Institute for AI and Beyond, Research Report 2020-23

Development of next generation AI by modeling brain information

Kenichi Ohki (Graduate School of Medicine, IRCN)
Kazuyuki Aihara (IRCN)
Hideki Nakayama (Graduate School of Information Science and Technology)

Formation of Hierarchical and Parallel Circuits in the Brain and AI

We elucidated the mechanism by which the connections connecting the many areas in the cerebral cortex are precisely formed during development (Murakami et al., 2022, Nature). The human cerebral cortex contains as many as 180 areas, and precise connections exist between them, forming hierarchical and parallel circuits. Hierarchical and parallel information processing by precise neural circuits connecting these areas is the basis for the complex and versatile intelligence of our brain.

Past studies of neural circuit development have investigated in detail how neural circuits form from the periphery to the entrance of the cortex (in the case of vision, from the retina to the primary visual cortex) and have revealed the mechanisms underlying their formation, but the mechanisms underlying the formation of the connections between cortical areas. However, the mechanism by which the connections between cortical areas are formed has remained largely unknown. As mentioned above, the human cerebral cortex contains as many as 180 areas, and the connections between these areas are thought to be made in thousands of pathways. In order to perform the complex information processing that is required for human intelligence, these myriad connections must be precisely wired in the three-dimensional brain, but the mechanism by which this is accomplished has not been understood.

In this study, we used the mouse visual system to elucidate the mechanism by which connections are formed between numerous visually related areas of the cerebral cortex. The mouse visual system contains a primary visual cortex and more than nine higher-order visual areas, and there are dozens of possible cortico-cortical connections between these areas. In this study, we found that the pathways connecting the retina to the primary visual cortex and many higher-order visual areas are formed first, before these cortico-cortical connections are formed. Furthermore, it was shown that retina- derived spontaneous activity propagating along these pathways conveys retinal location information to the primary and higher visual areas, which serves as an instruction signal to form precise connections between the primary visual cortex and the corresponding locations in many higher visual areas.

Current artificial intelligence is evolving in the direction of deep learning with many layers. Although parallel and distributed processing has been partially incorporated through the use of multiple channels, it is not designed to explicitly parallel processing of widely different features, such as shape and motion, or faces and buildings. In addition to hierarchical processing, parallel distributed processing is one of the major principles in the cerebral cortex, and it is thought to be what allows our brains to acquire complex and general-purpose intelligence. The above results show that the circuits responsible for parallel and distributed processing are formed by using information propagated through previously unknown circuits connecting the retina and cortex as an instruction signal. This principle may be useful for the development of general-purpose artificial intelligence by incorporating not only hierarchical processing but also parallel and distributed processing.

Variability in Brain Activity and Adversarial Examples in AI

By incorporating properties of information processing in humans and other animals into AI, we developed a new method to overcome vulnerability to adversarial examples (Ukita & Ohki, 2023, Neural Network). Among the properties known in human and animal neurons, we focused on variability in neuronal activity. Variability refers to the property that neuronal activity is not always the same despite the same external conditions, such as sensory input. In visual information processing in animals, variability exists not only in the retina, which is located at the input of information processing, but also in the brain, which is located at the later stage of information processing. Variability or noise in the input part of information processing is considered important for training circuits that can respond to variations in information from the outside world. In fact, research has been conducted in deep neural networks to overcome vulnerability to adversarial attacks by adding variability in the input layer. However, the significance of introducing variability in the later hidden layers, as in the animal brain, was not clear.

Therefore, we first devised a new method of adversarial attack. The adversarial examples generated by this method are not only misrecognized by the deep neural network, but also have the following two properties: first, in the input layer of the deep neural network, the distance between the adversarial examples and the original image is far; second, in the hidden layer of the deep neural network, the distance between the adversarial examples and the original image is close. In this study, adversarial examples were generated by this method using various image data sets. Variability was then introduced in the input or hidden layer of the deep neural network, respectively, to determine whether the adversarial examples were classified into the correct category or misclassified like the adversarial examples. The results showed that the percentage of adversarial examples classified into the correct category increased much more when variability was introduced into the hidden layer than when it was introduced into the input layer. In other words, introducing variability in the hidden layer rather than the input layer successfully reduced the vulnerability to adversarial attacks in this case. This study shows that introducing variability in the hidden layer, which is located in the later stages of information processing in deep neural networks, can reduce vulnerability to certain adversarial attacks. This method is expected to increase the possibility of creating AI that more closely resembles the behavior of humans and other animals. In the field of neuroscience, various hypotheses have also been formulated and tested regarding the significance of variability in the neurons of the brain. It is possible that variable neuronal activity in the brain reduces vulnerability to adversarial examples such as those generated in this study, making puzzling behavior less likely to occur.

Color Processing in the Brain and AI

We determined how color and shape information is represented in the primary visual cortex of primates (Chatterjee et al., Nature Commun., 2021). It was not known how color information is represented in the primary visual cortex, especially whether red/green information transmitted by the parvocellular pathway and blue/yellow information transmitted by the koniocellular pathway merge or are separated in the primary visual cortex. We showed for the first time that red/green and blue/yellow information merge in the blob (a module of about 300 microns in diameter specialized for color information) in the primary visual cortex, and that these two pathways do not merge completely but only partially to form a map of hue information including intermediate colors. Furthermore, it was clarified that the blob represents color information at low spatial frequencies (such as the surface of an object) and no shape information, while just outside the blob, color information and shape information are combined and represented, and further outside the blob, only shape information at high spatial frequencies is represented and no color information is represented. In the current deep learning, R, G, and B information is input as it is, but it may be possible to achieve primate-like object recognition if the information is converted into red/green (R-G), blue/yellow (B-(R+G)/2), and brightness (R+G) channels like primates' visual system. In addition, depending on the spatial frequency, some channels may not require shape or color information, which may also contribute to primate-like object recognition.

