

NCSA Internship Program for Cyberinfrastructure Professionals

DANIEL LAPINE, National Center for Supercomputing Applications, University of Illinois

VOLODYMYR KINDRATENKO, National Center for Supercomputing Applications, University of Illinois

LUISA-MARIA ROSU, Illinois STEM Education Initiative, University of Illinois

In 2017, National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC) established a pilot internship program for cyberinfrastructure (CI) professionals. The program, funded by NSF's Office of Advanced Cyberinfrastructure (OAC) (award 1730519), was designed to address the shortage of a workforce with the specialized skills needed to support advanced CI operations. The program was envisioned to provide internship opportunities for individuals who want to gain first-hand experience in the CI operations at a supercomputing center, and develop and refine instructional materials to serve as a template that is openly distributed for use by other centers and institutions to train CI professionals. Program interns are selected from a pool of applicants with the main selection criteria of having a completed classwork equivalent to an associate degree and a demonstrated interest in a career in CI operations. Interns work directly with a group of NCSA engineers in one of the areas of CI focus to gain hands-on experience in the deployment and operation of high-performance computing (HPC) infrastructure at a leading HPC center. The expectation is that interns will enter a workforce that will develop, deploy, manage and support advanced CI at other universities, centers, and industry to meet the needs of the national computational science research community across academia and industry.

CCS Concepts: • **Social and professional topics** → **Adult education; Computer engineering education; Computing occupations.**

Additional Key Words and Phrases: cyberinfrastructure, HPC, training, internship

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1 INTRODUCTION

In today's world, innovation and economic prosperity are impossible without the use of advanced computing and big data. Scientific and engineering communities heavily rely on the advanced cyberinfrastructure (CI) resources for conducting cutting-edge research and developing new products and services that improve quality of life of citizens. As these comprehensive and highly interoperable CI resources are becoming ubiquitous, their deployment and operation requires a workforce with highly specialized knowledge and skills. For these kinds of jobs, the relevant job titles are Systems Engineer and System Administrator. Systems engineers are concerned with the design and management of computer systems and CI subsystems (Security, Storage, Networking, Web services, etc.) over their lifespan. System administrators are responsible for the configuration, operation, and user support on computer systems within a specified

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CI. These jobs are required to support complex, multi-user computer systems, such as servers, clusters, and clouds. CI professional implies a person tasked with either the design, implementation, administration, or support of those using CI resources, typically requiring some overlapping skills of system engineers, administrators, and experienced users.

Our internship program specifically concerns the training for the system engineers and administrators who operate significant CI resources, such as high-performance computing (HPC) facilities, at academic, research, and industrial centers. The skillset needed to efficiently deploy and operate modern CI cannot be acquired via a college coursework alone. Most universities and colleges do not offer practical hands-on training that is essential for this type of work. Our internship program creates a place where individuals interested in becoming HPC system engineers and administrators can gain real work experience in system deployment and operation based on the existing NSF-funded CI.

The goals for this internship program include:

- **Expanding the talent pool** by attracting and supporting professional development of minority and underrepresented groups in the field of CI.
- **Providing** motivated individuals the **opportunity** to obtain real-world CI operational experience through a short, full-time program in an area supported by NSF for its programmatic needs.
- **Developing training materials and identifying best practices** that will be contributed back to the community to be used stand-alone or in combination with other internship programs to train next-generation CI professionals.

The key challenges the internship program addresses include:

- **Skill development.** Individuals entering the workforce too often lack the knowledge and experience related to operation of large-scale CI. They may know about Linux administration, or network security, or other relevant topics, but they typically do not possess the deep knowledge of the variety of technologies that contribute to the ability to operate an advanced CI.
- **Lack of appropriate education and training programs.** Individuals interested in becoming system engineers or administrators have little choices when it comes to finding appropriate education and training. Courses offered at colleges and universities typically prepare students to become developers of the new technology, not the operators of the existing systems.
- **Career pathway.** Individuals interested in becoming system engineers or administrators often do not qualify even for entry-level jobs in this field and they do not have a clear way to enter the profession. Many end-up engaging in self-study or receiving on-the-job training. The proposed program establishes a clear career pathway to enter the CI professionals workforce.

