Computing Requirements of Sri Lankan Scientific Community

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Abstract— Significant improvements in Information and Communication (ICT) infrastructure over the last decade put Sri Lanka among the top developing nations for ICT-led economic and social growth. While ICT has also contributed to increased research outcomes through better access to world-class knowledge, research resources, and other researchers, overall growth and significance of research findings are not in par with most of the top developing nations. In this research, through surveys and interviews, we explore the current state of computing resources available for research, as well as the needs and challenges faced by researchers. We identified a number of challenges, including shortage of computational and storage resources, cost of software licenses, limited awareness of alternative tools, inadequate programing skills among graduate students, unavailability of research computing support staff, unreliable infrastructure, and organizational constraints. We further discuss potential solutions to address some of these technical and nontechnical challenges.

Keywords— Applied computing; computing literacy; research computing; scientific community

I. INTRODUCTION

Information and Communication (ICT) infrastructure in Sri Lanka has improved significantly over the last decade. Consequently, it was ranked 76 in the Networked Readiness Index (NRI) 2014 [1], above all of its South Asian neighbors. However, Sri Lanka still ranks below most of its South Asian counterparts when it comes to research impact [2] and innovation [3]. ICT could play a major role among many factors that can contribute to improving the number of publications and significance of research findings, as it enables better access to world-class knowledge, research resources, and collaboration opportunities with other researchers. In fact, as contemporary science and technology research is becoming increasingly complex, multi-disciplinary, and data driven, scientists from virtually every discipline need to perform extensive computational work. However, while there is an emphasis on developing the Sri Lankan research community through increased access to publication databases, funding, and research allowances, relatively less attention is given to the development of research infrastructure and necessary skills.

It has been identified that greater developments in ICT, High Performance Computing (HPC), and cloud computing infrastructures lead to innovation-driven economies [4]. For example, Europe has identified HPC as one of the key enablers in advancing research and innovation in the 21st century [5]. Accordingly, the European Commission has outlined a road map prioritizing key areas of developments to promote and sustain HPC research and HPC-led research [5]. While such a development road map can also be applied to the rest of the world, each country also needs to understand where it stands and its unique needs and priorities. In this research, we attempt to answer some of these questions by identifying the current state of computing resources available for research, as well as needs and challenges faced by researchers. Such an understanding is essential to develop a road map to promote, adopt, expand, and sustain research computing resources in the country.

We conducted an online survey to identify the current state of research computing resources in the country. The study also analyzed the needs and challenges faced by researchers. 147 researchers from public and private universities, research institutes, and industry participated in the survey. The background of these researchers includes Engineering, Computer Science, Natural Sciences, Medicine, Social Science, Accounting and Management, and Agriculture. We also discuss further issues and potential solutions that were identified through several HPC workshops and interviews conducted by our HPC Lab over the last two years. Scientists from both computational and non-computational sciences across several disciplines and universities participated in these discussions.

We identified a number of issues, including shortage of computational resources, cost of software licenses, inadequate use of free and open source tools, limited programming skills among graduate students, unavailability of support staff, unreliable infrastructure, and organizational constraints. We further discuss several potential short and long term solutions to address these technical and nontechnical issues.

Section II presents the research methodology. Summary of findings from the survey and discussions is presented in Section III. Section IV discusses potential solutions to address the identified issues and challenges. Concluding remarks are presented in Section V.

II. METHODOLOGY

To determine the computing requirements of a large number of researchers in the Sri Lankan scientific community, an online survey was conducted. The survey component development for this study included three phases, namely, a) compo-

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nent identification, b) component cohort and questionnaire design, and c) component verification and review. Based on initial discussions with several scientists from both the computational and non-computational sciences (across several disciplines and different universities) important survey components were identified. The questionnaire consisted of 11 questions. Out of the 11 questions, 5 of them were MSQs and focused on demographic details and level of usage. The rest were open ended and were used to assess participants' research interests, available computing resources, resources they would like to have access to, level of satisfaction, and challenges they face and how they overcome some of those.