Mathematical Modelling Analysis of the Brain

First, using data on spontaneous activity measured from the mouse brain to implement a reservoir neural network with a dynamic and feedback connections was studied to reproduce dynamics of the brain's spontaneous activity on the neural network, and reservoir computing with the Hidden-FORCE method, a new learning method for recurrent networks was developed by improving the Full-FORCE method. Then, by applying this method, we successfully reproduced and predicted a part of the wide-area spontaneous activity data with a recurrent neural network through learning in a data-driven manner using the spontaneous activity data measured from the mouse brain. In parallel, the MD-RS method was developed, which uses the Mahalanobis distance of reservoir states for time series anomaly detection. The proposed method is capable of high-performance on-line time series anomaly detection with shorter training data and fewer computational resources than conventional methods.

Next, we developed the formulation of a learning rule that extends the conventional scalar coupling coefficients to response kernels, and a mean-field analysis method for nonlinear networks consisting of the Stuart-Landau oscillators with noise as a basic model for mathematical modelling of the dynamical spontaneous activity of the cortex. On the other hand, we discovered neural activity related to a logical thinking process using categorical information in neuroscience experiments using monkeys, and analyzed the mechanism of logical thinking in the brain by constructing its theoretical model. The results are expected to lead to a further understanding of higher cognitive functions in humans and to future applications in the development of artificial intelligence that enables logical thinking. Using the same data, a new theoretical model has also been constructed using machine learning methods from the perspective of dynamical systems to analyze the mechanism of information updating that takes place in the brain.

Furthermore, as a part of the spatiotemporal pattern analysis of the brain, we focused on a neural network model of the inferior olive nucleus, which is rich in electrical synaptic connections, and showed that the strength of electrical synaptic connections controls spatiotemporal patterns such as synchronous and chaotic firing, and proposed recurrent neural networks for solving combinatorial optimization problems.

Brain-type Mathematical Data Analysis of Large-Scale Data

First, for the construction of a next-generation AI, we proposed new AI prediction theory for predicting changes in various complex large-scale data, the 'autoreservoir computation' method, and developed a mathematical method for utilizing spatial information of numerous big data observed from real complex systems for the prediction of specific target variables. This 'autoreservoir computation' can be expected to improve prediction accuracy of diverse complex systems for which prediction is quite important (P.Chen et al., Nature Communications, 2020). Considering the spatiotemporal data analysis of the brain, a new data science based on nonlinear dynamics analysis was also proposed based on original ideas such as dynamical network biomarkers and autoreservoir neural networks, which advances the traditional data science that is dominated by statistical analysis (J. Shi, et al. National Science Review, 2021).

A multi-step stochastic approximation method using Nesterov acceleration was also analyzed theoretically for the stochastic composite convex optimization problem. Convergence of the expected value of the function value in a candidate solution was proved, and the characterization of the probability tail of the function value was also explained. Such an algorithm could be useful for parameter estimation in energy-based models of the spatiotemporal dynamics of the neural systems (e.g. Ising and coupled oscillator models).
Furthermore, research has been initiated on causal analysis in the framework of dynamical systems using mutual information as an indicator. This research could be useful for analyzing causality in neural activity and the importance of pathways and nodes in neural networks.
These brain-type mathematical data analysis techniques for large-scale data have been applied to various fields, including genetic analysis, earthquake alerts and countermeasures against COVID-19 pandemic (Y.Tong et al.,.PNAS, 2023).

Neuro-Symbolic AI

We have developed several search and inference methods to achieve fast end-to-end learning as a whole in neural networks that incorporate modules containing discrete operations (Neural Module Networks). This is a basic technology useful for incorporating and utilizing some kind of known structure and knowledge in neural networks in a top-down manner, and challenges the major theme of artificial intelligence; the fusion of induction and deduction. In this project, for example, it is expected to be applied to image recognition AI that incorporates knowledge of neurophysiology.

First, we focused on the approach of relaxing a discrete search problem into a continuous problem. We addressed the problem of searching data augmentation policies in image recognition, and we succeeded in making the conventional data augmentation search method several hundred times faster by introducing differentiable search technique (Hataya et al., ECCV, 2020). By parameterizing image transformations and their selection operations and expressing them as continuous functions, hyperparameters can be adjusted using the standard back propagation method, resulting in a significant speedup. In (Hataya et al., ECCV, 2020), a proxy task using distribution matching was used, but further improvement in recognition accuracy was achieved by further increasing scalability and enabling learning that directly minimizes the validation error even on large datasets (Hataya et al., WACV 2022).

We are also studying a more general approach that performs discrete search as is. While this approach requires searching for intermediate labels representing combinations of modules, we have developed a fast search method using an efficient graph representation. We applied the proposed technique to an visual reasoning tasks and achieved highly accurate visual question answering (VQA) and graph reading (Wu et al., ACCV, 2020). Furthermore, the technique was applied not only to an image recognition task, but also to mathematical reasoning task in natural language processing, and achieved higher accuracy than existing methods (Wu et al., COLING 2022).

Connecting External Knowledge to Neural Networks

One of the major advantages of the neuro-symbolic AI described above is that external knowledge can be seamlessly connected. This can be a useful approach to quickly update AI knowledge in an open world, or to provide AI with common sense knowledge and control to ensure that it conforms to the norms of society.

