`: Pointer to first free word at EOF
- `fSeekFree`: Pointer to FREE data record
- `fNbytesFree`: Number of bytes in FREE
- `fNfree`: Number of free data records
- `fNbytesName`: Number of bytes in name/title
- `fUnits`: Number of bytes for pointers
- `fCompress`: Compression level

Logical Record Header (TKEY)
- `fNbytes`: Length of compressed object
- `fVersion`: Key version identifier
- `fObjLen`: Length of uncompressed object
- `fDatime`: Date/Time when written to store
- `fKeylen`: Number of bytes for the key
- `fCycle`: Cycle number
- `fSeekKey`: Pointer to object on file
- `fSeekPdir`: Pointer to directory on file
- `fClassName`: class name of the object
- `fName`: name of the object
- `fTitle`: title of the object
Tree structure
Math

- 3-Vectors and transform
- 4-Vectors and Lorentz Transformations
- Matrix computations
- Numerical algos: derivation, integration, etc
- Minimization functions
- PDF-based analysis
- All standard C, C++ functions: GSL, STL, Boost, etc
Event Display
GUI
GUI

Root Shower Event Display

ROOT Shower Monte Carlo
Event Display

Done - Total particles: 5612 - Waiting for next simulation
Particle = e+, E = 3.503e-002
Data analysis

Resolution in S9 at Corner of Xtals 204/224/205/225 @ 120 GeV without compensation

Fit results

Mean = 120.0635
Sigma = 0.6942
Sigma/Mean = 0.58%
chi2/Ndf = 1.91
Data analysis
Data analysis
Integration with other tools

Interpreters:
• C++ (Cling)
• Python
• Ruby (not in ROOT6 yet)

Simulation software:
• Geant-3, Geant-4
• Pythia-6, Pythia-8

• DB: MySQL, Postgres, Oracle, SQLite, ODBC
• CAD: OpenCascade
• OpenFOAM, R
• Grid, AFS, ...
Integration with other tools

Interpreters:
- C++ (Cling)
- Python
- Ruby (not in ROOT6 yet)

Simulation software:
- Geant-3, Geant-4
- Pythia-6, Pythia-8

- DB: MySQL, Postgres, Oracle, SQLite, ODBC
- CAD: OpenCascade
- OpenFOAM, R
- Grid, AFS, …
Integration with other tools

Interpreters:
- C++ (Cling)
- Python
- Ruby (not in ROOT6 yet)

Simulation software:
- Geant-3, Geant-4
- Pythia-6, Pythia-8

- DB: MySQL, Postgres, Oracle, SQLite, ODBC
- CAD: OpenCascade
- OpenFOAM, R
- Grid, AFS, ...
Higgs discovery

ATLAS Preliminary

Data 2011, $\sqrt{s} = 7$ TeV, $\int L dt = 4.8$ fb$^{-1}$

Data 2012, $\sqrt{s} = 8$ TeV, $\int L dt = 5.9$ fb$^{-1}$
Higgs discovery

2012 8 TeV

CMS preliminary
\( \sqrt{s} = 8 \text{ TeV} \ L = 5.3 \text{ fb}^{-1} \)

- Data
- 2 prompt \( \gamma \)
- 1 prompt \( \gamma \) 1 fake \( \gamma \)
- 2 fake \( \gamma \)
- Drell-Yan
- \( H \rightarrow \gamma \gamma \ (125 \text{ GeV}) \times 5 \)
Higgs discovery
Scope of applications

Outside of HEP and Nuclear Physics ROOT is used in:

• astronomy
• biology, bioengineering, bioinformatics
• computational neuroscience
• finance
• machine learning
• medicine
• natural language processing
Community

Visit root.cern.ch for details and downloads!

Mail list, forums and jira are available for discussion and reports.

Most user issues from novice till expert level are discussed.

Upstream is quite effective in patch review.

Thank you for attention!