Report of the 2016 NSF CyberBridges Workshop

October 21-22, 2016

Rochester, New York

Linwei Wang
Rochester Institute of Technology

Thomas Hacker
Purdue University

Suzanne Shontz
University of Kansas

Table of Contents

1.0 Executive Summary

The fifth NSF CyberBridges workshop for ACI CAREER and CRII awardees was held on October 21 – 22, 2016 at the Rochester Institute of Technology in Rochester, NY. This workshop was dedicated to the discussion of the growing challenges and potential solutions to support interdisciplinary research and education in cyberinfrastructure (CI). This theme was selected to recognize a common and priority problem that has coherently emerged from discussions in prior CyberBridges workshops: the increasing need of an interdisciplinary workforce in CI, and the inability of the dominant disciplinary model of current higher education to adequately support the development and growth of such an interdisciplinary CI workforce.

A total of 12 NSF CAREER or CRII awardees and 6 invited speakers participated in the workshop. The invited speakers presented on the coherent theme of the challenges and solutions to support interdisciplinary work in three broad areas: Programs and Centers, Research, and Education. Presentations in each area were followed by two focused discussion sessions to identify the priority root causes underlying the challenges in each area, and to devise initial solutions to ameliorate these problems.

Through the invited presentations and the discussions, participants of the workshop identified the following priority problems that need to be addressed, and potential initial strategies that can be implemented at different levels to address these problems.

- The initial high investment necessary to establish an inter/multidisciplinary effort compared to usual disciplinary work
    - Problems: This includes the longer period of time for incubating an interdisciplinary center or program, the challenge and extra effort in teaching an interdisciplinary course due to the diverse background of students and the preparation of course materials across multiple disciplines, and the time and overhead needed to establish common communication ground and group management for an effective research collaboration.
    - Solutions: The potential solutions include encouraging recognition of the additional efforts and overhead necessary for multidisciplinary work, training soft skills and management skills for faculty, and streamlining and optimizing administrative burdens related to collaboration.
- The lack of reward structure to evaluate and recognize interdisciplinary work
    - Problems: This includes the lack of incentive for the participation and leadership in interdisciplinary centers/programs, the lack of metrics for generation of artifacts and tools as a result of interdisciplinary work, and the lack of recognition and rewards for the extra efforts required for interdisciplinary teaching.
    - Solutions: The potential solutions include faculty-level memorandum of understanding initiated at hiring to ensure the recognition of non-traditional artifacts generated from interdisciplinary work, interdisciplinary centers or

    colleges that grant tenure, and incentives from the administration level to encourage and support interdisciplinary activities.

- The inherent challenges in seeking and securing funding
    - Problems: This includes difficulties to secure funding to sustain an interdisciplinary center or program once established, to identify appropriate funding mechanisms to support interdisciplinary research, to seek funding for preliminary work necessary to write competitive proposals, and to seek funding that is significant enough to support larger, multiparty research teams.
    - Solutions: The potential solutions include seeking overt and clear support from NSF leadership for new and collaborative projects.

2.0 Workshop Overview

Beginning in 2012, the community of NSF CAREER awardees funded by the Division of Advanced Cyberinfrastructure (ACI) within the Directorate for Computer and Information Science and Engineering (CISE) at the NSF has met annually at individual workshops with the objective of providing a venue for CAREER awardees to meet other early career faculty working in the areas of cyberinfrastructure and computational- and data-enabled science engineering and to learn about and discuss advances and pressing problems in topical areas related to cyberinfrastructure from senior leaders from academia and government laboratories. The workshops helped to build bridges among early career faculty and faculty leaders in the areas of education and research that involve cyberinfrastructure. Over the past four years from 2012 to 2015 (reports from prior workshops [1][2][3][4] are available on the web, and are accessible from http://cyberbridges.org/2016/past-conferences.html), the workshop has been attended by 71 unique NSF CAREER faculty awardees from 55 unique institutions, 19 unique keynote speakers from 16 unique institutions, and 21 unique NSF speakers and program directors – a total of 111 unique attendees over the four-year period. Of the 71 CAREER awardees, 43 attended one workshop, 15 attended two workshops, 8 attended three workshops, and four attended all four workshops. Two of the keynote speakers (Sushil Prasad and Ed Seidel) attended two of the workshops, and seven NSF speakers and program directors attended two workshops.

The 2016 workshop, different from prior workshops, had a more focused theme on the challenges and solutions for supporting interdisciplinary research and education. The specific objectives of the workshop were to 1) identify priority problem areas that constitute the fundamental causes of the challenges in interdisciplinary CI research and education, and 2) devise an initial set of strategies, approaches, and potential solutions that could be implemented at a personal, organizational, and/or national level to ameliorate these problems. To facilitate a focused discussion, the 2016 workshop was organized to bring together a smaller cohort of faculty members compared to prior years. In the meantime, to include faculty members at all career stages, the attendees were extended to CRII awardees. Overall, the workshop was attended by nine NSF CAREER awardees, three NSF CRII awardees, and six invited speakers from eighteen institutions.

The workshop was structured to provide adequate time for focused discussions and networking centered on the topic areas of supporting interdisciplinary centers/programs, research, and education. The 1.5-day workshop was divided into three sessions, each focusing on one of the following three topic areas: interdisciplinary centers/programs, interdisciplinary research, and interdisciplinary education. Each session included two presentations by invited senior leaders in the topic area, and two discussion sessions with one focusing on identifying priority problems to be addressed in the topic area, and the other focusing on devising initial solutions to ameliorate the identified problems. The format of each session is an alternation of the invited presentations and the discussion sessions, with each presentation followed by a breakout discussion session. At the end of each breakout session, a scribe in each group briefly reported on a summary of the discussions in the group.

2.1 Workshop Attendees

Nine NSF CAREER awardees, three NSF CRII awardees, and six invited speakers attended the workshop, from eighteen institutions. Nine of these attendees were funded at least in part through the Division of Advanced Cyberinfrastructure, while others held awards funded through two other directorates and three other divisions, including Materials Research (MPS/DMR), Chemical, Bioengineering, Environmental and Transport Systems (ENG/CBET), and Civil, Mechanical and Manufacturing Innovation (ENG/CMMI). Figure 1 summarizes the distribution of CyberBridges 2016 attendee CAREER and CRII funding sources.

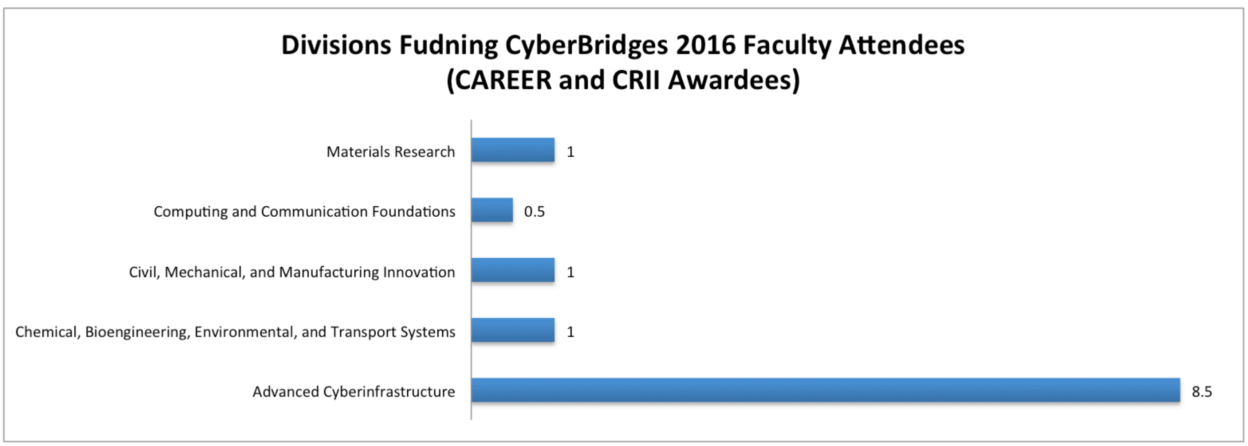


Figure 1. Distribution of NSF divisions funding 2016 CyberBridges Workshop attendees.

2.2 Attendee Selection Process

Because of the focus of this year's workshop on interdisciplinary challenges, the attendees were selected based upon two primary considerations. The first aim is to bring in an interdisciplinary set of researchers and educators in both cyberinfrastructure-focused and cyberinfrastructure-enabled research. This was achieved by reviewing the research interests and NSF-awarded project abstracts of the attendees. The second aim is to bring a cohort of faculty members with a balanced set of career stages ranging from early, mid-career, to senior levels. In specific, this workshop extended the attendee selection from NSF CAREER awardees to CRII awardees to involve early-stage interdisciplinary researchers. In addition, a prioritized invitation process was used so that individuals who have frequently attended previous CyberBridges workshops, i.e., those who have maintained an active presence in the CI community, were invited first. Among the five attendees who were selected from those attended previous workshops, one attended all four previous workshops, two attended three of the previous workshops, one attended two of the previous workshops, and one attended one of the previous workshops. Finally, ACI funded or co-funded CAREER/CRII awardees were invited first, followed by awardees from other NSF directories and divisions whose research has an important computational- and data-enabled component.

Figure 2. Eighteen workshop participants attended the 2016 CyberBridges Workshop. Shown here is the workshop during the interaction between the invited speaker and the audience.

3.0 Workshop Themes

Under the unifying theme of supporting interdisciplinary CI research and education, the topic areas of this workshop were divided into three areas: 1) interdisciplinary program and centers; 2) interdisciplinary research; and 3) interdisciplinary education. Each topic area consisted of two invited talks given by senior leaders in each area, mixed with two breakout sessions among all workshop attendees to identify the priority problems and devise initial solutions in supporting interdisciplinary efforts in each topic area.

