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Research Topics and Keywords

The scientific study of consciousness | Information closure theory of consciousness (ICT) | Sense of Agency | Cognitive Neuroscience | Computational Neuroscience | Theoretical Neuroscience | Artificial Intelligence | Collective System | Information Theory | Bayesian Inference | Machine Learning | Deep Learning | Data Science | Electroencephalogram (EEG) | Magnetoencephalography (MEG) | Transcranial magnetic stimulation (TMS)

Current Position

Assistant Professor
Rikkyo University, Japan
Apr 2023 - Present

Career History

Project Assistant Professor
Department of Precision Engineering, The University of Tokyo, Japan
Mar 2022 - Mar 2023

Researcher
Araya Inc., Japan (Japanese AI start-up)
Jan 2017 - Jan 2022

- Information-theoretical and neuroscientific research on human and artificial consciousness
- AI research on intrinsic motivation and program synthesis
- Machine learning and deep learning applications on business projects

Education

PhD Sep 2012 - Sep 2017

- **Supervisors:** Prof. Anil Seth, Prof. Ryota Kanai
- **Thesis:** The role of predictive processing in conscious access and regularity learning across sensory domains

Department of Informatics, University of Sussex, UK
Sackler Centre for Consciousness Science, University of Sussex, UK

M.S. Sep 2007 - Jul 2009

- **Supervisors:** Prof. Denise Hsien Wu, Prof. Wen-Jui Kuo
- **Thesis:** Early Influence from Numerical Magnitude on Temporal Processing

Institute of Neuroscience
National Yang-Ming University, Taiwan

B.S. Sep 2002 - Jun 2006

Department of Engineering Science
National Cheng Kung University, Taiwan

Research Tools

- **Programming Languages:** Python, R, Matlab
- **Data Science and Artificial Intelligence:** Machine Learning, Deep Learning (PyTorch)
- **Neuroscience:** Electroencephalogram (EEG), Magnetoencephalography (MEG), Transcranial magnetic stimulation (TMS), Transcranial current brain stimulation (tCS)
- **Mathematics:** Information Theory, Bayesian Modeling and Inference

Language

- Taiwanese (native)
- Mandarin Chinese (native)
- English (fluent)

Awards and Honors

- Scholarship funded by Sackler Centre for Consciousness Science, University of Sussex, UK, 2012-2016
- School of Engineering and Informatics PhD Scholarship, University of Sussex, UK, 2012-2015
- Government scholarships for study abroad (GSSA), Taiwan 2011

Research Grants

- **Grant-in-Aid for Scientific Research (A) (24H00707)**
  - Project Title: Community First Theory: A theory and experiments on Evolution of Individuality, Diversity and Spontaneity
  - Project Leader: Prof. Takashi Ikegami
  - Project Period: 2024 – 2026
  - Funding Amount: ¥50,000,000
  - Funding Source: Japanese Government's KAKENHI Grant
- **Grant-in-Aid for Scientific Research (C) (24K15688)**
  - Project Title: Emergence, adaptation and cognitive cost in collective cognitive behavior
  - Project Leader: Dr. Sangati Ekaterina
  - Project Period: 2024 – 2026
  - Funding Amount: ¥5,000,000
  - Funding Source: Japanese Government's KAKENHI Grant
- **Grant-in-Aid for Scientific Research (C) (24K06485)**
  - Project Title: Elucidating the mechanism of formation and disappearance of number personification in elementary school students and its function in learning

  - Project Leader: Dr. Eiko Matsuda
  - Project Period: 2024 – 2026
  - Funding Amount: ¥5,000,000
  - Funding Source: Japanese Government's KAKENHI Grant
- **GoodAI Grants**
  - Project Title: Creating a new framework for multi-agent AI systems
  - Duration: 4/2021 - 3/2023
  - Funding Amount: $150,000
  - Collaborators: Martin Biehl and Nathaniel Virgo
- **Grants-in-Aid for Scientific Research: Activity Start-up (22K20679)**
  - Project Title: Reveal the Informational Nature of Conscious Self and Sense of Agency Under the Information Closure Theory of Consciousness
  - Duration: 2022 - 2023
  - Funding Amount: ¥3,000,000
  - Funding Source: Japanese Government's KAKENHI Grant
- **Rikkyo University Research and Education Promotion Fund**
  - Duration: 2022-2023

