The Fermilab Control System







Jim Patrick Fermilab October 4, 2006

Cutline

- Accelerator Complex Overview
- Control System Overview
- Selected Control System Features
- Migration Efforts
- Summary

Fermilab Accelerator Complex



Fermilab Accelerator Complex

- 400 MeV Linac (up to 15 Hz)
- 8 GeV Booster Synchrotron (up to 15 Hz)
- 120 GeV Main Injector Synchrotron (~0.5 Hz)
- 980 GeV Tevatron Superconducting Synchrotron/Storage Ring
- 8 GeV Debuncher/Accumulator for antiproton production
- 8 GeV "Recycler" for antiproton accumulation (same tunnel as MI) with electron cooling

The Run II Challenge

- Operate the Tevatron proton-antiproton collider at > 10 x the luminosity of the previous (1992-6) run (began Mar 2001)
 - Collider stores + pbar production
 - Incorporate Recycler ring (May 2004)
 - With Electron cooling (July 2005)
- Operate miniBooNE booster experiment (Dec 2001)
- Operate 120 GeV fixed target (Feb 2003)
- Operate NUMI high intensity neutrino beam (Dec 2004)
- Get all this working, all at the same time
- Meanwhile modernize the control system without affecting commissioning and operation of the above
- Simultaneous collider and fixed target operation new to Fermilab⁶

Control System Overview

- Known as "ACNET"
- Dates from early 80's; substantial evolution over the years
- Unified control system for the entire complex
 - All accelerators, all machine and technical equipment
 - Common console manager can launch any application
 - Common software frameworks
 - Common timing system
 - Three-tier system
 - Applications
 - Services
 - Front-ends
- Distributed intelligence
 - System is tolerant to high level software disruptions



ACNET Protocol

- All elements communicate via the ACNET protocol
- Custom protocol developed in early 80's
 - Old, but ahead of its time and works very well
 - Difficult to program, but high level API hides details
 - Primary weakness is lack of transparent mixed type support Nevertheless often done with manual format translation
 - Get/Set devices
 - Single or repetitive reply; immediate, periodic, or on clock event
 - Devices only read by front-end on request
- Fast Time Plot (FTP)
 - Blocks of readings taken at up to 1440 Hz returned every 0.5 sec.
 - Snapshot
 - Block of 2048 readings taken at an arbitrary rate

Application Environment

Console environment

- VAX based; Now mostly ported to Linux
- Integrated application/graphics/data access architecture
- C language (+ legacy FORTRAN)

Java environment

- Platform independent; Windows/Sun/Linux/Mac all utilized
- Full access to entire control system
- Both have a standard application framework that provides a common look and feel
- All applications launched from "Index Pages"
 - Separate for Console, Java environments
 - Tightly managed code in both environments
- Also some web browser applications of varying styles

Index Page (Console)



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Synoptic Display (Web)

- Drag&Drop Builder
- Uses AJAX technology

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Front-ends post (push) alarms to central server for distribution and display

| 🔝 Accelerator Alarms | |
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Central Layer

- Database
- Open Access Clients ("virtual front-ends")
- Java Servlets
 - Device access for web browser applications
- Alarms server
- Front-end download
 - Load last settings on reboot



Central Sybase database

Three parts:

- All device and node descriptions
- Application information
 - Used by applications as they wish
- Save/Restore and Shot Data database
- MySQL freeware database used for data loggers
 - Large volume of logged data would complicate Sybase
 - Not for general application use

Open Access Clients (OACs)

- "Virtual" front-ends; speak ACNET
- Several classes:
 - Utility Data loggers, scheduled data acquisition, virtual devices
 - Calculations Both database driven and custom
 - Process control pulse to pulse feedback for fixed target lines
 - Bridges to ethernet connected scopes, instrumentation, etc.
- Easy access to devices on multiple front-ends
- Friendlier programming environment than VxWorks
- Access to database, high level operating system features
- Clock events available via ethernet multicast
- Over 100 in the system

