Supporting information:

- Page 2 – Research computing services in UIT at a glance.
- Page 3 – How to estimate total costs of operations? Staff list.
- Page 4 – Current estimated costs for hardware and TCO.
- Page 5 – The current funding model for research computing at UIT.
- Page 6 – Growth in services.
- Page 9 – Highlights of services from FY16.
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http://www.chpc.utah.edu
RESEARCH COMPUTING SERVICES IN UIT AT A GLANCE (http://www.chpc.utah.edu)

- **User services / consultation** – Our staff work with research groups and individuals to optimize, enable, and to innovate their research computing needs. These services range from design, engineering and deploying solutions to best practices, training, and code maintenance / optimization. The bulk of staff effort in the unit centers on user services and consultations. Consultations with research group leads are done as a team that spans user services and technical support.

- **Compute cores** – Our staff currently operate ~20,000 cores in the Downtown Data Center (DDC) and most of these compute nodes are owned by individual research groups. The gear is mostly commodity Intel or AMD cores, however some of the nodes include special purpose resources including big memory, GPU and multi-GPU nodes, and Intel Phi. Our staff is always willing to help engineer and deploy new solutions. More than 50% of our HPC usage is from pre-emptible free cycle mode on otherwise idle researcher hardware!

- **Virtual machines (VMs)** – Our staff help with deploying and customizing VMs for researchers. Currently this totals to ~230 Linux and ~30 Windows VMs. To keep costs reasonable, our VM farm is based on commodity hardware and achieves performance through distribution of resources – the VM farm is not intended for high performance or very high utilization. A significant challenge is customization, and this is done on a case-by-case basis as resources allow. Given limited people resources, growth here is not sustainable.

- **Storage** – Over ~14 PB of usable storage, mostly RAID6, is deployed at the DDC. Of this space, ~3.2 PB of the total is in high performance Lustre or Isilon parallel file systems. We aim for 5 years of warranty and this can often be extended to 7 years (in year 4 or 5) for modest cost. For the past few years, deployed storage has effectively doubled every year.

- **Backup** – Enabled daily/incremental for modest home directory resources (capped at 1 TB per group) and only quarterly for project space (if you purchase two sets of tapes and ask) due to hardware and personnel limitations. The current backup solution is not sustainable and puts campus research data at risk. While we work with ITS/UIT to develop campus wide data services we are also investigating alternative Cloud-like object store solutions.

- **Data movement services** – We maintain ~12 both general and special purpose data transfer nodes (DTNs) that utilize the science DMZ to securely bypass the campus firewall for large scale file transfer. Both single server and clustered endpoints are enabled for Globus (https://www.globus.org) at both 10 Gbps and 40 Gpbs connectivity. We also enable a guest transfer service (up to 5 TB shared) where anyone with a valid uNID can create a temporary account to let others transfer data in/out. Our team also has considerable experience with data movement to the cloud, most notably with Google Drive and Amazon.

- **Protected environment (PE)** – The PE is a secure and siloed data, compute and VM environment for restricted data (including PHI, HIPAA and Export Control regulated data). It currently supports ~64 active projects and is the base infrastructure for the secure REDCAP environment for data collection and management that is extensively used in the HSC. Much of the current data and compute infrastructure in the PE is off-warranty.

- **Experimental resources** – These include the Apt “bare metal” hardware, a test Hadoop/Spark cluster for big data analytics, prototype object store and VM environments, and support for the Ricci group’s CloudLab (http://cloudlab.us) experiment.

- **Backend services** – Our staff maintain Jira (issue tracking), Confluence (wiki), WWW, XDMoD/XALT (usage and performance monitoring), Perfsonar (network monitoring), and a variety of other services to streamline, facilitate and enable our research computing support.

- **Desktop support** – The INSCC building is multidisciplinary and spans multiple colleges. Historically, CHPC has served as the IT-professional equivalents for residents (or former residents) in INSCC. CHPC also provides support to others that contribute funds (albeit through an arbitrary and poorly defined funding model that currently totals ~91K/year).
How do we estimate total costs of operations? Actual costs and effort reporting

**Hardware costs:** These costs are calculated as total cost of hardware and necessary infrastructure (PDU’s, high speed/low speed networking, IB cards, network cables, etc.) not including the physical racks, not including the core network switches (Internet2, 40 GB), and also at present not including back-end services (loggers, Jira, …)

**Downtown Data Center costs:** At present and by agreement, research computing pays ~1/3 of the costs of people at the DDC—the so called CAM charges and pays actual power costs metered at the racks. In FY17, this is estimated to be ~$800K.

