

## Scientific Software Engineering & Data Management X-ray Science Division (XSD), Advanced Photon Source Effort Plan for FY18 and FY19

The APS Scientific Software Engineering & Data Management group provides leadership and scientific software engineering expertise in the areas of data analysis, data management, high-performance computing, visualization, mobile applications, and workflow and orchestration applications in support of world-class photon sciences at the APS. This mission is realized through the creation of a core software application portfolio in prioritized areas, including coherence, imaging, and high-energy techniques, as well with software tools for data access and management, and data streaming for real-time feedback. Effort is aligned with facility priorities and strategies, which at this time include scientific software and data management tools critical to the techniques enabled by the APS-U, and is used in a transparent, flexible, and well-documented manner.

SDM believes it can uniquely enable great science (and x-ray synchrotron techniques) by creating great scientific and data management software. This is a key component in the creation of beamlines of the future, and is critical to the success of the APS-U project. Well-formed collaborative teams of software engineers, computer scientists, algorithm developers, beamline staff, users, peer groups, and other facilities and institutions develop the SDM group's software portfolio. The group works closely with the XSD-CXS group to implement new algorithms and mathematical methods, and with the XSD-BC group to integrate data analysis with beamline data acquisition systems. This document will be reviewed and updated at least once a year.

### Project Summaries

Project	Summary	FY18 SDM FTE	FY19 SDM FTE
MONA	Project aimed at integrating bluesky with APS HPC data analysis packages and other tools to enable automated experiment feedback.	0.5	0.5
APS / NSLS-II Data Collaboration	Synergize collaborations and best leverage scarce resources to provide optimal value and interoperability among facilities in the area of data acquisition, management, analysis, and visualization.	0.25	0.25
Bragg Coherent Diffraction Imaging (CDI) Software	Implement and parallelize genetic algorithms and phase retrieval methods for the Bragg CDI technique.	0.5	0.5
Correlation Toolkit	Develop a real-time HPC-enabled set of tools for time-based correlation data analysis.	0.75	0.75
General-Purpose Reciprocal-Space Mapping (RSM) Tools	Continue development and deployment of high-performance RSM tools.	0.75	0.75
X-ray Fluorescence Mapping (XFM) Software	Develop HPC-enabled fitting library and tools for fast elemental mapping.	0.75	0.75

Support for Ptychography Software	Provide ongoing support for ptychography reconstruction software and tools, and integration with complementary techniques.	1.0	1.0
Data Quality & Feedback Tools	Toolkit and framework to verify quality of collected data and provide feedback during and after acquisition.	0.5	0.5
Workflow & Data Management Tools	Continue application of analysis workflow, web portals, and data management and distribution tools at APS beamlines.	0.5	0.5
Beamline Data Streaming Prototype	Prototype software and infrastructure for real-time acquisition, streaming, analysis, and storage needed for APS-U and future beamlines.	0.25	0.25
Real-time Feedback & Data Acquisition System for APS-U Accelerator	Software framework and tools for the collection of data used for controls, statistics and diagnostics of technical systems for the MBA accelerator.	0.75*	0.75*
Component Database (CDB) for APS-U	An electronic system for tracking and documenting accelerator and beamline components.	0.75*	0.75*
Support for HT-HEDM Beamline Project	Develop and integration of auto-alignment/calibration tools and mail-in automation software with existing systems for the new HT-HEDM beamline.	TBD	TBD
Visualization Tools	Application and/or development of advanced visualization tools for APS beamline data analysis and experiment feedback.	0.0**	0.0**
Coherent Surface Scattering Imaging (CSSI) Software	Implementation of high-performance CSSI and GISAXS software applications.	0.0**	0.0**
Multi-modal XRF Tomography	Develop robust near real-time software for XRF tomography once algorithm development is complete	0.0**	0.0**
Multi-modal Diffraction Tomography	Develop robust near real-time software for diffraction tomography once algorithm development is complete	0.0**	0.0**
Multi-modal XRF Ptychography	Develop robust near real-time software for XRF ptychography once algorithm development is complete	0.0**	0.0**
Laue Diffraction	Develop high-performance computing tool kit for the new Laue depth reconstruction algorithm	0.0**	0.0**

\* APS-U Funded – Pending FY18 ERA

\*\* Additional funding/effort levels will enable the XSD-SDM group to take on additional projects and add further capabilities at the APS.