There are numerous programs tailored towards CI contributors and users, but very little is done for the CI professionals. For example, HPC training programs at the National Institute for Computational Sciences (NICS) [7] offer short courses on various tools and techniques for CI users. CI-Tutor hosted at NCSA [2] offers on-line courses on code analysis and optimization, development for parallel systems, but there are no courses on CI deployment and operation. HPC University [3] lists many courses in Linux use and shell development, but not to the level of system administration. We are not aware of any internship programs at National Labs for CI professionals. For example, Argonne National Lab offers numerous internship programs for students [5], however none of them is about deploying and managing CI. The closest activity is Linux Cluster Institute (LCI) [1], which provides intensive five-day Linux system administration workshops. The LCI was co-founded by NCSA; it organizes an annual workshop that offers training and hands-on experience in high-performance clustered computing. Our internship program augments some elements of LCI training approach and goes well beyond and above the LCI workshops in scope and depth.

The internship program is currently in its third year. So far, we have completed six sessions, put seventeen candidates through the program and plan to offer next session in Fall 2020. The program has been evaluated by the University of Illinois I-STEM team. In this paper we outline the structure of the program as well as report results of the program evaluation.

2 TRAINING PROGRAM DESIGN

2.1 Program Setup

The internship program is structured as follows:

Interns are hosted at NCSA for the duration of 3-3.5 months. They are expected to work full-time and are paid a stipend. Typically, two internship sessions per year are offered: mid-August to mid-December and mid-January to mid-May. The program is designed to support up to five interns in each of these sessions. Interns undergo intensive training in system engineering, maintenance, and administration during the first week and rotate between each of the operational groups at NCSA during the second week of the internship in order to gain an understanding of each group's technologies, role, and responsibilities.

After the training, each intern is placed in a specific operational group for the rest of the internship where he/she focuses on the specific technologies the group is supporting. Each intern has a mentor in the group in which he/she is placed with whom he/she works for the duration of the internship on group-specific projects.

During the last month, interns are also offered an option to work on an independent project in the Innovative Systems Lab (ISL) to build a small-scale system or develop and deploy novel services on an existing cloud or HPC infrastructure.

2.2 Program Environment

Most of the NCSA operational groups can host the interns. No group is asked to host more than one intern at any given time. Groups have the option to be "available" or "unavailable" for upcoming terms, based on their current staffing and workload. The intern training is limited to those tasks and scopes already within group's current duties. The team leads and/or designated mentors are accomplished system engineers with many years of experience and are highly qualified to mentor the interns.

Interns are assigned office space in the NCSA building and are provided with desktop computers sufficient for the internship program. Most of the work requires remotely accessing HPC systems, with infrequent access to the actual hardware. Interns have access to the NCSA machine room that hosts ISL systems. Access to other facilities is provided as needed. ISL is a lab-like environment built to enable evaluation and experimentation with upcoming computer architectures, storage, and interconnect technologies.

We have identified nine operational groups at NCSA that focus on providing support for specific set of technologies, e.g., storage or networking, that can host interns. Below we describe these groups' purpose and training objectives.

HPC Systems. This group is tasked with architecting, deploying and operating NCSA's large scale and HPC systems in the support of open science. The system engineers coordinate with the various projects and other infrastructure groups to achieve specific usage and availability goals for each system and its community of users.

Training objectives for interns include: 1) Basics of Linux administration: OS installation, package management, OS configuration, user control; 2) Basics of job flow: resource managers, schedulers, queuing and reservations; 3) Basics of cluster administration: hardware, node deployment, workflow monitoring, troubleshooting, file system administration, user/group admin; 4) Software deployment, user environment management, other systems tasks as needed. Minimal

required experience for intern candidates include good written and verbal communication skills, basic Linux OS use, and ability to work with others.

Storage Enabled Technologies. The group architectures, implements, and manages the hardware and software systems for providing reliable storage across NCSA and for UIUC campus. The storage engineers are deeply involved in the configuration of the compute environments from the hardware, the systems overall usage model, software and the users of the system. The group is part of the overall system management team to provide the best experience for the users of the specific systems and achieve the goals of the resource set forth by the funding agencies of the system.

