THE DIII–D COMPUTING ENVIRONMENT: CHARACTERISTICS AND RECENT CHANGES

by
B.B. McHARG, Jr.

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ABSTRACT

The DIII–D tokamak national fusion research facility along with its predecessor Doublet III has been operating for over 21 years. The DIII–D computing environment consists of: real-time systems controlling the tokamak, heating systems, and diagnostics, and systems acquiring experimental data from instrumentation; major data analysis server nodes performing short term and long term data access and data analysis; and systems providing mechanisms for remote collaboration and the dissemination of information over the world wide web. Computer systems for the facility have undergone incredible changes over the course of time as the computer industry has changed dramatically. Yet there are certain valuable characteristics of the DIII–D computing environment that have been developed over time and have been maintained to this day. Some of these characteristics include: continuous computer infrastructure improvements, distributed data and data access, computing platform integration, and remote collaborations. These characteristics are being carried forward as well as new characteristics resulting from recent changes which have included: a dedicated storage system and a hierarchical storage management system for raw shot data, various further infrastructure improvements including deployment of Fast Ethernet, the introduction of MDSplus, LSF and common IDL based tools, and improvements to remote collaboration capabilities. This paper will describe this computing environment, important characteristics that over the years have contributed to the success of DIII–D computing systems, and recent changes to computer systems.

1. INTRODUCTION

DIII–D is a tokamak fusion energy research facility located at the DIII–D National Fusion Research Facility operated by General Atomics (GA) for the United States Department of Energy (DOE). This facility studies high temperature plasmas approaching fusion reactor-like conditions with results applicable to next generation fusion devices. The tokamak operates in a pulsed mode producing discharges (called "shots") of 5–10 s duration every 10–15 min, with 30–40 shots per operating day.

DIII–D has been in operation since 1986, and its predecessor, Doublet III, operated from 1978–1984 from much the same facility. The GA Fusion computing environment consists of real-time systems controlling the experiment; systems acquiring experimental data from instrumentation; major data analysis server nodes performing short term and long term data access and data analysis; and systems providing mechanisms for remote collaboration and the dissemination of information over the world wide web. The computer systems which support this facility as well as post experiment data analysis have undergone dramatic changes over the course of the last 21 years as program needs, facility hardware, and the computer industry have evolved. In this process, many important characteristics have evolved which have been important in contributing to the success of the facility and are still present today. These characteristics are not necessarily unique to DIII–D but it is important to recognize some of these contributors to success which include: 1) computer infrastructure improvements, 2) distributed data and data access, 3) computing platform integration, and 4) remote collaborations.

One of the most significant driving forces for change in the DIII–D computing environment is the constantly increasing quantities of data. Figure 1 illustrates the largest shot acquired versus fiscal year since DIII–D began operation in 1986 and extrapolated to future years. Although this is the largest shot, it is nevertheless representative of the data quantity acquired. Figure 2 illustrates the total quantity of data acquired per fiscal year, also extrapolated to future years. These extrapolations indicate the need for continued upgrades and modernization of computing
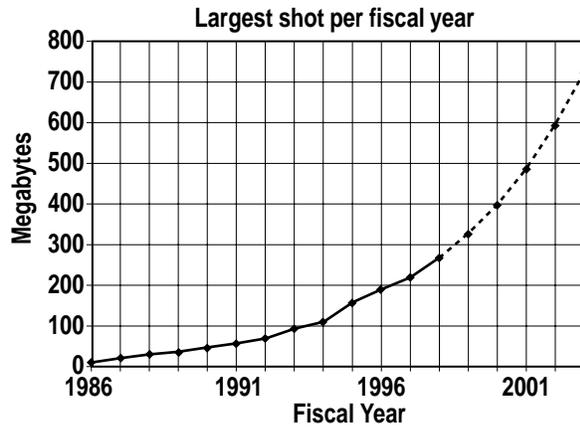
Fig. 1. Largest shot in megabytes per fiscal year.
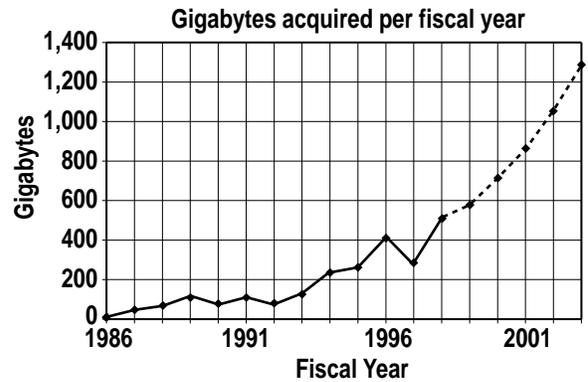
Fig. 2. Gigabytes acquired per fiscal year.

facilities. These increases in data are driven primarily by: 1) digitization of data at faster rates, 2) longer discharge pulses, 3) more diagnostics on the tokamak, and 4) more researchers examining data with more sophisticated and timely analysis.