## Project Details

### MONA

Team: Barbara Frosik (SMD), Arthur Glowacki (SDM), Faisal Khan (SDM), Ke Yue (SDM), Doga Gursoy (CXS), Tekin Bicer (CXS/MCS), et al.

FY18 SDM Effort: 0.5 FTE

FY19 SDM Effort: 0.5 FTE

Out Years: TBD

Summary: Project aimed at integrating bluesky with APS HPC data analysis packages and other tools to enable automated experiment feedback.

## **APS / NSLS-II Data Collaboration**

Summary: Synergize collaborations and best leverage scarce resources to provide optimal value and interoperability among the APS and NSLS-II in the area of data acquisition, management, analysis, and visualization.

Team: Arthur Glowacki (SDM), Doga Gursoy (CXS), John Hammonds (SDM), Faisal Khan (SDM), Pete Jemian (BC), Nicholas Schwarz (SDM), Brian Toby (CXS), Andrey Yakovenko (SRS), NSLS-II Staff, et al.

FY18 SDM Effort: 0.25 FTE

FY19 SDM Effort: 0.25 FTE

Synergize collaborations and best leverage scarce resources to provide optimal value and interoperability among the APS and NSLS-II in the area of data acquisition, management, analysis, and visualization. The APS will target the adoption of bluesky for new beamlines, including the APS-U suite of beamlines. The NSLS-II and the APS will aim to share APS developed HPC code bases and modify them for use by both facilities. Both facilities will integrate existing data management tools with the bluesky suite of acquisition tools, and with streaming HPC-enabled data analysis tools. Together both facilities will investigate tools and technologies for advanced visualization capabilities.

Effort in this area may overlap significantly with other projects described in this document. See the *APS / NSLS-II Data Acquisition, Management, Analysis, and Visualization Working Group Collaboration Report* and the *APS / NSLS-II Data Acquisition, Management, Analysis, and Visualization Working Group FY18 – FY19 Plan* for more detailed information and timelines.

## **Bragg Coherence Diffraction Imaging (CDI) Software**

Summary: Implement and parallelize genetic algorithms and phase retrieval methods for Bragg CDI techniques.

Team: Barbara Frosik (SDM), Ross Harder (MIC), et al.

FY18 SDM Effort: 0.5 FTE

FY19 SDM Effort: 0.5 FTE

Out Years: TBD

A genetic algorithm approach to CDI phase retrieval will improve coherent imaging in two aspects. The first is to enable the recovery of highly reproducible images from a given data set. The second is to render previously impossible to image samples amenable to CDI, opening the door to a greater scientific impact for the method. The basic idea is to do the same phasing process with tens to thousands of random starting points. The diversity of results is then exploited to arrive at a highly reproducible image of the sample. Another aspect of genetic algorithm approaches is in the “fitness” criterion used to evaluate the population of results. This can be tuned to enable phase retrieval of datasets that have previously been

impossible to produce images from. It is desired to implement and parallelize software for fast processing by non-expert beamline users.

Current processing time of a 100 MB sample using serial MATLAB code takes 60 minutes using limited parameters. Current data acquisition time for a 100 MB data set is 20 minutes, and will decrease after the completion of the AP-U. Attaining a robust image of a sample in a computation time nearer the data acquisition time will allow nearer real-time feedback into the experimental parameters. The experimenter may begin to do guided, carefully executed experiments. Currently, the vast majority of Bragg CDI users will benefit from semi-real-time phase retrieval for their data. It will also open the instrument up to far less sophisticated CDI users. This technique will be critical to one or more APS-U beamlines.

