LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type Technical Note	**LIGO-T970159-04-**	**E**	10/24/97

LIGO Data Analysis System Design Requirements

LIGO Integration Group

Distribution of this draft:

This is an internal working note
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1 INTRODUCTION

1.1. Purpose

The purpose of the LIGO Data Analysis System (LDAS) is to provide for both on-line and off-line data analyses of LIGO data which are designed to:

- Detect and analyze gravity waves from astrophysical sources.
- Assist in the initial characterization and diagnosis of LIGO interferometer performance.
- Monitor end-to-end interferometer performance using techniques sensitive to the extraction of GW signals from the data stream.
- Provide long-term storage of LIGO data
- Provide access to the data archive.

The on-line capability described herein will be able to provide computational resources and access to data for both diagnostics support functions and for real-time signal processing and detection. Sufficient flexibility is provided to accommodate various signal processing concepts.

The off-line component will concentrate computational and archive resources at one site. It will rely on high-bandwidth connectivity over the LIGO wide area network (WAN) to provide access to the database and the computational resources to remote users.

The on-line and off-line components will be highly integrated in design and will have most functions in common. In addition, it is the intent to implement these functionalities with a common software base.

1.2. Scope

The LDAS is to be developed to meet the requirements set forth in this document. The LDAS shall have the means to:

[A] Provide on-line data analysis capability to each of the LIGO Observatories. This capability includes the following:

- A means to extract physical strain from the interferometer output(s) and to utilize relevant ancillary channels (e.g., PEM) to remove instrumental or environmental signatures.
- A means to process strain data through real-time detection algorithms for both performance monitoring and scientific purposes. Sufficient computing power to allow processes to keep up with the incoming datastream shall be provided. Sufficient margin shall also be provided to accommodate maintenance down times and other system inefficiencies.
- A means to cross-correlate data (either time series or event lists) from multiple interferometers.
- A means to store data frames and analysis results (local to the Observatory LAN) to short term storage media. This functionality will be provided by the LIGO DAQS resources, with possible augmentation by LDAS.
- A means to access both “live” and short term archived data via the Observatory LAN and the LIGO WAN. Access shall be subject to available bandwidth and demand.

- Means to retrieve, concatenate and extract specific channels of recent data from the on-line storage system.
- Sufficient automation to run continuously and autonomously during periods of normal operation.
- A means to display and visualize results of analyses over the Observatory LAN.

[B] Provide off-line data analysis capability. This capability is likely to be concentrated at one LIGO Laboratory site but shall be available "seamlessly" throughout the Laboratory. This capability includes:

- A means to reduce the raw data to science data representing calibrated GW strain data and a reduced subset of ancillary data and a data quality descriptor.
- A means to archive, retrieve and distribute reduced datasets acquired over a period of time at least 5 years in duration.
- A means for duplicating reduced datasets either for backup or for distribution.
- A means to access the data archive via the LIGO WAN by the LIGO Laboratory and LIGO Scientific Collaboration with sufficient bandwidth to support database manipulation at the off-line site by remote users.
- A standardized interface for visualization tools to allow observers to see and interpret results from various analyses.
- Sufficient computing margin to enable multiple analyses to be conducted in parallel.

Specifically not considered to be within the scope of the LDAS are:

- Data analysis functions performed at centers other than the LIGO Laboratory Facilities.
- The on-line diagnostics system used for stimulus-response characterization, transfer function determination, and calibration functions. However, it is expected that software developed for the LDAS will find utility within the diagnostics system.
- Simulations shall be provided separately from, but coordinated with, the LDAS.

1.3. Definitions

LDAS LAN: The local area network (LAN) dedicated to supporting LIGO Data Analysis Systems. Access is managed through user accounts and passwords.

Observatory LAN: The local area networks (LAN) associated with the observatories. Access to the Observatory LAN and the associated network resources are managed through user accounts and passwords.

LIGO WAN: The wide area networks (WAN) used to connect the observatories, the LIGO institutions, the off-line analysis system and the broader LIGO community. Access between sites on the LIGO WAN will be through telnet, rlogin, ftp and WWW protocols.

On-Line: Data are considered to be "on-line" if they are readily available to clients via the LDAS networks from short term storage.

On-Line Analysis System: The system which processes the data stream in real-time for performance monitoring and for the detection of astrophysical events which are time-critical. There shall be two similarly configured systems at both LIGO Observatories. If it is deemed desirable, the systems can be configured to process their respective data streams using different algorithms.

Off-line Analysis System: The system which is used to reduce, archive, retrieve, analyze and duplicate datasets after these have been collected and transmitted to the data repository site. The system shall also provide interfaces to LDAS computational resources to members of the LIGO Scientific Collaboration.

Real-time data: The LIGO datastream written to disk cache by the CDS DAQS. The actual latency in the data is determined by the length of frames and access time to read these off the media.

Real-time analysis or processing: Analysis of data so that the information contained in them can be extracted on a time scale sufficiently short so that it is possible to influence either the improvement or maintenance of detector operational performance or the collateral detection of a potential astrophysical event by other detector systems (outside of LIGO).

Time-critical:

[i]Scientific: having the potential to influence the operation of other (non-LIGO) astrophysical or astronomical detection systems so that these instruments may be employed to observe the same phenomenon detected by LIGO (or vice-versa). The time scale for *time criticality* will range from fractions of an hour to fractions of a day or even longer.

ii]Operations: having the potential to allow recovery of a LIGO interferometer from off-nominal operation by virtue of the information extracted from the LIGO datastream.

Metadata: The descriptive data about data; metadata typically consists of (but is not limited to) catalog, index, content, configuration, citation, signiture data that is used to describe data.

1.4. Acronyms

- CACR Center for Advanced Computing Research (Caltech)
- CDS Control and Data System
- CSU Compute Server Unit
- DAQS Data AcQuisition System
- DDU Diagnostic Distribution Unit
- DIU Data Ingestion Unit
- DRU Data Reduction Unit
- DVU Data Visualization Unit
- GUI Graphical User Interface
- IFO Interferometer
- LAN Local Area Netwrok
- LDAS LIGO Data Analysis System
- LIGO Laser Interferometer Gravitational Wave Observatory
- LMDB LIGO Meta Data Base (non-frame data)

- MPI Message Passing Interface
- MTB(C)F Mean Time Before (Critical) Failure
- MTTR Mean Time To Repair
- NFS Network File Services
- PEM Physical Environment Monitoring (System)
- RH Relative Humidity
- SCU Signal Conditioning Unit
- SNR Signal to Noise Ratio
- SRS Software Requirements Specifications (Document)
- TBD To Be Determined
- WAN Wide Area Network
- WWW World Wide Web

1.5. Applicable Documents

The following documents contain relevant design and specification data for the LDAS.

Table 1: Applicable Documents

Document Identifier	Description	Comments
M970065	White Paper Outlining the LDAS for LIGO I	
T970140	LIGO LDAS Software Specification and Design Requirements	In process
T970100	LIGO System Software Design Issues	
	Paraflow User's Guide	Author: R. Williams, CACR
T970078	Interferometer Diagnostics Tests and Tools	Draft
T960009	CDS Data Acquisition System Design Requirements Document	
T950054	CDS Control and Monitoring Design Requirements Document	
T960010	CDS Data Acquisition System Conceptual Design	
T960108	Interferometer Diagnostics Conceptual Design	
T960107	LIGO Inteferometer Diagnostics System Design Requirements	
VIRGO-SPE-LAP-5400-103	Frame Library Users Manual	
T970130	Specification of a Common Data Frame Format for Interferometric Gravitational Wave Detectors (IGWD)	
T970160	LIGO Data Analysis System Conceptual Design	

2 GENERAL DESCRIPTION

2.1. Specification Tree

This document is part of an overall LIGO system requirements specification tree. This particular document is highlighted in the Figure 1.

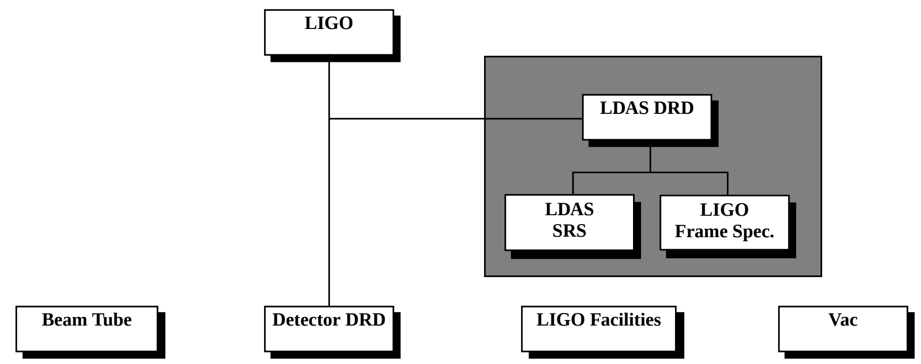

Figure 1 LIGO Document Tree

2.2. Product Perspective

The LDAS is divided into two primary functional units as shown in Figure 2.

These are:

- On-line LDAS: The on-line segment consists of two functionally identical but independent units located at the LIGO Observatories (Hanford, WA and Livingston, LA). Each provides the capability to run real-time detection algorithms and also the ability to provide end-to-end insight into interferometer behavior for specific signal types. The system interfaces to the LIGO DAQS for accessing the real-time data. It also has a limited one-way interface (data displays for operators) for interferometer diagnostics to provide performance metrics based on non-Gaussian noise characteristics. The site LAN may be used to access the data cache by scientific analysis workstations at the site. There will also be limited ability to access the real-time data remotely by other LIGO Laboratory sites.

- Off-line LDAS: The off-line component will likely reside at Caltech's CACR and provides several functions: data ingestion, reduction, and compression for long term archiving; data retrieval; multi-user (independent) refined analysis of LIGO data. Access to the archive will be via a wide area network (WAN) capable of providing high throughput access to the archive. The baseline provides for regular transfer of data tapes from the LIGO Observatories to the off-line analysis center. Once data tapes are received, they will be processed in a yet to be defined manner to extract/compress/refine the science data for the permanent archive.

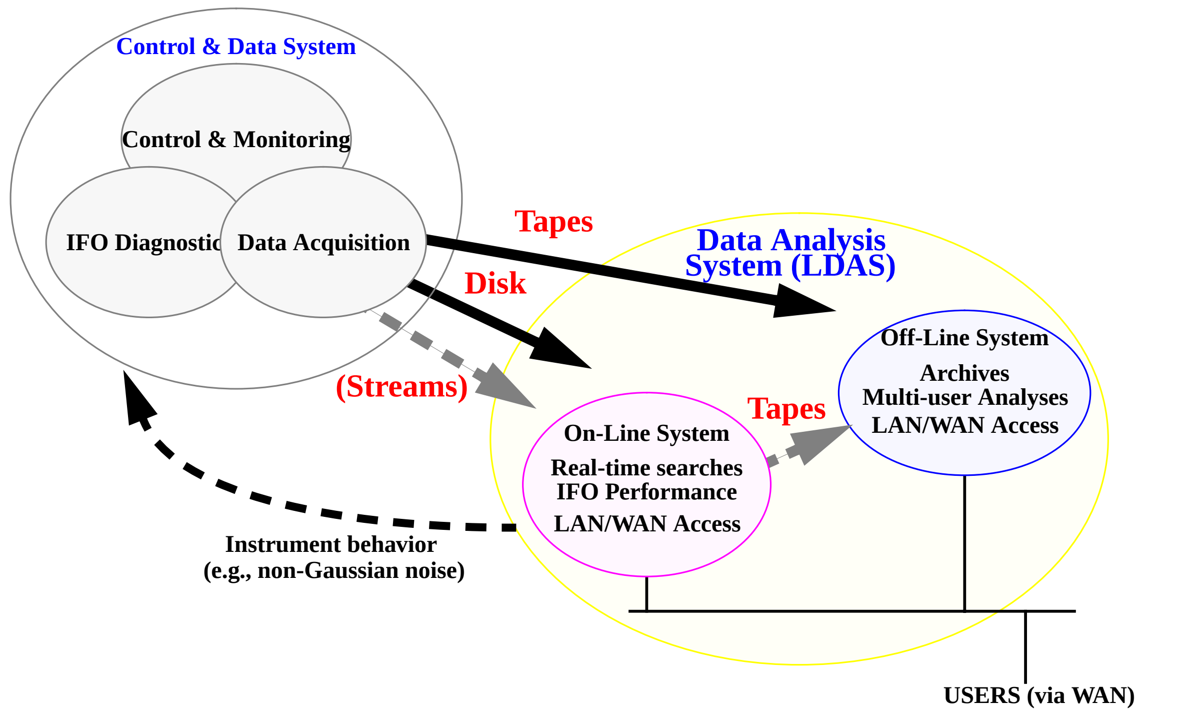

Figure 2 LDAS Functional Units. LAN or WAN refers to the local area networks either within a Laboratory site or between sites.

The on-line and off-line systems shall be independent; however, where it is required, those critical databases or components will be "linked" or "mirrored" between them. The systems will be highly integrated so that, for example, a remote user will be able to access either the on-line or off-line system with identical user interfaces and commands (or at least using identical paradigms, when true "identity" is not feasible).