Recent changes and additions to the computing environment which build on prior successful characteristics include: 1) a dedicated storage system and a hierarchical storage management system for raw shot data, 2) software and hardware infrastructure improvements, 3) new data analysis methods using MDSplus, LSF, and common IDL based tools introduced by the Data Analysis Applications Group, and 4) improvements to remote collaboration capabilities.

This paper is intended to point out some of the computer system features that have contributed to the success of the DIII–D program. The computing environment will be described, along with its important characteristics and recent changes.

2. THE COMPUTING ENVIRONMENT

GA Fusion facilities are split into two parts, the experimental facility, and the fusion office buildings and computer center located 1.5 miles away [1]. The DIII–D facility contains the DIII–D tokamak and a wide range of computing systems including various control systems, data acquisition systems, and some analysis systems. These are connected together by an Ethernet network. An FDDI link connects the DIII–D facility to the office buildings and computer center. The computer center is the location of the main CPU server, HYDRA, that provides compute cycles for data access, data analysis, and code development for general users; the raw shot data server, ATHENA; the server for MDSplus data, ATLAS; as well as some VMS systems and UNIX workstations utilizing LSF (Load Sharing Facility) clustering to more effectively utilize CPU cycles for data analysis. The offices and computer center utilize Ethernet with some use of FDDI networking. Fast Ethernet has just recently been introduced to both the offices and the DIII–D facility.

3. COMPUTER INFRASTRUCTURE IMPROVEMENTS

In the last 20 years, faster and more powerful computers coupled with the growth of computer networking technologies have led to the capability to acquire more data and to analyze data in ever greater detail thus improving the efficiency of running experiments. For Doublet III the "analysis" computer was a single 16 bit mini computer sharing a disk with a single "data acquisition" computer [2]. Today, there are over 15 different computer systems acquiring data that is immediately available for analysis on over 25 different computers at GA alone. Since appropriate software has enabled access to data regardless of location, data is available anywhere on the internet, and analysis can (and does) take place on remote systems.

Systems have been continually upgraded over the years to take advantage of newer computing technologies and to meet the needs of the research community. Providing general computing cycles for the analysis of data by both onsite and offsite users is an important requirement. The initial minicomputer was quite inadequate for the task. As a result, upgrades have progressed from Modcomp 16 bit minicomputers for Doublet III, to PDP-11's to a DEC-10, to multiple VMS systems, and most recently, to UNIX systems of several types.

One of the most significant areas of improvement has been networking. Initially data was shipped to a DEC-10 for analysis in "real-time" over a slow synchronous link (50 Kb/s, then 100 Kb/s, and finally 230 Kb/s rates). At the start of DIII–D, true networking within the GA Fusion division began, initially among VAX-VMS computers using DECnet at 1 Mb/s and later at 10 Mb/s Ethernet. Data was transferred from the data acquisition computer to the VAX computer over a Hyperchannel 50 Mb/s link, which provided more timely data availability. Later TCP/IP networking began to be used and FDDI at 100 Mb/s. True networking resulted in a major shift in the way data was handled after a shot.

4. DISTRIBUTED DATA AND DATA ACCESS

The PTDATA code is the single mechanism for accessing DIII–D raw shot data. Distributed data access began from the start of DIII–D with the shift to data access from remote systems. Network task-to-task communication was developed as part of PTDATA so that specific data could be accessed by many analysis codes on different computers over the network without all the data (or entire files) being moved over the network. This led to a very significant achievement in that there was complete independence of data location and user location [3].

Other data access characteristics have also been valuable. Data are available for user inspection and analysis as soon as initially written to disk. Codes do not have to wait for all data to be present for a diagnostic before some data can be accessed. Data compression was added at the start of DIII–D as a means of having more data online and decreasing network traffic. Compression has been a major benefit to allowing more online shot data [4]. When TCP/IP networking was added, it opened up the capability for versatile wide area networking. PTDATA was modified to be able to handle TCP/IP as well as DECnet. As a result, data could be accessed not only within GA but essentially from anywhere on the internet. During operations of DIII–D, PTDATA has been routinely used for many years to access data from Lawrence Livermore National Laboratory (LLNL) for analysis, and has also been used from Oak Ridge National Laboratory (ORNL) and Princeton Plasma Physics Laboratory (PPPL) as well.

