Data Acquisition, Diagnostics & Controls (DAQ)

Technical Status

NSF Review of Advanced LIGO Project
held April 25 – 27, 2011
at the LIGO Livingston Observatory

Rolf Bork, CIT

LIGO-G1100458-v2
2011 April 11

Project cost for DAQ - $4.4M

DAQ Functions

- Provide a global timing and clock distribution system to synchronize all realtime control and data acquisition.
- Provide a common Control and Data System (CDS) infrastructure design and standards for use in all aLIGO subsystem controls.
  - » Real-time applications development tools and code library
    - – Including “hard” real-time operating system, I/O drivers and inter-process communications.
  - » Computer and I/O standards
- Provide all software necessary to synchronously acquire and archive data.
- Provide all computing and networking hardware as necessary to collect data from the various subsystems, format the data and write the data to disk.
- Provide a standard set of diagnostic tools for use in all control subsystems, including ability to:
  - » Inject arbitrary waveforms into realtime control systems
  - » Set and acquire data from defined testpoints on demand
  - » Distribute both diagnostic data and acquired data channel to operator stations
  - » Provide data visualization and analysis tools in support of operations and commissioning.

DAQ Functions (Continued)

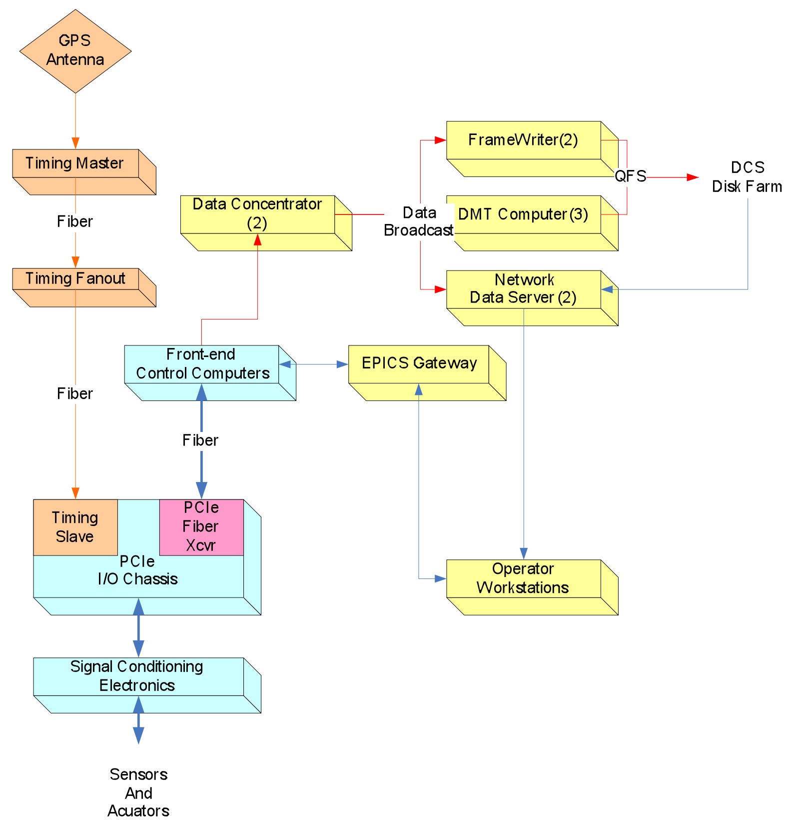
- Provide computers, I/O hardware and software for the acquisition of Physical Environment Monitoring (PEM) data.
  - » New interfaces for existing PEM sensors
- Computers and infrastructure software for the Diagnostic Monitoring Tools (DMT)
  - » Specific application software provided by LSC members
- Control room computers and associated networking, including a common set of operations support software.
- Provide off-line test and development systems for both sites

DAQ System
Data Acquisition Requirements

- Provide a hardware design and software infrastructure to support real-time servo control applications
  - Deterministic to within a few μsec.
  - High performance to support servo loop rates from 2048Hz to 65536Hz
  - Built-in diagnostic and data acquisition features
- Acquire and record up to 15MBytes/sec continuously from each interferometer.
  - ‘Fast’ data channels at rates from 256 to 32768 samples/sec (Up to 3000/IFO)
  - ‘Slow’ data channels at up to 16 samples/sec, with up to 70K channels per interferometer
- Provide capabilities to acquire (but not record) an additional 15MB/sec of diagnostic data.
- Write data in LSC/VIRGO standard Frame format to disk system provided by Data and Computing System (DCS).
  - Provide local disk to allow up to two weeks of data storage
- Provide an internal data distribution system to communicate diagnostic and acquired data to operator stations and Diagnostic Monitoring Tool (DMT) computers.

