In the fall of 1998, President Judith Rodin convened a Faculty Planning Committee on Cognitive Neuroscience to initiate the inaugural effort of Life Science, Technology, and Policy, an academic priority of the Agenda for Excellence. *Over the academic year, the committee explored how Penn can distinguish itself in this emerging interdisciplinary field. President Rodin invites comment by Friday, June 4, 1999, from the University community on the faculty committee's proposal, which appears here in its entirety. Comments may be sent to Dr. Rodin at* president@pobox.upenn.edu.

Proposal for a Center for Cognitive Neuroscience at the University of Pennsylvania

Summary

The confluence of recent scientific advances in cognitive science and neuroscience, and national attention on the study of the physical basis of the human mind, have led to the emergence of cognitive neuroscience as a new discipline. Penn is poised to become one of the leading institutions in the world for study and research in this critical new field. Given the nascent state of the discipline, the existence on campus of a small but thriving and collaborative group of cognitive neuroscientists, and the fortuitous mixture of resources and infrastructure already in place, this goal is attainable, and the time is ripe. The work of the interdisciplinary Faculty Planning Committee on Cognitive Neuroscience, appointed in the fall of 1998 by President Judith Rodin and chaired by Provost Robert Barchi, has yielded a set of recommendations to move the University forward in this important area.

In this report, the committee proposes the immediate establishment of a Center for Cognitive Neuroscience to provide both the physical and intellectual focus for this evolving discipline on Penn's campus. The inter-school, inter-departmental Center would initially operate within the context of The Mahoney Institute for Neurological Sciences, taking advantage of the campus-wide neuroscience linkages provided by the Institute. Critical to the new Center will be an expedited increase in the number of cognitive neuroscientists at Penn; dedicated, contiguous space for these investigators in the short term and optimal space for the long term; and improved capabilities for neuroimaging and image analysis.

A Center for Cognitive Neuroscience has great potential for interdisciplinary research and study among faculty and students in a number of schools, departments, institutes, and programs. Also significant is the promise of a Center to strengthen related academic programs on the undergraduate and graduate levels. These educational innovations will help attract the very best students to Penn, in turn enhancing our ongoing efforts to attract the very best faculty to train them.

I. Cognitive Neuroscience

What is the physical basis of the human mind? This question has been asked by philosophers and scientists for thousands of years. Yet, until very recently, the answer seemed out of reach. However, a number of developments within cognitive science and neuroscience have provided both a theoretical framework and powerful new methods for addressing this issue. As a result, the 1990s, declared by President George Bush as the Decade of the Brain, has brought remarkable advances in our understanding of human perception, memory, thought and action. These advances have sparked the development of a new discipline called cognitive neuroscience.

Cognitive neuroscience can be defined as the study of the mechanisms by which the intact brain processes, stores, retrieves and integrates information in order to make judgments, generate flexible responses to the environment, and arrive at self-awareness. In cognitive neuroscience, these mechanisms are investigated through studies of the brain as an integral, functioning unit.

The theoretical framework of cognitive neuroscience derives in part from cognitive science in psychology. Traditional cognitive science has provided both a general frame of reference and specific theories couched within that framework. At the most general level, cognitive science has enabled us to theorize about the relation between mental states and brain states while being neither strictly reductionist ("this piece of knowledge is this piece of brain") nor dualists ("mind and brain are two independent things"). Within cognitive science, mental states are viewed as informational states of the brain. A crucial development in cognitive science was the application of these general theories to information processing within large, highly interconnected networks of relatively simple but defined processing elements, similar to neurons. This approach leads to concepts and formalisms for reasoning about the behavior of populations of neurons that can be radically different from simple extrapolations of individual neuronal behavior.

The impetus for the development of cognitive neuroscience has also come from the extraordinary advances in molecular, cellular, and systems neuroscience. These advances have defined the molecular architecture and cellular characteristics of neurons, the fundamental building blocks of the brain's infrastructure processing system. Research in systems neuroscience has taught us a tremendous amount about how and where these neurons, numbering in the tens of billions in the human brain, communicate with each other. Taken as a whole, these contributions from modern neuroscience define the system by which the theories of cognitive neuroscience must be bounded.

Parallel advances in clinical neuroscience provide a third contributing force to the development of cognitive neuroscience. The study of human patients with focal brain lesions provides another window on the role of particular brain regions in cognition, and has been greatly facilitated by the advent of better structural neuroimaging such as MRI for lesion localization. The extension of studies to patients with more complex brain disorders using functional imaging promises to provide an approach to a systems-based understanding of human cognitive processes and their integration with emotional state. A better understanding of the molecular pathology that leads to clinical cognitive and behavioral disorders in humans can also prove relevant to understanding the function of the normal brain.

