Grid Computing for LHC

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08 September 2010/Karlsruhe
Building blocks of matter and their interactions - describe well current observations, but missing pieces

Higher energy: Reproduce conditions of early Universe

TeV energy scale: Expect breakdown of current calculations unless a new interaction or phenomenon appears

Many theories, but need data to distinguish between them
The LHC and Experiments

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4 LHC Experiments

ATLAS

CMS

LHCb

ALICE
Detectors built and operated by a large team

Worldwide Collaboration of over 3000 physicists and engineers in ATLAS and CMS each + similar in LHCb and ALICE
• 2010: 30-50 pb$^{-1}$, „Re-discover” Standard Model: J/ψ, W, Z, top
• 2011: up to 1 fb$^{-1}$ at $\sqrt{s} = 7(8)$ TeV
Collisions at the LHC

Proton-Proton-Kollisionen
2835 Teilchenbündel (Bunch)

$10^{11}$ Protonen / Bunch
Kollisionsrate 40 MHz (25 ns)

Schwerpunktsenergie 14 TeV
(= 7400 x Ruheenergie der kollidierenden Teilchen)

Schwerpunktsenergie der kollidierenden Quarks und Gluonen bis einige TeV

~25 pp-Kollisionen pro Bunch-Kollision

Interessante Ereignisse: $10^{-9} - 10^{-11}$ unterdrückt!
Trigger and Event Sizes

High Level-1 Trigger (1 MHz)

- LHCb

High No. Channels
High Bandwidth (1000 Gbit/s)

- ATLAS CMS

Triggerrate [Hz]

10^5
10^4
10^3
10^2

10^4
10^5

10^6
10^7

Ereignisgröße [Byte]

- KTeV
- HERA-B
- CDF II
- D0 II
- BaBar
- CDF, D0
- H1
- ZEUS
- UA1
- NA49
- LEP

- ALICE

- High Data Archives (PetaBytes)
Challenges in Data Analysis

Data volumes
- LHC experiments produce and store several PetaBytes/year

CPUs
- Event complexity (large number of channels) and number of users demands: at least 100000 fast CPUs based on computing model

Software
- The experiments have complex software environment and framework

Connectivity
- Data should be available 24/7 at a high bandwidth
Higgs-Search: $H \rightarrow WW^{(*)} \rightarrow \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu$ für 1 fb$^{-1}$

Monte Carlo events needed:

- 4 mass points: $m_H = 130 - 190$ GeV: 100k + 500k Systematic studies
- Background: $Z/\gamma^*$: 2M, $t\bar{t}$: 500k, $WW+WZ+ZZ$: 200k, $W+$jets: 1M
- Total: 4.3M
- Time for simulation: 200h @ 10000 CPUs with 0.5h/event (no overhead)

Data:

- $10^9$ Events/year
- ≈ 50d time for reconstruction @ 10000 CPUs with 45s/event
Average Analyse at LHC II

Analysis:

- $10^6$ data events from trigger and skim pre-selection
- Estimated time:
  - 1 week MC+data at 1 CPU with 10Hz
  - 4h MC+data at 1000 CPUs (Tier2-share)
  - Optimization of analysis demands much more time

Scaling up:

- Assume 2000 physicist with same analysis
- Time: 3h at 100000 CPUs
- Shown analysis is not the most time consuming
- Analysis with jets need much more CPU-time
- All given time: without additional overhead
Grid Infrastructures

- Heterogeneous grid environment based on 3 grid infrastructures:
  - Production System (Panda): centralized MC simulation and Data reconstruction
  - Distributed Data Management (DQ2): centralized data movement
  - Distributed User Analysis: de-centralized individual analysis

- e.g. 3 major ATLAS Grid areas:
Grid Infrastructure

What is needed - some grid components:

- Compute Element (CE)
- Storage Element (SE)
- Batchsystem
- Datenspeicher (Storage Element)
- Informationssystem
- Workload Manag. System (WMS)
- Grid Middleware
  - LFC (Datei-Katalog)
  - Dateitransfer

Rechenzentrum - Site

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**Worldwide resources**

- Today >140 sites
- ~150k CPU cores
- >50 PB disk
Experiment Models and Tier Structure

- Models all based on the MONARC tiered model of 10 years ago
- Several significant variations, however
ATLAS Production System Jobs - last year

Up to 50k simultaneous jobs - structure related to SW releases and simulation campaigns
Refining the data by: Add higher level info, Skin, Thin, Slim
≈ 80 Tier1/2/3 sites managed by DQ2 right now
Excellent experience so far: the whole offline and computing organization + GRID infrastructure performing very well.

