HEPS

Machine Learning for Accelerators/High Energy Photon Source (HEPS)

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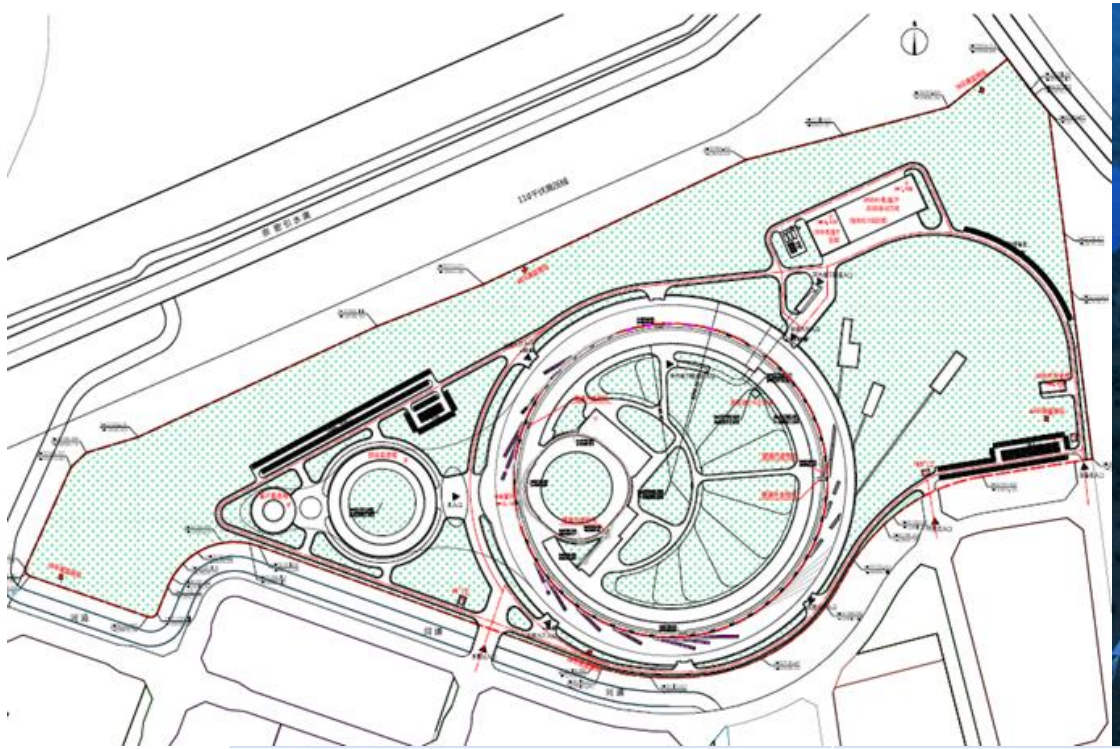
Outline

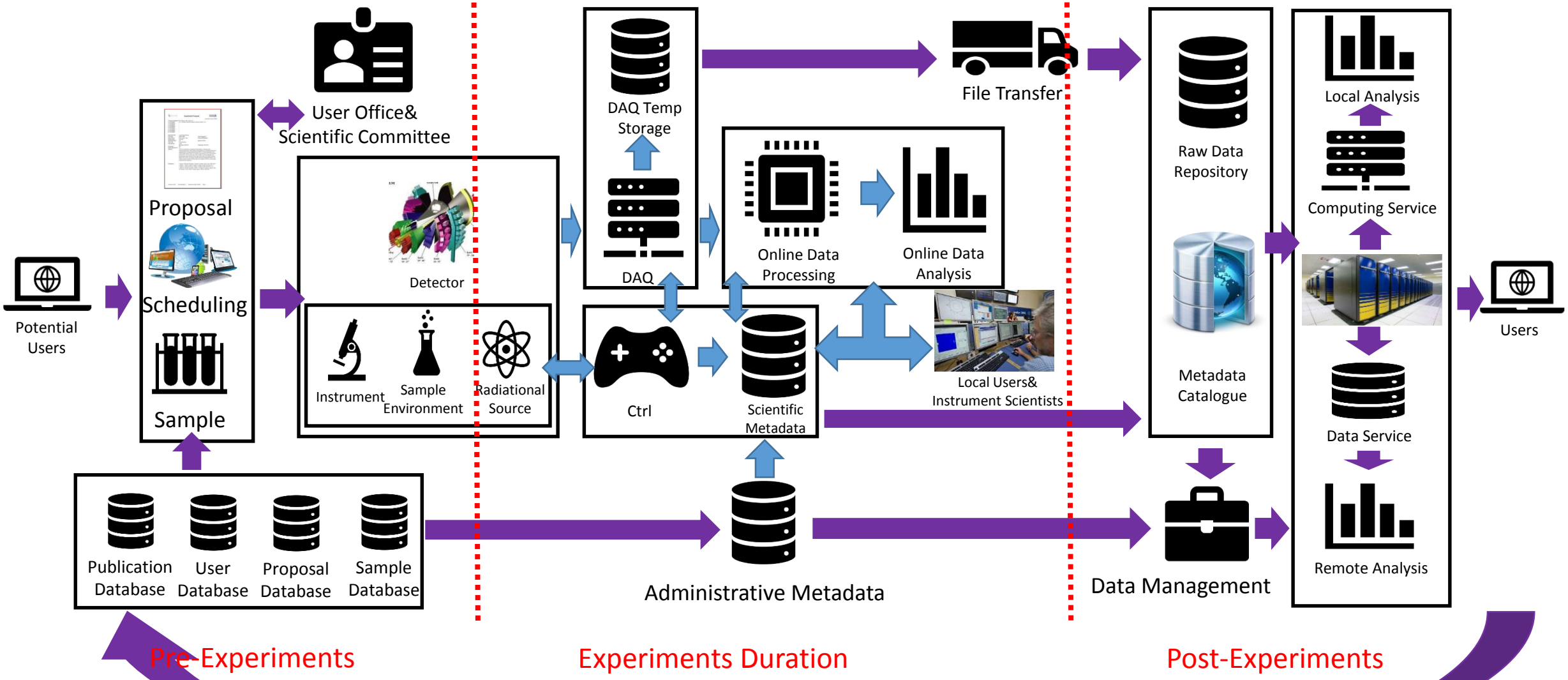
1. Introduction
2. Software Architecture for HEPS ML
3. Preparation for Machine Learning
4. ML Application Examples
5. Summary

Introduction

- HEPS– 4th generation synchrotron light source, 7BA-lattice
- Construction period – Jun. 2019 – Dec. 2025, ~US$700M

