UNIVERSITY of ROCHESTER

Board of Trustees Meeting
October 10, 2013
Agenda Item No. IV.
University Research Strategic Plan 2013
Robert Clark, Senior Vice President for Research
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INTRODUCTION

Research is a central part of the University of Rochester mission. The University comprises over 700 research active faculty, approximately 1,000 doctoral students, and over 250 postdoctoral trainees engaged in scientific research. The university's annual research expenditures were approximately $375M for fiscal year 2013. This creates numerous research opportunities for undergraduates and masters students, many of whom also engage in research activities. The following delineates strategic plans to maintain and enhance the vitality of the research mission at the University and to maintain our standing among the leading research universities in the nation. The plan has been formulated based on an awareness of significant financial challenges for maintaining or enhancing research activities, particularly in biomedical research, the largest component of the University's research portfolio. Thus, in general we foresee limited, targeted growth in the research enterprise, and seek to find new ways to combine

and support existing expertise to ensure the development of novel, cutting edge studies with the ultimate goal of maximizing the impact of our collective investment.

Individual units within the university have developed their own strategic plans specific for the needs and activities of those units. It is the goal of this report to identify common themes across different units within the university and to take advantage of synergistic interests to maximize the benefit of investments across the institution. We also seek to identify missed opportunities for collaboration and to forge connections across schools based on common interests.
The committee identified four broad areas of research synergy across the University: Data Science, Research Foundations for a Healthier Society, Light and Sound, and Energy and the Environment. In addition, we identified an emerging emphasis on community engagement and the translation of research discoveries into practical benefits for society.

I. THE ROCHESTER INSTITUTE FOR DATA SCIENCE

Data Science is one of the defining disciplines of the 21st Century. Without conducting extensive research, it is safe to say that every major research university is investing in high performance computing resources and data science.

The field has evolved as a hybrid of research in statistics, electrical and computer engineering, computer science, and scientific computing, driven largely by the proliferation of data in the digital age. Roughly speaking, statistics provides mathematical foundations; computer science, algorithms and infrastructure; and scientific computing, methods for numerical simulation, model fitting, and optimization that have been developed across the sciences, engineering and medicine - biology, electrical and computer engineering, physics, economics, and so on. The division of labor between traditional disciplines is not in reality so clean cut: for example, some computer science research is focused on mathematical foundations, research in scientific computing can lead to general algorithms and infrastructure, and work in statistics can extend into algorithms and application domains.

Data Science can also be characterized by the research goals that mark the leading edge of the field. These include:

- **Developing methods for discovering, or deriving, models of phenomena from large data sets.** This goes beyond hypothesis testing, or running simulations to discover the implications of a model; an ultimate goal of data science is to automate the process of hypothesis formation itself.
- **Developing methods for integrating and interpreting highly heterogeneous and noisy data**. While science traditionally focuses on analyzing experimental data, gathered under carefully controlled conditions, leading-edge work in data science often focuses on finding patterns in unstructured information that was created for other purposes - for example, natural language texts or photographs - and with integrating structured and unstructured data.
- **Managing the movement and analysis of data between a multiplicity of sensing and computing platforms**. Technology to produce and store data has outstripped our ability to transport or analyze data by orders of magnitude. The multicore revolution is turning ordinary workstations into massively parallel supercomputers, but software tools and methodologies for harnessing this power lag far behind. A key research goal is to develop an infrastructure for big data analytics that seamlessly ties together sensing and computing platforms ranging from supercomputers to personal mobile devices.

We build upon enormous strengths in Data Science including the Health Science Center for Computational Innovation, the Department of Computer Science in Arts, Sciences and Engineering, Biostatistics in the School of Medicine and Dentistry, and historic achievements in machine learning and artificial intelligence. More than 100 principal investigators have been awarded a total of $307 million in research relying in part upon high performance computation during the past three years.

Center for Integrated Research Computing. In support of higher performance computing research, the Center for Integrated Research Computing (CIRC) was established in 2008 through a collaboration between River Campus and Medical Center faculty and administrators. Over the past 5 years, the total number of users of CIRC has grown to 650 and includes faculty, students, and research staff from over 40 departments and centers at the University of Rochester. To support faculty-led computational and data-intensive research activities, CIRC staff includes a director with a research faculty appointment, 3 computational scientists trained at the doctoral level, and 3 specialized system administrators. With the Blue Gene/Q and BlueHive systems, CIRC has over 240 teraFLOPS of computational capacity and 640 terabytes of high-speed data storage. CIRC staff maintain over 140 unique software packages and programming libraries for assisting a range of diverse projects, such as de novo sequencing of genomes and astrophysical simulations. CIRC holds monthly research symposia and regular workshops to help Medical Center and River Campus investigators use computation and data science technologies. Over 30 symposia and 3 poster sessions have been hosted over the past 5 years. These sessions have allowed over 150 faculty research groups across the university to participate in discussions and collaborations centered around the theme of using computing technology in research.

UR's expertise in data science is currently dispersed across many different departments and divisions of the university. While there are collaborations between individual groups of researchers, there is no umbrella organization that brings them all together. Many fundamental advances in data science, however, have resulted from collaborations between scientists in seemingly disparate disciplines. For example, collaborations between physicists, mathematicians, electrical and computer engineers, and computer scientists created concepts and tools that are widely used in analyzing complex network systems, ranging from social networks to cellular signaling systems. Such cross-disciplinary training in data science will be vital for strengthening graduate research and education in this rapidly evolving field, and opportunities for supporting such activities exist (e.g., Adam Frank of Physics recently submitted an NSF IGERT proposal for interdisciplinary training in data science).

The creation of an Institute for Data Science is a university priority. The distinct advantage of creating an institute is that it will enable the coalescence of multiple individual centers in data science that are emerging from domain specific applications. To support the Institute, faculty growth will be critical. Coupled to the growth is the need for space properly configured to support research as well as house visiting faculty and postdocs and accommodate a small administrative office. To leverage replacement faculty searches, emphasis for hiring will be placed upon data science in discipline specific domains. The objective is to recruit a cohort of energetic new faculty in a variety of departments (e.g., Biology, Biomedical Genetics, Biostatistics, Electrical and Computer Engineering, Computational Biology, Computer Science, Medicine, Microbiology and Immunology, Neurology, Physics, Political Science, Psychiatry, etc.) for whom data science is a critical component of their work, either as developers or users, and who are eager to collaborate. The university will find ways to support collaborations in research and graduate education between researchers in schools distributed across the River Campus and clinicians and scientists from the many departments in URMC.