Training objectives for interns in this group include: 1) Basics of Linux administration: OS installation, package management, OS configuration, Puppet or Bright Cluster or other configuration management; 2) Basics of storage administration: basic RAID levels, hardware vs software RAID, monitoring and escalation configurations, file system configuration (GPFS, Lustre, ZFS, etc.), quotas and user management, script/tool development; 3) Physical infrastructure: hardware deployment and cable management, tape storage subsystem. An ideal candidate for this group would already have some Linux administration skills.

Advanced Visualization Lab. Group's role is to create visualizations from massive numerical supercomputer datasets for inclusion in science films. Group's production software/hardware pipeline incorporates both commercial, academic rendering, and advanced computing production environments. This work involves Linux system administration, including but not limited to: installing and managing various software, managing license servers, file servers, web servers, setting up new workstations, porting environments to new systems, etc.

Training objectives for interns include: 1) Basic Linux system and storage-system administration: installation, configuration, troubleshooting, security; 2) Basics of group's visualization pipeline: data management, software, file management, rendering; 3) Systems software development: for distributing large number of Linux-process tasks across a set of compute nodes, a database and a suite of small software utilities to track and report dependencies across data-processing and image-handling pipeline. Preferred minimal experience for intern candidates is to be familiar with command-line Linux, Python, Perl or C++ language, computer security, networked systems, software development, database experience.

Innovative Technologies Services. This group builds and deploys effective production infrastructure to support science and technology projects. In the basic structure the group supports all small and mid-sized computing resources inside NCSA. The system engineers and programmers in this group work to provide new and better services as research teams need new methods to build their projects. The group builds systems from desktops to cloud-based computing resources.

Training objectives for interns include: 1) Basics of production services: monitoring and notification systems, authentication and authorization, service management within Linux environments; 2) Virtual machines: understanding production virtualization, learning about desktop and server virtualization options, operating systems within an open-source cloud; 3) Cloud computing: understanding of public and private cloud options, setting up storage for a cloud computing system, working with OpenStack to setup private cloud. Preferred qualifications for intern candidates are: coursework in programming or scripting, some understanding of Linux, interest in trying new technologies and learning to make software and services work.

Data Analytics and Visualization. The group is tasked with supporting science teams utilizing NSF HPC resources as well as furthering the state of scientific visualization through cutting-edge research.

Training objectives for interns include: 1) HPC simulation data: data parallelism, concepts of parallel data analysis and visualization; 2) Parallel I/O: parallel file systems, performance tuning, I/O libraries, data layouts; 3) HPC visualization:

software suites, data layouts, simulation vs. data analysis, integrating visualization into an HPC scientific workflow. Ideal candidates for internship in this group would already have some visualization-related coursework.

Innovative Software and Data Analysis. The group conducts research and development in general-purpose CI, addressing specifically the growing need to make use of large collections of non-universally accessible, or individually-managed data and software (i.e. executable data). The group attempts to address these needs through the development of a common suite of internally and externally created open source tools and platforms that provide means of auto- and assisted curation for data and software collections.

Training objectives for interns in this group include: 1) Introduction to Atlassian programs: Confluence (Wiki page creation), JIRA (task management), BitBucket (source code management), HipChat (team communication); 2) Coding environment setup: configuration of laptop/desktop for standard office use, configuration of laptop/desktop for programmatic development environment; 3) Introduction to basic agile project management: task planning, task management, team project communication, collaborator communication, documentation in an agile environment; 4) Testing: automated in-code tools such as Pytest, AVA or Wallabyjs, load or stress testing, validation and verification testing; 5) Virtual system deployment: CentOS VMs, Docker containers, Kubernetes containers, working with these in a cloud computing environment such as OpenStack and Amazon web services. Preferred experience for intern candidates is to have good written and verbal communication skills, software development experience, coursework in or familiarity with web development tools such as HTML, CSS, REST, database coursework or familiarity with MySQL, MongoDB or PostgreSQL.

Science and Engineering Applications Support. This team provides expertise in the areas of application porting, debugging, performance tuning, optimization and scaling to the NCSA Blue Waters partner community. The team also provides advanced application support in some science and engineering domains (Chemistry, Fluid Dynamics, Numerical Methods, Cosmology) as well as algorithm development and programming model implementation. The team also provides benchmarking and evaluation services.