**Staff costs – Effort reporting:** Quarterly, we ask staff to fill out effort reports outlining their percent efforts in the various research computing service areas or resource buckets (i.e. HPC, storage, VMs, user services, …). This is a qualitative, approximate, and somewhat arbitrary exercise since many of the staff work in multiple service areas and since they normally work together as a team to engineer and deploy services. At present we do not separately breakout security but this is included in costs. The breakout is shown in the figure below.

Based on this approximate effort breakdown and our budgeted projected costs (i.e. total costs not including the hardware budget), we can outline the effective cost per service or total cost of operations (TCO). The most significant costs are in “User Services” and the “Help Desk” which accounts for approximately ~30% of the budget. These services are mainly used by new or naïve users or when rolling out new or extensive technology (purchased by research groups).

For more information about the staff, see: [https://www.chpc.utah.edu/about/staff.php](https://www.chpc.utah.edu/about/staff.php)

- **User Services** – Anita Orendt, Wim Cardoen, Martin Cuma, +all staff
- **HPC** – Brian Haymore, Sam Liston, Guy Adams, Wayne Bradford
- **Virtualization** – Julia Harrison, David Richardson, David Heidorn, Steve Harper
- **Storage** – Sam Liston, Brian Haymore, David Richardson
- **Security** – Wayne Bradford, Steve Harper, David Richardson
- **Backups** – Irv Allen, David Heidorn
- **Networking** – Joe Breen, Jacob Evans
- **Data Centers** – Alan Wisniewski
- **Integrated Workstation Support** – Irv Allen, David Heidorn
- **Students** – ~2-7 employed in various areas including HPC, network, security, and VMs
- **Administration** – Thomas Cheatham, Julia Harrison, Janet Ellingson
- **Help Desk** – Part-timers
We currently support three different engineered storage solutions. 

- Compute nodes: We currently deploy the latest generation commodity processors with FDR Infiniband connectivity at a cost of ~$6-8K per node depending on memory requirements with a 5-year warranty. While we at present guarantee 5-years of support, we will often extend life if rack space is available and the hardware is not problematic. These costs include the incremental network/port costs. Total cost recovery (including staff, DDC, and power charges) adds ~50% to the node cost. Technically, if we want to include costs of off-warranty gear TCO will be somewhat higher. Total cost per fully loaded HPC rack (not including hardware costs) is ~$26K/year.

- Storage: We currently support three different engineered storage solutions.
  - RAID6 spinning disk: In FY16 we charged for the fabricated asset $210/TB (usable) with a 5-year warranty. With the release of higher capacity drives, this cost has dropped to ~$160/TB. Total cost of operations (TCO) without backup is ~$73/TB-year and ~$200/TB-year with backup, in addition to the hardware costs. Without back-up, this is an ~2.25x additional cost to the hardware. [The current tape backup solution is costly and people intensive — this is an impetus for rolling out object storage.]
  - Lustre parallel file systems: We are still working out the numbers, but the cost is ~$300/TB (usable) with a 5-year warranty. TCO effectively doubles or triples the cost.
  - Object storage: We deployed ~1 PB in August 2016. It is accessed more like a cloud than a regular disk mount. The cost per usable TB is ~$65/TB for a single copy. Either multiple copies can be maintained or alternatively users can choose erasure encoding (similar to RAID). With a 6+3 erasure encoding (meaning you can lose three drives or three servers before losing data) in our initial deployment the cost per usable TB is ~$100-110. TCO is similar to RAID6 but will shrink with growth, as will per TB cost.

- Backup: Home directory backup is free on our current tape hardware and project space is only backed up quarterly, by request, if you purchase two sets of tapes. Tapes are ~$35 and hold 2.5 TB raw. The costs of disk above with back-up include the cost of replacement or upgraded tape hardware. We do not have reliable estimates of TCO and reiterate that the current backup solution is not sustainable and puts campus research data at risk.

- Virtual machines (VMs) and the Protected Environment: Current hardware costs are free, but would be similar to HPC node costs. However, if we consider TCO, the costs would be ~$870 per VM and ~$30/GB RAM (beyond the first 1 GB) per year (including hardware). Data costs are equivalent to the RAID6, although slightly higher for the protected environment due to the need for self-encrypting drives. A significant challenge is customization, and this is done on a case-by-case basis as resources allow. Given limited people resources, growth here is not sustainable and we do not have a good cost model for customization services. At present we are not a re-charge center and do not have an easy means to charge for these services, beyond hardware / fabricated asset costs.

