Fine-Grained Parallelism in cmsRun

Lessons learned in the attempt
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13 May 2010

Project purpose

- “fine-grained” portion of effort to bring concurrency to cmsRun.
- Fine-grained means:
    - Only local modifications to code.
    - No change in *results* allowed, only change in *performance*.
- Investigate use of one of the popular “toolkits” for concurrent programming
    - Intel TBB: excellent library, but intrusive
    - OpenMP: “simple” design, not intrusive

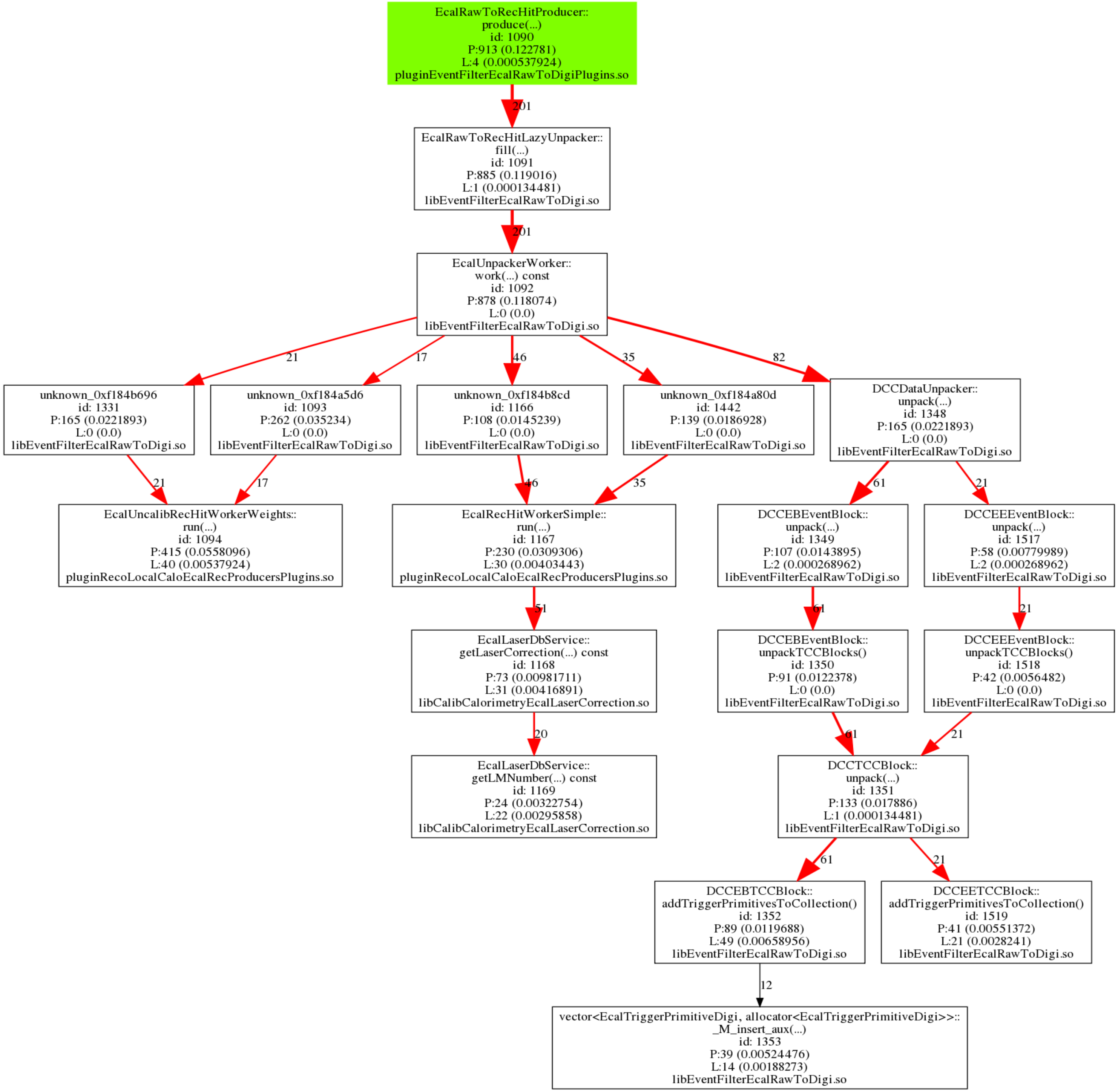
Plan of attack

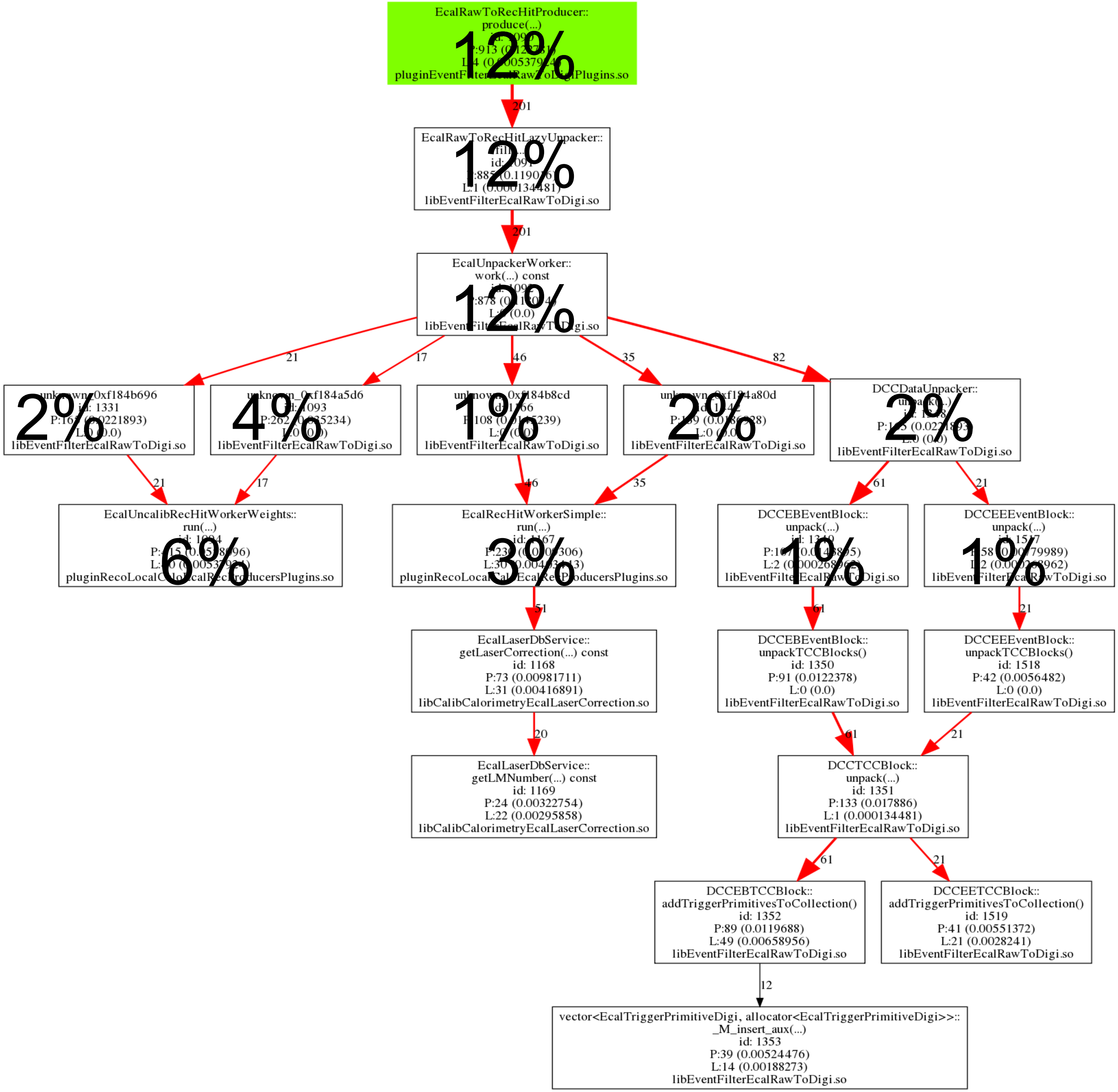
- Identify a portion of CMS code that is suitable for localized concurrency:
  - takes significant time, enough to be worth the effort – tend toward higher-level functions,
  - is not *inherently* serial,
  - has no *accidental* serialization, or can have such removed – tend toward lower-level functions,
  - deals with sufficient data to benefit from OpenMP-style concurrency (*e.g.*, parallelization of loops).
- See if application of OpenMP improves speed.