1. <u>Supporting Interdisciplinary Program and Centers</u>

Invited speakers

Jose-Marie Griffiths, Dakota State University

Dr. Jose-Marie Griffiths, President of Dakota State University in South Dakota, has significant experience in the creation of various centers and programs at many different types of institutions. She spoke to attendees about how she created the Madison Cyber Labs, i.e., MadLabs, at Dakota State University. The focus of the MadLabs is cybersecurity. In each lab, a research cluster was formed around a subfield of cybersecurity, such as digital forensics, banking security, and cybersecurity education. Dr. Griffiths presented a case study on the creation of MadLabs.

The goal of the case study was to establish MadLabs and to secure buy-in from the South Dakota Board of Regents and approval from the South Dakota State Legislature for an associated research and development facility at Dakota State University. Achieving this would help Dakota State University retain its position of leadership in cybersecurity. In particular, the university had a large number of cybersecurity students and a large College of Computing; it was well-regarded by the National Science Foundation, the Federal Bureau of Investigations, and the Department of Homeland Security in this area. So the establishment of MadLabs and a research and development facility for cybersecurity represented an important opportunity for the university. The South Dakota Board of Regents had established research-based economic development by state universities as a priority, particularly since South Dakota had been losing a significant number of college graduates to other states due to a lack of appropriate employment opportunities. Hence it was important to establish how MadLabs would keep and leverage South Dakota's talent and expertise through the creation of opportunities for economic development through research. It was argued that Dakota State and Madison could be a hub of economic development for the region based on cybersecurity resources by building upon South Dakota's leadership role in national defense. It would also be important to brand/position the university as one that offered technology-intensive and technology-infused degrees and also conducted cybersecurity research. A video on the MadLabs concept was created and was presented to the Board of Regents and the State Legislature to great effect; economic development was a key component of the video. A large dinner was also held with prospective donors in order to seek donations for the research and development facility. A significant amount of time was also spent building relationships with alumni, donors, and partners in addition to university faculty and the university administration.

There were several challenges to be addressed throughout the creation of MadLabs. One challenge was determining how to navigate the political climate in South Dakota involving the Board of Regents, the State Legislature, and the other state institutions. The strategy adopted to navigate the political landscape in South Dakota is summarized above in the case study report. A second challenge was the hiring of new faculty. Many faculty have been at Dakota State University for a long time, and the university is now trying to hire some new faculty. In order to build a pipeline of faculty, they decided to start a postdoctoral program. The goal is to train the postdocs and keep them on as new faculty. Another challenge was fundraising. Now that funds have been committed for the building, funding must be raised for ongoing MadLabs activities.

Figure 3. Presentation by invited speaker Dr. Jose-Marie Griffiths

Michael Sacks, University of Texas at Austin

Prof. Michael Sacks, Director of the Center for Cardiovascular Simulation (CCS) at the University of Texas at Austin, gave a presentation to attendees on his efforts to establish the center. CCS spans the Institute for Computational and Engineering Sciences (ICES) and the Department of Biomedical Engineering (BME). At the time of the workshop, CCS had been in existence for about nearly five years.

The goal of the CCS is to bring together a team of researchers to conduct research in computational modeling and simulation of the cardiovascular system. A major focus of CCS is the biomechanical function of the heart valves. CCS builds on the existing strengths of ICES and BME. In particular, ICES is a world-class institute with strengths in computational science and engineering, and BME is a department with strengths in experimental biomedical engineering. Collaborations with surgeons are also essential to the success of CCS.

Dr. Sacks presented a SWOT analysis as a mechanism for presenting challenges and solutions that arose in the creation of CCS. In regards to strengths, ICES is a world-class institute with top faculty, top-notch infrastructure and resources, high-quality students and postdoctoral fellows, and the potential for supplemental philanthropic support. CCS can take advantage of all of these strengths through its relationship with ICES. CCS has phenomenal opportunities to act as a center for computational excellence, along with ICES, in collaboration with the new Dell Medical School and Texas's top medical centers in the nation. The trends in medicine and medical devices are moving towards the use of computational methods for assessment, design, and in-silico experimentation, and CCS can be a leader in this area.

In regards to weaknesses, there are challenges that stem from the interactions between centers/institutes and departments. In particular, large, well-funded departments want to do everything themselves instead of working in a collaborative manner. In addition, faculty members in such departments often have an ivy-tower mentality and only want to do work they perceive as top-level fundamental work, hence leaving the applied work to others. In such departments, conducting research in collaboration with another department can be perceived as a negative contribution. The research that is perceived as acceptable and beneficial and what is not is very personal and very subjective. For these reasons, it can be difficult to do transdisciplinary research, i.e., computational medicine in the context of a center as opposed to individual research departments. There are also academic culture differences to navigate when working with collaborators from other departments.

There are also threats to CCS, many of which are related to the difference in the structures of centers/institutes versus those of departments. In particular, departmental structures that evolved for the purposes of meeting the education mission are not ideal for transdisciplinary research institutes/centers. Another threat is the inability for faculty lines to reside in non-traditional departmental structures. There is also a challenge to get the right people interested in participating in the research center. Steady funding sources and sunset plans are also needed, as centers typically last for about ten years. Institutional rivalries – both external and internal – can also threaten a center.

In conclusion, Dr. Sacks advised that it is important to have a vision when initiating a research center/institute and to stick to that vision without worrying about what others may think. It is important to stay very focused despite this not being an easy thing to do. In the beginning, people may not be open-minded and may be turf conscious. Eventually people will believe in your idea once they see the center being successful.

Breakout sessions

Problems associated with establishing an interdisciplinary center or institute

Blue group (Scribe: Metin Aktulga)
The group identified several conflicts regarding the organizational structures and policies between traditional academic units and interdisciplinary research centers and institutes which may hinder the successful incubation of such centers and institutes. First, the group noted that interdisciplinary research, by its very nature, takes a significant amount of time to bear tangible results. This is because researchers from different fields need to learn how: (1) to talk to each other, (2) to understand priorities in a different field than their own, and (3) to develop solutions through cross-fertilization. To establish a sustainable collaboration, the researchers must be able to identify mutually beneficial avenues of research. Such avenues are not immediately apparent at first sight. Thus, a major issue is balancing the expectations of academic units within a university environment, which are typically focused on short-term outcomes, whereas an interdisciplinary research center or institute needs a long-term investment for it to take off.

Evaluation of research outcomes is another issue. Often research involving a cyberinfrastructure component will have software or other computational tools as a part of the outcomes. Over the years, publication media has adapted to such outcomes by establishing new tracks for software within existing journals and by establishing new journals dedicated to open source software. However, development of a solid cyberinfrastructure for high-quality science and engineering requires significant resources, often in the form of human hours, and the criteria established for evaluating a faculty member's research in a traditional academic unit typically does not include metrics for measuring the significance of such research and development artifacts. Lack of proper evaluation metrics also leads to other issues. In fact, faculty's cyberinfrastructure research may receive a lower evaluation rating due to the lack of proper cyberinfrastructure evaluation metrics. Alternatively, some faculty may decide to pursue a research agenda devoid of a cyberinfrastructure component so as to receive higher evaluation ratings.

Other major challenges are related to faculty recruitment and retention. This is because centers or institutes in a university environment are typically not tenure-granting units (there are a few notable exceptions). As such, faculty who are part of these centers have tenure homes which are generally traditional academic units. It can be very overwhelming for a new faculty member to fulfill the expectations of his/her tenure-granting (home) department while trying to initiate interdisciplinary collaborations. This can create issues with both recruiting of faculty and retaining existing faculty in such centers/institutes.

Red group (Scribe: Lorena Barba)
The group identified several conflicts in regards to academic processes, the environment, materials, and people in centers and programs. For example, in regards to academic processes that affect research centers and programs, tenure-track faculty are primarily focused on earning tenure. There should be no penalty for early career researchers to participate in research centers or programs. In regards to the evaluation metrics for tenure, the path is clearer in traditional disciplines and less clear for interdisciplinary researchers. For example, interdisciplinary work often involves generation of artifacts and tools that may not be as valued as traditional means of contributing to science, such as generation of ideas and discoveries. Hence, pre-tenure interdisciplinary researchers are under tremendous pressure to establish themselves and to be successful in earning tenure.

Group members also noted a difference in how departments and centers are set-up. Department structures are inward looking due to the teaching mission. Given that classes are not taught through research centers, there is a conflict between teaching disciplines and research centers. Adding to the conflict is the fact that students want to get a degree in a certain discipline because it is clearer how such degrees align with expectations and job opportunities.

Challenging to navigate are the different cultures present in centers at various institutions. Some have deep silos, whereas others have a homogeneous “group think” mentality. At some institutions, there are old-fashioned traditions. Cultural divides are also present due to publishing in conference proceedings versus journal papers, whereas other disciplines even publish monographs. Disciplines themselves can even exhibit cultural divides. For example, in biomedical engineering, there is a huge schism between the informatics people and the PDE people, which makes it challenging to collaborate with people across the field. Connections can be made by people who are able to “bridge” computing with a domain science by talking the common language of each.

Another challenge in starting a research center or program is a lack of sufficient funding for the new effort to become sustainable. In fact, research centers fall apart often due to a lack of sustained funding.

Group members noted that a center that is run more like a department and has its own building has more changes of success. For example, this is how ICES is run.

Green group (Scribe: Baskar Ganapathysubramanian)
The group identified several challenges associated with establishing an interdisciplinary center or institute. First, the group noted that there is no incentive to build up interdisciplinary research teams. Academic departments and the institution should help incentivize the building of such teams via seed funding opportunities. Similarly, there is no appropriate reward structure that encourages participation and leadership of interdisciplinary research centers or institutes at the university and community levels. Potential incentives for this include chair professor positions as well as awards from professional societies. A third challenge is that tenure and promotion decisions are still made according to departmental silos which makes it hard to initiate interdisciplinary research and participate in interdisciplinary center as a junior faculty member. Finally, teaching interdisciplinary courses for the next generation of scientists and engineers does not seem to be highly valued – especially if it cuts across departments which results in complicated financial/accounting issues. Accordingly, students often do not receive the training they need to participate in interdisciplinary research initiatives.

