BMI 871 Computational Brain-Mind

A Distance Learning Course

July 20 - August 7, 2015

http://www.brain-mind-institute.org/

Brain-Mind Institute (BMI) — Available via Internet

This course introduces computational principles of biological brain, which give rise to the various functions of mind. An emphasis is on regarding the brain as a highly integrated developmental system so that the models and principles are applicable to small biological brains (e.g., fruit flies), large biological brains (e.g., humans), and artificial ones (e.g., machines and robots). The material integrates knowledge in computer science, neuroscience, psychology (also cognitive science), biology, electrical engineering, physics, mathematics, and other related disciplines. The course is suited for faculty, senior researchers, postdocs, and graduate students in any discipline — natural sciences, engineering, and social sciences — who are interested in studying how the brain-mind works. The subjects include: Computational development of biological brains. Machine's symbolic representations. Brain's emergent representations and architectures. Brains as emergent Turing Machines. Brain's spatial representations. Brain's temporal representations. Perception, cognition, attention (bottom-up and top-down), learning, behaviors, abstraction, reasoning, decision making. Vision, audition, touch, multimodality, and integration. Modulatory system: reinforcement, motivation and emotion. The above subjects are detailed down to neuronal computation, cutting across levels of molecules, synapses, cells, circuits, systems, brains, experience, functions, and group intelligence.

Examples of fundamental discipline questions to be discussed:

Biology: How do individually autonomous cells interact to give rise to animal behaviors?

Neuroscience: From an overarching perspective, how does the brain self-organize?

Psychology: How does an integrated brain architecture realize many psychological learning models (e.g., classical conditioning and instrumental conditioning)?

Computer Science: Why is the automata theory (e.g. Turing Machine) a special case of the brain's neural network theory?

Electrical Engineering: How does a brain perform general-purpose nonlinear control, beyond Kalman filtering?

Mathematics: How does a brain perform general-purpose high-dimensional, nonlinear optimization?

Physics: How do meanings arise from physics?

Lectures: A 3-week distance learning course.

Files: The access information for the course files is from the instructor.

Instructor: Juyang (John) Weng

Course web: `http://www.brain-mind-institute.org/bmi-871.html`

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Prerequisites: Knowledge comparable to that taught in the following courses is necessary for understanding the necessity and rationale of the material to be taught.

1. BMI 811 Biology for Brain-Mind Research
2. BMI 821 Neuroscience for Brain-Mind Research
3. BMI 831 Psychology for Brain-Mind Research
4. BMI 841 Mathematics for Brain-Mind Research
5. BMI 851 Electrical Engineering for Brain-Mind Research
6. BMI 861 Brain-Automata

Physical science and social science applicants are all encouraged. Those who have not learned the automata theory are encouraged to take BMI 861. However, this course is self-contained for exams.

Text: J. Weng, *Natural and Artificial Intelligence: Introduction to Computational Brain-Mind*, BMI Press, 2012. ISBN: 978-0-9858757-2-5. Available at Amazon and the web site of the BMI Press.

Homework: There will be homework assignments from the problems in the text book. Homework is due but not graded. It is recommended for understanding the course material and useful for exams.

Quizzes: Quizzes are short multiple-choice problems to be completed during live lectures from which the video files were taken.

Exams: Three exams, one for each week.

Grading: Three exams equally weighted, each counted as 100%/3. Homework is not counted for the total score. Pass: the total score is 60% or above. Those who successfully pass will receive a BMI 871 Certificate.

Topics: The planned topics are

1. Muddiness of tasks: Who understands a task, the human programmer, the genome or the agent?
2. Brain-mind representations: symbolic models and emergent models
3. Human brain and mental development, skull open vs. skull closed
4. Animal learning theories and models
5. Brain-mind architectures, the dorsal and ventral streams and their motor causality
6. Supervised, reinforcement, and communicative learning
7. Brain areas: emergent features, working memory and long-term memory
8. Brain's spatial processing: object, background, and attention (bottom-up and top-down)

9. Brain's temporal processing: automata and spatiotemporal attention for events
10. Behaviors: concept learning, natural languages, limb manipulation
11. Modulatory system: punishment, reward, novelty, uncertainty, confidence, emotion
12. Multimodal integration through development, including vision, audition, touch
13. Skill development, skill transfers, and generalization
14. Multi-agent societies, governments, science of management, religion, and laws
15. Examples of early experimental developmental systems
16. Applications, impacts and future directions

Time Schedule

- Week 1, Day 1, Monday: Chapter 1 Agents and Tasks
- Week 1, Day 2, Tuesday: Chapter 2 Representation and Search
- Week 1, Day 3, Wednesday: Chapter 3 Autonomous Development
- Week 1, Day 4, Thursday: Chapter 4 Neurons and Features (I)
- Week 1, Day 5, Friday: Chapter 4 Neurons and Features (II)
- Week 2, Day 1, Monday: Chapter 5 Properties of Representation
- Week 2, Day 2, Tuesday: Chapter 6 Brain-Mind Architecture
- Week 2, Day 3, Wednesday: Chapter 7 Spatial Processing (I)
- Week 2, Day 4, Thursday: Chapter 7 Spatial Processing (II)
- Week 2, Day 5, Friday: Chapter 8 Temporal Processing
- Week 3, Day 1, Monday: Chapter 9 Modulation (I)
- Week 3, Day 2, Tuesday: Chapter 9 Modulation (II)
- Week 3, Day 3, Wednesday4: Chapter 10 Generalization (I)
- Week 3, Day 4, Thursday: Chapter 10 Generalization (II)
- Week 3, Day 5, Friday: Chapter 11 Group Intelligence

Supplemental readings that provide background knowledge

1. M. F. Bear, B. W. Connors, and M. A. Paradiso, *Neuroscience: Exploring the Brain*, 3rd edition, Lippincott Williams & Wilkins, Baltimoore, 2007.

2. J. B. Reece, L. A. Urry, M. L. Cain, S. A. Wasserman, P. V. Minorsky, and R. B. Jackson, *Campbell Biology*, 9th edition, Benjamin Cummings Publishers, San Francisco, 2011.

3. P. S. Churchland and T. J. Sejnowsky, *The Computational Brain*, The MIT Press, Cambridge, MA, 1996.

4. M. Cole, S. R. Cole and C. Lightfoot *The Development of Children,* Freeman, New York, 2004.

5. P. Dayan, L. F. Abbott, *Theoretical Neuroscience*, Taylor & Francis, New York, NY, 2001.

6. M. Domjan, *The Principles of Learning and Behavior: Active learning edition*, Thomson/Wadsworth, Belmont, CA, 2006

7. J. L. Elman and E. A. Bates and M. H. Johnson and A. Karmiloff-Smith and D. Parisi and K. Plunkett, *Rethinking Innateness: A Connectionist Perspective on Development*, MIT Press, Cambridge, MA, 1996.

8. J. Martin, *Introduction to Languages and the Theory of Computation*, 3rd edition, McGraw-Hill, New York, 2007.

9. E. R. Kandel and J. H. Schwartz and T. M. Jessell, *Principles of Neural Science*, 4th edition, McGraw-Hill, New York, NY, 2000.

10. W. K. Purves, D. Sadava, G. H. Orians and H. C. Heller, *Life: The Science of Biology,* 7th edition, Sinauer, Sunderland, MA, 2004.

11. K. Richardson, *Models of Cognitive Development*, Psychology Press, East Sussex, UK, 1998.

12. T. R. Shultz, *Computational Developmental Psychology*, MIT Press, Cambridge, MA, 2003.