A. Domains of Research Focus

Three domains of initial research focus have been identified: Predictive Health Analytics, Cognitive Systems, and Analytics on Demand. Critical challenges and enabling resources are identified in the subsequent sections.

Predictive Health Analytics

The biggest healthcare breakthroughs of the next century may not come from the development of particular "magic bullet" drugs, but from an increase in our ability to predict individual health outcomes on the basis of treatments, genomics, and lifestyle and behavioral factors. Doing this will require integrating a wide variety of heterogeneous data, including individual genomic data, patient outcome data, informal natural language records and reports. Increasingly, in-situ behavioral data gathered by and/or about particular subjects through smartphone health applications, wearable sensors, and social media is also an important part of a health profile.

Research in predictive health analytics brings together medical researchers, Computer Science, Electrical and Computer Engineering, Psychology, and other disciplines. Categories for expanded research in predictive health analytics include:

- **Suicide prevention**, based on integrating online social media data, individual behavioral data, and medical records.
- **Infectious disease tracking and predicting**. The University of Rochester is a leader in tracking and developing methods to control the spread of infectious disease. For example the University's Respiratory Pathogens Research Center, the only center of its kind in the nation, provides the NIAID Division of Microbiology and Infectious Diseases (DMID) with the capability of conducting translational and clinical research focused on the development and optimization of control measures for viral and bacterial respiratory pathogens. Researchers in Computer Science and URMC have received national attention for their work on using social media to predict disease using social media reports. URMC's recent application for its influenza Center of Excellence included proposed work on integrating clinical data with informal social media data.
- **Chronic heart disease care**. URMC is home to a world center for collection and analysis of cardiac data (the Telemetric and Holter ECG Warehouse). We can further leverage this resource by integrating other data sources to accelerate discovery and quantification of (more) health factors for chronic heart disease patients.
- **Predicting cancer treatment outcomes**. A major focus of research of URMC is understanding how to use individual genomic data to predict the outcomes of different treatments for cancer patients. Cancer research at the University involves four major focus areas, each involving between 20 and 50 faculty members from seven or more different departments and centers.

UR's projects in predictive health would benefit from additional investment in bioinformatics expertise in URMC, as well as in machine learning and data integration in Computer Science. Growth in these areas is critical to maintain our leadership role among the 60 universities across the country who have received a National Institutes of Health (NIH) Clinical and Translational Science Award (CTSA). URMC was one of the 12 vanguard institutions receiving one of these awards, and we successfully competed for renewal. During the last review it was made clear that we will need to augment our biomedical informatics infrastructure to

compete successfully for the next round of funding. Connecting to a broad-based Institute for Data Science would be optimal for the Rochester Clinical and Translational Science Institute (CTSI), and a connection to CTSI, with its rich clinical research data sets, will augment the strength and attractiveness of the Data Science Institute, enabling us to attract top data scientists working on these complex research questions.

Cognitive Systems

One of the most ambitious and exciting domains in data science is to model and/or replicate human perception and cognition. UR is uniquely positioned to address this challenge, as it is home to internationally recognized research in cognitive science and artificial intelligence (AI). While cognitive scientists tend to focus on models of human performance, and researchers in AI focus on achieving task-level competence regardless of the physiological plausibility of the methods used, these approaches are linked in "speaking the same language" of statistical inference. Increases in our understanding of how the brain makes sense of the world can lead to new algorithms for practical problems in machine vision, machine audition, computational linguistics, and automated reasoning. Likewise, engineering advances in each of those problems can suggest new hypothetical mechanisms to brain scientists.

We use the phrase "cognitive systems" for this section to indicate a broad vision that encompasses (at least) researchers in Brain & Cognitive Science, Clinical and Social Sciences in Psychology, Neurology, Computer Science, Electrical & Computer Engineering, Linguistics, and the Eastman School of Music. Opportunities for interdisciplinary collaborations in this area are almost limitless, and the problems to be examined are a fundamental part of the BRAIN Initiative recently announced by the White House as a societal Grand Challenge. Due to the dual fundamental and practical aspects of cognitive systems, a wide range of federal agencies (including NSF, NIH, DARPA/DoD, IARPA, and NIST) are targeting external funding for the area.

While cognitive systems is an active field of study, we are exceptionally competitive in this field with over thirty faculty members from seven different departments participating in living cognitive systems. To retain that edge, it is critical that we build on our strengths with investments in faculty positions in AI, including machine learning, computer vision and audition, and computational linguistics, as well as cognitive science.

Areas in which we can build significant strength are those related to language sciences and linguistics. Linguistics plays a key role in tying together computer science and cognitive science research in language processing, Enrollments in our classes in linguistics are at record levels, as are job opportunities for graduates who know both linguistics and computing. Enlarging the faculty in relevant areas of linguistics and language sciences would also allow UR to offer an MS program in computational linguistics - a degree program that has proved to be highly popular at several of our peer universities.

Analytics on Demand

A few years ago, the choice of computing platform for data analytics was relatively simple: a workstation, cluster, or supercomputer, depending upon the scale and nature of the problem. The picture is far more complex today. One reason is the growing scale of data that can be easily captured and stored - terabytes (= 1000 gigabytes) or petabytes (= 1000 terabytes) are not unusual. (ONE gigabyte provides sufficient storage for approximately 150 mp3 music files or approximately 300 digital images from your camera.) The time required to transmit data between the point of capture or storage and the point of analysis can become a limiting factor. It

may be necessary, for example, to perform analysis and data-reduction at the point of capture, because it would take too long to transmit the raw data to a centralized server. Another reason is the proliferation of new platforms (e.g. smartphones) and potentially disruptive computing hardware with thousands of central processing units.

A programmer or scientist today must take the characteristics of the target data-capture, storage, and analysis chain and computing platforms into account to create an efficient and scalable system. If this is not done with care and expertise, most of the resources can go to waste; for example, a task may run more slowly on a supercomputer than on a cell phone. The growing ubiquity of parallel-processing systems exacerbates the problem because writing efficient code to run in parallel on computing systems is far more challenging that writing code for a single system.