Potential solutions to support interdisciplinary centers and institutes

Blue group (Scribe: Linwei Wang)
The group identified several potential solutions which could aid in the establishment of interdisciplinary research centers and institutes. First, when an interdisciplinary faculty member is hired, a memorandum of understanding outlining the expectations for the faculty member's research (e.g., how they will split their time between various academic units, what are appropriate metrics for their scholarship, etcetera) should be signed by the department chairs and the dean. This MOU should be revisited at the time of tenure and promotion. Second, the group determined that the purpose of creating an interdisciplinary research center is to create an identity, a research focus, and a branding that can be used to reach out to other institutions/groups to initiate new collaborations. It is important to recognize that, although not all institutes can be huge efforts like the Beckmann Institute at the University of Illinois Urbana Champaign or ICES at the University of Texas at Austin, it is still important to create a center or institute for the above reasons. Third, the group noted that it is possible to mix the research mission of an institute with the educational mission of the university. For example, ICES has a doctoral program. This is unique because the university wants degrees to be granted by academic departments. Similarly, the SUNY Buffalo has a Computational and Data-Enabled Science and Engineering (CDSE) Ph.D. program, which is similar to the doctoral program at ICES, and is not attached to a department. The group felt that doctoral programs attached to centers are a good thing if they are set-up correctly. Another model is the placement of a

doctoral program at the college level, such as is the case at Rochester Institute of Technology.

Red group (Scribe: Thomas Hacker)
The group discussed potential solutions to several problems, which were: 1) no reward or penalty for early career faculty who engage in interdisciplinary work; 2) an inwardly focused departmental structure; and 3) existing criteria for tenure and promotion. Many potential approaches for addressing the problems were discussed by the group. From this set of potential solutions, the group identified several that were deemed to have the most potential for making an impact that were likely to be implementable. The first of these was the need to establish the sense that interdisciplinary work is valued within the institution. Second, the need for funding agencies to set the tone for valuing interdisciplinary work to communicate the value of this type of work to colleges, departments, and faculty who evaluate tenure and promotion cases. Third, another potential approach is to establish a methodology that could be broadly used to evaluate the value and impact of software and data artifacts created by early/mid career faculty. Finally, there is the need for recognizing the contributions of all of the members of an interdisciplinary team, and the value of the contribution as a co-partner in an interdisciplinary effort.

Green group (Scribe: Alexander Alexeev)
The group identified several potential solutions to promote the establishment of interdisciplinary research centers and institutes. Their discussion emphasized the role of the administration in supporting interdisciplinary research and facilitating interactions between various departments. In particular, the Dean's Office could provide incentives in order to encourage faculty to embark on interdisciplinary research activities. Faculty should see the support from the administration as a clear sign as to the importance of interdisciplinary research. Similarly, it helps them realize the clear benefits associated with developing interdisciplinary research programs involving multiple departments despite the associated risks. It is also important to streamline and minimize the administrative burden placed on interdisciplinary faculty related to collaborating with faculty in different units. For example, it should be straightforward to submit a research proposal with faculty across departments and colleges. This includes not needing to be concerned with various models of overhead distribution across campus.

2. Supporting Interdisciplinary Education

Invited Speakers

Jeffery Humpherys, Brigham Young University

Dr. Jeffery Humpherys from Brigham Young University (BYU) talked about his experience with a new and successful degree program in applied and computational mathematics that he spearheaded in BYU. He discussed the national challenge that mathematics is becoming a barrier for people to go into STEM, and described his experiences with several funded efforts in trying to attract and retain students into STEM by empowering them with mathematics.

Dr. Humpherys first discussed the IMPACT (Interdisciplinary Mentoring Program in Analysis, Computation, & Theory) program that, funded by the NSF Division of Mathematical Sciences, aimed to develop a new model for research & education in math sciences with integrated strengths in computation. This one-year program consisted of summer boot camp and school-year research, with an aim to allow students to see the common mathematical concepts underlying many different problems in different disciplines. While this program produced significant outcomes after five years of funding by the NSF followed by four years of corporate scholarships, Dr. Humpherys noted several important lessons learned that eventually led to his vision in the new degree program. Most importantly, it was learned that large-scale undergraduate research is financially unsustainable without heavy financial support. Instead, a model is needed to truly integrate research and mentoring into the curriculum, and this curriculum model needs to be tightly coordinated to allow more efficient teaching. There is also a need to rethink how to teach computation and to incorporate applications in courses.

These experiences led to the design of a new degree program from the ground up. Despite initial resistance, this degree program is now in its fourth year of running with excellent outcome. Dr. Humpherys outlined a few major components that made the program successful. This includes a new and modern curriculum that cut through the jargons of various disciplines, a horizontal integration to give students a broad exposure to several interdisciplinary fields, training in leadership and soft skill, the integration of a computer lab with every course to foster strong technical skills in computation and data analytics, and the integration of research and mentoring into the curriculum through term projects. Finally, Dr. Humpherys concluded the talk with two important and useful strategies that made the degree program successful and efficient: a lock-step model for integration across topics, and a cohort model for retention and team building.

Sushil Prasad, National Science Foundation

Dr. Sushil Prasad from the National Science Foundation described a new NSF program *Training-based Workforce Development for Advanced Cyberinfrastructure (CyberTraining)* that aims to prepare, nurture and grow the national scientific workforce for creating, employing and supporting advanced CI leading to advancing cutting-edge science and national economic wellbeing and security. This is a cross-cutting program that concerns the community of CI professionals, contributors, and users. It encourages the development of informal training and cross-training models in CI computational and data science topics for these three communities. It also aims to broaden the access and adoption of CI by various institutions and scientific communities. Dr. Prasad encourages the PIs to think about challenging problems such as how to prepare better scientific workforce for advanced CI, to broaden the adoption and accessibility of shared computing and data resources, to complement and leverage the state-of-the-art in curricular offerings and materials, to create alliances and backbones for collective impact, to provide on-demand personalized accessibility, to explore innovative ways of attracting students into computational disciplines, to identify areas of workforce demands and career pathways, to innovate training, curriculum, and educational models and their sustainability, and to leverage and contribution to NSF cyberinfrastructure and research projects. The long-term goal of this program is to lead to an educational CI ecosystem that can enable "computational and data science for all", to establish deeper cross-discipline engagement, to develop instructional material and curricula that can guide best practices in teaching guidelines and standard formulations for minimum skill sets, to establish clear career growth pathways for CI communities, and to result in an ubiquitous and scalable educational cloud infrastructure for online education in CI and other multidisciplinary areas. Dr. Prasad encouraged all workshop attendees to consider this funding program as an opportunity to contribute to interdisciplinary CI education.

Breakout sessions

Problems related to Interdisciplinary education

Blue group (Scribe: Dominik Schillinger)
The blue group discussed a number of obstacles that impede the introduction of interdisciplinary components in established classes and the implementation of new classes with an interdisciplinary focus. From a faculty point-of-view, there is the defensive attitude of established educators who object to existing classes getting less time in the curriculum. It is a natural attitude that everyone tends to think his or her (disciplinary) class material is the most important. Another key obstacle is to motivate faculty to teach those classes, which would go beyond typical materials in established

syllabi. To establish new classes, there is a significant starting effort in terms of preparing new course modules and compile materials, which requires a lot of work, in particular as interdisciplinary textbooks that cover all course aspects might not exist. From a student point-of-view, there are several other obstacles. Students are often unprepared to take interdisciplinary classes due to lacking background in fundamentals, in particular mathematics and physics. In this sense, it is unclear for educators who want to establish interdisciplinary course components to understand what can be expected from students. Another potential problem in this context is to maintain student demographics in these classes, in particular with respect to equal participation of women and underrepresented groups. Attaining top grades is a major concern for students, so they will tend not to risk their GPA by taking a "hard" class, which focuses on fundamental topics in mathematics, computer science and computational engineering. Special certificates and certifications that complement the regular degree could be a suitable tool to motivate students to take those classes.

Green group (Scribe: Suzanne Shontz)
Attendees in the green group noted several challenges with interdisciplinary education. From the student perspective, students might not want to enroll in a class which they feel is more challenging, as they will be required to learn the language of another discipline. Students may be concerned that their GPAs will be lower as a result. In addition, STEM majors often include a large number of required classes and very few electives, thus making it harder for students to fit in an interdisciplinary course as an elective. Students at the undergraduate level would likely have a difficult time acquiring sufficient depth in a single discipline (as is often required for employment at the bachelor's level) by enrolling in an interdisciplinary program. In contrast, graduate students are more likely to gain the skills needed for employment at the master's or doctoral level from participating in an interdisciplinary graduate program.

From the faculty perspective, it can be challenging to teach such a course, as students come from different majors and thus different backgrounds. To make such a class understandable for the students, faculty often need to add parallels between the material being taught and several other fields, which can be hard for faculty who have been trained in one field to accomplish. Administration of interdisciplinary courses is also difficult, as it can be hard to coordinate the scheduling of such courses among interested departments. Faculty are also expected to teach a certain number of courses each year for their respective departments. Thus, it is often not clear which course faculty should remove from their teaching load in order to offer an interdisciplinary course.

Departments also face challenges in regards to offering interdisciplinary courses. For example, at some universities, departments only receive tuition dollars for majors enrolled in the course, as opposed to all students who enroll in it. Second, it can be difficult to release a faculty member from teaching one of their departmental courses in order to teach an interdisciplinary course. It is also challenging to then evaluate the faculty member on teaching such a course.