Hourly Peaks to Tier-1s of 600MB/s

Mean is 60.5 minutes
Target is 60 minutes

>500 individuals submitting jobs
Data transfers 2010

Data transfer capability today able to manage much higher bandwidths than expected and planned

- Data transfer rates per week in 2010
Data transfers 2010

Data transfer capability today able to manage much higher bandwidths than expected and planned

- Data transfer rates per day in 2010
ATLAS Data Transfers

Total throughput of ATLAS data through the Grid: 1 Jan - 31 July 2010

- **MB/s per day**
  - Jan: 6 GB/s
- **Start of 7 TeV data-taking**
- **Data and MC reprocessing**
- **Start of 10^{11} p/bunch operation**

**MC reprocessing**

**~2 GB/s (design)**

**Peaks of 10 GB/s achieved**
Naive assumption: Grid ≈ large batch system

- Provide complicated job configuration for Workload Management System
- Find suitable experiment software, installed in the Grid (100 CEs, 30 Software versions)
- Locate the data on different storage elements
- Job splitting, monitoring and book-keeping
- etc.

⇒ Need for automation and integration of various different components

Several ways lead into the Grid!
Every experiment has built own system on top of grid middleware:

- Grid infrastructure middleware - different workflows
- work-arounds for grid middleware problems
- Often batch-like analysis, Alice uses PROOF in addition

Similar SW stack in experiments:

- SW environment in C/C++ and Root
- Analysis-Grid-Tools in script language (Python)
- Grid data transfers (SRM, FTS)
- Workload Management (glite WMS)

Similar Ansatz, but experiment dependent:

- Crab (CMS), Ganga (LHCb/ATLAS)
- Various monitoring packages
- Pilot Job Workload Management:
  - e.g. Dirac (LHCb), Panda (ATLAS), Alien (Alice))
- Data management:
  - e.g. Phedex (CMS), DQ2 (ATLAS)
Data is centrally being distributed by DQ2 - Jobs go to data
Distributed Analysis: Ganga

How to combine all different components: **Job scheduler/manager: GANGA**
Job Scheduling

Job Push mode
- Dependent on information system and site status
- Decentralized
- Better control of site policies
- Ganga: LCG and NG backend

Job Pull mode
- Workarounds for some Grid problems
- Data pre-staging
- Panda clients or Ganga Panda backend
**Example Job Workflow**

1. **User**
   - User code
   - Input Dataset

2. **Ganga Client**
   - Environment parsing
   - Dataset Database query
   - User Area tar ball creation
   - Job(s) submission

3. **Grid Worker Node**
   - Environment setup
   - Inputfile List generation
   - Athena code execution
   - Stage-out outputfiles

4. **Monitor Jobs**
   - Output files download
   - Output files merging
   - Jobs resubmission

5. **Output Sandbox retrieval**
Number of analysis users and jobs I

LHCb: CPU at Tier 1s 60% user and 40% reconstruction; >200 users 30k jobs/day

ALICE: >250 users ~1300 jobs on average over 4 months
**Number of analysis jobs II**

- CMS:
  - >500 individuals submitting jobs

- ATLAS:
  - Compare ATLAS number with daily $\sim 50$-100k production jobs
  - Since start of 7 TeV collisions large increase of jobs and users

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**ATLAS:**

Panda DA Resource Usage 2010 (N Jobs Weekly)

- N Finished
- N Failed

Week number

N jobs

- 0 to 2,000,000
- 500,000 to 1,500,000
- 1,000,000 to 2,000,000
Current user problems and Support

User support is very important but time consuming

Central ticketing system for site or grid middleware problems: GGUS

- Site or experiment experts try to solve problems
- Often „one-way” communication

Support mailing list for analysis tools

- Central discussion board for „all” problems
- Discussion of several people
- E.g. in ATLAS and LHCb:
  - Before: only developers as experts - very time consuming
  - Now: experiment shift teams with shift credits
  - Very busy mailing list
  - Hope: user-to-user support similar to open-source projects

- Sites are more stable but still day to day glitches
Infrastructure Tests - Analysis stress tests

ATLAS is/has been testing sites with very high automatic generated analysis load: HammerCloud http://hammercloud.cern.ch/

Now also available of CMS and soon for LHCb

Differences Analysis vs. MC Production:

• „unorganized” user analysis vs. „organized” MC production
• User Analysis puts much higher load on SE compared to CPU dominated simulation

Tests of different work-flows:

• Sequential AOD analysis of MC data
• Sequential cosmics analysis with DB/Frontier/Squid access

Some highlights:

• Analysis tools generally stable and reliable
• Some weak spots detected in site infrastructures, especially in input file access mode lots of tuning potential
Resource Evolution

Need foreseen @ TDR for T0+1 CPU and Disk for 1st nominal year

NB. In 2005 only 10% of 2008 requirement was available. The ramp-up has been enormous!
Prospects and Evolutions

- Infrastructure demonstrated to be able to support LHC data processing and analysis
- Spin off in different areas
- A reliable and robust service of many components necessary
- Significant operational infrastructure behind it
- Adapt to future technologies:
  - Improve data storage and data access
  - multi-core CPUs
  - Virtualisation
- Network is much better than initially anticipated
  - Rethink data access models
- Experiments have truly distributed models