Front-Ends

- Several architectures:
- MOOC Minimally Object-Oriented Communication
 - Processors all VME (VXI) based
 - Links to many other form factors such as CAMAC, Multibus, etc.
 - VxWorks Operating System
 - ~325 in the system
- IRM Internet Rack Monitor
 - Turnkey system with 64 channel ADC + DAC + Digital I/O
 - ~125 in the system
- Labview Used for one or few of a kind instrumentation
- Support for wide variety of commercial instrumentation
 - Scopes, spectrum analyzers, signal generators, DVMs, …
 - Ethernet->GPIB; direct ethernet

Sequencer Overview

- The Sequencer is an accelerator application which automates the very complex sequence of operations required to operate the collider (and other things)
- Operation divided into "Aggregates" for each major step
 "Inject Protons", "Accelerate", etc.
- Aggregates are described in a custom command language
 - Easily readable, not buried in large monolithic code
 - Easily modified by machine experts
- Each Aggregate contains a number of simple commands
 - Set, get, check devices
 - Wait for conditions
 - Execute more complex operations implemented as ACL scripts or specially coded commands
 - Start regular programs

Tevatron Collider Operation



Sequencer Overview

The Fermilab complex employs "distributed intelligence"

- Separate sequencer instances for TeV, MI, pbar, recycler
- Lower level programs to control complex operations such as collimator movement for scraping
 - Sequencer just issues high level control commands
- All possible waveforms preloaded into ramp cards and triggered by clock events
- "States" concept used to provide synchronization



- ACNET devices owned by STATES process
- When a state device is set, it is reflected to the rest of the control system
- Thus can be used to trigger actions, do synchronization
- Condition persists in time unlike clock events
- Examples
 - Collider State
 - Mostly follows previous state diagram
 - Inject Protons, Inject pbars, Accelerate, HEP, etc.
 - Collimators Commands for collimator movement
 - Go to Initial Position; Remove Halo, Retract for Store
 - Wire scanner calculation complete
 - Node in system has restarted

Waveform Generators

- Magnets need to do different things at different times in the machine cycle and for different cycle types
- Rather than redownload on each cycle, function generator cards built that preload up to 32 waveforms
 - Correct one for a part of the cycle triggered by clock event
 - Waveforms are functions of time and fast data frame values
 - On board processor does smooth interpolation
- Thus waveforms need not be downloaded at each phase of the machine cycle
 - Enhances reliability
 - Reduced dependence on high level software in stable operation

Sequenced Data Acquisition – Shot Data Analysis

- Record data at each step in collider operation into a dedicated database
- Compute and track injection efficiencies, emittance growth, luminosity, …
- Variety of tools to extract, analyze data
 - Web reports created in real time
 - "Supertable" summary web page + Excel spreadsheet
 - Many predefined plots available on the web
 - SDA Viewer spreadsheet like Java application
 - SDA Plotter plot snapshots and fast time plots
 - Java Analysis Studio input module
 - Java API for custom programs

SDA Reports



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Data Loggers

- 70 instances running in parallel on individual central nodes
- Allocated to departments to use as they wish, no central management. Continual demand for more
- ~48,000 distinct devices logged
 - Rate up to 15 Hz or on clock or state event (+ delay)
- 80 GB storage per node in MySQL database
 - Circular buffer; wraparound time depends on device count/rates
- Data at maximum 1 Hz rate extracted from each logger to "Backup" logger every 24 hours
 - Currently 850 million points extracted per day
 - Backup logger is available online => data accessible forever



Variety of retrieval tools available

- Standard console applications, Console and Java environments
- Web applications
- Java Analysis Studio
- programmatic APIs

Data Logger Plots



Security

Limit access to the control system

Control system network inside a firewall with limited access in/out

Limit setting ability

- Privilege classes (roles) defined
- Roles assigned to users, services, nodes
- Proper role required to set a device
- Applications outside MCR start with settings disabled
 - Settings must be manually enabled. Times out after some period

Applications started outside MCR exit after some period of inactivity

Remote Access

- Console environment via remote X display
 - Generally can't do settings
- Java Applet version of console
 - Can't do settings
- Java apps can be launched from anywhere via Webstart
 - Access to inner parts of control system only via VPN
 - "Secure Controls Framework" API for applications w/o VPN
 - Kerberos authentication for low level communication
 - Web based applications access system via servlets