Red group (Scribe: Thomas Hacker)
The group, for which the conversation was focused on problems, discussed the areas of environment, management policies, and process. In term of environment, the challenge is how to teach a class in which students have very diverse backgrounds, which is a challenge for interdisciplinary classes. Also, establishing prerequisites for a class is a challenge when students have very diverse backgrounds, and students as undergraduates do not have a clear vision of who they could be (professional identity) at the end of their studies. Changing the curriculum can be very difficult due to the inflexibility of the curriculum. Faculty need to be more active as a body in reviewing and updating the curriculum. In terms of management and policies, for pre-major students, most of the courses are taught by teaching faculty.

Figure 4. Invited speaker Jeffery Humpherys participates in a breakout discussion

Solutions to problems related to Interdisciplinary education

Blue group (Scribe: Paul T Bauman)
The group discussed multiple aspects in the challenges for interdisciplinary education but focused mostly on strategies that can be achieved at the program level. Two of the attendees in this group come from institutes that have an interdisciplinary computing PhD program that is not tied to a traditional disciplinary department but has faculty affiliations from across the campus. The group felt that an interdisciplinary program like such is an effective top-down approach to support interdisciplinary education, as policy and procedures can be put in place to ensure an interdisciplinary curriculum at design (by the proper balance of core courses and elective courses) and to recognize faculty effort in developing such course materials. Challenges do exist in ensuring a proper balance of depth and breadth that are suitable for the enrolled students who are expected to have a background that is more diverse than those enrolled in a traditional disciplinary program. It requires continuous revision and updating of the curricula as the program grows and expands.

Red group (Scribe: Thomas Hacker)
The group considered several possible solutions and recommended several to the problems challenging interdisciplinary education. The first recommended solution is that faculty should have a formal process for program review to facilitate the adjustment of course content. Also, in the freshman year, it can be helpful to allow more experiment in terms of classes, and to ask faculty to give a "sales pitch" for later multidisciplinary courses. Also, it is recommended to use a combination of lectures and labs for multidisciplinary types of courses to ease learning for student, and to add required content focused on "soft skills" to train students to work better with others.

Green group (Scribe: Alexander Alexeev)
Attendees in the group came up with various potential solutions as to how interdisciplinary topics could be taught. First, it would be helpful to front load information into lower level classes. Second, courses should focus on both depth and breadth of knowledge and learning. Third, it would be helpful for interdisciplinary courses to be team-taught. For example, a computational mathematician and a geologist could team-teach a course on the use of numerical optimization methods in groundwater simulations. Fourth, it would be helpful for computer scientists and mathematicians to spend time talking with scientists and engineers and vice versa. Fifth, textbooks are important to ensure that courses developed as a result of interdisciplinary collaboration among faculty from different departments will be continued even if one of the involved faculty leaves the program. Sixth, more interdisciplinary graduate programs are needed so that students will be trained to innovate in the 21st century. Seventh, the outcomes of reports such as the SIAM Computational Science and Engineering Research and

Education Report should be adopted. Finally, attendees felt that discussions pertaining to a national level policy on interdisciplinary education are needed.

3. Supporting Interdisciplinary Research

Invited Speakers

Paul Avery, University of Florida

Dr. Paul Avery from the University of Florida discussed the issues involved in building cyberinfrastructure for petascale science, focused on multidisciplinary collaborations among high-energy physicists, and computer scientists and technologists. He described his experiences with the NSF funded GirPhyN project, iVDGL, ExTENCI, and the Open Science Grid projects. The primary driver for the projects he has been involved in is high-energy physics, with the goal of studying particle collisions at high energy to gain insights into fundamental particles. He also described his experiences with Compact Muon Solenoid project located at the Large Hadron Collider at CERN. Over time, he has observed that the physics projects have grown in scale in terms of people, costs, and institutions to a truly global enterprise. One important aspect he mentioned is the enculturation of people to work to succeed in a collaborative environment. The collaborative infrastructure includes CI as well as meeting technology (e, g. video conferencing) to help facilitate the activities of the physics community. He also found that a close working relationship with the funding agencies was helpful. The CMS collaboration, for example, includes 3381 scientists and engineers from 173 institutes in 40 countries. The LHC has already collected around 500 Petabytes of data so far. Dr. Avery also described multi-institution grid projects. Dr. Avery descried some of his experiences with GriPhyN that involved collaboration with computer scientists. The goal of the project was to develop and research ways of using distributed computing for data-intensive science. Computing research areas in this project included efforts in Pegasus, Swift, and Globus. He also described iVDGL, which focused on a combination of CS and Physics projects, with the goal of developing CI for large experiments.

The advantages of working together in a joint effort included: a culture that allowed participants to share results and best practices; and an environment that allowed the project to achieve ambitious CI goals for the nation. The Trillium project was a joint effort that coordinated activities from Gri2003, iVDL, PPDG, and GriPyhN. He discussed factors that allowed the Trillium project to succeed: common personnel, an established collaborative and multidisciplinary culture; a broad base of computing and software expertise; and the deep involvement of leadership. Also, the goal of building a concrete artifact, as well as the support of funding agencies helped the project to succeed. Dr. Avery finished up with a description of challenges for large CI projects. These challenges included managing the complexities of a multidisciplinary collaboration across multiple institutions; cultural differences among disciplines; understanding and addressing sociology of managing a large collaboration; and motivating subprojects to work toward common goals.

Carol Woodward, Lawrence Livermore National Laboratory

Dr. Carol Woodward discussed her experiences with multidisciplinary work from the perspective of her experience working in a national laboratory. She described the typical project lifecycle that is followed when conducting projects at the Center for Applied Scientific Computing (CASC) at Lawrence Livermore National Laboratory. This cycle has three constituent elements: 1) application needs that drive research into the development of software libraries, tools, and modules; 2) writing software to translate the results of the research; and 3) deploying the software into applications. Dr. Woodward described four examples of multidisciplinary projects that ranged from dislocation dynamics to subsurface flow. She described her experiences and challenges involved in each of the four projects. The challenges in these projects included: getting an adequate level of information about the underlying mathematical models as well as a test framework that could be used to test methods, and the need for clearly articulated technical goals and test problems; communication across disciplines within the teams; and the definition of specific problem requirements needed to make the resulting code relevant to solving the problem. Overall, the challenges in engaging in multidisciplinary work she described are: 1) the long ramp-up time needed to move up the learning curve across disciplines; 2) finding the right kinds of problems with potential for both early results as well as long-term impact; 3) establishing work roles across domains; and 4) developing synergistic collaborations that can fully leverage the expertise of all of the members, instead of one group assuming that they know the best solution without a sufficiently deep understanding of the problems and approaches used in the other domains. Effective functional leadership is essential to help manage the work and to keep the project moving forward. Dr. Woodward's recommendations to help to create successful multidisciplinary collaborations include: addressing the social aspects of building trust through frequent communication; considering the group to be a team ("we" instead "us and them"); forging common project goals that are beneficial to everyone on the team; and ensuring a fair distribution of credit for the work across the team. She recommended that universities consider how to value multidisciplinary work for promotion and tenure, such as the value of multiple authored papers and the significance and impact of the software developed by team.

Breakout sessions

Problems related to Interdisciplinary research

Red group (Scirbe: Hari Sundar)
The group discussed the factors that contributed to problems related to interdisciplinary research. These factors include the areas of sociology, funding agencies, resources, and management. In the area of sociology, establishing a common ground for communication (such as establishing the definitions of terms), managing group dynamics (such as overlap in expertise), establishing trust, and developing a mutually beneficial collaboration rather than simply providing expertise, represent critical problems that can affect the team. In the area of funding agencies, the hierarchical division of NSF into domains for funding as well as review panels unnecessarily complicates the process of seeking funding for researchers interesting in pursuing funding for multidisciplinary projects. In terms of resources, the confluence of larger, multiparty research teams and the need for all involved to receive a significant level of funding in a funding environment in which there are limited allocated funds makes it difficult to build well-functioning multidisciplinary efforts. This is complicated by the significant additional effort and overhead needed to successfully manage a multidisciplinary effort.

Green group (Scribe: Omar I. Abdul-Aziz)
The group discussed several issues. The first was the problem of finding people with expertise in specific domains on university campuses. Ideas such as collecting researcher resumes into a searchable central database were discussed. The second area focused on seeking funding for preliminary work necessary to write competitive proposals. This is an issue when seed funding is not readily available from universities. Another area was in the topic of cybersecurity for sharing and storing data. The final areas were related to effective collaborations, the problems related to a gap in understanding the other collaborators' domain knowledge and research problems in their area, and the need to train students to value and engage in multidisciplinary work.

Blue group (Scribe: Dominik Schillinger)
The group discussed the challenges and pitfalls related to participating in interdisciplinary research project from the point-of-view of a researcher who is providing expertise in computing. It is important for the researcher to be able to maintain their own interests in a project that may be focused primarily on domain outcomes. This is especially important for junior researchers who need to attain tenure. To address this, it is critical that these researchers be given a degree of latitude necessary from them to establish and pursue research components within their own discipline in addition to the domain outcomes they are helping to achieve. Moreover, the reward structures within their department and

college needs to value the additional work needed beyond the usual level of effort necessary to create and sustain interdisciplinary efforts.

Solutions to problems related to interdisciplinary research

Red group (Scribe: Thomas Hacker)
The group discussed potential approaches for problem solving related to interdisciplinary research. The lists below include recommended (*) actions. The approaches that ranked highly doable in terms of implementation were: encourage the development of generalists – the need for "T" type of people who are generalists as well as having great depth in one area; (*) provide training on behavior styles and cross-generational differences (soft skills); (*) seek overt and clear support from NSF leadership for new and collaborative multidisciplinary projects; providing substantive experiences in multidisciplinary projects for students; organize faculty and appointments to allow and encourage faculty to be engaged and involved in more than one discipline and to foster innovation and entrepreneurship in faculty; broaden the perception of academic output to include artifacts than papers alone; and seek to encourage recognition of the additional efforts and overhead necessary for multidisciplinary research.