A pilot survey was conducted with seven participants in the component verification stage. Findings from these responses and additional feedback on how participants interpreted the questions were used to measure the consistency of the components and ensure that the wording, presentation, average time taken to complete, length, and sequencing of questions were appropriate.

The total population for the survey is 2,759. It included researchers of 12 state universities [6], five private universities, three research institutes, and seven Research and development (R&D) teams of software development companies. Selected 12 state universities included University of Colombo, Jaffna, Kelaniya, Moratuwa, Peradeniya, Rajarata, Ruhuna, Sabaragamuwa, Sri Jayewardenepura, Wayamba, as well as the Open University and Uva Wellassa University. When considering the designations of lecturer or above, the total faculty from related disciplines is 2,596. Among the private universities/institutes in the country, 5 of them have been selected based on the research contributions and activities. Those include the Sri Lanka Institute of Information Technology, South Asian Institute of Technology and Medicine, Asia Pacific Institute of Information Technology, Horizon Campus, and Kothalawala Defence University. The total number of related faculty is 55. 38 researchers are currently working at three research institutes, namely, Nanotechnology Institute, Institute of Fundamental Studies, and Arthur C Clarke Institute. Several international software development companies have their R&D centers in Sri Lanka. We consider seven of those companies, namely, WSO2, Lirneasia, MillenniumIT, Simcentric, Aepona, Virtusa, and 99x Technology. About 70 researchers are working for these companies.

Quota sampling method [7] was used when distributing the online survey. The sample for this survey is 651, which is 23.6% of the total population. This is sufficient to achieve approximately 5% precision level and 95% confidence level, with an expected response rate of 50% [8]. The sample includes 553 faculty from state universities, 28 faculty from private universities, 26 researchers from research institutions, and 44 researchers from R&D centers.

We also analyzed issues and potential solutions that were further identified through several HPC workshops and interviews conducted by the HPC Lab of the Dept. of Computer Science and Engineering, University of Moratuwa over the last two years. Scientists from both computational and non-computational sciences across several disciplines and universities participated in these discussions.

III. ANALYSIS

A total of 651 questionnaires was emailed and 147 valid answered were received. Which indicates an overall response rate of 22.6%. While this is below the planned response rate of 50%, it is still sufficient to achieve 10% precision level and 95% confidence level [8]. We first present the demographic data and then present the current state of research computing resources. Finally, the needs and challenges faced by researchers are discussed.

A. Demographics

Fig. 1 shows the survey responders categorized according to their major area of research. The majority of the researchers is from Engineering and Computer Science (CS), which represented 23.1% and 17% of the total respondents, respectively. Next three major areas of research includes Medicine (12.9%), Natural Science (12.2%), and Accounting and Management (10.9%). Area of specialization of researchers were so diverse. For example, major engineering-related areas include Civil, Chemical, Electrical, and Mechanical engineering. CS related areas include Big Data, Bioinformatics, HPC, Machine Learning, and Software Engineering. Medicine related disciplines include Biotechnology, Forensic Medicine, Immunology, Microbiology, Robotic Surgery, and Telemedicine. Biology, Chemistry (Biochemistry, Computational, and Organic), Physics (Cosmology and Energy), and Nanotechnology were among the popular Natural Science (NS) related areas. Areas of specialization in Accounting and Management primarily include Entrepreneurship, Finance, Human Resources, and Marketing. Most of these areas of interests rely on computing resources for research.

Title of 79 (53.7%) participants was Senior Lecturer or above. 37 (25.2%) participants were Lecturers. Rest consisted of R&D Engineers, Research Assistants, Research Fellow, and Postgraduate Students. 30 (20.4%) participants were under age 30, 51 (34.7%) between the age 31 - 40, and the rest were above age 40. These statistics reflect the demographic distribution of researchers in Sri Lanka, where most of them are from the academia, with the title of senior lecturer or above, and an age of 35 or above [6].

