Neuroscience Working Group Report

Executive summary

100 College could have major positive impacts on the neuroscience community at Yale, not only for the labs that could be co-located in that space, but also for the general scientific community. By collating ideas from colleagues across campuses, we provide here specific suggestions for uses of this asset. Our recommendations include scientific foci that would benefit from co-location, core requirements for a successfully integrated community, and programs that would help extend the benefits of 100 College across campuses. Common among these suggestions is the conceptualization of 100 College as a nexus between neuroscience groups across Yale, including those that will not be co-located to 100 College. Implementing these recommendations will enable better integration of the neurosciences at Yale in a way that benefits the institutional research and educational missions.

Preamble

In its report of June 2018, the University Science Strategy Committee (USSC) identified "Neuroscience: from Molecules to Mind" as one of top-five priority areas for strategic institutional development during the next decade. The USSC report recognized that "*the current organization of neuroscience at Yale is arranged based upon the history of the field at Yale*" and recommended "*to establish a nucleating entity in Neuroscience that will drive innovation and push the boundaries of neuroscience research*".

Building on the recommendations of the USSC, Yale identified space in 100 College as an asset that could be used to enhance neuroscience research. To obtain input from the neuroscience community about how best to use this asset, the Provost's office sent out a call for ideas, titled "Multidisciplinary Ideas in Neurosciences," which was open to all researchers with interests in neuroscience. The Provost's office also convened a committee, called the Neuroscience Working Group (NWG), which included representatives of different scientific communities across the University. The NWG was charged with making scientific recommendations, based on the proposals received, on how best to use 100 College to integrate research in neuroscience at Yale.

In this report we summarize the scope, process, and recommendations of the NWG for the use of 100 College. We believe that the development of 100 College will broadly impact the neuroscience community at Yale. This report therefore presents recommendations beyond just filling and developing the 100 College space. It includes recommendations that, in combination with the uses of 100 College, will benefit the neuroscience community across schools and departments, in accordance with the recommendations of the USSC report.

Scope of the Charge

The NWG committee was charged in May of 2019 with evaluating the proposals offered by colleagues in response to the call for ideas. The committee consisted of 11 members, with primary appointments in 10 different departments across YSM, FAS, and SEAS.

To appreciate the NWG's recommendations, it is important to first understand what this committee was not. It was not a committee to originate new visions for neuroscience at Yale, to develop fundraising efforts, or to select, like a study section, "winning proposals". Instead, the committee was specifically tasked with evaluating submitted proposals in the context of the neuroscience

landscape across the University. Emphasis was placed on advising Yale on how the 100 College Street space could be used as an asset to integrate the ideas of the broad neuroscience community (as expressed in their proposals) and to create new opportunities for synergy and growth in these areas.

Thus, the objective of the NWG was to make recommendations, built upon our colleagues' ideas for neuroscience, that will allow 100 College to become an inclusive nexus for neuroscience across Yale.

Summary of the Process

In April 2019, Vice Provost Strobel sent an email to all neuroscience faculty at Yale calling for ideas for clusters of faculty who could be co-located to create stronger interactions and collaborations. Faculty from all relevant schools responded to the call and collectively submitted 35 proposals, which included 134 faculty participants. The NWG was convened in order to produce a scientific recommendation to the Provost's office for how a nexus for neuroscience could be organized at 100 College, based on the submitted cluster proposals and scientific considerations across the University.

From May to October 2019, the committee and associated sub-committees met over 10 times, roughly every 2-4 weeks. The meetings centered around how best to align the different submitted research clusters, and how different research groups could benefit from co-location. A key point of discussions was how the space at 100 College could be used to enhance neuroscience research across the campus and to develop synergies between researchers working in different areas of neuroscience. The NWG also considered the broader impacts that this new space could have on neuroscience across Yale, and how this space could act as a common resource to bring about collaborations. These evaluation approaches required new processes that went beyond simple ranking of submitted proposals. Cluster analyses using keywords and participant names were performed to group proposals with similar approaches, scientific questions or members. Proposals were individually read by all committee members and thoughtfully discussed in several 90-minute session meetings to identify points of synergy and integration, as well as outliers regarding ideas and methodologies. Participant researchers were individually consulted for benefits (or costs) resulting from potential moves to 100 College. This information was systematically collated, discussed and eventually prepared by the working group into the recommendations found here. When conflicts of interest arose, committee members explicitly acknowledged them and when necessary recused themselves in deliberations to keep the process focused on the institutional scientific priorities.