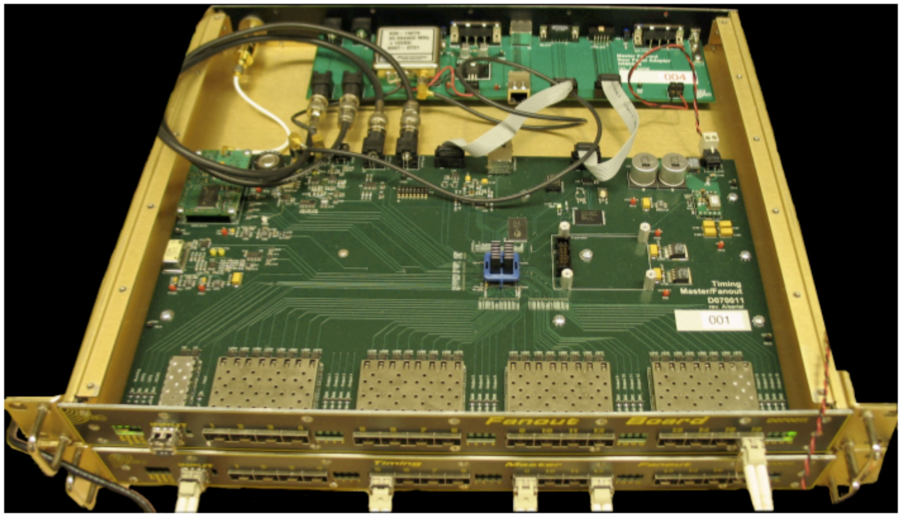
DAQ System Design Overview

- Timing system provides clocks to PCI Express (PCIe) modules in I/O chassis.
- PCIe modules interface to control computer via PCIe fiber link.
- Control computer acquires data and transmits to DAQ data concentrator (DC) via network.
- DC assembles data from all controllers and broadcasts full data blocks every 1/16 second.
- FrameWriter computers format data and write to disk (32sec. data frame)
- Network Data Server (NDS) provides data on demand either live or from disk.

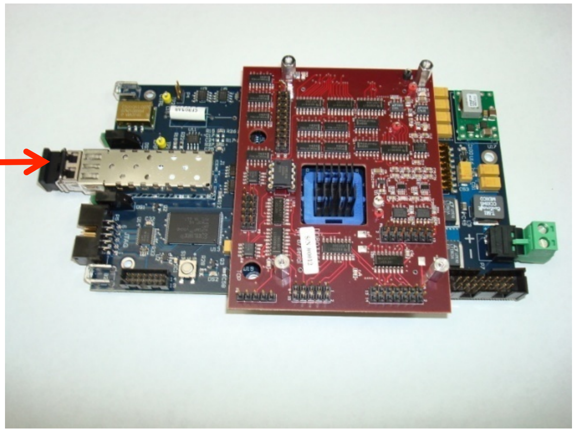


Timing Distribution System (TDS)

- Contracted to Columbia Univ. for manufacture and test after a joint development effort. Design described in the journal *"Classical and Quantum Gravity" under Imre Bartos et al., 2010 Class. Quantum Grav. Vol. 27, No. 8, 084025*



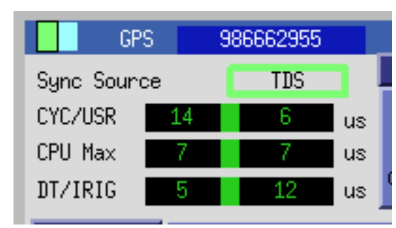
IRIG-B Timing Fanout
Provides accurate time information to computers.



Timing Slave provides accurate clocks
At 65536Hz to ADC/DAC modules.

TDS
IRIG-B Distribution Unit

- IRIG-B system used to provide time information, in GPS seconds, to DAQ and control computers.
  - » Includes standard timing slave card to get time information from TDS.
  - » Outputs IRIG-B standard time code
    - – DC Level Shift format
  - » Commercial IRIG-B Receiver modules in computers for accurately setting time in GPS seconds.
  - » Time accuracy to better +/- 1 µsec.
  - » Second source of system time verification, along with duotone signal acquired from timing slave in I/O chassis.



Timing Distribution System Status

-110 Timing Slaves, 60 DuoTones, 4 FanOuts and 2 Masters have been delivered to LIGO sites (CIT, LLO, LHO)
- Timing slave units also used to synchronize RF distribution system.

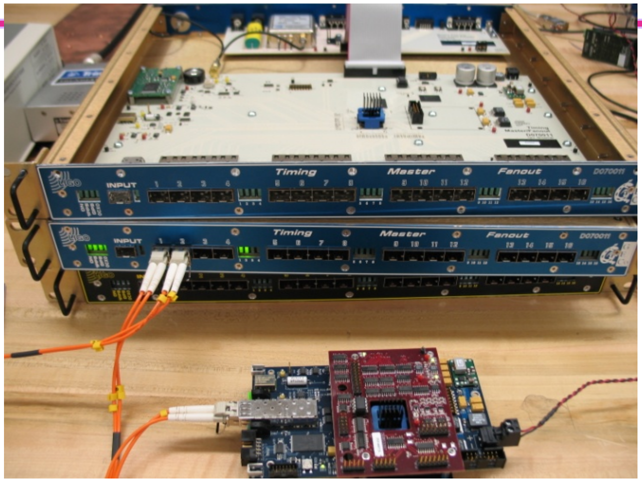
-Slave-DuoTone assemblies are integrated into DAQ I/O

-All Master chassis are manufactured

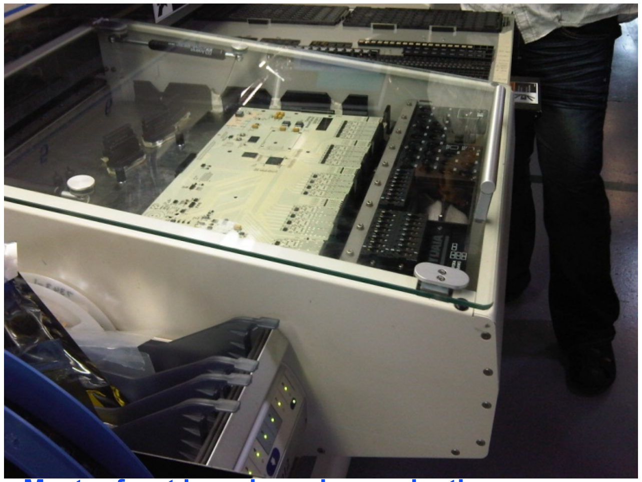
-Production of remaining Fanouts is scheduled

-Comparator boards are manufactured, chassis builds started.

-All IRIG-B boards are manufactured, chassis builds ongoing.



