Advances in Grid Computing for the FabrIc for Frontier Experiments Project at Fermilab

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Abstract.

The FabrIc for Frontier Experiments (FIFE) project is a major initiative within the Fermilab Scientific Computing Division charged with leading the computing model for Fermilab experiments. Work within the FIFE project creates close collaboration between experimenters and computing professionals to serve high-energy physics experiments of differing size, scope, and physics area. The FIFE project has worked to develop common tools for job submission, certificate management, software and reference data distribution through CVMFS repositories, robust data transfer, job monitoring, and databases for project tracking. Since the project’s inception the experiments under the FIFE umbrella have significantly matured, and present an increasingly complex list of requirements to service providers. To meet these requirements, the FIFE project has been involved in transitioning the Fermilab General Purpose Grid cluster to support a partitionable slot model, expanding the resources available to experiments via the Open Science Grid, assisting with commissioning dedicated high-throughput computing resources for individual experiments, supporting the efforts of the HEP Cloud projects to provision a variety of back end resources, including public clouds and high performance computers, and developing rapid onboarding procedures for new experiments and collaborations. The larger demands also require enhanced job monitoring tools, which the project has developed using such tools as ElasticSearch and Grafana, in helping experiments manage their large-scale production workflows. This group in turn requires a structured service to facilitate smooth management of experiment requests, which FIFE provides in the form of the Production Operations Management Service (POMS). POMS is designed to track and manage requests from the FIFE experiments to run particular workflows, and support troubleshooting and triage in case of problems. Recently a new certificate management infrastructure called Distributed Computing Access with Federated Identities (DCAFI) has been put in place that has eliminated our dependence on a Fermilab-specific third-party Certificate Authority service and better accommodates FIFE collaborators without a Fermilab Kerberos account. DCAFI integrates the existing InCommon federated identity infrastructure, CILogon Basic CA, and a MyProxy service using a new general purpose open source tool. We will discuss the general FIFE onboarding strategy, progress in expanding FIFE experiments presence on the Open Science Grid, new tools for job monitoring, the POMS service, and the DCAFI project.

1. Introduction

Fermilab has become the world’s foremost laboratory for research in neutrino and precision muon physics, and also plays critical roles in experiments studying all physics drivers in high-energy
physics. The current and future precision muon and neutrino experiments require large amounts
of computing resources, similar in scale to non-LHC collider experiments which collaborations
several times larger than the neutrino experiments. Most of the neutrino and muon experiments
have one to two orders of magnitude fewer collaborators than LHC experiments, and thus
may lack available effort to design a completely new analysis framework, job submission
system, or batch cluster. The FabrIc for Frontier Experiments (FIFE) Project [1, 2] is an
integrated effort within the Fermilab Scientific Computing Division to address these challenges
by bringing experiments and service providers together to develop a common, modular toolkit
that meets the experiments’ requirements for job submission and monitoring, file delivery
and cataloging, storage solutions, analysis and reconstruction frameworks, and collaboration
services such as databases and document storage. The corresponding tools and services include
the job submission (JobSub) infrastructure [3], the SAM file delivery and catalog metadata
service (described in detail in Ref. [4]), the Intensity Frontier Data Handling Client for data
movement [5], and the ART framework for reconstruction and analysis [6]. Figure 1 shows
these components inter-operate in the case of analysis or reconstruction jobs. Creating a set of
common tools that work for a diverse set of experiments saves an immense amount of effort on
each experiment that would otherwise be duplicated. It also makes it easier for a physicist to
work on multiple experiments, as is common in neutrino physics. The modular nature of the
toolset allows experiments to adopt as many components as they wish, and to substitute in their
own components where desired.

The experiments using the JobSub infrastructure are now typically running between 15,000
and 30,000 combined jobs per day around the world, and transferring approximately 1.8 PB
per week in and out of Fermilab’s public dCache [7] system, as shown in Figure 2. While these
numbers do not equal those of an LHC experiment, they are now of the same order of magnitude,
and will continue to increase each year. The tools and services offered by FIFE to the neutrino
and precision muon experiments will also need to be scaled up to the levels of throughput and
reliability that the LHC experiments have.