## **Correlation Toolkit**

Summary: Real-time HPC-enabled set of tools for time-based correlation data analysis.

Team: Faisal Khan (SDM), Suresh Narayanan (TRR), Alec Sandy (TRR), et al.  
FY18 SDM Effort: 0.75 FTE  
FY19 SDM Effort: 0.75 FTE  
Out Years: TBD

Time-based correlations are an important analysis tool used to study the dynamic nature of complex materials. The recent development and application of higher-frequency detectors allows the investigation of faster dynamic processes enabling novel science in a wide range of areas resulting in the creation of greater amounts of image data that must be processed within the time it takes to collect the next data set in order to guide data collection. The increased brightness afforded by the APS-U project will compound this data processing challenge by producing data with higher count rates.

The current-generation HPC-enabled correlation system has been in use since February 2013, primarily by the Small-Angle X-ray Photon Correlation Spectroscopy (SA-XPCS) beamline at 8-ID-I, where it has been used by every user group at that beamline for multi-tau, and, more recently, two-time correlation analysis. These and other correlation algorithms will be critical to the techniques used by many APS-U first experiments. In order to serve a larger community of dynamics driven experiments, such as image correlations for materials exploration and high-speed imaging techniques, a real-time, general-purpose correlation toolkit implementing more advanced correlation methods using parallel computational and algorithmic techniques, and deployed on high-performance computing (HPC) resources is required. This work will leverage effort related to workflow and management tools, and data streaming and analysis tools for real-time correlation analysis.

## **General-Purpose Reciprocal-Space Mapping (RSM) Tools**

Summary: Continue development and deployment of high-performance RSM tools.

Team: John Hammonds (SDM), Jonathan Tischler (SSM), et al.  
FY18 SDM Effort: 0.75 FTE  
FY19 SDM Effort: 0.75 FTE  
Out Years: TBD

This project aims to continue development of a general-purpose tool for reciprocal-space mapping at the APS. The tool allows users to examine a volume of data and select portions on which to apply transformations that convert detector pixel locations from diffractometer geometry to reciprocal-space units, and then map pixel data on to a 3D reciprocal-space grid. It can map data acquired using 4- and 6-circle diffractometers, and with scans taken over angles or energy, and can operate via a graphical user

interface, or in batch processing mode. Data too big to fit entirely into memory at one time is processed in smaller chunks and reassembled to form the final output volume, allowing users to process arbitrarily large input datasets.

This tool has the potential to serve an even larger number of APS beamlines, and will be critical to a number of APS-U beamlines and high-energy diffraction experiments. It is currently in regular use for scattering and diffraction experiments at the 33-BM and 33-ID beamlines, for micro-diffraction analysis at 34-ID, and for time-resolved diffraction work at 7-ID. Development is underway for WA-XPCS analysis at 8-ID, and for data exploration with inelastic x-ray measurements at 30-ID. Fast tools for reciprocal-space mapping using distributed computing resources are needed to make nearer real-time decisions regarding the next set of data that is collected. This work will leverage effort related to workflow and management tools, and data streaming and analysis tools for real-time analysis.

## **Support for Ptychography Software**

Summary: Provide ongoing support for ptychography reconstruction software and tools, and integration with complementary techniques.

Team: Ke Yue (SDM), Junjing Deng (MIC), Stefan Vogt (XSD-ADMIN), Youssef Nashed (MCS), et al.  
FY18 SDM Effort: 0.5  
FY19 SDM Effort: 0.5  
Out Years: TBD

Ptychography is one of the exemplar APS-U enabled techniques, and will be one of the largest data producing techniques post APS-U. Proper support and development of existing tools, complementary use with other APS-U planned techniques, such as fluorescence ptychography, and integration with data streaming infrastructures mentioned in the description of other projects in this document is needed. Provide support and new feature development for existing GPU-based ptychography code base.