In addition to these potential solutions, the approaches discussed that potentially have great impact were: (*) train more leaders to manage projects, select personnel, project management, and communications; deliberately manage where faculty/students sit, interact, and work to avoid grouping people by discipline, and mix things up to encourage the development of new multidisciplinary collaborations.

Green group (Scribe: Lawrence Loewe)
Laurence Loewe submitted a synopsis related to strengthening those aspects of science that are fundamental to its operation, performed by almost all researchers, however not appropriately recognized. His analysis suggests that under certain circumstances these aspects can be grouped by allowing inclined researchers to mostly focus on corresponding tasks and greatly increase their overall efficiency by batching them. Some of these aspects of science might be well captured by roles such as teachers, explorers (break new ground), toolmakers (establish new approaches), producers (make new observations), integrators (connect knowledge scattered across disciplines), debuggers (question reproducibility of results and identify sources of errors), and guardians (protect hard won expertise from falling into oblivion and help shape research agendas by pointing out gaps of knowledge through mentoring and reviewing). Given the right cyber infrastructure for enabling efficient communication and search of known results, such specialization could boost research efficiency by leveraging scaling effects from batching, if indeed these researchers

are allowed to focus on their respective strengths. However, introducing such an approach beyond a carefully controlled pilot would be premature at the current point in time, since a sufficiently stable cyber infrastructure is missing and no substantial analyses of side effects of undesirable consequences have been conducted. For example, it is unclear whether such streamlining might reduce the serendipity of unforeseen results that have proven to be among the most useful results from science (such as antibiotics).

Blue group (Scribe: Linwei Wang)
The group discussed several potential solutions to support interdisciplinary research. From the individual faculty point-of-view, the group's discussion centered around the need to find one's identify and maintain one's interest within an interdisciplinary collaboration. Because of various reasons including the different culture and research focuses across disciplines, there are often "colliding interests" for different members within a team of interdisciplinary collaboration. In such a situation, it is important for an individual researcher to be clear about both the common goal of the team and its impact, as well as his/her own individual contribution to this common goal and how that reflects to his/her contribution to his/her own disciplines. Related to this, it is also important for the individual researcher to make sure that there are "publishable" deliverables that can both be recognized by the inter-disciplinary community and his/own disciplines. Overall, it is recommended that an individual researcher should maintain a balanced portfolio of both leading roles and supporting roles in various research collaborations. From the organization's point-of-view, it is critical to have a proper reward structure in place to recognize the role a researcher plays in interdisciplinary research, both for a leading role and for a supporting role. This includes (but is not limited to) the recognition of co-authors in collaborative publications, co-investigators in collaborative projects, co-advising or team-advising of students, etc. From the community's point-of-view, efforts such as "the journal of open software" are excellent examples of providing venues to recognize interdisciplinary research and the increasing role of computing in interdisciplinary research.

4.0 Attendee Feedback Survey

We conducted an anonymous survey of attendees using Survey Monkey to collect attendee feedback about the workshop as well as to seek feedback on potential improvements for the workshop. The number of attendees who responded to the survey was 9 out of a possible 18 attendees (50%). Table 1 below describes a portion of the survey results. The entire survey along with responses are contained in Appendix A.

Table 1. Workshop survey responses reported as the mean and standard deviation (SD) of individual survey responses. Survey participants answered questions on a Likert Scale

with the mapping: Strongly Disagree (SD = 1), Disagree (D = 2), Neither Agree nor Disagree (AD = 3), Agree (A = 4), and Strongly Agree (SA = 5).

Question	Mean	SD
The topic of supporting interdisciplinary research, education, and programs/centers is of interest and relevance.	4.89	0.33
The disciplinary areas of workshop attendees were sufficiently broad to facilitate discussions regarding challenges in interdisciplinary research, education, and programs/centers.	4.89	0.33
It was useful to include attendees from assistant professors through full professors to facilitate discussions regarding challenges in interdisciplinary research, education, and programs/centers.	4.56	1.01
The workshop format (keynote talks followed by focused breakout discussions) was useful and engaging.	4.67	0.5
The talks were relative, informative, and interesting.	4.78	0.44
The breakout discussion sessions were useful and engaging.	4.44	0.73
There were sufficient opportunities for networking and collaboration.	4.22	1.09
The hotel accommodations, meeting space, and meals were adequate.	4.44	0.73
The workshop was helpful in identifying priority problems in supporting interdisciplinary research, education, and programs/centers.	4.67	0.5
The workshop was helpful in identifying initial solutions to the challenges in interdisciplinary research, education, and programs/centers.	4.00	0.71
The length of the workshop (1.5 days) is sufficient.	4.44	0.53
The number of attendees is about right.	4.11	0.60
Which of the following two workshop formats would you find more useful?		

Focus on one theme alone, such as supporting interdisciplinary research, education, and centers/programs.	2
Focus on an ensemble of themes covering Cyberinfrastructure research and education.	7

Different from previous workshops, this year we focused on the topic of supporting interdisciplinary centers/programs, research, and education. Workshop attendees agreed that this topic is of interesting and relevance. They also agreed that that the disciplinary areas of workshop attendees were sufficiently broad to facilitate discussions. They agreed less strongly that it was useful to include attendees from assistant professors through full professors to facilitate discussions. Opposite suggestions were received regarding this question, where some suggested that "it would have been more helpful to focus the workshop towards associate professors through full professors and administrators" while another suggested that "the attendee spectrum could be broadened to include participants from the postdoc/graduate and possibly even undergraduate types of researchers".

In terms of workshop format, the attendees agreed that to have invited talks and breakout sessions were useful and engaging, that the talks were informative and interesting, that the breakout discussion session was useful and engaging, and that there were sufficient opportunities for networking and collaboration. Although two respondents felt that more time was needed for networking.

Attendees agreed that the workshop was helpful in identifying priority problems in supporting interdisciplinary research, education, and programs/centers. The consensus of agreement is less strong regarding whether the workshop was helpful in identifying initial solutions to the challenges in interdisciplinary research, education, and programs/centers.

Attendees strongly agreed that the hotel accommodations, meeting space, and meals were adequate. Attendees also agreed that the length of the workshop was sufficient, and less strongly agreed that the number of attendees was about right.

When asked whether they would find it more useful for the workshop to focus on one theme alone such as supporting interdisciplinary research, education, and program/centers, or to focus on an ensemble of themes covering CI research and education, two respondents chose one single theme and seven chose an ensemble of themes. These data suggest that future workshops should consider including an ensemble of themes with supporting interdisciplinary research, education, and centers/programs as one theme of the discussion.

In additional comments, there were suggestions to involve more agencies such as NIH, DOE, and DOD in addition to the NSF in workshops focused on supporting interdisciplinary research, education, and centers/programs, to have greater emphasis on life science/biomedical research and linking with traditional engineering/math, and to use more focused and specific deliverables for the workshop.

5.0 Observations from the Workshop

From the presentations and discussions during the workshop, we distilled several observations in each of the thematic areas of the workshop.

To support interdisciplinary centers or programs, there are challenges in both its incubation and sustainability. The need for a significant amount of time for interdisciplinary work to bear tangible results often conflicts with the expectations of academic units that are typically focused on short-term outcomes. There is also the challenge to secure sufficient funding for the new effort to become sustainable. Another challenge comes from faculty recruitment and retention because interdisciplinary centers or programs are typically not tenure-granting units. Furthermore, the established criteria for tenure and research evaluation typically do not include metrics for generation of artifacts and tools as a result of interdisciplinary work. Therefore, it can be overwhelming for a faculty member to fulfill the expectations of his/her tenure-granting (home) department while trying to initiate interdisciplinary collaborations. Lastly, there is a conflict between teaching disciplines and research centers, while teaching an interdisciplinary course cutting across departments could result in complicated financial/accounting issues. Three potential solutions to the above challenges include: 1) a memorandum of understanding outlining the expectations for the faculty member's interdisciplinary work as he or she is hired into an interdisciplinary research or program, 2) to mix the research mission of an interdisciplinary center/program with the educational mission of the university through, for example, interdisciplinary graduate programs attached to the center/program, and 3) to strengthen the role of the administration in supporting interdisciplinary research and facilitating interactions between various departments, and to streamline and minimize the administrative burden placed on interdisciplinary faculty.

To support interdisciplinary education, the challenges arise from the faculty, student, and administration sides. For a faculty member to teach interdisciplinary courses, he or she faces resistance of faculty to make space in the curriculum for new content, as well as the difficulty and extra effort needed to prepare interdisciplinary course materials given a diverse range of background and preparedness in students. For a student to take interdisciplinary courses, there is a concern of the preparation in prerequisites and the unwillingness to take classes that might harm their GPA. Administration of interdisciplinary courses is also difficult, as it can be hard to coordinate the scheduling of such courses among interested departments. Three potential solutions include: 1) use special certificates and certifications that complement the regular degree to motivate students to take multidisciplinary classes, allow more experiment in terms of course offerings in the freshmen year, and use a combination of lectures and labs for multidisciplinary types of courses to ease learning for student, 2) develop interdisciplinary programs as an effective top-down approach to ensure an interdisciplinary curriculum at design and to recognize faculty effort in developing such course materials, and 3) provide a formal process for program review to facilitate the adjustment of course content and promote team-teaching for multidisciplinary courses.

