CONFERENCE ON RESEARCH AT THE INTERFACE OF THE LIFE AND PHYSICAL SCIENCES: BRIDGING THE SCIENCES

Richard Swaja (NIBIB), Bruce Hamilton (NSF), Ken Dill (UCSF), Claire Fraser (TIGR), and Jose Onuchic (UCSD)

February 4, 2005

Executive Summary

A "Conference on Research at the Interface of the Life and Physical Sciences: Bridging the Sciences" was conducted on November 9, 2004, at the Holiday Inn Select Hotel in Bethesda, Maryland. The meeting was sponsored by the National Institutes of Health (NIH) National Institute of Biomedical Imaging and Bioengineering and the National Science Foundation (NSF) and planned by an Interagency Coordinating Committee. The conference was held in response to a recommendation from a May 10, 2004, interagency workshop that a meeting of scientific researchers be conducted to obtain community input on how to bridge the life and physical sciences.

To meet this objective, the following three questions were considered:

1. What are high-priority issues and opportunities that will ultimately require the combined application of the physical, computational, social, and life sciences to address?

2. What are major challenges and barriers to bridging the sciences?

3. What actions or approaches are necessary to bridge the sciences and realize the potential benefits?

A total of about 170 people attended this meeting including 29 invited primary discussants from the life, physical, and interface sciences; investigators from a broad range of scientific disciplines; Congressional staff; and representatives of universities, technical societies, media, foundations, and Federal agencies. The one-day program consisted of two sets of breakout and plenary sessions aimed at addressing the three questions and developing consensus results.

The following topics were identified by the conference participants as high-priority opportunities that will need to be addressed by collaborations among the sciences:

- *Large-scale global problems* – Major issues of global consequence that require multi-disciplinary approaches include climate change, national security, complex diseases, emerging diseases, environmental remediation, energy production and distribution, and food production.

- *Healthcare in the 21st Century* – Significant advances in healthcare that will require bridging the sciences include personalized medicine, disease prediction, disease prevention, early diagnosis, early treatment, regenerative medicine, and reparative medicine.

- *Multi-scale phenomena* – This topic includes bridging the vast scales of time, space, and organization in biosystems and natural systems and involves discovering physical principles that govern multi-scale phenomena and linkages.

- *Molecular-level measurement tools* – To enable understanding of fundamental biological and physical processes, measurement and imaging tools that provide molecular-level spatial resolution in living cells and temporal detection of chemical species in a single living cell are required.

- *Predictive understanding of biological systems* – This item involves developing quantitative approaches/computational models to analyze "omics" data to gain fundamental insights into biological processes.

- *Biological complexity* – Understanding the complexity of living systems will enable understanding the bases of health and disease.

- *Integrating biological and physical systems* – The ability to integrate organic and inorganic systems will enable advances in a broad range of applications including manufacturing, medicine, environment, and energy.

The following areas were identified as contributing to challenges and barriers to bridging the life and physical sciences:

- *Education and training at all career levels* – There is insufficient investment of resources to develop researchers experienced in both the life and physical sciences and able to work comfortably at the interface.

- *High-risk, long-term research* – Opportunities and administrative mechanisms for support of high-risk, long-term research characteristic of basic scientific investigations in the physical sciences are inadequate and eroding especially when biomedical applications are not initially apparent.

- *Problems to coalesce scientific communities* – Scientific disciplines are presently too compartmentalized and do not have sufficient opportunities and incentives to encourage and sustain collaborations.

- *Research infrastructure* – Facilities and tools, communication and interaction opportunities, and information management capabilities dedicated to supporting collaborative research and "team" science are inadequate.

- *Cultural differences across disciplines* – Experts in scientific disciplines often have an inadequate appreciation for the expertise and potential of other disciplines and an imperfect ability to communicate with them.

Participants identified the following as novel actions that could catalyze, support, and sustain collaborations among scientific disciplines:

- *Identify and support well-defined, large-scale, complex problems (i.e., "big" research problems or grand challenges) that will drive multi-disciplinary research and nucleate the broad scientific community* – Large-scale problems of national or global interest could provide foci for multi-disciplinary collaborations and enable pursuit of results in terms of project objectives rather than disciplinary interests.