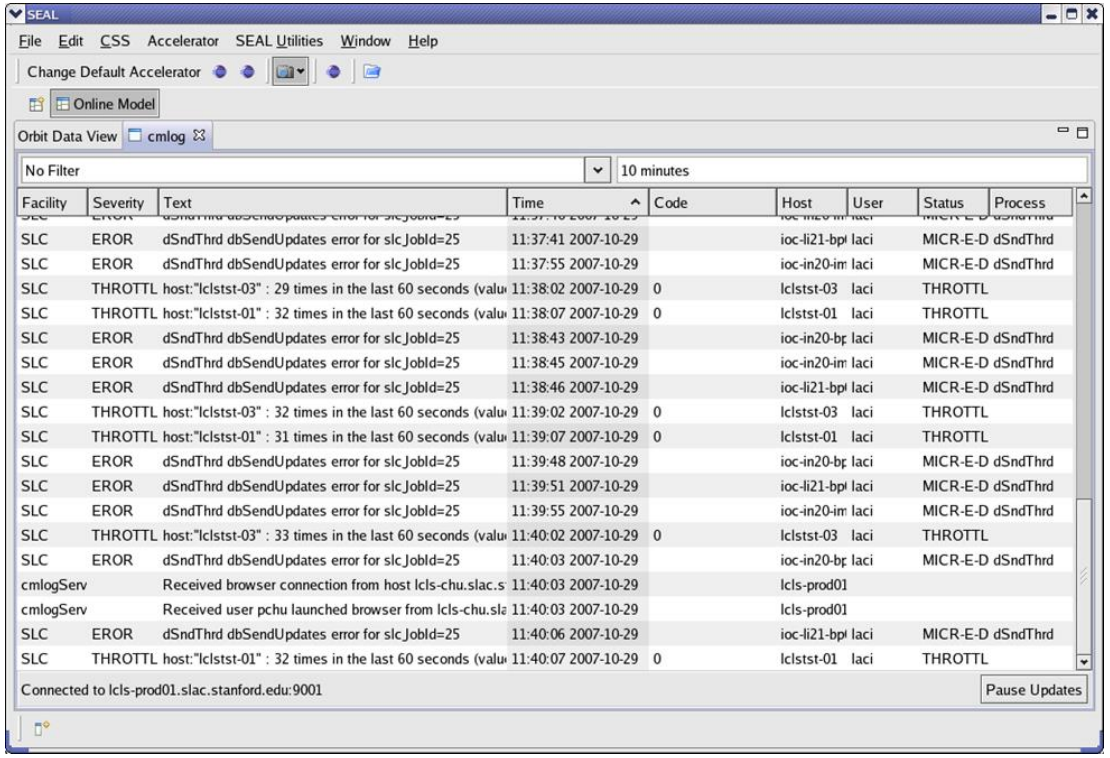


User Facility Software Architecture (courtesy F.Z. Qi)



Central Message Logging System

- Recording every action occurred in the system
- CMLog data format
- CMLog database (noSQL)
- C/C++/Java/Python API
- CMLog client viewer
- Can serve for MPS postmortem analysis



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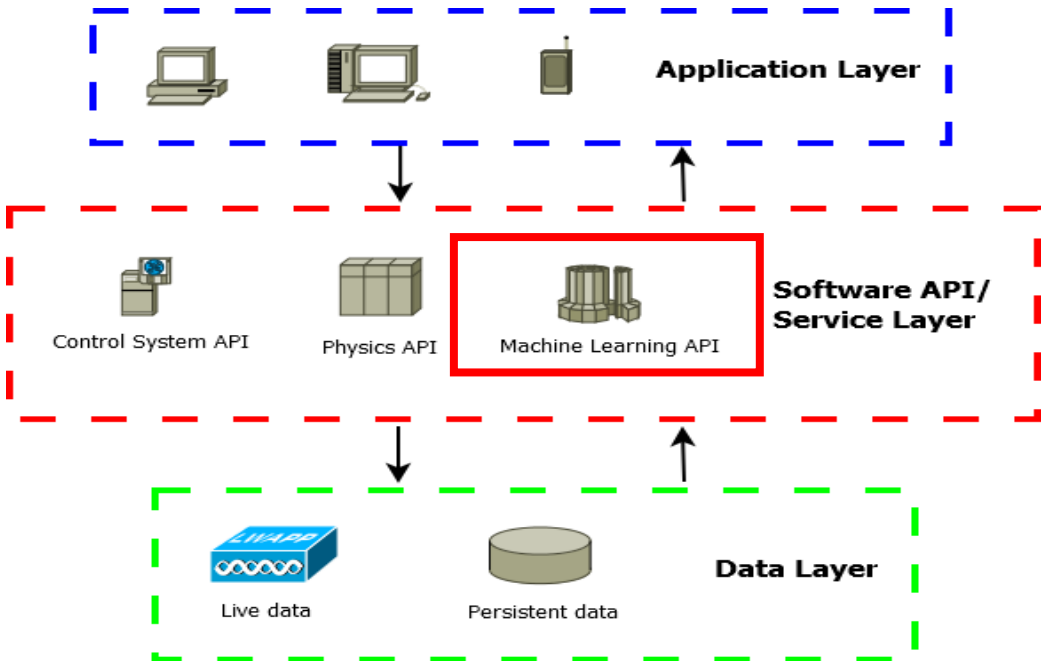
High-level Application Architecture



- Collecting as much data as possible
  - Central messaging logging
  - Operation logging
  - …
- Data Pre-processing
  - Clean up
  - Line up

- Programming applications with 3 categories of APIs
  - Software re-usability, cut development time
  - General-purpose, physics, and Machine Learning (ML)
- Standard data formats & popular algorithms

