Abstract. With the exponential growth of LHC (Large Hadron Collider) data in 2011, and more coming in 2012, distributed computing has become the established way to analyse collider data. The ATLAS grid infrastructure includes almost 100 sites worldwide, ranging from large national computing centers to smaller university clusters. These facilities are used for data reconstruction and simulation, which are centrally managed by the ATLAS production system, and for distributed user analysis. To ensure the smooth operation of such a complex system, regular tests of all sites are necessary to validate the site capability of successfully executing user and production jobs. We report on the development, optimization and results of an automated functional testing suite using the HammerCloud framework. Functional tests are short lightweight applications covering typical user analysis and production schemes, which are periodically submitted to all ATLAS grid sites. Results from those tests are collected and used to evaluate site performances. Sites that fail or are unable to run the tests are automatically excluded from the PanDA brokerage system, therefore avoiding user or production jobs to be sent to problematic sites.

1. Introduction
The ATLAS computing model foresees extensive usage of grid resources to cope with the large amount of storage space and processing power required to analyze LHC data [1]. The primary event reconstruction of collider data from the ATLAS detector takes place at the Tier-0, the computing facility at CERN, and at primary computing facilities worldwide, the so-called Tier-1s. The production of Monte Carlo (MC) simulated data is taken care of at Tier-1s, and at secondary facilities around the world, the Tier-2s. Both activities are centrally managed, and will be generically referred to as production in the following. The amount of data processed in production jobs since the beginning of 2012 is shown in Fig. 1. The output datasets from production activities are distributed to the Tier-2s, and additional analysis facilities, the Tier-3s. At Tier-2s and Tier-3s, both MC and LHC data can be analyzed by the physics users.

The ATLAS grid infrastructure includes almost 100 sites worldwide, with different sizes, architecture and storage systems. Operating smoothly such a complex system requires the development of automated monitoring and validation tools. HammerCloud [2] is a tool which allows for automated testing of grid resources. Within HammerCloud, test jobs using sample applications are submitted to one or more ATLAS grid sites, and the outcome of each job
(success or failure) is individually monitored. According to the concurrent number, frequency and length of the test jobs, two types of tests can be defined: stress and functional.

During stress tests, a large amount of jobs is submitted for a limited period of time to one or more sites (usually on-demand), and the site performance under heavy load can be evaluated. Stress tests are used to help commissioning new sites, or to compare site performances after software or hardware changes.

Functional tests are short applications running at high frequency at all sites for an undefined amount of time (new tests are automatically resubmitted). Results from functional tests are used to measure the site availability as a function of time, and allows the site administrators or grid operators to take action in case of failures. In particular, sites failing the functional tests can be automatically excluded from job brokerage on a temporary basis, thus optimizing the usage of grid resources.

**Figure 1.** Data processed by production jobs at the ATLAS Tier-0 and Tier-1s. Figure from [3].

The HammerCloud framework is currently used by ATLAS, CMS and LHCb, and is extensively described in [2, 4, 5]. Functional tests developed for production and analysis activities in ATLAS are described in section 2 and the auto-exclusion policy in section 3. Discussion of the results can be found in section 4.

### 2. Functional tests

Within the HammerCloud framework, functional tests are regular tests executed at all grid sites, aiming to check that the site is able to accept and execute successfully analysis and/or production jobs. Functional test jobs are short applications that mimic a typical analysis or production pattern. Each functional test is defined by the application that is run at the sites. Varying the executed application, several functionalities can be tested. Currently 17 functional tests are being run daily by HammerCloud, with various combinations of:
• ATLAS software versions [6];
• input datasets (collider and Monte Carlo);
• different input data format;
• site data access method (direct I/O, FileStager, copy-to-scratch);
• analysis applications: simple user analysis, ntuple dumper;
• production applications: event generation, simulation and reconstruction;
• submission backends: PanDA (Production and Distributed Analysis system) [7], gLite WMS (Workload Management System) [8], and ARC (Advance Resource Connector) [9].