We use the term Analytics on Demand to refer to the challenge of creating tools and systems for large-scale data analytics that relieve the end-user - the scientist or programmer - from the need to understand the details of particular platforms and chains of platforms. The scientist writes a program that describes the basic algorithm for the task; the system then takes over, and determines how to divide and parallelize the work in order to make optimal use of resources. Faculty in Computer Science and in Electrical and Computer Engineering are already working on parts of this vision.

Two kinds of investments are needed to put these pieces together and extend them to make Analytics on Demand a reality. The first is programming support: academics are great at prototyping new tools, but often poor at providing polished versions and providing support. (One of the exceptions is the parallel synchronization libraries produced by the UR Computer Science systems group.) Supporting software is also difficult or impossible because developers (e.g., graduate students) may change to other problems. Growing the programming staff in the Center for Integrated Research Computing (CIRC, see above) with the goal of taking on the support of locally created tools could help solve this problem.

B. Summary of Needed Investment

By providing a physical space in which to gather expertise in data sciences, while adding critical personnel including computational support staff and faculty focused on specific application areas where the University already has significant strengths, we will enable the University to elevate the capabilities and impact of existing research programs and place ourselves among the leaders in the field of Data Sciences. Specifically, to enable data science,

- 20 faculty lines will be established between 2013 – 2018.
- Approximately 30,000 net square feet of space will be dedicated to the research initiative.

C. Need for improved IT infrastructure and support

To support the Data Sciences initiative, improvements will need to be made to our IT infrastructure. There are a number of difficulties in the present research computing environment that should be addressed. These problems are complex, and their solution may require fundamental changes in the organization and oversight of research computing. We identify the following goals:

- Establish a research computing environment where the primary focus of its administration is to serve the needs of the research enterprise. Currently, researchers

in SMD must abide by rules and policies established for the clinical enterprise, and they have little input into governance policies, which tend to be significantly more restrictive than policies in force for other researchers at the University. This creates many unanticipated difficulties for carrying out basic research operations, and makes it more difficult to collaborate with colleagues outside the Medical Center. Appropriate re-structuring of security firewalls is needed to protect personal health information and ensure compliance with federal laws under the Health Insurance Portability and Accountability Act (HIPAA) while providing the research community greater freedom to communicate and transfer research information.

- Provide support for high-performance research computing, not only in terms of hardware, but particularly in terms of software tools and support personnel who can serve as a resource for faculty in need of high performance computing but who do not have the background or training to make use of this important resource as it is currently configured.
- Provide for secure data storage and accessibility. New federal regulations place requirements on federally funded researchers to make their data available publicly, yet currently there is no resource to enable researchers at the University to accomplish this in a systematic fashion.
- Provide resources for education and training of researchers so that they can take advantage of modern high performance computing tools.
- Develop a financial strategy that will provide the necessary support to ensure a robust, researcher-oriented IT infrastructure for research computing.

II. RESEARCH FOUNDATIONS FOR A HEALTHIER SOCIETY

Biomedical research represents the largest segment of the University's research portfolio. In the Medical Center alone there are over 550 faculty members with federal funding for their research programs, and the total research expenditures for the Medical Center topped $230M in the fiscal year ending in 2013. The proximity of the Medical Center to the River Campus has provided myriad opportunities for collaborations between researchers in the Medical Center and those in Arts Sciences and Engineering (AS&E). Of the dozen-plus research areas identified in the Medical Center strategic plan, essentially all have established or potential research partners in Arts, Sciences and Engineering. Rather than recapitulate the entirety of the Medical Center plan, we focus here on a few thematic areas of collaboration.

A. Imaging

The importance of advanced imaging techniques in biomedical research cannot be overstated. The ability to detect and visualize events at the organ, tissue, cell, and molecular scales is often the key to progress in our understanding of how living systems function. Specific topic areas where there are existing or potential collaborations include:

- Cancer detection and characterization. Much of imaging research at the University is focused on detection and characterization of cancerous tissue. These include optical, ultrasound and MR imaging techniques and analysis of these images to extract information about the location and character of cancers. The research seeks to provide improved accuracy and more detailed characterization of tumors, and delivering on these goals at lower costs and less risk to patients than current technologies provide.

- Immunological function and analysis of immune cell trafficking. The use of optical imaging approaches to track the location, migration and interactions among immune cells is one of the most important developments in research into immune function and understanding how the immune system works. Collaborations between the Institute of Optics and the Department of Microbiology and Immunology are making novel contributions to this important research direction.
- Brain activity and the effects of therapeutic agents on brain activity. The Rochester Center for Brain Imaging (RCBI) is an important resource for evaluating brain function. An emerging collaboration between RCBI and the Center for Human Experimental Therapeutics (CHET) will enable detailed evaluation of the effects of experimental therapeutics designed to affect brain function. An upgrade to the magnet facility is needed to support those and other studies.

B. Drug development and drug delivery

The development of novel therapeutics and the use of nanomaterials and biomaterials for the enhancement of their therapeutic benefits hold enormous promise for treating and curing a wide range of diseases and injuries.

- "Smart scaffolds" for repair of musculoskeletal tissues that release growth factors and anti-infectives to encourage regrowth and prevent infection. The ability to use artificial materials to enhance healing is highly advanced in the area of musculoskeletal disease, and a number of these approaches are already in clinical use. Collaborations between engineers in the Hajim school and researchers in the Center for Musculoskeletal Research are continuing to develop ever better materials to treat a wide variety of musculoskeletal disorders. These collaborations have helped to maintain the Centers' prominence as the #1 funded musculoskeletal research group in the nation.
- The effects of RNA on cell function and the use of RNA to treat disease. The UR has unique strength in RNA Biology, which has been recognized by the establishment of the UR Center for RNA Biology. The Center seeks to discover new knowledge about RNA structure and biology, and to apply these discoveries to clinically relevant problems – including the development of novel therapeutics that either target RNA or are comprised of RNA. To achieve this mission, faculty in the College of Arts, Sciences and Engineering are actively collaborating with faculty in the School of Medicine and Dentistry (SMD). One recent such collaboration showed that nanoparticles can be successfully used to deliver small interfering RNAs (siRNAs) that can protect salivary glands against damage induced by radiation. This breakthrough may eventually lead to a cure for the most common and debilitating consequence of radiation treatment for head and neck cancer: "dry mouth", which causes difficulty with speaking and eating, rampant dental caries and decreased quality of life in many cancer survivors.
- Cell Adhesion as a therapeutic target. To form functional tissues, cells must adhere to and communicate with each other and the surrounding extracellular matrix (ECM). Defects in these communication processes underlie key aspects of many diseases, and therefore represent important therapeutic targets. Biomedical engineers (Hajim School), immunologists, and pharmacologists (SMD) are presently studying how the mechanical properties of blood cells regulate their adhesion, and how this effects the body's response to injury and infection.