Accountability

- Considerable usage information is logged
 - Who/what/where/when
 - Most reports web accessible
- Settings
- Errors reviewed each morning
- Database queries
- Device reads from Java clients
- Application usage
- Clock (TCLK) events
- State transitions

Some issues

- Short device names, flat name space
- Old fashioned GUI in console environment
- Lack of standard machine configuration description
- Lack of integration with models
- Lack of integration with Matlab and related tools
- Weak inter-front end communication
- Specific to Fermilab environment, no attempt at portability

Java Migration

- Migration from VAXes essential and overdue
 - Projected life of complex > 2010
- Work on Java based architecture started in 1998
 - Incremental, replace VAX code one piece at a time
 - Maintain ACNET protocol for interoperability between old/new
- Required infrastructure was created prior to 2001 run start
- SDA implemented; continually evolved to meet needs
 - Data acquisition + analysis tools
- Most VAX OACs converted to Java and new ones written
- Java versions of many utility applications written
- Some machine applications written, framework not widely embraced by machine departments
 - Extensive operational usage in electron cooling
 - Pbar source department also has many expert Java applications

Console Port to Linux

- In early 2004, realized migrating all applications to Java not practical
- Incremental strategy to port VAX console code to Linux
 - Infrastructure then one application at a time; no functional changes
- Web based tracking of progress
- Much harder than anticipated
 - Large volume of code ~3.5M non-comment lines
 - Interdependencies between primary and secondary applications
 - K&R C -> ANSI C++
 - C++ compiler required for variable argument capability
 - Stricter compiler did catch some actual bugs
 - "BLOBs" in the database and in flat files and over network
 - Dual Hosted console manager developed
 - Present single console to user; run application on correct platform





Infrastructure port completed ~late 2005

Applications port expected to be complete by end of 2006

Linux usage in operations began at end of shutdown in June 2006

Very modest impact on operations. No lost collider stores!

Services port expected to be complete by mid 2007 (next shutdown)

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Modernizing BPMs and BLMs

BPMs in Recycler, Tevatron, Main Injector, Transfer Lines

- Performance issues
- Obsolete hardware technology
- Need for more BPMs in transfer lines
- Replaced with a digital system using Echotek VME boards
- Beam Loss Monitors in Tevatron and Main Injector
 - Obsolete hardware technology
 - Additional features needed with more beam in MI, Tevatron
 - Replaced with new custom system (in progress)
- All were replaced in a staged manner without interruption to operations
 - Library support routines provided common data structure for both old and new systems during the transition period
- Enormous improvement in performance and reliability

Collider Peak Luminosity



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Collider Integrated Luminosity



Recent observation of Bs mixing by CDF

NUMI Performance



Best current measurement of neutrino oscillation despite problems with target, horn, etc.

MiniBooNE Performance



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Accelerator Future

- Tevatron collider is scheduled to run for ~3 more years
- Emphasis for complex will then be neutrino program
 - Recycler + pbar accumulator will be converted to proton stackers for NUMI – overlap fill with Main Injector ramp
 - NUMI beam power could reach ~1 MW with full upgrade
 - NOvA experiment approved 2nd far detector in Minnesota
- Fixed target test beams for ILC detector R&D
- ILC accelerator test facilities under construction
 - These will not use ACNET but instead probably some combination of EPICS and the DESY DOOCS system used at TTF
 - Detailed strategy not yet determined
 - Some interoperation efforts with EPICS; bridging in middle layer

Summary

The control system has met the Run II Challenge

- Accelerator complex has gone far beyond previous runs in performance and diversity of operational modes
- Unified control system with solid frameworks and distributed intelligence was instrumental in this success
- During accelerator operation the control system has been substantially modernized
 - Incremental strategy essential
 - It is hard to upgrade a large system while operating!
 - It is hard to get people to upgrade a system that works!
 - The control system will finally be VAX-free at the next major shutdown currently scheduled for June, 2007
 - Control system will be viable for the projected life of the complex