- Data movement services: These are currently provided for free. TCO would include node and associated network hardware and portions of the Globus contract (if we continue to provide support to Globus noting that costs are projected to rise for Globus from ~$10K/yr to ~$40K/yr).

- Desktop support: The INSCC building is multidisciplinary and spans multiple colleges. Historically, CHPC has served as the IT-professional equivalents for residents (or former residents) in INSCC. CHPC also provides support to others that contribute funds (albeit through an arbitrary and poorly defined funding model that currently provides revenue of ~91K/year). Currently we have ~two people that provide these services (in Windows and Apple space) with HPC support from the other system administrators.
THE CURRENT FUNDING MODEL FOR RESEARCH COMPUTING AT UIT

Research computing in University IT (CHPC) of Utah is supported by a number of sources. The bulk of the ~$3.5-4.5M in funding is from the discretionary F&A pool. These sources are:

- **F&A pool**: ~$3.2-3.6M was requested for FY17 (depending on 1-time requests). This is used mainly for personnel (salary and benefits). There is also non-personnel budget for supplies, software, training, travel, and equipment. *This year's equipment request is $250K.*
- **Grants**: This is variable from year to year. We are moving away from the model where a percentage of time of specific employees are drafted into an individual's research project (since this dilutes their total effort available to the campus) unless the research project has broader impact in terms of providing better or more innovative services across campus. Examples include CC-NIE support for developing the science DMZ and equipment proposals. We continue to seek out funding opportunities that fund research that can more broadly strengthen and enable the campus IT infrastructure. We plan to use these funds mostly for temporary employees and workforce development (students, graduate students, and postdocs) or equipment to remain sustainable.
- **Departmental buy-in**: Some departments provide funds in return for desktop support (atmospheric sciences, BMI, …). Currently this only totals ~$91K in FY17.
- **State support**: There is a small and underfunded state line for the Director. This is typically used to pay personnel with high benefit costs since this line includes benefits. This compares with ~30% of the UIT budget from state funds.
- **Utah State University**: USU has recently out-sourced research computing support to the University of Utah. We are still negotiating the costs to USU which will likely be on the order of ~$150-200K/year.
- **U of U startups or non-research units**: By agreement with the VPR's office, full cost recovery (TCO) is charged, as estimated previously, unless the appropriate Senior VP designate grants an exemption. At present this is a very small portion of operations or a small source of discretionary funds and is not actively being marketed or explored except where there are special needs (restricted data, protected environment).
- **UIT funds**: None, with the exception of some temporary student positions on a case-by-case basis, negotiated yearly.
- **Student computing fees, R&R, colleges/schools**: None.

Access to resources by any researcher at the University of Utah is free, albeit resources are limited. A small general pool of HPC resources is allocated by the CHPC allocations committee, quarterly with a maximum awarded allocation of 250K core hours per quarter. No new general HPC resources were acquired in FY16 (with the exception of some planned multi-GPU specialized hardware) due to reduced hardware budgets, yet usage has increased significantly since over 50% of HPC utilization is occurring using idle cycles on research owned equipment. At present, long-term storage space (beyond 50 GB of home directory space\(^1\)) is not provided. Users can use /scratch space (which lasts 30 days) or they must purchase storage or move it elsewhere. At present, we do not allocate or charge for VMs or space in the PE or the open VM farm, and access and customization is visited on a case-by-case basis as resources allow.

To *get dedicated access to compute or data resources, researchers can buy hardware at cost*. The costs include associated infrastructure (but not physical racks or network core infrastructure). The ownership of the fabricated asset is transferred to the research group. Research computing staff engineer, deploy, and maintain the hardware/software. For the compute hardware, in return for this service, any idle cycles must be made available to the general community in a pre-emptible fashion. Researcher purchases of equipment are effectively subsidizing general campus users and help make up for reduced hardware budgets.