- Targeted drug delivery for the treatment of cancer. Many modern therapeutics are biologically derived molecules that cannot traverse the digestive system, and that work best when targeted to specific tissues of interest. This is particularly true in cancer therapeutics where there is an enormous need for improved treatment regimens. Collaborations between engineering and members of the Cancer center are working to develop new targeted drug delivery systems that promise to be the next generation of cancer therapeutics.

C. Molecular signaling in relation to cell function, age, and disease.

The understanding and analysis of fundamental molecular signaling pathways and their relation to cell function are fundamental to developing novel treat modalities and molecular therapeutics for treating disease and mitigating the effects of aging. Specific topics areas include:

- Oxidative stress, energy metabolism and aging. A large body of evidence from model organism experiments and more recently from human population studies has established a close connection between energy metabolism and aging. Translational research projects exploiting these discoveries have led to the formation of start up companies (such as Sirtris and Rochester-based Calorics) that aim at interventions that target metabolic diseases and age-associated degenerative processes. Oxidative stress is also a driver of aging and a key contributor to many diseases, such as neurodegeneration, cardiovascular pathologies and lung disease, and represents an important therapeutic target. Synergies between the work of faculty in AS&E and at the medical center present strong opportunities for collaboration and for the translation of new insights into the molecular and cellular basis of aging, into potential therapeutics and novel interventions.

D. Social and behavioral approaches to improve health

The importance social interaction and opportunities for using social networks and behavioral interventions to predict and reduce unhealthy behaviors is an important emerging field in medical practice. Rochester has long been recognized for its bio-psycho-social approaches to medicine, and we are well positioned to assume a leadership position in this field. The development of novel monitoring and interventional procedures and understanding how these interventions impact community health will be important for enhancing medical care in the coming decades. For example, recent studies have explored how social networks can play a role in the communication and spread of emotion ("affect spread"), including the spread of very negative affect ("suicide contagion"). Furthermore, the ways that preventative care can reduce overall health costs are critical issues for our Society, both for health and economic welfare. The University has a number of innovative programs within this broad area of study.

- Suicide contagion and affect spread through social networks. "Copycat" suicides occur when a person seeks to emulate another suicide. In these instances, the initial suicide serves as a model for subsequent suicides – a phenomenon known as "suicide contagion". A closely related phenomenon is that of "emotional contagion", which refers to the sharing of emotions between individuals and groups. To reduce the risk of suicide contagion, conventional media sources in the U.S. typically do not report suicides (other than celebrity deaths). However, there are no such constraints around the reporting of suicide through social media such as Twitter and FaceBook. This becomes a special concern within marginalized populations. UR researchers in Computer Science and Psychiatry have developed new methods to examine the communication and spread of health information through social media, including

affective messaging and emotional contagion in Twitter, particularly among at-risk youth. The long-term goal of these efforts is to develop more effective interventions to prevent the spread of depressive affect and to reduce the risk of suicide contagion.

- Smoking cessation, weight management, and human motivation. Despite widespread efforts to promote smoking cessation, tobacco use continues to be the leading cause of preventable death in the US. This is in large part because most people who stop smoking relapse within a year. Rochester psychologists and clinicians in AS&E, The Department of Medicine, the School of Nursing, and the Center for Community Health have collaborated to develop a novel intervention based on self-determination theory (SDT) to facilitate long-term tobacco abstinence, which has been shown to be highly cost-effective and to increase long-term tobacco abstinence. This and other approaches being explored by university researchers have important implications for the development of more effective interventions for other conditions – including weight loss programs, medication adherence and personal health maintenance.
- Health economics and improving health care delivery. U.S. health reform is intended to contain rising health care expenditures while improving access, and enhancing cost-effectiveness. This presents important new challenges as the health care system shifts from a fee-for-service payment model to one that emphasizes disease prevention and maintenance of community health. Medical center clinicians and scientists are actively engaged in exploring new approaches to improve the cost-effectiveness of care across our region (including our quarternary care academic medical center and smaller regional community hospitals and partners). Examples include an internationally recognized program in Geriatric Fracture care, programs that increase access to care for persons with movement disorders, as well as multidimensional treatment models for childhood asthma. Understanding and optimizing the economic impact of these programs is a critically important research objective that presents an ideal opportunity for future collaboration between the medical center and the Simon School. In addition, emerging work that is being done in telehealth is going to require extensive interdisciplinary research in health communication and cognitive science to understand the requirements of communication systems needed to transform what is now face-to-face provider/patient and provider/provider contact to electronic interactions. These collaborations to improve healthcare delivery will tap new funding sources such as the Center for Medicare & Medicaid Innovation (CMMI), the Agency for Healthcare Research and Quality (AHRQ), Patient Centered Outcomes Research Institute, and the Department of Veterans Affairs.

E. Neuromedicine

Neuromedicine ranges in scope for cellular and molecular studies of neural cell function to systems level analysis of how neurological systems function. The range of expertise in these areas spans multiple departments and centers in both SMD and AS&E. A key strategic objective will be to recruit new leadership to the Neuromedicine effort to guide the development of synergistic interactions among the many neuroscience researchers at the University. Areas of exiting strength include:

- Systems, Cognitive, and Computational Neuroscience. Overall, there are more than 30 well-funded systems, cognitive, and computational neuroscience faculty that are currently distributed among six or more departments across the University. This group of interactive and collaborative scientists is making key new discoveries on

brain function and developing new therapeutic approaches to several mental health and neurological disorders. Collectively this group is well positioned to compete effectively for the new White House, BRAIN Initiative, which has targeted $100 million "to better understand how we think, learn, and remember." Current areas of collaborative focus include studies of sensory systems and perception, with a focus on translating the latest knowledge about how sensory information is represented and processed in the brain into new rehabilitative approaches. Emerging approaches will harness researchers understanding of neural plasticity to enable the restoration or enhancement of perceptual functions, including the maintenance of these capabilities as we age.