## **X-ray Fluorescence (XRF) Microscopy Software**

Summary: High-performance computing (HPC) enabled fitting library and tools for fast elemental mapping of x-ray fluorescence microscopy software.

Team: Arthur Glowacki (SDM), Wendy Di (CXS), Stefan Vogt (MIC), et al.  
FY18 SDM Effort: 0.75 FTE  
FY19 SDM Effort: 0.75 FTE  
Out Years: TBD

XRF imaging typically involves the creation and analysis of 3D data sets, where at each scan position the full spectrum is recorded. This allows one to later process the data in a variety of different approaches, e.g., by spectral region-of-interest (ROI) summation with or without background subtraction, principal component analysis, or fitting. Additionally, it is possible to sum up the per pixel spectra over selected spatial ROIs so as to improve the photon statistics in such a spectrum.

The XRF microscopy technique is a staple technique that will be used by many APS-U beamlines in combination with other x-ray acquisition modalities, such as fluorescence tomography and fluorescence ptychography. The increase in intensity and smaller spot size due to benefits of the APS-U will drastically increase data size and data rates for this technique. In order to facilitate real-time data analysis and fast feedback for experiment steering, HPC-enabled implementations of common elemental mapping algorithms and data I/O schemes that facilitate streaming data, and appropriate user interfaces are required. This work will leverage effort related to workflow and management tools, and data streaming

and analysis tools for real-time analysis, and can serve in conjunction with existing tomography software to provide analysis code for fluorescence tomographic reconstructions.

## **Data Quality & Feedback Tools**

Summary: Toolkit and framework to verify quality of collected data and provide feedback during and after acquisition.

Team: Barbara Frosik (SDM), Francesco De Carlo (IMG), Doga Gursoy (CXS), Jonathan Almer (MPE), et al.  
FY18 SDM Effort: 0.5 FTE  
FY19 SDM Effort: 0.5 FTE  
Out Years: TBD

Confirming the quality of data that has been and is being collected is critical to the efficient and effective use of experiment beam time at the APS. Without such quality checks experimenters are collecting “in the dark” and may discover issues only after beam time is over. As data volumes and rates increase due to the further deployment of higher frame-rate detectors and the increase in flux and coherence afforded by the APS-U project, and due to the complexity of novel experiments enabled by the APS-U project, the ability to check data quality in real-time in order to alert experimenters to potential data collection issues, and to be able to provide feedback and automatically adjust experiment parameters is necessary.

These tools and framework provide a mechanism for monitoring data and applying appropriate and user definable quality checks to experiment data. It can verify that EPICS PV values are within expected ranges, monitor files and compare them against predefined schemas, and apply mean, standard deviation, and delta mean statistical methods to data. Further work is required in order to catalog results for use as a log, and as input to machine learning algorithms for real-time, automated feedback. This work will synergize with other effort related to workflow and management tools, and real-time data streaming and analysis tools.

## **Workflow & Data Management Tools**

Summary: Continue application of analysis workflow, and data management and distribution tools at APS beamlines.

Team: Arthur Glowacki (SDM), Dariusz Jarosz (SDM), Sinisa Veseli (SDM), et al.  
FY18 SDM Effort: 0.5 FTE  
FY19 SDM Effort: 0.5 FTE  
Out Years: TBD

As data rates and volumes increase due to a combination of advances in detector technologies, increased use of multi-modal acquisition techniques, and the planning benefits of the APS-U project, current manual data workflow and management mechanism will not be sufficient. The APS has a need for tools and infrastructure that automate analysis pipelines, maintain and track data ownership, catalog metadata, provides data distribution endpoints and Software as a Service (SaaS) web interfaces for data analysis, etc.