Training objectives for the interns include: 1) HPC application performance analysis: basics of application performance, understanding HPC architecture; 2) Use of tools of the trade: porting tools, debugging and debuggers, performance tools; 3) Best practices: job workflows, coding, application I/O. An ideal candidate for an internship in this group should be familiar with programming, experienced with Linux OS, have good knowledge of computer architecture, and be able to work with others.

Incident Response and Security. This team is responsible for the protection of the center's digital assets and those of key partners. A 24/7 incident response team performs full digital forensics and coordinates with law enforcement and other institutions. Preventative security is provided by vulnerability management program, risk assessments and security architecting, automatic blocking, to name a few. The team runs over 60 servers to provide monitoring, logging and other security services, including one of the largest production Bro clusters in the world. The team is also responsible for training staff, notifying reliant parties of new vulnerabilities, creating policies and promoting security awareness. Finally, the team participates in several organizations and maintains collaborations with Extreme Science and Engineering Discovery Environment (XSEDE), CERN, and others in the community.

Training objectives include: 1) Vulnerability management scanning, reporting and analysis, vulnerability risk notifications; 2) Development of the host activity database and analysis system, updating system contact database; 3) Developing detection rules for emerging threats, log analysis and anomaly identification; 4) Keep up-to-date about new vulnerabilities, research and report risks to system owners. Interns with prior cybersecurity related coursework are best suited to work in this group.

Network Engineering. The team designs, builds, and supports network infrastructure to advance science by meeting the needs of NCSA's high-performance systems, its national user community, staff, and partners. The team emphasizes reliability and performance while acting as an early adopter of new technologies. The group works with systems and storage architects to design and implement their high-speed interconnects, provide network performance testing and tuning expertise, monitor networks utilization, and provide all levels of network troubleshooting assistance. It also provides core network services, such as DNS and DHCP, as well as utilization reporting, for all systems connected to the network and maintains a rich variety of high-speed WAN links that connect NCSA to national research networks, commodity Internet services, and the UIUC campus network.

Training objectives are: 1) Basic understanding of layer 1 networking: fiber and copper concepts for networking, physical and thermal network design considerations; 2) Network troubleshooting: use basic networking tools like ping, traceroute, and tcpdump, understand and track down physical connectivity problems; 3) Production services: access to network systems, security considerations with network design, authentication and authorization to networking equipment; 4) Basic network configuration: configuring IP addresses, configuring gateway addresses, understanding DHCP. Preferred experience for intern candidates includes an understanding of Ethernet network basics, basic understanding of Unix operating systems (preferably FreeBSD), ability to articulate technical requirements, and proficiency in troubleshooting problems and deducing causes of problems.

2.3 Program Elements

The Internship program includes 1) intensive training during the first week of the internship, 2) shadowing different operational groups during the second week, 3) working with the selected group for the rest of the internship, 4) working on an independent project in ISL, and 5) participating in other professional development activities at NCSA.

In the first week of the program, interns go through a training conducted by engineers from various operational groups. This training is structured to both teach some key elements of system administration and give a broader overview of the roles of each operational group in the NCSA CI ecosystem. Some presentations are very technical in nature whereas other presentations provide an overview of group's activities. The objective is to expose the interns to the overall structure of a complex CI environment, educate them about the role of different sub-disciplines, and teach basics of system administration tasks across different operational groups.

In the second week of the program, interns rotate between different operational groups. At the end of the first week, they submit a list of the groups they would like to shadow for a day. They are then scheduled to enable one intern per one group per one day shadowing letting them experience how the groups operate on a daily basis. In practice, they are attached to a particular mentor on a per group basis and follow them throughout their workday. The objective of this activity is to give the interns a better understanding of the day-to-day work activities and the type of work each operational group is engaged with.

At the end of the second week, interns are asked to rank their preferences for the groups they would like to spend the rest of their internship. Based on this ranking, leaders of the groups together with the program leader assign interns to specific groups. This approach enables to match interns' interests and abilities with the operational groups' needs and availability.