- Autism spectrum disorders. Although previously considered rare, ASD is now estimated to occur in approximately 1 in 88 individuals. ASD is a developmental disorder of prenatal origin related to genetic risk and environmental events, with limited treatment options and a lifetime care cost that often exceeds $2,000,000. UR has national prominence in clinical, translational, and basic ASD research – and has proposed the formation of a comprehensive Autism Research Center that will leverage our institutional strengths with the goal of optimizing the future health, well being, and opportunities of individuals with ASD and their families. UR investigators in AS&E and at the SMD are presently conducting fundamental research on multisensory processing and communication, neurobiology, neurotoxicology, and genetics of ASD, as well as randomized clinical trials of behavioral and pharmacological interventions. The long-term goals of the Autism Research Center include accelerating the translation of discoveries about biological mechanisms into novel treatments and improved early identification.

In addition to the strengths in cognitive neurosciences there is potential to build novel collaborative interactions among other research groups. Prominent existing programs include:

- Neuromuscular disorders- with a focus on muscle degenerative disorders whether genetic (Duchenne dystrophy, myotonic dystrophy) or age related.
- Neurodegeneration and neuroinflammation- with a expertise in progressive human neurodegenerative disorders such as Alzheimer and Parkinson diseases, but also with a focus on rare disorders such as Huntington and Batten disease affecting children and adults.
- Center for translational neuroscience (cells & gene therapy; glial biology & therapeutics).

F. Environmental medicine and the impact of energy policies

Heightened interest in fracking and natural gas drilling has generated enormous controversy between environmentalists and the gas industry. An accurate understanding of the potential hazards of fracking and its potential health consequences based on sound scientific investigation should ultimately drive decisions on these issues. Our expertise in Earth and Environmental Sciences and in Environmental Medicine place the University in a position to provide important input that can guide rational and well-informed decisions on these issues.

III. LIGHT AND SOUND

Of the many ways that we perceive our world, light and sound constitute two major interconnected research areas that are recognized strengths at the university. Thus, there are substantial opportunities for collaboration and synergy among faculty working in the areas of

vision and optics, and hearing and sound. Our goal is to build synergy within and across these areas.

A. Vision and Optics

The Institute of Optics has long been recognized as one of the premier centers for research and training in the optical sciences. In addition to contributions to medical imaging outlined above, an important collaboration between researchers in the Institute of Optics, the Center for Visual Science (CVS) and the David & Ilene Flaum Eye Institute (FEI) is emerging with the goal of restoring sight to the visually impaired. The University of Rochester is fortunate to have a unique and multi-faceted approach to vision science, encompassing basic as well as clinical science through CVS and FEI. CVS is an internationally renowned, multi-disciplinary center consisting of 32 faculty from across the University that has made significant contributions to advancing our understanding of visual system structure and function. The FEI was designated as a UR Center of Excellence in 2012. Committed to excellence in research, education, patient care, and technology transfer, the FEI has grown dramatically in all of its missions. It is one of the fastest growing eye departments in the United States. There is considerable overlap in the scientific goals and scientists of CVS and FEI, facilitating the creation of a unified plan for achieving leadership in a number of critical areas of visual research. While CVS will always maintain its core strength in basic visual science, and FEI will always concentrate primarily on eye disease, both are ideally positioned to work in concert to rapidly develop a translational theme in visual science – preserving vision as well as restoring sight in patients with diseased or damaged visual systems. The synergy is even more compelling since the National Eye Institute (NEI), the primary funding source for vision research, has recently selected vision restoration as its single audacious goal for the next decade.

The multidisciplinary nature of vision research fits well with major initiatives across both campuses of the University of Rochester and among many departments and centers. For instance, pursuing this endeavor will also entail large-scale measurements of visual system neural activity using a variety of techniques including multi-electrode, multi-site recording, optical imaging and fMRI. The analysis, visualization and modeling of these massive data sets will fit well with the University's initiative in Data Science, providing an important application for developing the technologies of large-scale data mining, machine learning and neural computation. The new Center for Medical Technology Innovation could play a critical role in the development of the next generation of retinal and cortical prosthetic devices. An initiative on vision restoration is also attractive because of its commercial potential as the incidence of macular degeneration and other blinding diseases grows dramatically with an aging population.

i. Existing areas of strength:

Vision restoration

Rochester is the only institution that has successfully transfected genes to express channel rhodopsin in nonhuman primate eyes, which gives us an enormous advantage in pioneering the optogenetic approach to vision restoration. The effort to correct neural deficiencies with a retinal prosthetic complements our world-leadership position in correcting optical defects in the eye for vision enhancement. In addition, we have the only investigators worldwide capable of monitoring the neural activity of ganglion cells, the output cells of the retina, in the intact animal eye. This capability will also be key to the development of a retinal prosthesis. This expertise is complemented by investigators with expertise in retinal development and retinal cell biology.

Imaging the eye

Rochester invented retinal cameras equipped with adaptive optics with higher resolution than has ever been achieved in the living eye. Our lead in this area positions us better than anywhere else in the world to quantify retinal changes following the introduction of any retinal prosthetic whether it be optoelectronic, optogenetic, or stem cell-based. The unique technologies developed at Rochester enable us to use optical techniques to detect molecular processes, image ganglion cells of the optical system using autofluorescence and imaging the retinal vasculature at the cellular level.

Visual cortical function and plasticity

Rochester has a world-class group of investigators studying how visual information is represented and transformed by neural circuits in the cerebral cortex, how population activity of cortical neurons gives rise to visual perception, and how cortical circuits adapt and reorganize to changing sensory input. Our strengths in this area makes us uniquely positioned to tackle the problem of how the cortex adapts to vision restoration and to develop novel therapeutic approaches to facilitate recovery of visual perception following restoration of sensory inputs.

Vision Correction

UR has world leadership in the use of wavefront technology to correct the eye's optics better than has ever been possible before. This technology is leading to ever higher standards for vision correction. Researchers are engaged in development of personalized correction of refractive error using contact lenses, intraocular lenses, and corneal manipulations and in identifying the underlying pathophysiology and new treatments for disease affecting the anterior segment of the eye (ocular surface, cornea, and lens).

ii. Summary of proposed investments

There are three areas in which recruitment of additional faculty resources will have substantial impact in bringing this effort to international prominence. The programs will seek to hire scientists with active research in the area of retinal prosthetic development, others in the area of restoring health to the cornea and lens of the eye, and researchers focused on clinical trials, including big data analytics of patient populations in relation to predicting the onset of eye disease and responses to therapeutic intervention.