However, these fundamental advances would not have brought cognitive neuroscience to the present state without the advent of novel functional neuroimaging methods that enable scientists to measure regional brain activity on-line as normal humans perform cognitive tasks. These include bloodflow-based methods, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), and methods based on the electrical and magnetic fields associated with neural activity, such as event-related potentials (ERPs) and magnetoencephalography (MEG). The development of artificial neural networks has also helped relate the data of neuroscience to theories of cognition, both by evaluation

of the interactions between individual neuron behavior to system behavior and by modeling the effects of focal lesions in highly interactive systems in which reorganization is a possibility. Furthermore, important developments in optical, electronic, and computer technology are crucial to cognitive research. Finally, research with animal models now allows certain questions about the mechanisms of cognition to be addressed.

We at Penn are not alone in our optimism for the future of cognitive neuroscience. Numerous private and federal agencies have recently decided to support this new field. Among private foundations, for example, the Pew Charitable Trusts, the McDonnell Foundation, and the Howard Hughes Medical Research Institute all have new and expanding programs in cognitive neuroscience. Several agencies within the federal government have sponsored cognitive neuroscience initiatives, including NINDS, NIMH, NIDA and ONR. In the past two or three years, most of the Ivy League universities have made appointments in cognitive neuroscience. Several leading institutions have announced plans for major growth in this area, including the hiring of multiple faculty in cognitive neuroscience and in some cases the construction of new research facilities and buildings. These include, among others: Columbia, Cornell, Dartmouth, Duke, Harvard, Johns Hopkins, MIT, Princeton, UC Berkeley, University of Pittsburgh Medical School/Carnegie Mellon, and Washington University.

In the fall of 1998, President Judith Rodin requested that a committee be formed to consider cognitive neuroscience as the inaugural effort of Life Sciences, Technology, and Policy, an academic priority in *Agenda for Excellence*, the University's strategic plan. The chair of the committee is Provost Robert Barchi. The members of the committee are:

Mark D'Esposito, School of Medicine; Marc Dichter, School of Medicine; Martha Farah, School of Arts and Sciences; Steven Fluharty, School of Veterinary Medicine; Robert Lenox, School of Medicine; Charles O'Brien, School of Medicine; Samuel Preston, School of Arts and Sciences; Edward Pugh, School of Arts and Sciences; and Alan Rosenquist, School of Medicine.

II. Why Penn?

Cognitive neuroscience is sufficiently new that no single institution has yet attained a dominant position. A few universities, including Penn, have small but growing groups of cognitive neuroscientists. Penn has the additional, and perhaps unique, advantage of having many key intellectual resources in clinical and basic neuroscience and psychology, as well as major areas of infrastructure already on hand. These include:

- Excellent basic and clinical neuroscience. This provides a firm grounding in the study of the brain, from molecular to systems level research, and spanning a range of clinical concerns.
- University-wide matrix for collaboration and support. Penn has a tradition of cross-department and cross-school collaboration, as well as an existing infrastructure for the interdisciplinary development of cognitive neuroscience, namely the David Mahoney Institute for Neurological Sciences. The Mahoney Institute links faculty in different departments and different schools, fostering interdisciplinary research and education in the neurosciences.
- Intellectual strength in cognitive science, including a world-class Institute for Research in Cognitive Science. This Institute provides a wealth of supportive expertise on human information processing. Significant synergy should exist between IRCS and the proposed Center for Cognitive Neuroscience.
- Several large and well-characterized patient populations with disorders of relevance to cognitive neuroscience research, including stroke and neurosurgery patients who often have relatively discrete and focal lesions, dementia patients who often serve as models of semantic memory loss, and psychiatric patients whose diseases may affect specific brain systems of relevance to cognition.
- Access to state-of-the-art functional neuroimaging, using a full array of methods including fMRI, PET, and SPECT to address questions in cognitive neuroscience.

Thus, relative to other institutions mounting initiatives in cognitive neuroscience, Penn begins the process in an enviable position.

III. Relation of Cognitive Neuroscience to Other Groups on Campus

The President's committee invited representatives of a number of different groups and individuals within the University to communicate their views on cognitive neuroscience, either by letter or oral presentation. Brief summaries pertaining to the groups are provided here.