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\(^1\) Note that the home directory space goes off-warranty August 2017 with no obvious funding to replace.
GROWTH IN SERVICES PROVIDED AND USAGE

New research groups and users supported: The bulk of user support in research computing is supporting, training, and advising new researchers and research groups while also maintaining service for our core users. Below are tables of the number of new PI’s and new courses we support and also distinct new users over the past few years. Note that these are users of any of our resources, not just traditional HPC cluster users, but it doesn’t contain all users of our resources since we independently let some of the cores manage access to their resources on our infrastructure. This includes the very large set of users of the REDCap resource supported by the Bioinformatics Core of the CTSA; we provide the infrastructure for REDCap—which includes issue tracking, hardware and software—but do not at present monitor statistics of usage. Research computing at UIT also supports the Genomics Bioinformatics Core and their compute infrastructure for processing their sequencing results and here also we do not keep track of all the groups that utilize those resources (in other words an individual user comes in through a common username for the core).

<table>
<thead>
<tr>
<th>Time period</th>
<th>New PIs</th>
<th>New courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1-2/25/16</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>7/1-12/31/15</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td>1/1-6/30/15</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>7/1-12/31/14</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>1/1-6/30/14</td>
<td>16</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time period</th>
<th>New users</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1-2/25/16</td>
<td>131</td>
</tr>
<tr>
<td>7/1-12/31/15</td>
<td>268</td>
</tr>
<tr>
<td>1/1-6/30/15</td>
<td>214</td>
</tr>
<tr>
<td>7/1-12/31/14</td>
<td>216</td>
</tr>
<tr>
<td>1/1-6/30/14</td>
<td>184</td>
</tr>
</tbody>
</table>

VMs and the Protected Environment (PE): Outside the PE, we support ~260 VMs. Inside we support ~64 VMs. Example projects include the Utah Autism Study, Asthma Tracker, Aspire, CUSP, CCTS, NIH dbGaP human genomics data, Diacom, Utah Air Quality, Biospeciman, CATissue, Genetics IPF Pulmonary, census, Williams Syndrome, Virgo, Varranker, and REDCap among others. The PE was initially deployed in 2009 with 8 VMs, 24 GB RAM, 1 TB disk, 20 cores, and 6 researchers. As of March 2016, we are up to 64 VMs, 237 GB RAM, 10 TB disk, 132 cores, and 120 researchers. Still many HSC and restricted data users are not aware of the PE. As pointed out in the Deloitte audit of the clinical enterprise, a significant risk is clinical research data. Moreover, we believe that human genetics data will soon be regulated as restricted data; in fact, the current dbGaP requirements fit better within the PE than within the open HPC clusters. Therefore, we have been educating users about controls for restricted data and even prototyping this for the UCGD as a pilot for potentially moving all their hardware and disk resources (100’s of nodes and PB’s of disk) into the PE. As awareness continues to grow, we expect the PE to grow significantly. Therefore, we submitted a NIH S10 proposal to replace the PE in May 2015; it received a priority score of 31 and was held “pending” for potential end of the year funding. We were informed it will likely not be awarded so we submitted a resubmission in May 2016. Unfortunately the bulk of the PE hardware is off-warranty. We submitted a one-time request to fund a scalable infrastructure replacement for the PE however this was not approved.
HPC: As noted, individual research groups purchased most of the hardware deployed in the DDC. The plot on the right shows monthly usage. The blue represents usage from allocations from the *general* pool of HPC resources that were purchased through our operations budget in previous years. The green represents usage by research groups that own nodes (*owner nodes*). The significant red usage is “guest” access; in other words, otherwise idle compute cycles get used on owner nodes in a pre-emptible manner. With this policy, users are able to leverage the considerable investments of the owners (on newer and faster hardware). Given the trends, the modest hardware budget to research computing in UIT (requesting $250K in FY17) is used for innovative and specialized research computing solutions and needs including VMs, object storage, data transfer nodes, and special purpose hardware (multi-GPU, Hadoop/Spark) *rather than for traditional HPC*. Although the growth is not immediately obvious in the plot (data only from April 2015– due to the change in our monitoring and queuing environment), the table below shows growth in usage from January 2015 to December 2015. Usage in December was very high despite it being—or maybe because it was—a holiday month, although equivalent high utilization was also observed in January and February of this year.