B. The Institute of Sound

The University of Rochester and the surrounding Rochester community are home to a remarkable array of activities devoted to the study of the many aspects of sound. These range from basic research in acoustics, hearing, speech, language, and auditory neuroscience across the natural, applied, social, and medical sciences at the University, to hearing-related translational and clinical research at the UR Medical Center, to the creation of new audio, ultrasonic, and music related technologies in the Hajim School of Engineering, and to music study and performance at the world renowned Eastman School of Music. There also are many existing linkages to groups outside of the University such as the NTID (National Technical Institute for the Deaf) at RIT, other RIT departments and programs in Audio Technology, Video Games, and Music, and the Hearing Loss Association of America. We propose to build a collaborative environment for these many strengths in a new **Institute of Sound**.

The Institute of Sound will build upon our existing research foundation and bring together researchers and students from across the university to engage in interdisciplinary research in sound and related fields. By making targeted strategic investments, the University of Rochester

will become recognized as the home of the world-leading institute for the study of sound in all of its aspects; indeed there is no better place in the world than Rochester to establish such an Institute. The mission of the proposed Institute would be: to identify, encourage, and support research collaborations among UR faculty and with groups outside of the University, to jointly pursue major research funding opportunities, to provide seed funding for new projects with the potential to grow into major, well-funded interdisciplinary programs, to develop and maintain shared research facilities and resources, to encourage and coordinate strategic faculty and postdoctoral research fellow hiring to bridge research areas and exploit synergies among ongoing research groups throughout the University, and to engage in outreach activities to spread the word about the groundbreaking intellectual, technical and artistic endeavors of the Institute.

i. Existing Strengths at the UR

There is a longstanding tradition of interdisciplinary collaboration in areas related to sound at the University of Rochester. This includes the Rochester Center for Biomedical Ultrasound, collaborations between the Eastman School and The College in music, audio technologies, and music perception and cognition, research in auditory neuroscience, hearing, and language, and clinical research in otolaryngology and the National Center for Deaf Health Research. At a minimum, there are sound-related research activities in the following departments and Centers of the University:

Arts, Science and Engineering: Brain and Cognitive Sciences, Biomedical Engineering, Computer Science, Electrical and Computer Engineering, Linguistics, Mechanical Engineering, Music, the Rochester Center for Biomedical Ultrasound, the Music Research Lab, UR Libraries including the Sibley Music Library

Eastman School of Music: Music Theory, Composition, Music Education, Winds, Brass and Percussion, Organ

Medical Center: Imaging Sciences, Audiology, Otolaryngology, Family Medicine, Nursing, Pharmacology and Physiology, Echocardiology, Neurobiology and Anatomy, Center for Navigation and Communication Sciences, CTSI, and the National Center for Deaf Health Research

The Institute of Sound would engage faculty and students from the undergraduate level through the graduate and post-doctoral levels from the many departments listed above as well as from new academic programs such as those in Audio and Music Engineering and Digital Media Studies.

ii. Research Themes of the Institute

The research activities of the proposed Institute can be collected into three broadly defined areas.

Sound in Music and Entertainment

At the intersection of music and engineering there are a host of opportunities for developing novel technologies with the potential for significant social impact in the way that we perceive and produce music. These include novel ways to access, recognize, and search for music; development of machines that model and mimic human music perception and cognition with the goal of developing machines that match or exceed the music recognition and transcription capabilities of trained musicians; new music representations based on theoretic analysis of music that capture the expressive features of performance; new musical instruments and interfaces,

some that will enable disabled individuals to express themselves in music; and new devices and environments for communicating with sound.

Sound in Medicine and Biology:

There are three principle ways in which sound impacts medicine and biology. First, the use of ultrasound as an imaging modality and as a therapeutic modality has transformed many areas of patient care. Rochester has long been a leader in developing new uses for biomedical ultrasound, and strategic investments will enable us to maintain this leadership position. Second, the treatment and care of patients with hearing abnormalities is rapidly growing area of medicine, particularly in light of the aging boomer generation and the consequences of all those rock concerts they attended in their youth. The collective expertise of Rochester faculty places us in a unique position to develop novel hearing prosthetics and improved methods for aiding the hearing impaired, including the development of alternative representations of sound information for the hearing impaired. Third, the analysis of naturally occurring sounds can be diagnostic in a wide range of situations from medical care to the environment. For example, reliability of clinical diagnoses may be improved by understanding the acoustic cues employed by trained physicians (cardio-pulmonary, respiratory, others), and by replicating and extending diagnostic capabilities with machine-assisted and machine-based sound analysis. Audio surveillance can also be applied for assessing the state of the environment, for insect, bird and animal population estimation and monitoring, and, using underwater acoustics, for monitoring and classifying fish and sea mammal populations.

Sound in Speech, Hearing, Language, and Communication:

The University of Rochester has an especially rich research environment in the area of Speech, Hearing, Language and Communication. Creation of the Institute of Sound is expected to enhance collaboration and synergy among faculty working in multiple areas within this common theme. Specific areas include Speech Production and Perception; Autism and Speech Processing; Hearing and Performance Impairments in Musicians; Brain function and Acquired Hearing Loss; Language Interpretation; Music Training and Its Effect on Nonmusical Cognition; Speech Enhancement for Improved Communication between Humans and Machines; and Enabling people to Better Interact with Information using combinations of sound, visual and haptic sensory stimuli.

iii. Summary of proposed investments

Considering the potential gains in research productivity and international recognition that can be achieved, the proposed investments for establishing an Institute of Sound are relatively modest. Ideally, physical space for sound research should be provided, approximately 2500 net square feet, including a large anechoic room for acoustical measurements, reverberant rooms for acoustical and speech perception experiments, sound-proof rooms for audition and cognition experiments, and office and collaboration space for researchers (total space costs, < $1M). From a staffing perspective, funding of post-doctoral fellowships to help build multidisciplinary research teams spanning the university is a primary need, plus and technical and administrative staff and related operating expenses would total approximately $250K/year. Two strategically targeted faculty members in acoustics/signal processing and in music cognition would add needed expertise ($800K startup plus $150K ongoing salary and benefits support for each faculty member).