Biological Basis of Behavior Program. One of the most popular undergraduate majors on campus, with an unusually high number of students participating in undergraduate research projects and matriculating to postgraduate degree programs.There are currently not enough classes offered in cognitive neuroscience to satisfy student demand, and the planned growth in cognitive neuroscience faculty would solve this problem.

David Mahoney Institute for Neurological Sciences. The Mahoney Institute links faculty in different departments and different schools, fostering interdisciplinary research and education in the neurosciences. With its long history of campus-wide collaborative research and educational activities, the DMINS can provide a valuable framework for the development of a new cognitive neuroscience initiative. The Institute is the home for Penn's large Neuroscience Ph.D. program.

Department of Bioengineering. Neuroengineering, the study of computation in neural networks and the development of engineering designs based on neural networks, is a major focus of research and teaching in this department. This program shares with cognitive neuroscience the view of the nervous system as a computational device. Although the neural systems studied in neuroengineering are typically more elementary than those investigated in most studies of cognition, the overlap between the fields is rapidly increasing.

Department of Neurology. The diagnosis and treatment of cognitive impairments, common following neurological disease and injury, will benefit from advances in basic cognitive neuroscience. Cognitive neurology is already an established clinical subspeciality that focuses on disorders such as memory loss and dementia. Cognitive neuroscience is therefore a component of this department's research and teaching functions, and an area identified for future faculty growth.

Department of Neuroscience. This department has traditionally emphasized the analysis of the nervous system at a more elementary level than cognitive systems, but the research of several faculty members makes contact with issues of cognitive neuroscience. Future plans for faculty recruitment in this department include hiring individuals specializing in cognitive neuroscience.

Department of Pediatrics. This department is home to established cognitive neuroscience-related initiatives and would welcome the opportunity to collaborate on an initiative in cognitive neuroscience. Related pediatric initiatives include: the Neuroscience Research Group; the Mental Retardation/Developmental Disabilities Research Center; a University-affiliated program for Leadership and Education in Neurodevelopmental Disabilities; a training grant in neurodevelopmental disabilities; and a proposed Pediatric Mind-Brain Institute.

Department of Psychiatry. Psychiatry houses a range of faculty research programs of relevance to cognitive neuroscience, including studies in primates and humans of cognitive disorders associated with schizophrenia and cognitive/motivational factors in drug addiction. The faculty size, funding base, and facilities of this department are considerable, and it is described as an engine that could help move the cognitive neuroscience initiative forward.

Department of Psychology. Cognitive neuroscience is considered to be a high priority for future faculty and program development in this department. Within the graduate program, there is high demand for cognitive neuroscience training, and a disproportionate number of the best applicants identify cognitive neuroscience as their field of interest. Under-

graduate Psychology majors, as well as Biological Basis of Behavior majors, would also benefit from growth in cognitive neuroscience.

Department of Radiology. This department currently houses the University's facilities, equipment, and most supporting research in functional imaging. The Center for Advanced Magnetic Resonance Imaging and Spectroscopy (CAMRIS) includes 1.5 Tesla and 4 Tesla bore MR systems dedicated 100 percent to research, and an animal facility with three MR systems. The department's PET facility has two scanners, one whole-body and one brain-only. Although there will be great opportunity for collaboration between radiology and cognitive neuroscience, the location and use of the existing MR systems indicate the future need for a magnet dedicated exclusively to cognitive neuroscience.

Department of Rehabilitation Medicine. Rehabilitation of brain-injured patients is a major component of this department's mission. The rehabilitation of cognitive impairments requires an understanding of the neural mechanisms of normal cognition, as well as mechanisms of learning and recovery. Cognitive rehabilitation and cognitive neuroscience thus share key research concerns.

Institute for Research in Cognitive Science. IRCS is arguably the leading center in the world for language-oriented cognitive science, including computational linguistics, psycholinguistics, and aspects of machine learning relevant to language acquisition. It has also maintained strong, though more limited, programs in perception/action and logic/computation. In recent years IRCS has also been supportive of cognitive neuroscience. This Institute welcomes a more focused effort in developing those areas of mutual overlap between their interests and those of the proposed cognitive neuroscience center.

IV. Building Cognitive Neuroscience at Penn

Our goal is to establish Penn as one of the leading institutions in the world for study and research in cognitive neuroscience. Given the newness of the field, the existence on campus of a small but thriving and collaborative group of scientists, and the fortuitous mixture of resources and infrastructure already in place, this goal is attainable, and the time is ripe. A number of further steps are needed.