To support interdisciplinary research, there is a challenge in the large investment needed to establish a common ground for communication, managing group dynamics, establishing trust, and developing a mutually beneficial collaboration. This is compounded by the lack of reward structures to value the additional work needed beyond the usual level of effort necessary to create and sustain interdisciplinary efforts. In addition, there is a difficulty in seeking funding for researchers interesting in pursuing funding for multidisciplinary projects, seeking funding for preliminary work necessary to write competitive proposals, and seeking funding that is significant enough to support larger, multiparty research teams. The potential solutions include 1) to encourage the development of people who are generalists as well as having great depth in one area; 2) to organize faculty and appointments to allow and encourage faculty to be engaged and involved in more than one discipline and to foster innovation and entrepreneurship in faculty; 3) to broaden the perception of academic output to include artifacts and seek to encourage recognition of the additional efforts and overhead necessary for multidisciplinary research; 4) to seek overt and clear support from NSF leadership for new and collaborative multidisciplinary projects; and 5) to provide substantive experiences in multidisciplinary projects for students.

6.0 Lessons Learned from the Workshop

CyberBridges 2016 was the 5th workshop held in the past 5 years and we have identified some "lessons learned" to benefit future workshops. As a fifth-year "anniversary", the workshop was different from the past workshops in several ways. First, all the workshop talks and breakout discussions were designed to focus the discussions on the challenges and potential solutions to supporting interdisciplinary research, education, and programs/centers. This was intended to reflect on the common theme emerging from past four years of workshops and to provide a venue to discuss both the problems as well as the potential solutions to problems of interest to the ACI community. The attendees found this topic relevant and of interest. Second, the workshop was smaller in the number of attendees (12 versus 30+ in the past) to allow a more intimate discussion on the theme. The attendees found that the size of the workshop was appropriate for the intended discussions. Finally, the workshop was held on the campus of the Rochester Institute of Technology, Rochester, NY. This was a change from previous years when the workshops were held in various venues near the National Science Foundation. This location was economical and also helped to encourage all the attendees to stay on site and participate in all sessions of the workshop.

Through the post-workshop survey, however, it appeared that the attendees did indicate a preference for a "bigger" workshop with multiple themes, rather than a focused workshop dedicated to the discussion of one single theme. For future workshops, a potential direction for consideration is to return to the original format of the CyberBridges workshop, with perhaps one session within the workshop to focus on discussions on topics (such as the support of interdisciplinary research, education, and centers/programs) relevant to the community. Another potential direction for consideration is to open the workshop to the general ACI community and to welcome non CAREER-awardee attendees.

Acknowledgements

Our efforts in planning and conducting the CyberBridges workshop were supported by Lorrie Jo Turner (Rochester Institute of Technology). This workshop was supported by the National Science Foundation Award ACI-1646656.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] Hacker, T., & Shontz, S. (2012). Developing the Next Generation of Cyberinfrastructure Faculty for Computational and Data-enabled Science and Engineering.

[2] Shontz, S., & Hacker, T. (2013). Report of the 2013 NSF CyberBridges Workshop on Developing the Next Generation of Cyberinfrastructure Faculty for Computational and Data-enabled Science and Engineering.

[3] Hacker, T., & Shontz, S. (2014). Report of the 2014 NSF CyberBridges Workshop on Developing the Next Generation of Cyberinfrastructure Faculty for Computational and Data-enabled Science and Engineering.

[4] Wang, L., Hacker, T., & Shontz S. (2016). Report of the 2015 NSF CyberBridges Workshop: Development the Next Generation of Cyberinfrastructure Faculty for Computational and Data-enabled Science and Engineering.

Appendix A. Detailed Survey Results

The complete detailed text questions and attendee responses to the survey sent out to attendees are described below.

In the first section, survey participants answered questions on a Likert Scale with the following numeric assignment. Strongly Disagree (SD = 1), Disagree (D = 2), Neither Agree nor Disagree (AD = 3), Agree (A = 4), and Strongly Agree (SA = 5).

1. The topic of supporting interdisciplinary research, education, and programs/centers is of interest and of relevance.
   Responses: (0) SD, (0) D, (0) AD, (1) A, (8) SA
   Results: Mean Value: 4.89

2. The disciplinary areas of workshop attendees were sufficiently broad to facilitate discussions regarding challenges in interdisciplinary research, education, and programs/centers.
   Responses: (0) SD, (0) D, (0) AD, (1) A, (8) SA
   Results: Mean Value: 4.89

3. It was useful to include attendees from assistant professors through full professors to facilitate discussions regarding challenges in interdisciplinary research, education, and programs/centers.
   Responses: (0) SD, (1) D, (0) AD, (1) A, (7) SA
   Results: Mean Value: 4.56

4. The workshop format (keynote talks followed by focused breakout discussions) was useful and engaging.

   Responses: (0) SD, (0) D, (0) AD, (3) A, (6) SA
   Results: Mean Value: 4.67

5. The talks were relevant, informative, and interesting.
   Responses: (0) SD, (0) D, (0) AD, (2) A, (7) SA
   Results: Mean Value: 4.78

6. The breakout discussion sessions were useful and engaging.

   Responses: (0) SD, (0) D, (1) AD, (3) A, (5) SA
   Results: Mean Value: 4.44

7. There were sufficient opportunities for networking and collaboration.

   Responses: (0) SD, (1) D, (1) AD, (2) A, (5) SA
   Results: Mean Value: 4.22

8. The hotel accommodations, meeting space, and meals were adequate.

   Responses: (0) SD, (0) D, (1) AD, (3) A, (5) SA
   Results: Mean Value: 4.44

9. The workshop was helpful in identifying priority problems in supporting interdisciplinary research, education, and programs/centers.

   Responses: (0) SD, (0) D, (0) AD, (3) A, (6) SA
   Results: Mean Value: 4.67

10. The workshop was helpful in identifying initial solutions to the challenges in interdisciplinary research, education, and programs/centers.

    Responses: (0) SD, (0) D, (2) AD, (5) A, (2) SA
    Results: Mean Value: 4.00

11. The length of the workshop (1.5 days) is sufficient.

    Responses: (0) SD, (0) D, (0) AD, (5) A, (4) SA
    Results: Mean Value: 4.44

12. The number of attendees is about right.

    Responses: (0) SD, (0) D, (1) AD, (6) A, (2) SA
    Results: Mean Value: 4.11

The next questions asked about the attendees' preferences about two different workshop formats that have been used in the past CyberBridges workshops.

13. Which of the following two workshop formats would you find more useful?

    a. Focus on one theme alone, such as supporting interdisciplinary research, education, and centers/programs.

       Responses: 22.22% (2)

    b. Focus on an ensemble of themes covering Cyberinfrastructure research and education.

       Responses: 77.78% (7)

The final questions provided an open form to allow participants to provide written feedback:

14. Please suggest potential focus areas that you would find useful for future CyberBridges workshops.
    a. I would like to see a workshop focused on supporting interdisciplinary cyberinfrastructure research and programs/centers which is co-sponsored by NSF, DOE, NIH, and DOD. NSF is just one piece of the puzzle. It's likely that more impact can be made if more agencies participate in the discussions.
    b. While I really appreciated the networking opportunities, there were several attendees with whom I did not have a chance to interact. This was primarily because of the way the breakout sessions were organized and not a sufficient(ly long) opportunity to socialize. That said for me it was an extremely productive workshop.
    c. Computational Reproducibility from the user (i.e. scientific programmer) perspective: what to do.
    d. Computational Reproducibility from the tool-maker perspective (i.e. makers of software to be used by others) what should they do.
    e. How to select (or develop) high-quality open source software.
    f. Develop a guide for collaborating across disciplines: what usually works and what usually doesn't.
    g. Develop a guide for communicating across disciplines.
    h. Particular types of scientific research, their challenges and how to navigate them in a trans-disciplinary context.
    i. Requirements for a programing language that works well across disciplines.
    j. Greater emphasis on life science/biomedical research and linking with traditional engineering/math.

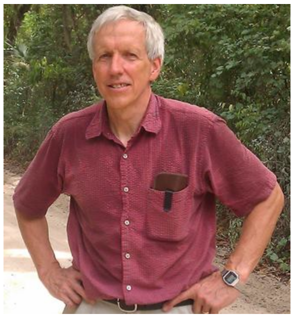
15. Additional comments.
    a. While it is important to involve assistant professors in the dialogue, I believe it would have been more helpful to focus the workshop towards associate professors through full professors and administrators. It's unlikely there will be much impact from the workshop given that there was not a large presence of senior leaders.
    b. In addition, faculty seemed to focus more on problems than on solutions. This was likely because the target audience for the workshop was mostly junior faculty.
    c. More time was needed for networking. It seems that people were constantly wondering off from the workshop (e.g., many people left early, others skipped the dinner, etcetera). I found it difficult to do a sufficient amount of networking with people given people did not stay at the workshop and in the room for the entire event. The room was also too small to provide for sufficient networking.
    d. I would have liked to see more NSF program directors present. Is it possible to hold the workshop near NSF again in the future?
    e. I would not recommend holding another workshop at this hotel. There were many problems with the hotel ranging from billing to room lists to shuttle service, etcetera.
    f. This was a great workshop and I would love to participate in future workshops.
    g. Additionally the attendee spectrum could be broadened to include participants

from the postdoc/graduate and possibly even undergraduate types of researchers. It might be harder to pick the "right" ones, but their perspectives on how trans-disciplinary research is either encouraged or hindered can be very enlightening for the overall goals. They might not bring the "solutions" (as they don't always know what's possible), but they could be good at saying, how a proposed solution would work for them.

h. Very good workshop overall. I felt that the break out sessions could have used more focus and specific deliverables.