By connecting an external knowledge graph to a neural network (Transformer), we have proposed and realized the world's first anticipation captioning, which predicts and describes the future situation of given images (Vo et al., CVPR 2023). In this method, some seed concepts are first extracted from a given image sequence using object detection techniques, and then various related concepts are searched for by using the seed concepts as a starting point in a search over the external knowledge graph. This makes it possible to broaden the concept to include things that are not necessarily included in the given images, which can be useful for various future predictions. Similarly, by searching dictionary data consisting of images and text during inference, we have realized a zero-shot image captioning method that can also recognize unknown objects (Vo et al., CVPR 2022). These results are a forerunner of retrieval-augmented generation (RAG), which has been attracting attention in the field of generative

AI in recent years. When performing RAG, pseudo-correlation within the retrieved information can have a negative impact. For this, we have extended (Vo et al., CVPR 2022) to further improve the image captioning performance of modern multimodal LLMs by adding a mechanism to reduce pseudo-correlation (Li et al., CVPR 2024).

Image Recognition Models and Methods

We have conducted a number of studies aimed at improving fundamental performance in various aspects of image recognition, including accuracy, speed, and robustness. First, we considered convolutional neural networks, the most basic image recognition model, and proposed a high-speed architecture that performs convolutional operations in the frequency domain using discrete cosine variation (Xu et al., IJCNN 2021). We also developed an image recognition method that is robust against unknown noise during inference by performing learning-based quantization in image and feature space (Hataya et al., IJCNN 2022; Kishida et al., ICPR 2022).

Furthermore, we developed a learning method that mitigates model bias caused by datasets (Li et al., ICCV 2023). Although there have been many studies on model bias, ours is the first attempt in the world to deal with the general case where both the content and number of biases are unknown, and this is achieved by appropriately ensembling a large number of bias-reduced models obtained by counterfactual learning. This method has the potential to contribute not only to model bias mitigation but also to various important issues in deep learning, such as improving explainability and resistance to shortcuts and adversarial noise.

Image Generation Models and Methods

We have also done many studies on image generation to improve the quality and practicality of generation. In particular, we have obtained many results on adversarial generative networks (GANs), one of the representative image generation models. First, we are systematically developing methods for training GANs from small amounts of data and incomplete data (Katsumata et al., ICASSP 2021; Katsumata et al., CVPR 2022; Katsumata et al., WACV 2024). Other techniques with broad applicability include enhancing the quality of image generation by improving discriminative networks and introducing intermediate distributions (Yang et al., Access 2022; Yang et al., WACV 2023), and compressing GAN models through pruning (Vo et al., WACV 2022).

Furthermore, based on these basic technologies, we have developed a number of applications such as multilingual handwritten text generation (Jan et al., ACMMM 2021; Jan et al., ICDAR 2023), natural text removal from images (Jan et al., WACV 2020), story image sequence generation (Chen et al., EMNLP 2022), and many other applications.

References

1. Huu Hoang, Eric J. Lang, Yoshito Hirata, Isao T. Tokuda, Kazuyuki Aihara, Keisuke Toyama, Mitsuo Kawato , Nicolas Schweighofer. Electrical coupling controls dimensionality and chaotic firing of inferior olive neurons. **PLoS Computational Biology** 16(7): e1008075 (2020. 7. 30)
2. Pei Chen, Rui Liu, Kazuyuki Aihara, and Luonan Chen: "Autoreservoir computing for multistep ahead prediction based on the spatiotemporal information transformation," **Nature Communications**, Vol.11, Article No.4568, pp.1-15 (2020) (2020.9.11)
3. Hagihara KM, Ishikawa AW, Yoshimura Y, Tagawa Y, Ohki K. Long-Range Interhemispheric Projection Neurons Show Biased Response Properties and Fine-Scale Local Subnetworks in Mouse Visual Cortex. **Cereb Cortex.** 2020 Oct 16:bhaa297. doi: 10.1093/cercor/bhaa297. (2020.10.16)
4. Yoshito Hirata and Kazuyuki Aihara. Deep Learning for Nonlinear Time Series: Examples for Inferring Slow Driving Forces. **International Journal of Bifurcation and Chaos**, Vol.30, No.15, 2050226, pp.1-13 (2020). (2020.12.15)
5. Seiji Uenohara and Kazuyuki Aihara. Time-Domain Digital-to-Analog Converter for Spiking Neural Network Hardware. **Circuits, Systems, and Signal Processing**, doi: 10.1007/s00034-020-01597-2 (2020). (2020.12.11)
6. Hagihara KM, Ishikawa AW, Yoshimura Y, Tagawa Y, Ohki K. “Long-Range Interhemispheric Projection Neurons Show Biased Response Properties and Fine-Scale Local Subnetworks in Mouse Visual Cortex.” **Cereb Cortex.** 31(2):1307-1315. doi: 10.1093/cercor/bhaa297 (2021.01.05).
7. Soumya Chatterjee, Kenichi Ohki, R Clay Reid. “Chromatic micromaps in primary visual cortex” **Nature Communications.,** .Vol.12: 2315. doi: 10.1038/s41467-021-22488-3 (2021.04.19).
8. Daisuke Inoue, Akihisa Okada, Tadayoshi Matsumori, Kazuyuki Aihara, Hiroaki Yoshida, "Traffic Signal Optimization on a Square Lattice with Quantum Annealing," **Scientific Reports**, Vol.11, Article No.3303, pp.1-12 (2021). (2021.2.10:online)
9. Jifan Shi, Kazuyuki Aihara, Luonan Chen, "Dynamics-based data Science in Biology," **National Science Review**, Vol.8, No.5, nwab029, pp.1-6 (2021). (2021.2.12:online)
10. Mikio Hasegawa, Hirotake Ito, Hiroki Takesue, Kazuyuki Aihara, "Optimization by Neural Networks in the Coherent Ising Machine and its Application to Wireless Communication Systems," **IEICE Transactions on Communications**, Vol.E104-B, No.3, pp.210--216 (2021). (2020.9.1:online, 2021.3:print)
11. Shunya Okuno, Koji Ikeuchi, Kazuyuki Aihara, "Practical Data-Driven Flood Forecasting Based on Dynamical Systems Theory," **Water Resources Research**, Vol.57, No.3, e2020WR028427, pp.1-18 (2021). (2021.2.11:online, 2021.3:print).
12. Kwang Su Kim, Keisuke Ejima, Shoya Iwanami, Yasuhisa Fujita, Hirofumi Ohashi, Yoshiki Koizumi, Yusuke Asai, Shinji Nakaoka, Koichi Watashi, Kazuyuki Aihara, Robin N. Thompson, Ruian Ke, Alan S. Perelson and Shingo Iwami, "A quantitative model used to compare within-host SARS-CoV-2, MERS-CoV and SARS-CoV dynamics provides insights into the pathogenesis and treatment of SARS-CoV-2," **PLOS Biology**, Vol.19, No.3, e3001128, pp.1-19 (2021). (2021.3.22:online)