The final project in ISL starts in the last month of the internships. We typically have several projects for interns to choose from; we also allow interns to propose their own projects. Examples include building additional performance monitoring functionality for HPC systems, setting up small HPC clusters, working on application performance tuning

on exotic architectures, etc. We attempt to provide projects where all the interns can provide input based on their group affiliation.

We encourage the interns to participate in NCSA-wide seminars and meetings as well as organize a meeting with NCSA Director and give a tour of Blue Waters facilities. We meet with the interns regularly to advise and mentor.

In Spring 2020, due to COVID-19 pandemics, the interns continued to work but shifted to remote work in March with project coordination moving solely to online chat, email and remote meetings using Zoom and Skype for business, per each group's standard.

3 RESULTS

3.1 Program Participants

Table 1 lists data about the interns who have participated in the program. Column “Number of minority, female interns” lists the number of interns from minority and underrepresented groups in the field of CI in response to goal 1. The “Outcome” column lists the number of interns who, after completing the internship, went to work in the fields related to CI, thus fulfilling second program's objective.

Table 1. Aggregate Data about Program Interns

Term	Number of interns	Number of minority, female interns	Outcome
Fall 2017	4	1	2
Spring 2018	2	0	2
Fall 2018	2	1	0
Summer 2019	3	1	3
Fall 2019	3	1	2
Spring 2020	3	1	1

3.2 Program Evaluation

Program evaluation has been conducted by I-STEM team [6] and has utilized a value-engaged, educative approach [4]. The evaluation employs multiple methods in response to each of the four evaluation questions listed below. Data has been collected via pre- and post-program survey of the program participants (both interns and NCSA mentors) and focus group interviews. We provide results of evaluation after five terms of the program.

The four evaluation criteria are: **1) Implementation:** Is the CI internship program implemented on schedule and as planned? **2) Effectiveness:** Are key components of the internship program educational initiatives (diverse academic background recruitment, mentors' training, team working in the operational groups, HPC/cloud system demonstrations, social events integration) operating effectively? How might they be improved? **3) Impact:** What outcomes, immediate (e.g. quality of interaction within the operational groups, identification of relevant knowledge and skills for CI professionals) and mid-term (e.g. revised attitudes, knowledge, and skills) are associated with participation in the internship program? **4) Institutionalization:** How and to what extent are elements of the program becoming institutionalized? What opportunities and barriers exist? The four evaluation questions are applied at specific locations on the program model illustrated in Table 2. The program logic guides the evaluation.

Evaluation results for each of these key questions are summarized below.

Table 2. Program model

Resources	Activities	Outputs	Short-term outcome	Intermediate and long-term outcome	Impact
Training resources	1st week training	Training materials	New attitudes, knowledge, skills and behaviors	Interns use the training and the skills obtained through the program to strengthen the CI community	CI Professionals Community Workforce Development
Mentors and operational groups	2nd week rotation				
Interns/ participants	Intern-mentor pairing	Completion of the program	Increased awareness regarding CI professionals		
NCSA CI	Projects				
Career development	Seminars, professional development events	Participant satisfaction	Identify better practices for training CI professionals	Establish the career pathway for CI professionals to enter the workforce	
NSF funding					

Implementation. Program leadership saw that so far, the recruitment and selection process for interns has been implemented as anticipated. The first week orientation activities were well implemented, and interns were satisfied (100%) with the content of the activities. However, interns had mixed response on the implementation of seminars and professional development events. Mentors had a wide range of feedback to many elements of the program including selection and placement of interns in the lab, overall program structure and organization, amount and type of communication between mentors and program leadership, understanding of program goals and expectations, and quality of intern's deliverables. After the first two cohorts, program leadership learned that some aspects of the program were not as necessary as they had anticipated.