B. Current State

Fig. 2 illustrates the types of research activities that utilize computing resources. Percentage of research that utilize re-

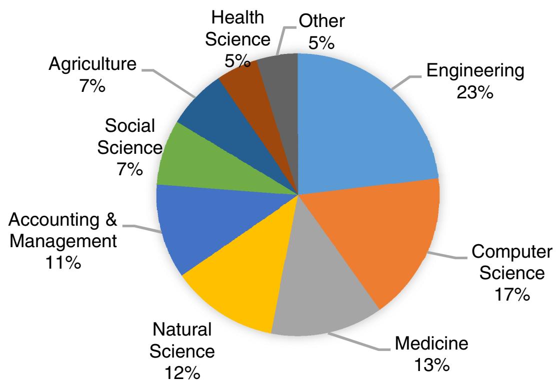

Fig. 1. Distribution of major area of research.

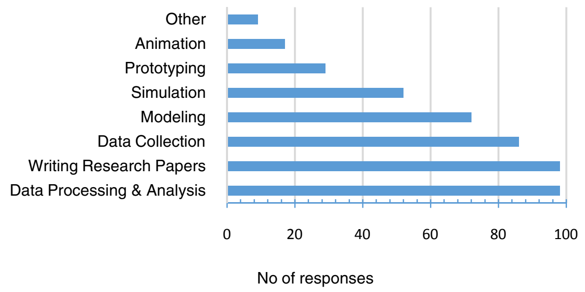

Fig. 2. Research activities that utilize computing resources.

search computing is shown in Fig. 3. Primary activities include data collection (86), data processing and analysis (98), and paper writing (98). While 60.5% of the researchers indicated that more than 60% of their research utilize computing resources, majority of the usage is for these three activities. Modelling (72), simulation (52), prototyping (29), and animation (17) are other frequent research activities. All researchers working on modelling belong to CS, Engineering, and NS disciplines. NS-specific disciplines include Computational Chemistry, Cosmology, High Energy Physics, and Nanotechnology. While simulation and prototyping are primarily used by researchers from CS and Engineering, few researchers from NS, Social Science (SS), Agriculture, and Medicine also use them in research. Based on interviews, it was realized that to what extent a none CS or Engineering researcher adopts research computing for modelling, simulation, prototyping, and data processing and analysis depends on his/her ICT competency than the area of expertise. As expected, ICT adoption was higher among researchers under the age of 35. While 60% of the survey participants are from none CS and Engineering disciplines, these findings indicate that their use of computers for research is relatively low (except for paper writing).

Fig. 4 and 5 illustrate types of hardware and software used for research, respectively. Most frequently used hardware resources include portable storage, desktops, and servers. 41 researchers had access to servers while 11 had access to clusters. In most cases, researchers had access to independent computing silos with only one or two servers and users. A couple of these servers were in the cloud. Specification of most of these servers include 2-8 cores and 4-16 GB RAM. Three researchers mentioned that they have access to 16-32 core nodes with 32-64 GB RAM. In many cases, these computing resources were available from a different institute (than the researcher's own institute) either within Sri Lanka or outside. This was also the case for all the clusters access by researchers, where they were located in USA, UK, Australia, Singapore, and several other Western European countries. It seems that researchers who did their postgraduate studies in these countries still have access to some of those resources through their supervisors and research colleagues. R&D teams from the industry also relied on external resources and public clouds like Amazon web services. However, surprisingly, a very few researchers shared each other's resources locally, leading to many small computing silos. Researchers also considered portable hard drives, USB flash drives, 3G Dongles, smart phones, and data acquisition cards as essential components in research data collection, processing,

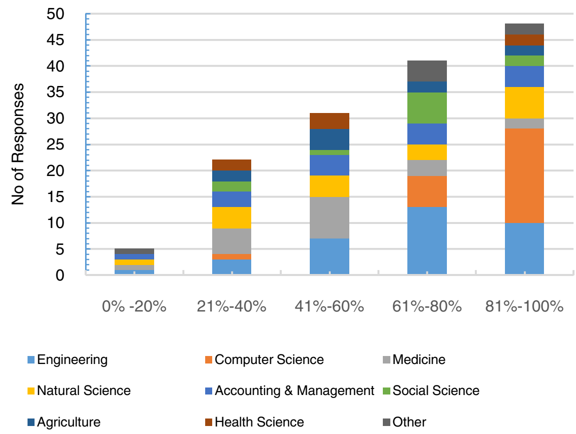

Fig. 3. Percentage of research that utilize research computing.