2.3. Product Functions

The primary on-line functions of the LDAS are:

1. To process the interferometer output to generate a best-estimate, calibrated strain data time series in real-time.
2. To process the strain data through one or more real-time detection algorithms. This procedure generates an event list, including time of occurrence, limited parameters extraction(e.g., mass, strain magnitude, distance to source, limited direction to source using both LIGO sites, etc.), and likelihood that the event is a true signal.
3. To provide site-to-site communications to exchange low bandwidth time domain data for correlations, event lists and/or higher bandwidth time domain data when event triggers occur.
4. To provide feedback to detector operations on instrument behavior with regard to end-to-end performance. There is no planned signal feedback loop for this function.
5. To provide quick-look analyses at the LIGO Laboratory sites.

The primary off-line functions of the LDAS are:

6. To provide the means to process and reduce the raw datastream for archival storage.
7. To provide a repository for LIGO archives remotely located from Observatory sites.
8. To provide access and retrieval capabilities from the LIGO archive for scientific users performing off-line (i.e., non-time critical) analysis.
9. To provide analysis tools and libraries for performing a variety of astrophysical searches with LIGO data, including: more refined (e.g., deeper) searches than are possible on-line (for supernovae and binary inspiral chirps); searches that are either not necessary or not feasible to be performed on-line (searches for periodic signals, stochastic background, and novel sources); research on new search techniques that need validation or refinement.

2.4. Interfaces

Figure 3 depicts the interfaces to the LDAS.

DAQS/CDS Network - LDAS On-line. This interface will allow a stream to be established from the framebuilder to the on-line data system. Such a path will allow real-time access to streaming data and may be used to perform LDAS functions in support of diagnostics.

DAQS/SCSI - LDAS On-line. This interface is the primary path for data. DAQS writes to the short-term mass storage system and LDAS can access the data on the disk system. Data service to analysis functions is provided by LDAS.

LDAS On-line - LIGO Laboratory Sites. This interface provides access to the real-time data and short-term mass storage via the LIGO WAN on a limited bandwidth basis.

DAQS/Tape System - LDAS Off-line Archive. This interface provides the path for delivering data to the archive center from the sites. At present the baseline is for bulk transport of media (tapes) from sites to Caltech. As network bandwidths increase in the future, the LDAS on-line - LIGO Laboratory Site link may become the primary pathway.

LDAS Off-line - LIGO Laboratory Sites/Computing Centers. This interface provides the ability to access the archived data via the LIGO WAN.

LDAS On-line - Diagnostics. The linkage between diagnostics and the on-line system is of two types. First, common software libraries are available for both on-line analysis and diagnostics. Secondly, results of on-line analyses can be used to deduce instrument performance.

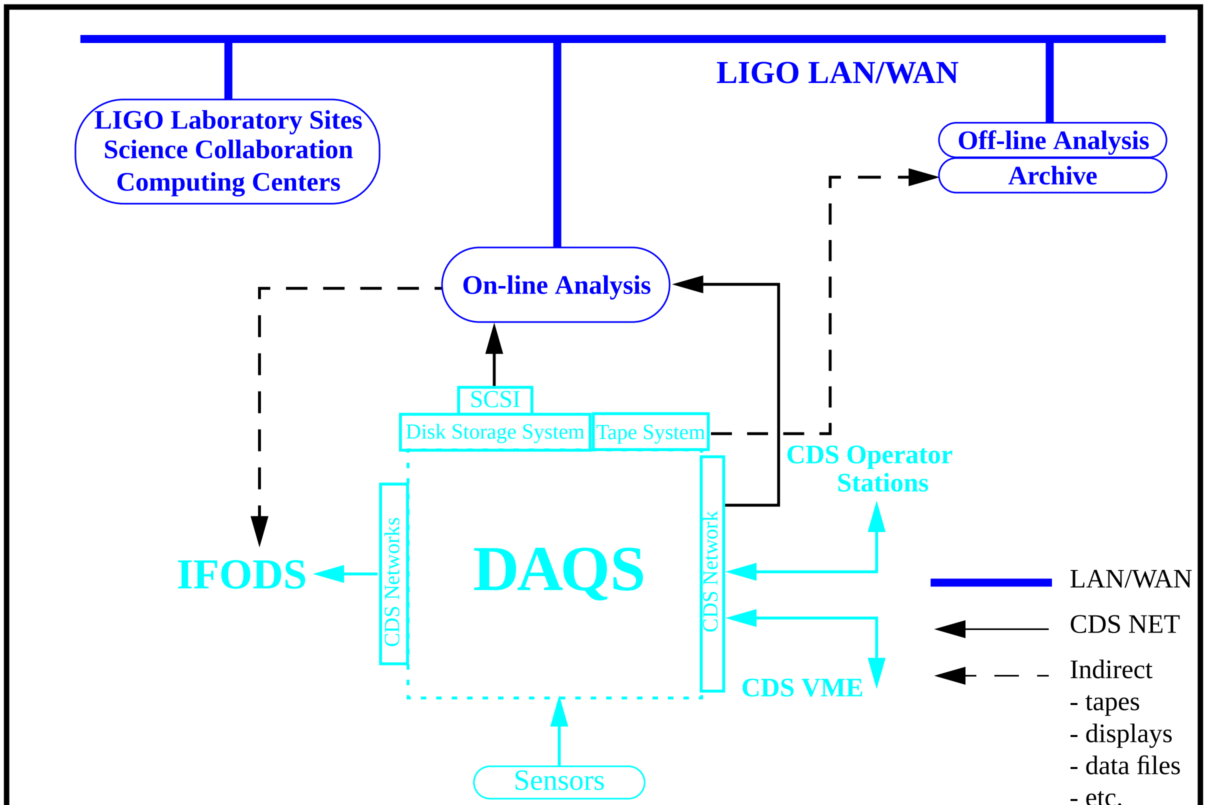

Figure 3 LDAS Interfaces

2.5. Functional Description

To assist in defining the requirements in following sections, the LDAS has been broken down into functional units, along with a concept of data flow through the functional blocks.

2.5.1. On-line functionality

The on-line system is dedicated to distributing and processing the real-time data stream for the extraction of gravitational wave strain (best estimate) and the processing of this signal for the presence of significant events.

The functional units are shown in Figure 4 below and defined as follows:

- Data distribution: That hardware and software which supplies the function of providing to other processors and users the LIGO data stored as frames on the DAQS short term (volatile) disk cache system. It provides access to the DAQS configuration meta-database.
- Calibration, cross-correlation and regression: That hardware and software which supplies the function of extracting a best estimate of strain from the raw data stream.
- Composite veto generation: The hardware and software that processes selected sets of signals and user provided parameters and/or algorithm options to qualify data and instrument performance.
- Event detection: That hardware and software that processes in real-time the calibrated strain signal and associated ancillary signals (e.g., PEM vetoes, etc.) for the identification

of likely events of interest.

- Event/data processing: That hardware and software which supplies the function of displaying, visualizing, or managing the results of analyses on the data stream for presentation to the users or operators.
- LAN/WAN: That hardware and software which supplies the function of allowing remote researchers to access the short-term data at the observatories and archived data from the off-line system.

The functional units described above will be available at each of the observatory sites independently.

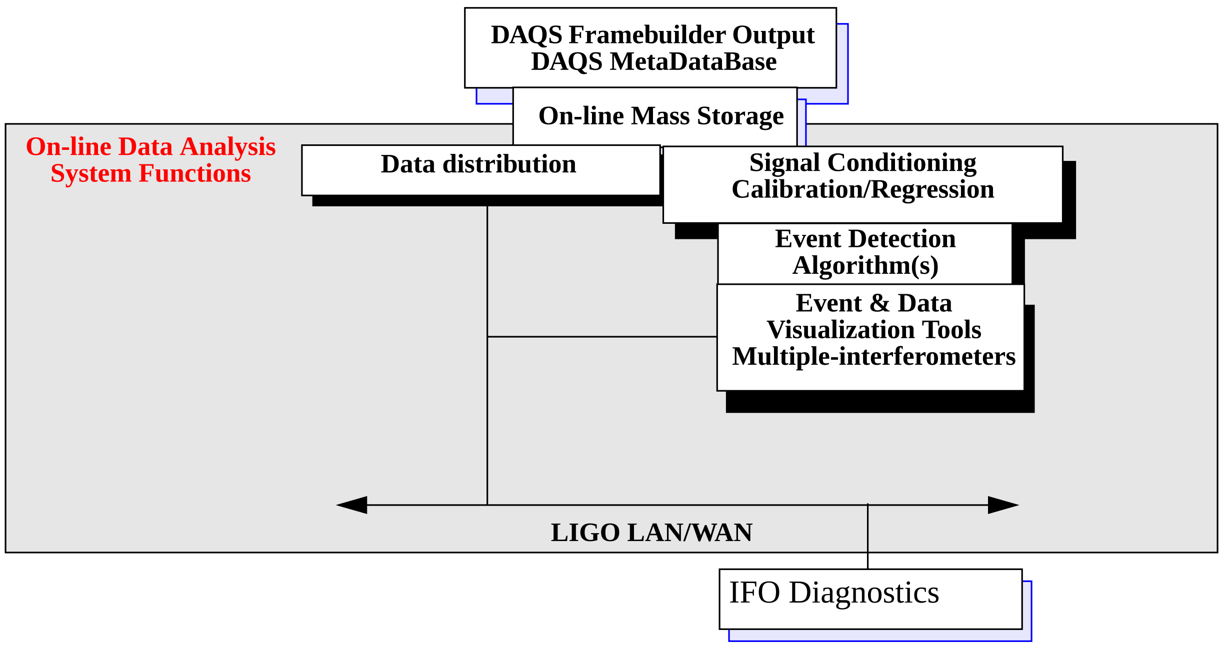

Figure 4 LDAS Functional Block Diagram: On-line Analysis

2.5.2. Off-line functionality

The off-line functional units are shown in Figure 5 below and defined as follows:

- Data distribution: That hardware and software which supplies the function of providing to other processors and users the LIGO data stored as frames in the LIGO data archive. It also provides access to the LIGO metadatabase (see section 3.1.3.).
- Signal conditioning -- calibration, cross-correlation and regression: That hardware and software which supplies the function of extracting a best estimate of strain from the raw data stream.
- Data reduction: That hardware and software that processes the raw LIGO data delivered by the observatories and combines/reduces/compresses the data for long term archival.
- Event detection algorithm(s): That hardware and software that processes calibrated strain signal and associated ancillary signals (e.g., PEM votes, etc.) for the identification of

likely events of interest.

- Event/data visualization: That hardware and software which supplies the function of displaying, visualizing, or managing the results of analyses on the archived data for presentation to the researchers.
- LAN/WAN: That hardware and software which supplies the function of allowing remote researchers to access the LIGO data archive at the repository.

The functional units described above will be installed at Caltech, resident within the CACR, but controlled by LIGO. They will be accessible over WAN/LAN network infrastructures to all the LIGO Laboratory sites and to members of the Scientific Collaboration.

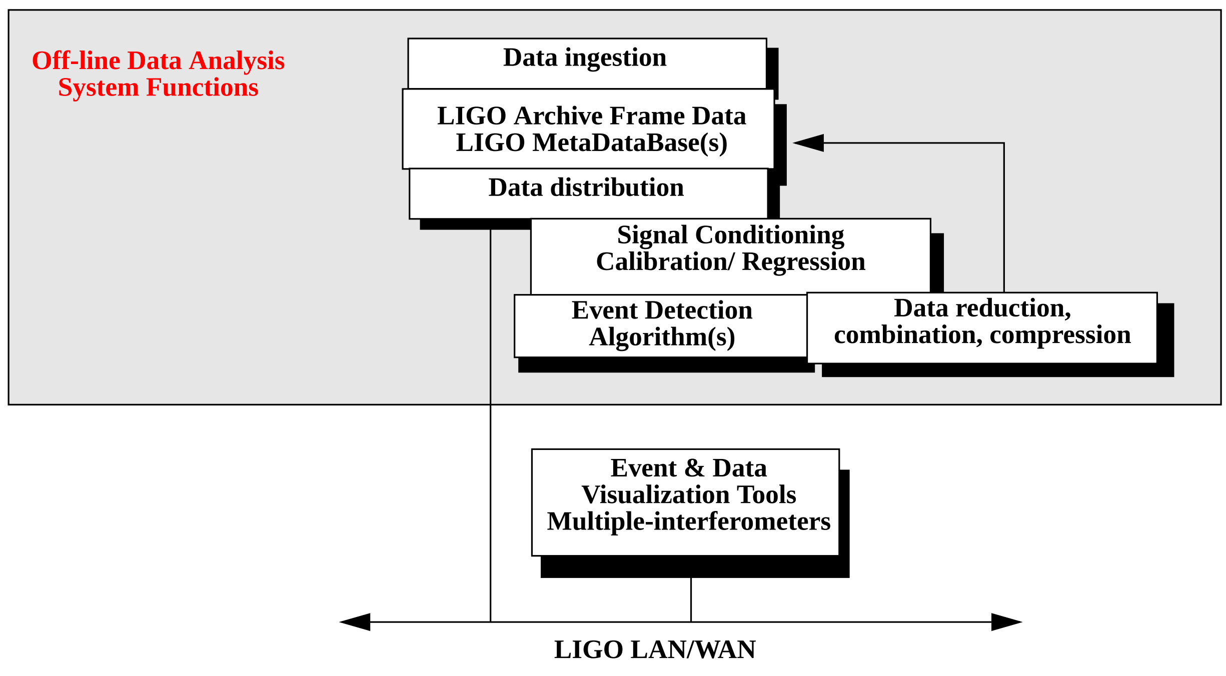

Figure 5 LDAS Functional Block Diagram: Off-line Analysis

The data flows associated with the on- and off-line systems are shown in an approximate manner below in Figure 6 and Figure 7. These analysis flows will be fine-tuned as the system definition evolves.