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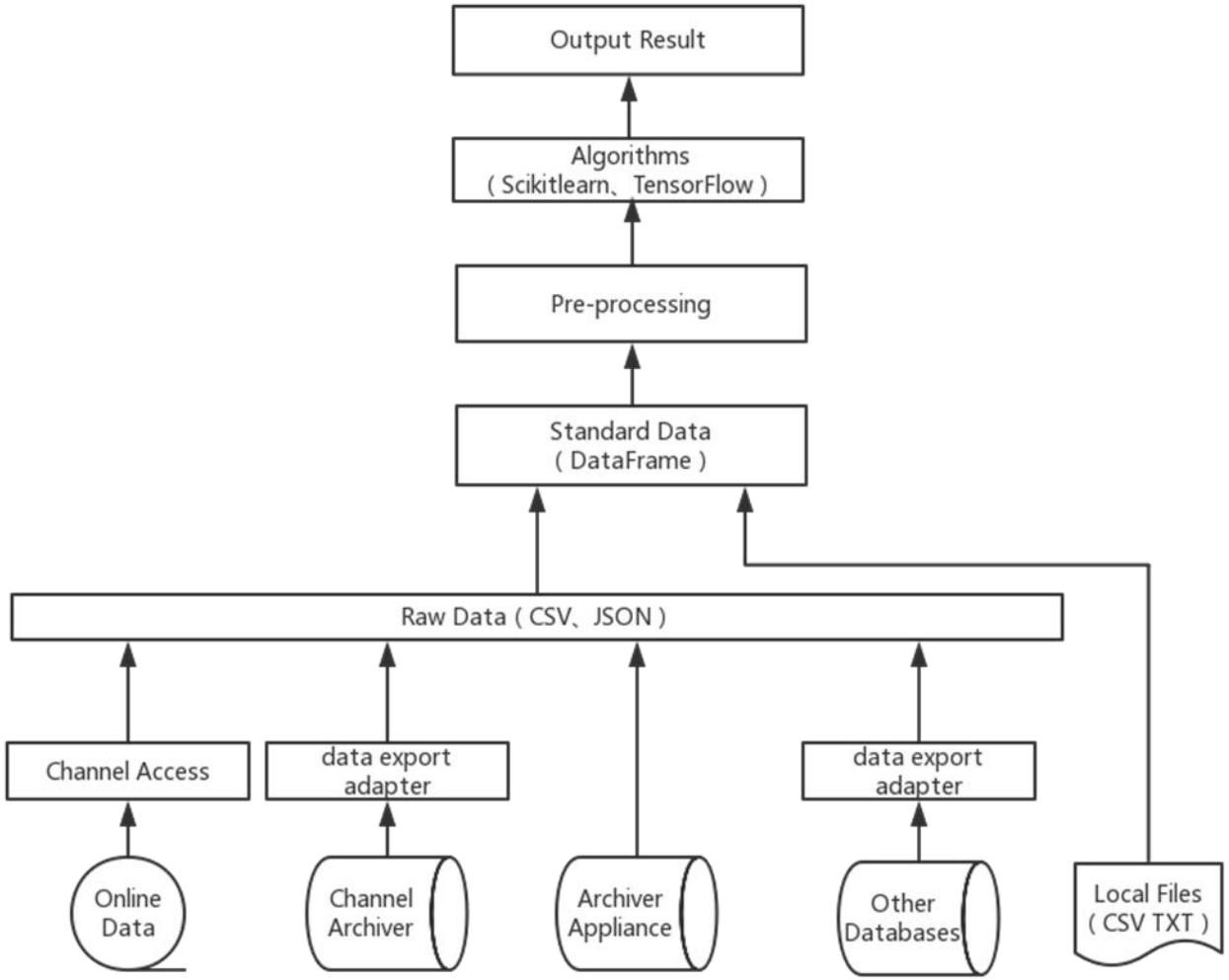
Machine Learning Platform

- Getting data
- Pre-processing data
- Applying algorithms
- Displaying results
- Applying results/predictions



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ML Platform General Ideas

Machine Learning in Python

Scikit-learn/TensorFlow

- Simple and efficient tool for data mining & data analysis
- Built on NumPy, SciPy, and matplotlib
- Open source, commercially usable - BSD license

Machine Learning in MATLAB

MATLAB Machine Learning Toolbox

Data Preparation Example for Machine Learning

Data Collection

- Archived accelerator data
- Experiment data from Data Acquisition (DAQ) systems
- PVLogger (EPICS based) or time synchronized meta data
  - Define own EPICS PV list, logging period easily
  - Aligned timestamp PVs
  - MySQL DB
  - Periodic logging
  - On-demand logging

SVC_ID	SVC_NM
physics	region physics
NULL	NULL

SNAPSHOT_PER	SNAPSHOT_PER_NAM
0	no logging
1	1 sec
60	1 min
900	15 min
3600	1 hr

SNAPSHOT_RETENT	SNAPSHOT_RETENT_NM
0	forever
86400	1 day
2592000	30 days
7776000	90 days
15552000	180 days
31536000	1 yr

```
import sys
import math

from java.util import *

from xal.service.pvlogger import RemoteLoggingCenter

rL = RemoteLoggingCenter()

# prepare comments for the snapshot
time = Date()
comments = time.toString()

# take a snapshot
snapshotId = rL.takeAndPublishSnapshot( "Region physics", comments);
```

Data Handling

Data Sources

- EPICS live data
- TXT/Excel Files
- EPICS Channel Archiver
- EPISC Archiver Appliance
- Other data sources (e.g. PVLogger)

Output Data Format

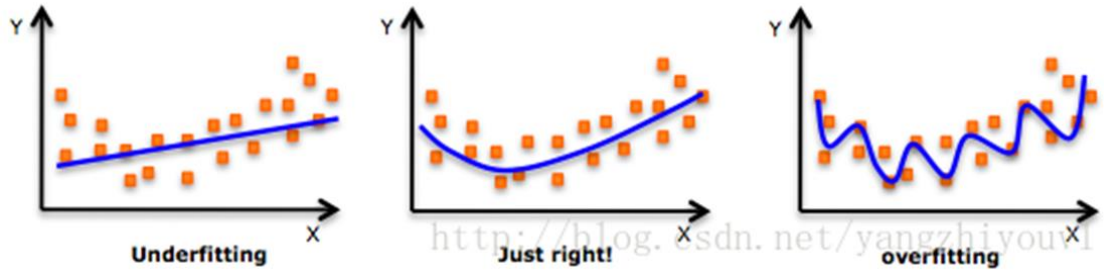
- Pandas DataFrame
- TXT/Excel Files
- Other format: HDFS

Code Snippet

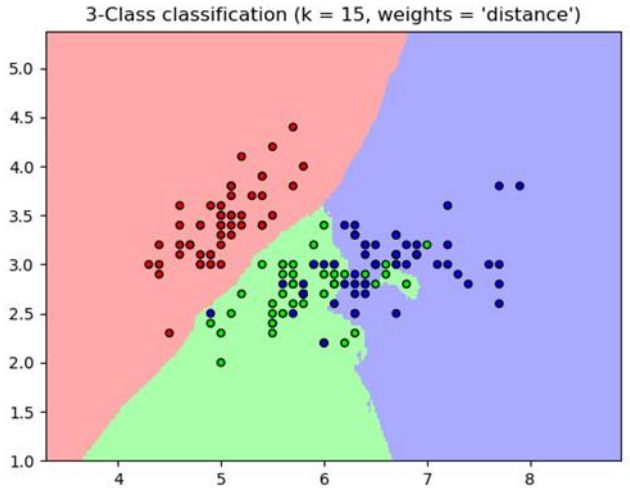
```
pvnames=['BIBPM:R1OBPM02:XPOS','BIBPM:R1OBPM03:XPOS','BIBPM:R1OBPM04:XPOS]
#also can load pvnames from files
engine=LoadData.getKey(server_addr,pvnames)
data=LoadData.getFormatChanArch(server_addr,engine,pvnames,start_time='11/30/2018
14:15:00',end_time='11/30/2018 14:16:00',merge_type='outer',interpolation_type='linear',
fillna_type=None,how=0)
```