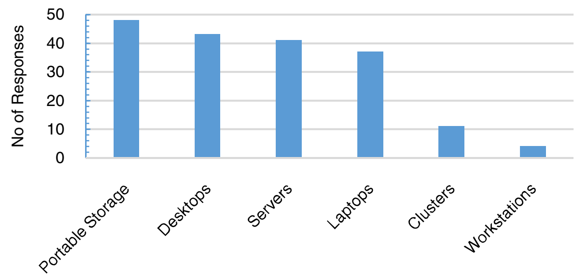

Fig. 4. Types of hardware used for research.

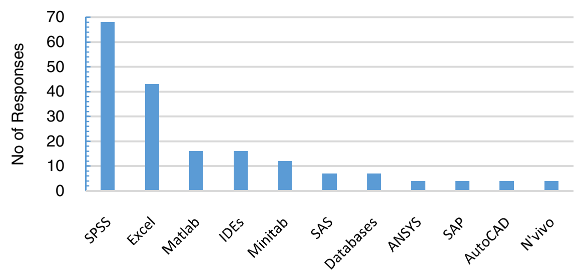

Fig. 5. Types of software frequently used in research.

and transfer. As seen in Fig. 5 majority of the software used for research includes statistical and data analysis software such as SPSS, Microsoft Excel, Minitab, SAS, and N'vivo. As the researchers from Accounting and Management, Economics, Statistics, and SS represented only 21% of the sample, this is an indication that researchers from other disciplines also frequently use these tools for data processing and analysis. Matlab, ANSYS, LabView, SciLab, SciDavis, Solidworks, WaterCAD, Water GEMS, ArcGIS, AutoCAD, and ChemCAD were among the popular engineering software. Popular CS related tools include development tools (e.g., Visual Studio, NetBeans, Eclipse, and IntelliJIdea), databases (e.g., MySQL, Oracle, SQL Server, Access), and many custom applications. Gaussian and HyperChem were among the popular Computational Chemistry tools. Many more tools were included in the *Other* category, reflecting the diversity of research-specific tools.

In summary, researchers primarily relied on research computing resources for data collection, processing, and analysis, and the main tools include desktops, laptops, and statistical packages. This is a good indication that ICT is helping researchers to simplify the research process. There are also a significant number of researchers doing modelling, simulation, and visualization, which utilize servers and clusters.

C. *Needs and Challenges*

We then asked researchers about the types of research computing resources that could enhance their research. Fig. 6 shows the key resources that they wish to have for research activities. Majority of the researchers mentioned SPSS and particularly the newer, licensed versions of SPSS. Other statistical software such as Excel, Minitab, SAS, N'vivo, and EViews were frequently recommended. Researchers also mentioned that access to clusters, servers, and high-end workstations can allow them to work on more computationally intensive problems that require more CPU time, memory, and storage. Many-core servers, high-memory servers, Graphical Processing Unit (GPU) cards, and HPC clusters were among the recommended hardware resources. A significant number of researchers wish to have access to newer laptops and desktops, particularly in cases where those resources are not either given by their institutions or maintained by them. 26 participants were quite content with the resources they already have access to. When analyzed the current resources used by those researchers, the majority of them used desktops and laptops and run commercially available, off-the-shelf research tools.

Even though Lanka Education And Research Network (LEARN) increased the bandwidth of all public universities by ~4× in 2013 [9], several researchers recommended having even faster access to the Internet. Rate limiting university connections during the daytime has caused problems with researchers who access resources that are outside their institute or country. Inability to perform bulk transfer of data generated and processed at these remote sites has become a major concern.