For the on-line system, the following functions are supported:

- Frame retrieval & concatenation/channel extraction: this functionality provides the manipulation of frame data. It consists of a data server and a library of functions which may be invoked either in a data analysis flow or as stand alone. These functions include: scanning of frame headers and providing graphical or textual reports, creating long time series for individual channels from many individual frames, writing out new frames, etc. Users wishing to perform their own analysis outside of the LIGO-provided LDAS may utilize these functions by linking to the library with their software.
- Calibration/channel cross-correlation/regression: this functionality allows a user to manipulate multiple channels of data to improve sensitivity or SNR in the gravity wave channel.

A linear process which mixes a number of signals can be inverted to obtain the regressed signals. The functionality allows for spectrally filtered signals to be regressed by considering the spectral dependence of the regression coefficients.

- PEM/IFO Veto processing: ancillary PEM (or interferometer) signals collected simultaneously with the GW channel may be manipulated to provide discrete (Boolean) or analog triggers that may be used downstream to qualify GW data. Veto processing may involve Boolean logic or deadband settings on RMS or other metrics of signal quality.
- On-line searches -- matched filtering: for astrophysical processes which are believed to be sufficiently well-understood that gravitational waveforms may be calculated *a priori*. This technique requires a set of templates spanning a multi-dimensional parameter space and the ability to correlate the real-time waveform with this array of templates. Peak detection or other likelihood estimators are used to flag potentially meaningful high SNR correlations between the datastream and the dictionary of potential waveforms. This technique is expected to be useful for detection of binary inspiral waveforms. It is possible to also use model-independent (i.e., non-astrophysically based) templates for signal characterization.
- On-line searches -- model independent filters and performance assessment: in addition to filters using matched templates derived from astrophysical principles, the real-time data stream will also be processed by model-independent filters or processes useful in generating visual representations of machine behavior. These will include, for example, processes to produce frequency-time representations of the data (spectrograms). Also, algorithms designed to extract or track sharp spectral features (e.g., line harmonics or wire violin resonances) will be implemented.
- Event list generation/visualization tools: filter or detection algorithm outputs meeting criteria for consideration as true alarms will be compiled as event lists containing sufficient information about the event type, detection technique, and epoch of detection (instrument performance during that time) to enable multiple interferometer cross-checks and cross-correlations to be performed in near real-time. This includes the functionality to catalog events in the metadatabase. Tools will be developed to display event lists and the results of other analysis. It consists of a library of functions which can be invoked either in a data analysis flow or as stand alone. These functions include: scanning frame headers and providing textual or graphical summaries, creating long time series for individual channels from many individual frames, writing out new frames, etc. Users wishing to perform their own analyses outside of the LIGO-provided LDAS may link to this library with their own software.

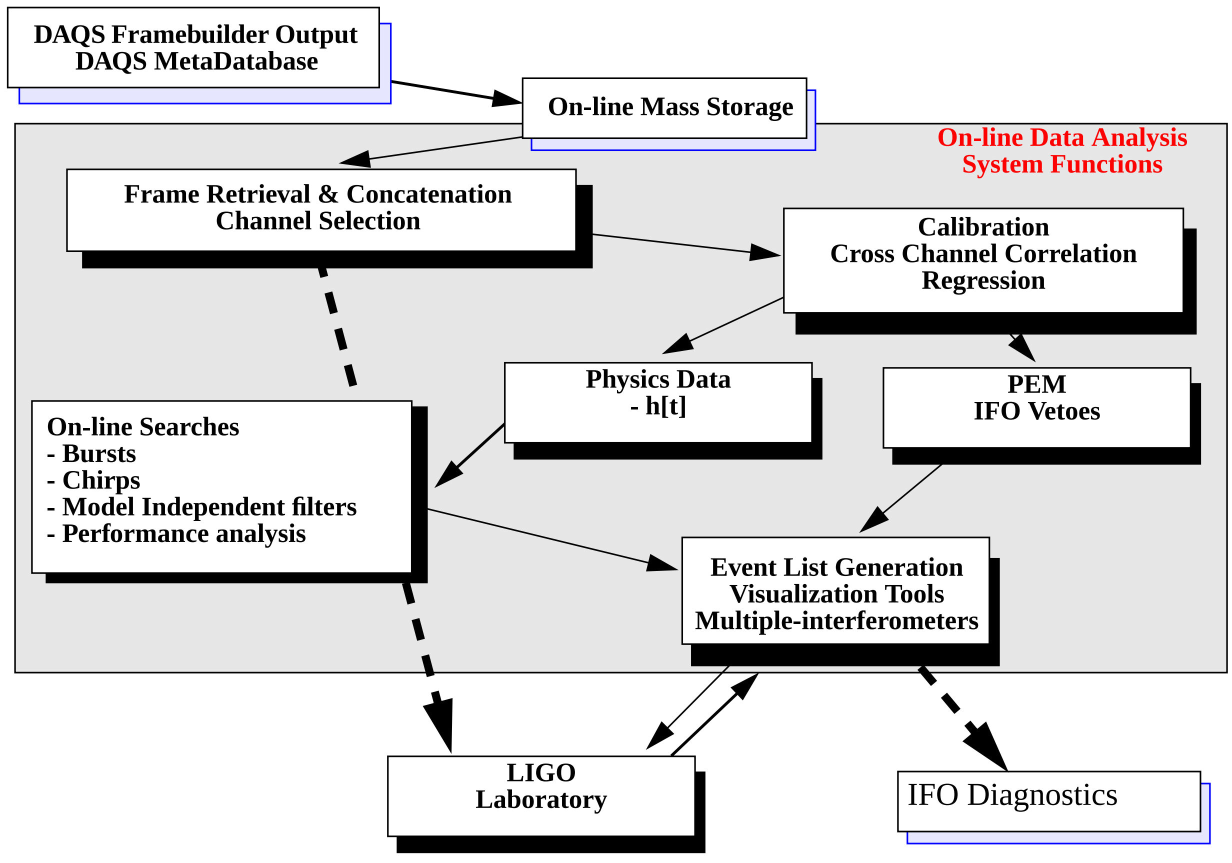

Figure 6 LDAS Flow Block Diagram: On-line Analysis

The off-line analysis flow is depicted in Figure 7. The elements are defined as follows:

- Data ingestion: this functionality provides the ability to take raw frame data, as it is recorded at the observatories and delivered to the archive, and to transfer the data to LIGO archive-compatible media.
- Frame retrieval & concatenation/channel extraction: this functionality provides the manipulation of frame data.
- Calibration/channel cross-correlation/regression: this functionality allows a user to manipulate multiple channels of data to improve sensitivity or SNR in the gravity wave channel. A linear process which mixes a number of signals can be inverted to obtain the regressed signals. The functionality allows for spectrally filtered signals to be regressed by considering the spectral dependence of the regression coefficients.
- PEM/IFO Veto processing: ancillary PEM (or interferometer) signals collected simultaneously with the GW channel may be manipulated to provide discrete (Boolean) or analog triggers that may be used downstream to qualify GW data. Veto processing may involve Boolean logic or deadband settings on RMS or other metrics of signal quality.
- Off-line searches -- optimal (matched) filtering. All the capabilities discussed for the on-line system, but capable of handling a larger volume of templates and consequently pro-

viding the ability to search a larger parameter space. Included under the general heading of optimal filtering are: chirp detection to greater distances and lighter mass systems than are feasible on-line; searches for periodic sources; searches for stochastic (broadband) backgrounds; searches for transient or burst sources; presently unforeseen phenomena.

- Off-line searches -- model independent filters and performance assessment: in addition to filters using matched templates derived from astrophysical principles, the data may also be processed by model-independent filters. These will include, for example, processes to produce frequency-time representations of the data (spectrograms). Also, there will be running algorithms designed to extract or track sharp spectral features (e.g., line harmonics or wire violin resonances).
- Event list generation: filter or detection algorithm outputs meeting criteria for consideration as true alarms will be compiled as event lists containing sufficient information about the event type, detection technique, and epoch of detection (instrument performance during that time) to enable multiple interferometer cross-checks and cross-correlations to be performed.
- Database reduction and consolidation: data from multiple interferometers, after having been calibrated, may be processed together to enhance SNR by looking for coincident signals for multiple interferometers. In addition, reduced physics data and suitable data qualification signals will be produced for archival and long-term storage.

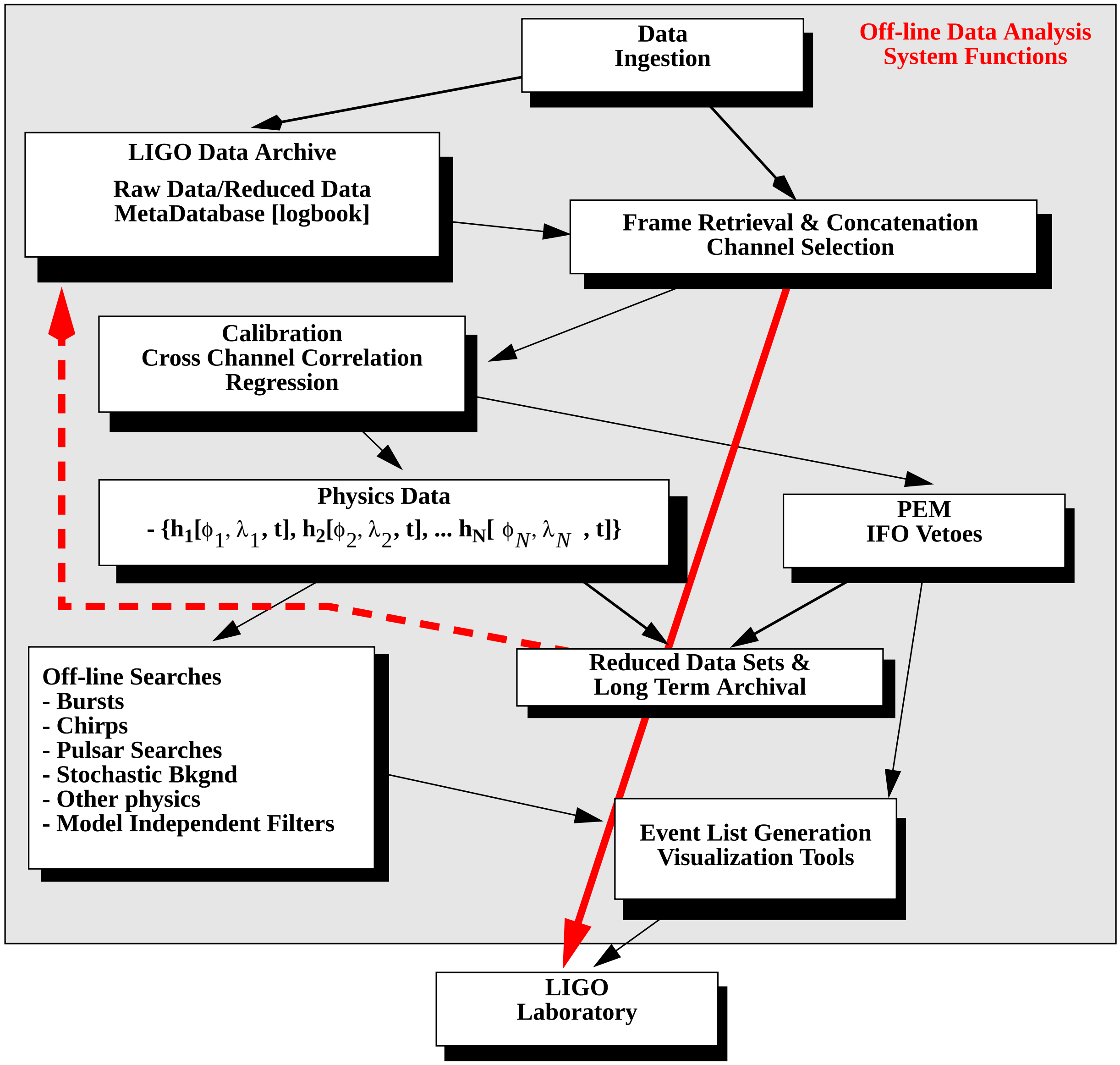

Figure 7 LDAS Flow Block Diagram: Off-line Analysis

2.6. General Constraints

2.6.1. Standards

Certain standards have been, and are being, developed by the LIGO which are documented under the data analysis functions. These include a specification for the common frame data format, software design issues and standards. LDAS shall adhere to these standards, particularly where the LDAS interfaces to remote users outside the Laboratory.