The APS team will place great emphasis on leveraging best-in-class tools, rather than on developing new systems. For example, they will continue to work closely with the Globus Services team in order to not duplicate effort and best leverage DOE and ANL resources. Open source tools will be used in order to best meet the needs of the APS in an efficient and cost effective manner. Of particular importance for the next two years is the development of online portals for XRF and XPCS analysis.

## **Beamline Data Streaming Prototype**

Summary: Prototype software and infrastructure for real-time acquisition, streaming, analysis, and storage needed for APS-U and future beamlines.

Proposed Team: Faisal Khan (SDM), Arthur Glowacki (SDM), Barbara Frosik (SDM), John Hammonds (SDM), Sinisa Veseli (SDM), TBD, et al.

FY18 SDM Effort: 0.25

FY19 SDM Effort: 0.25

Out Years: TBD

Increases in data rates from newer generation detectors combined with increases due to the APS-U required the APS to rethink how data acquisition, analysis, and storage is addressed. Collecting full datasets before any processing occurs is not sufficient to address the real-time feedback needs of APS-U beamlines. Further, foreseen data rates may be too large for traditional storage mechanisms to accommodate, and the anticipated data rates of some APS-U beamlines (up to 1 PB per day) make copying data or transport of data to users' home institutions infeasible.

The purpose of this project is to prototype software and hardware tools and infrastructure needed for fast data streaming and interoperability with real-time analysis and data quality code bases currently under development. It will target XPCS and XRF as initial use cases with the aim to produce a standard set of tools and guidelines for other beamlines and techniques to follow. The project should find synergies with the APS-U feedback and acquisition system, and data management and workflow tools, and be applicable to acquisition techniques that collect data which may be incrementally processed as it is acquired, such as ptychography and diffraction space mapping.

## **Real-time Feedback & Data Acquisition System for APS-U Accelerator**

Summary: Software framework and tools for the collection of data used for controls, statistics and diagnostics of technical systems for the MBA accelerator.

Proposed Team: Sinisa Veseli (SDM), Ned Arnold (CTL), John Carwardine (APS-U), et al.

FY18 SDM Effort: 0.75 FTE\*

FY19 SDM Effort: 0.75 FTE\*

Out Years: TBD

The real-time feedback and data acquisition (RTFB/DAQ) system is a software framework and associated tools that enable fast data collection for controls, statistics, and diagnostics associated with the state-of-the-art embedded controllers utilized by the APS-U project MBA-based accelerator design. The DAQ software interfaces with several technical subsystems to provide time-correlated and synchronously sampled data that can be used for commissioning, troubleshooting, performance monitoring, and early fault detection. The key features of the system include capability to acquire data from multiple subsystems at various sample rates, support for continuous data acquisition, and the ability to route data to any number of applications. Future work will focus on extending system functionality to provide access to BPM turn-by-turn data, as well as power supply monitoring.

## **Component Database (CDB) for APS-U**

Summary: An electronic system for tracking and documenting accelerator and beamline components.

Proposed Team: Dariusz Jarosz (SDM), Sinisa Veseli (SDM), Ned Arnold (CTL), John Carwardine (APS-U), et al.

FY18 SDM Effort: 0.75 FTE\*

FY19 SDM Effort: 0.75 FTE\*

Out Years: TBD

The APS-U project aims to replace the existing APS storage ring under an aggressive one-year schedule for removal, installation and testing. Management of the thousands of components to be installed in such a short time represents a significant challenge. The Component Database (CDB) is a tool for organizing and tracking components and designs used for the APS storage ring upgrade. It helps capture component documentation, provides a repository for inspection and measurement data (e.g. electronic travellers), and supports logging of component history through the component's life cycle. CDB is built around relational database, web portal, and REST web service technologies, and provides users with a number of options for accessing the system. In particular, it serves as a user portal for finding all known information about a specific component or a design. To that end, CDB provides links and interfaces to external systems commonly used at APS, such as various drawing and document management systems, procurement applications, etc. Future efforts will focus on extending the system capabilities to capture cable connections, enabling access via mobile applications, and providing custom views for different user groups.