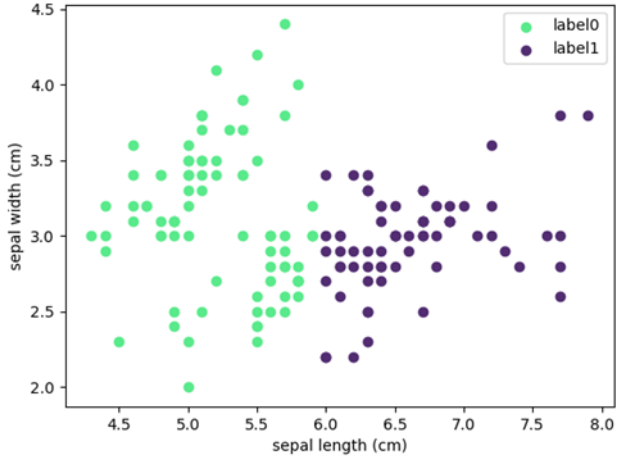
Algorithms

- Regression
  - Linear Regression
  - Bayesian Linear Regression
  - Polynomial Regression
- Decision Tree
- K-Nearest Neighbors
- Clustering
  - K-Means
  - DBSCAN
- Multi-layer Perceptron (MLP)
- …



http://blog.csdn.net/yangzhiyou11





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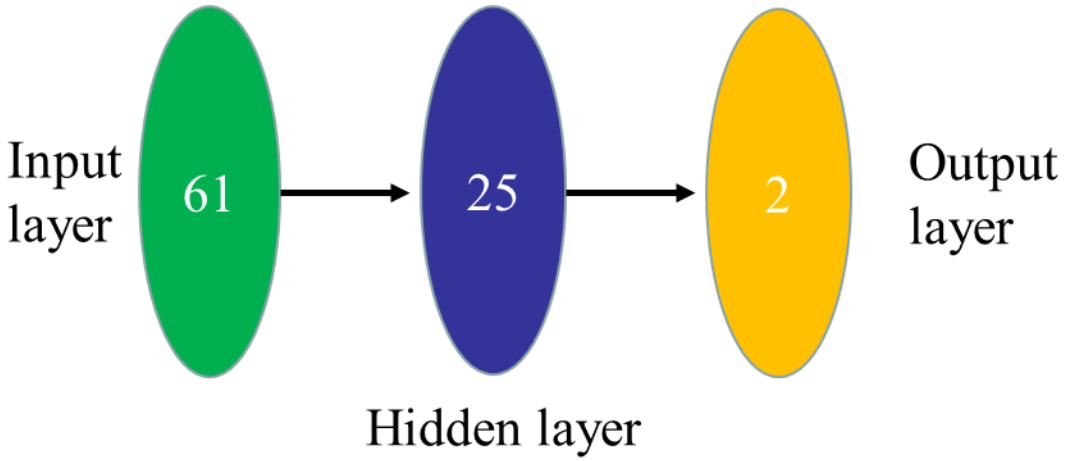
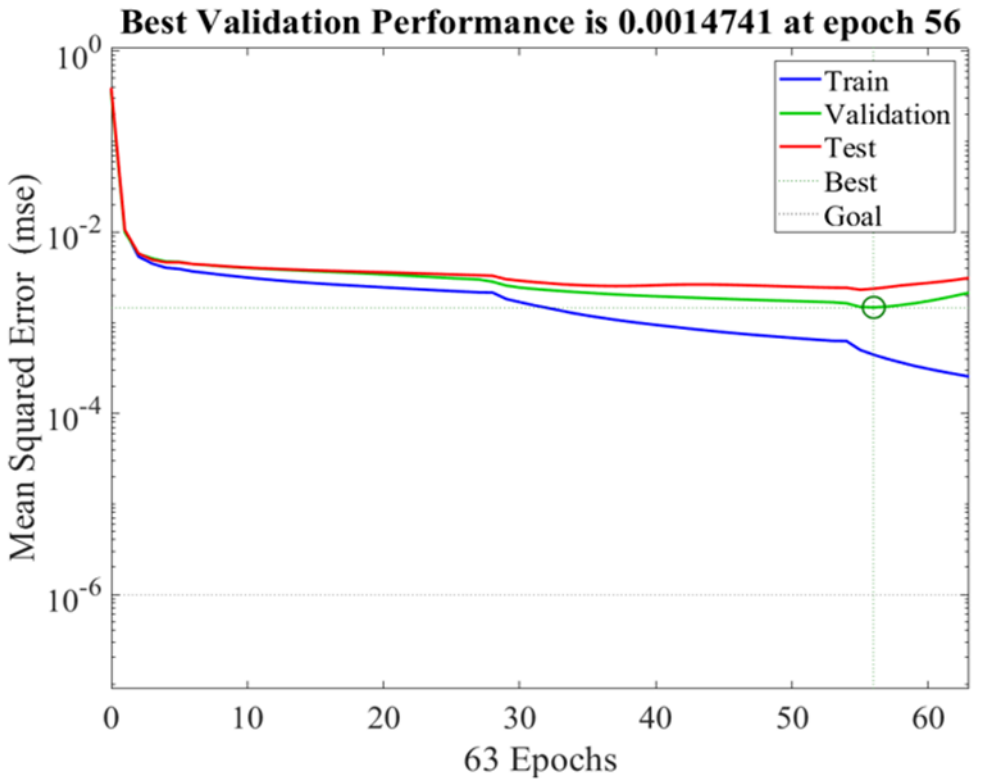
ML for HEPS Lattice Design [1]

- Using DNN for HEPS lattice design
  - Highly nonlinear model
  - Applying HEPS optimized lattice data
  - Optimize brightness (BN) and dynamic aperture (DA)



