Neuroinformatics Research in Vision (NRV) Project

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Abstract:

The coordinated efforts on Neuroinformatics Research in Vision (NRV) project to build a neuroinformatics portal for vision science in Japan, the "Visiome" (Vision + Ome) Platform is presented. We first introduce the general concepts underlying the neuroinformatics and then focus on general scheme of the project.

1. Introduction: Background and Scope

In a recent report by the Organization for Economic Cooperation and Development (OECD) Global Science Forum Neuroinformatics Working Group [1, 2], there is documented a pressing need for a concerted international effort to help researchers understand brain mechanisms and functions by use of fusing information technology. These efforts to integrate the diverse methodologies of neuroscience, if properly carried out, will assist in improving the utility and availability of the vast quantities of high quality data, models, and tools being developed by brain and neuroscience researchers. In turn, this will result in further advancement of scientific research in many disciplines, stimulate promotion of technological and sustainable development, and facilitate the equitable sharing of high quality databases in the brain sciences.

The task of understanding a functional brain system is hindered by the inevitable necessity of tight focus and specialization of researchers in the field. This fragmentation makes the synthesis and integration of disparate lines of evidence exceptionally difficult. In order to address this difficulty, an organized framework is needed that facilitates integration and provide a fertile ground for sharing information. This agenda requires the establishment of a new discipline, aptly named "Neuroinformatics". Neuroinformatics undertakes the challenge of developing the mathematical models, databases, data analyses, and tools necessary for establishing such a framework. We have undertaken this task and are using the extensive literature and available data on the visual system to develop a neuroinformatic platform.

The major emphasis of the neuroinformatics platform is the organization of neuroscience data and knowledge-bases to facilitate the development of computational models and tools. An additional aim is to further international interdisciplinary cooperation. This becomes especially important in light of the emerging realization that understanding and developing models of brain processes of one functional area can be significantly facilitated by knowledge of processes in different functional areas, e.g., vision and audition, areas that have recently been found to interact in remarkably multi-modal ways.

Equally important are considerations of the complexities of neuronal processes that require detailed descriptions of sub-systems. Consequently, a significant goal is to explore how abstractions at different levels are related, e.g. the pathways from molecular to system levels. Another goal is the development of the computational approaches that support effective and efficient modeling across levels of aggregation of sub-systems.

Experimental advances over the past two decades have shifted the development of models away from speculation toward models that are tightly constrained by biological data. At the same time, experimentalists have found it useful to incorporate computational methods into their research strategy. At each step, a concise description of the relevant experimental data is interwoven with computational models with a sound theoretical basis. This combined approach has demonstrated its ability to contribute to a better understanding of brain functions.

The data currently published in scientific journals is often in a form that lacks sufficient information for the development of alternative models or even the replication of the modeling results reported. This result is often a consequence of experimenters selecting values for the independent variables that result in data poorly suited to model development. A more interdisciplinary involvement in experimental design and manuscript review would serve to ameliorate this significant problem. The research community may need to ensure that manuscripts that are published provide enough information to make possible the replication of the model to allow evaluation of appropriateness, validity, and generalizability. This is the trend not only in neuro- and brain-sciences but also in biology in general [3]. This may necessitate the introduction of information science technology in experimental design, analysis, modeling, processing, transmission, storage, integration, and utilization of information in a manner analogous to the role currently played in the neuroscience community by statisticians.

Neuroinformatics is a novel research paradigm that endeavors to fill this gap by providing a rich environment for the integration of experimental techniques with mathematical and information science technologies. In particular, mathematical models are used for the description and integration of data and results that are obtained from a number of research fields. These mathematical models serve as a platform to support the simulation experiments that are vital for the study and comprehension of brain functions and mechanisms. Mathematical modeling thus plays a key role in neuroinformatics. It serves as the common language for systematic interdisciplinary understanding.

2. The Neuroinformatics Research in Vision (NRV) Project

The NRV project is the first neuroinformatics project in Japan. It started in 1999 under the auspices of Strategic Promotion System for Brain Science of the Special Coordination Funds for Promoting Science and Technology at the Science and Technology Agency (now under the Ministry of Education, Culture, Sports, Science and Technology- MEXT) with the primary aim of building the foundation of neuroinformatics research in Japan. Because of the wealth of research in vision science in Japan, the promotion of experimental, theoretical, and technical activity in vision research is the NRV project's top priority [4].