<table>
<thead>
<tr>
<th></th>
<th>Jan 2015</th>
<th>Dec 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of groups with “kingspeak” owner nodes</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>Number of groups with general allocation</td>
<td>58</td>
<td>64</td>
</tr>
<tr>
<td>Number of groups running at least one job</td>
<td>66</td>
<td>84</td>
</tr>
<tr>
<td>Number of users running at least one job</td>
<td>166</td>
<td>192</td>
</tr>
<tr>
<td>Number of core hours used</td>
<td>5.7 million</td>
<td>9.0 million</td>
</tr>
</tbody>
</table>

**Data:** The plot on the right shows deployed storage increases from 2012 through January. At the end of last year we were at ~5.75 PB and now we have over 10 PB of data storage deployed with an additional 2 PB on order.

As mentioned, a significant concern is the lack of a sustainable and scalable campus-wide solution to back-up this data. We are beginning to work with UIT infrastructure and ITS on such a solution while also, in parallel, investigating alternative data solutions including deployment of an affordable local/private “Cloud” using open source object storage approaches. When the prototype object storage capabilities prove successful, we intend to explore wider adoption. One beneficial feature of object storage is the ability to distribute the data (to different data centers) as this provides for better disaster recovery. With object storage, users can dial in their level of data reproduction and integrity (noting that higher integrity or more copies inherently leads to higher cost).
Data movement: Globus is a tool and interface to facilitate large scale, parallel, and fast data transfer among endpoints (which can be a user’s desktop or dedicated data transfer node (DTN) at a particular site). Globus, previously supported by the NSF, has moved into a model that aims to become self-sustainable. Therefore, they have reached out to research computing centers on campuses to charge for the service. In the interest of being a good partner, and also to facilitate the development of services within Globus we desire (including Ceph/object store awareness and HIPAA/restricted data compliance) we bought in at the level of ~$12K/year in FY16 (for 10-20 TB/month of data transfer). Based on our regular usage, we move more like ~40+ TB/month so they want us to pay ~$40-50K/year (which we politely refused). Many of our DTN’s are used by specific research projects and Globus should approach these projects directly; moreover, as basic Globus is free and there are also more clunky free tools available, there is no way for them to enforce. This is a general issue as funding agencies drop support for software and it either becomes commercial or continuously ramps up the costs. To support research computing on campus, we aspire for open source alternatives, where feasible.

Globus update: The have moved away from a bandwidth model, however the project costs of necessary licenses will grow to ~$40K/year. As the CHPC User Advisory Committee recommends this as a critical service for the campus, we need to explore means to fund this.
HIGHLIGHTS OF SERVICES FROM FY16

- **Innovative capabilities**: USTAR Center for Genetic Discovery (UCGD) – Moved and deployed hardware from the Marth lab, deployed 1.8 PB of new Lustre parallel file systems and 1.2 PB of Isilon parallel file system storage, and deployed 56 dedicated compute nodes for the Yandell, Marth, and Quinlan labs in the UCGD. This required extensive cooperation of HPC system administration staff, the network team, extensive physical work and cabling, and involved user services for documentation and training. This was the first fully parallel file system installed in the past five years by our group and our first Lustre deployment. The work required specialized training from vendors and is estimated to have consumed ~1.5 months of time by many of the research computing staff. With this new parallel file system and compute nodes, UCGD was able to perform 30x whole genome sequencing processing in a world record of 8 minutes! [http://ucgd.genetics.utah.edu/fastqforward-just-got-faster/](http://ucgd.genetics.utah.edu/fastqforward-just-got-faster/)

- **Innovative solutions for campus**: Explorations of Ceph and object storage technologies. For ~1 year, our storage team has been investigating, training, prototyping, and deploying on old hardware open source Ceph solutions for object storage. In August 2016 we deployed our first production object storage environment (~$110K) of ~1 PB usable space using nine servers and a 6+3 erasure encoding deployment (50% overhead, but can lose 3 disks or 3 servers without losing any data).

- **Innovating next-generation HPC**: We are actively working to push the boundaries of HPC through the creation of dynamic clusters with specific network, security, compute and storage characteristics. We continue to collaborate with School of Computing faculty and staff to develop different techniques that might support more users in a secure and isolated fashion by dynamically spinning up “bare-metal” hardware into specific cluster images with associated networks. As it continues to develop, this work will become the underpinnings for better security and enhanced compliance in our protected environment and provide solutions for supporting, differentiating and siloing different protected projects within the protected environment.