- *Increase support and develop appropriate mechanisms for long-term, high-risk research* – Funding and appropriate opportunities are needed to support long-term research in the physical sciences that may have no initial obvious biomedical application but may underpin advances in biology and medicine in addition to being fundamentally important for discovery and innovation in the physical sciences.

- *Develop and maintain infrastructure required to support multi-disciplinary research and communication* – Adequate shared and centralized large-scale and multi-use facilities and research tools are needed to enable collaborative research and "team" science and to provide central physical locations and locations enabled by the tools of cyberinfrastructure where scientists from different disciplines can interact.

- *Provide opportunities and support for multi-disciplinary education and training programs at all career levels aimed at ensuring a sustainable workforce of investigators equipped with the necessary technical expertise, appreciation of the physical and life sciences, and problem-solving abilities to conduct research at the scientific interface* – Support and opportunities are needed for education and training programs that provide strong mathematics and science backgrounds from levels K through16, incorporate biology-related problems into physical science curricula and vice versa, enable integrated and team-based approaches to problem solving, and provide research experiences along the career path.

One of the suggestions for implementing the actions identified at this conference was a national effort aimed at bridging the sciences. Such an effort will require strong coordination and cooperation among academia, industry, national laboratories, technical societies, and Federal agencies and should not adversely impact existing programs that encourage and support collaborative research.

Current plans are for the NIH and NSF coordinators to convene a meeting of Federal agency representatives to discuss results of the May 10 workshop and this conference and to determine a course of action. Other plans are to post this report on the NIBIB and NSF Web sites and to have the extramural co-chairs meet with NIH and NSF leadership to discuss results of the conference. Complete information about this meeting is available on the Internet at http://www.nibib.nih.gov/publicPage.cfm?pageID=2867.

Conference Proceedings and Results

Background

Many of the remarkable advances in biology and medicine that have been achieved during the past century have been underpinned by breakthroughs in the physical sciences. Most recently, the successes of the Human Genome Project have made two things clear – (l) biological mechanisms are much more complex than previously thought and (2) the physical and mathematical sciences have critical roles to play in understanding biology. However, benefits of bridging the sciences go both ways. Disciplines such as systems biology and earth systems science, and applications such as the use of neural network models to simulate ecological systems are two examples of how deeper understanding of complex systems can be approached through collaborations among physical, computational, behavioral, social, and biological scientists and engineers. Advances resulting from multi-disciplinary approaches provide an unprecedented sense that a deeper understanding of the natural world can be achieved at all levels – spatially, temporally, and organizationally. Such scientific understanding can impact major complex national and global issues such as emerging infectious diseases, longer life expectancy, energy resources, climate change, environmental sustainability, national security, food production, and individual and species differences and their implications for evolution and extinction. The question for the broad scientific community is how to effectively bridge the sciences and realize the potential benefits.

In recognition of the importance of scientific collaborations, language in the House of Representatives reports accompanying the FY 2004 Appropriations Bill suggested that the National Institutes of Health (NIH) and the National Science Foundation (NSF) convene an interagency conference to discuss how research at the interface can be strengthened. In response to this language, an "Interagency Workshop on Research at the Interface of the Life and Physical Sciences" (http://www.nibib.nih.gov/publicPage.cfm?pageID=2869) was conducted on May 10, 2004, at the NIH. Ten Federal agencies with substantial interests and responsibilities associated with the physical and life sciences were represented. One of the primary recommendations from this workshop was that a meeting of scientific researchers be held with the goal of obtaining community input on how to effectively bridge the life and physical sciences.

In response to this recommendation, a "Conference on Research at the Interface of the Life and Physical Sciences: Bridging the Sciences" was conducted on November 9, 2004, at the Holiday Inn Select Hotel in Bethesda, Maryland. The conference was sponsored by the NIH's National Institute of Biomedical Imaging and Bioengineering (NIBIB) and the NSF, and was planned by an Interagency Coordinating Committee which included representatives from the Department of Energy, Environmental Protection Agency, National Aeronautics and Space Administration, National Institute of Standards and Technology, NIH, and NSF. A list of Coordinating Committee members is given in Appendix A of this report. Extramural Conference Chairs were Drs. Ken Dill (UCSF), Claire Fraser (TIGR), and Jose Onuchic (UCSD). Intramural Chairs were Drs. Bruce Hamilton (NSF) and Richard Swaja (NIBIB).