We propose the immediate establishment of a Center for Cognitive Neuroscience, which will provide both the physical and intellectual focus for this evolving discipline on our campus. This inter-school, interdepartmental Center will initially operate within the broader framework of the Mahoney Institute for Neurological Sciences, in order to take advantage of the campus-wide neuroscience linkages provided by the DMINS. The Center will be led by a director or co-directors and will include the guidance of an executive committee with representatives from the schools of which the Center will draw its faculty. The Center will have space and financial resources that contribute to its own programmatic development.

A critical and early step for this new center will be to quickly increase the number of cognitive neuroscientists at Penn. Intellectual "critical mass" is important for research, for teaching, and for the ability to sustain the initiative with center, program project, and training grants. Critical mass is our most pressing need as we head into the next few years during which the academic hierarchy for cognitive neuroscience is likely to become established. Contiguous space must be identified to house these investigators and their support personnel in the short term and optimal space created for the long term. Finally, improved capabilities for neuroimaging and image analysis must be created.

Core and affiliated faculty. Recognizing that there are currently a number of Penn faculty whose research is focused exclusively on cognitive neuroscience, other faculty whose research bears some relevance to cognitive neuroscience, and still others with an interest in the area but no actual research contact, we propose a layered organization for the new center.

A small group of faculty deeply committed to this new area will comprise the "core," and will play the major role in developing the Center through fund-raising, the development of educational programs, recruiting of new faculty, and design of future space. This core group will be housed together as soon as space can be identified. Other faculty would have different degrees of affiliation, with participation in some of the core activities just described; those closest to the core may have shared office space in the Center. The more peripheral faculty will participate in Center intellectual and educational initiatives and provide input to Center governance, but would be housed wholly within their home departments.

Recruitment of additional core faculty. We identify the need for six to eight additional cognitive neuroscientists, at least two of whom may be established senior investigators. The Center will contribute resources to these recruitments and Center faculty should be actively involved in the selection process. We envision these recruitments distributed across a number of departments, the most likely ones being Psychology, Biology, Psychiatry, Neurology, and Neuroscience. Hiring decisions should be made jointly between the department and a cognitive neuroscience search committee. Of note, the Neurology Department has recently made an offer to a young cognitive neuroscientist, and Psychology plans to search for a junior cognitive neuroscientist next year.

In addition to these recruitments, there is also a pressing need to recruit one or more imaging scientists, with expertise in fMRI data acquisition and analysis, into Radiology, Physics, or Biostatistics. Radiology is currently searching for an MRI physicist, and Biostatistics made an offer to an expert in image analysis. The successful completion of these searches is important for the imaging component of cognitive neuroscience at Penn.

Space. The core faculty now at Penn have labs in three different buildings that are widely separated on campus. The immediate identification of contiguous space for these core faculty will greatly improve the intellectual life of our current cognitive neuroscience community and allow greater sharing of resources, including computational facilities for data analysis. In view of the likely recruitment of several more core faculty in the next two years, such interim space should be large enough to accommodate three additional junior faculty. The space should be convenient for faculty who have frequent business both at the School of Medicine and at the Psychology Department.

We envision the need for planning now for a larger space to accommodate the growing core faculty and Center facilities. It would be desirable to have the BBB undergraduate major housed in the same space. Ideally, this larger space should be in close proximity to the eventual locations of Psychology and Biology, and convenient to the School of Medicine.

Imaging. A new scanner for fMRI, dedicated to cognitive neuroscience, is an expensive but important component of Penn's initiative. It will enable full access to this key method for all Penn's cognitive neuroscience researchers; expand the educational opportunities for students who wish to learn about cognitive neuroimaging; facilitate our faculty recruiting efforts in cognitive neuroscience; and allow the further development of new data acquisition techniques and data analysis techniques to improve cognitive neuroimaging research at Penn and elsewhere. Two grant proposals have recently been submitted to cover some of the cost of this facility.

However, fMRI is only one of the many potential imaging modalities that may be useful for this evolving discipline. The new Center should provide for the development and eventual implementation of complementary techniques such as evoked potential analysis and magnetoencephalography. It should build on the currently available assets at Penn in brain imaging. These include a lab for the production of radio-labeled ligands for studying neurotransmitters and brain metabolism, a cyclotron and a new ultra-high resolution LSO head PET camera dedicated for brain research.

Primate research. Research with animal subjects, particularly primates, will be an increasingly important research strategy for cognitive neuroscience. Primate research allows the testing of hypotheses about the neuronal mechanisms of cognition in a direct way. We have yet to

determine whether the best way to incorporate this methodology into Penn's initiative is to include a dedicated cognitive neuroscience primate facility within the new Center, or to share a primate facility and research capabilities with other groups on campus. Relevant considerations include the research access and the distance between the eventual location of the Center and its potential partners such as the Psychology, Biology, and Neuroscience departments across campus, and the importance of primate facilities versus other uses of space and capital for the first round of faculty recruits. The optimal solution will best be determined as the future space needs of key departments are resolved.

