Expressing Parallelism with ROOT

https://root.cern

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This Talk

ROOT helps scientists to express parallelism

- Adopting **multi-threading** (MT) and **multi-processing** (MP) approaches
- Following explicit and implicit paradigms
  - **Explicit**: give users the control on the parallelism's expression
  - **Implicit**: offer users high level interfaces, deal with parallelism internally

All available in ROOT 6.08 !

- General purpose parallel executors
- Implicit parallelism and processing of datasets
- Explicit parallelism and protection of resources
- R&Ds: functional chains and ROOT-Spark

See also Status and Evolution of ROOT by A. Naumann in this track!

General Purpose Parallel Executors

Parallel Executors

- **ROOT::TProcessExecutor** and **ROOT::TThreadExecutor**
  - Same interface: **ROOT::TExecutor**
  - Inspired by Python's *concurrent.futures.Executor*
- **Map, Reduce, MapReduce** patterns available

```
ROOT::TProcessExecutor pe(Nworkers);
auto myNewColl = pe.Map(myLambda, myColl);
```

A Word about the Runtime

- Multiprocessing: ROOT provides its own utilities
- Threading: adopted **Threading Building Blocks (TBB)**
  - Optional installation, necessary for multithreading
  - Task based parallelism
  - Build system builds and installs it if requested and not available
  - Interfaces not exposed directly
    - ➢ Complement with other runtimes in the future

https://threadingbuildingblocks.org

Implicit Parallelism in ROOT

Implicit Parallelism: Processing Trees

Case 1) Parallel treatment of branches - read, decompress, deserialise in parallel

- Immediately useful with sequential (and thus possibly not thread-safe) analysis code
- Example: PyROOT uses TTree::GetEntry() !

```
ROOT::EnableImplicitMT();

auto file = TFile::Open("http://root.cern.ch/files/h1/dstarmb.root");
TTree *tree = nullptr; file->GetObject("h42", tree);

for (Long64_t i = 0; tree->LoadEntry(i) >= 0; ++i) tree->GetEntry(i);
```

No change in user code required

Case 2) Parallel treatment of entries

ROOT::TTreeProcessor class, relies on **TTreeReader**

- One task per *cluster* scheduled: No duplication of reading+decompression
- See later for programming model example