Appendix B. Speaker and Attendee Biographies and Photos
Biographies were current as of October 2016, at the time of the workshop

Speaker Biographies



Paul Avery received his Ph.D. in High Energy Physics from the University of Illinois in 1980 and is Professor of Physics at the University of Florida. He was a long-term member of the CLEO collaboration where he pursued research on heavy quark production and decays, developing and implementing several statistical techniques that have been widely adopted. He currently participates in the CMS experiment at CERN, Geneva, where he is working on the physics of the Higgs boson as well as developing distributed computing infrastructure. Dr. Avery is a Fellow of the American Physical Society and has served on numerous national and international committees and panels, including the 2013 Topical Panel on Computing in High Energy Physics and the 2001 sub-Panel on the long-term future of HEP. He has been a recognized leader in a number of initiatives aimed at developing advanced grid and networking for science. He served as Director of two national NSF-funded Grid projects, GriPhyN and the International Virtual Data Grid Laboratory (iVDGL) from 2000 – 2007, was co-PI of three NSF-funded projects in which grid computing and advanced networking are major components: CHEPREO, UltraLight and DISUN and was PI of the ExTENCI Computing project from 2010-2013. Avery is a co-PI and founding member of the Open Science Grid (www.opensciencegrid.org) which operates a national Grid cyberinfrastructure for research communities in science and engineering.

José-Marie Griffiths is President of Dakota State University in Madison, South Dakota, U.S.A. She has previously served as Vice President for Academic Affairs at Bryant University in Smithfield, Rhode Island, as the Dean of the School of Information and Library Science at the University of North Carolina at Chapel Hill, Chief Information Officer at the University of Michigan, Vice Chancellor at the University of Tennessee-Knoxville, and Vice President for King Research, Inc. She has a B.Sc. with honors in Physics, a Ph.D. in Information Science and a Post Doctorate in Computer Science and Statistics, all from University College London, London, England. The importance of Griffiths work has put her in demand for numerous policy boards, while also attracting significant research support. She has been awarded presidential appointments from two United States Presidents, including The National Science Board, the U.S. President's Information Technology Advisory Committee, and the U.S. National Commission on Libraries and Information. She has had appointments to multiple projects as lead or key personnel for over 28 United States federal agencies, departments and offices. Dr. Griffiths has carried out projects and/or served in advisory roles on projects in science and technology with over 20 major corporations as well as over 30 countries.

Jeffery Humpherys received his Ph.D. in Mathematics from Indiana University in 2002 and was an Arnold Ross Assistant Professor at The Ohio State University from 2002-2005, before joining the faculty at Brigham Young University in 2005. Jeff has won grants from the National Science Foundation, including a CAREER award in 2009. He also received the Young Scholar Award from BYU in 2009. Jeff has published papers in partial differential equations, operations research, applied probability, numerical analysis, and dynamical systems theory. He has served as a technical and scientific consultant for several companies, particularly businesses specializing in information technology, financial services, healthcare, retail, and manufacturing. His current research interests are in healthcare analytics and social networks.

Michael Sacks is the W. A. "Tex" Moncrief, Jr. Simulation-Based Engineering Science Chair and a world authority on cardiovascular biomechanics. His research focuses on the quantification and modeling of the structure-mechanical properties of native and engineered cardiovascular soft tissues. He is a leading international authority on the mechanical behavior and function of the native and replacement heart valves. He is also active in the biomechanics of engineered tissues, and in understanding the in-vitro and in-vivo remodeling processes from a functional biomechanical perspective. Dr. Sacks is currently director of the ICES Center for Cardiovascular Simulation and Professor of Biomedical Engineering.

His research includes multi-scale studies of cell/tissue/organ mechanical interactions in heart valves and is particularly interested in determining the local stress environment for heart valve interstitial cells. Recent research has included developing novel multi-scale models of the mitral valve and bioprosthetic heart valves, as well as constitutive models of ventricular myocardium that allow for the separation of the individual contributions of the myocyte and connective tissue networks.

Sushil K. Prasad (BTech'85 IIT Kharagpur, MS'86 Washington State, Pullman; PhD'90 Central Florida, Orlando - all in Computer Science/Engineering) is a Program Director for the National Science Foundation CISE/ACI Division of Advanced Cyberinfrastructure. He is a Professor of Computer Science at Georgia State University (GSU) and Director of Distributed and Mobile Systems (DiMoS) Lab. He has carried out theoretical as well as experimental research in parallel and distributed computing, resulting in 120+ refereed publications, several patent applications, and about $3M in external research funds as principal investigator and over $6M overall (NSF/NIH/GRA/Industry). Sushil has been honored as an ACM Distinguished Scientist in Fall 2013 for his research on parallel data structures and applications.

Carol Woodward is a computational mathematician in the Center for Applied Scientific Computing (CASC) at Lawrence Livermore National Laboratory (LLNL). Her research focuses on nonlinear solvers and time integration methods for large-scale applications and parallel architectures as well as in code and calculation verification. She leads the development and deployment of the SUNDIALS package of time integrators and nonlinear solvers. Some applications Dr. Woodward has worked with include subsurface flow, atmospheric climate physics and dynamics, core collapse supernova, power grids, fusion, and materials science. Dr. Woodward serves as Chair of the Society of Industrial and Applied Mathematics (SIAM) Activity Group on Geosciences and as an At-Large member for the Association for Women in Mathematics Executive Committee. In addition, she serves on the editorial boards for the SIAM Journal on Scientific Computing, Advances in Water Resources, and ACM Transactions on Mathematical Software and has served on numerous organizing committees for national and international meetings. In 2015 Dr. Woodward was one of 15 early- and mid-career scientists and engineers recognized by LLNL for exceptional technical achievement. She served as Numerical Methods Group Leader and Postdoctoral Program Manager in CASC and six years as an elected member of the SIAM Council.

Faculty Attendees

Omar I. Abdul-Aziz is an Assistant Professor of Civil & Environmental Engineering at the West Virginia University (WVU), Morgantown, WV. He obtained a Ph.D. from the University of Minnesota, Twin Cities in 2008, M.Sc. from the University of Waterloo, Canada in 2004, and B.Sc. from the Bangladesh University of Engineering and Technology, Dhaka in 2002, all in Civil Engineering. He was a tenure-track Assistant Professor of Civil & Environmental Engineering at the Florida International University (FIU), Miami, FL during 2011-15. Prior to joining FIU in Fall 2011, he worked as a scientist with the U.S. Geological Survey (USGS) and University of Washington, Seattle. Dr. Abdul-Aziz conducts state-of-the-art, highly interdisciplinary research in the interface of ecological and water resources engineering, incorporating topics related to the coupled human-natural systems and sustainability sciences/engineering. He developed the Ecological and Water Resources Engineering Lab (http://www.ewrel.fiu.edu/) at FIU. His current research focuses on *developing robust, user-friendly engineering models* to predict and assess (1) wetland and forest greenhouse gas (GHG) fluxes and carbon sequestration (funded by NSF and NOAA); (2) stream/river water quality and ecosystem health (funded by NSF and US DOE); and (3) urban stormwater flooding and drainage sustainability under extreme climate events (funded by the State of Florida).

Website: https://ewrel.fiu.edu/

NSF CAREER project: The goal of my NSF CAREER project is to investigate and robustly predict stream water quality and ecosystem health in complex urban-natural basins.

Areas of collaboration

- Modeling and predictions/forecasting of urban flooding and drainage sustainability, as well as that of stream/river water quality and ecosystem health.

Alexander Alexeev is an Associate Professor in the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology. He obtained his Ph.D. degree in Mechanical Engineering in 2003 from the Technion - Israel Institute of Technology. He joined Georgia Tech in 2008 after finishing his postdoctoral studies at TU Darmstadt in Germany and at the University of Pittsburgh. He uses modeling and simulations to solve problems at the intersection of engineering, medicine, and biology. His research interests include mesoscale modeling of complex fluids, soft and active materials, interfacial phenomena, and microfluidics. Website: http://cfms.gatech.edu/ NSF CAREER project The project goal is to develop mesoscale computational model of stimuli-sensitive polymer networks that can explicitly capture micromechanics, transport properties and responses to environmental stimuli.

Areas of collaboration x high performance computing x computational fluid dynamics x mesoscale and particle based computational methods.

Lorena Barba is an Associate Professor of Engineering and Applied Science at the George Washington University. Previously, she held faculty positions in Mechanical Engineering at Boston University and in Applied Mathematics at University of Bristol, UK. She has a PhD in Aeronautics from the California Institute of Technology (2004). Her research interests include computational fluid dynamics, especially immersed boundary methods and particle methods for fluid simulation; fundamental and applied aspects of fluid dynamics, especially flows dominated by vorticity dynamics; the fast multipole method and applications; and scientific computing on GPU architecture. Prof Barba is an Amelia Earhart Fellow of the Zonta Foundation (1999), a recipient of the EPSRC First Grant program (UK, 2007), an NVIDIA Academic Partner award recipient (2011), a recipient of the NSF Faculty Early CAREER award, is an NVIDIA CUDA Fellow and a leader in computational science and engineering internationally.

Website: http://lorenabarba.com

Paul T. Bauman joined the University of Buffalo as an Assistant Professor in the Mechanical and Aerospace Engineering department in 2014. He is also a core faculty member of the Computational and Data-Enabled Science and Engineering program. He earned his in B.S., M.S., and Ph.D. at the University of Texas at Austin in 2002, 2003, and 2008, respectively.
Dr. Bauman has previously studied hypervelocity impact as well as developed numerical methods for multiscale models of polymers used in semiconductor manufacturing. More recently, his research focus has been on developing modern numerical methods for studying chemically reacting flows and bringing them together with algorithms for quantifying uncertainty in engineering problems related to hypersonic flows and combustion. In addition to more than 15 years of software development experience in scientific computing environments, Dr. Bauman is a core developer of the libMesh finite element library and a lead developer of both the GRINS multiphysics framework, built on libMesh, and the Antioch thermochemistry library.

Website: http://www.mae.buffalo.edu/people/full_time/p_bauman.php

Baskar Ganapathysubramanian is an Associate Professor of Mechanical Engineering and Electrical and Computer Engineering at Iowa State University. His research interests are in multi-scale multi-physics modeling, design of materials and processes using computational techniques, and stochastic analysis. The recent focus of his group is on advanced energy technologies including solar cells, and green buildings. Ganapathysubramanian completed his PhD and MS from Cornell University and holds a BS degree from the Indian Institute of Technology-Madras.