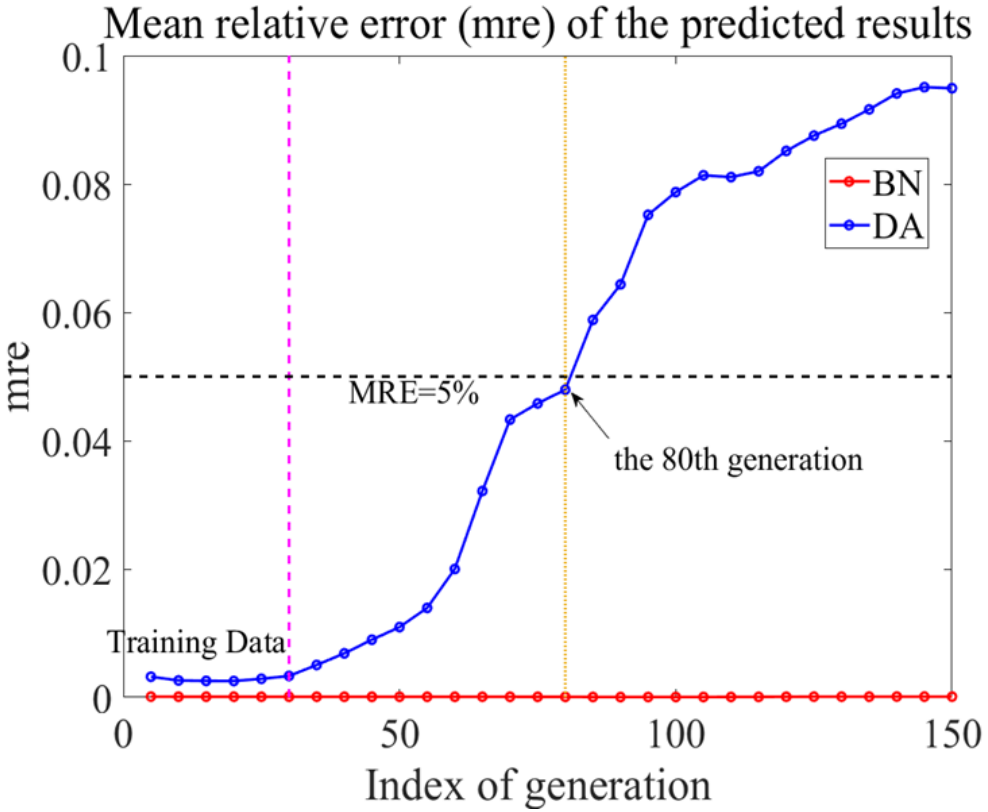


ML for HEPS Lattice Design [2]

- The DNN method can predict the BN close to 100% and DA over 95% at 80th generation

	Single thread (s)	62-thread parallel computing (s)
DNN	0.3944	0.0092
Particle Tracking	78020	1414.2
Improvement	O(5)	O(5)

DNN is 5 Orders better efficiency than Particle Tracking!



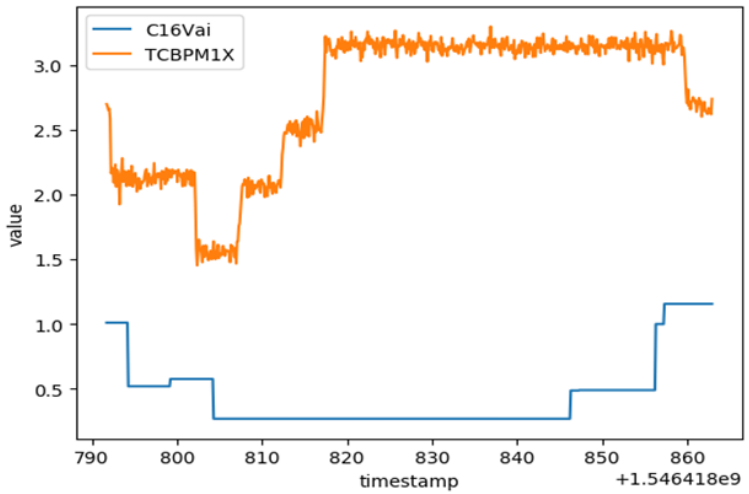
Machine Learning at Work

A test for BEPC-II timestamp correction

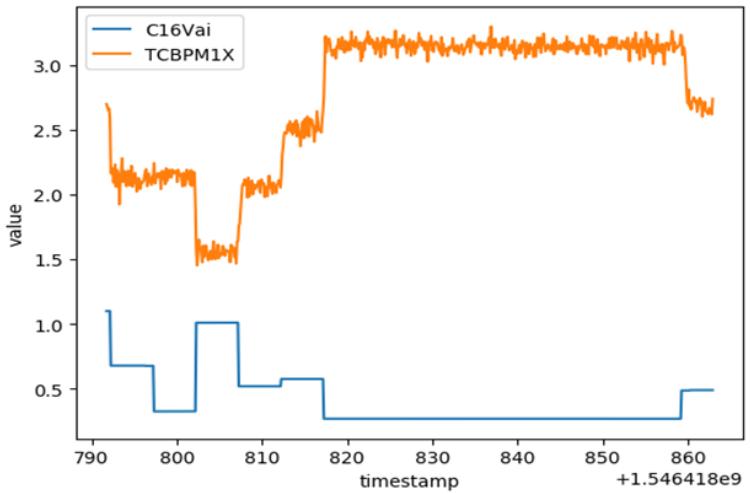
- Correlation function $R = [1 - \int \zeta (h(f_1(t + dt)) - f_2(t))]$
- Objective function $\arg\max R(dt)$

f1(t)&f2(t) : The relation between 'value' and 'timestamp' of two systems(such as correctors with BPM).
h(): Projection of one group of value to another.
ζ(): Integral coefficient. (Remove interference and noise. Keep normalization)

Input data



return

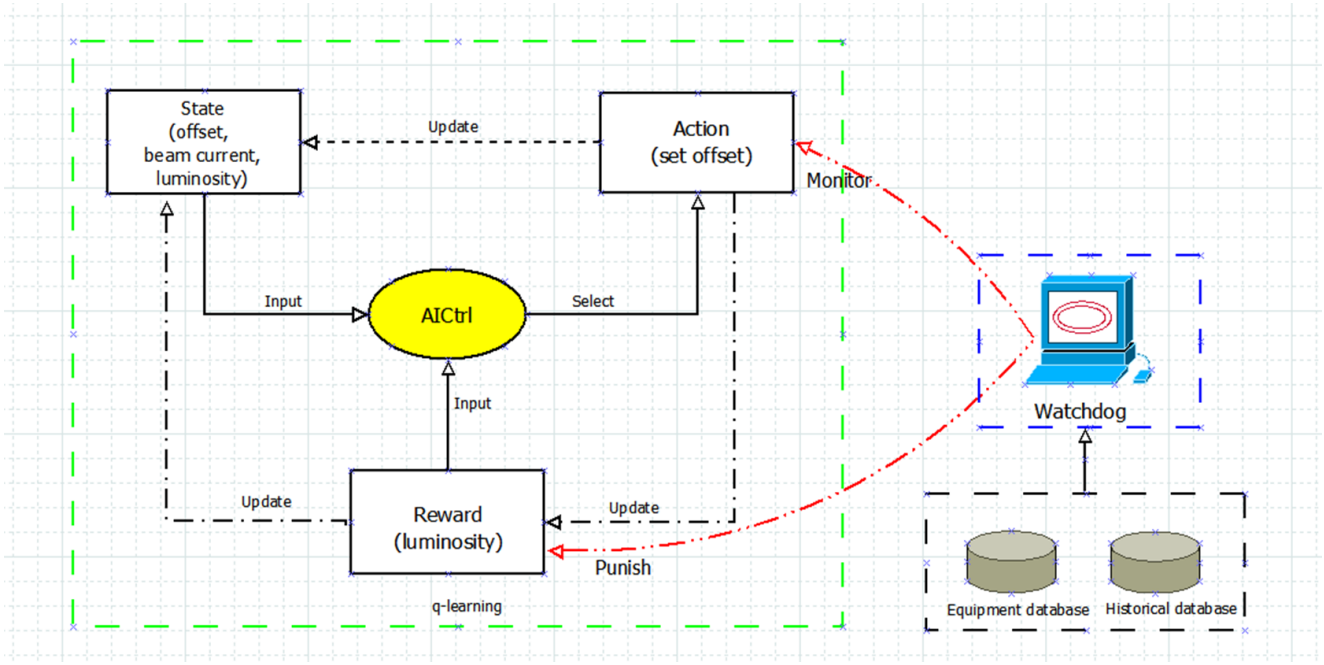


Accelerator Intelligent Control System [1]