- First looked at reconstruction executable
  - ttbar simulation sample
  - CMSSW_3_1_0, arch=slc4_ia32_gcc432
- Revisited with newer executable, running HLT
  - Simulated L1 trigger skim sample
  - CMSSW_3_2_1, arch=slc4_ia32_gcc432
  - CMSSW_3_3_0, arch_slc5_amd64_gcc432

cmsRun in HLT

- Analysis of profiling data turned up one good candidate: EcalRawToRecHitProducer::produce (~12% of total program time)
- The following slide shows the (trimmed of rare path) call paths
- Investigation of these routines revealed much (accidental?) serialization – local changes could not introduce useful parallelization.


EcalRawToRecHitProducer::
produce(...)
id: 1090
P:913 (0.122781)
L:4 (0.000537924)
pluginEventFilterEcalRawToDigiPlugins.so
201
EcalRawToRecHitLazyUnpacker::
fill(...)
id: 1091
P:885 (0.119016)
L:1 (0.000134481)
libEventFilterEcalRawToDigi.so
201
EcalUnpackerWorker::
work(...) const
id: 1092
P:878 (0.118074)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
21
17
46
35
82
unknown_0xf184b696
id: 1331
P:165 (0.0221893)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
unknown_0xf184a5d6
id: 1093
P:262 (0.035234)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
unknown_0xf184b8cd
id: 1166
P:108 (0.0145239)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
unknown_0xf184a80d
id: 1442
P:139 (0.0186928)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
DCCDataUnpacker::
unpack(...)
id: 1348
P:165 (0.0221893)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
21
17
46
35
61
21
EcalUncalibRecHitWorkerWeights::
run(...)
id: 1094
P:415 (0.0558096)
L:40 (0.00537924)
pluginRecoLocalCaloEcalRecProducersPlugins.so
EcalRecHitWorkerSimple::
run(...)
id: 1167
P:230 (0.0309306)
L:30 (0.00403443)
pluginRecoLocalCaloEcalRecProducersPlugins.so
DCCEBEventBlock::
unpack(...)
id: 1349
P:107 (0.0143895)
L:2 (0.000268962)
libEventFilterEcalRawToDigi.so
DCCEEEventBlock::
unpack(...)
id: 1517
P:58 (0.00779989)
L:2 (0.000268962)
libEventFilterEcalRawToDigi.so
51
61
21
EcalLaserDbService::
getLaserCorrection(...) const
id: 1168
P:73 (0.00981711)
L:31 (0.00416891)
libCalibCalorimetryEcalLaserCorrection.so
DCCEBEventBlock::
unpackTCCBlocks()
id: 1350
P:91 (0.0122378)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
DCCEEEventBlock::
unpackTCCBlocks()
id: 1518
P:42 (0.0056482)
L:0 (0.0)
libEventFilterEcalRawToDigi.so
20
61
21
EcalLaserDbService::
getLMNumber(...) const
id: 1169
P:24 (0.00322754)
L:22 (0.00295858)
libCalibCalorimetryEcalLaserCorrection.so
DCCTCCBlock::
unpack(...)
id: 1351
P:133 (0.017886)
L:1 (0.000134481)
libEventFilterEcalRawToDigi.so
61
21
DCCEBTCCBlock::
addTriggerPrimitivesToCollection()
id: 1352
P:89 (0.0119688)
L:49 (0.00658956)
libEventFilterEcalRawToDigi.so
DCCEETCCBlock::
addTriggerPrimitivesToCollection()
id: 1519
P:41 (0.00551372)
L:21 (0.0028241)
libEventFilterEcalRawToDigi.so
12
vector<EcalTriggerPrimitiveDigi, allocator<EcalTriggerPrimitiveDigi>>::
_M_insert_aux(...)
id: 1353
P:39 (0.00524476)
L:14 (0.00188273)
libEventFilterEcalRawToDigi.so


EcalRawToRecHitProducer::
produce(...)
12%
pluginEventFilterEcalRawToDigiPlugins.so
201
EcalRawToRecHitLazyUnpacker::
12%
id: 1091
L:1 (0.000134481)
libEventFilterEcalRawToDigi.so
201
EcalUnpackerWorker::
work(...) const
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libEventFilterEcalRawToDigi.so
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2%
id: 1331
libEventFilterEcalRawToDigi.so
unknown_0xf184a5d6
4%
id: 1093
libEventFilterEcalRawToDigi.so
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libEventFilterEcalRawToDigi.so
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libEventFilterEcalRawToDigi.so
DCCDataUnpacker::
2%
libEventFilterEcalRawToDigi.so
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21
EcalUncalibRecHitWorkerWeights::
run(...)
6%
EcalRecHitWorkerSimple::
run(...)
3%
pluginRecoLocalCaloEcalRecProducersPlugins.so
DCCEBEventBlock::
unpack(...)
1%
DCCEEEventBlock::
unpack(...)
1%
51
61
21
EcalLaserDbService::
getLaserCorrection(...) const
id: 1168
P:73 (0.00981711)
L:31 (0.00416891)
libCalibCalorimetryEcalLaserCorrection.so
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libEventFilterEcalRawToDigi.so
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_M_insert_aux(...)
id: 1353
P:39 (0.00524476)
L:14 (0.00188273)
libEventFilterEcalRawToDigi.so