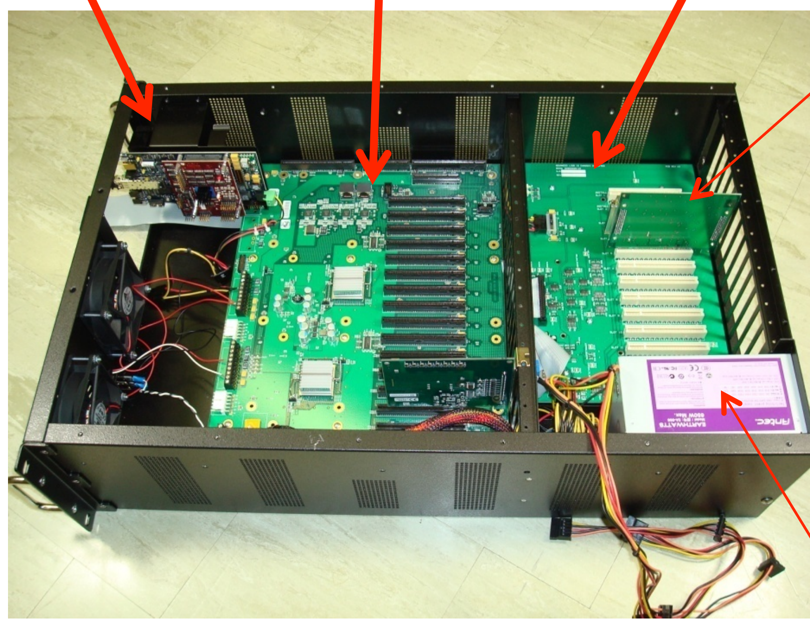
Slave-DuoTone pair being tested at Columbia



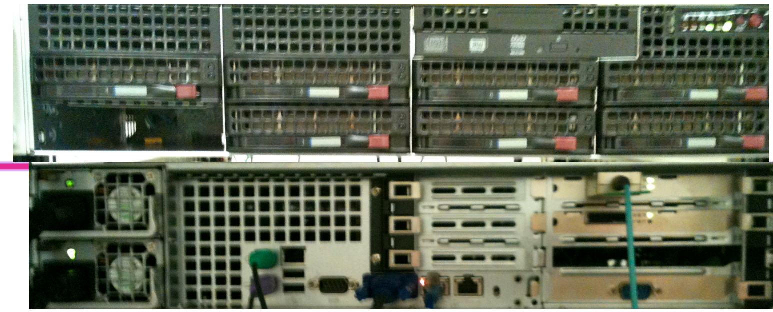
Master front boards under production

CDS Standard
PCI Express I/O Chassis

- Commercial PCIe expansion motherboards.
- Custom I/O timing and interface backplane.
- I/O interface modules provide timing and interface between PCIe module connectors and field cabling.
- Two fiber optic links.
    - To timing distribution system via timing slave module.
    - To computer, via fiber optic PCIe link.



CDS Standard Computers



- Supermicro X8DTU-F Motherboards
  - » Fulfills BIOS PCI-e card mapping and real-time stability requirements
- Single Xeon X5680 processor with six cores at 3.33GHz
- Up to 4 full height + 1 half-height PCIe slots
- Two GigE Ethernet ports
  - » Separate EPICS/DAQ networks
- No disk drives installed in computers used for real-time control
  - » Operated as diskless-node from central boot server
- Operating Systems
  - » Gentoo with Linux kernel 2.16.34, plus LIGO RT patch
  - » Ubuntu Linux for CDS servers and other non-real-time computers

Networking

- Ethernet backbones for most applications
  - » GigE switches with fiber uplinks from end stations
  - » GigE switches with 10G uplink options for corner station
    - – 10G uplink for DAQ and video connections
  - » 10G switches for DAQ Broadcasts
- Low latency networks for real-time data communications.
  - » Initial LIGO type reflected memory (for long runs to end stations)
  - » PCIe network, employing reflected memory software (corner station computers)

PCI Express (PCIe) Real-time Control Network

- Low Latency (1.25usec)
- High speed (10Gbit/sec)
- Cable or Fiber connections
  - CX-4 cable to 3 meters
  - Multi-core fiber to 100 meters
- Stackable 10 port Switches
- Reflected Memory Mode
  - Data broadcast to same memory location on each computer on the network.

Corner to End Station Real-time Control Network

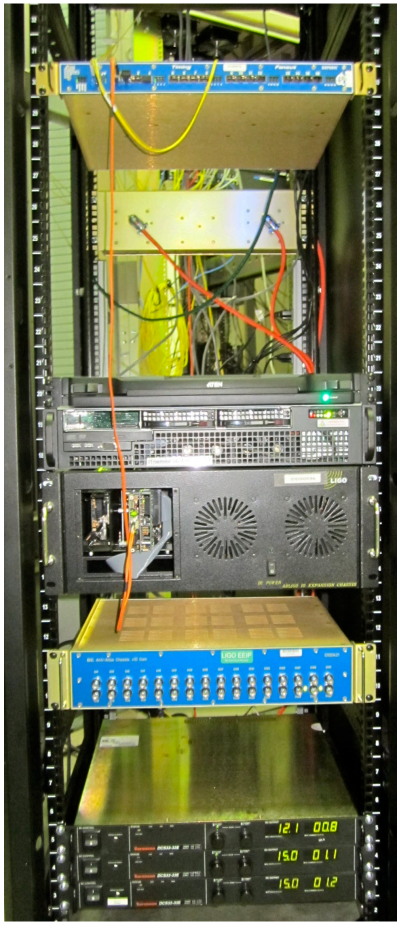
- Loop topology
- Low Latency (700nsec/node)
- High speed (2Gbit/sec)
- Fiber connections
  - Up to 10km
- Bypass Switch provided at each location
- Reflected Memory
  - Data broadcast to same memory location on each computer on the network.