Teaching Experience

- **Department of Psychology, Rikkyo University**
  - Project-Based Seminar
  - Theories of Consciousness & Cognition, remote lecturer at the Graduate Institute of Mind, Brain and Consciousness (GIMBC), Taipei Medical University, Taipei, Taiwan (Sep 2023 - Jan 2024)
- **Instructor, Department of Informatics, University of Sussex, UK**
  - Machine Learning
  - Programming Concepts
  - Mathematical Concepts
  - Software Engineering
  - Computation Theory and Limits of Computation
- **Mentoring Students:**
  - Yi-Shan Cheng (PhD, OIST): Co-supervised with Prof. Kenji Doya (2023-)
  - Ayato Narikawa (MSc, The University of Tokyo): Co-supervised with Prof. Wen Wen (Apr 2022 - Apr 2024)
  - Ned Wilson Eames (MSc, The University of Sussex): Co-supervised with Dr. Ryota Kanai (Sep 2013 - Aug 2014)
  - Sara Souissi (MSc, The University of Sussex): Co-supervised with Dr. Ryota Kanai (Sep 2012 - Aug 2013)

Organised academic events as a principal organiser

- **Consciousness Research Network (CoRN) 2021**
  - Role: Organizing committee member
  - Event: Virtual meeting, 7th-9th July 2021
  - Website: conresnet.org/corn-2021
- **Combining Information-theoretic Perspectives on Agency (CIPA)**
  - Role: Principal organiser
  - Event: Workshop at The University of Tokyo, Japan
  - Date: January 28th - 29th 2020
  - Website: cipa-workshop.weebly.com

Invited Talks

- "The sense of agency from active causal inference" at Aware and Alive: ASSC27 Satellite Symposium on Embodied and Phenomenological Perspectives on Consciousness, Hokkaido University Museum, Sapporo, Japan, July 10, 2024
- "The sense of agency as active causal inference" at TeaP 2024, University of Regensburg, Germany, March 20, 2024
- "From Cells to Souls: Insight from informational properties of consciousness to complex multi-level systems and individuality" at Evolution of Community Complexity, University of Tokyo, Aug. 4, 2023
- "Introduction to the Information Closure Theory of Consciousness" at Okinawa Institute of Science and Technology (OIST), Mar. 2023
- "Many questions, some math, two hypotheses, and one theory" at National Yang Ming Chiao Tung University, 2021
- "A brief introduction to the Information Closure Theory of Consciousness and its future" at the Graduate Institute of Mind, Brain and Consciousness (GIMBC), Taipei Medical University, 2021
- "Can we know if we are living in a simulation? From information closure theory of consciousness to scientific discovery of the universe" at Consciousness Research Network (CoRN), 2021
- "Information Closure Theory of Consciousness" at Institute of Cognitive Neuroscience, National Central University, Taiwan, 2020
- "Information Closure Theory of Consciousness" at Consciousness Club Tokyo, 2020

Publications

- Cheng, Y.-S., Chang, A. Y. & Doya, K. (2025). Information-Theoretical Analysis of Team Dynamics in Football Matches. *Entropy*, *27*(3). DOI: 10.3390/e27030224
  #collective system #information theory
- Chang, A. C.-Y., & Wen, W. (under review). Bayesian integration in sense of agency: Understanding self-attribution and individual differences.
  #consciousness #sense of agency #bayesian inference
- Wen, W., Aktas, H., Chang, A. Y.-C., Mei, J., Suzuishi, Y., Nagai, Y., & Nobusako, S. (under review). Action plan diversity in children during control exploration: Link between action and sense of agency.
  #consciousness #sense of agency #deep learning