The functional tests currently used by the auto-exclusion policy (see section 3) are shown in Fig. 2. Each analysis job processes only the first 100 events from the input datasets, in order to keep the duration of the test jobs short. Production test jobs typically take longer, and the number of input events is tuned to have job length similar to that of analysis functional tests. Typical job turn-around time is 10-20 minutes for analysis applications, and 20-30 minutes for production applications. HammerCloud takes care of having approximately 1 job from each functional test running at each site. Functional tests run for 24 hours. After this time is elapsed, jobs that are still running are killed, and a new test is started. A 24-hour test consists of approximately 5000 completed jobs. Each job is individually monitored, and the results are stored in a database. On the HammerCloud website [10], a detailed summary of statistics and metrics for each functional test (see Fig 3) is available.

![Figure 2. Functional tests currently running in HammerCloud. Figure from [10].](image_url)
detailed analysis. However a small amount of failures is endemic to such a complex system, and cannot be avoided. The daily number of production and analysis jobs completed at ATLAS grid sites in the period January-April 2012 can be seen in Figs. 4(a) and 4(b). The success rate is \( \sim 94\% \) for production jobs, and \( \sim 80\% \) for user analysis jobs. The latter includes \( \sim 10\% \) of jobs cancelled by the user himself. A constant error rate of 5-10\% is observed, mostly related to temporary failures of the grid infrastructure, i.e. storage element problems, network instabilities, ... . Aim of the automatic site exclusion strategy described in this section is to effectively cope with such instabilities.

Analysis and production job submission to problematic sites would result in an inefficient usage of the grid resources. To identify sites which are unavailable, a specific suite of functional tests have been developed. Four functional tests are used to evaluate the site capability of executing analysis jobs: they consist in a sample user analysis code and an ntuple-dumper running on both LHC and MC samples. Production functional tests include: event generation, simulation (with three different software versions), and reconstruction. In total, 4 (5) functional tests are used for the auto-exclusion policies of analysis (production) sites. They will be referred to as Analysis (Production) Functional Tests or AFTs (PFTs) in the following.

The number of AFT and PFT jobs completed in a time period of one month is shown in Figs. 5(a) and 5(b). The performances of both suites of tests are stable, and the measured failure rate is approximately 3\% for PFTs and 5\% for AFTs. Note that those numbers also include scheduled site downtimes. Since the particular combination of code and input datasets used in AFTs and PFTs are completely under control of HammerCloud operators, and have been tested to work together beforehand, the failure rates in AFTs/PFTs can be directly related to site problems.

A site which has been identified as problematic by HammerCloud is automatically excluded
from job brokerage in PanDa. The following \textit{blacklisting} procedure has been implemented, using jobs from AFTs (PFTs) which completed in the last 3 (4) hours:

P1: the last three jobs from any single test have failed;

P2: the last two jobs from any single test and the last job from another test have failed;

P3: the last job from three separate tests have all failed.

If any of the above policies is true, the site is excluded from job brokerage. When a site is
blacklisted for analysis (production), no new analysis (production) jobs are brokered at the site, jobs that are already queued are put on hold and rebrokered after 3 hours (if the site is still auto-excluded). Only AFT and PFT jobs can be brokered at the site. ATLAS grid operators and site administrators are notified by email of the auto-exclusion.

HammerCloud evaluates the auto-exclusion policy every 30 minutes. If the test jobs are succeeding, the site is automatically whitelisted. The whitelisting policy is the following:

P4: the last two jobs from all tests have succeeded.

Figure 5. Daily number of completed production (a) and analysis (b) functional test jobs submitted by HammerCloud at ATLAS grid sites. Figure from [3].
The site is whitelisted if P4 is true, and P1, P2, P3 are false. Note that a site must be able to successfully execute jobs from all functional tests in order to be whitelisted. However the opposite of this condition, i.e. jobs from one or more tests are not executed at the site, does not trigger the blacklisting procedure.

The real-time status of the auto-exclusion for both analysis and production sites is shown on the HammerCloud website (see Figs 6(a) and 6(b)). Sites marked in red are auto-excluded, sites in yellow are at risk, meaning that some jobs have failed but not enough to trigger any of the auto-exclusion policies P1, P2, P3. If not enough jobs were completed to evaluate P1, P2 and P3, the site is shown in gray. The same information is also propagated to other ATLAS monitoring services, such as the ATLAS Site Status Board [11], and the Service Availability Monitor [12].