Objectives

The overall objective of the one-day conference was to obtain input from the scientific community on how to bridge the life and physical sciences. To meet this objective, the following three questions were considered:

1. What are high-priority issues and opportunities that will ultimately require the combined application of the physical, computational, social, and life sciences to address?

2. What are major challenges and barriers to bridging the sciences?

3. What actions or approaches are necessary to bridge the sciences and realize the potential benefits?

Participants

A total of about 170 people attended this meeting including 29 invited primary discussants from the life, physical, and interface sciences; investigators from a broad range of scientific disciplines; Congressional staff; and representatives of universities, technical societies, media, foundations, and Federal agencies. Attendance was open to the public up to the limit dictated by the seating capacity of the plenary room. Appendix B is a list of invited primary discussants who provided initial perspectives to begin discussions and served as co-chairs for the breakout sessions. The primary discussants represented a broad scope of physical, biological, medical, mathematical, engineering, computational, and interface (i.e., bioengineering, biophysics, bioinformatics, imaging, etc.) sciences and were selected by the Interagency Coordinating Committee based on recommendations and input from scientific societies, research organizations, and Federal agencies.

Program

The conference agenda is attached as Appendix C to this report. The program consisted of two sets of breakout and plenary sessions aimed at addressing the three questions and developing consensus results. Morning sessions considered questions 1 and 2, and the afternoon sessions addressed question 3. Breakout sessions consisted of three groups with mixed life science and physical science expertise led by an extramural conference chair and a primary discussant. Three Federal agency representatives were also assigned to each breakout group to serve as information resources and to assist with information management. Appendix D lists breakout group assignments including co-chairs and agency representatives. Following the breakout sessions, results from each group were presented by the co-chairs at the beginning of the plenary sessions and used as bases for developing conference results.

Opportunities for Bridging the Sciences

Conference participants identified the following items (not in priority order) as important issues and opportunities that will need to be addressed by collaborations among the physical and life sciences (response to question 1). The list includes global and broad scientific topics that primarily focus on biomedical applications.

- *Large-scale global problems* – Major issues of global consequence that require multi-disciplinary approaches include climate change, national security, complex diseases, emerging diseases, environmental remediation, energy production and distribution, and food production.

- *Healthcare in the 21st Century* – Significant advances in healthcare that will require bridging the sciences include personalized medicine, disease prediction, disease prevention, early diagnosis, early treatment, regenerative medicine, and reparative medicine.

- *Multi-scale phenomena* – This topic includes bridging the vast scales of time, space, and organization in biosystems and natural systems and involves discovering physical principles that govern multi-scale phenomena and linkages.

- *Molecular-level measurement tools* – To enable understanding of fundamental biological and physical processes, measurement and imaging tools that provide molecular-level spatial resolution in living cells and temporal detection of chemical species in a single living cell are required. Novel physical and computational approaches to nano-scale imaging of biological systems can provide these tools.

- *Predictive understanding of biological systems* – This item involves developing quantitative approaches/computational models to analyze “omics” data to gain fundamental insights into biological processes. Associated issues include (1) determining how physical forces and chemical interactions affect the structure and function of cells and larger systems and (2) developing quantitative models to describe these interactions.

- *Biological complexity* – Understanding the complexity of living systems will enable understanding the bases of health and disease. Topics associated with this opportunity include understanding (l) relationships among sequence, structure, function and information content; (2) emergent behavior; and (3) networks of reactions and system interactions.

- *Integrating biological and physical systems* – The ability to integrate organic and systems will enable advances in a broad range of applications including manufacturing, medicine (prosthetics, sensors, and devices), environment (pollutant and toxin detection), and energy.