Challenges faced by researchers can be categorized under (a) access and funding, (b) knowledge and skill, and (c) infrastructure and logistics. According to the responders' feedback the major challenge was the access to research computing resources. Due to funding limitations majority have access only to primitive resources such as desktops, laptops, and external hard drives. Among the researchers with access to servers, most of them have access only to a single server. In cases where desktops, workstations, servers, and other research tools were purchased through a research fund, researchers were unable to secure a stream of follow up funding to expand their resources or even to maintain the existing ones. In a few cases, particularly where the resource was donated/purchased through foreign funding, researchers were not able to justify the low utilization of resources and relatively poor research outcomes, when it comes to the next round of funding. When they rely on external resources, accessing them at the right time is a problem, e.g., when a major conference deadline is approaching.

Limited access to relevant research software was the next major concern. A significant number of researchers were either relying on old versions of licensed software or used new ones without obtaining the appropriate licenses. This prevents them

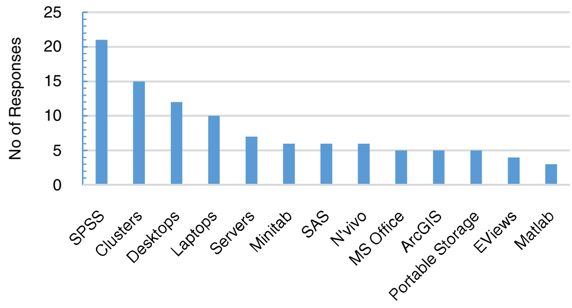

Fig. 6. Software and hardware resources requested for research.

from accessing state-of-the-art features, utilizing extended features of a particular tool set, and running larger and more complex experiments/simulations. Such limited or unlawful use of tools stems from several factors. First is inadequate funding to purchase state-of-the-art tools even when they are available with academic/research discounts. Second, in cases where initial funding was available to buy a particular license, continuous funding was not available to renew the license or buy the latest version. Third, custom codes/scripts written by researchers (e.g., when they were postgraduate students) or others to extend the functionality of those tools, did not work directly on newer versions of the tool. The budgeting priority for building necessary research infrastructure is minimal in many situations and it is directly affecting to researchers' productivity.

Next set of challenges comes from researchers' knowledge and skill. Most researchers were trained on a particular tool set (especially during their postgraduate studies in a developed country) and preferred to stick to them. Most of these tools are proprietary; hence, explain why software licenses are a major concern. When ask "why not switch to open source tools without paying license fees", researchers expressed several concerns. While many have heard about alternative tools, most of them never tried these tools. Once that tried them were frustrated, as open source tools usually do not work out of the box, had a steeper learning curve, and some of them ran only in Linux. They prefer the better user experience given by proprietary tools which enables them to focus on the research than worrying about other challenges paused by open source tools. Programing skills of postgraduate students (particularly in NS, SS, Medicine, and Accounting and Management) were inadequate to extend these tools. While most of them have taken an introductory programming class during undergraduate days, complexity of production-level software is far from what they experienced in computer labs. While the required source-code-level changes are usually minor, it was very difficult for them to even identify which part of the code needs to be changed. As a consequence, some research teams even struggled to port custom codes/scripts from one version of the tool to another. There is also a general lack of interest in programming among the postgraduate students from disciplines such as NS, SS, Medicine, Accounting and Management, and Agriculture. However, while 55% of our survey participants were above the age of 35, it was mostly the younger researchers from these disciplines who were using research computing resources more frequently. Work-life balance was also raised as a concern.

Being busy all the time prompted researchers to use already familiar tools than trying on new ones. Inability to spend a lot of time with postgraduate students to mentor them and help them get acquainted with research tools and infrastructure was another related issue.