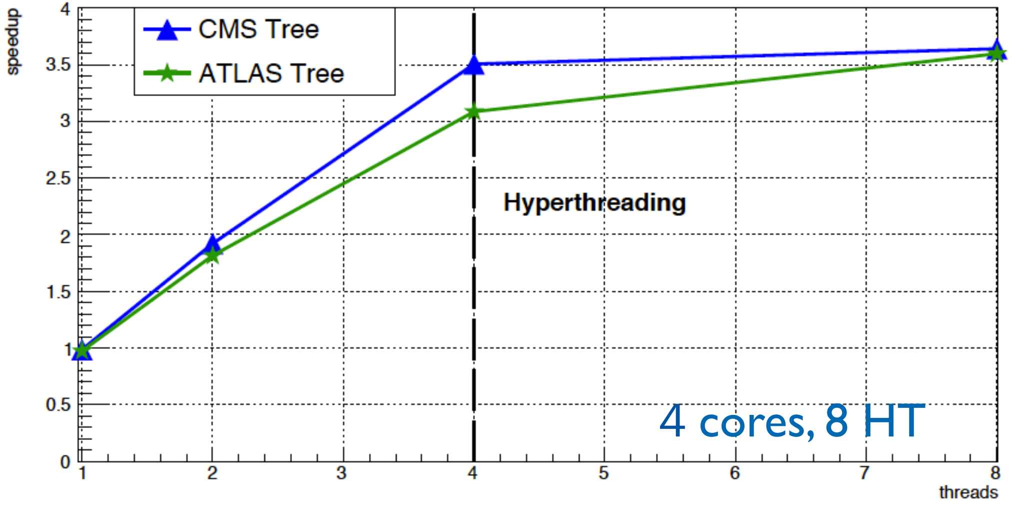
Implicit Parallelism: How To

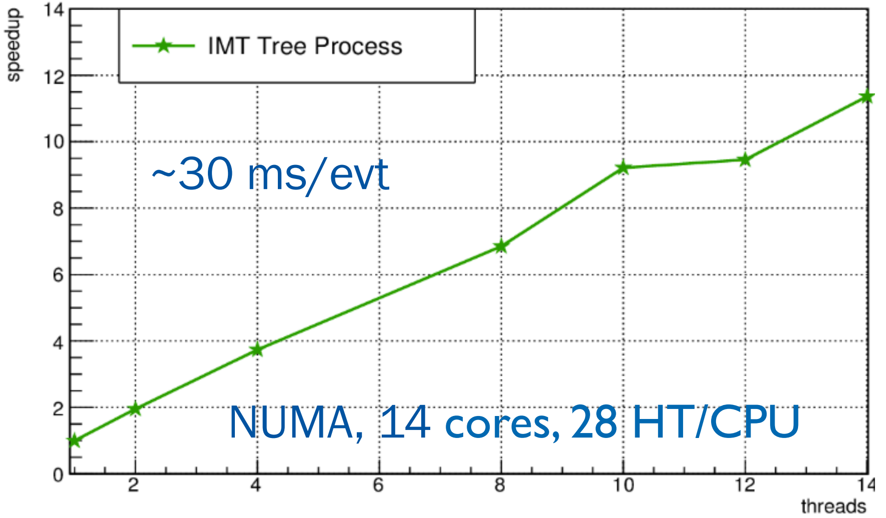
```
ROOT::EnableImplicitMT()
```

-Dimt=ON for configuring ROOT with CMake!

ROOT takes care of packetising work and submit it to the runtime

A Performance Figure





Parallel treatment of branches

- Only read, decompress, deserialize entire dataset
- **CMS**: ~70 branches, GenSim data
- **ATLAS**: ~200 branches, xAOD

Parallel treatment of entries

- Basic analysis of MC tracks
- 50 *clusters* in total (cluster=task)
- Unbalanced execution with more than 10 threads

Explicit parallelism and protection of resources

Protection of Resources

A single directive for internal thread safety

`ROOT::EnableThreadSafety()`

- Some of the code paths protected:
  - Interactions with type system and interpreter (e.g. interpreting code)
  - Opening of TFiles and contained objects (one file per thread)

New utilities, none of which in the STL:

- **ROOT::TThreadedObject<T>**
  - Separate objects in each thread, lazily created, manage merging
  - Create threaded objects with *ROOT::TThreadedObject<T>(c'tor params)*
- **ROOT::TSpinMutex**
  - STL interface: e.g. usable with std::condition_variable
- **ROOT::TRWSpinLock**
  - Fundamental to get rid of some bottlenecks

Usable with any threading model

Programming Model

Manages one object per thread, transparently

```
ROOT::TThreadedObject<TH1F> ptHist("pt_dist", "pt_dist", 128, 0, 64);
ROOT::TTreeProcessor tp("tp_process_imt.root", "events");

auto myFunction = [&](TTreeReader &myReader) {
    TTreeReaderArray<ROOT::Math::PxPyPzEVector> trks(myReader, "tracks");
    while (myReader.Next()) {
        for (auto& trk : trks) myPtHist->Fill(track.Pt());
    }
};

tp.Process(myFunction);
auto ptHistMerged = ptHist.Merge();
```

"Work item"

Mix ROOT, modern C++ and STL

More about the programming model in the backup slides!

Two R&D Lines

Functional Chains R&D

- We are constantly looking for opportunities to apply implicit parallelism in ROOT
- "Functional Chains" R&D being carried out
  - Functional programming principles: no global states, no for/if/else/break
  - Analogy with tools like ReactiveX*, R dataframe, Spark
  - Gives room for optimising operations internally

Can this be a successful model for our physicists?

```
import ROOT
f = ROOT.TFile("aliDataset.root")
aliTree = f.Events
dataFrame = TDataFrame(aliTree)

dataFrame.filter(sel1).map(func2).cache().filter(sel3).histo('var1:var2').Draw('LEGO')
```

Express analysis as a chain of functional primitives.

