Computational foundations of mind, evolution, and society*

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Abstract

This two-part course focuses on the key insight into the nature of mind and society — namely, that minds and their social dynamics are fundamentally computational processes and can only be ultimately understood as such.

1 Part I: Computing the mind

The first, foundational part of the course states, motivates, and supports the idea that cognition (in all its aspects, including emotions, consciousness, etc.) reduces to computation [Edelman, 2008, 2012]. Students are introduced to a number of conceptual tools for thinking about natural behavior and the cognitive information processing that underlies it, including statistical learning from experience and the use of patterns distilled from past experience in guiding future actions. The application of these tools to the understanding of natural minds and to advancing the goals of artificial intelligence (AI) is illustrated on selected examples drawn from the domains of perception, memory, language, problem solving, decision making, reasoning, intelligence, and creativity. The material is conceptually advanced and moderately technical. It is based on readings drawn from a **textbook** that has been written by the instructor especially for his course at Cornell: *Computing the Mind: How the Mind Really Works* (Oxford University Press, 2008).

1.1 Key information

- The **prerequisite** for this part of the course is prior exposure to basic science and to working with data (statistics). Reading comprehension and speaking fluency in English is an absolute requirement.
- The course will be taught over a period of 6 weeks, 5 days/week, in 1.5-hour units, for a total of 45 hours (see separate detailed schedule).[1]

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[1]For reference purposes, a standard 14-week version of this course as it has been taught at Cornell University — Psych 3140/6140 Computational Psychology — can be found here.

- The required **readings** for each unit are drawn from the textbook (the list appears in the next section). To best prepare for this course, read it ahead of time, then reread each section before the corresponding material is discussed in class.

1.2 The units

The material is divided into 20 units. Following is the list of unit topics, along with the textbook sections that you must read for each unit:

1. The subject matter of psychology. The fundamentality of computation. [1.1–1.3]
2. The blind men and the elephant. [2.1–2.5]
3. The Marr-Poggio research program and methodology. [4.1-4.3]
4. Perception I: representation spaces. [5.1, 5.2]
5. Probability and the Bayes Theorem. [A.1]
6. Perception II: constancies, learning and generalization. [5.3, 5.4]
7. Perception III: perceptual truth. [5.5]
8. Managing action; motor control. [6.3, 8.4]
9. Action and reward; reinforcement learning. []
10. Language I. [7.1]
11. Language II. [7.2, 7.3]
12. Language III. [7.5]
13. Graphical models; reasoning. [8.3]
14. Induction, general intelligence, and IQ. [8.5]
15. Problem solving I. [8.2]
16. Problem solving II. Analogy, and creativity. [8.5]
17. Neural computation I: tuning. [3.1]
18. Neural computation II: assemblies and readout.
19. Neural computation II: learning, timing, dynamics. [3.3]
20. Brains vs. computers: a perspective on AI.

2 Part II: Computing societies

The second part of the course focuses on the role of computational simulation in two disciplines — evolutionary science and sociology — which are both uniquely important to the understanding of the world we live in, and at the same time uniquely difficult to study by the traditional scientific method, which tries to derive mathematical models from experimental data. In both these domains of study, scientists often resort to simulation, using an agent-based modeling (ABM) approach. In evolutionary ABM, simulated actors (agents) carrying various traits of interest share an environment in which they undertake actions and compete for resources. The agent's cumulative outcomes determine its fitness, which in turn affects its chances for reproduction. The effectiveness of traits can then be assessed by tracking their prevalence in the population over evolutionary time. Similarly, in computational social science, the ABM approach involves simulated agents with controlled cognitive abilities, "personalities," and interpersonal attitudes. The social dynamics that arises out of the agents' interactions is then analyzed and used to support theory development.