The first goal of the NRV project is the construction of mathematical models for each level of the visual system: single neuron; retinal neural circuit; and higher visual function. The second goal is the building of integrated resources for neuroinformatics, by utilizing information science technologies within the research support environment that we have named the 'Visiome Platform'. The third goal is to develop new vision devices based on brain-derived information processing principles. Figure 1 shows the overall structure of the NRV project.

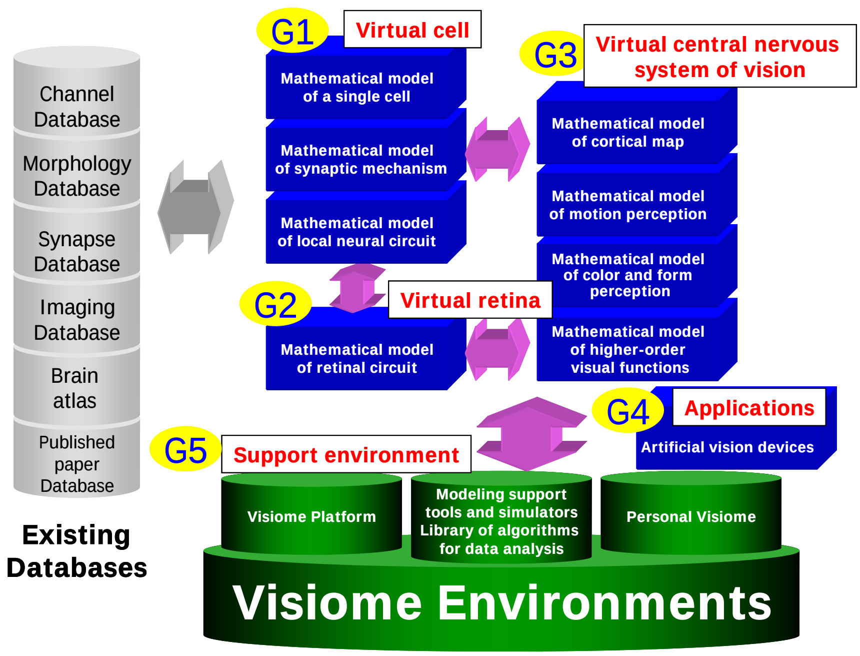

Figure 1. Concepts of the Neuroinformatics Research in Vision Project

The development of the NRV project requires an active collaboration of individuals and groups across many fields. These individuals and groups, without whom the NRV project could not have been carried out, are listed in the Appendix with their areas of expertise delineated. Their considerable effort is essential to the ongoing success of the project and the knowledge and dedication they are contributing is gratefully acknowledged. Further information about the project can be found in the NRV website (tentatively) http://www.neuroinformatics.gr.jp/. Following are the outlines of the NRV Project research groups.

Group 1: Modeling a single neuron by mathematical reconstruction

The intracellular information processing mechanism of nerve cells can be described by mathematical models. This group carries out the construction of "virtual cells" by integrating knowledge obtained from molecular biology, biophysics, electrophysiology and anatomy to produce models of single neurons. Such mathematical models can reproduce behavior of realistic neurons on a scale from molecular to simple spatial neural circuits over time domains from sub-millisecond to a year. The "virtual cells" are considered to be the smallest functional units of a model family.

Group 2: Realization of virtual retina based on cell physiology

The retina is an excellent preparation for studying brain structure and function as well as neural signal processing in the brain, in part because it is a very accessible and self-contained part of the brain. Consequently, large amounts of research results on all aspects of retinal visual information processing are available. A mathematical model of a retinal neural circuit is being constructed from neuro-physiological experimental data and from the characteristics of single neurons obtained from Group 1. This retinal neural circuit will form the basis of a "virtual retina". Multiple circuits will be integrated into a mathematical model of the retinal- neural-circuit information processing mechanism that encompasses everything from the light energy conversion mechanism in a photoreceptor (the input) to the encoding mechanism of impulse sequence in a ganglion cell (the output cell of retina).

Group 3: Study on the visual function by computational and systems' approach

Two paths of information flow are known to exist in the visual system: One path processes information related to intrinsic object properties and object discrimination, such as color and shape. The other path is concerned with motion discrimination and position (spatial vision). This group evaluates the information processing mechanisms in the object discrimination pathway and constructs mathematical models of visual perception.