IV. THE ROCHESTER CENTER FOR ENERGY AND THE ENVIRONMENT

The University of Rochester has a core set of research expertise in science, engineering, and medicine that forms the foundation for developing internationally recognized research programs

in energy technology and the impact that our energy choices are likely to have on the environment and human health. The synergies between programs could be greatly enhanced through collaborative research space in a new science and engineering building. A new research center would focus on: 1) carbon-neutral energy technology, 2) understanding the human health implications of energy resources, and 3) climate-carbon cycle interactions. New faculty hires associated with this research center would integrate with the Data Science Initiative.

A. Carbon-neutral energy technology

The University of Rochester is uniquely positioned to leverage research expertise in energy and environmental sciences to support a transition to carbon-neutral energy resources while also fundamentally advancing science and technology, engaging with the regional community to improve the economy and educating our nation's future scientific and engineering leaders. Thirty-two faculty from six different departments are currently working in areas related to this topic. At present, there are highly regarded research programs in solar concentrators, photovoltaics, the production of hydrogen fuel from water using solar energy, fuel cells, and biofuels, and the energy-efficiency of end-user systems among others. The Laboratory for Laser Energetics (LLE) is a world renowned facility for studying laser fusion energy and supports a number of fundamental research programs on high energy density plasma physics, optics, and materials science. The OMEGA laser facility is the second largest in the World, after the NIF at Lawrence Livermore, and the largest high energy density physics user facility. It includes the 60-beam high-energy laser OMEGA and two of the highest energy, short-pulse (ps) laser beams (OMEGA-EP). OMEGA is the world largest facility for the development of direct drive laser fusion, the most promising approach to inertial fusion energy.

B. Human Health

Every form of energy production and use impacts human health, whether carbon based or alternative. Exposures to gases, particulates, manufacturing products, and radiation all have the potential to impact fetuses, children, and adults, as well as vulnerable and susceptible populations. The University of Rochester and the Medical Center has a rich history of identifying and quantifying the health impacts of toxicants ranging from gases such as ozone, to particulates including nanoparticles, radiation, phthalates and toxic metals such as lead and mercury, and over 29 faculty members currently work on health issues either directly or indirectly related to environmental factors. Importantly, we have used human epidemiology and modeling systems (in vitro and in vivo) to analyze, define etiologies and mechanisms, and mitigate these effects. We are one of a handful of human clinical testing exposure facilities in the USA and have been supported by federal agencies including the Environmental Protection Agency (EPA), the Air Force and the NIH, and the automobile, pharmaceutical, and manufacturing industries for these studies. Our data have been used to inform public and local policy in the US and around the world. Energy sources change, and we are learning more of their effects on human health. These effects take many forms, from pulmonary and cardiovascular disease, to damage to bone, the nervous system and the developing fetus. A growing area of research is the effects of early life exposures to the development of adult disease. An example of this is exposure of premature infants to lung ventilation (hyperoxia) and the later development of adult lung disease. All of these exposures are potentially preventable and prevention is at the center of our health care reform policies.

Increased interactions between the river campus and the medical center focusing on the impact of new energy resources offers a unique opportunity to identify, test and mitigate

toxicities of different energy sources. Opportunities for funding are diverse, from the EPA and Health Effects Institute to the NIH, industry, DARPA/DOD, pharma and manufacturing. Specific areas of expertise and focus include: 1) the role of inhalation of toxicants, 2) the role of environmental pollutant and epigenetic changes and 3) the role of environmental toxicants and exposure in children on the subsequent development of adult disease. Another example is the exposure to environmental obesogens in utero that can contribute to childhood and adult obesity, a major health epidemic in the US. Opportunities for research are matched by equal opportunities for education and national and international service and contributions to regulation of toxicities across the globe.

C. Climate-carbon cycle interactions

Researchers in Earth and Environmental Sciences at the University of Rochester have investigated changes in atmospheric, oceanographic, Earth, and ecosystem processes on timescales of only a few years to millions of years. Global climate has changed on all of these timescales and the global scientific community has reached a near consensus that global climate is continuing to change due to a combination of natural and man-made factors. Observational data show that the Earth's carbon cycle is being altered at an unprecedented rate by human activities. The resulting accumulation of carbon in the atmosphere and oceans is contributing to global warming, ocean acidification, and sea level rise. However, a key challenge is the considerable uncertainty surrounding the magnitude and speed of these changes. At the core of uncertainty about the rate and magnitude of future warming is the complex and imperfectly understood interaction between global climate and various components of the carbon cycle. While the extent of atmospheric temperature changes caused by greenhouse gas fluctuations is relatively well-known from modern and paleo investigations, the global dynamics - and their associated feedbacks and timescales - are less known. In the modern context, it is unknown how long elevated levels of greenhouse gases will persist in the atmosphere after anthropogenic emissions have terminated mainly because the long-term fate of carbon composing carbon dioxide and methane, two major greenhouse gases, is unknown. Likewise, CO_2 sequestration, CO_2 reduction methods, and the inevitable transition to carbon-neutral energy sources could reduce projected CO_2 emissions, further altering the modern CO_2 budget.

We propose to build on the current research at the University of Rochester in Earth and Environmental Science (EES), Physics and Astronomy (PAS), Chemistry, and Computer Science (CS), to establish a leading program in the study of climate - carbon cycle interactions. We will build our strength in this area through collaborative hiring of several key strategic new faculty hires in direct support of the Data Sciences initiative to support carbon cycle modeling, atmospheric modeling, and/or Earth system analytics to complement our current strengths in field and laboratory-based investigations.

D. Summary of proposed investments

It is significant that much of the needed growth in Carbon cycle research depends on implementation of large-scale data analytics. Thus the need for increased expertise in environmental modeling aligns directly with proposed growth in Data Sciences. In light of this it would also be beneficial to co-locate scientists focused on energy and the environment with investigators in data science to facilitate these interactions. Targeted research areas for new hires in this space include carbon cycle modeling, earth surface processes, and earth system analytics.

V. UR RESEARCH IN THE LOCAL AND GLOBAL COMMUNITY

The University of Rochester takes very seriously its role as a member of the larger community, locally, nationally, and globally. Research provides many opportunities for us to participate actively in the community. Funding provided by government agencies has focused more and more on societal relevance, which has led our researchers to focus more on the need to "translate" discoveries in the basic sciences and engineering to services and products that positively impact society and the economy. Thus, translational research has become a major emphasis of researchers throughout the University. In addition, we engage in partnerships with other universities, research institutes and corporations. Through these partnerships, we enhance the breadth and quality of the research being done at the University of Rochester and also expand our reputation and recognition among peer institutions. Finally, we are mindful of the global impact that our research can have, both through international collaborations and in developing new technologies and discoveries that can benefit the developing world.