13. Keisuke Ejima, Kwang Su Kim, Shoya Iwanami, Yasuhisa Fujita, Ming Li, Roger S. Zoh, Kazuyuki Aihara, Taiga Miyazaki, Takaji Wakita and Shingo Iwami: “Time Variation in the Probability of Failing to Detect a Case of Polymerase Chain Reaction Testing for SARS-CoV-2 as Estimated from a Viral Dynamics Model,” **Journal of the Royal Society Interface**, Vol.8, No.177, 20200947, pp.1-7 (2021.4.21).
14. Hirofumi Ohashi, Koichi Watashi, Wakana Saso, Kaho Shionoya, Shoya Iwanami, Takatsugu Hirokawa, Tsuyoshi Shirai, Shigehiko Kanaya, Yusuke Ito, Kwang Su Kim, Takao Nomura, Tateki Suzuki, Kazane Nishioka, Shuji Ando, Keisuke Ejima, Yoshiki Koizumi, Tomohiro Tanaka, Shin Aoki, Kouji Kuramochi, Tadaki Suzuki, Takao Hashiguchi, Katsumi Maenaka, Tetsuro Matano, Masamichi Muramatsu, Masayuki Saijo, Kazuyuki Aihara, Shingo Iwami, Makoto Takeda, Jane A. McKeating, and Takaji Wakita: "Potential anti-COVID-19 Agents, Cepharanthine and Nelfinavir, and their Usage for Combination Treatment," **iScience**, Vol.24, No.4, 102367, pp.1-14 (2021.4.23).
15. Komei Kurasawa, Kota Hashimoto, Aohan Li, Koya Sato, Kensuke Inaba, Hiroki Takesue, Kazuyuki Aihara, and Mikio Hasegawa: "A High-Speed Channel Assignment Algorithm for Dense IEEE 802.11 Systems via Coherent Ising Machine," **IEEE Wireless Communications Letters**, doi: 10.1109/LWC.2021.3077311 (2021.5).
16. Keisuke Ejima, Kwang Su Kim, Christina Ludema, Ana I. Bento, Shoya Iwanami, Yasuhisa Fujita, Hirofumi Ohashi, Yoshiki Koizumi, Koichi Watashi, Kazuyuki Aihara, Hiroshi Nishiura, and Shingo Iwami: "Estimation of the Incubation Period of COVID-19 using Viral Load Data," **Epidemics**, Vol.35, 100454, pp.1-6 (2021.3.15:online, 2021.6: print).
17. Shoya Iwanami, Keisuke Ejima, Kwang Su Kim, Koji Noshita, Yasuhisa Fujita, Taiga Miyazaki, Shigeru Kohno, Yoshitsugu Miyazaki, Shimpei Morimoto, Shinji Nakaoka, Yoshiki Koizumi, Yusuke Asai, Kazuyuki Aihara, Koichi Watashi, Robin N. Thompson, Kenji Shibuya, Katsuhito Fujiu, Alan S. Perelson, Shingo Iwami, Takaji Wakita: "Detection of Significant Antiviral Drug Effects on COVID-19 with Reasonable Sample Sizes in Randomized Controlled Trials: A Modeling Study," **PLOS Medicine**, Vol.18, No.7, e1003660, pp.1-20 (2021.7.7).
18. Hiroshi Yamashita, Hideyuki Suzuki, and Kazuyuki Aihara: "Accelerating Numerical Simulation of Continuous-Time Boolean Satisfiability Solver Using Discrete Gradient," **Communications in Nonlinear Science and Numerical Simulation**, Vol.102, 105908, pp.1-14 (2021.5.24:online, 2021.11:print).
19. Changhee Han, Leonardo Rundo, Kohei Murao, Tomoyuki Noguchi, Yuki Shimahara, Zoltán, Ádám Milacski, Saori Koshino, Evis Sala, Hideki Nakayama, Shin'ichi Satoh. Electrical coupling controls dimensionality and chaotic firing of inferior olive neurons. **BMC Bioinformatics** 22(Suppl 2):31 (2021). (2021. 4. 26)
20. Seiji Uenohara and Kazuyuki Aihara, "Time-Domain Digital-to-Analog Converter for Spiking Neural Network Hardware," **Circuits, Systems, and Signal Processing,** Vol.40, 2763-2781 (2021). (2020.12.11:online, 2021.6: print)
21. Yong Dam Jeong, Keisuke Ejima, Kwang Su Kim, Shoya Iwanami, Ana I Bento, Yasuhisa Fujita, Il Hyo Jung, Kazuyuki Aihara, Koichi Watashi, Taiga Miyazaki, Takaji Wakita, Shingo Iwami, and Marco Ajelli, "Revisiting the Guidelines for Ending Isolation for COVID-19 Patients," **eLife**, Vol.10, e69340, pp.1-20 (2021.7.21).
22. Yoshito Hirata, José M. Amigó, Shunsuke Horai, Kazuhiko Ogimoto, and Kazuyuki Aihara, "Forecasting Wind Power Ramps with Prediction Coordinates," **Chaos**, Vol.31, No.10, Article No.103105, pp.1-7 (2021). (2021.10.4:online, 2021.10:print)