### **Support for HT-HEDM Beamline Project**

Summary: Develop and integration of auto-alignment/calibration tools and mail-in automation software with existing systems for the new HT-HEDM beamline.

Proposed Team: TBD SDM Members, et al.

FY18 SDM Effort: TBD

FY19 SDM Effort: TBD

Out Years: TBD

Work in this area will be applicable to many other APS beamlines, including 1-ID and 12-ID. Project deliverables are currently being scoped.

### **Visualization Tools**

Summary: Application and/or development of advanced visualization tools for APS beamline data analysis and experiment feedback.

Proposed Team: TBD SDM Member, et al.

FY18 SDM Effort: 0.0 FTE

FY19 SDM Effort: 0.0 FTE

Out Years: TBD

Visualization is often critical to experiment data analysis. Visualization of data from tomographic imaging, micro-diffraction, and high-energy diffraction beamlines is already a challenge that will become more pressing in the near future. With the increase in data volumes being generated by higher frame-rate detectors, and as novel multi-modal techniques are enabled due to the benefits of the APS-U project and planned as a part of the APS-U's first experiments, e.g. x-ray fluorescence microscopy data coupled with coherent diffraction imaging, advanced visualization techniques will be needed in order to gain understanding and insight from this data, both as a part of post-acquisition processing and to allow user intervention during data collection. The application, augmentation, and/or development of capable data visualization tools, such as ParaView, on advanced computational resources are needed in order to cope with these large and complex data streams.

### **Coherent Surface Scattering Imaging (CSSI) Software**

Summary: Implementation of high-performance CSSI and GISAXS software applications.

Proposed Team: TBD SDM Member, Zhang Jiang (TRR), Jin Wang (TRR), et al.

FY18 SDM Effort: 0.0 FTE

FY19 SDM Effort: 0.0 FTE

Out Years: TBD

CSSI and the non-coherence dependent complementary technique, GISAXS, will be critical techniques used at a number of APS-U beamlines. Algorithm and model development are currently underway.

Proposed LDRDs will further required development in this area, however, software coding effort will be needed in order to fully realize the benefit of these developments once sufficient algorithmic advances are made.

### **Multi-modal XRF Tomography**

Summary: Develop robust near real-time software for XRF tomography.

Proposed Team: TBD SDM Member, et al.

FY18 SDM Effort: 0.0 FTE\*\*

FY19 SDM Effort: 0.0 FTE\*\*

Out Years: TBD

Algorithmic work is currently underway in the XSD-CXS group. Performance and engineering work will commence once algorithmic proof-of-concept is complete.

### **Multi-modal Diffraction Tomography**

Summary: Develop robust near real-time software for diffraction tomography.

Proposed Team: TBD SDM Member, et al.

FY18 SDM Effort: 0.0 FTE\*\*

FY19 SDM Effort: 0.0 FTE\*\*

Out Years: TBD

Algorithmic work is currently underway in the XSD-CXS group. Performance and engineering work will commence once algorithmic proof-of-concept is complete.

### **Multi-modal XRF Ptychography**

Summary: Develop robust near real-time software for XRF ptychography.

Proposed Team: TBD SDM Member, et al.

FY18 SDM Effort: 0.0 FTE\*\*

FY19 SDM Effort: 0.0 FTE\*\*

Out Years: TBD

Algorithmic work is currently underway in the XSD-CXS group. Performance and engineering work will commence once algorithmic proof-of-concept is complete.

### **Laue Diffraction**

Summary: Develop high-performance computing tool kit for the new Laue depth reconstruction algorithm.

Proposed Team: TBD SDM Member, et al.

FY18 SDM Effort: 0.0 FTE\*\*

FY19 SDM Effort: 0.0 FTE\*\*

Out Years: TBD

Algorithmic work is currently underway in the XSD-SSM group. Performance and engineering work will commence once algorithmic proof-of-concept is complete.