This document represents the committee's recommendations on two fronts: (1) a proposed organization for neuroscience in 100 College based on the received proposals and (2) ideas at 100 College and beyond that would enhance neuroscience across the University.

The Committee's Approach

Advances in the neurosciences require integrating knowledge across scales, advancing technical capabilities, and generating new ideas that arise from merging the diverse subfields of neuroscience. The space at 100 College provides a resource to co-locate labs from across campus to achieve these ends. It can act as a neuroscience nexus that enhances interactions, not only among researchers located in that space, but also across the entire Yale neuroscience community.

By relocating some neuroscientists to a new common space, any plan for 100 College will create new ties among researchers, but also potentially disrupt ties that currently exist. Thus, along with benefits, there will also be costs of any relocation plan. To account for both benefits and costs, we focused on two considerations in thinking about how to organize the space at 100 College. First, suggestions for co-location should make scientific sense and be aligned with the research goals of faculty who would move. Second, the space at 100 College should be conceptualized as a nexus for the neuroscience community beyond the labs that would be physically located there. This second point extends to ensuring that critical mass is maintained in neuroscience communities across campus.

In this report, the NWG makes specific recommendations for a scientific organization of 100 College, and presents proposals to make 100 College an inclusive nexus for neuroscience research, with resources and tools to benefit and connect neuroscience labs across Yale. The successful implementation of these recommendations would have a strong impact on neuroscience at Yale, from research to undergraduate and graduate neuroscience education. We sought to align our recommendations with those institutional goals, including the use of space for student programs, classrooms, and other resources.

Recommended Research Focus Areas

Based on the submitted proposals and Yale's strengths in neuroscience, we recommend that the University co-locate research groups at 100 College to strengthen and advance the following five focus areas (in alphabetical order):

- Building blocks of cognition
- Development
- Multiscale circuits
- Neurocomputation
- Neurodegeneration

These five focus areas represent a broad swath of neuroscience at Yale. Each one is defined broadly, and collectively they encompass several scales of research, from molecules to mind and behavior. They were also chosen because they interact productively with one another. The individual reports on each focus area constitute the bulk of this report. They were generated by representative subcommittees, using the proposals submitted by the neuroscience community, and vetted by the committee at large.

This report includes the thematic recommendations of the NWG in Appendix 1. The NWG has submitted a more detailed version, which lists the specific proposals and the research groups associated with the various proposals. These will be the starting point for discussion by the relevant deans and chairs. These discussions will lead to continued refinement of the requirements necessary for programming of 100 College.

Creating an Inclusive Nexus for Neuroscience

This report aims to support a neuroscience community that spans the campus and enhances the research of those in 100 College as well as the research of those not in the building. We recommend including the following features at 100 College to nucleate interactions among researchers across campus:

- Space and funding for collaborative projects across campus, including offices ("hotel space") for non-resident scientists;
- Space for collaboration and social interaction, including seminar rooms;
- Space for student programs and classrooms, as well as core facilities, and other common resources.

Beyond 100 College Street

All of neuroscience at Yale cannot fit into the space 100 College Street, nor should it. This should be viewed not as a problem, but as a strength. Yale has diverse groups studying neuroscience in locations across campus, each with different neighbors, ties, and synergies. These differences enhance neuroscience research at Yale and constitute valuable neuroscience communities in their own rights. In tandem with the resources devoted to neuroscience at 100 College, the university should ensure strong support for neuroscience in other locations across campus, including groups at the Medical School, on Hillhouse Avenue, and on Science Hill. This distributed support will permit 100 College to act as a nexus—a meeting point for the diverse neuroscience research across the university.

A number of areas of strength in neuroscience at Yale do not fit comfortably into the existing space designated at 100 College, yet are critical parts of the neuroscience community. For example, to apply findings at the molecular level to human diseases, and vice versa, one must use animal models, including non-human primates. Yale has a historical strength in systems neuroscience and a unique capability in the area of non-human primate research that cannot be brought to 100 College. This area is currently below a critical mass and thus will benefit from further recruitment and resources. Neuroscience research at 100 College, as well as elsewhere at Yale, will also require the addition or extension of core support facilities, many of which will need to be located outside of 100 College. These recommended resources, even when not located at 100 College (see Appendix 3), are essential to the success of endeavors at 100 College and beyond.