2.6.2. Availability

LIGO is designed to operate continuously, 24 hrs/day, every day of the year, with a reliability that will enable the Laboratory to keep three interferometers on-line *at least* 75% of the time. Even so, with the sensitivity of the initial LIGO interferometers, present models of astrophysical processes anticipate few detectable events occurring within the course of a year. Therefore, the LDAS must have a high reliability and availability to maximize the opportunity for detections.

2.6.3. Data Compression

For the gravity wave channel and those (few) additional channels which, through operational experience, are identified as necessary for cross-correlation and regression with the GW channel in order to improve SNR, the LDAS must not employ lossy or imperfect data compression techniques such that the full resolution of the data archived can not be recovered.

For other ancillary or auxiliary channels, it will be acceptable to provide compression of otherwise alternative description of the datastream in a lossy manner.

2.7. Assumptions and dependencies

The LDAS requirements described below and the conceptual implementation described in the adjoining documentation assume the following:

- The Detector delivers a fully functional DAQS as described in the relevant documentation. The data are written in frame format to a disc cache system which is available to the on-line LDAS. This also includes the availability from DAQS of data in-range logic flags to identify saturated or aliased waveforms. This is required for those channels which may be regressed against the GW channel.
- The Detector implements the interferometer diagnostics system described in the relevant documentation. This assumption implies that the LDAS does not need to provide real-time (signal) feedback information to the LIGO interferometers. The extent of the LDAS - Diagnostics System interface shall be primarily through the operator or scientist. The sharing of data or parameters derived by diagnostics routines (e.g., calibrations, regression parameters, etc.) will be done through frame-based data.
- LDAS, in combination with DAQS, will provide for an on-line (volatile) data storage system capable of accommodating a volume of data sufficient to provide overlap between shifts.
- To the greatest extent possible, it is desired to be able to process the datastream in real-time and on-line. This includes providing for the exchange of detection event lists between LIGO sites.
- To the greatest extent possible, it is desired to provide quick-look capability of the on-line data to LIGO Laboratory researchers located at any of the LIGO Laboratory Sites.
- The off-line system is not directly interfaced to the on-line system.
- Data reduction (and to whatever extent possible, data compression) shall be accomplished as far upstream in the data acquistion process as possible in order to enable LIGO to archive reduced datasets for at least 5 years. The data reduction factor is primarily dictated by the cost to archive and process the raw data. As a target, a minimum volume reduction of 10X is assumed. As a minimum, the GW channel, calibrated in strain, shall be archived

permanently.

3 REQUIREMENTS

3.1. Characteristics

3.1.1. On-Line System Performance Characteristics

3.1.1.1 Operation

Normal

In normal operation, the on-line LDAS shall provide data distribution, signal conditioning and on-line storage for event detection and interferometer performance assessment (diagnostics) functions. As a minimum, the on-line capabilities shall accommodate the full LIGO data stream at each site for at least 8 hours ("reduced datasets" may be accommodated for proportionately longer intervals). As a minimum, the system shall access and serve to other processes and users the quantity of data prescribed by DAQS design for each site and simultaneously perform those additional functions as prescribed in later sections of this document for each functional unit of the LDAS.

Configuration

The system hardware shall be configurable to execute any generic signal processing, conditioning and detection algorithm functions. To the greatest extent possible, specialized hardware shall be avoided. Also, graceful degradation and reconfiguration of systems shall be possible[1].

3.1.1.2 User Interfaces

Various interfaces shall be provided for users of the LDAS. General requirements are given here, with more detail in the various functional unit requirements sections which follow.

On-line Operator Interfaces

The LDAS shall provide X-windows based user interfaces at researcher stations for the on-line event detection monitoring and interferometer performance assessment.

Application Programmer Interfaces

The LDAS shall provide an API in the form of ANSI standard C language functions to enable external, user developed software to access the on-line data.

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1. Graceful degradation means that at least one "critical" component may fail without causing complete system failure. The ability to keep up with the data stream may, however, be impaired until the system becomes fully functional again. Hot-swappable hardware technology is an example of this desired feature; so is cluster architecture of peer workstations operating in an MPI environment. On the other hand monolithic architectures involving multiple processors on a single motherboard are considerably less graceful in their degradation modes.

Web interface

Data access to remotely located users shall be provided via web browser-based interfaces. These shall allow mobile or remote users to log in and scan or access various displays providing up-to-date detector status and event summaries. Of course, such performance shall be bandwidth-limited subject to the internet provider access capability.

Quick-look Functions and Displays

This functionality has potential overlap with DAQS and diagnostics capabilities. As system designs evolve, they will be reviewed to ensure consistency and to remove unnecessary redundant capabilities. As a baseline, LDAS shall provide various user interface facilities for “quick-look” of various data channels being acquired by the system (i.e., the facilities for investigating data taken over the previous 8 hour period for the full data set or correspondingly longer period of time for reduced data sets). These facilities shall include the ability to:

- View snapshot and/or running window of individual data channels
- View user selected data channels at rates to 10Hz in a single value text field.
- View time series arrays of operator selected channels (up to 1024 samples, with selectable time frames and data decimation factors) from 1sec frames.
- View data trend information from the previous 8 hours of operation.
- View frequency-time plots (periodograms) of the interferometer output channels.
- Provide data on narrowband features being tracked or removed.
- Provide data on quality and amount of excess noise in the data stream.
- Provide summary data on event detections.
- Provide summary data reflecting data quality and event discrimination information.

3.1.1.3 Flexibility and Extensibility

The requirements set forth in this document represent a minimum set of requirements for development of a base system under the LIGO construction phase in the time frame necessary to commission an initial system. At a later date, additional capabilities will be added as these necessities are identified. Therefore, the LDAS design shall show flexibility and extensibility to accommodate technology changes and additional future needs.

Because LIGO is creating a new community of researchers in a nascent field, the user model that will evolve is presently unknown. To the greatest degree possible, LIGO is designing a system representative of the best which the various astronomical and particle physics experiences have proven useful. This is especially true in the area of software design and development.

The hardware implementation shall support MPI parallel-processor software programming and shall be extensible in a modular sense. The hardware shall, to the greatest extent possible, employee components which are POSIX compliant.

3.1.1.4 Data Distribution Unit (DDU)

The data distribution unit is at the interface with the DAQS. This system accesses the mass storage media which are shared jointly with the DAQS. The Short Term Storage Unit (STSU) is being designed and delivered by the DAQS. The Data Server Unit comprises sufficient controller/server capacity to retrieve frame-based data and to distribute them to other processes such as diagnostics, analysis, and data transmission to other LIGO sites (if applicable).

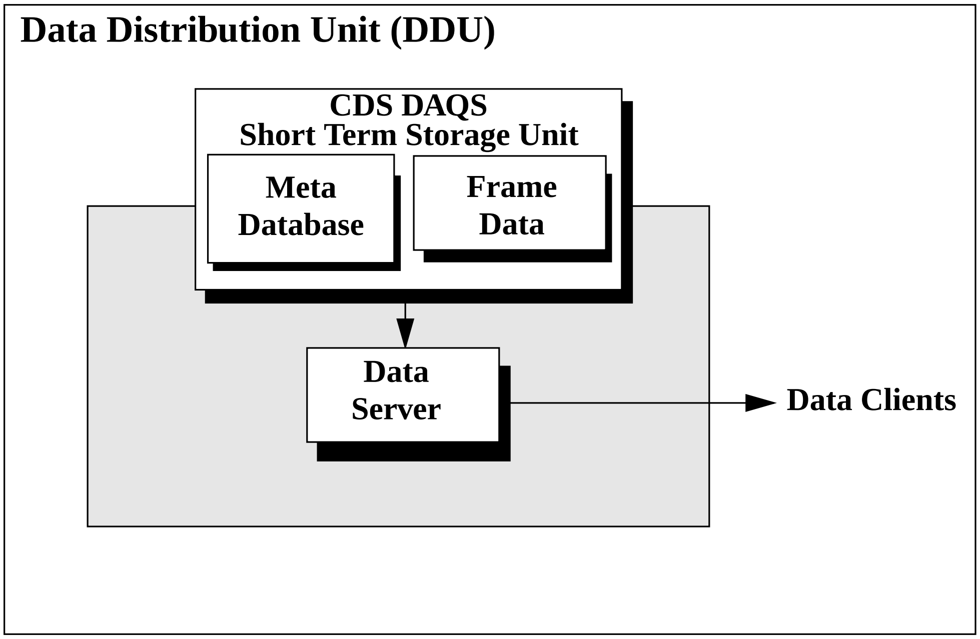

Figure 8 Data Distribution Block Diagram

Interfaces

DDU shall provide the front end interfaces to other LDAS functions for the purposes of distributing data over the LIGO LAN and WAN. These interfaces shall be in accordance with specifications in the section on interfaces.

Overall Data Storage and Distribution Capacity

Sufficient mass storage will be provided by DAQS and LDAS jointly to continuously acquire the number of data channels and at the rates described in the tables of estimated data rates which appear in LIGO-T960009 (Tables 1 & 2, CDS DAQS design document).The system shall accommodate up to 8 hours minimum of such data.

The DDU shall be able to serve at least 5 requests for data access from independent clients. An example of five clients would be: diagnostics; on-line event processing algorithm(s); on-duty staff; remote users. For each individual case, bandwidth of access will be dictated by LAN and WAN limitations.

Network Distribution of Data

The DDU shall be capable of serving data to multiple processors and processes at rates consistent with ATM service (OC3 initially, and eventually increasing to OC12). Access to the on-line data shall be available, as needed, at the site acquiring the data and also remotely to LIGO Laboratory sites. Remote users of data shall have access to data in a read-only mode. Access shall invoke adequate security measures to ensure only authorized access.

Diagnostics

The DDU shall provide diagnostics of data server systems, including:

- State information, including:
  > Fault, including description of fault condition
  > Ready: DDU configured and ready to serve data
  > Serving: DDU is acquiring data normally
- Present Configuration
- CPU Usage
- Data rates and user numbers, locations, IDs

Operation

Normal

In normal operation, the DDU shall distribute data in accordance with its loaded capabilities and provide the defined self-diagnostic information and statistics.

Reconfiguration

Service connections to clients may be opened and broken without affecting other services.

Power Up

On application of power to the DDU, the LDAS shall be designed in such a fashion that the DDU automatically is set up in ready mode.

User Interface

X-windows

An X-windows based interface shall be provided which, at minimum:

- Allows the user(s) to access and query the metadatabase associated with the raw frame data.
- Provides the user(s) with data summary information extracted from either frames or metadatabase.

Web interface

Data access to remotely located users shall be provided via web-based technology interfaces (e.g., JAVA). These shall allow mobile or remote users to log in and scan or access various data channels or trend data. Such performance shall be bandwidth-limited subject to the internet provider access capability.

3.1.1.5 Signal Conditioning Unit (SCU)

The LDAS shall provide a signal conditioning processor (or group of processors), which shall perform the functions of:

- Signal calibration
- Cross-channel spectral correlation and regression
- Narrowband feature detection and extraction
- Conditioned/preprocessed data displays, including time-frequency distributions and other characterizations intended to identify and flag nominal and off-nominal interferometer behavior.

The system of hardware performing these functions is termed the Signal Conditioning Unit (SCU). The SCU at each site shall be provided with sufficient computational capacity to keep up with the real-time data stream from the corresponding number of interferometers operating at that site.

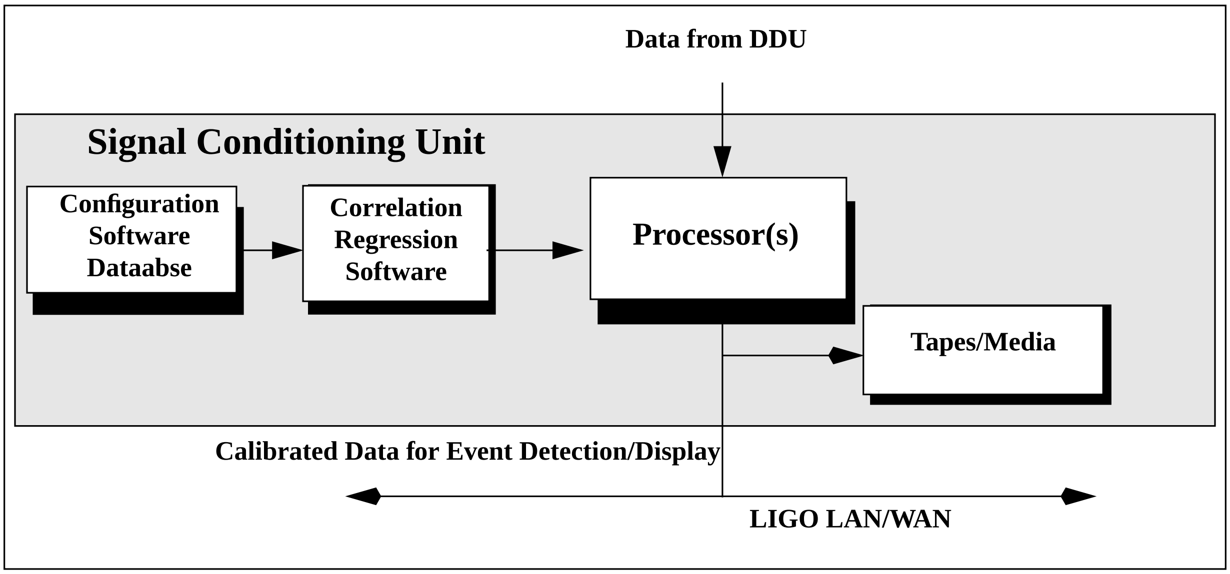

Figure 9 Signal Conditioning Block Diagram

Operation

Normal

In normal operating mode, the Signal Conditioning Unit shall accept data from the LDAS DDU and process that data according to correlation and regression algorithms defined as part of its configuration. The SCU, in turn, shall make these regressed data available to the event detection algorithm processors (described in following sections). The SCU shall meet the overall performance specifications of the LDAS and its other functional units.