Effectiveness. Most interns expressed their expectations for the internship program were met but some expressed they would have preferred to have more time in the program. Interns recognized their reasons for participating in the program were met and that it gave them hands-on experience. They noted they would have liked to have more interaction with other interns in the program. There were mixed reactions toward individual projects which led to the suggestion to have more time in the program:

"What I think was really beneficial, though, was having an overall project of working with a particular data set. This was some data from one of the current Blue Waters graduate fellows, and using it to practice

what I was learning was kind of a way to do a smaller version of what a visualizer would actually do in collaboration with a researcher."

while another intern remarked:

"Make sure to allow time to spare allocation of work"

Interns' interactions and communication with the program leadership was regarded as positive. Interns perceived that communication and interaction with project mentors was neutral or satisfactory. Typical days for interns varied but most of them commented they had flexibility and that their project-based work varied allowing them to constantly learn. The networking opportunities provided by the program received mixed reviews. Some participants commented that there were some aspects of the program that didn't happen that could have improved these opportunities (in particular, being exposed to CI community networking events more often during the program). Most interns were satisfied or very satisfied with the overall program but expressed that a little more understanding between what they were doing, and the overall goals of the program would be beneficial. Interns expressed many aspects of the program that stood out to them including listening to the different groups in the program talk about their work, working with a team on a project, and interacting with NCSA community.

Impact. Interns commented that there were many things they learned through the program. Some common themes were communication skills, knowledge in specific technical programs including Linux, Jira, Docker, and Github, and a better understanding of HPC and what a day-to-day work life would be like. Program mentors perceived that interns were engaged and that they had learned specific content knowledge and skills. Some interns stated this program either changed their ideas for their career progression or refined it:

"I really did enjoy my time at the NCSA, truly learned a lot, am now not only aware but also interested in careers in these areas, and am grateful for the opportunity to participate and the investment of the people involved."

They cited a better understanding of the technical aspects of the job to their changes:

"simply what high performance computing is and how the many different technical areas involved fit together is important because it gives me a basic understanding of what is involved in the workflows of such scientific research and a better sense of what jobs there are in HPC"

Program leadership also noticed that one of the impacts of this program was interns being able to see if this is a field they want to pursue. Interns emphasized strengths of the program in the experiences it provided, e.g.,

"Security practices in an organization. The day to day working in an organization is not something I learned in school and I think this is an important aspect for freshers to learn to be ready to enter the workforce."

and the connections they made.

Institutionalization. Program leadership mentioned the first year taught them many things that would be beneficial to learn from and change for the upcoming cohorts. Interns and program leadership experienced some struggles with administering the stipend; the issues were resolved by the second year. In general, the first two years offered program leadership the opportunity to experiment with alternatives to implementation of the program in order to facilitate eventual institutionalization.

Table 3 illustrates in percentages the degree of satisfaction with various aspects of the program as they have been described above in the results.

Table 3. Interns satisfaction with various aspects of the program. 12 out of 14 interns participated in this post-program survey.

Satisfaction/ Aspect of the program	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied
Overall experience		8.33%	8.33%	33.33%	50%
Expectations for the program were met			16.67%	16.67%	66.67%
Interns specific reasons for participation were addressed			8.33%	25%	66.67%
First week orientation activities				66.67%	33.33%
Interns satisfied with their project	8.33%	8.33%	8.33%	41.67%	33.33%
Other professional development activities, events, seminars		8.33%	8.33%	50%	33.33%
Networking opportunities		8.33%	16.67%	33.33%	41.67%
Interaction with Mentor			16.67%	25%	58.33%
Interaction with other program participants			16.67%	75%	8.33%
Interaction with program leaders			8.33%	58.33%	33.33%
Stipend			33.33%	58.33%	8.33%

3.3 Lessons Learned

The program is a pilot training offering practical, hands-on approach that is essential to prepare system engineers and administrators who operate CI resources. After 3 years involving the participation of 17 interns and 10 mentors the program design shaped in a better format. Though there were some elements of the program that have not been implemented as planned, overall, the program followed the initial schedule of activities, adding several changes following the first year's implementation of the program. Based on this experience, we learned the following: 1) Better communication between mentors and interns about program structure and expectations is necessary to ensure overall satisfaction with the program. 2) To increase effectiveness, we need to increase the interactions the interns had with each other. 3) Communicating with interns about how program activities align with the program goals including how current elements of the program offer networking opportunities that have not been taken advantage by some of the participants is one priority for the program.

The program is having an impact on interns and the thoughts for improvement given by interns are taken into consideration for future cohorts.

We are taking the lessons that were learned and finding ways to begin institutionalizing the program, possibly to offer certification. We have been developing more robust and stable training materials and the program logic has been re-shaped accordingly. We are looking at ways to engage with other partners to extend the program beyond the original plan.

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