Challenges and Barriers to Bridging the Sciences

Conference participants recognized that some challenges related to multi-disciplinary collaborations and "team" science have been suggested at previous workshops, conferences, and studies. Within the context of this conference, the following areas (not in priority order) were identified as contributing to barriers to bridging the life and physical sciences (response to question 2):

- *Education and training at all career levels* – The lack of programs to develop researchers trained in both the life and physical sciences and able to work comfortably at the interface was emphasized throughout the conference. There is insufficient investment of resources to foster the professional training and education necessary to maintain a sustainable workforce capable of conducting collaborative research and adapting to national dynamics. A key contributing factor is the lack of adequate multi-disciplinary education and training opportunities at all career levels (including K-16) that provide (l) adequate mathematics and science backgrounds, (2) biology-related problems incorporated into physical science courses and vice versa, (3) integrated and team-based approaches to problem solving, and (4) research experiences and opportunities. Challenges to creating and sustaining such programs include (l) organizational barriers that create competitive instead of cooperative environments between departments and organizations, (2) cultural differences between disciplines and agencies, (3) lack of innovative approaches in education, and (4) inadequate reward and recognition systems for multi-disciplinary research and training efforts.

- *High-risk, long-term research* – Opportunities and administrative mechanisms for support of high-risk, long-term research characteristic of basic scientific investigations in the physical sciences are inadequate and eroding especially when biomedical applications are not initially apparent. Proposal review, progress evaluation, and renewal criteria associated with current grant mechanisms are generally not appropriate for this type of research.

- *Problems to coalesce scientific communities* – Scientific disciplines are presently too compartmentalized and tend to focus research on disciplinary interests. There are insufficient and inadequate opportunities and incentives to encourage and sustain collaborations that could nucleate the scientific community. Coordinated opportunities to solve well-defined major global problems and to provide specific goals for long-term collaborative research are not available.

- *Research infrastructure* – Facilities and information management capabilities dedicated to supporting collaborative research and "team" science are inadequate. There is a lack of shared and centralized large-scale and multi-use facilities and research tools that provide central locations where physical and life scientists can interact. These items are costly to develop and maintain, but are needed to stimulate multi-disciplinary research on a national level. In addition to research tools, adequate cyberinfrastructure does not currently exist to facilitate connected information management, data and resource access, and communication and networking capabilities.

- *Cultural differences across disciplines* – Experts in scientific disciplines often have an inadequate appreciation for the expertise and potential of other disciplines and an imperfect ability to communicate with them. Difficulty in communicating across disciplines (i.e., the lack of a common language or the difficulty in learning another language) is frequently identified as a major barrier for scientific collaboration. Also, distinct systems of values exist between the life and physical sciences due primarily to differences between educational and occupational environments and missions. In addition, hostility to "disruptive" change to the *status quo* and new technologies in segments of the life and physical science communities can inhibit acceptance and support of new approaches or advances that characterize multi-disciplinary collaborations.

Actions and Approaches to Bridge the Sciences

The following novel actions that could catalyze, support, and sustain collaborations among scientific disciplines were identified during the conference (response to question 3 – not in priority order):

- *Identify and support well-defined, large-scale, complex problems (e.g., "big" research problems or grand challenges) that will drive multi-disciplinary research and nucleate the broad scientific community* – Large-scale problems of national or global interest could provide foci for multi-disciplinary collaborations and enable pursuit of results in terms of project objectives rather than disciplinary interests. Identifying and supporting such problems that need to be answered by bridging the sciences could impact ecosystems and social issues as well as human health. Related efforts could require cooperation among Federal agencies and would stimulate collaborations among scientific disciplines on a national level.

- *Increase support and develop appropriate mechanisms for long-term, high-risk research* – Funding and appropriate opportunities are needed to support long-term research in the physical sciences that may have no initial obvious biomedical application but may underpin advances in biology and medicine. Such research is also fundamentally important for discovery and innovation in the physical sciences. In addition to funding, this item involves developing grant mechanisms that include appropriate proposal review, progress evaluation, and renewal criteria. Participants emphasized that funding for such opportunities cannot detract from existing successful, short-term programs that support collaborative research. Attendees also recognized that science is a diverse enterprise and that while high-risk, long-term research could bridge the sciences, support must be provided for the broad range of multi-disciplinary research projects from short-term, small-scale (individuals or small groups of investigators with modest equipment needs) through long-term, large-scale (multi-organizational teams with significant equipment requirements).

- *Develop and maintain infrastructure required to support multi-disciplinary research and communication* – Shared and centralized large-scale and multi-use facilities and research tools are needed to enable collaborative research and "team" science and to provide central physical locations and locations enabled by the tools of cyberinfrastructure where scientists from different disciplines can interact. Support must be provided for both the development and maintenance of such facilities. In addition to basic research equipment, connected computing and networking infrastructure is needed to provide broad access to data and resources.