- Oi, H., Wen, W., Chang, A. Y.-C., Uchida, H., & Maeda, T. (2024). Hierarchical analysis of the sense of agency in schizophrenia: Motor control, control detection, and self-attribution. *Schizophrenia, 10*(1), 79.
  #consciousness #sense of agency
- Suzuishi, Y., Chang, A. Y.-C., Wen, W., Fujita, M., & Iinuma, K. (2024). Examining sensory attenuation in visual domain using SSVEP. *OSF*.
  #cognitive neuroscience
- Chang, A. Y.-C., Oi, H., Maeda, T. & Wen, W. (2024). The sense of agency from active causal inference. *bioRxiv*, 2024.01.29.577723. DOI: 10.1101/2024.01.29.577723
  #consciousness #sense of agency #deep learning #computational neuroscience
- Takahashi, K., Glinski, B., Salehinejad, M. A., Jamil, A., Chang, A. Y.-C., Kuo, M.-F., & Nitsche, M. A. (2024). Induction and stabilization of delta frequency brain oscillations by phase-synchronized rTMS and tACS. *Brain Stimulation*, *17*(5), 1086–1097. DOI: 10.1016/j.brs.2024.09.003
  #neuroscience
- Wen, W., Mei, J., Aktas, H., Chang, A. Y.-C., Suzuishi, Y., & Kasahara, S. (2024). Control over self and others' face: exploitation and exploration. *Scientific Reports*, *14*(1), 15473. DOI: 10.1038/s41598-024-66316-2
  #consciousness #sense of agency #deep learning
- Wen, W., Chang, A. Y.-C. & Imamizu, H. (2024). The sensitivity and criterion of sense of agency. *Trends in Cognitive Sciences*. DOI: 10.1016/j.tics.2024.03.002
  #consciousness #sense of agency
- Wen, W., Hamada, H., Suzuishi, Y. & Chang, A. Y.-C. (2023). What does the sense of agency mean for humans? *The Japanese Journal of Psychonomic Science*, *42*(1), 53–64.
  #consciousness #sense of agency
- Sangati, E., Sangati, F., Cheng, Y.-S. & Chang, A. Y.-C. (2023). Between Individual Brains and Collective Behavior: Multi-level Emergence in a Group Formation Task. *ALIFE 2023*, 30. DOI: 10.1162/isal_a_00616
  #collective system #information theory #artificial intelligence
- Cheng, Y.-S., Chang, A. Y.-C. & Doya, K. (2023). Information-Theoretical Analysis of Team Dynamics in Football Matches. *Asia-Singapore Conference on Sport Science*.
  #collective system #information theory
- Chang, A. Y. C., Biehl, M., Yu, Y., & Kanai, R. (2020). Information Closure Theory of Consciousness. *Frontiers in Psychology*. DOI: 10.3389/fpsyg.2020.01504
  #consciousness #information theory #consciousness theory
- Kanai, R., Chang, A. Y.-C., Yu, Y., Magrans de Abril, I., Biehl, M., & Guttenberg, N. (2019). Information generation as a functional basis of consciousness. *Neuroscience of Consciousness*, *2019*(1), niz016.
  #consciousness #consciousness theory
- Schwartzman, D. J., Schartner, M. M., Ador, B. B., Simonelli, F., Chang, A. Y.-C., & Seth, A. K. (2019). Increased spontaneous EEG signal diversity during stroboscopically-induced altered states of consciousness. *BioRxiv*, 511766. DOI: 10.1101/511766
  #consciousness #cognitive neuroscience
- Yu, Y., Chang, A. Y. C., & Kanai, R. (2019). Boredom-Driven Curious Learning by Homeo-Heterostatic Value Gradients. *Frontiers in Neurorobotics*, *12*. DOI: 10.3389/fnbot.2018.00088
  #artificial intelligence #deep learning