There is an opportunity to integrate basic and translational neuroscience by coordinating the development of new research space at 100 College and the new Clinical Neuroscience Center. The Clinical space will be a potential site for interesting research on human electrophysiological recordings, brain-machine interface studies, and neuromodulation work. Similarly, to integrate neuroscience across campus, the plans for 100 College should coordinate with departments across campus, including those without large neuroscience footprints and those for which a neuroscience footprint could be established in the future (like SEAS).

Relationships with other USSC priorities

The five proposed research focus areas identified by this committee resonate with, and depend on, other USSC priority areas, particularly integrative data science and inflammation science.

With respect to data science, the committee concluded that there should be significant attention to computational neuroscience both in developing 100 College and in investing in neuroscience across the university. Bringing together computational scientists and neuroscientists will impact important strategic areas such as genomics, proteomics, brain-machine interface, neuroengineering, computational modeling, machine learning, neuroinformatics, and systems research. Developing these interactions will require close coordination with departments such as

Computer Science and Statistics & Data Science, and should be integrated with the computational neuroscience focus area (see Appendix 1).

With respect to inflammation, there are important opportunities of synergy in the topic of neuroinflammation. These efforts are critical for understanding mechanisms of neurodegeneration and neural repair, one of the focus areas included in this report. Further links with other departments, such as vascular biology and immunology, would benefit these efforts.

Summary of Appendices

Appendix 1: Detailed descriptions of individual focus areas

Appendix 2: Summary of ideas to foster interaction among neuroscientists at 100 College and beyond

Appendix 3: Summary of cores needed to support neuroscience research at 100 College and beyond

Appendix 4: Neuroscience Working Group committee membership

Appendix 1: Detailed descriptions of individual focus areas

Building Blocks of Cognition (BBC): from Molecules to Behavior

The brain is an object of scientific fascination because of what it *does*. It allows us to recognize people and navigate our environment, to represent information in the absence of sensory input, to make plans and pursue goals, to have conscious experience and communicate with language, to reminisce about the past and to predict the future, and to form productive and just societies. These complex human behaviors are rooted in core mental operations collectively known as "cognition". These operations can be studied in terms of the behaviors they generate, and in humans can be interrogated with non-invasive imaging of brain regions and networks. However, this is the greatest specificity that can be achieved in the healthy human brain, given ethical considerations and existing technology. As a result, we do not understand how the basic functional units of the brain—from molecules, to cells, to local circuits—give rise to cognition. The goal of this cluster is to identify and relate these building blocks of mental operations in order to provide a complete mechanistic explanation for brain-wide function and complex behavior.

We propose to focus on the neurobiological basis of five key mental operations that can be studied across species and at different levels, and for which Yale has existing expertise: *recognition*, how we label and categorize sensory inputs (perception); *selection*, how sensory inputs get prioritized based on intrinsic salience and goals (attention); *maintenance*, how we hold onto and manipulate information no longer present in the environment (working memory); *valuation*, how we assess the utility of cues and actions to behave appropriately and efficiently (decision-making); and *storage*, how we lay down traces of experiences so they can be later retrieved and relied upon (memory).

Our approach to understanding the building blocks of these mental operations is radically new. What is currently done at Yale and elsewhere is that human researchers, who are able to study complex behavior, claim to have uncovered neural mechanisms based on coarse and indirect brain imaging, while animal researchers, who have the tools to characterize neural mechanisms precisely, claim to study cognition but use species with fundamentally different brains and behaviors from those seen in human beings. There are limitations to collaborations between these two camps. We propose to unite human researchers willing to think about and incorporate molecular and cellular approaches (e.g., helping design tasks for animals that more closely mirror their human studies) with animal researchers willing to work on the human brain and complex behavior (e.g., molecular analysis of resected and post-mortem human brain tissue).

This ambitious plan requires researchers to be open-minded about supplementing their research programs. To help facilitate this, we have identified four key areas of strength at Yale: First, for more direct analyses of cognition in behaving humans, we will combine non-invasive approaches in healthy individuals such as whole-brain fMRI and MEG and scalp-based EEG and fNIRS with neurophysiological studies of patients who allow for intracranial recording and stimulation. Second, to uncover the building blocks of cognition, we will study the distinct circuit architectures and molecular mechanisms that underlie diverse mental operations, including human brain tissue. Third, to bridge human cognition with basic building blocks, we will apply cutting-edge molecular and cellular manipulations of cognition in living animals, including the use of genetically altered primates and other model organisms. Fourth, to elucidate general principles of how complex behavior arises from basic building blocks in a hierarchical architecture, we will draw inspiration from (and also inspire) links between brain circuitry and computer systems.