Unreliable infrastructure and appropriate staff to manage them is another challenge. Reliable access to electricity and the Internet was a major concern. While electricity supply was more stable in Western province, rest of the country does not experience the same quality of service. In either case, most institutions as a policy used generators only during the working hours. Not many research computing facilities were backed up by an Uninterrupted Power Supply (UPS). Even the ones that had UPSs, were not able to sustain power failures beyond 10 - 20 min (such prolonged failures are somewhat common in certain parts of the country). These have resulted in many failed computational tasks and damages to the hardware. One of the participants mentioned that "all our servers are shutdown at 5:00 pm on weekdays and remained so during weekends to protect the hardware we acquired with much effort". On many campuses wired and wireless access to the Internet is slow, unreliable, and have prolonged outages. Several researchers even mentioned that the unavailability of a university branded e-mail address prevented them from signing up for some of the free tools and services available for academics. All most all institutions do not have a research computing support staff. Hence, the researchers had to manage resources by themselves. This has led to many frustrating experiences as the skill set of most researchers were not adequate to deal with hardware and software issues. Ones without a strong CS background have had several arguments with hardware/software vendors when it comes to maintenance of resources, transfer of licenses from one node to another, and warranty terms. Some even mentioned that day-to-day issues such as viruses tend to disrupt their processing and data archives. Researchers were not much aware of the resources currently available in the country and how to collaborate and share those resources with each other. Sometimes, there are self-enforced constraints on working with other research teams within the same or other institutions. These infrastructure and logistical issues have resulted in poor access and availability of research computing resources.

IV. POTENTIAL SOLUTIONS

Next, we discuss several solutions suggested and/or already used by researchers, as well as our own ideas to address some of the identified challenges. Recommended solutions can be broadly categorized as short-term vs. long-term solutions.

One of the key short-term solutions is to educate the researchers on the available resources, alternative tools, and right computing platforms. Researchers need to be educated on small-scale computing facilities (1-3 servers in most cases) available in several institutions and how to access them. As most of the existing computing facilities are not heavily used 24×7, it is beneficial to share these resources with each other without limiting to organizational boundaries. Moreover, such collaborations could lead to better communication among researchers and new interdisciplinary research projects that are mutually beneficial. While it is understandable that resource sharing will create new problems related to priority, ownership, and coordination, we believe that the benefits outweigh the issues caused by sharing. Over the last three years, we have been sharing several workstations (some with GPUs) in our HPC lab with a few researchers within and outside our university. Setting simple guidelines on when to run their computations, transfer data over the network, and what resources to use have been effective in minimizing coordination issues. However, there have been cases where we had to ask researchers to stop their computing at times to run our own critical tasks or for maintenance purposes. In cases where they need to transfer large volumes of data, we have suggested them to come to our university and transfer the data via the university LAN (rather than going into server room). Another alternative is to educate researchers on internationally available resources such as "AWS in Education Research Grants" and International Centre for Theoretical Physics (ICTP), Italy. However, lack of accreditation and not having an institute branded e-mail address can cause issues while tapping into some of these resources.

Significant efforts need to be put into educate the researchers on alternative tools and how to use them. For example, tools such as R, Octave, and Open Office are frequently used alternatives to SPSS, Matlab, and Excel. They are free, open source, and also available for the Windows platform. A series of workshops could be conducted on the available tools and how to use them. It is important that these workshops are customized to specific disciplines.

Promotion of interdisciplinary research is a key solution to address some of the knowledge and skill related issues. It is both a short term and long term solution. One possibility is to connect with a CS research group and get their help in developing necessary research tools and accessing their computing resources. However, there have to be mutual benefits in terms of research outcomes where both parties should be able to present the research outcomes in their respective domains. For example, the CS research team should see this as a good CS research problem than just writing a program. They should see it as a good opportunity to develop new algorithms or optimize existing ones, application of technology to a new domain or new piece of hardware, scalability problem, etc. Whereas the researcher from none CS domain should be able to show how the use of computers lead to more accurate results in less time or enable them to tackle hard problems. Projects that require more coding than research are more desirable for undergraduate projects in CS, as they usually focus on the development of products using state of the art tools. It is even better, if students across disciplines works on the same project at the same time. This will also help create the next generation of researchers who appreciate the value of interdisciplinary research and who know how to work with other scientists. Such collaborations build interdisciplinary research communities, who can justify the need and utilization of expanded research computing facilities. Internationally, such interdisciplinary communities have initiated many mega projects that results in numerous applied, fundamental, and transitional research findings. Sri Lankan researchers also need to be educated on such overall benefits, as they seem to believe it is too hard and lead only to applied research. Curriculum level changes can be introduced to reduce the widening knowledge and skill gap. For example, it is beneficial for any undergraduate to have basic programming and statistical data analysis skills regardless of the discipline, as it is useful in any work setting. Discipline specific modules such as computational Chemistry, computational Physics, and Bioinformatics may be introduced to promote the awareness among undergraduate and postgraduate students.