23. Rui Liu, Jiayuan Zhong, Renhao Hong, Ely Chen, Kazuyuki Aihara, Pei Chen, and Luonan Chen, "Predicting Local COVID-19 Outbreaks and Infectious Disease Epidemics based on Landscape Network Entropy," **Science Bulletin**, pp.2265-2270 (2021). (2021.3.26:online, 2021.11.30:print)
24. Kazuyuki Aihara, Rui Liu, Keiichi Koizumi, Xiaoping Liu, and Luonan Chen, "Dynamical Network Biomarkers: Theory and Application," **Gene**, Vol. 808, Article No.145997, pp.1-10 (2022).(2121.10.6:online, 2022.1.15:print)
25. Yusuke Sakemi , Kai Morino, Takashi Morie, and Kazuyuki Aihara, "A Supervised Learning Algorithm for Multilayer Spiking Neural Networks Based on Temporal Coding Toward Energy-Efficient VLSI Processor Design," **IEEE Transactions on Neural Networks and Learning Systems**, doi: 10.1109/TNNLS.2021.3095068, pp.1-15 (2022). (2021.7.21:online, 2022:print)
26. (Review）: Jifan Shi, Kazuyuki Aihara, Luonan Chen: "Dynamics-based data Science in Biology," **National Science Review**, doi: 10.1093/nsr/nwab029 (2021.2.12:online; 2021.5:print).
27. (Review）: Rui Liu, Kazuyuki Aihara, and Luonan Chen: "Collective fluctuation implies imminent state transition: Comment on "Dynamic and thermodynamic models of adaptation" by A.N. Gorban et al.," **Physics of Life reviews**, Vol.37, pp.103-107 (2021.7).
28. Kondo S, Kiyohara Y, Ohki K. Response Selectivity of the Lateral Posterior Nucleus Axons Projecting to the Mouse Primary Visual Cortex. **Front Neural Circuits.** 2022 16:825735 (2022). (2022.2.28)
29. Murakami T, Matsui T, Uemura M, Ohki K. Modular strategy for the development of hierarchical visual network in mice. **Nature** 608:578-585. (2022).
30. Tezuka Y, Hagihara KM, Ohki K, Hirano T, Tagawa Y. Developmental stage-specific spontaneous activity contributes to callosal axon projections. **Elife.** 11:e72435. (2022).
31. Jifan Shi, Kenji Kirihara, Mariko Tada, Mao Fujioka, Kaori Usui, Daisuke Koshiyama, Tsuyoshi Araki, Luonan Chen, Kiyoto Kasai, and Kazuyuki Aihara: "Criticality in the Healthy Brain," **Frontier in Network Physiology**, Vol.1, Article No.755685, pp.1-9 (2022). (2022.1.18: online)
32. Jifan Shi, Luonan Chen and Kazuyuki Aihara: "Embedding Entropy: A Nonlinear Measure of Dynamical Causality," **Journal of the Royal Society Interface**, Vol.19, No.188, Article No.20210766, pp.1-12 (2022). (2022.3.30: online)
33. Seiji Uenohara and Kazuyuki Aihara: "A 18.7 TOPS/W Mixed-Signal Spiking Neural Network Processor With 8-bit Synaptic Weight On-Chip Learning That Operates in the Continuous-Time Domain," **IEEE Access**, Vol.10, pp.48338-48348 (2022). (2022.4.26:online)
34. Naoya Fujiwara, Tomokatsu Onaga, Takayuki Wada, Shouhei Takeuchi, Junji Seto, Tomoki Nakaya, and Kazuyuki Aihara: "Analytical Estimation of Maximum Fraction of Infected Individuals with One-Shot Non-pharmaceutical Intervention in a Hybrid Epidemic Model," **BMC Infectious Diseases**, Vol.22, Article No.512, pp.1-11 (2022).
35. Yang Li, Jifan Shi, and Kazuyuki Aihara: "Mean-Field Analysis of Stuart-Landau Oscillator Networks with Symmetric Coupling and Dynamical Noise," **Chaos**, Vol.32, No.6, Article No.063114, pp.1-23 (2022). (2022.6.3: online)
36. Jifan Shi, Kazuyuki Aihara, Tiejun Li, and Luonan Chen: "Energy Landscape Decomposition for Cell Differentiation With Proliferation Effect," **National Science Review**, nwac116, pp.1-8 (2022). (2022.6.17: online)