Networking – Progress

- All Ethernet switches have been procured and delivered for all three interferometers.
  - » All network switches have been configured for L1 and H2.
  - » Network switch and cabling installation in progress.
    - – Corner station and one end station complete at LLO.
    - – H2 DAQ and MSR switchs installed.
      - Waiting for new Electronics Equipment building for H2
- All real-time networking equipment procured and delivered.
  - » Systems installed and running at both sites.

Physical Environment Monitoring Infrastructure

- For aLIGO, PEM system will provide control as well as DAQ
  - » On-line Adaptive Filtering and feed-forward control.
- One computer + 1 I/O chassis at each station and at corner station.
- Re-use existing PEM sensors
- Up to 128 channels of ADC + 8 channels of DAC
  - » I/O connections via AA/AI chassis with BNC connections.
- Progress
  - » Computers, I/O chassis and ADC/DAC modules have all been procured and delivered.
  - » 6 of the 12 AA Chassis have been built and tested.
  - » LLO End Station system under test ------------------→

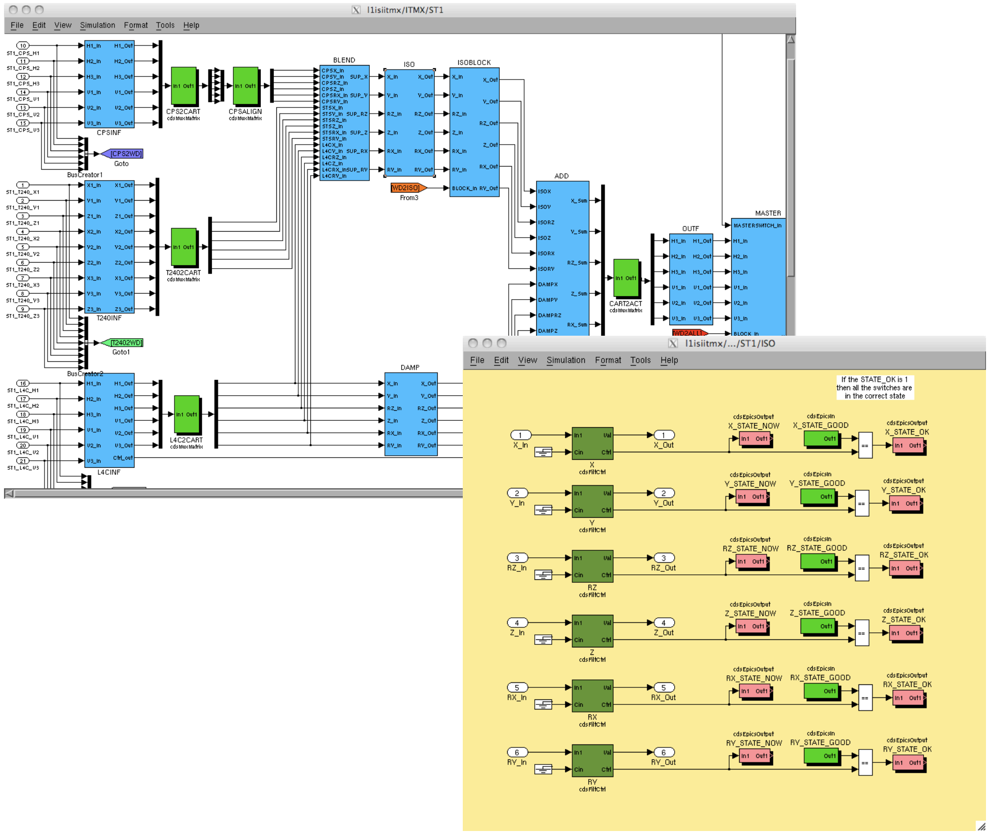


DAQ
Computing / Storage Equipment

- Data Concentrator (DC) (2)
  - » Collects data from all real-time control computers and broadcasts to 10GigE network.
  - » One unit on-line, second hot backup
- FrameWriter (2)
  - » Receive data from DC
  - » Format data into LVC standard Frame format
  - » Write data to disk
    - – Local
    - – Data Analysis group disk farm
- Network Data Server (NDS) (2)
  - » Provides real-time or stored data on request to various control room software tools
    - – NDS clients also developed for Perl, Python and Matlab
- Two computers running Solaris operating system to connect disk systems via QFS.
- 24 TByte Local Disk