A successful outcome of this cluster will be the production of fundamental principles about how cognition and behavior are encoded in the building blocks of the brain — principles we hope will generalize to other computational frameworks. This may in turn advance the field of AI, offering

the birth of explainable and safe AI, and serving as a counterpoint to current "black-box" AI approaches.

Development

Neural development encompasses the formation of the nervous system at multiple levels, including the specification of neurons, glia, and other non-neuronal support cells; the migration and differentiation of neural and non-neural cells; the formation of synaptic connections; the refinement of neural circuits; and the maturation of cognitive and behavioral processes. Neural development involves basic cellular and genetic mechanisms. At the same time, because many human cognitive, behavioral, and psychiatric disorders result from dysregulation of key developmental mechanisms, examining behavior and cognition is a critical element of the study of neural development. By examining both normal and perturbed developmental processes at varying scales, from genes and cells to circuits/systems and behavior, we can gain key insights into how nervous systems are constructed to achieve their function, and how defects in development lead to dysfunction.

It will therefore be important to include the study of basic developmental mechanisms, perturbation of development in neurodevelopmental disease, and analyses of how developmental mechanisms influence circuits/systems-level neural functions across different organisms. It is also critical to facilitate interactions with other areas, including modeling or 'big data' analyses, multiscale circuits, neurodegeneration, cell biology and biomedical engineering. An emerging area of potential collaboration is at the interface with neuroimmunology, where interactions between neural cells and non-neural cells (i.e., microglia and astrocytes) have been proposed as mediators of axonal and synaptic plasticity during circuit development.

Core questions that can only be addressed by bringing distinct groups together:

- How does critical period plasticity contribute to the maturation of synaptic and circuit function?
- How does the genetics underlying cellular diversity interface with brain development in health and disease?
- What are the basic cellular and genetic mechanisms that govern normal development?
- What is the relationship between cellular, synaptic, and circuit development and the maturation of cognitive and behavioral processes in the brain?
- How do interactions between neuronal and non-neuronal cells guide development?

Multiscale Circuits

In neural circuits, connected neurons receive, modify, and transmit signals, performing the operations that underlie brain function. Circuits of varying scales throughout the brain are responsible for sensation, memory, decision-making, motor control, and learning. Because circuits transform information as it moves between neurons, the study of circuits is fundamentally the study of interactions among neurons in the brain. These interactions do not occur in isolation, and include poorly understood modulatory contributions from glial cells, as well as neighboring tissues such as the immune system and the vasculature. At the smallest scales, neural circuits include the study of synaptic transmission and plasticity, while at the largest scales, it reaches to questions of behaviors such as sensory processing, decision-making and cognition. In between are many levels of study of populations of neurons across model systems, from invertebrates to humans. Investigating circuits at scales and across systems is key to uncover how brains perform their most basic and most advanced functions. These insights also inform our understanding of the pathophysiology underlying neural disease states.

We note that at Yale, a community of labs across departments and programs have focused on understanding these questions in the visual system, so co-location and increased interactions among these groups could result in added synergies towards understanding visual processing.

At its boundaries, it will be important to integrate the study of circuit function with clusters related to development (critical to understanding wiring of circuits), and cognition (critical to understanding an emergent property of circuit function). In addition, the techniques developed and used by individuals pushing the boundaries of how to make sense of large data sets will be essential for making progress in understanding circuit function at both the theoretical and experimental levels.

Neurocomputation

This cluster is different from the others in that it cuts across fields within and outside of neuroscience, and may even be integral to all of the other clusters. Computation is essential to interpreting findings in many fields, yet also develops new methods and theories. The goals of the Neurocomputation cluster are (1) to build infrastructure and expertise in brain-inspired computational science, (2) to develop theoretical models that can guide neuroscience experiments, and (3) to create teams that can draw meaningful inferences and explanations from large datasets.

Within the proposals, and the Yale community more broadly, there are roughly three classes of computational neuroscience work. The work of individual PIs often bridges these different classes.