37. Takayuki Hosokawa, Muyuan Xu, Yuichi Katori, Munekazu Yamada, Kazuyuki Aihara and Ken-Ichiro Tsutsui: "Monkey Prefrontal Single-Unit Activity Reflecting Category-Based Logical Thinking Process and Its Neural Network Model," **Journal of Neuroscience**, Vol.42, No.33, pp.6380-6391 (2022). (2022.7.8: online)
38. Keisuke Ejima, Kwang Su Kim, Ana I. Bento, Shoya Iwanami, Yasuhisa Fujita, Kazuyuki Aihara, Kenji Shibuya, and Shingo Iwami: "Estimation of Timing of Infection from Longitudinal SARS-CoV-2 Viral Load Data: Mathematical Modelling Study," **BMC Infectious Diseases**, Vol.22, Article No.656, pp.1-9 (2022). (2022.7.28: online)
39. Yong Dam Jeong, Keisuke Ejima, Kwang Su Kim, Woo Joohyeon, Shoya Iwanami, Yasuhisa Fujita, Il Hyo Jung, Kazuyuki Aihara, Kenji Shibuya, Shingo Iwami, Ana I. Bento, and Marco Ajelli: "Designing Isolation Guidelines for COVID-19 Patients with Rapid Antigen Tests," **Nature Communications**, Vol.13, Article No.4910, pp.1-9 (2022). (2022.8.20: online)
40. Seiji Uenohara and Kazuyuki Aihara: "A Trainable Synapse Circuit Using a Time-Domain Digital-to-Analog Converter," **Circuits Syst Signal Process**, doi: 0.1007/s00034-022-02168-3 (2022). (2022.9.16: online)
41. Yuji Okamoto, Mitsuhito Hirano, Kai Morino, Masashi K. Kajita, Shinji Nakaoka, Mayuko Tsuda, Kei-ji Sugimoto, Shigehisa Tamaki, Junichi Hisatake, Hisayuki Yokoyama, Tadahiko Igarashi, Atsushi Shinagawa, Takeaki Sugawara, Satoru Hara, Kazuhisa Fujikawa, Seiichi Shimizu, Toshiaki Yujiri, Hisashi Wakita, Kaichi Nishiwaki, Arinobu Tojo, and Kazuyuki Aihara: "Early Dynamics of Chronic Myeloid Leukemia on Nilotinib Predicts Deep Molecular Response," **npj Systems Biology and Applications**, Vol.8, Article No.39, pp.1-10 (2022).(2022.10.13: online)
42. Rui Yang, Raphael Shu, and Hideki Nakayama: "Improving Noised Gradient Penalty with Synchronized Activation Function for Generative Adversarial Networks," **IEICE Transactions on Information and Systems**, Vol.E105-D, No.9, pp.1537-1545, (2022). (2022.9.1: online)
43. Rui Yang, Duc Minh Vo, and Hideki Nakayama: "Stochastically Flipping Labels of Discriminator's Outputs for Training Generative Adversarial Networks," **IEEE Access**, Vol.10, pp.103644-103654, (2022). (2022.9.28: online)
44. Tomonari Murakami, Kenichi Ohki　Thalamocortical circuits for the formation of hierarchical pathways in the mammalian visual cortex.　**Frontiers in neural circuits** 17 1155195-1155195 2023
45. Jumpei Ukita, Kenichi Ohki　Adversarial attacks and defenses using feature-space stochasticity　**Neural Networks** 167 875-889 2023
46. Ruixiang Li, Kenichi Ohki, Teppei Matsui　Ketamine-induced 1-Hz oscillation of spontaneous neural activity is not directly visible in the hemodynamics. **Biochemical and Biophysical Research Communications** 2023
47. Tanita Frey, Tomonari Murakami, Koichiro Maki, Takumi Kawaue, Naoki Tani, Ayaka Sugai, Naotaka Nakazawa, Kei-ichiro Ishiguro, Taiji Adachi, Mineko Kengaku, Kenichi ohki, Yukiko Gotoh, Yusuke Kishi, Age-associated reduction of nuclear shape dynamics in excitatory neurons of the visual cortex **Aging Cel**l 22(9) 2023
48. Takashi Kanamaru, Takao K. Hensch, and Kazuyuki Aihara: "Maximal Memory Capacity Near the Edge of Chaos in Balanced Cortical E-I Networks," **Neural Computation**, Vol.35, No.8, pp.1430--1462 (2023).
49. Chengming Zhang, Yiwen Yang, Shijie Tang, Kazuyuki Aihara, Chuanchao Zhang, and Luonan Chen: "Contrastively Generative Self-Expression Model for Single-Cell and Spatial Multimodal Data," **Briefings in Bioinformatics**, Vol.24, No.5, bbad265, pp.1-13 (2023)

50. Yuyan Tong, Renhao Hong, Ze Zhang, Kazuyuki Aihara, Pei Chen, Rui Liu, and Luonan Chen: "Earthquake Alerting based on Spatial Geodetic Data by Spatiotemporal Information Transformation Learning," **Proceedings of the National Academy of Sciences of the United States of America**, Vol.120, No.37, e2302275120, pp.1--12 (2023).
51. Chihao Zhang, Kangning Dong, Kazuyuki Aihara, Luonan Chen, and Shihua Zhang: "STAMarker: Determining Spatial Domain-Specific Variable Genes with Saliency Maps in Deep Learning," **Nucleic Acids Research**, gkad801, pp.1-13 (2023).
52. Junya Sunagawa, Hyeongki Park, Kwang Su Kim, Ryo Komorizono, Sooyoun Choi, Lucia Ramirez Torres, Joohyeon Woo, Yong Dam Jeong, William S. Hart, Robin N. Thompson, Kazuyuki Aihara, Shingo Iwami, and Ryo Yamaguchi: "Isolation May Select for Earlier and Higher Peak Viral Load but Shorter Duration in SARS-CoV-2 Evolution," **Nature Communications**, Vol.14, Article No.7395, pp.1-13 (2023).
53. KuanChao Chu and Hideki Nakayama. Two-Path Object Knowledge Injection for Detecting Novel Objects with Single-Stage Dense Detector. **IEICE Transactions on Information and Systems**. Vol.E106-D, No.11, pp. 1868-1880, 2023.