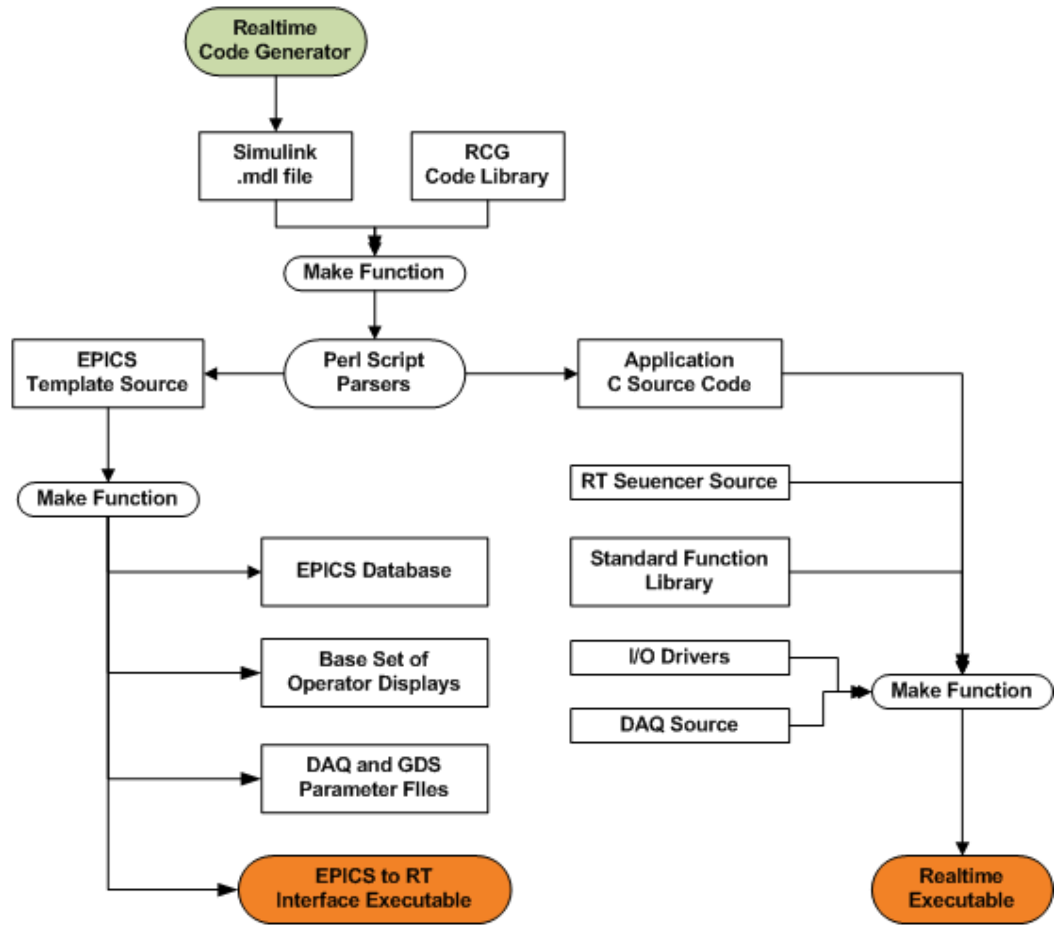
Software
Real-time Application Support

- Continued refinement of graphical tool for real-time code generation (“RCG”).
- Allows control application development and documentation without having to know a programming language.
- Allows programming staff to concentrate on development and test of common code modules.



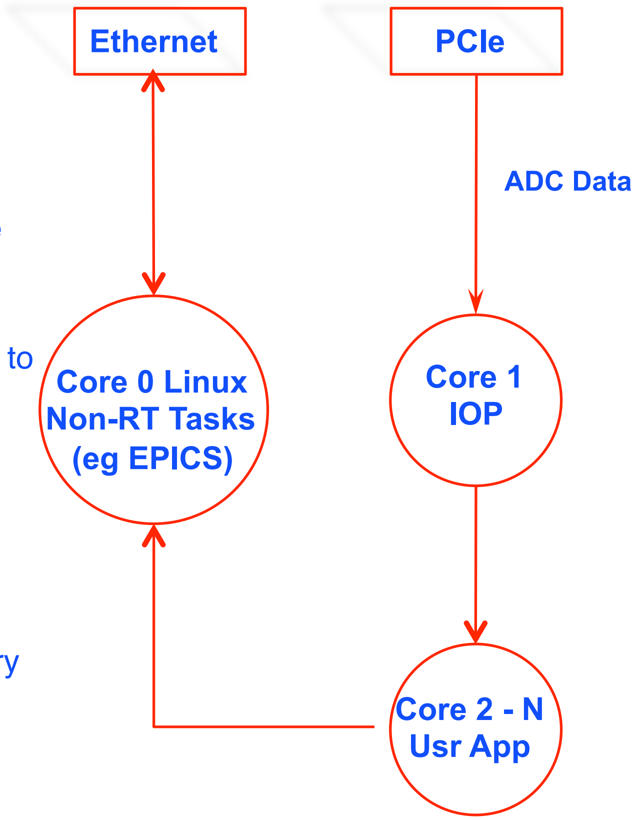
Software
Real-time Application Build Process

- Build and save RCG model.
- make 'modelName'
  - Perl scripts parse the model file to determine signal connections and code flow
  - Perl scripts generate EPICS and real-time source code.
  - Compiler is invoked to link common code libraries and produce real-time and EPICS executable software.
- make install
  - Moves executables to target directories for load onto real-time computers.
  - Channel descriptor files generated for use by DAQ and GDS
  - Basic set of operator displays generated.