- Data: this class thinks deeply about how to analyze, visualize, and interpret the often massive, noisy, and dynamic datasets acquired in neuroscience
- Theory: this class develops mathematical theories and builds computational models informed by the brain and behavior to arrive at a formal understanding
- Infrastructure: this class is interested in optimizing computing systems and algorithms to accelerate data analysis and build intelligent machines, including high-performance computing, cloud services, neuroinformatics, neuromorphic chips, etc.

There remains a division between data and theory classes, partly driven by training and the mathematics involved, and partly driven by different intellectual goals and interests. Nonetheless, these classes often blend together in particular projects or labs.

A key concern in incorporating computational neuroscience into 100 College is to not break up groups of data scientists, computational theorists, and their collaborators elsewhere on campus (who, we note, in many cases have just started to coalesce). For instance, the QBio Institute was recently established to study biological computation, with an emphasis on theory, including neuroscience. Taking that into account, hoteling or other mechanisms that promote partial residence at 100 College will thus be essential for the proposed computational cluster to work, as to encourage participation of the entire computational community. Moving groups, such as the entire S&DS department, could be another solution, with the added benefit of increasing the representation of FAS in the building, but with associated costs as well. Because of these considerations, we strongly recommend that this focus on computation at 100 College Street be organized in consultation and collaboration with the groups currently engaged in this sort of research, listed below.

Beyond moving existing faculty, we also recommend seeding a cluster of new faculty hires to be sited at 100 College. The following are exciting areas of institutional growth:

- Computational vision
- Machine learning
- Natural language processing
- Wearables, mobile computing, low-power chip design (e.g., neuromorphic hardware)
- Real-time operating systems, secure embedded systems
- High-performance computing spanning server systems to larger distributed systems
- Brain-computer interface, neuroprosthetics, neuroengineering

Finally, to increase interdisciplinary participation we propose that the University create an independent postdoctoral fellowship program. These prestigious postdocs would be based in 100

College, could bridge across faculty, and would receive research funding (a potential model is the CV Starr program at Princeton).

Where computational neuroscience work now exists on campus, both virtual and physical
QBio (institute) physical
S&DS (dept) physical
CS (dept) physical
Swartz Initiative (center) virtual
CBDS (center) virtual
YCRC (admin) physical
Gibbs Professorships (initiative) virtual
TRIPODS (center) virtual

Neurodegeneration

The majority of age-related brain disorders are associated with neurodegeneration, a complex and poorly understood collection of chronic cellular changes that affect both neuronal and non-neuronal brain cells. Neurodegeneration eventually leads to synaptic loss, cell death and glial changes that disrupt neural networks and can cause progressive cognitive, motor and sensory dysfunction. Neurodegenerative pathologies such as Alzheimer's disease are major public health problems and remain some of the most challenging diseases from a therapeutic point of view, with all clinical trials having failed in the past 2 decades. A major challenge for rational therapeutic design is our rudimentary understanding of the cellular and neural network mechanisms underlying these multifactorial age-related conditions, including a lack of knowledge about the heterogeneity in cell biology that renders distinct cell types and circuits uniquely vulnerable in different disorders.

The study of these fundamental cellular pathways, with the aspiration of using that knowledge to tackle neurodegenerative diseases, represents an opportunity area for integrated multidisciplinary research that could bridge cellular neuroscience, a key area of strength at Yale, with other areas of excellence such as cell biology, genomics, immunology, pharmacology and clinical neurosciences. The interest in this research area at Yale is perhaps represented in the fact that a third of all cluster proposals submitted are directly related or touch on Cellular Neuroscience and Neurodegeneration. Despite its strength at the investigator level, and building on the successes of programs such as the CNNR, better efforts could be made at an institutional level on Cellular Neuroscience and Neurodegeneration to bolster the initiative and integrate across campuses.