Integration of primate research facilities with the Center should be carried out in the context of planning for primate research across the University and should be consistent with all appropriate protocols governing the humane treatment of animals in scientific research. As we initiate planning for the growth of the Center into larger space and address opportunities for funding and joint development of resources, the capitalization and space requirements of primate access and facilities must be addressed.

V. Educational Initiatives in Cognitive Neuroscience

Undergraduate Education

The University of Pennsylvania has a longstanding commitment to excellence in education that relies upon the inclusion of faculty across departments and schools in the undergraduate mission. This "one university" approach is particularly well-suited to the new educational opportunities created by the emergence of cognitive neuroscience. The establishment of a Center for Cognitive Neuroscience (CCN) will enhance educational programs throughout the University, all of which contribute to Penn's position in the forefront of innovative undergraduate education. For instance, the curriculum of the Cognitive Science major supported by IRCS would be strengthened, as would undergraduate majors in Psychology, Biology, and Philosophy. The major beneficiary of the educational initiatives spawned by the CCN will be the Biological Basis of Behavior (BBB) program.

The BBB program is an interdisciplinary undergraduate major in which students explore the relationship between behavior and its neurological bases. The BBB here has established Penn as a leader in undergraduate neuroscience education, but in order to continue to successfully integrate the newest and most exciting research into its undergraduate teaching, BBB must foster a curriculum that is responsive to these developments. A recent survey of the more than 350 BBB majors indicates that cognitive neuroscience is the most exciting area to students, yet the BBB program presently can offer only one such course (BBB249).

A Center for Cognitive Neuroscience would permit seamless integration of newly recruited faculty into the BBB educational program. First, the core course (BBB109) could be revised to include greater emphasis on cognitive neuroscience. Second, with a new CCN, the BBB program would be able to include a new course in cognitive neuroscience as well as upper-level electives that focus on special topics in this area. Third, the research opportunities provided to every BBB major would be enhanced by developing new supervised research experiences in this area. Ultimately, these curricular developments would enable the BBB program, together with other components of the undergraduate curriculum, to offer a concentrated program of study in cognitive neuroscience, distinguishing Penn as one of the only institutions offering this popular and new field of research at the undergraduate level.

Graduate Education

The University of Pennsylvania has an outstanding tradition of graduate education in neuroscience that is evident in the activities of many graduate groups including Psychology, Bioengineering, Biology, Pharmacology and Neuroscience. The creation of a Center for Cognitive Neuroscience would benefit the educational objectives of all of these graduate groups, most notably Neuroscience and Psychology. The administrative home of the Neuroscience Graduate Group is the David Mahoney Institute for Neurological Sciences (DMINS), a campus-wide organization that presently includes 138 faculty members. Fifty-five members of the DMINS in 17 different departments from throughout the University constitute the Neuroscience Graduate Group. About 60 percent of the Graduate Group membership has research interests that extend to the behavioral level; however, only a few faculty are characterized as cognitive neuroscientists. The collaborative efforts of these scientists provide the beginnings of a Cognitive Neuroscience group, but if Penn is to remain a leader in graduate neuroscience education, it must recruit more faculty members to join this small but active nucleus.

This need for more faculty in cognitive neuroscience is reflected in our graduate curriculum. As presently organized, only one of 15 electives is devoted to cognitive neuroscience (INSC 592). Moreover, the popularity of this course invariably results in students being turned away. The establishment of the CCN at Penn would allow us to better meet the needs of our current graduate students. It would also substantially enhance our ability to recruit the best new graduate students, since 40 percent of the applicants to the Neuroscience and Psychology Graduate Groups express interest in cognitive neuroscience.

Conclusion

A Center for Cognitive Neuroscience should be created as an academic priority within Penn's *Agenda for Excellence*. This Center will provide both the physical and intellectual focus for this evolving discipline on our campus. An expedited increase in the number of cognitive neuroscientists at Penn; dedicated, contiguous space for these investigators in the short term and optimal space for the long term; and improved capabilities for neuroimaging and image analysis will all be crucial to the new Center. A Center will encourage and support interdisciplinary research and study, strengthen related academic programs, and help the University attract the best students and faculty, thereby making Penn a leader in cognitive neuroscience.

Faculty Planning Committee on Cognitive Neuroscience

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