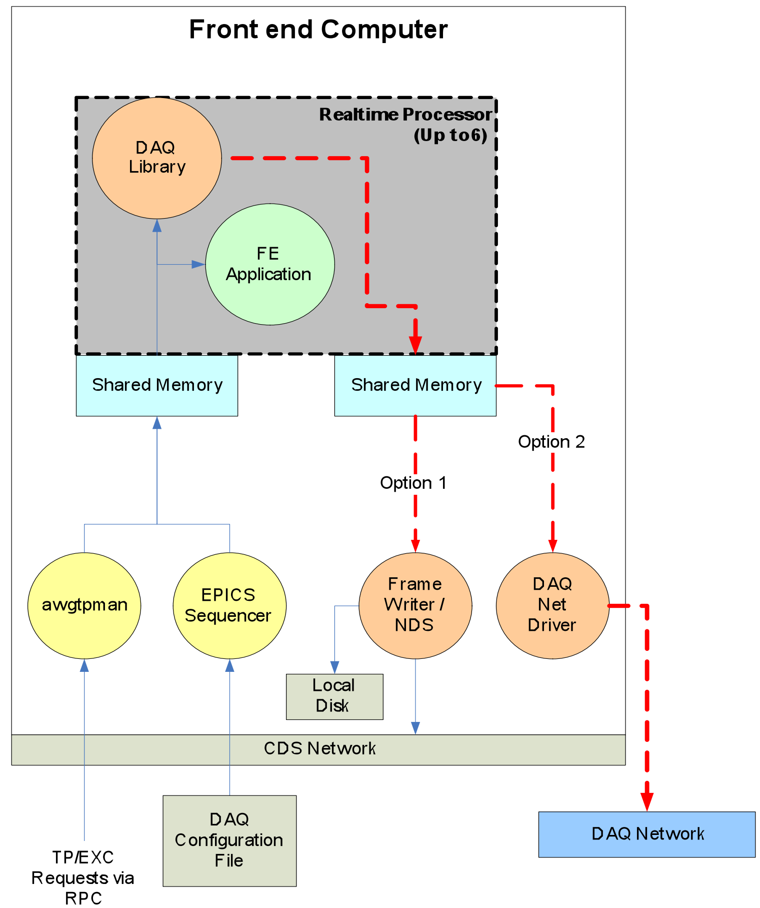
Real-time Core and Patch

- aLIGO Real-Time (RT) code not "traditional"
  - » No pre-emptive operating system scheduler
  - » No interrupts, semaphores, priorities, ensuing context switching, etc.
- Each RT app locked to its own CPU core
  - » Using custom patch to Linux kernel "play dead" routine
    - – Notifies Linux scheduler that CPU is going down and unavailable for interrupts/task assignment.
    - – Inserts RT app code instead of Linux idle routine.
    - – Removal of RT app brings the CPU "back to life" and reconnects to Linux as a useable resource.
  - » RT code runs in continuous loop
    - – Triggered by arrival of ADC data in local memory (polling or MONITOR/MWAIT CPU instructions)
      - • ADC modules set up to automatically transfer data to computer memory on clock trigger
    - – Never switched out ie always resident on stack, in cache, memory
- For each RT computer, there is a special case model called an Input/Output Processor (IOP)
  - » Controls startup timing and synchronization.
  - » Maps and initializes all of the PCIe I/O interfaces
  - » Triggers and monitors user applications.
  - » Always running, allowing user apps to come and go, as necessary



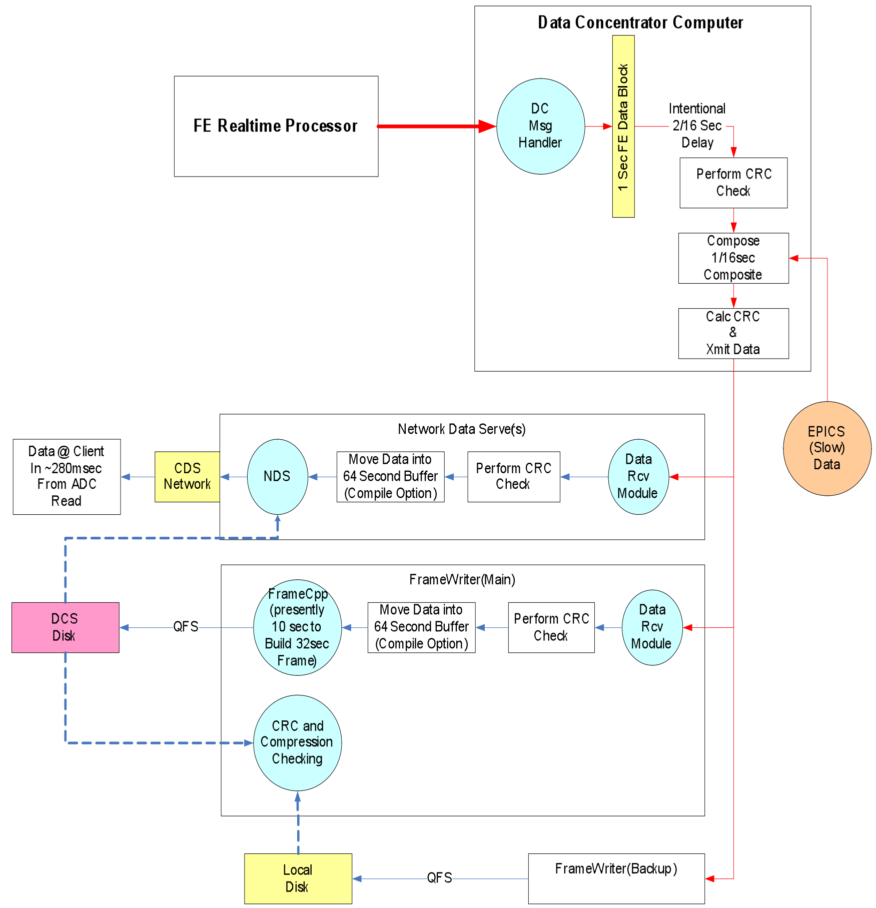
DAQ System
Front-End Software Design

- A common DAQ library is compiled into each FE application.
- Acquires data at user defined rates and transmits data as 1/16sec data blocks:
  - » For archive, as described in a DAQ channel configuration file.
  - » Test point and excitation channel data on demand
    - – As requested via the arbitrary waveform generator/ test point manager (awgtpman)
  - » Supports aggregate (DAQ+TP) data rate of 2MB/sec per FE processor
  - » CRC checksums and timestamps sent with all data blocks
- Supports various configurations
  - » (1) Data to FrameWriter/NDS software on same computer via shared memory
    - – Allows a complete stand-alone system to support various subsystem test stands
  - » (2) Data to shared memory, with separate network software
    - – Supports multiple FE applications on same computer
    - – Relieves RT front end code from network error handling and other possible delays