2.1 Key information

- As with Part I, reading comprehension and speaking fluency in English is an absolute requirement. Furthermore, the key **prerequisite** for this part of the course is an ability to write code, in any programming language. **If you cannot program, you will not be able to complete a project and should not take this course**. We will use the Python programming environment, which can be easily mastered by anyone with prior experience in Java, Scheme, or any other popular language. Playing with Python before the course starts will make it easier for you to keep up with the material (see https://mesa.readthedocs.io/en/master/).
- The course will be taught over a period of 4 weeks, 5 days/week, in 1.5-hour units, for a total of 45 hours (see separate detailed schedule).
- The required **readings** are academic papers, which will be made available in PDF format, as a zipped archive. You should try to read each paper *before* its assigned date, but please note that the papers will be thoroughly explained and discussed in class.
- The **final project**, due on the last day of class, will consist of a summary paper and a presentation of the ABM simulation, which you will develop during the course. **Note:** group projects (2-3 students per group) will be acceptable.

2.2 The units

The material is divided into 20 units. Following is the list of unit topics, along with the paper(a) that you must read for each unit:

1. General introduction. Cognitive psychology, social psychology, and sociology. *Nothing in biology makes sense except in the light of evolution* [Dobzhansky, 1973]. The multilevel nature of explanation in "special" sciences:
    - *Cause and effect in biology* [Mayr, 1961].
    - *On aims and methods in ethology* [Tinbergen, 1963].
    - *From understanding computation to understanding neural circuitry* [Marr and Poggio, 1977].

2. In-depth discussion: *The extended evolutionary synthesis: its structure, assumptions and predictions* [Laland, Uller, Feldman, Sterelny, Müller, Moczek, Jablonka, and Odling-Smee, 2015]; *Tinbergen's four questions: an appreciation and an update* [Bateson and Laland, 2013].

3. A view from cognitive and social psychology: *Computational models of collective behavior* [Goldstone and Janssen, 2005].

4. A view from sociology: *From factors to actors: computational sociology and agent-based modeling* [Macy and Willer, 2002].

5. Intro to ABM:

   - *A guide for newcomers to agent-based modeling in the social sciences* [Axelrod and Tesfatsion, 2006].
   - *Pattern-oriented modeling of agent-based complex systems: lessons from ecology* [Grimm, Revilla, Berger, Jeltsch, Mooij, Railsback, Thulke, Weiner, Wiegand, and DeAngelis, 2005].

6. ABM toolkits:

   - Preferred: Python + Mesa; read https://mesa.readthedocs.io/en/master/
   - Older/simpler: NetLogo [Wilensky, 1999].

7. Case study: happiness. Background reading (book): *The happiness of pursuit* [Edelman, 2012]. Examples:

   - *Agent-based simulations of subjective well-being* [Baggio and Papyrakis, 2014].
   - *Between pleasure and contentment: evolutionary dynamics of some possible parameters of happiness* [Gao and Edelman, 2016a].
   - *Happiness as an intrinsic motivator in reinforcement learning* [Gao and Edelman, 2016b].

8. Case study: inequality.

   - *Inequality in nature and society* [Scheffer, van Bavel, van de Leemput, and van Nes, 2017].
   - *The spread of inequality* [Rogers, Deshpande, and Feldman, 2011].
   - *Computational justice: simulating structural bias and interventions* [Momennejad, Sinclair, and Cikara, 2019].

9. Case study: morality.

   - *Testing the theory of morality-as-cooperation in 60 societies* [Curry, Mullins, and Whitehouse, 2019].
   - *The evolution of political systems* [Gintis, van Schaik, and Boehm, 2015].

10. Morality (cont).

    - *The evolution of altruistic punishment* [Boyd, Gintis, Bowles, and Richerson, 2003, Boyd, Gintis, and Bowles, 2010].
    - *Altruistic punishment and other theories* [Smirnova, 2019].

11. Prepare project proposal.
12. Prepare project proposal.
13. Presentation and discussion of project proposals.
14. Work on project.
15. Work on project.
16. Work on project.
17. Work on project.
18. Work on project.
19. Work on project.
20. Project presentations.

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