* https://reactivex.io

The ROOT-Spark R&D

- HEP data: statistically independent collisions
- Lots of success: PROOF, the LHC Computing Grid
  - Can we adapt this paradigm to modern technologies?
- Apache Spark: fault-tollerant, in-memory distributed computation framework
  - Written in Scala, bindings for Java, R and Python (our bridge to ROOT)
  - Widely adopted in data-science community

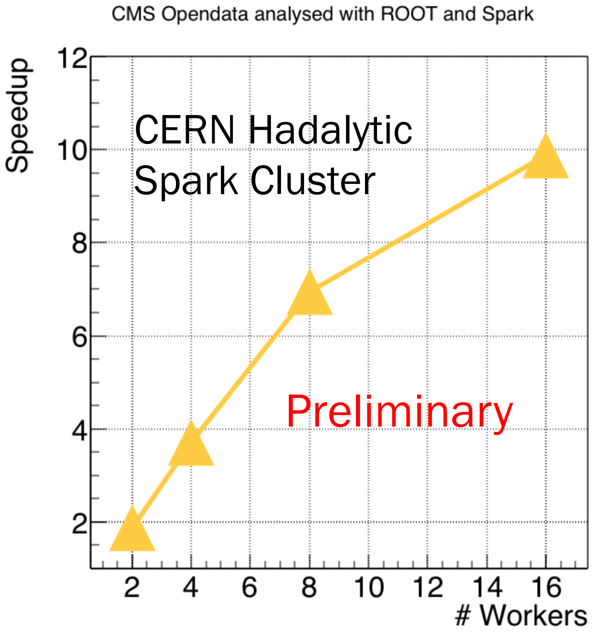
In collaboration with CERN IT-DB-SAS and IT-ST-AD

Our idea:

1) Use Spark to process with PyROOT + C++ libraries / C++ code JITted by ROOT
2) Cloud storage for software and data (CVMFS and EOS)
3) Identical environment on client and workers

Our First Test

- CMS Opendata http://opendata.cern.ch/record/1640
  - Analyse kinematic properties of generated jets
- Read ROOT files natively with PyROOT
  - Get back merged histograms
- IT managed Spark cluster at CERN
  - Client is LXPLUS node
- Easy setup: source a script



We can run on CMS Opendata with ROOT exploiting an already existing Spark cluster

See also SWAN: Service for Web base ANalysis by E. Tejedor, Wed 11:45 Track 6

Bottomline

- ROOT is evolving and following a modern approach
  - ROOT namespace, new classes …
- General purpose MT and MP executors (e.g. map, mapReduce patterns)
- Utilities to facilitate explicit parallelism, complement STL
  - ROOT as a "foundation library"
- Provide access to implicit parallelism
  - Formulate solution using certain interfaces, ROOT takes care of the rest

All this delivered in ROOT 6.08

The future:

- Find new opportunities for implicit parallelism, e.g. functional chains
- Continue exploring new technologies, e.g. Apache Spark and other runtimes

Backup

Programming Model

```
ROOT::EnableThreadSafety();
ROOT::TThreadedObject<TH1F> ts_h("myHist", "Filled in parallel", 128, -8, 8);

auto fillRandomHisto = [&](int seed = 0) {
   TRandom3 rndm(seed);
   auto histogram = ts_h.Get();
   for (auto i : ROOT::TSeqI(1000000)) {
      histogram->Fill(rndm.Gaus(0, 1));
   }
};

std::vector<std::thread> pool;

for (auto s : ROOT::TSeqI(1, 5)) pool.emplace_back(fillRandomHisto, s);
for (auto && t : pool) t.join();

auto sumRandomHisto = ts_h.Merge();
```

Fill histogram randomly from multiple threads

Mix ROOT, modern C++ and STL seamlessly

Programming Model

```
ROOT::TProcessExecutor mpe(4);

auto fillRandomHisto = [](int seed) {
    auto h = new TH1F("myHist", "Filled in parallel", 128, -8, 8);
    TRandom3 rndm(seed);
    for (auto i : ROOT::TSeqI(1000000)) {
        h->Fill(rndm.Gaus(0, 1));
    }
    return h;
};

ROOT::ExecutorUtils::ReduceObjects<TH1F*> rf;
auto sumHisto = mpe.MapReduce(fillRandomHisto, ROOT::TSeqI(10), rf);
```

Fill histogram randomly from multiple threads

Seamless usage of processes

Return type inferred from work-item signature

TTree I/O Objects