Group 4: Realization of artificial vision devices and utilization of silicon technology for recording and stimulation

Movement detection is based on spatio-temporal information processing in vision. It is one of the most basic and important visual functions for all living creatures. This group carries out research on the realization of new devices, circuits, and networks that implement the visual information processing mechanisms of movement detection in semiconductor devices or circuit functions. It aims at the development of the analog-digital hybrid vision device with abilities that exceed human vision (for example, ultra-high speed). Also a utilization of a silicon crystal growth technology for development of new electrodes array for recording and stimulation of neural cells

Group 5: Fundamental neuroinformatics research and development

The total support environment for experimental data analysis, model parameter estimation, simulations, etc. is being developed. The results of this project will be made available on the internet in a database (NRV environment) that integrates morphological and physiological knowledge, mathematical models, related studies, and references.

3. The VISIOME Environment: a Database and Simulation Environment for Neuroinformatics

Understanding brain functions requires integration of information at diverse levels of aggregation, from the molecular level to the neuronal network level. The huge amount of information that is needed makes it almost impossible for any individual researcher to develop an integrated view of the brain. To address this problem in the context of the NRV project, an integrated neuroinformatics system for vision neuroscience (the "Visiome Environment", environment is being developed, as a test bed of neuroinformatic tools. The Visiome environment is comprised of four components

Visiome Platform (neuroinformatics database system)

The Visiome platform <http://platform.visiome.org/> is a database system that provides published references with reusable programs/scripts of mathematical models, experimental data, analytical tools, and related information. By executing model programs, researchers can see how the models work or compare their own results with other experimental data, improve or integrate models, and formulate their own hypothesis into a model. They can also export /import their own models, data, and tools to the database for sharing with colleagues.

The Visiome platform also provides a novel tree-structure index system (Visiome Index) of research in vision neuroscience. The indexed database contains not only the extensive relevant literature, but, by virtue of its tree structure, allows the user to access the code of a model described or referenced in any paper as well as any supplementary data, provided the authors have made such material available. It will support researchers in their quest to understand the visual system from the perspective of visual functions and assist in the construction of models based upon their own hypotheses.

Visiome Simulation Server (online simulation server)

Our concept of shared modeling programs over the internet, is expected to be an effective way to facilitate the testing of proposed models by other investigators. At present, such testing is still hampered by incompatibilities between model developer by problems such as software version conflicts and hardware incompatibilities. The Visome platform's simulation server provides a common site with simulation capability. It contains a high-performance simulation engine for analysis, computation and simulation. Users who want to test model scripts can access the simulation server through a web browser. On the Visome site they can execute available model scripts, and view or download their results. It is also an efficient method of distributing model scripts from the platform for execution on a local computer. We recognize that this approach may not be suitable for very large-scale models or for very old programs that require special purpose or obsolete computer systems for their execution. The simulation server can not only facilitate utilization of models of current interest but can also serve as an archival site for older models of historical interest.

SATELLITE (System Analysis Total Environment for Laboratory - Language and InTeractive Execution)

A vital component of neuroinformatics development is the improvement of the research environment for information management, data analysis and model simulation in laboratory. SATELLITE is a collection of powerful tools for experimental data analysis and simulation of mathematical models. A wide range of functions for data acquisition, filtering, frequency analysis, parameter estimation and visualization are available. The programming capability of SATELLITE provides automatic execution of a command sequence in a script file. Script files that are written and used by researchers in experiment and modeling should be considered precious resources of techniques and know-how for many scientists and students. Consequently, NRV is specifically designed to provide and exchange scripts via the Visiome platform.

Personal Visiome (Neuroinformatics Database for laboratories)

Personal Visiome is database system for personal/individual or laboratory use by neuroscience and neuroinformatics researchers. The system can store and organize/maintain all kinds of files, such as PDF files of literature, image files and experimental data. The display of contents in Personal Visiome can be customized by each user or group. An agent in Personal Visiome can automatically access neuroinformatics, neuroscience and related database sites based on Visiome Index, and collects useful information (newly published paper, updating of homepage, conference information, and so on) for each user. This system, working within the Visiome platform for collaboration, allows for content registration, searching and updating.

4. Conclusion

The Visiome Environment establishes a virtual environment for global electronic collaborations by providing researchers with useful tools for simulation and data analysis as well as reusable models and data. We anticipate an expansion of this project to the neuroscience community in Japan and if successful, international collaboration will inevitably follow.

