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Abstract—**Since the beginning of the National Spherical Torus Experiment's (NSTX) research activities in 1999, open-source and collaborative software have been used extensively for experimental operations. The software included Experimental Physics and Industrial Control System (EPICS) and the Model Data System plus (MDSplus). This paper will begin with a retrospective of ten years of integrated computing, control, and data analysis on NSTX. A variety of practical issues will be reviewed such as: system reliability, availability, and maintainability; using open source software with commercial-off-the-shelf (COTS) hardware; obsolescence and remaining current. Recent improvements, current status, and emerging issues will be presented. Numerous proposals for NSTX upgrades have been made that will extend the performance and operating lifetime of NSTX. In light of this, a collective strategy for improving NSTX's collaborative software model for a new decade of operations will be examined.**

Keywords - control systems, data acquisition, software.

I. Introduction

During the design of NSTX in the late-1990's decisions about the Central Instrumentation and Control system (CI&C) [1] needed to be made with strong consideration given to the project's construction cost and schedule. Elements of the CI&C included integrated process control, plasma control, networking, data acquisition and analysis, and synchronization. The NSTX cost and schedule included many 'site credits' which included components of the recently-shutdown Tokamak Fusion Test Reactor [2] experiment. For all practical purposes this eliminated the so-called 'green field' approach, one in which the CI&C could be built upon a completely new foundation of hardware and software technologies. The requirement to integrate legacy instrumentation such as Computer Automated Measurement And Control (CAMAC), various brands of programmable logic controllers (PLC), and a decentralized (personnel) organization for providing controls for NSTX's engineering subsystems (e.g. water, vacuum and gas handling, neutral beams) called for a solution that could be rapidly customized to quickly support the first plasma milestone, yet modular to accommodate upgrades and new requirements and technologies. The CI&C design that emerged and supported initial operations [3,4,5] was a composite of legacy equipment, energy-research de facto standards, and COTS products. Many of the application software elements were based upon open source and collaborations.

NSTX has now been operating for almost 10 years. Much of the original CI&C equipment and software is still being used. Due to the modular design there have been numerous upgrades to the original system. Most upgrades have been implemented to eliminate critical dependencies on obsolete technologies; a few upgrades have been made to improve performance and capability, such as the addition of real-time Plasma Control Software (PCS) [6]. The trend for software upgrades has clearly been to include open source, therefore the cost for the software, licenses, and maintenance contracts are zero. The trend for hardware upgrades has been to use products that include a communications layer which can be interfaced with the open source software.

This paper will describe CI&C's practical experience with the open source software model.

II. An Informal Disclaimer

Software agreements, costs, copyright, patent, and other legal aspects of software are specific to each package. The usage agreement sometimes limits the manner in which the software is used, modified, and distributed. In addition the policies of the institutions that distribute or receive such software may also bear limitations. In general, open source has no restrictions; collaborative software may incur a modest cost or 'in kind' cost sharing. Due to the practical nature of this paper, such details will not be elaborated upon further and the limitations have not been an issue for NSTX.

III. NSTX's Open Source Software Packages

Some of the open source software that contributes to CI&C is shown below:

- Linux – an Enterprise distribution. Includes modules developed by thousands of individuals.
- EPICS [7] – Integrated Control and SCADA. NSTX uses interfaces to CAMAC, MODBUS, AB-DCOM, LabVIEW, IDL,C, numerous clients.
- MDSplus [8] – Data Acquisition, Storage, visualization. NSTX uses interfaces to CAMAC, D-Tacq, LabVIEW, IDL.
- PCS [9] – Integrated real-time plasma control. Commercial and collaborative software from General Atomics Corp. NSTX uses interfaces to FPDP, MDSplus, IDL.
- SharedAppVnc [10] – Control Room display wall. Software developed at Princeton University that allows users to share individual windows from their workstations on a large screen. Runs on Mac, Windows, and Linux.

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- System Imager [11] – Used to manage and deploy a common Linux distribution to EPICS OPI (Operator Interface terminals).
- PERL – a scripting-like programming language.
- Apache web server, OpenOffice, Gtk, Eclipse IDE, CVS, and numerous other common packages.

IV. Open Source Justification

NSTX included open source software from the beginning and because of its success the trend has been to replace proprietary components with open source where practical. NSTX was the first large magnetic fusion energy project to include open source to the degree that it has. Some USDOE programs in the High Energy Physics realm [12,13] had been moving in that direction for years and indeed, influenced NSTX's early design. Recent fusion devices such as the Korean Superconducting Tokamak Advanced Research (KSTAR) [14], the Experimental Advanced Superconducting Tokamak (EAST) [15], and the National Compact Stellarator Experiment (NCSX) design [16], use open source software in a manner similar to NSTX.