- *Provide opportunities and support for multi-disciplinary education and training programs at all career levels aimed at ensuring a sustainable workforce of investigators equipped with the necessary technical expertise, appreciation of the physical and life sciences, and problem-solving abilities to conduct research at the scientific interface* – Support and opportunities are needed for education and training programs that provide strong mathematics and science backgrounds from levels K through 16, incorporate biology-related problems in physical science curricula and vice versa, enable integrated and team-based approaches to problem solving, and provide research experiences along the career path. In addition to budgetary and program support, scientific community action is needed to overcome existing organizational barriers (cooperation and not competition among departments and organizations, reward systems, and faculty recognition), cultural differences among the disciplines and organizations, and reluctance to accept innovative approaches in education.

Throughout the conference, participants articulated the view that effectively facilitating research at the scientific interface will require action and support from the broad scientific community and Federal agencies. Within the scientific community, cooperation and coordination among academia, industry, national laboratories, and technical societies are needed to address some of the challenges and barriers and to implement some of the actions identified at this meeting. One of the suggestions for providing the necessary focus and coordination was a national effort aimed at bridging the sciences. Factors that need to be considered for such an effort include program oversight, budget dynamics, and Federal agency missions. It was also recognized that successful programs that encourage and support collaborations among scientific disciplines currently exist, and that a national effort should not adversely impact these programs.

Summary

This conference represents the second phase of Federal agency response to language in the FY 2004 House Appropriations Report that recognized the importance of research at the interface of the life and physical sciences. Results of the first phase (the May 10 interagency workshop) and this conference delineate important challenges and suggest potential actions for bridging the sciences. Implementing these suggestions will require cooperation among the broad scientific community (including academia, industry, national laboratories, and technical societies) and Federal agencies. Current plans are for the NIH and NSF coordinators to convene a meeting of Federal agency representatives to discuss results of the May 10 workshop and this conference and to determine a course of action. Other plans are to post this report on the NIBIB and NSF Web sites and to have the extramural co-chairs meet with NIH and NSF leadership to discuss results of the conference. Complete information about this meeting is available on the Internet at http://www.nibib.nih.gov/publicPage.cfm?pageID=2867.

Acknowledgements

The authors extend sincere thanks to the members of the Interagency Coordinating Committee listed in Appendix A for their dedicated and focused efforts to develop the plans and program for this meeting. Special acknowledgment is given to Stacy Wallick of the NIBIB for her invaluable efforts in coordinating all aspects of meeting logistics and administration. Thanks are also extended to Colleen Guay-Broder, Cheryl Fee, and Mary Beth Kester of the NIBIB for their help with meeting conduct, information preparation, and liaison with attendees. The contributions of Todd Merchak, Theresa Smith, and Elijah Weisberg of the NIBIB for information management during the conference are gratefully acknowledged. Sincere thanks and special recognition is extended to Arthur Ellis and Sohi Rastegar of the NSF who were invaluable at moderating the plenary sessions and extracting useful output from a large amount of information in a short time.

APPENDIX A

INTERAGENCY COORDINATING COMMITTEE FOR THE CONFERENCE ON BRIDGING THE SCIENCES

November 9, 2004

Denise Caldwell (NSF)
Arthur Ellis (NSF)
John Emond (NASA)
Cheryl Fee (NIBIB)
Colleen Guay-Broder (NIBIB)
Bruce Hamilton (NSF) – Co-Chair
Angela Hight-Walker (NIST)
Eric Jakobsson (NIGMS)
Mary Beth Kester (NIBIB)
Albert Lee (NIST)
Mark Lee (NASA)
Wendy Liffers (NIDCR)
Linda (Lee) Magid (NSF)
Anne Plant (NSTC)
Sohi Rastegar (NSF)
Richard Swaja (NIBIB) – Co-Chair
David Thomassen (DOE)
Stacy Wallick (NIBIB)
Edward Washburn (EPA)
Anthony Wolbarst (EPA)