AICtrl

- Could be applied to many conditions, such as beam loss reduction, luminosity optimization and so on
- Based on deep learning and reinforcement learning, it is better to find good condition with historical data then merely manual tuning

Application on luminosity optimization



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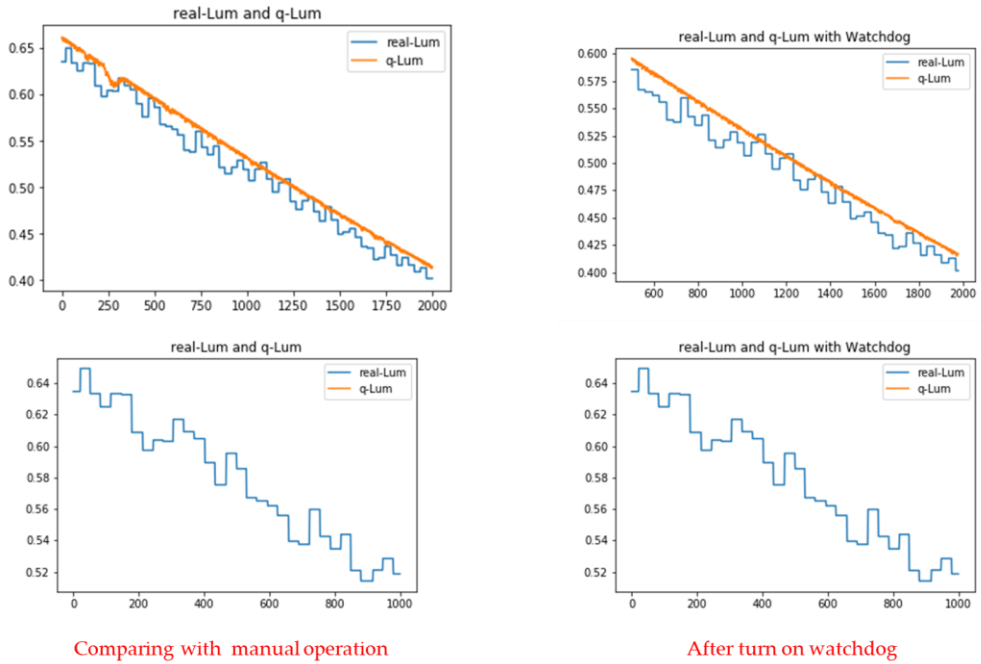
Accelerator Intelligent Control System [2]

- Application on luminosity optimization by adjusting vertical beam position offset
  - Comparing with manual tuning, AICtrl can make luminosity always in a good state
  - Strange behavior could be avoided by simply turning on the watchdog



Comparing with manual operation

After turn on watchdog

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Next Steps

- An Application “Template”
- Setting up virtual accelerator environment for ML App tests
- Setting up Hadoop environment
- Setting up GPU computing
- Getting more operation data

Summary

- HEPS Control/Data Systems designed for ML
- Overall consideration, modularized implementation
- Machine Learning for Accelerator Platform prototyped
- Many application ideas are emerging
- Collaborations are welcome

Thanks for your attention!

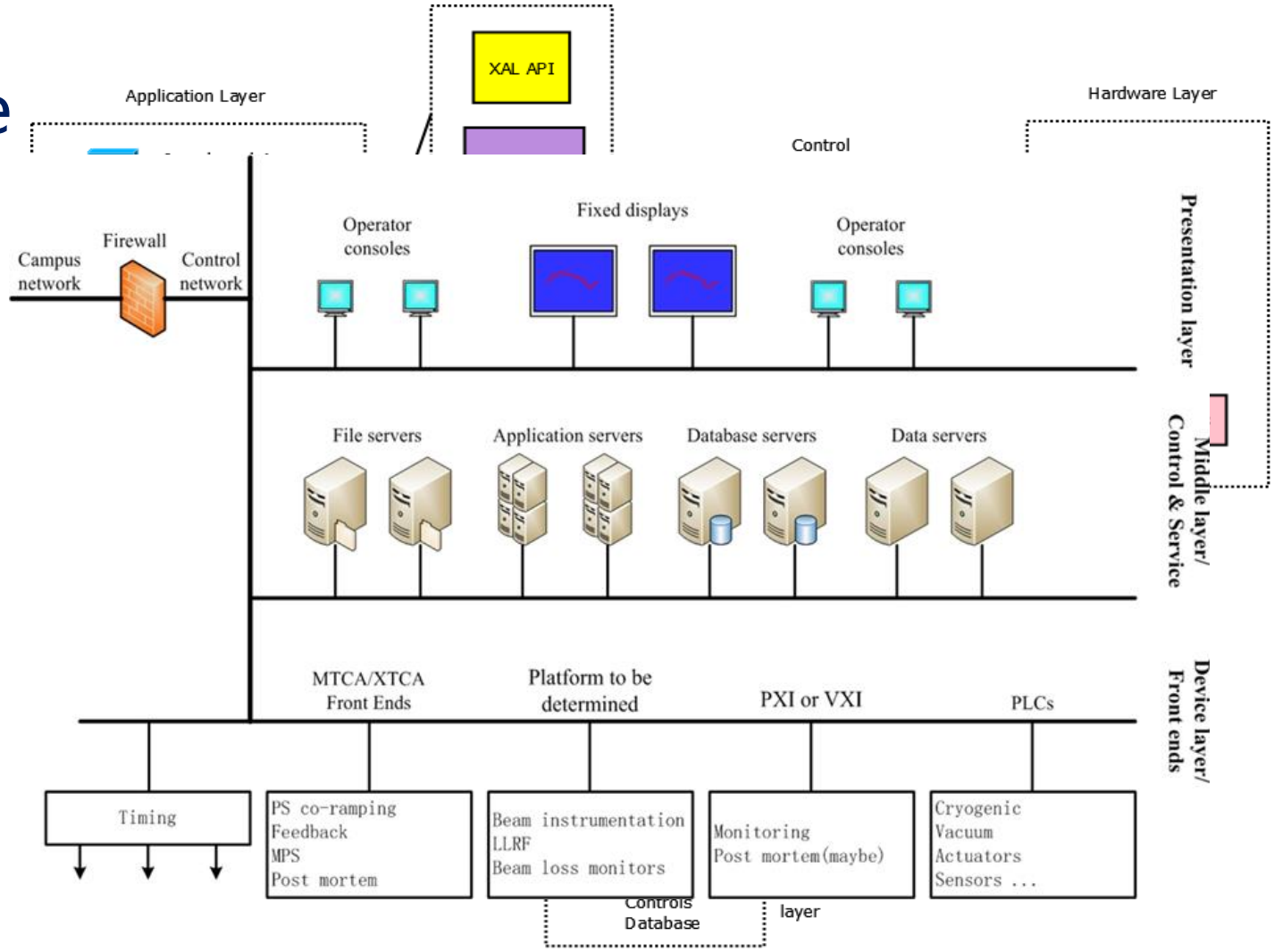
Machine Learning Platform Source Code Repository