- Chang, A. Y.-C., Schwartzman, D. J., VanRullen, R., Kanai, R., & Seth, A. K. (2017). Visual Perceptual Echo Reflects Learning of Regularities in Rapid Luminance Sequences. *The Journal of Neuroscience*, *37*(35), 8486–8497.
  #consciousness #computational neuroscience
- Ward, J., Rothen, N., Chang, A. Y.-C., & Kanai, R. (2017). The structure of inter-individual differences in visual ability: Evidence from the general population and synaesthesia. *Vision Research*, *141*, 293–302.
  #consciousness #cognitive neuroscience
- Chang, Acer Y.-C., Seth, A. K., & Roseboom, W. (2017). Neurophysiological signatures of duration and rhythm prediction across sensory modalities. *BioRxiv*. DOI: 10.1101/183954
  #cognitive neuroscience #machine learning
- Schauer, G., Chang, A. Y.-C., Schwartzman, D., Rae, C. L., Iriye, H., Seth, A. K., & Kanai, R. (2016). Fractionation of parietal function in bistable perception probed with concurrent TMS-EEG. *Scientific Data*, *3*, 160065.
  #consciousness #cognitive neuroscience
- Chang, A. Y.-C., Kanai, R., & Seth, A. K. (2015). Cross-modal prediction changes the timing of conscious access during the motion-induced blindness. *Consciousness and Cognition*, *31*, 139–147.
  #consciousness #cognitive neuroscience
- Hung, Y.-H., Pallier, C., Dehaene, S., Lin, Acer Y.-C. Chang, Tzeng, O. J.-L., & Wu, D. H. (2015). Neural correlates of merging number words. *NeuroImage*, *122*, 33–43. DOI: 10.1016/j.neuroimage.2015.07.045
  #cognitive neuroscience
- Chang, A. Y.-C., Tzeng, O. J. L., Hung, D. L., & Wu, D. H. (2011). Big Time Is Not Always Long. *Psychological Science*, *22*(12), 1567–1573
  #cognitive neuroscience

Conference Presentations

- Chang, A. Y.-C., Yu, Y., & Kanai, R. (2018). A Neural Coarse Graining Theory of Consciousness. *Association for the Scientific Studies of Consciousness (ASSC 22)*.
- Chang, A. Y.-C., Rufin VanRullen, Ryota Kanai, & Anil K. Seth. (2015). Unconscious Temporal Predictive Processing Revealed by 10 Hz Perceptual Echo. *19th annual meeting of the Association for the Scientific Study of Consciousness*, Paris.
- Chang, A. Y.-C., Kanai, R., & Seth, A. (2013). Cross-modal prediction changes the timing of conscious access during the motion-induced blindness. *The 17th Annual Meeting of ASSC*, San Diego, USA.
- Chang, A. Y.-C., Wu, S.-W., Tzeng, O. J.-L., & Wu, D. H. (2012). The neuromagnetic responses elicited by dynamic value computations during decision making. *18th Annual Meeting of the Organization for Human Brain Mapping*, Beijing, China.
- Chang, A. Y.-C., Liang, W.-K., Lin, C.-Y., Tzeng, O. J.-L., & Wu, D. H. (2010). The brain activity associated with time perception: A comparison between MEG and EEG signals. *Society for Neuroscience Meeting*.
- Chang, A. Y.-C., Tzeng, O. J.-L., Hung, D. L., & Wu, D. H. (2009). The Influence of Numerical Magnitude on Perception and Motor Reproduction of Time. *16th Annual Cognitive Neuroscience Society Meeting*.