Website: http://www.me.iastate.edu/bglab/

NSF CAREER project: A predictive modeling framework to explore fabrication of organic solar cells.

Areas of collaboration
- Parallel adaptive mesh generation
- Data-mining
- Inverse problems

Thomas Hacker is a Professor of Computer and Information Technology at Purdue University. Dr. Hacker's research interests center around high-performance computing and networking on the operating system and middleware layers. Recently his research has focused on cloud computing, cyberinfrastructure, scientific workflows, and data-oriented infrastructure.

Website: https://polytechnic.purdue.edu/profile/tjhacker

NSF CAREER project: Dr. Hacker's research is focused on understanding the reliability characteristics of large scale HPC systems and seeks to improve the reliability profile of computational jobs that utilize these systems.

Areas of collaboration
- Reliability
- High performance computing

Laurence Loewe is an Assistant Professor in the Laboratory of Genetics and works in the interdisciplinary Wisconsin Institute for Discover at the University of Wisconsin-Madison. Since his training as a biologist, he has continued to wonder how computers could improve the efficiency of biological research. As a result, he has become both lead technical architect and the first biological user for the new modeling language Evolvix. Its development formally started with his NSF CAREER grant. This work has required him to cross disciplinary boundaries in order to understand how complex dynamical systems change in the real world – a key purpose of Evolvix. His research is motivated by the vision to enable the efficient computational navigation of mechanistic fitness landscapes of real-world systems as defined in evolutionary systems biology. A key goal of this new field is to integrate intra-organismal areas like molecular systems biology and trans-organismal areas like population genetics with the help of simulations. Building reasonable models for this effort draws on research spanning many decades and requires rigorous integration of all relevant data. Thus, instable programming languages pose a substantial obstacle to the efficient reuse of existing models, as new versions regularly force costly reimplementation. In search for a long-term backwards compatible modeling solution, he has been developing naming and versioning techniques that facilitate essential disambiguation tasks. These capabilities have enabled new perspectives on the design of programming languages, which have been influencing how he has been developing the architecture for Evolvix (http://evolvix.org/concept). The resulting concepts have been instrumental for improving the usability of Evolvix, as he works on turning the original declarative prototype into the first general-purpose programming language designed by biologists, for biologists. Biology would greatly benefit from a language with built in support for handling typical biological data and its unpleasantries, which consume much programming time in computational biology. In order to develop the strongest possible links between simulations of circadian clocks and their real-world counter parts, his group has been developing FlyClockbase by integrating 25 years' worth of time series observations for circadian clocks in fruit flies. This pilot has been fundamentally shaping how Evolvix generally handles uncertainty and gaps in data.

Website: https://wid.wisc.edu/people/laurence-loewe/

NSF CAREER project: Design, implement, and test enough of Evolvix to ensure it simplifies accurate modeling of highly concurrent systems across biology in ways that accurately represent relevant uncertainties. Challenges include data modeling and storage, parameter estimation and globally distributed computing.

Areas of collaboration

- Review language design for stability and simplicity of how advanced features are integrated.
- Parser and compiler construction for integrating diverse fundamental programming paradigms.
- Architectures for organizing reliable, persistent, concurrent, and searchable memory for storing complex networks of diverse elements.

H. Metin Aktulga is an Assistant Professor in the Department of Computer Science and Engineering at Michigan State University. He received his B.S. degree from Bilkent University in 2004, M.S. and Ph.D. degrees from Purdue University in 2009 and 2010, respectively. Before joining MSU in 2014, he was a postdoctoral researcher in the Scientific Computing Group at the Lawrence Berkeley National Laboratory. Dr. Aktulga's research interests are in the areas of high performance computing, applications of parallel computing, big data analytics and numerical linear algebra. He primarily works on the design and development of parallel algorithms, numerical methods and software systems that can harness the full potential of state-of-the-art computing platforms to address challenging problems in large scale scientific computations and big-data analytics problems. A distinguishing aspect of his research is the close collaborations that he has built with domain experts in a wide range of fields such as molecular modeling and simulation, computational materials science, and nuclear physics.

Website: http://cse.msu.edu/~hma/

Areas of Collaboration:

- Molecular modeling and simulation
- Sparse matrix computations
- Large-scale eigenvalue problems
- Fast methods for Helmholtz systems
- High performance data analytics

Dominik Schillinger is an Assistant Professor in the Department of Civil, Environmental, and Geo- Engineering at the University of Minnesota, Twin Cities. His research interests are in computational mechanics, where he works on the development and implementation of novel discretization techniques for the analysis of solids, structures and fluids that overcome limitations of today's standard numerical tools. Dominik holds M.S. degrees in structural engineering and computational mechanics from the University of Connecticut, Storrs, and the University of Stuttgart, Germany, as well as a Ph.D. degree from the Technical University of Munich, Germany. His work has been recognized by the **IACM John Argyris Award** of the International Association for Computational Mechanics, the GAMM **Richard-von-Mises Prize** of the International Association of Applied Mathematics and Mechanics, and the ICE **Zienkiewicz** Medal of the Institution of Civil Engineers. In 2016, Dominik received a CRII Award from the Directorate for Computer & Information Science & Engineering of the National Science Foundation.

Website: http://www.tc.umn.edu/~dominik/

Research interests: Dominik strives to re-think the process of how geometric models are transferred into analysis-suitable discretizations at a fundamental level. To this end, he develops new computational methods that enable seamless integration and automation, with applications from design optimization in aerospace engineering to predictive simulation-based diagnosis and treatment in medicine. Dominik's vision of future simulation tools includes a single engineer who conceives, creates, and interprets a large ensemble of simulations in a time-critical period, and fully automated patient-specific simulations that can be run autonomously in hospitals.

Areas of Collaboration:
- Numerical analysis of finite element methods
- Multiphysics simulations, in particular fluid-structure interaction
- High-performance computing
- Optimization
- Variational and PDE-based methods for image processing and segmentation
- Experimental biomechanics and mechanobiology, in particular bone and cardiovascular liver mechanics

Suzanne Shontz is an Associate Professor in the Department of Electrical Engineering and Computer Science at The University of Kansas (KU). She is also affiliated with the Graduate Program in Bioengineering and the Information and Telecommunication Technology Center. Suzanne's research is in parallel scientific computing and focuses on the development of meshing and numerical optimization algorithms and their applications in medicine, image processing, electronic circuits, and materials. Suzanne is the recipient of a 2011 NSF PECASE Award from President Obama for her research in computational- and data-enabled science and engineering. She also received a 2011 NSF CAREER Award for her research on parallel dynamic meshing algorithms, software, and theory for simulation-assisted medical interventions. Along with Thomas Hacker of Purdue University and Linwei Wang of the Rochester Institute of Technology, she is a co-chair of the 2015 NSF CyberBridges Workshop. She and Thomas Hacker co-founded the NSF CyberBridges Workshops and served as co-chairs of the workshops in 2012-2014. Suzanne chaired the 2010 International Meshing Roundtable, the premier conference in unstructured mesh generation, and has served on numerous program committees for international conferences in computational- and data-enabled science and engineering. She is also an Associate Editor of the De Gruyter Open Book Series in Medicine.

Website: http://people.eecs.ku.edu/~shontz

NSF CAREER Project

The goal of my NSF CAREER project is to research and develop parallel dynamic meshing algorithms, theory, and software for use in the design of patient-specific treatments for diseases such as deep vein thrombosis and hydrocephalus.

Areas of collaboration
- Biomechanics modeling
- Medical image processing
- Shape and topology optimization

Hari Sundar is an Assistant Professor in the School of Computing at the University of Utah since Fall 2014. He was previously at the Institute for Computational Engineering & Sciences at the University of Texas at Austin as a Research Associate. He received his Ph.D. from the University of Pennsylvania in 2009.
Dr.Sundar's research focuses on the development of computationally optimal parallel, high-performance algorithms, that are efficient and scalable on state-of-the-art architectures. It is driven by applications in biosciences and geophysics, such as cardiovascular mechanics, medical image analysis, and seismic wave propagation. A major contribution of his research has been the development of parallel algorithms for the solution of elliptic, parabolic, and hyperbolic PDEs using non-uniform discretizations based on Galerkin and discontinuous Galerkin schemes. Dr. Sundar's research has resulted in the development of state-of-the-art distributed algorithms for adaptive mesh refinement, geometric multigrid, fast Gauss transform and sorting.

Website: https://www.cs.utah.edu/~hari

Linwei Wang is an Associate Professor in the PhD Program of Computing and Information Sciences at the Rochester Institute of Technology in Rochester, NY. Her research interests center around data-driven modeling, statistical inference, and data inversion of complex systems, with application to computational physiology and personalized biomedicine. She currently directs the Computational Biomedical Lab in RIT, with a recent research focus on personalized modeling of *in-vivo* cardiovascular systems using noninvasive biomedical data, and its application to improve patient care in cardiac arrhythmia and other heart diseases. Her research is funded by the National Science Foundation and the National Institutes of Health. Her NSF CAREER. Dr. Wang obtained her bachelor degree in Optic-Electrical Engineering from Zhejiang University (China) in 2005, her master degree in Electronic and Computer Engineering from Hong Kong University of Science and Technology in 2007, and her PhD in Computing and Information Sciences from RIT prior to joining the faculty of RIT in 2009.

Website: http://phd.gccis.rit.edu/linweiwang/

NSF CAREER project: Dr. Wang's NSF CAREER projects investigates the improvement of data-driven inference and learning by the integration of physics-based modeling, with a driving application in healthcare and medicine.

Areas of collaboration

- Multi-physics, multi-scale modeling and simulation
- Statistical inference & optimization

- Machine learning
- Signal and image analysis
- High performance computing
- Scientific visualization