APPENDIX B

INVITED PRIMARY DISCUSSANTS FOR THE CONFERENCE ON BRIDGING THE SCIENCES

November 9, 2004

Rafat Ansari (National Aeronautics and Space Administration)
Ronald Arenson (University of California – San Francisco)
Michelle Buchanan (Oak Ridge National Laboratory)
Tony Chan (University of California –Los Angeles)
Susan Davidson (University of Pennsylvania
Ken Dill (University of California – San Francisco) – Co-Chair
Douglas Eaton (Emory University)
Claire Fraser (The Institute for Genomic Research) – Co-Chair
Jeffrey Fredberg (Harvard University)
Karl Freed (University of Chicago)
Donald Giddens (Georgia Tech)
Jacquelyn Gervay-Hague (University of California – Davis)
Sol Gruner (Cornell University)
William Hendee (University of Wisconsin)
J. Milburn Jessup (Georgetown University)
Cato Laurencin (University of Virginia)
Gerald Loeb (University of Southern California)
Jose Onuchic (University of California – San Diego) – Co-Chair
Himadri Pakrasi (Washington University)
Norbert Pelc (Stanford University)
Etta Pisano (University of North Carolina)
Dagmar Ringe (Brandeis University)
Al Sacco (Northeastern University)
Maxine Singer (Carnegie Institution)
Sam Stupp (Northwestern University)
Dewitt Sumners (Florida State University)
Jill Trewhella (University of Utah)
Isiah Warner (Louisiana State University)
John Wooley (University of California – San Diego)

APPENDIX C

AGENDA FOR THE CONFERENCE ON RESEARCH AT THE INTERFACE OF THE LIFE AND PHYSICAL SCIENCES

Tuesday, November 9, 2004
Holiday Inn Select Hotel
Bethesda, Maryland

8:00 AM	Welcome and Orientation – Dr. Richard Swaja (NIH/NIBIB)
8:15 AM	Charge to Participants –Dr. Joseph Bordogna (NSF) and Dr. Elias Zerhouni (NIH)
8:30 AM	Breakout Session I: Opportunities and Grand Challenges for Research at the Interface
9:45 AM	Break
10:15 AM	Plenary Session I: Summary Reports from the Three Breakout Groups and Discussion
11:30 AM	Lunch
11:45 AM	Working Lunch – Breakout Session II: Bridging the Life and Physical Sciences
1:15 PM	Break
1:45 PM	Plenary Session II: Summary Reports from the Three Breakout Groups and Discussion
3:00 PM	Summary of Results and Discussion – Dr. Bruce Hamilton (NSF)
3:30 PM	Adjourn

APPENDIX D

BREAKOUT SESSION ASSIGNMENTS FOR THE CONFERENCE ON BRIDGING THE SCIENCES

Red Group (Versailles 3)

Chair – Ken Dill (UCSF)
Michelle Buchanan (ORNL) – 1
Susan Davidson (Penn) – 2
Douglas Eaton (Emory)
Jeffrey Fredberg (Harvard)
Karl Freed (UChicago)
Gerald Loeb (USC)
Etta Pisano (UNC)
Albert Sacco (NortheasternU)
Dewitt Sumners (FSU)

Agency Representatives:
John Emond (NASA)
William Heetderks (NIH.NIBIB)
Edward Washburn (EPA)

White Group (Versailles 4)

Chair – Jose Onuchic (UCSD)
Donald Giddens (GaTech) – l
Sam Stupp (Northwestern) – 2
Rafat Ansari (NASA)
Ron Arenson (UCSF)
Jacquelyn Gervay-Hague (UCDavis)
J. Milburn Jessup (Georgetown)
Himadri Pakrasi (WashingtonU)
Maxine Singer (Carnegie Institution)
Isiah Warner (LSU)

Agency Representatives:
Denise Caldwell (NSF)
Angela Hight-Walker (NIST)
Christine Kelley (NIH/NIBIB)

Blue Group (Delaware Room

Chair – Claire Fraser (TIGR)
Dagmar Ringe (Brandeis) – 1
Norbert Pelc (Stanford) -2
Tony Chan (UCLA)
Sol Gruner (Cornell)
William Hendee (Wisconsin)
Cato Laurencin (UVa)
Jill Trewhella (Utah)
John Wooley (UCSD)

Agency Representatives:
Bruce Hamilton (NSF)
Albert Lee (NIST/NIH)
David Thomassen (DOE)

*1 indicates co-chair for Breakout Session 1 (morning), and 2 indicates co-chair for Breakout Session 2 (afternoon).