Configuration

The SCU shall be configurable to run arbitrary calibration and regression algorithms consistent with the capacity of the hardware.

The hardware implementation shall be extensible in a modular fashion using to the greatest extent possible general purpose processing hardware.

Diagnostics

The SCU shall provide self diagnostics, including, at minimum, the same information as described for the DDU.

3.1.1.6 Compute Server Unit (CSU)

The calibrated and regressed data stream data will be processed for the possible presence of GW signature events in near real-time. The purpose of this is to provide as early as possible an indication that an astrophysical event has been observed and to provide end-to-end performance assessment. A number of major classes of GW sources will be searched for on-line: transient or burst phenomena having short durations; chirp waveform phenomena, having durations spanning the range 10 s < T < 1000 s; searches, based time series lasting of order one week ($T > 6 \times 10^5$ s), for periodic sources located at predefined and well-localized positions on the sky. Upper and lower limits are not hard numbers.

The real-time processing of the data stream shall be done by the Compute Server Unit (CSU). In addition there will be a high speed data communications network dedicated to the processors. The algorithms presently identified as likely candidates for initial analyses rely on matched or optimal filtering techniques in the frequency domain and utilize a large number of template waveforms for correlation with the interferometer data stream. The system also contains sufficient fast-access mass storage to accommodate the template database.

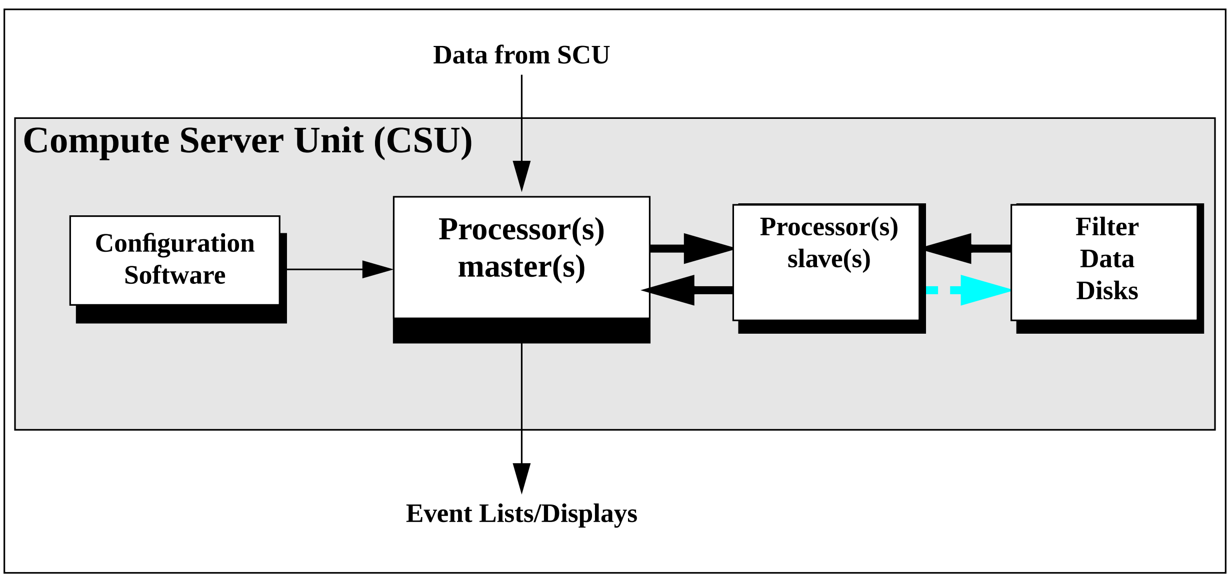

Figure 10 Compute Server Unit Block Diagram

General Requirements

As a minimum, event detection algorithms shall be provided on-line for the detection of burst or transient events and for chirped signals.

Computational Capacity

The processors running the event detection algorithm(s) shall be of sufficient capacity to keep up with the real-time data streams for their respective site. Hanford must accommodate two interferometer data streams and Livingston one.

Filter Storage Capacity

The CSU shall provide sufficient data storage capacity to accommodate the optimal filter database.

Filter Recalculation

The CSU shall be able to calculate the optimal filter bank when the instrument noise floor changes sufficiently to require this. The calculation shall be capable of being performed as a background task without affecting the real-time processing of data with the current set of filters. This task may be off-loaded to or shared with other processors in the LDAS which are available.

Filter Retrieval

The CSU shall be capable of retrieving the required filter database from mass storage at a sufficient data rate capable of keeping up with the datastream.

Diagnostics

CSU shall be provided with self diagnostics, including:

- Overall operational status
  > Fault, including cause information
  > Drive and media status
  > Data rates

User Interface

A user interface shall be provided, which includes:

- CSU diagnostic information
- Storage capacities and usage
- Status of data analysis in progress
- Ability to configure, start/stop data runs

3.1.1.7 Control & Monitoring/Data Visualization and Display Unit (DVU)

Data processed by LDAS shall be available for display at any portion of the data flow. Thus, graphical results of the signal conditioning stream or event algorithm processing unit shall be available for display. The software configuration and analysis flow status shall be displayed and available through a user console. The DVU also provides access to and management of the event metadatabase as it develops.

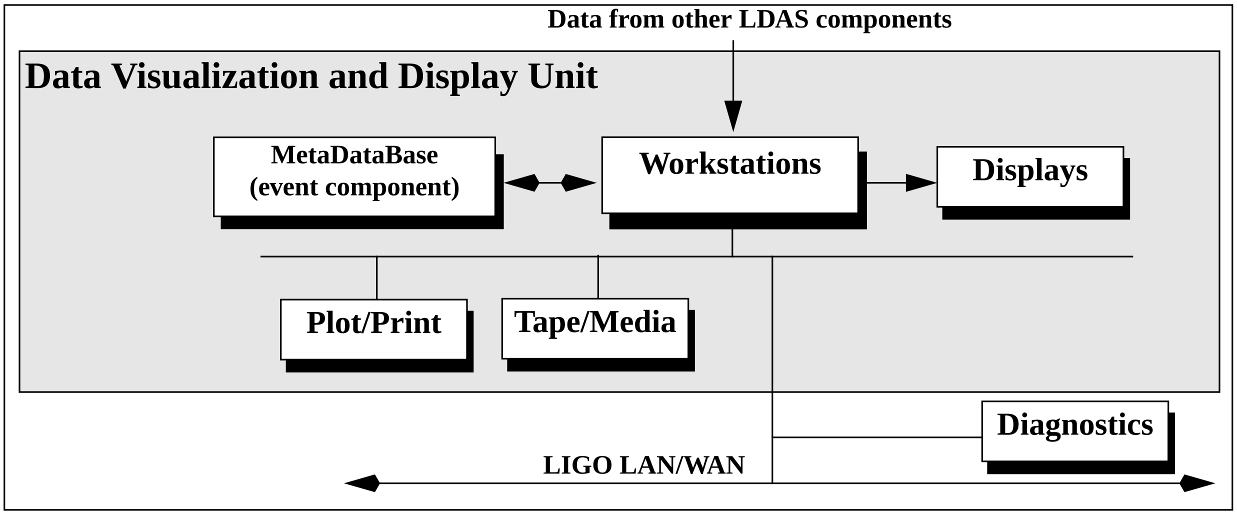

Figure 11 DVU Block Diagram

General Requirements

- The DVU shall provide the ability to initiate, configure, and download the on-line data analysis flow. Furthermore, it shall be possible to interrupt or redefine this functional process from any console providing the DVU function.
- There shall be a provision to check and compare analysis system configurations at both observatories to preclude incompatible operational modes.
- The data visualization unit shall be capable of continuously displaying and updating information at the same or greater rate than the results are being generated.
- Displayed information includes, but is not limited to, power spectra and trends; frequency-time spectra; instrumental narrowband feature characteristics; spectral cross-correlations among significant channels coupling to the GW channel; event summary statistics and histograms.
- APIs shall be provided to allow researchers to access and display the information provided in a variety of data analysis environments including, but not limited to, Mathematica, MATLAB, IDL. All graphical objects generated by the DVU shall be standardized for display and interpretation by commercial graphical data visualization packages, programs or environments.

Operation

Normal

During normal operation, the DVU shall continuously display the results of the analysis processes being run on-line. Displays shall include time series representations, frequency domain representations, and multi-dimensional representations of event filters. Event summaries include statistical or likelihood analyses, directionality (if applicable), instrument broadband noise characterizations, narrowband feature characterizations, and candidate astrophysical event characterizations.

Power Up

On power up, the DVU shall perform all necessary self diagnostics and await configuration and start commands.

Fault

On failure of a connection to datastream, the DVU shall provide a visual and audio notification to its console.

Diagnostics

DVU shall be provided with self diagnostics:

- Overall operational Status
  - > Fault, including information on the cause of the fault
  - > Config: DVU available for operation but has not been configured
  - > Ready: DVU available and configured for operation
  - > Display: DVU is on-line and receiving/displaying data
  - > Store: DVU is writing data to media for storage and retrieval
  - > Transmit: DVU is transmitting data to a remote LIGO site

User Interface

DVU *Control*

An X-windows based user interface shall be provided which allows users of the LDAS to control the following DVU parameters:

- Start/Stop DVU displays and archival
- Switch DVU sources (if outputs from multiple algorithms are available)

DVU *Status Information*

An X-windows based or web technology based (JAVA) user interface shall be provided, which depicts the following minimum information on the DVU:

- Configuration
- Status
- Run Number/Description
- Start time (time present run started)
- Elapsed time (time since present run was started)

In addition, for each media drive associated with an DVU, the following information shall be displayed:

- Status
  - > Fault, along with fault information
  - > Ready: DVU is ready to accept and display data
- Capacity
- Start Time (Time when writing started to the present media loaded in the drive)
- Elapsed Time (Since present media on drive was started)
- Data Rate

- Data or piped stream source(s)

Web interface

Data display to remotely located users shall be provided via web browser-based interfaces. These shall allow mobile or remote users to log in and scan or access various data channels or trend data. Such performance shall be bandwidth-limited subject to the internet provider access capability.

3.1.2. Off-Line System Performance Characteristics

The LDAS off-line component consists in part of dedicated hardware provided by LIGO and also shared resources available to LIGO by virtue of its association with CACR.

3.1.2.1 Operation

Normal

In normal operation, the off-line LDAS shall provide capabilities to process and reduce the raw data set in preparation for long-term archival and distribution. The dedicated LIGO hardware shall be the production system and will perform reprocessing and reduction of raw data volume in preparation for archival. Part of the off-line system function shall also be the ingestion of newly arrived raw data from the observatories for subsequent transfer to HDSS-compatible media and eventual archival.

The off-line component shall also provide the capability for remote and local users to access the LIGO archive. Access includes the ability to scan the data for summary reports and statistics, as well as the ability to process the data stream through filtering and detection algorithms using distributed networks of processors. Similar functionalities provided on-line are provided off-line, including the capability of regressing and cross-correlating multiple data streams in order to improve SNR.

As a minimum, the off-line capabilities shall include the ability to process data volumes through detection algorithms spanning periods of up $\sim 10^6$ s at a time. This time span corresponds to the 10% of the full LIGO data volume for one interferometer (i.e., 90% compression or reduction of the raw data by the time analyses are performed), assuming the DDU serves 6 individual and comparable analyses which are being conducted simultaneously: other utilizations of disk cache resources are also possible, providing fewer users with longer time stretches for data analysis. The off-line component shall make use of existing LIGO WAN infrastructure to distribute data and processing tasks to other LIGO sites and also sites of LIGO Scientific Collaborators.

Configuration

The system hardware shall be configurable to execute any generic signal processing, conditioning and detection algorithm. To the greatest extent possible, specialized hardware shall be avoided. The hardware shall be capable of performing multiprocessor parallelized computations. Distribution of computational tasks shall be possible over a distributed network not necessarily co-located with the data archive (e.g., national computing centers).

Data storage and archival functions shall be implemented with an extensible design.

3.1.2.2 User Interfaces

Various interfaces shall be provided for users of the LDAS. General requirements are given here, with more detail in the various functional unit requirements sections which follow.

Off-line Operator Interfaces

The LDAS shall provide X-windows based user interfaces at researcher stations for off-line event detection monitoring and interferometer performance assessment. Moreover there shall be an interface capable of being utilized on multiple platforms running UNIX.