A recent market survey [17] by the ITER Control, Data Access and Communication system (CODAC) group summarizes the reasons open source fits projects like NSTX so well. In part:

- "ITER is seeking for longevity and for a scalable and progressing solution. In that respect, the commercial solutions may not fulfill the needs, either suffering from company strategy changes, merges and acquisitions or drastic changes in the products evolving at the IT speed."
- "There is a heavy trend in the scientific community to develop tools and to focus on open source software. We have to bear in mind that ITER I&C requirements cannot be fully listed from the beginning and that ITER scientists will want to get changes when using the solution or even develop tools themselves."
- "Indeed the most important ITER requirement, as an experimental facility, is that the other requirements will change."

COTS software still fulfills a critical need. Certain programs, such as IDL and LabVIEW, have become de facto standards in the community and over the years a significant, reusable code base has been produced. For field

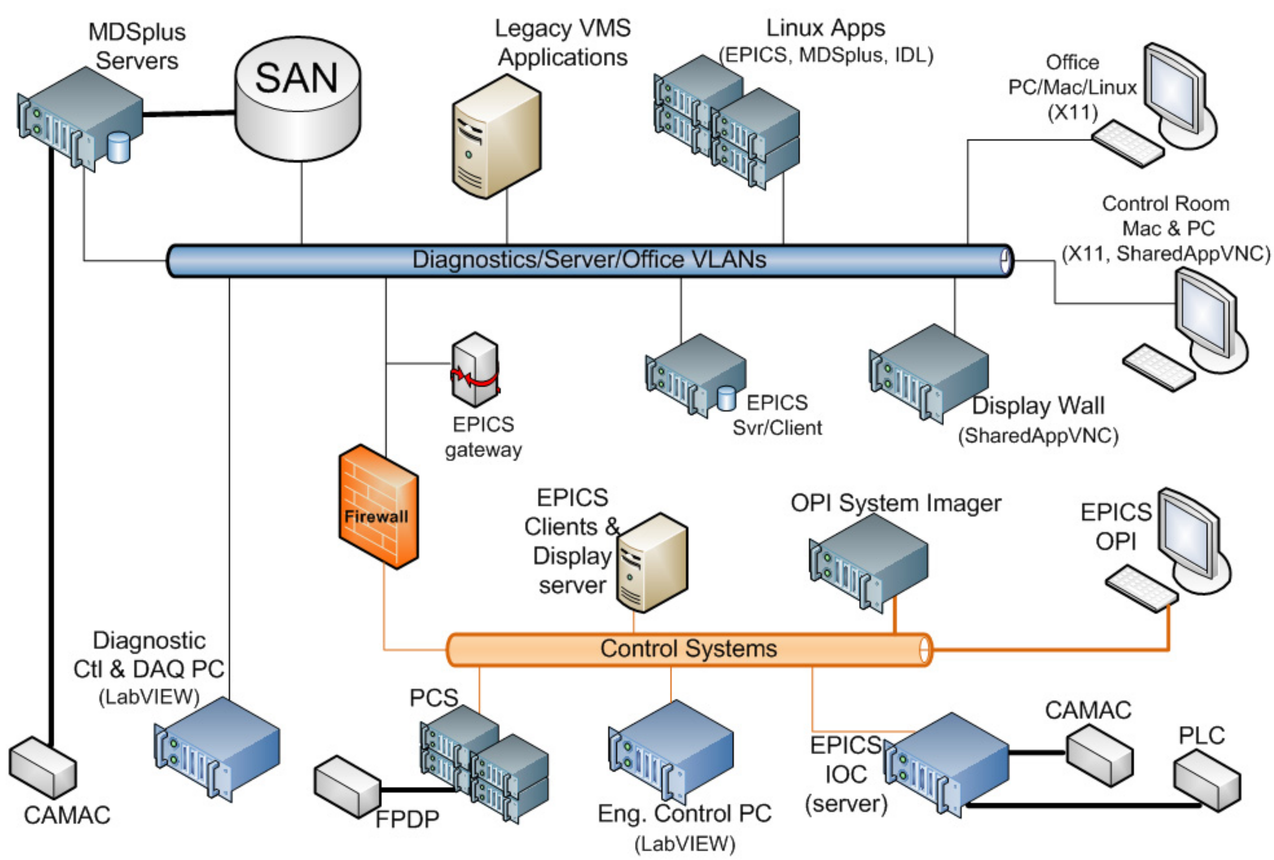

Fig. 1 Simplified depiction of NSTX Computing system The diagram indicates the principal scientific software that runs on the computer.

instrumentation, PLC's and Distributed Control Systems (DCS) use proprietary software which usually runs on the Microsoft Windows operating system. In this case, the critical feature for NSTX is that a well-established and documented communication protocol is available for the PLC/DCS, such as MODBUS [18] or OPC [19]. NSTX's open source software readily supports common protocols such as these.

V. SOFTWARE QUALITY

Project and Engineering management may be reluctant to use open source software due to concerns about software quality and support. Some of the characteristics of software quality are: engineering culture and ethics; value and cost; improvement; quality assurance; verification, validation (and certification); reviews and audits; defect characterization [20]. Regardless of whether software is commercially developed or an open source project, diligence to software quality spans a wide range. NSTX considers quality in all acquisitions. The three main software packages (EPICS, MDSplus, and PCS) had an established history of supporting experiments like NSTX. In the time since NSTX's first plasma, the core developers have remained enthusiastic, have been quick to respond to technical inquiries, and have updated their products for new technologies and industry practices.