- **Saving money via open source solutions**: The campus previously had a site license for Red Hat Satellite software which is a set of tools to manage different Linux distributions (including deployment, monitoring and patching) on varied resources. This was a very convenient way to manage software distributions on our hardware. Unfortunately, Red Hat continuously was increasing the price. Over the summer, with the help of a student worker, we replaced our satellite instance with Spacewalk (which is the open source back-end of Red Hat Satellite). Not only did the student get trained, we now have a fully functional software management environment for all of our Linux clusters and documentation, best practices and recipes for Spacewalk that can be shared with others.

- **Saving money via open source solutions**: Previously our queuing and batch management solution utilized a commercial solution from Adaptive Computing and the PBS/Torque/Moab software. During the early days of Adaptive, and even prior, we worked closely with the developers and added many features that could tune queue and scheduling priorities in very flexible ways. As the company matured, we no longer had a special relationship, feature addition slowed, and price continued to climb. We therefore switch to the Slurm software for this purpose. Not only did this bring us closer in alignment with ACI-REF peers and national resources, we were able to implement equivalent functionality (including job pre-emption) and save costs. At present, as we are still in the initial deployment and desire additional features, we have moved the software costs from Adaptive to SchedMD which provides consultation and adds features with strong customer service. In future years we expect to be able to drop the consulting and just use the open source Slurm environment.
- **Sustainability (goal):** We are starting to engage with faculty from engineering to better monitor the power requirements of compute loads and to analyze the data for patterns and optimizations. More to come, as this work develops over the next year.

- **New capabilities:** With successful deployment of a Dell/Intel Lustre parallel solution and after many years of meeting with DDN, Inc. (Data Direct Networks) multiple times per year, a new academic sales force came on board and promised 85% price discounts. These discounts made their hardware competitive or more cost effective than the Dell solution for the first time with the highest Lustre parallel file system performance. Two ~700 TB systems were recently deployed, one for a specific research group and the other will augment the `/scratch` space on the compute clusters. Until this recent addition, we only had available ~200 TB of `/scratch` space with not nearly as favorable performance characteristics.

- **Monitoring usage and efficiency:** In a partnership of user services, HPC and virtualization staff we deployed the open source XDMoD and XALT tools to monitor the clusters. XDMoD provides very detailed information on usage of our resources. A snapshot for today (7 March 2016) from [http://xdmod.chpc.utah.edu](http://xdmod.chpc.utah.edu) is below:

For even deeper usage monitoring (at the level of how many cores/node, memory, software, libraries, …) the XALT software monitors running jobs to look for those that may be using only 1 code per node, or too much memory, less efficient libraries, or other anomalous operations. This information can alert the user services staff to potential opportunity for training a user on how to better and more efficiently utilize our resources, point out code optimization needs, and highlight specialize library, language or code usage for more focused training.
Leveraging research group “owner” hardware purchases for the campus: As discussed previously, due to implementing the queue/scheduling priorities to capture idle cycles, we have made available a large percentage of the compute cluster usage on otherwise idle compute nodes. As the jobs are pre-emptible by those with allocation, this does not impact the research group’s ability to use their nodes or allocation of resources.

Experimental resources: We continue collaborations with Clemson University faculty supporting experimental data transfer nodes and software defined networking across the US. We are supporting resources for collaborations with Department of Energy ESnet and Indiana University. As part of prototype collaborations with the Flux group of the School of Computing, we have a prototype network in a lab environment for development of innovative ways of managing enterprise networks. We also support resources used in collaborations with Internet2, Florida International University, Mid-Atlantic Exchange (MAX), Indiana University, and others. This includes physically hosting Internet2 VMs for separate disaster services.

Advanced networking: We provide dedicated switch infrastructure to research groups across 615 Arapeen (BMI/CTSA), 421 Wakara (BMI/CTSA, Thatcher 4th floor (Theoretical Chemistry), LS Skaggs (Medicinal chemistry and associated labs), Sutton (Geophys and other groups), Browning (Atmospheric sciences), and groups within INSCC. With the campus NOC, we co-manage the equipment in Arapeen, Wakara, Thatcher, and LS Skaggs. We work tightly with the CMES group in the support of constituents in Sutton and Browning. We also work tightly with the Math and Physics IT groups to support the faculty within INSCC. Beyond simple bandwidth and low latency connections, CHPC provides advanced network technologies through both research and production mechanisms to the campus. CHPC collaborates closely with Utah Education Telehealth Network and the campus NOC to support Software Defined Networking at the front door of several large research testbeds. Our staff provide the day to day liaison and support of the advanced technologies. For example, we provide the advanced network and VM infrastructure for supporting the University of Utah web presence via IPv6 protocols (next generation of network protocols), the high speed interconnects for clusters, and we work with research groups across the campus and nationally to troubleshoot and optimize network implementations in support of the domain science workflows.