5. COMPUTING PLATFORM INTEGRATION

Strong emphasis has always been placed on the ability to integrate new hardware or software into the DIII–D environment. Initial computing at Doublet III used 16 bit Modcomp minicomputers. However there were soon diagnostics acquiring data on PDP-11 systems. These systems acquired data and wrote their output to a dual port CAMAC memory mailbox, which was then read by the main data acquisition system. Thus the data could then be treated like any other data. New computer platforms have frequently been introduced both by GA personnel and outside collaborators. When the VMS systems were introduced, MicroVAXs began to replace the PDP-11s. The network, evolving in parallel, integrated these computers into the rest of the system. Data was written on the local system, then acquired over the network, and incorporated into the main DIII–D shot file. The introduction of UNIX systems at DIII–D brought new challenges since they have a very different operating system with a different networking protocol. This led to the separation of the shot file into multiple parts. It was then possible for an independent system to acquire data with whatever software it was running, and write it to local disk in the DIII–D shot file format. The data was accessible from anywhere, and other software later compressed the data and moved it to an archiving system. The capability to integrate diverse computing platforms into the DIII–D environment and into analysis systems as well remains the paradigm for today. The latest introduction is data acquired on PC systems running Windows 95/98 or NT.

6. REMOTE COLLABORATION

GA has a long history of collaborations with other fusion programs around the world. Raw data has always been publicly available for analysis. Computer systems at remote sites are now playing an increasing role in data analysis. Through the Remote Experimental Environment (REE) program, DIII–D became the focus of remote collaboration and remote control of DIII–D. Cameras and microphones were installed in the DIII–D control room and conference room to enable audio/video remote access. A DCE computing environment was established between GA and LLNL. This effort culminated in the demonstrated use of the Plasma Control System from LLNL and thus operation of the tokamak [5].

7. HIERARCHICAL STORAGE MANAGEMENT OF RAW SHOT DATA

Timely data availability has been a prime requirement of the research community. A major improvement was made two years ago with the purchase of a separate computer and storage system dedicated to serving the raw shot data with 100 GB of RAID disk storage, 2.5 times as much storage as before.

A limitation on data availability had been the restoration of archived data from tape. This restoration was only available from 7 a.m.-midnight, Monday through Friday. Also because a person was required to mount the tape, there were often delays in data restoration that could take hours and, in some cases, days.

In the last year and a half, a 600 GB optical jukebox, 2.2 TB DLT tape library, and Hierarchical Storage Management (HSM) software were procured and implemented and now provide unattended 24 hour/day 7 days/week access to raw shot data for every DIII–D shot ever taken. More storage space and unattended access have led to a substantial improvement in data availability and response time to the restoration of shot data.

Another benefit of the HSM system is the automation of data archiving. Data is copied to a different HSM volume from which it is automatically copied to DLT tape for permanent archiving. Two copies are made, one to remain on site, and one for offsite storage in the event of loss of the onsite data.

Figure 3 illustrates the position of the HSM system with respect to raw data flow in the DIII–D environment. The dotted line represents the flow of data to disk storage, and the dashed line represents the flow of data from disk to the user. Data flows initially to a diagnostic's disk. After data compression, it is moved to the shot server system, ATHENA, where it becomes part of the HSM system. If not accessed, data will eventually migrate to optical media, and later to tape media. Data archiving also takes place within the HSM system. Data flows to the user via PTDATA calls from either the shot server or one of many local diagnostic disks. Also listed are the operating systems supported for data acquisition and data access.