Unlike a corporate entity, the developers and maintainers of open source packages often have no financial or career commitment to the package and therefore may leave at any time. If there are only a few members of the open source project this could lead to its end of life, in which case the users would need to maintain the software themselves or find a replacement product. In either case the requisite technical expertise may not be available in-house and the overall project could be put at risk. In the case of EPICS, the core developers are numerous, work at world-class laboratories, and are professionals with a significant career interest in the software collaboration. EPICS is in effect sponsored by all of the experiments themselves, thus ensuring a high degree of quality and support. There is an active user base, a mailing list for reporting bugs and announcements, regular collaborator meetings, and a website and wiki. MDSplus and PCS have a smaller team of core developers and a smaller user base, but have a similar support model as EPICS. Other open source packages are more typical of the open source community and have small development teams; these types of packages have either another solution available or serve a limited role at NSTX.

Over the years the software support has been excellent, however most of the NSTX open source packages share shortcomings in a couple of the aforementioned quality characteristics: documentation and training. Users often struggle at the outset when using the larger open source projects. The quality and uniformity of documentation varies since it has been produced over a range of years and contributed by different people and organizations, with diverse engineering cultures. Sometimes formal training is offered but it is not regularly scheduled and not professionally managed. User forums and websites offer an array of training aids. The practical learning curve is a function of an individual's capability and degree of motivation and more importantly, mentoring by either an in-house expert or a liaison with experienced personnel at another institution.

VI. A DECADE OF EXPERIENCE AT NSTX

Since the project's beginning, NSTX operations have been supported with a foundation of free and low-cost software. The authors have direct experience working with the open source software on NSTX. A few have experience from other experiments that used commercial and custom software. Without question, the open source solution has been a great success. Through collaboration, the open source software has kept pace with emerging commodity computing technologies.

Throughout NSTX's operating period, computing upgrades have been implemented. These were sometimes done due to a crisis situation, such as dwindling VMS (operating system) support, or a vendor stopping support for an older hardware or software product. Many discretionary incremental upgrades have been postponed due to limited engineering resources. As commercial support for older technologies wane many of these discretionary upgrades will rise in priority. Furthermore, planned upgrades to the performance and capabilities of NSTX [21] call for a renewed effort to replace obsolete CAMAC technology and improve data acquisition mechanisms. The integration of various replacement technologies have already been demonstrated at other laboratories, so the endeavor is fairly well defined.

The continuing rise of cyber attacks targeting corporate and government institutions adds another aspect of open source software – cyber security mechanisms [22]. From the system point of view, the open source must not contain elements that make it susceptible to cyber attack. For example, at PPPL, computer usage policies prohibit the use of most Linux distributions since the availability of timely and vetted security patches cannot be depended upon. Though unlikely, an open source module could have 'hidden' features that compromise security. This can be difficult to detect. Note, these cyber issues also apply to proprietary, closed software. It could be argued that the latter is a more perilous situation since the source code cannot be independently scrutinized for security threats.

There are some open source challenges that remain unmet. These include training and documentation for the newcomer, as mentioned in the Software Quality section. In addition, the larger open source projects can contain hundreds of thousands of lines of code so a comprehensive understanding by local engineering is impractical. Given NSTX's limited engineering resources, it turns out that there is usually one local 'guru' for each open source package; this is also the case for COTS software in some circumstances. This places the project at risk since one person retiring or otherwise leaving the project creates a critical technical support issue; one that could have a significant learning curve.

VII. Conclusion

The outlook for integrating more open source into the NSTX CI&C is promising. As software collaborations grow, additional features are added and improvements are made that keep pace with the rapid advancement of information technology. NSTX will benefit as incremental upgrades are introduced to improve the reliability, availability, and maintainability of the NSTX CI&C.

As stated earlier, the open source collaborations have made technical advances that are applicable to NSTX's mission. Some of the areas that NSTX CI&C plans to look into are: broader 64-bit application support, EPICS toolsets such as OPC, Control System Studio (CSS), Java technologies, python scripting, and a wiki. NSTX's aging CAMAC equipment and computer interfaces are in need of replacement; the open source and fusion communities have demonstrated numerous paths for this [23].

ITER has expressed interest in some of the same open source packages that are used at NSTX, notably EPICS (at this point in time). Together with our global partners, NSTX has the operations-relevant experience to make contributions to the ITER CODAC design and prototype activities.

Acknowledgment

The success of NSTX's open source software, especially in the early days, would not have been possible without the generous support from the Advanced Photon Source project at Argonne National Laboratory, the Alcator C-Mod folks at MIT, and our esteemed PPPL colleague Phyllis Roney for her many years of dedication to the fusion program.

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