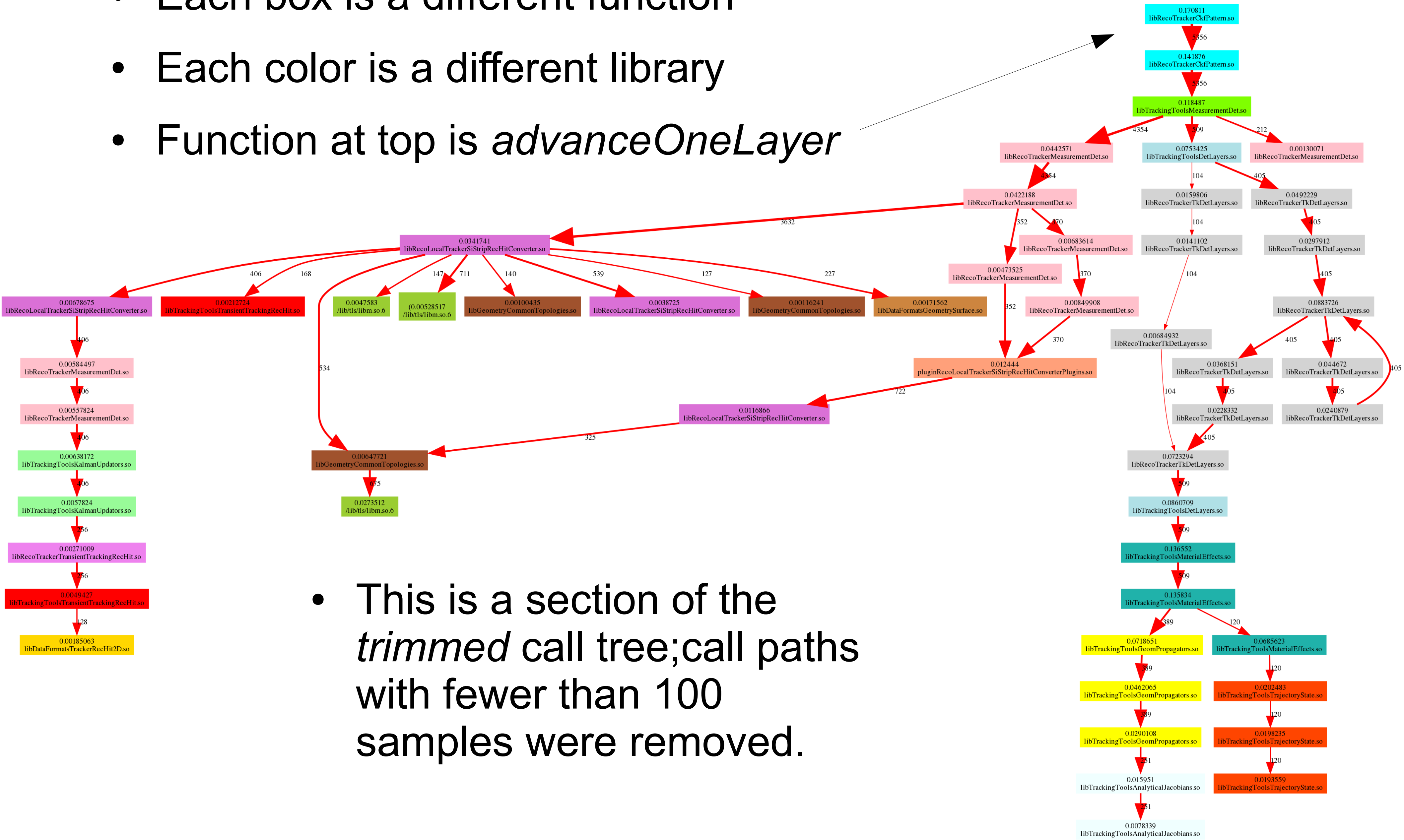
Hard-to-parallelize code structure

- Common usage of OO techniques makes for code that is not easy to parallelize
  - OO techniques *encapsulate* state for ease of understanding the code...
  - but encapsulated state, when also *shared*, prevents parallelization.
- Much of this sharing is *accidental* not *essential*.
- Maybe we need to learn from the *functional* programming community
  - pass state *to* algorithms when we want parallelism.