- https://github.com/NicoleQiao/MLPlatform

Backup Slides

Controls and Online/Offline Software

- Databases: online/offline
- Control systems
- Physics Modeling
- Services
- API
  - commonly used modules
- Online Applications
- Offline applications
  - Lattice Design w/ ML



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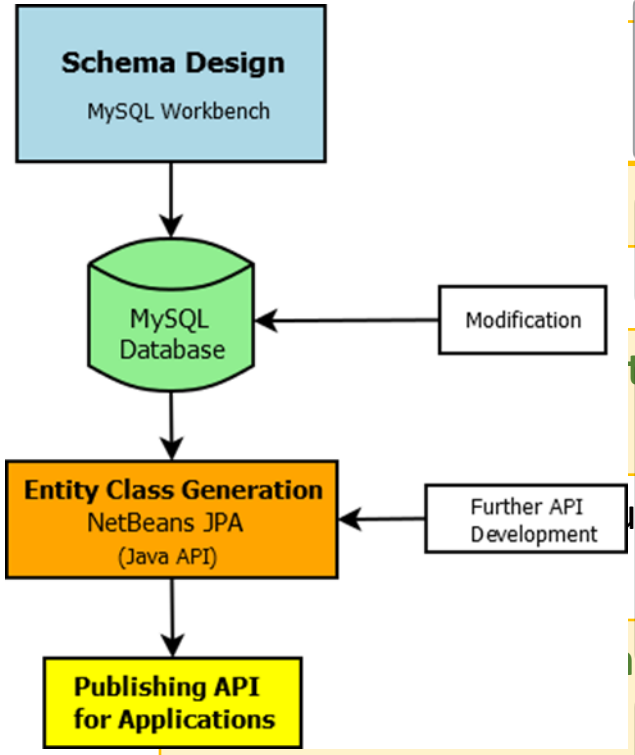
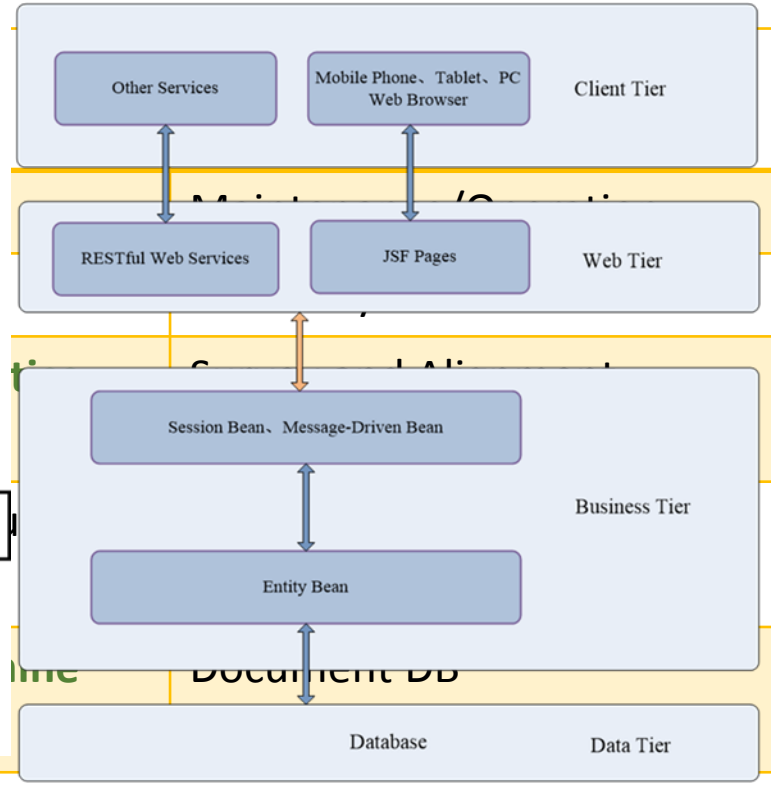
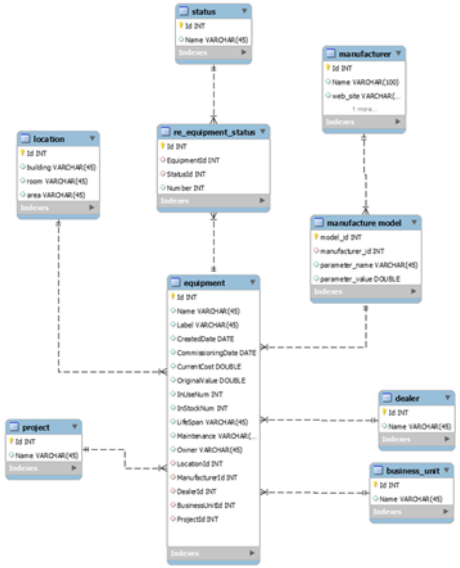
Databases

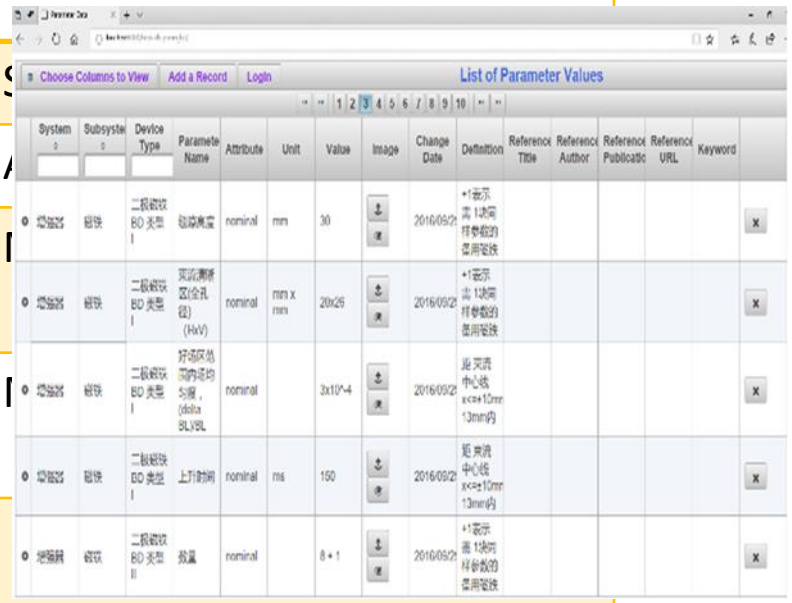
- 17 database domains in plan
- MySQL or Microsoft SharePoint/SQL