The goal of this cluster is to understand basic cellular physiology to cure neurodegenerative disease. To achieve this, we recommend bringing together a multidisciplinary group of investigators, rooted at 100 College but with impact on clinical and basic research areas across the University. Their expertise should advance the understanding of neurodegeneration at the cellular and systems levels and could eventually propel the development of novel therapeutics, biomarkers and diagnostic tools. At the core of the cluster we envision a strong presence of investigators with expertise in cell biology of neurons and non-neuronal cells in the nervous system, closely interacting with general cell biologists and scientists with expertise in biophysics, genetics and pharmacology, among other disciplines. Close interaction with vascular biologists and immunologists will be key as the immune system and vasculature have emerged as critical for the pathogenesis of neurodegenerative disorders. Essential to this cellular aspect of the initiative will be the ready availability of imaging expertise and cores including: *in vivo* optical imaging, novel electron microscopy and super-resolution microscopy tools. Likewise, close interaction with departments of Genetics, Statistics & Data Science, and clinical neurosciences (Neurology, Psychiatry, Neurosurgery, etc), will promote the discovery of neurodegeneration risk genes that can further stimulate mechanistic cell biological research. A potentially interesting area of synergy may be between cell biology and organic chemistry, which may lead to development of novel therapeutics and human imaging diagnostic tracers in collaboration with the PET center. In addition, strengthening the interactions with the stem cell center will be essential for the potential development of cell therapies for brain disorders as well as for modeling human diseases using systems such as brain organoids and cultured induced pluripotent stem cells. Also important to this initiative will be establishing links between researchers in this cluster and the Yale Center for Molecular Discovery (YCMD, in the West Campus) to promote the investigation and screening of potentially translatable medicines.

Beyond the cellular biology of neurodegeneration, this cluster seeks an understanding of how cellular disruption leads to neural network dysfunction. Thus, we propose close interactions of researchers with expertise in the cellular basis of behavior in various organisms ranging from invertebrates to primates. For this it will be essential to strengthen the institutional capabilities around rodent behavioral phenotyping, human and nonhuman primate brain banks, and new transgenic primate models that can recapitulate autosomal dominant disease in higher brain circuits. It will also be important to enhance the interactions with human behavioral and brain imaging researchers to ultimately translate findings to human disease.

Appendix 2: Summary of ideas to foster interaction among neuroscientists at 100 College and beyond

There are a number of design features and resources that are needed to facilitate research interactions at 100 College from across the university, especially as traveling between campuses can be challenging on a tight schedule. These include:

- Seminar rooms, including one that can hold at least 50 people, given the large numbers of faculty interested in each of these areas throughout the university
- Open areas with whiteboards and coffee service for casual/spontaneous conversations (e.g., natural gathering points, such as on higher floors with views of the harbor)
- Flexible cafeteria policies, such as faculty lunch privileges similar to those already offered at the College (important enticement for FAS faculty and encourages interactions with students)
- Temporary "hoteling" offices allocated on a semi-regular basis based on need and use, both for faculty and for graduate students and postdocs sent for collaboration
- Free and accessible parking for those who come to 100 College for talks or to meet collaborators
- Pilot funds to promote new interdisciplinary collaborations that are difficult to fund externally until established
- "Neuro Shuttle" to enhance travel between the new clinical neuroscience building at the St. Raphael's campus and 100 College (and possibly to Hillhouse Avenue and Science Hill)

Appendix 3: Summary of cores needed to support neuroscience research at 100 College and beyond

The development of new cores, and the strengthening of existing cores, is vital to the success of cutting-edge neuroscience at 100 College, as well as to all neuroscience-related research at Yale. Cores provide key resources that are challenging for single investigators, or even single departments, to maintain on their own. They are also a way to enhance research for all neuroscientists at Yale. They provide meeting points for researchers. Cores are therefore catalyzing interventions that would help sustain a healthy research enterprise necessary for the interactions described above:

- **Neurogenomics Core**: Genotype-phenotype studies are at the heart of research in the Development and Neurodegeneration clusters. Rapid advances in single-cell techniques mean that this technology, combined with advances in machine learning (see Neurocomputation cluster), are supporting modern neuroscience across scales. Yale has extensive resources for sequencing of libraries at West Campus, but the construction of novel libraries using approaches such as FACS are not yet supported. A Neurogenomics Core would enable leveraging existing resources to create new services that benefit the research described.
- **Cell Core for Neuroscience**. With the advent of CRISPR, IPS neurons, neurospheres, and other cell-based methods, the opportunity for investigating questions in engineered cultured human neurons is enormous. A Cell Core for Neuroscience would allow access to these techniques. This core would benefit the Development, Multiscale Circuits, Neurodegeneration, and Neurocomputation clusters. A core like this, and associated research, would benefit from interactions with Systems Biology (West Campus) and SEAS.
- The current **Electron Microscopy Core** should be expanded to include pre-embedding immuno-EM and state-of-the-art serial EM, as these are increasingly required for data publication and are not standard services in the current design.
- **Viral Core for Neuroscience**: Viral tools are a critical element of most rodent neuroscience work in the developing and mature brain, and an emerging part of neuroscience research using non-human primates. A core for design and production of new viral tools for tracking, manipulating, and genetically modifying neurons would thus benefit the Cognition, Development, Multiscale Circuits, and Neurodegeneration clusters. Facilitating the ability of researchers in these clusters to rapidly iterate through experimental approaches will further provide researchers in the Neurocomputation cluster with focused datasets to motivate and constrain computational modeling.
- **Advanced Live Imaging Core:** Advances in imaging are driving much of modern neuroscience and are a key focus of the BRAIN initiative. At scales from nanometers to whole brains, live imaging is a key source of neuroscience data and optogenetic tools are becoming standard ways of manipulating cells and circuits *in vivo* to understand function. Yale has great imaging expertise across labs and departments, but in the absence of a central core it is not practical for most researchers to innovate and explore new imaging modalities. An Advanced Live Imaging Core would allow neuroscientists across campus to access these critical technologies. This core could interface with existing resources (See Neurotechnology below) and would benefit all clusters.
- A **Neurotechnology Core**. The committee express support to the neurotechnology core currently house in the Department of Neuroscience and argues that expansion of its services to benefit other neuroscience communities in campus is desirable.

- A **Rodent Behavior Core** with capacity to perform neurosurgeries as well as behavioral testing, would support the Cognition, Neurodegeneration, Development, and Multiscale Circuits clusters. This Core should be located within or adjoining to a rodent vivarium.
- A **Nonhuman Primate Core and Transgenic Facility** would provide a bridge between rodent and human research by providing cellular and molecular perspectives for the Cognition, Development, and Neurodegeneration clusters. A nonhuman primate brain bank (marmoset and rhesus monkey) can provide nervous system tissues to Yale researchers currently limited to rodent or invertebrate species. If successful, a new transgenic primate facility will allow the first modeling of genetic diseases in primates in the US, and will be especially important for neurodevelopmental and neurodegenerative disorders. This Core would need to be housed outside of 100 College.
- A **Human Neuroscience Core** located in 100 College would provide all clusters with access to the latest technologies for measuring and manipulating the healthy human brain. These include whole-brain approaches (MRI, MEG), scalp-based approaches (EEG, fNIRS, OPM, polysomnography), stimulation (TMS, tDCS), and behavioral testing (psychophysics, psychophysiology, VR, motion capture). This facility would provide a central resource for cutting-edge research, training, and education, and in particular advanced data analyses and translation between technologies. This facility is critical for attracting human neuroscientists from FAS to 100 College.
- A **Human Brain Bank** could be a resource that would support the Cognition and Degeneration clusters. It would need to be located outside of 100 College.

Appendix 4: Neuroscience Working Group committee membership

Amy Arnsten – Albert E. Kent Professor of Neuroscience and Professor of Psychology – Neuroscience Department

Abhishek Bhattacharjee – Associate Professor – Computer Science Department

Jessica Cardin – Associate Professor – Neuroscience Department

Damon Clark – Associate Professor of Molecular, Cellular and Developmental Biology and of Physics and of Neuroscience - Molecular, Cellular and Developmental Biology Department

Daniel Colón-Ramos – Dorys McConnell Duberg Associate Professor of Neuroscience and Associate Professor of Cell Biology – Neuroscience Department and Cell Biology Department

Jaime Grutzendler – Dr. Harry M. Zimmerman and Dr. Nicholas and Viola Spinelli Professor of Neurology and Neuroscience – Neurology Department

Marc Hammarlund – Associate Professor of Genetics and Neuroscience – Genetics Department and Neuroscience Department

Marina Picciotto – Charles B. G. Murphy Professor of Psychiatry and Professor in the Child Study Center, of Neuroscience and Pharmacology – Psychiatry Department

Susumu Tomita – Professor of Cellular and Molecular Physiology and Neuroscience – Neuroscience Department and Physiology Department

Nicholas Turk-Browne – Professor – Psychology Department

Harrison Zhou – Henry Ford II Professor of Statistics and Data Science – Statistics Department

Provostial representatives on the committee

Christopher Incarvito – Associate Provost – Provost's Office

James Slattery – Associate Provost for Research – Provost's Office