Web/JAVA Interfaces

The LDAS shall provide web technology based tools to enable remote users to query the data archive, retrieve (if needed or desired) frame data to a (remote) local disk storage system (bandwidth limited by internet connectivity), or to configure and submit larger data analysis tasks which can be configured using data flow visualization GUIs.

Application Programmer Interfaces

The LDAS shall provide API in the form of ANSI standard C language functions to enable external, user developed software to access the off-line data.

3.1.2.3 Flexibility and Extensibility

The requirements set forth in this document represent a minimum set of requirements for development of a base system during the construction phase in the time frame necessary to commission an initial system. At a later date, additional capabilities will be added. Therefore, the LDAS design shall show flexibility and extensibility to accommodate technology changes and additional future needs.

Because LIGO is creating a new community of researchers in a nascent field, the user model that will evolve is presently unknown. To the greatest degree possible, LIGO is designing a system representative of the best which the various astronomical and particle physics experiences have proven useful. This is especially true in the area of software design and development.

The hardware implementation shall support MPI parallel-processor software programming and shall be extensible in a modular sense. The hardware shall, to the greatest extent possible, employee components which are POSIX compliant.

3.1.2.4 Data Ingestion Unit (DIU)

The LIGO archive receives data from the observatories and makes them available to the LIGO Laboratory and Scientific Collaboration. The present baseline is to record raw data on high density tape media at the Observatories and to transport these to the archive site for further post-processing. As technological improvements become available, this will evolve to exploit the most efficient and cost effective implementation. Future options will include optical media and possibly direct transmission of data to the archive site.

The DIU shall provide the functionality of transferring data from the original media to media appropriate for the archive (DDU, see below).

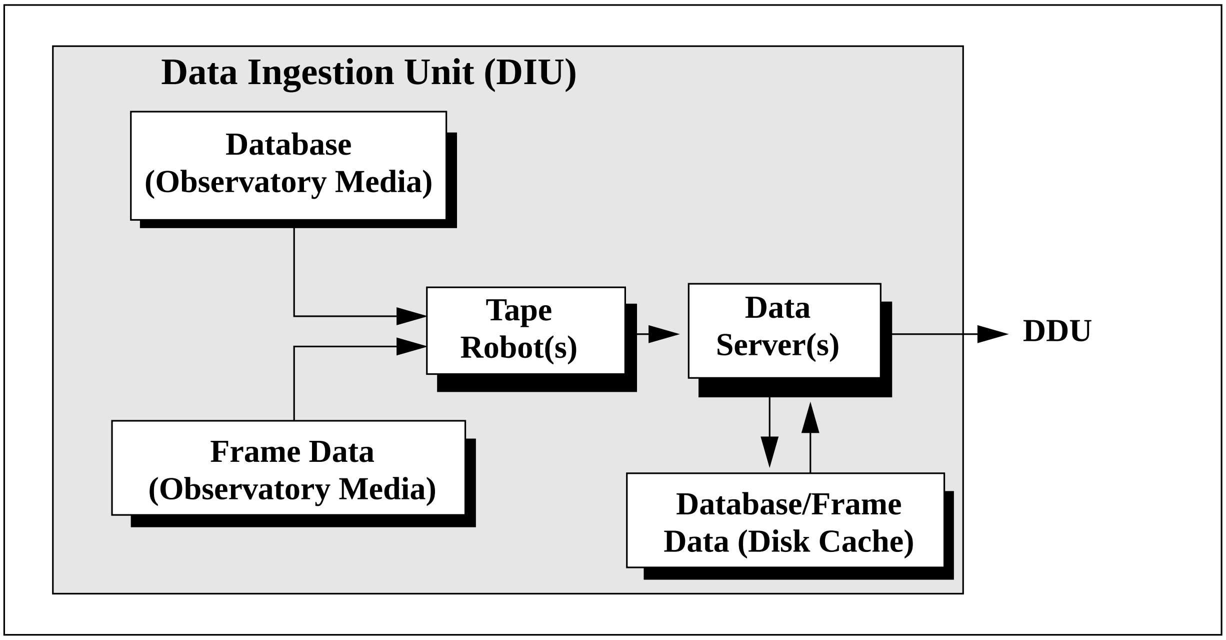

Figure 12 Data Ingestion (DIU) Block Diagram

Interfaces

DIU shall provide a front end interface to the DDU for the purposes of trasnferring frame data to the archive. This interfaces shall be in accordance with specifications in the section on interfaces.

Data Ingestion Capacity

The DIU provides for the transfer of LIGO data to the archive. As a minimum, this process shall be capable of keeping up with the rate at which are produced by the observatories. This implies the ability to ingest volume of data generated by all LIGO interferometers in a given epoch.

Diagnostics

The DIU shall provide diagnostics of data server systems, including:

- State information, including:
  > Fault, including description of fault condition
  > Ready: DIU configured and ready to serve data
  > Serving: DIU is serving data normally
- Present Configuration
- CPU Usage
- Data rates and user numbers, locations, IDs

Operation

Normal

In normal operation, the DIU shall ingest and trasnfer data in accordance with its configuration and provide the defined self-diagnostic information and statistics.

Reconfiguration

Service connections to users may be opened and broken without affecting other services.

Power Up

On application of power to the DIU, the LDAS shall be designed in such a fashion that the DIU automatically is set up in ready mode.

User Interface

X-windows

An X-windows based interface shall be provided which, at minimum:

- Allows the user(s) to access and query the metadatabase associated with the raw frame data.
- Provides the user(s) with data summary information extracted from either frames or meta-database.

Web interface

Data access to remotely located users shall be provided via web-based technology interfaces (e.g., JAVA). These shall allow mobile or remote users to log in and scan or access various data channels or trend data. Such performance shall be bandwidth-limited subject to the internet provider access capability.

3.1.2.5 Data Archival and Distribution Unit (DDU) - Frame based data and associated databases

The data archive and distribution unit makes LIGO Frame Data available to the LIGO Laboratory and Scientific Collaboration.

The DDU shall provide the functionality of accessing data from the archive and making them avaialble for transfer to multi-processor parallel systems for pre-proceesing, signal detection processing, and post-processing.

The data server can also pipe or transfer the data directly onto the LIGO WAN at the bandwidth defined by the network. This functionality provides remote users with the option of downloading datasets to their local storage media for subsequent analysis without relying directly on off-line LDAS resources. The data server subsystem comprises sufficient controller/server capacity to retrieve frame-based data and to distribute them in suitable formats to client processes such as diagnostics, and analysis, and data transmission to other LIGO sites (if applicable).

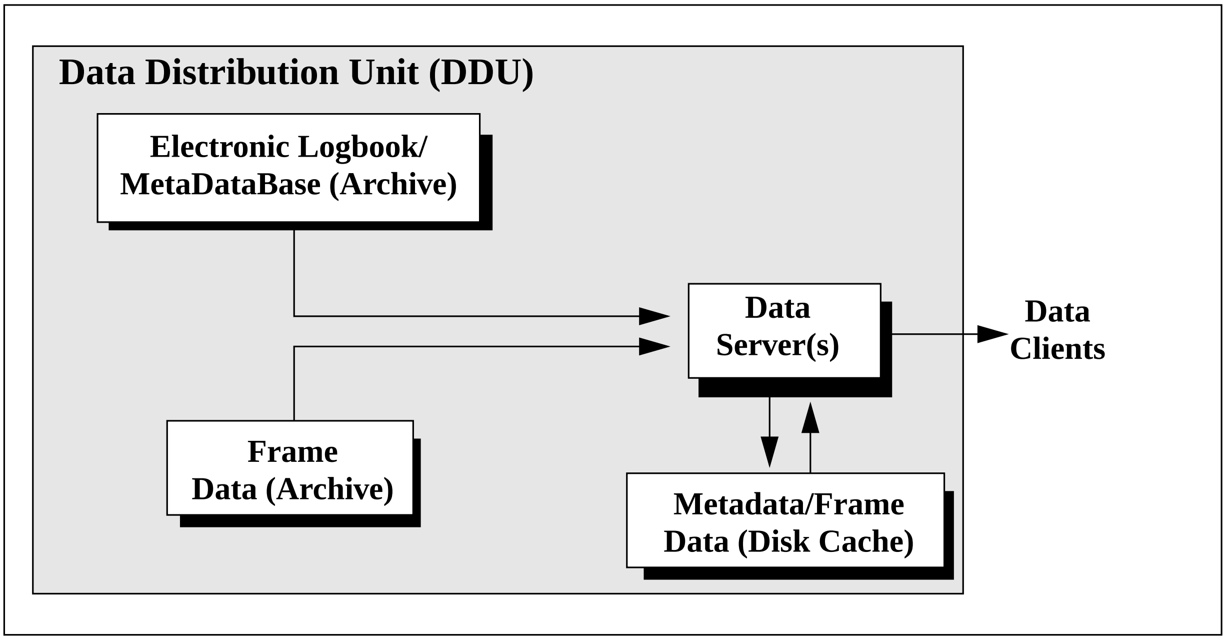

Figure 13 Data Archive (DDU) Block Diagram

Overall Data Storage and Distribution Capacity

The DDU provides long term storage of LIGO data. As a minimum, the archive shall provide for a 5-year "shelf life" of reduced data sets (see below).

The DDU shall be able to serve at least 6 clients. Disk cache volume shall be sufficient so that week-long stretches of data may be retrieved at bandwidths limited by LAN/WAN networking constraints.

Network Distribution of Data

The DDU shall be capable of serving data to multiple processors and processes at rates limited by the network communications hardware. Access to the off-line data shall be available to all sites of the LIGO Laboratory and members of the Scientific Collaboration. Access shall invoke adequate security measures to ensure only authorized access.

Data service to clients shall be primarily frame-based when "massive" amounts of data are involved: "small" data volumes will likely be accessible as audio, ASCII, or TBD "partial" data subsets in a simplified format. The DDU shall be configured to have an mean time between critical failures (MTBCF) of at least six months.

Diagnostics

The DDU shall provide diagnostics of data server systems, including:

- State information, including:
  > Fault, including description of fault condition
  > Ready: DDU configured and ready to serve data
  > Serving: DDU is serving data normally

- Present Configuration
- CPU Usage
- Data rates and user numbers, locations, IDs

Operation

Normal

In normal operation, the DDU shall distribute data in accordance with its configuration and provide the defined self-diagnostic information and statistics.

Reconfiguration

Service connections to users may be opened and broken without affecting other services.

Power Up

System power up and boot shall be performed from a dedicated workstation.

User Interface

The DDU shall provide front end interfaces to other off-line LDAS functions for the purposes of distributing data over the LIGO LAN and WAN. These interfaces shall be in accordance with specifications in the section on interfaces.

X-windows

An X-windows based interface shall be provided which, at minimum:

- Allows the user(s) to access and query the metadatabase associated with the raw frame data.
- Provides the user(s) with data summary information extracted from either frames or metadatabase.

Web interface

Data access to remotely located users shall be provided via web-based technology interfaces (e.g., JAVA). These shall allow mobile or remote users to log in and scan or access various data channels or trend data. Such performance shall be bandwidth-limited subject to the internet prvider access capability.

3.1.2.6 Signal Conditioning Unit (SCU)

The LDAS shall provide a signal conditioning processor (or group of processors), which shall perform the functions of:

- Signal calibration
- Cross-channel spectral correlation and regression
- Narrowband feature detection and extraction (if needed)
- Time-frequency distribution calculations
- Doppler corrections required for long-term integrations

The system of hardware performing these functions is termed the Signal Conditioning Unit (SCU). The SCU for the off-line system shall be provided by suitable configuration of a subset of the hardware which is available. It shall have sufficient computational capacity to process through a datastream at least as fast as the signal detection processing (downstream) algorithms can run on their parallelized hardware.

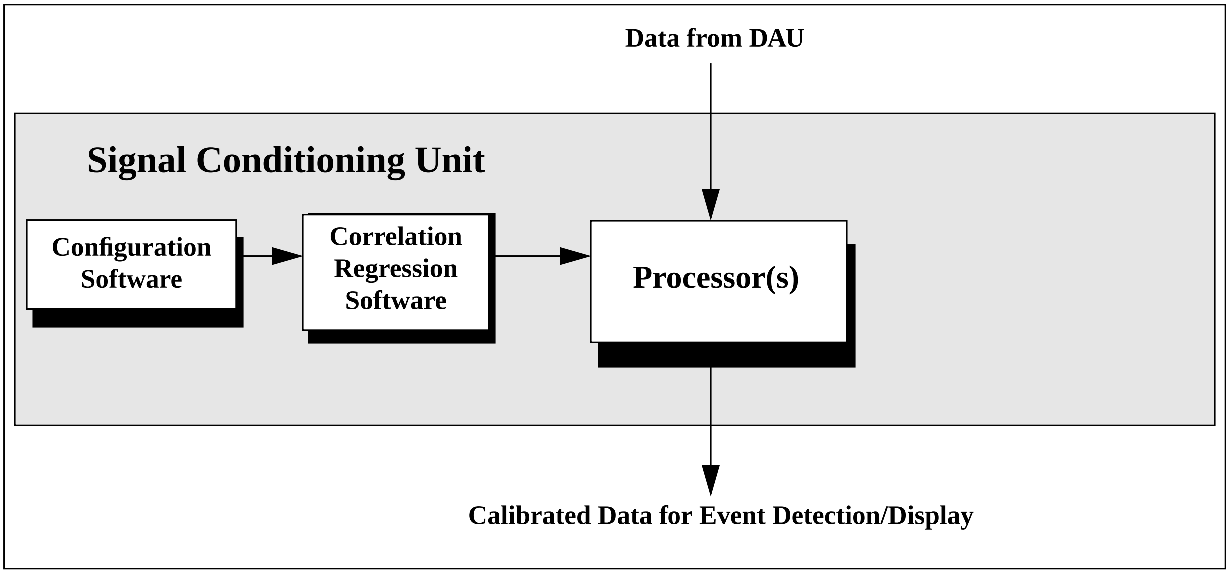

Figure 14 Signal Conditioning Block Diagram

Operation

Normal

In normal operating mode, the Signal Conditioning Unit shall accept data from the LDAS DAU and process that data according to correlation and regression algorithms defined as part of its configuration. The SCU, in turn, shall make these regressed data available event detection algorithm processors (described in following sections). The SCU shall have sufficient performance capacity such that the overall performance specifications of the LDAS and its other functional units are met.