Conference Papers

1. Ryuichiro Hataya, Zdenek Jan, Kazuki Yoshizoe, and Hideki Nakayama. Faster AutoAugment: Learning Augmentation Strategies using Backpropagation, In **Proceedings of the 16th European Conference on Computer Vision (ECCV)**, 2020. (2020.8.23)
2. Takumi Ohkuma and Hideki Nakayama, Efficient Base Class Selection Algorithms for Few-shot Classification, In **Proceedings of the ACM International Conference on Multimedia Retrieval (ICMR)**, 2020. (2020.10.28)
3. Yuxuan Wu and Hideki Nakayama, Graph-based Heuristic Search for Module Selection Procedure in Neural Module Network, In **Proceedings of the 15th Asian Conference on Computer Vision (ACCV)**, 2020. (2020.11.30)
4. Nina Sviridova, Pietro Artoni, Michela Fagiolini, Takao K. Hensch, and Kazuyuki Aihara, "Dynamical Characteristics of Wild-Type Mouse Spontaneous Pupillary Fluctuations*," **Proceedings of the 2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)**, pp. 853-856 (2021). (2021.12.9:online)
5. Seiji Uenohara and Kazuyuki Aihara, "CMOS Mixed-Signal Spiking Neural Network Circuit Using a Time-Domain Digital-To-Analog Converter," **Proceedings of the 2021 IEEE International Symposium on Circuits and Systems (ISCAS)**, doi: 10.1109/ISCAS51556.2021.9401230, pp.1-5 (2021). (2021.4.27:online)
6. Ikki Kishida, Hong Chen, Masaki Baba, Jiren Jin, Ayako Amma, and Hideki Nakayama. Object Recognition with Continual Open Set Domain Adaptation for Home Robot. **Proceedings of the IEEE Winter Conference on Applications of Computer Vision (WACV),** pp.1517-1526 (2021). (2021.1.6)
7. Hong Chen, Yifei Huang, Hiroya Takamura, and Hideki Nakayama. Commonsense Knowledge Aware Concept Selection for Diverse and Informative Visual Storytelling. **Proceedings of the 35th AAAI Conference on Artificial Intelligence (AAAI),** pp.999-1008 (2021). (2021.2.5)
8. Taiga Kashima, Ryuichiro Hataya, Hideki Nakayama. Visualizing Association in Exemplar-based Classification.

Proceedings of the 46th IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), pp.1780-1784 (2021). (2021.6.9)

9. Kai Katsumata, Hideki Nakayama. Semantic Image Synthesis from Inaccurate and Coarse Masks. **Proceedings of the 46th IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)**, pp.2285-2289 (2021). (2021.6.11)
10. Yuhao Xu, Hideki Nakayama. DCT-based Fast Spectral Convolution for Deep Convolutional Neural Networks. **Proceedings of the International Joint Conference on Neural Networks (IJCNN)** (2021). (2021.7.18)
11. Kai Katsumata, Ikki Kishida, Ayako Anma, and Hideki Nakayama. Open-Set Domain Generalization via Metric Learning. **Proceedings of the IEEE International Conference on Image Processing (ICIP)**, pp.459-463 (2021). (2021.9.22)
12. Hong Chen, Raphael Shu, Hiroya Takamura, Hideki Nakayama. GraphPlan: Story Generation by Planning with Event Graph. **Proceedings of the 14th International Conference on Natural Language Generation (INLG)**, pp.377-386 (2021). (2021.9.23)
13. Shisheng Wang, Hideki Nakayama. Stochastic Observation Prediction for Efficient Reinforcement Learning in Robotics. **Proceedings of the 4th IEEE International Conference on Multimedia Information Processing and Retrieval (MIPR)**, (2021). (2021.9.8)
14. Jan Zdenek and Hideki Nakayama. JokerGAN: Memory-Efficient Model for Handwritten Text Generation with Text Line Awareness. **Proceedings of the 29th ACM International Conference on Multimedia (ACMMM)**, pp.5655-5663 (2021). (2021.10.23)
15. Hong Chen, Hiroya Takamura, Hideki Nakayama. SciXGen: A Scientific Paper Dataset for Context-Aware Text Generation. Findings of the Association for Computational Linguistics: **EMNLP** 2021, pp.1483-1492 (2021). (2021.11.7)
16. Xun Shen, Masahide Morishita, Jun-ichi Imura, Makito Oku, and Kazuyuki Aihara: "Low-Sample-Size Data-Driven Re-stabilization of Gene Network Systems," **IFAC-PapersOnLine**, Vol.55, No.25, 241-246 (2022).(2022.10.10)
17. Yusuke Sakemi, Kai Morino, Takashi Morie, Takeo Hosomi, and Kazuyuki Aihara: "A Spiking Neural Network with Resistively Coupled Synapses Using Time-to-First-Spike Coding Towards Efficient Charge-Domain Computing," Proceedings of the 2022 **IEEE International Symposium on Circuits and Systems (ISCAS)**, pp.2152-2156 (2022). (2022.11.11)
18. Hiroshi Yamashita, Hideyuki Suzuki, and Kazuyuki Aihara: "Herding with Self-Organizing Multiple Starting Point Optimization," **Proceedings of the 2022 International Symposium on Nonlinear Theory and its Applications (NOLTA2022)**, pp.33-36 (2022). (2022.12.12)
19. Ryuichiro Hataya, Jan Zdenek, Kazuki Yoshizoe, and Hideki Nakayama: "Meta Approach to Data Augmentation Optimization," In **Proceedings of the IEEE Winter Conference on Applications of Computer Vision (WACV)**, pp.2574-2583, 2022. (2022.1.4)
20. Duc Minh Vo, Akihiro Sugimoto, and Hideki Nakayama: "PPCD-GAN: Progressive Pruning and Class-Aware Distillation for Large-Scale Conditional GANs Compression," In **Proceedings of the IEEE Winter Conference on**