DAQ System
Backend Software Design

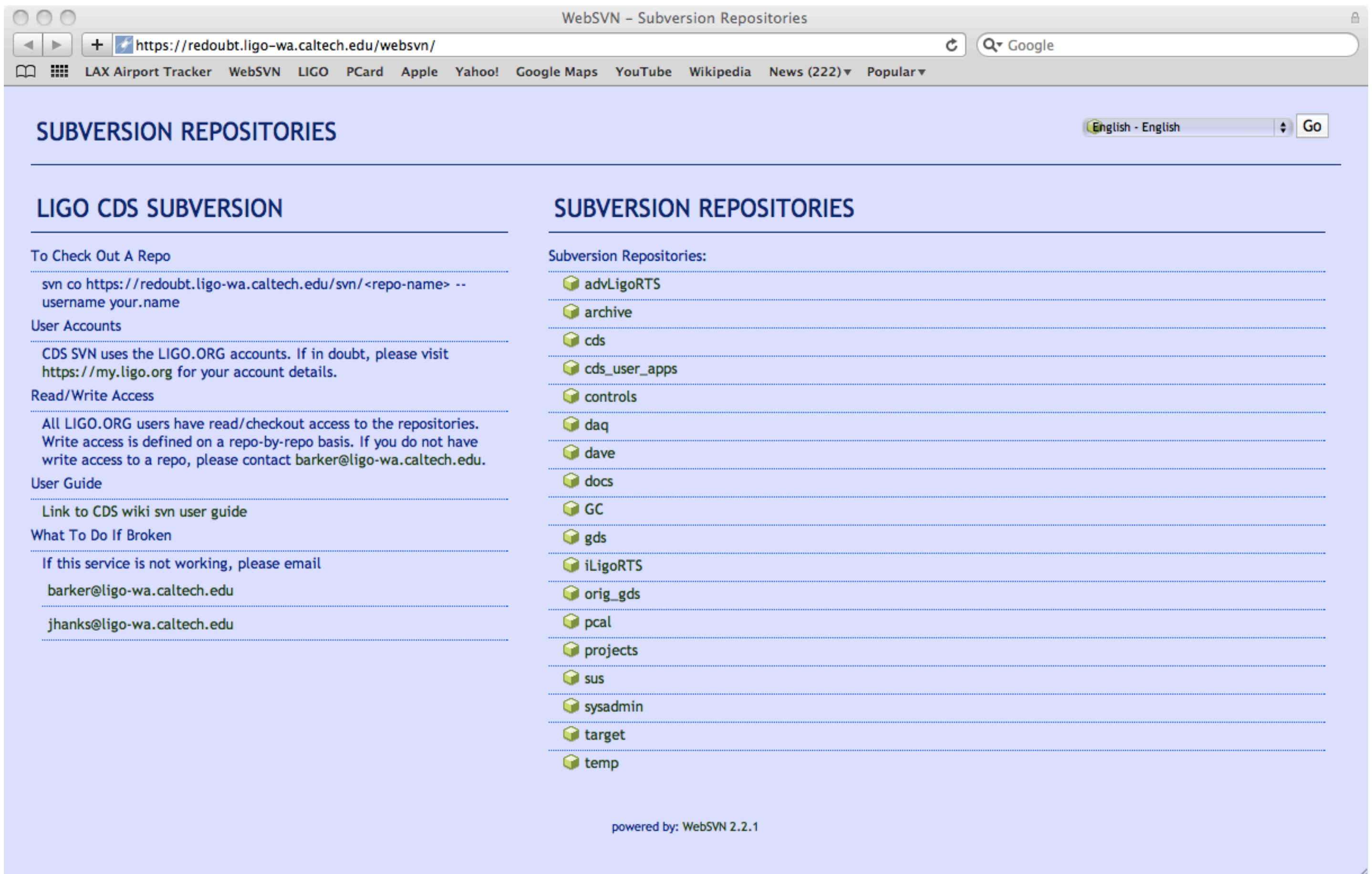
- Data Concentrator
  - » Collects 'fast' data from all FE computers via dedicated network
  - » Collects 'slow' (EPICS) data via CDS network
  - » Broadcasts combined data to upstream computers as 1/16 sec data blocks on to 10Gb Ethernet
- FrameWriter
  - » Format data into standard LIGO Frame using FrameCpp library, with data compression.
  - » Write data, via QFS, to DCS disk farm (32 second data file)
- Network Data Server (NDS)
  - » Provides live and archived data feeds, on request, to CDS operator stations



Software Version Control

- All software version control done using SVN
- Software developed by “core” group maintained in
  - advLigoRTS – DAQ and Real-time Code Generator (RCG) tools and other code required to support real-time operation.
  - Global Diagnostic System (GDS)
- Two control application developers SVN repositories
  - Seismic group (legacy)
  - CDS group supported SVN for all other user applications
- Documentation written which specifies CDS production system directory structure and proper linkage of various SVN branches.
- Working with subsystem application developers to form commonly structured SVN areas to ease link to production.

CDS SVN Repository



Software Reviews

- Driven by the high cost of commercial real-time OS, developed our own patch to GPL Linux to provide the real-time features that we require.
  - » Reviewed as part of meeting at AEI, Hannover, Germany last July
  - » AEI brought in two Linux consortium members, with expertise in real-time, as consultants for this review.
- Lab internal review held last November for DAQ software and real-time application development tools.
- Informal Reviews
  - » A number of meetings with AEI Hannover staff, who use our software on a number of projects, including updates to GEO subsystem controls and DAQ.
  - » Recently held two user/control application developers workshops, one day of which was devoted to going through the core software components part by part.