DATA FLOW

· · · **Data flow to disk**
– – **Data flow to user**

Data generated by diagnostic

VAX-VMS
Alpha-VMS   **DAQ computer node · · ·disk**
SunOS
Solaris
HP-UX
REALIX
COMPAQ UNIX

DIII–D
Office buildings/
computer center

Tape · · · · optical · · · ATHENA · · · · · · disk
library   jukebox

HP-UX
LINUX
IRIX
REALIX
COMPAQ UNIX
VAX-VMS
Alpha-VMS
SunOS
Solaris

User computer node

Data used
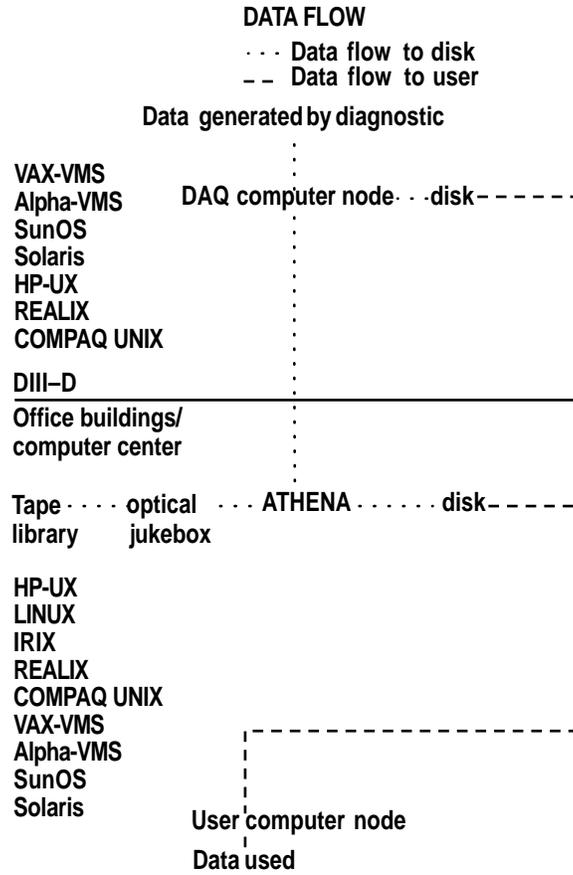
Fig. 3. Data flow to disk and to user.

8. RECENT INFRASTRUCTURE IMPROVEMENTS

The successful characteristic of computing infrastructure improvements to the GA Fusion program is being carried forward to the future by new changes recently made including: 1) deployment of Fast Ethernet both in the DIII–D facility and office buildings, 2) increasing network central file storage from 30 GB to 100 GB, 3) replacing older VMS systems with a VMS Alpha workstation for legacy applications, 4) upgrading the CPU server from a T-500 to a T-600, 5) providing additional analysis capabilities with a number of Compaq Alpha Unix workstations, 6) replacing the main data acquisition computer with a Compaq Alpha UNIX system, and 7) implementing a raw data caching mechanism for more efficiency by providing local access and reducing network traffic [6].

9. MDSplus, LSF AND COMMON TOOLS

Recently a Data Analysis Applications Group (DAAG) was formed within the GA Fusion organization with the purpose of improving data analysis capabilities for the research staff. This group has implemented innovative ideas for analysis improvement. Three significant thrusts include: 1) using MDSplus for purposes of organizing and using processed data [7,8], 2) the use of an LSF cluster (Load Sharing Facility) to more efficiently utilize workstation CPU cycles [9], and 3) the development of software tools based on IDL for data analysis and examination that can be commonly used by facilities to access and examine data from local or other facilities [10].

10. IMPROVEMENTS TO REMOTE COLLABORATION CAPABILITIES

There are currently plans to make significant improvements to enhance remote participation, both in the experimental facility itself as well as remote conferencing capabilities before next year's operations. These plans include the use of viewgraph equipment capable of putting images on the web, improved audio/video equipment for teleconferencing, improvements to the broadcasting of DIII–D operations, and improvements in the ability to communicate with personnel in the DIII–D control room during DIII–D operations [11].

11. FUTURE DIRECTIONS

Much has been learned over the last 20 years in the successful operation of computer systems in a fusion research facility. Much more will need to be done in the future to keep up with the continually increasing amounts of data, increased number of users, and new ways of examining and analyzing data. Fast Ethernet will continue to be deployed. Gigabit Ethernet and other technologies will be investigated and deployed where feasible. There is a trend toward more workstation usage on the desktop, but the use of CPU farms (an array of inexpensive CPUs) is also being considered. The popular Linux operating system is being investigated. Magnetic disk space expansion will continue to be needed both for user files as well as data files. The HSM system will need to be expanded through denser optical and tape media. Improvements to control and data acquisition systems will be needed as more capabilities continue to be added to those systems and more data is acquired. A major upgrade is also planned for the Plasma Control System. The DAAG will continue to look at new ways of visualizing data and improving data analysis. These continuing improvements will lead the DIII–D program into the future as a major international research facility for plasma physics and fusion energy science research.

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