Applications of Computer Vision (WACV), pp.2436-2444, 2022. (2022.1.4)

21. Kai Katsumata, Duc Minh Vo, and Hideki Nakayama: "OSSGAN: Open-Set Semi-Supervised Image Generation," In **Proceedings of the Conference on Computer Vision and Pattern Recognition (CVPR)**, pp.11185-11193, 2022. (2022.6.19)
22. Duc Minh Vo, Hong Chen, Akihiro Sugimoto, and Hideki Nakayama: "NOC-REK: Novel Object Captioning with Retrieved Vocabulary from External Knowledge," In **Proceedings of the Conference on Computer Vision and Pattern Recognition (CVPR)**, pp.18000-18008, 2022. (2022.6.19)
23. Ryuichiro Hataya and Hideki Nakayama: "DJMix: Unsupervised Task-agnostic Image Augmentation for Improving Robustness of Convolutional Neural Networks," In **Proceedings of the International Joint Conference on Neural Networks (IJCNN)**, pp.1-8, 2022. (2022.7.18)
24. Ikki Kishida and Hideki Nakayama: "Pixel to Binary Embedding Towards Robustness for CNNs," In **Proceedings of the International Conference on Pattern Recognition (ICPR)**, pp.2279-2285, 2022. (2022.8.21)
25. Yuxuan Wu and Hideki Nakayama: "Weakly Supervised Formula Learner for Solving Mathematical Problems," In **Proceedings of the International Conference on Computational Linguistics (COLING)**, pp.1743-1752, 2022. (2022.10.12)
26. Hong Chen, Duc Minh Vo, Hiroya Takamura, Yusuke Miyao, and Hideki Nakayama: "StoryER: Automatic Story Evaluation via Ranking, Rating and Reasoning," In **Proceedings of the Conference on Empirical Methods in Natural Language Processing (EMNLP)**, pp.1739-1753, 2022. (2022.12.7)
27. Hong Chen, Rujun Han, Te-Lin Wu, Hideki Nakayama, and Nanyun Peng: "Character-centric Story Visualization via Visual Planning and Token Alignment," In **Proceedings of the Conference on Empirical Methods in Natural Language Processing (EMNLP)**, pp.8259-8272, 2022. (2022.12.7)
28. Jiaxuan Li, Duc Minh Vo, and Hideki Nakayama. Partition-and-Debias: Agnostic Biases Mitigation via a Mixture of Biases-Specific Experts. **Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV)**, pp. 4924-4934, 2023.10.2.
29. Jan Zdenek and Hideki Nakayama. Handwritten Text Generation with Character-specific Encoding for Style Imitation. **Proceedings of the 17th International Conference on Document Analysis and Recognition (ICDAR)**. 2023.8.31.
30. Erica Kido Shimomoto, Edison Marrese-Taylor, Hiroya Takamura, Ichiro Kobayashi, Hideki Nakayama, and Yusuke Miyao. Towards Parameter-Efficient Integration of Pre-Trained Language Models in Temporal Video Grounding. **Findings of the Association for Computational Linguistics: (ACL)** 2023. pp.13101-13123,2023.7.7.
31. Minh Duc Vo, An Quoc Luong, Akihiro Sugimoto, and Hideki Nakayama. A-CAP: Anticipation Captioning with Commonsense Knowledge. In **Proceedings of the Conference on Computer Vision and Pattern Recognition (CVPR)**, pp.10824-10833, 2023.
32. Yi-Pei Chen, An-Zi Yen, Hen-Hsen Huang, Hideki Nakayama, and Hsin-Hsi Chen. LED: A Dataset for Life Event Extraction from Dialogs. **Findings of the Association for Computational Linguistics: (EACL)** 2023, pp.384-398, 2023.5.2.
33. Rui Yang, Duc Minh Vo, and Hideki Nakayama. Indirect Adversarial Losses via an Intermediate Distribution for

Training GANs. **Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision (WACV)**, pp.4641-4650, 2023.1.3.

34. Hiroyuki Yasuda, Takuma Osada, Mikio Hasegawa, Kazuyuki Aihara: "A Study on Coupling Functions for Performance Improvement of Decentralized TDMA Based on Desynchronization of Nonlinear Oscillators," **Proceedings of the 2023 International Symposium on Nonlinear Theory and its Applications (NOLTA2023)**, A4L-2, pp.160-163, 2023.9.26.