Student Success – ugoals: Research computing at UIT now has 7 part-time students working directly on various projects in HPC, advanced networking, active network measurement, storage, user support, security/compliance, and data center support. These students all have designated mentors for these projects and our staff also actively mentor graduate and undergraduate students (10+ over the past year) associated with different Principal Investigators as part of undergraduate and graduate projects within their specific disciplines.

Innovation / New knowledge – ugoals: We have been very active in network and HPC innovation in collaboration with the School of Computing (University of Utah, Indiana, Clemson, and others), genomics groups (University of Utah, Clemson), Astronomy groups and others. The work has yielded articles about CHPC regarding the Science DMZ (University of Utah Science DMZ Opens Doors to More Science, More Collaboration), publications in journals by CHPC staff (The Widening Gulf between Genomics Data Generation and Consumption: A Practical Guide to Big Data Transfer Technology), and papers by CHPC staff (KnowNet: Towards a Knowledge Plane for Enterprise Network Management). These publications have been in addition to the publications in which CHPC has received citations due to its support of the research community (see bibliography). CHPC has also been active in working with campus operations in exploring technologies such as Remotely Triggered Blackhole Routing/Unicast Reverse Path Forwarding on the Science DMZ as a technique for keeping security in line with high performance data transfers. CHPC has worked with the campus security and network teams to deploy these technologies into the main campus network borders. Our staff are currently working with
School of Computing Advance Network faculty, UIT Security, UIT NOC, and campus IT architects to investigate and prototype new methods of managing enterprise networks. School of Computing faculty, students, CHPC, and constituents of INSCC are working to create a prototype network management environment that will hopefully serve as a model for our campus and other institutions. The model would mix very fine grained network provisioning techniques with information from various security data sources to provide different security contexts within broader security zones.

- **Engaged community – ugoals:** Our staff are engaging with the Lassonde Entrepreneurship center to offer workshops that engage students in parallel programming, use of big data, use of compute cycles, and resources that research computing offers. We are also packaging allocation kits to offer students as part of the resources they can utilize in their entrepreneurial investigations. We want to be able to use our expertise to enable entrepreneurs in activities that require compute, storage, network, and security resources throughout their academic career and ultimately into their early forays into the community. Our staff also work tightly with the US Ignite and Utah-Ignite initiatives to take research and advanced technologies into the community and to help foster new private/public relationships. The White House has issued specific Office of Science and Technology directives to develop better public/private partnerships, create Smart Gigabit Cities (US Ignite), and to foster economic development through the use of advanced resources such as GENI technologies. We have been participating in the GENI communities for several years with School of Computing faculty and are now collaborating with UETN staff, UofU faculty, UVU faculty, and members of city and state government in support of these directives and initiatives.

- **Facilitating use of resources:** We recently deployed “modules” as a means to better provide support for different software libraries and versions. This not only enables users by making it easier to deploy their own software stacks but aligns us with best practices employed at other universities and on national resources.
QUOTES FROM USERS: Yearly we send out a survey to PI’s asking about publications, funding and to provide an opportunity to provide feedback on our services. Return of the survey is optional and it is not required to provide comments on our services. Here is a selection of quotes from research groups.

Bart Raeymaekers, Mechanical Engineering: We would not be able to do the simulations we do without the CHPC resources. It also enabled one of my PhD students to obtain three prestigious graduate fellowships from NSF, DOD, and DOE. The support we receive from CHPC is amazing. The team went above and beyond to help us run materials studio.

Chris Pennell, Utah Division of Air Quality: We've enjoyed the speed and reliability of CHPC resources. Having access to a high speed cluster means that our agency can drastically improve our air quality modeling efforts. CHPC staff has always been available to help us, even when we weren't sure our requests were reasonable. The public workshops on using CHPC resources (e.g., Slurm, Python) have helped us make quicker progress in our work.

Chris Hill, Biochemistry: The CHPC was essential for calculations that provided a preliminary EM image reconstruction that was important for an NIH RO1 grant proposal. That proposal received a priority score of 14% in the fall. The institute (NIGMS) is currently funding at about 20%. A funding decision will be made in the next few months. The proposal would have been much weaker without access to the CHPC resources.