Cable



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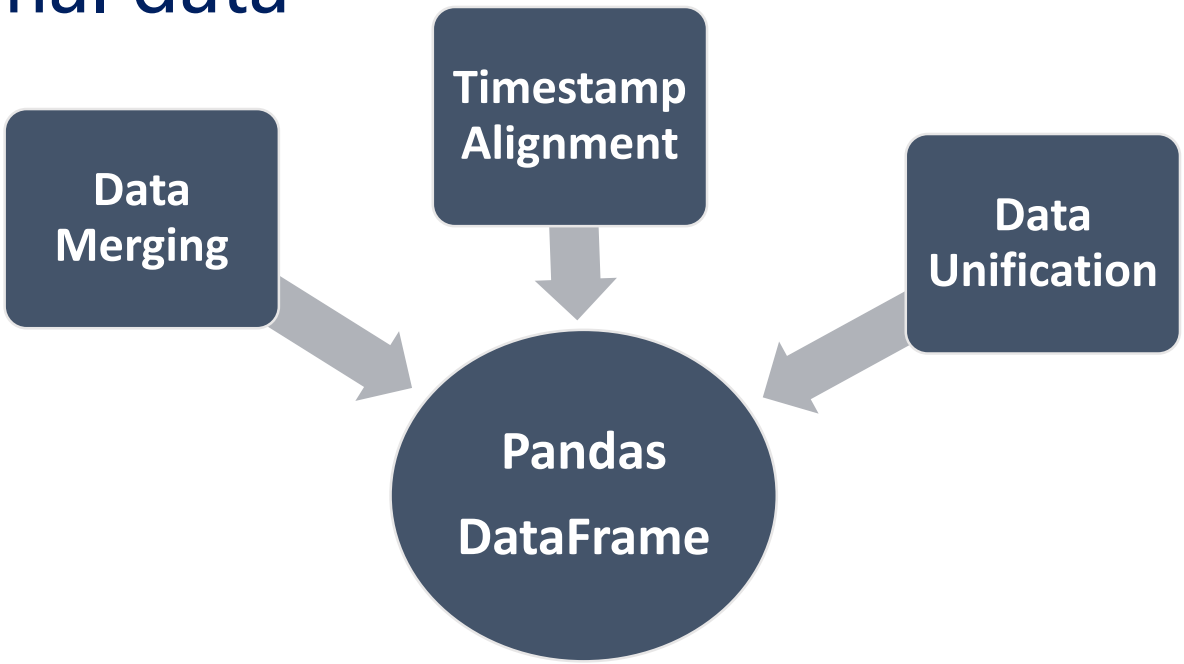
Data Export & Unification [1]

Raw data characteristics

- Large amount of PVs as model features
- Different PV has different acquisition period
- Handling null or abnormal data



Data Export & Unification [2]

For temporal data from archiver

PV Timestamp alignment

3 data line-up types:

1. Outer -> smallest time period -> data addition
2. Inner -> biggest time period -> data deletion
3. Defined time period -> data addition & deletion

- Standardization
- Normalization
- Discretization (quantization or binning)
- Encoding categorical features

Data Pre-processing [1]

Data quality check

Handling empty, abnormal, inconsistent data

- **Padding**

Not changing over time

Bad machine status

- **Interpolation**

Linear, nearest, polynomial, cubic, spline……

- **Neural network**

Predict uncertain data through NN algorithm based on known data

Data Pre-processing [2]

- **Data feature analysis**
  - distribution analysis
  - comparative analysis
  - periodic analysis
  - contribution analysis
  - correlation analysis
- **Diagnostic functions**
  - common statistical indicators
  - histograms
  - scatter matrix diagrams
  - correlation tables & associated heat maps
  - box plots

Where Can ML Be for Accelerators

- Basically, everywhere…
- Best fit: non-linear issues with sufficient and good quality data
- Entire accelerator life cycle needs ML
  - Accelerator design
  - Accelerator/beamline controls
  - Beam Tuning – online and offline optimization
  - Operation optimization – productivity,
  - Machine reliability – maintenance,
  - Human resources: who performs the best at work

ML Application Ideas [1]

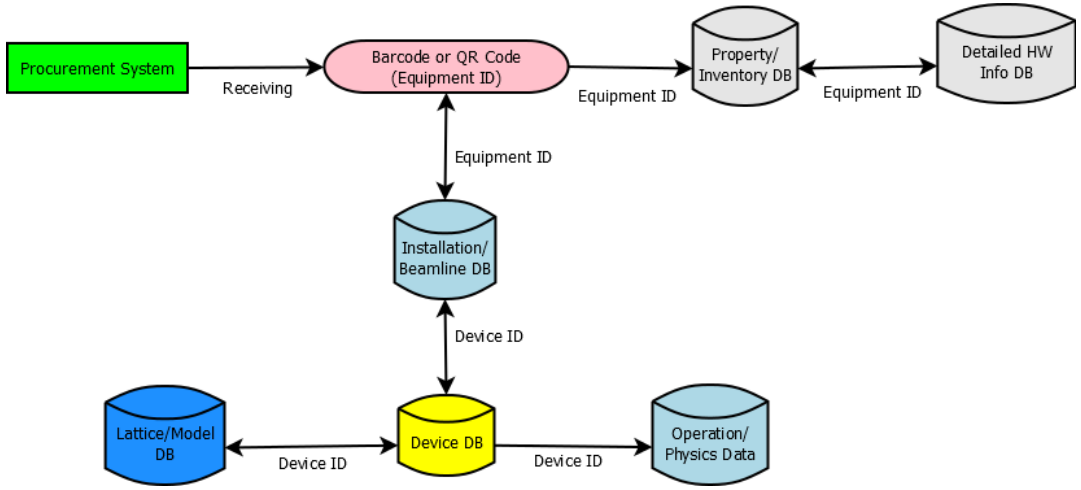
- Facility Operation Optimization
  - Use regression algorithms to improve the performance of key accelerator systems, such as high frequency cavity, superconducting system, water cooling system, etc.
- Beam Physics or experiment optimization
  - Apply the machine learning platform to beam physics optimization progress, to realize the automatic optimization of DA, emittance, current intensity, etc.
  - Data driven data acquisition
- Equipment maintenance
  - To avoid unexpected failures by analyzing equipment running data

ML Application Ideas [2]

- Big Data applications
  - Installing various sensors to collect as many data as possible
  - Data mining, data correlation, interdisciplinary data analysis
- Light source data center for data sharing
- Accelerator data archive center
  - Domestic and international data archive for various accelerator related data
- …

Project Control (Other Data)

- Procurement, Equipment
- Issue Tracking System, Maintenance, Operation Logbook…
- Work Breakdown Structure (WBS) for project management
  - Cost and schedule control/monitoring
- SharePoint based document system
  - Project Web site
  - Work flow control
  - Document and data sharing



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