We are planning to make our system available to the public, without restrictions, late in 2003. This Symposium commemorates the finishing of the NRV project by publicly announcing the availability of the initial version of the Visiome Platform. Decisions regarding levels of user privilege and other access restrictions will be considered only after public acceptance, user demand, and contributors' requirements have been assessed.

Our present system is designed as a feasibility study utilizing available technology. Flexibility was a primary consideration. When, as expected, the utilization of Visiome grows, an enhanced computer structure and more elaborate, universally appropriate, database access methods will be required. The input and collaboration of the user community, based on their experience with Visiome, will determine how and in what direction the system will be developed in the future.

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Appendix: NRV project research topics and members

Group 1: Modeling a single neuron by mathematical Reconstruction

1-1 Study on the analysis and modeling of single cell signaling
Masahiro Sokabe (Nagoya University)

1-2 Creation and analysis of 3D biochemical reaction models for neuronal cells
Kazutoshi Ichikawa (Fuji Xerox Co., Ltd)

1-3 Synaptic integration
Hiroyoshi Miyakawa (Tokyo University Pharmacy and life Science)

1-4 Research on dynamics of cultured neuronal networks
Akio Kawana (Takushoku University)

Group 2: Realization of virtual retina based on cell physiology

2-1 Physiological studies on ion channels and synaptic mechanisms of retinal neurons
Akimichi Kaneko (Seijo University)

2-2 Parallel information processing and neural coding in the visual system
Masao Tachibana (University of Tokyo)

2-3 A neuroinformatics study on the model of the vertebrate retina
Yoshimi Kamiyama (Aichi Prefectural University)

Group 3: Study on the visual function by computational and systems' approach

3-1 A mathematical model of cortical receptive fields and functional maps
Masanobu Miyashita (NEC)

3-2 A mathematical model of cortical dynamics
Shigeru Tanaka (RIKEN)

3-3 Computational models for color perception
Shigeki Nakauchi (Toyohashi University of Tech.)

3-4 Dynamics of the cortical network in the visual perception and cognition
Hidehiko Komatsu (NIPS)

3-5 Neural network model for detecting planar surface from optical flow in area MST of the visual cortex
Hiroaki Okamoto (Fujitsu Ltd.)

3-6 Neural network model of higher visual functions
Toshio Inui (Kyoto University)

3-7 Derivation of qualia from spatiotemporal activity patterns in neural networks
Yoshihide Tamori (Kanazawa Institute of Tech.)

3-8 Neural network model for the mechanism of visual pattern recognition
Kunihiko Fukushima (Tokyo University of Tech.)

3-9 Binocular information processing mechanism in the visual cortex
Izumi Ohzawa (Osaka University)

3-10 Network mechanisms of the response modulation in the primary visual cortex
Hiromichi Sato (Osaka University)

3-11Electrophysiological studies on how MST cell contribute 3-dimensional space perception
Hide-aki Saito (Tamagawa University)

3-12 Psychophysical study on spatiotemporal information processing by human visual system
Shinya Nishida (NTT Communication Science Lab.) (Collaborator)

3-13 3D Reconstruction of Non-Rigid Objects
Keisuke Kinoshita (ATR Human Information Science Lab.), Shigeru Akamatsu (Hosei University)

Group 4: Realization of artificial vision devices and utilization of silicon technology for recording and stimulation

4-1 Analog vision chip for early vision
Hiroo Yonezu (Toyohashi University of Tech.)

4-2 Analog-digital hybrid vision chips for motion processing systems based on direction-selective neural networks
Yoshihito Amemiya (Hokkaido University)

4-3 Fabrication of micro 3D sensor array with ultra -small Si wire electrodes and applications to measurement of retina cell potentials
Makoto Ishida (Toyohashi University of Tech.)

Group 5: Fundamental neuroinformatics research and development

5-1 Mathematical model of neural network for the insect brain
Hidetoshi Ikeno (Himeji Institute of Tech.)

5-2 Study on the learning algorithms for neural data analysis
Andrej Cichocki (BSI, Riken)

5-3 Mathematical algorithm for brain and neural system analysis
Yasunari Yokota (Gifu University)

5-4 Construction of a neuroinformatics database for neuronal visual system
Isao Yamaguchi (Fuji Xerox Co., Ltd.)

5-5 Development of computer support environment for neuroinformatics
Keisuke Takebe (Nagaoka National College of Tech.)

5-6 Research and development on building the integrative support environment for modeling and simulation
Yasuo Fujii (DSP Technology Co., Ltd.)