Configuration

The SCU shall be configurable to run arbitrary calibration and regression algorithms consistent with the capacity of the hardware.

The hardware implementation shall be extensible in a modular fashion using to the greatest extend possible general purpose processing hardware.

Diagnostics

The SCU shall provide self diagnostics, including, at minimum, the same information as described for the DAU.

3.1.2.7 Data Reduction Unit (DRU)

Data reduction from the raw form to processed or reduced data involves the processing of the datastream to reduce to the greatest extent possible instrumental or environmental signatures and also generating data QA discriminants which are useful in qualifying stretches of data according to their freedom from possible artifacts.

The calibrated and regressed data stream data will be processed to reduce the volume of ancillary data to be archived. As an example those channels exhibiting nominal behavior may be replaced with statistical descriptors (“trends”) which efficiently characterize the data stream without requiring time-series representation. One example would be to replace an epoch of data (e.g., 1 sec or 16384 samples) with the much reduced list {mean, standard deviation, maximum, minimum, median, skew,...}. Detailed information regarding how to achieve an acceptable data reduction factor is still being defined. At present, the flow-down to the LDAS off-line design is the requirement to support the computational load represented by such processing algorithms with sufficient margin to permit the reduction of data to keep pace with their production at the sites, and to allow for occasional reprocessing of the data stream as algorithms and calibrations evolve.

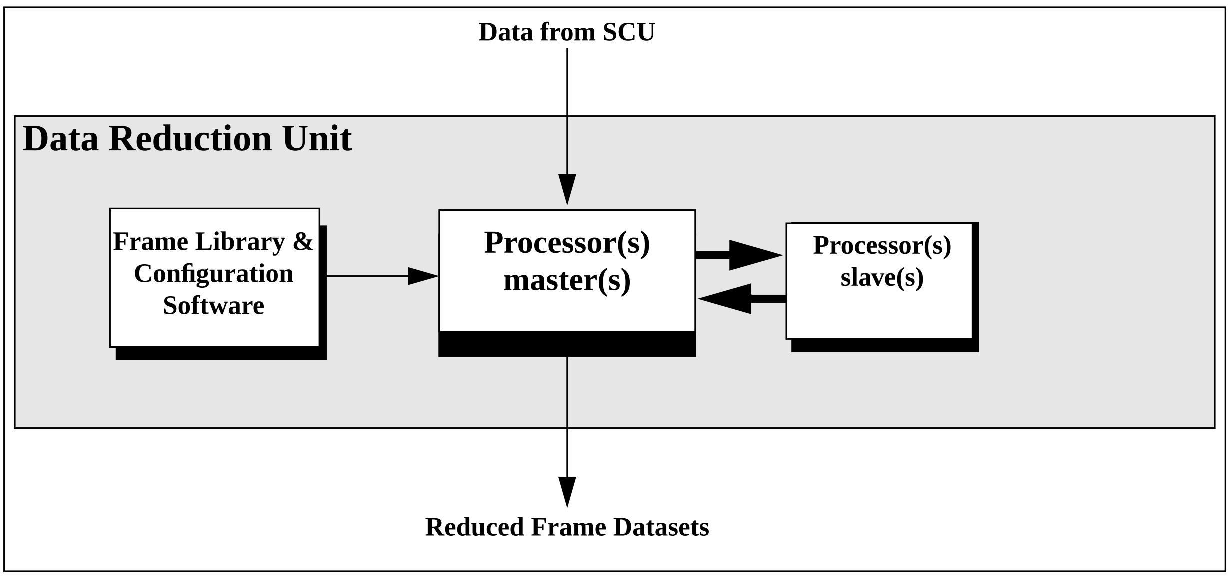

Figure 15 Data Reduction Unit Block Diagram

General Requirements

As a minimum, data reduction algorithms shall be provided to replace nominally behaving channels with trend data including statistical descriptors.

Computational Capacity

The processors running the data reduction algorithm(s) shall be of sufficient capacity to keep up with the data being delivered by both LIGO Observatories. The hardware implementation shall support multi-processor analysis and shall be extensible in a modular sense.

Output

The DRU output shall be capable of being written to mass media for long term storage. Output shall be in the form of frame data. The media shall be identical with what is used in the DAU. Optionally, additional media (e.g., CD-ROM or disks) may be utilized for producing multiple copies.

Diagnostics

DRU shall be provided with self diagnostics, including:

- Overall operational status
  > Fault, including cause information
  > Drive and media status
  > Data rates and compressions achieved

User Interface

A user interface shall be provided, which includes:

- DRU diagnostic information
- Storage capacities and usage
- Status of data reduction in progress
- Ability to configure, start/stop data runs

X-windows

An X-windows based interface shall be provided which, at minimum:

- Allows the user(s) to access and query the metadatabase associated with the raw frame data.
- Provides the user(s) with data summary information extracted from either frames or meta-database.

Web interface

Data access to remotely located users shall be provided via web-based technology interfaces (e.g., JAVA). These shall allow mobile or remote users to log in and scan or access various data channels or trend data. Such performance shall be bandwidth-limited subject to the internet prvider access capability.

3.1.2.8 Compute Server Unit (CSU)

The calibrated and regressed data stream data will be processed for the detection of GW signature events. The off-line system shall be designed to accommodate multiple users performing different types of analyses with the datasets. Signal detection algorithms will generally be tuned to the types of putative sources being searched for: transient or burst phenomena; chirped phenomena; stochastic (broadband) signals; narrowband (line) sources. The hardware shall be configurable to accommodate arbitrary algorithms and search strategies consistent with the computational capacity of the off-line system(s). This unit consists of high capacity parallel processors. In addition there will be a high speed data communications network dedicated to the processors. The algorithms presently identified as likely candidates for initial analyses rely on matched or optimal filtering techniques in the frequency spectral domain and utilize a large number of template waveform for correlation with the interferometer data stream. A suitable system also contains sufficient fast-access mass storage to accommodate the template database.

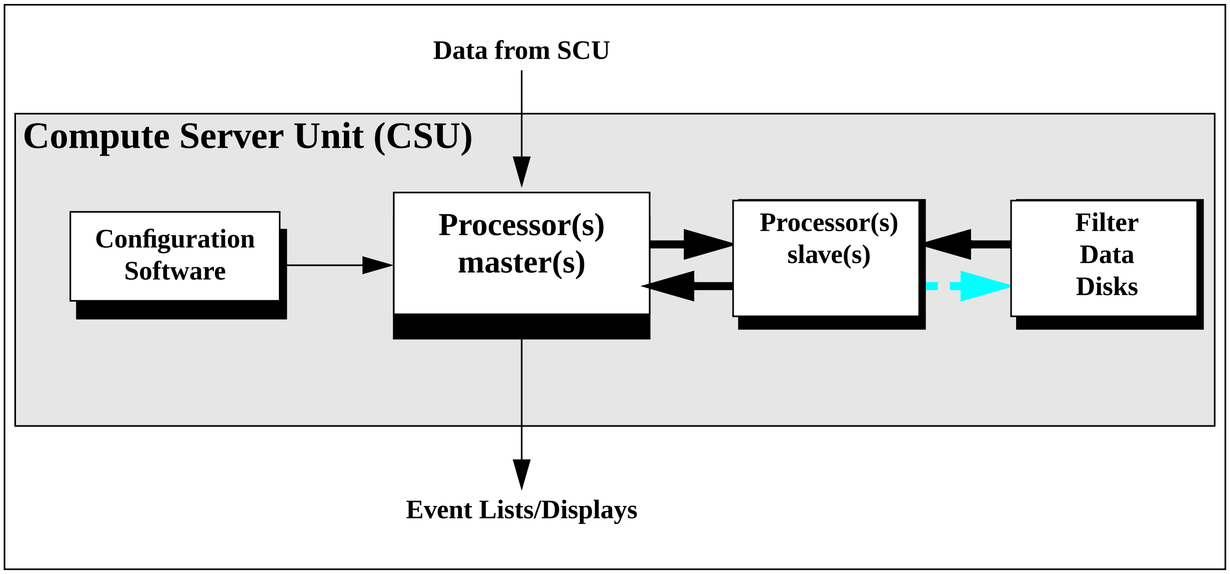

Figure 16 Compute Server Unit Block Diagram

General Requirements

As a minimum, detection algorithms shall be provided off-line for the detection of burst or transient events; for chirped signals to look for inspiral binary events in the mass regime(s) not accessible off-line; for directed periodic source searches; and for stochastic background detection.

Computational Capacity

As a minimum, LDAS shall provide one dedicated processing system, comparable to the site hardware in capacity, available for LIGO data analysis. The hardware implementation shall support parallel-processor software programming and shall be extensible in a modular sense. It is expected that sufficient additional processing capacity will be available through CACR to support up to four independent analyses at a time. The actual number of allowed analyses will be determined by the configuration and usage load of the CACR hardware.

Filter Storage Capacity

The CSU shall provide sufficient data storage capacity to accommodate a database of up to 500 GB (allowing inspiral searches down to approximately 0.4 solar masses).

Filter Recalculation

The CSU shall be able to recalculate the optimal filter bank when the instrument noise floor changes sufficiently . This task may be off-loaded to or shared with other processors in the LDAS which are available.

Filter Retrieval

The CSU shall be capable of retrieving the required filter database from mass storage at a sufficient data rate so that this part of the data flow is not a limiting factor in throughput.

Diagnostics

CSU shall be provided with self diagnostics, including:

- Overall operational status
  > Fault, including cause information
  > Drive and media status
  > Data rates

User Interfaces

A user interface shall be provided, which includes:

- CSU diagnostic information
- Storage capacities and usage
- Status of data analysis in progress
- Ability to configure, start/stop data runs

Web interface

Data analysis service to remotely located users shall be provided via web brower-based interfaces. These shall allow mobile or remote users to log in and submit data analysis tasks to the CSU.

3.1.2.9 Control & Monitoring/Data Visualization and Display Unit (DVU)

Data processed by LDAS shall be available for display at any portion of the data flow. Thus, graphical results of the signal conditioning stream or event algorithm processing unit shall be available for display.

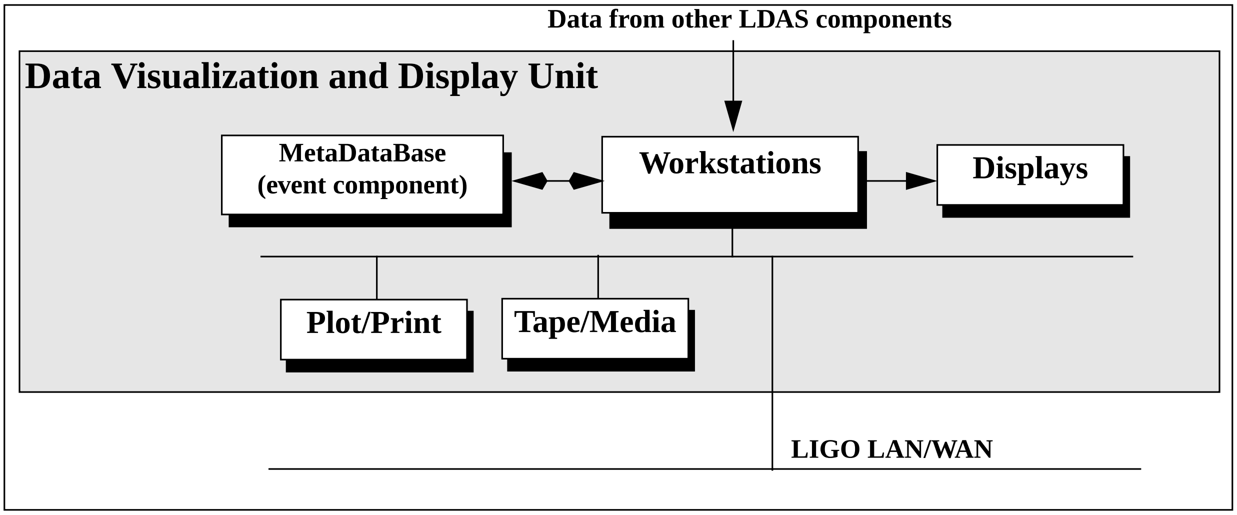

Figure 17 DVU Block Diagram

General Requirements

- The data visualization unit shall be capable of continuously displaying and updating information at the same or greater rate than the results are being generated.
- All graphical objects generated by the DVU shall be standardized for display and interpretation by commercial graphical data visualization packages, programs or environments including, but not limited to, Mathematica, MATLAB, IDL.