2. Expansion of Open Science Grid usage and international computing resources
The FIFE project aims to increase experiments use of opportunistic computing resources outside
of Fermilab. Since the Fermilab job submission infrastructure utilizes GlideinWMS [8] it is
a simple matter to gain opportunistic access to Open Science Grid (OSG) sites once the
GlideinWMS factories have been appropriately configured. All that experiments must do is
to ensure that their code contains no Fermilab-specific dependencies, and is available through
CVMFS repositories [9]. Adding opportunistic OSG computing to their available resources gives
experiments several times as many CPUs as they would have if they were to restrict themselves
to running at Fermilab. The Mu2e experiment has superbly leveraged available opportunistic
cycles on the OSG, and have consumed over 60 million CPU hours since spring 2015. Mu2e’s
peak OSG usage came in October 2015 with over 2.5 million opportunistic CPU hours in eight
days, with one day exceeding 500,000 hours, as shown in Figure 3. Mu2e has not incurred any
direct cost for those hours.

Nearly all of the FIFE experiments have international collaborators. Academic institutions
outside of the United States often have significant computing resources, but may not have
the ability to easily integrate them into the job submission systems used by the experiments.
FIFE experts have made significant progress on this front in the past year by utilizing the
GlideinWMS infrastructure, and following the OSG prescription for integrating new computing
sites. The ability of GlideinWMS to interface with a variety of different local batch systems such
as HTCondor, PBS, LSF, CREAM, or SLURM makes integration easier for local administrators.
There are currently five sites in Europe that can run jobs for one or more FIFE experiments.
The total integration time for new sites has been steadily decreasing, and in some cases has been
Figure 1. Diagram of the FIFE toolset architecture. Included are the job submission and monitoring tools, data transfer and storage options, and communication with remote sites. Physicists use the `jobsub_client` software package to interface with the jobsub HA server and HTCondor schedd. The GlideinWMS factory provisions job slots on computing resources both inside and outside of Fermilab, and then HTCondor and the VO Frontend match jobs to slots. User job output is normally sent to Fermilab public dCache as shown in the bottom right, which can also act as a high-speed frontend to tape storage. The SAM service provides file delivery and metadata cataloging (with the cataloguing via http), while the File Transfer Service (FTS) can automatically tag dCache and tape locations for new files in the SAM metadata catalog. Various WebUIs can provide other required information (e.g. detector or beam conditions) to the jobs.

only one week.

3. Monitoring
The computing needs of the FIFE experiments require a computing environment containing highly distributed compute and data storage systems. Administrators of these systems have a need to understand if the services are operating properly. Without a sophisticated set of monitoring tools it is not possible to understand the health and efficiency of the services and the interaction of those services. Problems with individual compute resources like remote grid sites or even local worker nodes may not be obvious for days or weeks if administrators don’t have automated methods of detecting them. By enabling the administrators to quickly and easily observe anomalies, problem resources can be identified quickly and remedied to maintain a high level of efficiency. Not only is it important to see anomalies in the system that are causing problems, but long term trend lines can be used to understand how services interact.

In the past each service (data handling, batch system, meta-data databases, etc) had their own monitoring systems. The FIFE project has adopted monitoring infrastructure based on common, open source tools such as the Elastic Search [15], Graphite [13], Prometheus [16], and Grafana [14] as illustrated in Figure 4. An integrated solution has allowed us to pull together performance numbers from all the systems and then compare the loads and characteristics of the services together. A service may be up but time series data ingested info Graphite and displayed
Figure 2. Top: Total volume of dCache transfers for FIFE experiments, April to October 2016. Bottom: Number of simultaneous running jobs by day for all FIFE experiments, April to October 2016. Each color represents a different experiment.

Figure 3. Opportunistic CPU hours consumed by the Mu2e experiment 1-8 October 2015. The colors represent different computing sites on the Open Science Grid.
in Grafana dashboards are essential to understand whether or not the services are performing as they should via long term time series baselines and data mining of log files. It is now much easier to see which virtual organization or user is causing a problem in our data handling system for example from distributed computing resources with dashboards that display the usage data together.

In addition to helping admins understand the system, users also benefit from an integrated monitoring solution. Gathering per user statistics allows a user to quickly and easily see thing such as low cpu efficiency. Perhaps the user’s analysis job is waiting on file delivery. Without an easy to understand interface with all of a user’s monitoring data collected into one place it is hard for that user to know not only what services the user is using behind the scenes but how to interpret the monitoring that individual service may be providing. The integrated Landscape solution the FIFE project is providing allows the users to understand quickly the status of the analysis jobs and hence makes them more efficient themselves.