Infrastructure issues such as poor wireless and wired networks can be addressed with proper reconfigurations and relocating wireless access points. However, enhancing network infrastructures is a long-term task that requires better planning and enhanced funding. In most cases, researchers are provided with an institute branded e-mail address. However, most of those e-mail services are unreliable and use old-fashioned user interfaces compared to contemporary services like Gmail and Yahoo. Hence, most researchers prefer to use their private e-mails or never bother to obtain an e-mail account from the institution. This can be overcome by educating researchers on how to configure their personal e-mail service to access institutional e-mail. Another alternative is to move campus e-mail services to Google Apps for Education or Office 365 Education which are much more reliable, easier to use, and free.

The key long-term solution would be to establish a national research computing facility. This facility could be setup as a cloud-based service enabling scientists to focus on running different research programs on different platforms without worrying about the hardware, software, and maintenance issues. As the resource requirements of scientists are so diverse, a cloud-based model is more appropriate because it can support multiple operating systems, research tools, and libraries. Moreover, those resources can be rapidly reconfigured as the users and their needs change. Infrastructure issues such as unreliable electricity, network access, and lack of research computing support staff can be overcome by making this service centralized and by having a dedicate administration team. Resource utilization should be relatively easier to justify as multiple research computing applications and users will utilize the same facility. Computing facility should be built using free and open source software. However, in cases where proprietary software is essential, few licenses could be purchased to cater for multiple scientists according to their license terms. Nevertheless, to promote the utilization, proper documentation and user education are essential. We are currently in the process of setting up a Proof of Concept (PoC) cloud-based facility by aggregating the resources already at the HPC lab. We also had a couple of discussions with local IT companies and a foreign institution on possible donations of refurbished or new computing and storage resources. However, to move these efforts beyond a PoC, we need to address two key issues. First, we need to extend existing open source cloud computing tools to provide resource and policy aware virtual machine scheduling as the facility is to be used by a diverse set of researchers with varying needs and access privileges. Initial work on resource and policy aware medium-scale clouds is presented in [10]. The second issue is the expansion and sustainability of the facility. While we are able to gather hardware resources through donations and man the facility through research funding (e.g., postgraduate students), additional funding is required to expand the facility and maintain it. One possibility is to uplift the facility as a national resource and cover its expenses through National Science Foundation (NSF) or a similar organization. Another option is to charge the researchers for the use of the facility on a cost recovery basis.

Further funding and budgeting priorities are the other long-term solutions. It is important for the funding sources to not only allow the procurement of computing resources but also to provide additional long-term funds to maintain those resources at least during their expected lifetime. While procurement of computing resources is usually allowed through most funding sources, they have restrictions on obtaining services. This is a problem when accessing cloud resources as it is categorized as a service. Therefore, funding sources should allow the use of research funds for utilizing cloud resources. In fact, funding for computing resources can be reduced, as the use of cloud services during a particular phase of a research project is usually more cost effective than purchasing a server and maintaining it throughout the research project. Most of the logistical issues can be overcome by appropriate budgeting priorities and keeping the necessary facilities accessible 24×7.

V. Summary

Through surveys and interviews, we explore the current state of computing resources available for research, as well as the needs and challenges faced by researchers. Existing computing resources are limited to small computing silos where a few scientists focus on running their programs on a set of independent computational nodes. To strengthen the research in the country, it is essential to improve access to resources, knowledge and skill of researchers, funding, infrastructure, and address logistical issues.

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