Operation

Normal

During normal operation, the DVU shall continuously display the results of the analysis processes being run on-line. Displays shall include time series representations, frequency domain representations, multi-dimensional representations of event filters. Event summaries include statistical or likelihood analyses, directionality (if applicable), instrument broadband noise characterizations, narrowband feature characterizations, and candidate astrophysical event characterizations.

Power Up

On power up, the DVU shall perform all necessary self diagnostics and await configuration and start commands.

Fault

On failure of a connection to datastream, the DVU shall provide a visual and audio notification to its console.

Diagnostics

DVU shall be provided with self diagnostics:

- Overall operational Status
  > Fault, including information on the cause of the fault
  > Config: DVU available for operation but has not been configured
  > Ready: DVU available and configured for operation
  > Display: DVU is on-line and receiving/displaying data
  > Store: DVU is writing data to media for storage and retrieval
  > Transmit: DVU is transmitting data to a remote LIGO site

User Interfaces

A user interface shall be provided, which includes:

- DVU diagnostic information
- Storage capacities and usage
- Status of data reduction in progress
- Ability to configure, start/stop data runs

X-windows

An X-windows based interface shall be provided which, at minimum:

- Allows the user(s) to access and query the metadatabase associated with the raw frame data.
- Provides the user(s) with data summary information extracted from either frames or metadatabase.

Web interface

Data access to remotely located users shall be provided via web-based technology interfaces (e.g., JAVA). These shall allow mobile or remote users to log in and scan or access various data channels or trend data. Such performance shall be bandwidth-limited subject to the internet prvider access capability.

DVU Control

X-windows/JAVA based user interfaces shall be provided which allows users of the LDAS to control the following DVU parameters:

- Start/Stop DVU displays and updates
- Switch DVU sources (if outputs from multiple algorithms are available)

DVU *Status Information*

X-windows/JAVA based user interface shall be provided, which depicts the following minimum information on the DVU:

- Configuration
- Status
- Run Number/Description
- Start time (time present run started)
- Elapsed time (time since present run was started)

In addition, for each media drive associated with an DVU, the following information shall be displayed:

- Status
  > Fault, along with fault information
  > Ready: DVU is ready to accept and display data
- Capacity
- Start Time (Time when writing started to the present media loaded in the drive)
- Elapsed Time (Since present media on drive was started)
- Data Rate
- Data or piped stream source(s)

Web interface

Data access to remotely located users shall be provided via web browser-based interfaces. These shall allow mobile or remote users to log in and receive data analysis results from analysis tasks they submit at an earlier time. Of course, such performance shall be bandwidth-limited subject to the internet provider access capability.

3.1.3. LIGO (non-frame) MetaDataBase (LMDB)

There will be an associated LIGO meta-database which maintains collateral information necessary to perform scientific and engineering analysis of LIGO data. This information is in various forms which are not readily conformable to frame-based storage. Moreover, it is expected that certain of these data will need to be accessed quickly and randomly (as opposed to sequentially, off a tape, e.g.). This database shall be termed the LIGO MetaDataBase (LMDB). The LMDB will likely be distributed among observatories and universities. Observatories will have the latest component, which will be transferred to the off-line LDAS site after a TBD period. During the TBD period, it will be possible to amend/emend/append to the metadatabase as information relevant to the epoch of data in question becomes available. When it is transferred to the off-line site, it will become permanent and the ability to retroactively edit the database (to append annotations., e.g.) shall need to be controlled. All additions to the metadatabase shall be time-stamped with the time of entry so that the history of the log can be deduced. Deletions will not be physically deleted, but the deleted status of the intended information shall be recorded and made available to all users querying the LMDB.

The LMDB and its distributed components shall not be duplicated. Rather, links shall be implemented to the different distributed components.

The user interface (query forms) shall be uniform and universal.

The meta-database may be a hydridized relational or object oriented database. The exact design is presently TBD. However, as a minimum, the types of information it shall contain will include:

- CDS-generated information:
  - configurational databases (the "settable parameters")
  - health/status information
  - trend summaries
  - etc.

- Detector diagnostics information:
  - test results
  - parameters/fits
  - in general, "the measurable parameters" defining the interferometer characteristics --
  - optical quantities;
  - transfer functions;
  - etc.

- Data analysis information:
  - non-LIGO data/events;
  - frame data tape summary data (index into the archived data)
  - LIGO events summaries (TBD)

3.1.4. Physical Characteristics

3.1.4.1 Electronic equipment housings

Standard computer hardware form factors shall be acceptable.

3.1.4.2 Weight Limits

LDAS equipment to be housed within the OSB shall not exceed weight limits imposed by the building raised floor loading capacities. LDAS equipment for the off-line system shall be consistent

3.1.5. Interface Definitions

3.1.5.1 Interfaces to other LIGO detector subsystems

Mechanical Interfaces

LDAS shall be provided with a component capable of ingesting the media cartridges delivered by CDS.

LDAS hardware at the observatories will co-exist in the same spaces as certain CDS components.

Electrical Interfaces

Network Connections

The LDAS (both on- and off-line) shall be capable of and compatible with network connections providing access to the LIGO Laboratory of the data and analysis results.

Electrical Power

Electrical power for LDAS equipment shall be provided at plug strips within the racks. Both surge protected only and UPS supplied power will be available.

3.1.5.2 Interfaces external to LIGO detector subsystems

Mechanical Interfaces

None

Electrical Interfaces

There may be, at some future date, the need to access, or provide access to, non-LIGO projects with the goal of exchanging data. This shall be accomplished using standard WAN protocols in force for linking the LIGO Laboratory sites.

3.1.6. Reliability

The Mean Time Before Failure (MTBF) for the LDAS shall be greater than TBD.

3.1.7. Maintainability

The Mean Time To Repair (MTTR) for any LDAS component shall be less than TBD.

3.1.8. Environmental Conditions

The LDAS shall meet all performance requirements when exposed to all specified natural and induced environments.

3.1.8.1 Natural Environment

Temperature and Humidity

All LDAS equipment shall meet the following temperature and humidity requirements.

Table 2: Environmental Performance Characteristics

Operating	***Non-operating (storage); does not include storage media***	***Transport***
+20 C to +30 C, 0-30%RH	-40 C to +70 C, 0-90% RH	-40 C to +70 C, 0-90% RH

Atmospheric Pressure

The LDAS equipment design must accommodate atmospheric pressure change from a maximum of 15.2 psi ambient to a minimum of 14.2 psi ambient.

3.1.8.2 Induced Environment

Vibrations

Not applicable.

Acoustic Noise

Not applicable.

Electromagnetic Radiation

The LDAS shall not degrade due to electromagnetic emissions as specified by IEEE C95.1-1991.

The LDAS shall not produce electromagnetic emissions beyond those specified in the LIGO EMC Plan.

3.1.9. Transportability

All items shall be transportable by commercial carrier without degradation in performance. As necessary, provisions shall be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation shall be utilized to prevent damage. All containers shall be movable by forklift. All items over 100 lbs. which must be moved into place within LIGO buildings shall have appropriate lifting eyes and mechanical strength to be lifted by cranes.

3.2. Design and Construction

3.2.1. Materials and Processes

3.2.1.1 Finishes

- Ambient Environment: Surface-to-surface contact between dissimilar metals shall be controlled in accordance with the best available practices for corrosion prevention and control.
- External surfaces: External surfaces requiring protection shall be painted or otherwise protected in a manner to be approved.

3.2.2. Component Naming

All tagging and naming of LDAS equipment shall be in accordance with LIGO naming standards as described in T950111 LIGO Naming Conventions.

3.2.3. Workmanship

All details of workmanship shall be of the highest grade appropriate to the methods and level of fabrication and consistent with the requirements specified herein. There shall be no evidence of poor workmanship that would make the components unsuitable for the purpose intended. All electronic circuits, modules and wiring shall be consistent with good engineering practice and fabricated to best commercial standards.

3.2.4. Interchangeability

The LDAS shall be designed to maximize interchangeability and replaceability of mating components. Using the Line Replaceable Unit (LRU) concept, the designs shall be such that mating assemblies may be exchanged without selection for fit or performance and without modification to the section, the unit being replaced or adjacent equipment. Mature, performance proven, standard, commercially available equipment shall not be modified unless it impacts safety.

3.2.5. Safety

This item shall meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements. A hazard/risk analysis shall be conducted in accordance with guidelines set forth in the LIGO Project System Safety Management Plan LIGO-M950046-F, section 3.3.2.

3.2.6. Human Engineering

The LDAS shall be designed and laid out in a manner consistent with applicable standard human engineering practices. Particular attention shall be paid to layouts of operator consoles/stations, work space and environmental conditions.

3.3. Documentation

3.3.1. Specifications

The following specifications shall be provided as part of the design process:

- LDAS Software Design Specification for all software to be developed as part of the system.
- LDAS - DAQS Interface Control Document (ICD)

3.3.2. Design Documents

The following design documents shall be provided:

- System overall design
- System software design

3.3.3. Engineering Drawings and Associated Lists

Engineering drawings, schematics, wire lists and cable routing lists shall be produced for the LDAS. To the greatest extent possible and practical, electronic copies shall be maintained and available on-line. All drawings shall be formatted according to LIGO standards.

3.3.4. Technical Manuals and Procedures

3.3.4.1 Procedures

Procedures shall be provided for, at minimum,

- Initial installation and setup of equipment
- Normal operation of equipment
- Normal and/or preventative maintenance
- Troubleshooting guide for any anticipated potential malfunctions LDAS

3.3.4.2 Manuals

The following manuals shall be provided:

- All manuals provided by commercial vendors for LDAS components
- Manuals for all LDAS custom designed electronics and software
- LDAS User's Manual

3.3.5. Documentation Numbering

All documents shall be numbered and identified in accordance with L950003 LIGO Document Numbering System.

3.3.6. Test Plans and Procedures

All test plans and procedures shall be developed in accordance with the LIGO Test Plan Guidelines, LIGO document TBD.

3.4. Logistics

The design shall include a list of all recommended spare parts and special test equipment required.

3.5. Precedence

In the event of conflicts between this requirement document and other LIGO documents, the order of precedence shall be in accordance with the LIGO Requirement Specification Tree.

3.6. Qualification

The LDAS design shall be qualified through a series of reviews as prescribed in the LIGO Detector Implementation Plan.

Qualification of various LDAS components and subsystems shall be in accordance with Section 4 of this document.

4 QUALITY ASSURANCE (QA) PROVISIONS

4.1. General

This system shall be tested in accordance with applicable LIGO QA standards.

4.1.1. Responsibility for Tests

The LIGO data group shall be responsible for performing and documenting all tests associated with the LDAS.

4.1.2. Configuration Management

Configuration control of specifications and designs shall be in accordance with the LIGO Configuration Management Plan.

4.2. Quality Conformance Inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by inspection, analysis, demonstration, similarity, test or a combination thereof. Verification method selection shall be specified by individual specifications, and documented by appropriate test and evaluation plans and procedures. Verification of compliance to the requirements of this and subsequent specifications may be accomplished by the following methods or combination of methods:

4.2.1. Inspections

Inspection shall be used to determine conformity with requirements that are neither functional nor qualitative; for example, identification marks.

4.2.2. Analysis

Analysis may be used for determination of qualitative and quantitative properties and performance of an item by study, calculation and modeling.

4.2.3. Demonstration

Demonstration may be used for determination of qualitative properties and performance of an item and is accomplished by observation. Verification of an item by this method would be accomplished by using the item for the designated design purpose and would require no special test for final proof of performance.

4.2.4. Similarity

Similarity analysis may be used in lieu of tests when a determination can be made that an item is similar or identical in design to another item that has been previously certified to equivalent or more stringent criteria. Qualification by similarity is subject to LIGO management approval.

4.2.5. Test

Test may be used for the determination of quantitative properties and performance of an item by technical means, such as, the use of external resources, such as voltmeters, recorders, and any test equipment necessary for measuring performance. Test equipment used shall be calibrated to the manufacture’s specifications and shall have a calibration sticker showing the current calibration status.

5 PREPARATION FOR DELIVERY

Packaging and marking of equipment for delivery shall be in accordance with the Packaging and Marking procedures specified herein.

5.1. Preparation

Equipment shall be appropriately prepared. For example, vacuum components shall be prepared to prevent contamination.

5.2. Packaging

Procedures for packaging shall ensure cleaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection shall be provided for shipping loads and environmental stress during transportation, hauling and storage.

5.3. Marking

Appropriate identification of the product, both on packages and shipping containers; all markings necessary for delivery and for storage, if applicable; all markings required by regulations, statutes, and common carriers; and all markings necessary for safety and safe delivery shall be provided.

6 NOTES