Based on experience with FIFEMON, similar technologies are being used in the Open Science Grid’s next-generation accounting tool, GRACC. This tool, intended as a long-term Gratia replacement, will provide the same information to service providers and users as Gratia does, but with an improved UI and a lower support burden.

**Figure 4.** Architecture of current monitoring system.

4. Workflow Management Tools
The FIFE toolset now includes a full meta-workflow management system that combines job and HTCondor DAG submission, file delivery via SAM, and job monitoring tools. This service, the Production Operations Management Service (POMS), is primarily intended for experiment production teams, but in future releases will be open to user analysis as well. The production team or end user defines a high-level ”campaign” structure that describes the input dataset, types of jobs to be processed, any dependencies or stages in the workflow structure, and the system will automatically set up and submit the proper job types, including any dependencies as required. POMS tracks the status of every job, and can automatically resubmit recovery jobs or DAGs with no user intervention if it detects a failure. The interface is either web-based via a REST API, or via a suite of command line tools. A database stores information about every job’s configuration, making it easy to resubmit certain stages of a workflow with different
settings. POMS also has a mode where the user can retain full control over job submission, and use POMS only for jobs monitoring and campaign progress tracking. We expect that POMS will greatly improve experiments’ productivity as they adopt it into their standard operations.

5. Continuous Integration
The FIFE project also aims to reduce the frequency of wasted computing and human resources. By providing a Continuous Integration (CI) system which detects commits to a shared repository and automatically builds and runs tests on the new software code changes can immediately surface any functional or integration errors. The CI system is a set of tools, applications and machines that allows developers to execute their validation tests with minimal effort. It is based on the open source Jenkins toolkit which offers a powerful tool for complex software, and associated database, testing interfaces, and web facilities. The system also provides reports on current and past build, along with information on pre- and post-install tests of the software. Automatic notifications include log information and location of files produced in certain CI stages, like physics validation.

6. Federated identities
One of the goals of the FIFE project is to enable easy and convenient access to computing resources at Fermilab for all collaborators. Currently, a FIFE collaborator must register first as a Fermilab user and must present a valid X.509 certificate, before being able to submit jobs or access data storage. This requirement burdens users with handling an extra set of authentication credentials and puts additional load on Fermilab for managing new user identities. The FIFE job submission system had previously lifted the burden of managing the X.509 authentication credentials from the user, but that required the user to have Fermilab Kerberos credentials and it required Fermilab to run its own Kerberos Certificate Authority (KCA). The KCA was expensive to run and was losing its software support, so that provided a strong motivation for finding a replacement.

The Distributed Computing Access with Federated Identities (DCAFI) [10] project implemented a new general purpose open source tool called cigetcert. cigetcert allows non-Fermilab collaborators to authenticate with their home institution credentials and to obtain certificates from CILogon Basic CA in order to access computing resources and data storage at Fermilab. The DCAFI architecture is shown in Figure 5.

Cigetcert facilitates the access by authenticating the user against the Identity Provider (IdP) at her home institution. If the home institution uses Kerberos like Fermilab does, and the user has valid Kerberos credentials, the authentication with the IdP is done transparently and automatically, otherwise the user has to enter a password once a week. The IdP generates a secured statement indicating that the user’s identity has been confirmed with her institution credentials. This statement, known as a SAML assertion, is passed to CILogon Basic CA for obtaining an X.509 certificate, which the user can present to access computing resources at Fermilab. Additionally, cigetcert stores a proxy certificate on the local disk and stores a longer-lived proxy in MyProxy for use by the job submission system to renew authentication so long-lived jobs can access storage. If the user does not have an X.509 certificate or it is expired, the FIFE job submission system now transparently calls cigetcert to obtain one.

The DCAFI project Phase 1 successfully deployed cigetcert for all Fermilab users, as well as the configuration of the Fermilab IdP to accept either Kerberos or password authentication. The corresponding X.509 Distinguished Names (DNs) are automatically registered for all Fermilab users; DNs from other institutions can be used but have to be registered manually by administrators. The goal of the future DCAFI project Phase 2 is to configure other InCommon IdPs and to create a web service with federated single-sign-on so users can register their own X.509 Distinguished Names (DNs) from their home institutions.
Figure 5. DCAFI architecture. There are three important pieces in DCAFI infrastructure: the InCommon Trust Federation, the CILogon Basic CA service and the MyProxy online credential repository. The InCommon Trust Federation\(^8\) is the identity federation for education and research institutions in the U.S. It enables Identity Providers to manage and share user identities with Service Providers in a secure and trusted framework. CILogon Basic CA\(^4\) is a Certificate Authority relying on the InCommon Trust Federation to authenticate users to provide X.509 certificates. MyProxy is an online credential repository service, where users can store their credentials and from where the credentials can be securely retrieved for later use.\(^{[11]}\)