4. Results

The auto-exclusion procedure described in section 3 is in place since May 2011 for analysis sites, and February 2012 for production sites. The success rate of AFTs and PFTs is shown in Figs. 7(a) and 7(b). Numbers from the above figures correspond to an observation period of one month (randomly chosen). The efficiencies have been fairly stable in time (most sites were already showing very good performances before HammerCloud introduction). In general, 80% of sites have an availability larger than 95%, also including scheduled downtimes. Remarkably, only 5% of the sites have availabilities smaller than 90%.

The auto-exclusion mechanism has been proven to be quite effective as debugging tool in narrowing down specific issues at a few problematic sites, which were drown in the multitude of failures from real user analysis jobs. This is due to the fact that functional test jobs are simple applications targeting specifically potential problems, such as storage element access, software installation, database access. ATLAS-wide testing such as provided by HammerCloud functional tests also allows to quickly react to general problems affecting the ATLAS central services, such as file catalogues, software release availabilities from CERN repositories and so on.

5. Conclusions

HammerCloud is a tool extensively used by ATLAS, CMS and LHCb. It provides an easy infrastructure to create tests to evaluate the performances (stress testing) and availability (functional testing) of grid sites. Functional tests developed to test ATLAS analysis and production sites have been described in this note. The HammerCloud framework is running since May 2010. Since June 2011 (February 2012) the site performances on AFTs (PFTs) are used to exclude from brokerage sites temporarily failing the tests. The efficiency of analysis (production) functional tests is approximately 95% (93%). Strict exclusion policies have been developed to increase the grid reliability, and to reduce the percentage of analysis and production jobs aborted due to network or storage failures. Results from AFTs/PFTs show that 80% of sites have an availability larger than 95%, even including scheduled downtimes.
Figure 6. Live auto-exclusion status for production (a) and analysis (b) sites. Figure from [13].
Figure 7. Success rate of production (a) and analysis (b) functional test jobs submitted by HammerCloud at ATLAS grid sites. Figure from [3].
References
[1] 2005 ATLAS computing: Technical Design Report Technical Design Report ATLAS (Geneva: CERN)
[2] van der Ster D, Elmsheuser J, Garcia M U and Paladin M 2011 Journal of Physics: Conference Series vol 331 (IOP Publishing) p 072036
[3] The atlas dashboard [Online] http://dashb-atlas-job.cern.ch/dashboard/request.py/dailysummary
[4] van der Ster D 2012 Experience in Grid Site Testing for ATLAS, CMS and LHCb with HammerCloud, these proceedings
[5] Legger F 2011 Journal of Physics: Conference Series vol 331 (IOP Publishing) p 072050
[6] Athena - the atlas common framework, version 8 [Online] http://atlas-computing.web.cern.ch/atlas-computing/documentation/swDoc/AthenaDeveloperGuide-8.0.0-draft.pdf
[7] Nilsson P 2008 Proceedings of XII Advanced Computing and Analysis Techniques in Physics Research. November 3-7, 2008. Erice, Italy. Editors: Thomas Speer (chairman), Federico Carminati and Monique Werlen. Published online at: http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid= 70., p. 27 vol 1 p 27
[8] Laure E, Fisher S, Frohner A, Grandi C, Kunszt P, Krenek A, Mulino O, Pacini F, Prelz F, White J et al. 2006 Computational Methods in Science and Technology 12 33–45
[9] Ellert M, Grünager M, Konstantinov A, Kónya B, Lindemann J, Livenson I, Nielsen J, Niinimäki M, Smirnova O and Wäänänen A 2007 Future Generation Computer Systems 23 219–240
[10] The hammercloud website [Online] http://hammercloud.cern.ch/hc/app/atlas/
[11] The atlas site status board [Online] http://dashb-atlas-ssb.cern.ch/dashboard/request.py/siteviewhome
[12] Duarte A, Nyczzyk P, Reticco A and Vicinanza D 2008 Journal of Physics: Conference Series vol 119 (IOP Publishing) p 052014
[13] The hammercloud robot website [Online] http://hammercloud.cern.ch/hc/app/atlas/robot/