A. Research Translation

To support research translation a number of centers and programs have been established. These include the federally funded CTSI (Clinical and Translational Sciences Institute), the state funded CEIS (Center for Emerging and Innovative Sciences), and University-funded centers including the recently established CMTI (Center for Medical Technology Innovation), and the Center for Entrepreneurship. All of these centers serve critical roles within the University, but a synergistic approach to business engagement has been identified as a need, and a new center is proposed to address this need.

i. Existing Centers

CTSI: The University of Rochester is one of 60 institutions nationwide with funding from the NIH to lead the emerging field of clinical and translational science and educate the next generation of translational researchers. The University received one of the first and largest of these awards ($40M in 2006) and received and additional $4M through competitive renewals making it one of the largest grant awards the University has ever received. The Institute assists researchers at the University of Rochester and across Upstate New York to produce innovative technology and methods that more efficiently and more quickly advance treatments to patients and communities. The CTSI is organized into various "key functions" that support the research community. The functions include biomedical informatics, community engagement, study design, biostatistics and ethics, pilot and collaborative studies, regulatory knowledge and support, and public-private partnerships, among others.

CEIS promotes economic development through industry-university collaboration and technology transfer. Based in the Hajim School of Engineering & Applied Sciences, it is one of 15 Centers for Advanced Technology (CATs) funded by NYSTAR, a division of the New York State Department of Economic Development. Staff within the center work primarily with faculty and scientists at the University of Rochester and the Rochester Institute of Technology, although research at other universities in New York is also supported. Their primary mission is to connect faculty and staff with potentially commercializable ideas with small, mid-sized, and large companies in the Finger Lakes region and across New York State.

CMTI has gotten its start via a one-year masters program based on the identification of clinical problems that can be addressed through engineering design. In the long term the Center seeks to become an effective interface between design training and expertise within the university and corporate partners in the medical device industry who can sponsor design projects and provide internship and employment opportunities for our students.

CE: The Center for Entrepreneurship, launched by the Ewing Marion Kauffman Foundation grant awarded to the University in 2003, serves to identify and create new partnerships among students, alumni, local businesses, and non-profit organizations. It coordinates and publicizes school-based experiences, including courses and signature programming, and informs faculty of grant and bridging fellowship opportunities. Its influence extends across the University as it encourages collaboration among the various schools to foster entrepreneurship education in a variety of forms and domains. It signature training program is a masters degree in Technical Entrepreneurship and Management (TEAM), which enrolls dozens of masters students training for entrepreneurial careers.

ii. The New Center for Business Engagement

An important strategic objective that will significantly enhance university relations with business partners is the establishment of a Center for Business Engagement. This center will be a synergistic collection of the principal units within the university that play key roles in establishing relationships with industry of all kinds. Units playing a role in the center will include:

- Office of Senior VP for Research
- Corporate Relations
- Technology Transfer
- University Counsel
- Office of Research and Project Administration
- The Career Center
- Alumni Relations

A key role for the center will be to track university interactions with different companies through the use of a "dashboard" that will summarize university relationships with the company, including licensing agreements, grant proposals and grants received, career services activity and internships, and a listing of UR alumni working at the company, all pulled from the data warehouse. As we build relationships with different corporations, a new computer-based tracking system ("Sales Force") will be used to keep track of all of our interactions so that efforts to develop relationships can be coordinated and well-targeted.

B. Research Partnerships

As we move forward with our research agenda, numerous opportunities arise for creating partnerships with other institutions, federal research and regulatory agencies, and industry. A recent example of a strategic partnership is the relationship between the Cancer Center and Roswell Park, which houses an enormous database of cancer patient data including genetic markers and disease outcomes, an enormous advantage as we move forward with bioinformatics approaches to the care and treatment of cancer patients.

The University will continue to support faculty-to-faculty collaborations across institutions locally, nationally and globally. One such example includes the Laboratory for Laser Energetics, which serves as a global resource for researchers in fusion energy and other domains of science requiring access to the OMEGA EP laser. The array of such collaborations across our institution are far too numerous and diverse to list, but are important to the vibrancy of our research and are regularly enabled by the Office for Research Projects Administration and fostered by the Office of Research Alliances.

C. A Global Presence

The University has many collaborations and interactions with Universities and research institutes around the world. We are also heavily engaged in study abroad for our own students and in recruiting international students to Rochester. International students are particularly important in supporting our research activities. Our faculty are internationally diverse, providing many opportunities for creating relationships abroad.

We advocate an international strategy that focuses on investments in relationships, not infrastructure. To maximize our partnerships, we propose leveraging current relationships, whether derived from study-abroad programs or faculty-to-faculty research collaborations. We will have the greatest institutional impact by concentrating our efforts in multiple domains with targeted, strategic, international partners. The newly established international office by the Provost provides critical support in this domain.

VI. THE INSTITUTIONAL ROLE

The funding landscape is ever changing, and economic pressures of late have greatly stressed modern research universities. The Office of the Sr. VP for Research has numerous operational activities related to the support of the University's research machinery, but several areas are important relative to our future success:

- Fostering collaborations across Schools and identifying common themes and opportunities for synergy that leverage strengths.
- Enabling internal and external engagement through effective communication and business engagement.
- Identifying critical, enabling resources for our research community that maximizes efficiency: shared instrumentation facilities, shared computing resources, infrastructure and space
- Enhancing infrastructure for technology commercialization and new venture creation.
- Monitoring and conveying an accurate picture of the funding landscape.

Success in the previously listed domains requires effective cooperation, coordination and communication across our university, and recent appointments in the Office of the Sr. VP for Research (Rick Waugh – Associate Vice President for Research) as well as the School of Medicine and Dentistry (Steve Dewhurst – Vice Dean and Associate Vice President for Research, Ed Puzas – Associate Dean for Basic Research, and Karl Kieburtz – Director of CTSI and Associate Dean for Clinical Research) and Arts, Sciences, and Engineering (Dave Williams – Dean of Research) make this possible.

VII. OPERATIONALIZING THE PLAN

The transition from strategic planning to implementation across the University of Rochester requires coordination and specific commitments on the part of deans representing the schools. To operationalize the plan, a business model is required and will be the subject of ongoing work.