7. Future Directions
The FIFE Project’s future focus will cover three main areas: helping to shape the HEP computing model of the future, lowering access barriers to computing resources, and improving our existing services. The HEP computing model of the future will likely include increased use of High Performance Computing (HPC) resources and cloud resources, both in terms of job processing and perhaps storage, and increased use of multi-threaded programs. The FIFE job submission infrastructure now allows experiments to run on allocation-based HPC resources, such as the Extreme Science and Engineering Discovery Environment (XSEDE) and the Ohio Supercomputing Center. We expect all future improvements in this area to be tightly coupled with the HEPCloud Project \(^{[17]}\), including the development of decision engines that can steer jobs to dedicated experiment resources, general opportunistic resources, or commercial clouds as appropriate to each experiments constraints.

Lowering access barriers consists of continuing to improve middleware such as JobSub \(^{[3]}\), and especially the work outlined in Section 6 regarding federated identities. The successful completion of Phase I enables work to start on Phase II, allowing users without Fermilab account
to access Fermilab resources using credentials from other trusted institutions. We expect this capability to become extremely useful for international collaborators who make very infrequent trips to Fermilab.

Several improvements are underway for the existing FIFE toolset. Modifications to SAM include a new tool suite that will enable general end users to more easily group analysis files according to general criteria, easily define and remove datasets, and bring SAMs advanced file delivery capabilities to small-scale analysis jobs. Another improvement underway for SAM is to begin allowing for a “send the jobs where the data are model, in addition to the traditional send the data to the jobs model. Improvements to POMS include a more robust set of command-line tools and options to automatically resubmit failed jobs with different resource requests. As always, FIFE will work to keep close interaction between developers and experiment liaisons to ensure that the tools are developed to match the experiments requirements as closely as possible.

8. Summary

The FIFE Project is a Fermilab-based initiative to lead the computing model for non-LHC experiments in all areas of high energy physics. FIFE provides a complete, modular set of tools to experiments, covering everything from job submission to storage to complete workflow management. The tools are usable for power users and newcomers alike, and provide common functionality for physicists participating in more than one experiment. The combined computing needs of experiments using the FIFE tools are now approaching the scale of a typical LHC experiment. Recent advances in the FIFE toolset include a completely new job monitoring system, full workflow management systems, a continuous integration suite, and access to international grid computing and High-Performance Computing resources. As HEP computing demands continue to increase, the computing model will necessarily evolve. The FIFE project will play a major role in shaping it, and in providing physicists on non-LHC experiments with the tools necessary to carry out their science programs.

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References

[1] M Kirby 2014 J. Phys.: Conf. Ser. 513 032049.
[2] D Box et al. 2015 J. Phys.: Conf. Ser. 664 062040.
[3] D Box 2014 J. Phys.: Conf. Ser. 513 032010.
[4] R A Illingworth 2014 J. Phys.: Conf. Ser. 513 032045.
[5] A L Lyon, M W Mengel 2014 J. Phys.: Conf. Ser. 513 032068.
[6] C Green et al. 2012 J. Phys.: Conf. Ser. 396 022020.
[7] P Fuhrmann and V Gulzow 2006 Euro-Par 2006 Parallel Processing (Springer) pp 11061113.
[8] I Sfiligoi et al. 2009 WRI World Congress on Computer Science and Information Engineering (CSIE2009), vol. 02, pp. 428-432.
[9] J Blomer et al. 2011 J. Phys.: Conf. Ser. 331 042003.
[10] J Teheran et al. 2016 Proc. of the 11th Annual Cyber and Information Security Conference, Article No. 10.
[11] J Basney et al. 2005 Soft. Pract. Exp. vol. 35, no. 9, pp. 801-816.
[12] https://fifemon.github.io/
[13] https://graphiteapp.org/
[14] http://grafana.org/
[15] https://www.elastic.co/products
[16] https://prometheus.io/
[17] G Garzoglio and O Gutsche 2015 J. Phys.: Conf. Ser. 664 012001.