Software Testing

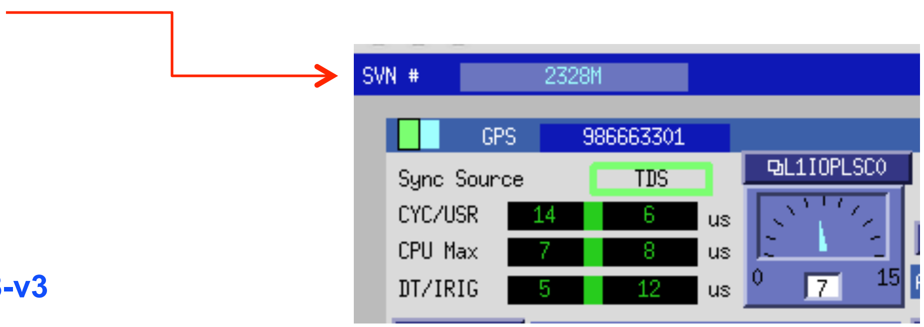
- In process of developing automated testing. In preparation:
  - » Added a number of new diagnostics to system.
  - » New scripting language interfaces to EPICS and NDS
    - – Perl and Python
- Caltech 40m lab interferometer controls upgraded to use aLIGO hardware/software. Part of the lab's mission is control/DAQ software test on an operating interferometer.
- Automated I/O chassis test system at Caltech used to verify I/O in new releases.
- Software also deployed in support of a number of seismic and suspension subsystem test stands.
  - » Users often operate/configure systems in ways not considered by software test developers.

Recommendations from NSF April 2010 Review

- Actively working to incorporate the recommendations, as listed in following bullets and next page. Many have been incorporated, but more work still to be done.
- Separate builds for development and production code
  - Action: Implemented SVN "tagged release" system for core software
- Development builds on regular, fast turnaround basis
  - Action: Already being done
- All builds exercise all component test suites (In process of incorporating)
  - Action: In process of documenting and automating test procedures.

Recommendations from NSF April 2010 Review

- Code install and operation on interferometers
  - » Only fixed production release code to be used on interferometer
  - » Clear structure for managing software module versions.
  - » Builds fixed and reproducible
  - » Only code from SVN
  - » Actions Taken:
    - – Additional SVN structure set up for user developed control applications
    - – Standard production code directory structure implemented and documented
    - – Control application developer training and SVN assistance
    - – Documentation of exactly which real-time control code will run on which processor
- Archival of software build metadata
  - » Action: In process of producing auto-generated EPICS database channels for code SVN tags, which are then saved as part of the Frame data.



Software Documentation

- Base set of documentation in place.
  - » Part of November 2010 review
- Software test procedure documents still need to be added.
- Document updates a continuous process.

CDS Software Documentation

(QA: **Uncertified**)

Abstract:
List of CDS software documentation for 2010 CDS software review.

Files in Document:
None

Topics:

- Meeting
- Data Acquisition System

Authors:

- Rolf Bork

Related Documents:

- LIGO-T0900603: aLIGO CDS Real-time Control Software Requirements
- LIGO-T0900607: AdvLigo CDS Realtime Sequencer Software
- LIGO-T0900638: CDS Real-time Data Acquisition Software
- LIGO-T0900612: AdvLigo CDS Design Overview
- LIGO-T1000560: CDS Software Development Plan FY11
- LIGO-T1000561: aLIGO CDS Software Test Plan
- LIGO-T1000587: aLIGO CDS Inter-Process Communication Software Design
- LIGO-T0900636: Frame Builder and Network Data Server
- LIGO-T1000588: aLIGO CDS Computer and Networking Rack Layouts
- LIGO-T080135: AdvLigo CDS Realtime Code Generator (RCG) Application Developer's Guide
- LIGO-T0900531: CDS Subversion Users Guide (wiki document)
- LIGO-T1000248: aLIGO CDS File System Directories
- LIGO-T1000379: CDS Environment Configuration Scripts
- LIGO-T1000496: aLIGO CDS Software Bug Reporting User Guide
- LIGO-T0900606: CDS Standard IIR Filter Module Software

DAQ System
Project organization

- Three software engineers at Caltech
  - » DAQ and realtime infrastructure software development
- Three additional software staff at sites
  - » Global Diagnostic Tools
  - » Additional control room tools
  - » System Administration
- Columbia University
  - » Manufacture and test of timing system
  - » Developed associated timing diagnostics software

DAQ System
Flow of Activities

- Software Development
  - » Focus on "short list" of additional features/bug fixes for RCG put forward during user group meetings.
    - – Updated Software Development Plan
  - » DAQ specific software development complete.
    - – Implement and verify DAQ test procedures and scripts.
    - – Preliminary performance tests have been run to 48MB/sec + 45K EPICS channels.
  - » Test and verify production release procedures.
  - » Complete/update documentation.
  - » Complete/verify implementation of NSF 2010 review recommendations
- Equipment Procurement
  - » Specify/Procure system servers and operator station computers.
- Installation
  - » LLO system in place.
  - » Install/test H2 system as building becomes available (May).
    - – System already built and ready to move in place.
  - » H1 system after Squeezing Experiment complete

Challenges, risks, and mitigations

- Technical
  - » Scaling from relatively small test systems to a large, integrated AdvLigo System
    - – Large scale testing continues
      - L1 system, with complete set of real-time computers in place.
      - Caltech 40m lab, on operational interferometer.
    - – Large number (>100K) of slow (EPICS) data channels of particular concern and focus of testing.
      - May require separate data frames for fast and slow data.
      - May require slow data be moved to DAQ as a separate transmission on fast DAQ network if EPICS channel access mechanism becomes overloaded.
- Cost
  - » Increased cost of Commercial Real-time Linux OS
    - – Mitigated by development of patch to GPL Linux.

DAQ System Summary

- Timing system component delivery and installation continues.
  - » Equipment necessary to support early commissioning activities are in place.
- LLO DAQ system and networking infrastructure installed and operational.
- LHO H2 DAQ and networking system operational and ready to move into place as space becomes available (late May).
- Two off-line DAQ / control application development/test systems operational, one at each site.
- Stand-alone systems installed and in constant use at sites, and elsewhere, to support testing of suspension and seismic isolation systems.
- Distributed systems installed and operational at CIT 40m lab, MIT LASTI, and at AEI/GEO in Germany.