Jay Gertz, Oncological Sciences: CHPC has been incredibly helpful in our research. The staff has been very responsive to our requests and there is very little down time. CHPC does a phenomenal job.

John Hurdle, BMI: CHPC is absolutely essential to the research that both of my labs conduct. My clinical natural language processing lab uses the interactive and cluster nodes in the Protected Environment daily. We also rely on the storage resources and that Environment. My nutrition data mining lab also uses CHPC Protected Environment resources daily. Swasey and the homerfs is the mainstay of that effort. We would not have been able to compete successfully for any of the grants described in the attachment above without CHPC resources. That lab also relies heavily on the availability of SAS. Additionally, the CHPC technical staff is super responsive to solving problems from the mundane to the complex. I have been working in computing environments since the 1980s, and I've never met a more helpful and pleasant technical staff.

Katherine Varley, Oncological Sciences: CHPC has been an essential and valuable tool in my cancer genomics research this year. I really appreciate the expert help and advice, prompt support, and expanding resources that CHPC offers. I highlight CHPC as an extremely valuable resource when recruiting new faculty to the UofU and when justifying the feasibility of ambitious studies in grant proposals.

Marc Calaf, Mechanical Engineering: CHPC resources have been crucial for the development of my research's group. The CHPC organization works extremely well, and provide an extremely valuable service to the U-research community.

James Steenburgh, Atmospheric Sciences: CHPC provides excellent support services for our numerical modeling and data analysis needs. We are atmospheric scientists, not computer scientists, and CHPC fills critical knowledge and technology gaps for my research group that we could not fill on our own.

Zheng Zheng, Physics & Astronomy: Computations with CHPC clusters and CHPC-supported astro clusters are crucial for my group's research work on studying galaxy clustering and Lyman-alpha radiation properties. Students, postdocs, and I benefit a lot from such resources and from interactions with CHPC staff.

Nathan Pace, Anesthesiology: Can run statistical models that outstrip capacity of my very capable desktop platforms.
**Thomas Kursar, Biology:** Over the past year the Coley/Kursar lab has begun to utilize CHPC's resources to a greater extent, primarily taking advantage of CHPC's storage and database services as well as Kachina for statistical analysis of our metabolomics data. Through the support of CHPC we have integrated our lab's data into a relational database housed and maintained by CHPC. This framework for data storage has increased our confidence in data integrity as well as facilitated easier access to our data. Beyond data storage we have also greatly benefited from the statistical computing performance of Kachina. Some of our analyses require bootstrapping and other iterative processes that have the potential take advantage of parallel computing. It has now become clear that without the performance boost of Kachina we would likely not be able to run some of these analyses.

**Peter Shen, Biochemistry, Cryo-EM facility:** CHPC plays a central role in my work and success as a scientist. My work involves intensive processing of large datasets and CHPC's access to high-end supercomputing resources enables me to quickly obtain results. CHPC also provides excellent support in maintaining a broad suite of software packages. I also could not be happier with my experience in interacting with CHPC staff. It is not uncommon to receive responses to my troubleshooting inquiries within a couple of hours -- even during non-working hours. I look forward to continuing to work with CHPC.

**Jamesina Simpson, Electrical & Computer Engineering:** Having CHPC resources is instrumental in my being able to obtain funding for our computational work (to be able to list it in the list of facilities available to my group). It is helpful in letting us to run small-scale codes, especially by undergraduates. It is also critical to our progress during gaps between our access to other larger supercomputers. The assistance my students / post-docs receive is also critical to our progress.

**Kyle Dawson, Physics & Astronomy:** The staff are always responsive, informative, reliable, and every positive thing you could imagine. I have not had a negative experience with CHPC and don't have a suggestion for doing anything more effectively.

**Jan Miller, Metallurgy:** Tremendous help for all - faculty, students, and researchers. Always willing to answer questions. Can't say enough good about CHPC resources and staff. We particularly owe Anita, and everyone. Thank you, thank you!

**Feng Liu, Material Science:** The computational resources provided by CHPC are the key for our research work, With sufficient computational hours and the enough data storage space, we were able to publish tones of high quality papers last year.

**Cindy Burrows, Chemistry:** The computational software packages provided by CHPC have been key for running calculations that allowed us to interpret results in 3 publications this year. Moreover, Anita Orendt has been an excellent source of information for addressing issues with DFT calculations and ensuring the results were correct.