cmsRun in reconstruction

- Output functions use considerable time but are not good candidates for *local* multithreading
  - parallel-capable i/o formats would be interesting
- As anticipated, tracking takes the most time.
- GroupedCkfTrajectoryBuilder::advanceOneLayer, and functions it calls, take 17% of program time.
- Analysis of this code also shows great complexity.

- Each box is a different function
- Each color is a different library
- Function at top is *advanceOneLayer*


0.170811
libRecoTrackerCkfPattern.so
5356
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libRecoTrackerCkfPattern.so
5356
0.118487
libTrackingToolsMeasurementDet.so
4354
509
212
0.0442571
libRecoTrackerMeasurementDet.so
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libTrackingToolsDetLayers.so
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libRecoTrackerTkDetLayers.so
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3632
352
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libRecoTrackerMeasurementDet.so
0.0141102
libRecoTrackerTkDetLayers.so
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libRecoTrackerMeasurementDet.so
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168
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711
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127
227
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libRecoTrackerTkDetLayers.so
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0.00557824
libRecoTrackerMeasurementDet.so
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libRecoLocalTrackerSiStripRecHitConverter.so
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libRecoTrackerTkDetLayers.so
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libRecoTrackerTkDetLayers.so
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325
405
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libTrackingToolsKalmanUpdators.so
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libGeometryCommonTopologies.so
0.0723294
libRecoTrackerTkDetLayers.so
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libTrackingToolsKalmanUpdators.so
0.0273512
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0.00271009
libRecoTrackerTransientTrackingRecHit.so
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libTrackingToolsMaterialEffects.so
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libTrackingToolsTransientTrackingRecHit.so
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libTrackingToolsMaterialEffects.so
128
389
120
0.00185063
libDataFormatsTrackerRecHit2D.so
0.0718651
libTrackingToolsGeomPropagators.so
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libTrackingToolsMaterialEffects.so
389
120
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libTrackingToolsGeomPropagators.so
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libTrackingToolsTrajectoryState.so
389
120
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libTrackingToolsGeomPropagators.so
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libTrackingToolsTrajectoryState.so
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120
0.015951
libTrackingToolsAnalyticalJacobians.so
0.0193559
libTrackingToolsTrajectoryState.so
251
0.0078339
libTrackingToolsAnalyticalJacobians.so

- This is a section of the *trimmed* call tree;call paths with fewer than 100 samples were removed.

Low-level concurrency for the future

- Accidents of current code prevent concurrency.
  - We need to “think parallel” up front.
  - We need to investigate parallel algorithms and data structures for higher-level tasks.
  - We need to devise and enforce easy-to-follow rules for making modules thread-safe.
- We need to understand how to interact with non-thread-safe utilities:
  - limit exposure in our own code
  - provide thread-safe patterns of use
  - work toward achieving thread-safety in utilities

What can we learn from others?

- Functional programming community
  - encapsulate higher-order functions
  - pass algorithm state to algorithms (reduce accidental sharing, make essential sharing explicit)
  - allows for optimizations that can be *proven* correct
- “Parallel” programming languages (Chapel, F-Script, Fortran 2008)
  - Use *whole aggregate* transformations & algorithms
  - Allow for libraries to provide means of parallelization

How do we do this in C++?

- Common wisdom: get it right first, then make it fast
  - But we have learned we can't afford to make it too slow first – must think parallel *early*
- Maybe we haven't done *enough* template programming – abstractions at the right level (per Stepanov's *Elements of Programming*)
- New C++ has valuable features
  - local (lambda) functions
  - better metaprogramming support

Thanks.

Trivial OpenMP example

```
#include <omp.h>
#include <iostream>
int main () {
  int th_id, nthreads;
#pragma omp parallel private(th_id)
  {
    th_id = omp_get_thread_num();
    std::cout << "Hello World from thread" << th_id << std::endl;
#pragma omp barrier
    if ( th_id == 0 ) {
      nthreads = omp_get_num_threads();
      std::cout << "There are " << nthreads << " threads" << std::endl;
    }
  }
}
```

- g++-mp-4.3 -o hello_mp -fopenmp hello_mp.cc