Current Ongoing Projects

- **Developing No-Report Paradigms for Objective Agency Measurement**
  - Focus: Creating and validating objective, no-report paradigms for studying the sense of agency, applicable to humans, non-human primates, and AI systems.
  - Goals: Develop novel behavioral tasks and objective physiological measures (eye-tracking, EEG) to reliably index implicit sense of agency, enabling comparative agency science across diverse systems.
    #consciousness #sense of agency #computational neuroscience #artificial intelligence
- **Emergence of Agency in Model-Based Artificial Agents**
  - Focus: Exploring the emergence of agency-like behavior in model-based AI agents trained with predictive processing and world modeling in simulated environments.
  - Goals: Identify minimal computational conditions for spontaneous agency emergence in AI. Compare emergent behaviors and internal representations of AI agents with biological agency mechanisms.
    #consciousness #sense of agency #artificial intelligence
- **Formalizing Sense of Agency with Information Theory and Active Causal Inference**
  - Focus: Creating a formal, information-theoretic framework to quantify the sense of agency, grounded in active causal inference.
  - Goals: Mathematically define agency as the capacity for active causal inference. Formalize behavioral signatures of active causal inference using information-theoretic measures. Develop objective, broadly applicable measures of the sense of agency, including for AI systems.
    #consciousness #sense of agency #information theory
- **NTIC-Driven Intrinsic Motivation for Robust and Adaptable AI**
  - Focus: Investigating Non-Trivial Information Closure (NTIC) as a novel intrinsic motivation for artificial intelligence.
  - Goals: Empirically evaluate NTIC as a driver of intelligent behavior in AI agents. Design and train AI agents to maximize NTIC as their intrinsic reward and analyze emergent properties like robustness, adaptability, and agency.
    #artificial intelligence #information theory
- **Quantifying Community Membership with Negative Co-information Metric**
  - Focus: Developing and validating negative co-information as a quantitative measure for identifying and assessing community membership within complex systems.
  - Goals: Develop a novel metric based on negative co-information to quantify community membership by identifying subsets of a system that exhibit non-trivial informational closure (NTIC) and active integration with other parts of the system; theoretically validate this metric's effectiveness in capturing community structure and integration.
    #collective system #information theory
- **Unified Theory of Intelligence: Working Memory, In-Context Learning & Universal Computation**
  - Focus: Exploring the theoretical convergence of working memory, in-context learning in LLMs, and the Universal Turing Machine, seeking shared computational foundations.
  - Goals: Develop a unified computational intelligence theory based on homoiconicity, formalizing the working memory/in-context learning/universal Turing machine analogy. Systematically compare these systems to

identify shared mechanisms and implications for understanding intelligence.
#artificial intelligence #deep learning

- **Addressing the Locality Problem of Consciousness with PID**
  - Focus: Investigating the "locality problem" of consciousness, specifically how unified conscious experience arises from distributed neural processing, while considering the locality of neural interactions.
  - Goals: Develop a novel extension of Information Closure Theory using Partial Information Decomposition (PID) to mathematically explain how unique and synergistic information dynamics contribute to unified and simultaneous conscious experience. Create a rigorous mathematical account of the integration and locality problem.
    #consciousness #information theory #consciousness theory

Current Collaboration Projects

- **Cerebellar-Enhanced Brain-Computer Interface for Speech Decoding**
  - Collaborator: **Chin-Hsuan Sophie Lin M.D. PhD**, University of Melbourne, Australia
  - Focus: Innovative Brain-Computer Interface (BCI) system development using wearable MEG technology and Large Language Models.
    #computational neuroscience #artificial intelligence #machine learning
- **Sense of Agency from Active Causal Inference**
  - Collaborator: **Prof. Wen Wen**, University of Tokyo and Rikkyo University, Japan
  - Focus: Neural and computational mechanisms underlying the sense of agency, emphasizing active causal inference.
    #sense of agency #computational neuroscience #deep learning
- **Multi-Agent Systems for Collective Reward Optimization**
  - Collaborator: **Dr. Sangati Ekaterina**, RIKEN, Japan
  - Focus: Design and analysis of multi-agent systems optimizing collective reward and credit assignment in complex environments.
    #collective system #artificial intelligence
- **Football Team Dynamics as a Model for Emergent Collective Behavior**
  - Collaborator: Prof. Kenji Doya, Okinawa Institute of Science and Technology (OIST), Japan
  - Focus: Analysis of emergent collective behavior in football teams using tracking data and information-theoretic approaches.
    #collective system #information theory
- **Information Closure and Emergence in ants' collective behavior**
  - Collaborator: **Prof. Takashi Ikegami**, University of Tokyo, Japan
  - Focus: Investigate and understand ants' aggregation collective behavior through information-theoretical approaches.
    #collective system #information theory