# COG260: Data, Computation, and The Mind

Instructor: Yang Xu (yangxu@cs.toronto.edu)

*See Quercus course page for details about session dates, time, and location.*

**Description**

This entry-level course takes an integrated approach to the study of the mind, drawing ideas mainly from cognitive science and computational sciences (e.g., computer science, statistics). Why is this integration important? From a scientific perspective, there has been extensive confluence between the fields of cognitive science and computational sciences over the past decades. For instance, many successful approaches to artificial intelligence have been inspired by discoveries about cognition, while models of cognition have benefited from formalisms and tools in computational sciences. Understanding this confluence requires the development of computational thinking, the abililty to formulate, analyze, and model cognition with computational tools. From a practical perspective, the rise of "big data" has made it imperative for students in cognitive science and related disciplines to acquire experiences and skills in data analysis and modeling through quantitative and computational means.

A common theme we will discuss in this course concerns *uncertainty*. We will explore how uncertainty might arise and pertain to cognitive functions such as number cognition, object recognition, categorization, communication, and judgment making. In doing so, we will also discuss methods for handling uncertainty drawn from exploratory data analysis, probability theory, statistics, and machine learning.

This course will involve a combination of lectures, labs, topic research, and a project. Each lecture will typically cover one topic of relevance to cognition. Each lab session will typically involve the analysis of a cognitive dataset, along with discussion of relevant computational concepts and methods. Students will also conduct topic research and participate in a course project where they formulate and test their own hypotheses based on a cognitive dataset. There will be no written exam in this course.

**Prerequisite** CSC108 (alternatively, CSC110 or CSC120); **Corequisite** COG250.

**Objectives**

1. Understand the role and treatment of uncertainty in different cognitive domains.
2. Acquire basic knowledge and skills for formulating and analyzing problems computationally.
3. Gain practical experiences in exploratory data analysis and scientific communication.

**Textbook**

We will read a combination of published papers and book chapters. We will use *Stats* as a reference textbook for elementary statistics and data analytics: De Veaux, R. D., Velleman, P. F., & Bock, D. E. (2012) *Stats: Data and models, 3rd edition*. Pearson. In addition, we will use the reference booklet *An introduction to Python for data science applications* (Salas, 2016) for programming and data analysis with Python, particularly Python Jupyter Notebook.

**Deliverables and Assessments**

Python Notebooks for the labs and the project write-ups should be submitted via Quercus. Required readings should be attempted after the lectures and some will be assessed through the labs. Reading materials, data, starter Python Notebooks, and submission links for the labs and the project will be posted on Quercus.

| | |
|---|---|
| Labs 1-5 | 55% |
| Topic research | 15% |
| Project proposal | 10% |
| Project presentation | 5% |
| Project report | 15% |

**Grading Scale**

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|---|---|---|---|---|---|---|---|
| 90 - 100% | A+ | 77 - 79% | B+ | 67 - 69% | C+ | 57 - 59% | D+ |
| 85 - 89% | A | 73 - 76% | B | 63 - 66% | C | 53 - 56% | D |
| 80 - 84% | A- | 70 - 72% | B- | 60 - 62% | C- | 50 - 52% | D- |
| | | | | | | 0 - 49% | Fail |

**Policies and guidelines**

- The use of artificial intelligence tools such as large language models or ChatGPT for solving problems in labs, producing code for the projects, and writing essays or reports, is not permitted. However, such tools may be used to facilitate learning and background research.
- Plagiarism is strictly prohibited and any such case if identified will be reported according to the university guidelines (see http://www.governingcouncil.utoronto.ca/Assets/Governing+Council+Digital+Assets/Policies/PDF/ppjun011995.pdf).
- Class presentations are expected from every student. Project reporting styles may follow the guidelines provided at http://advice.writing.utoronto.ca/types-of-writing/lab-report/.


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- Late assignments will be discredited at 1 point per delayed hour based on the submission time. Delays should be explained in writing at least 2 days prior to the due date.

**Schedule and readings (subject to minor adjustment as the course progresses)**

- **Session 1** Introduction + Jupyter Notebook

  Required reading (post-session):

  – Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63(2), 81–97.

  *Optional readings (consider these as supplementary materials only):*

  – Chomsky, N. (1956). Three models for the description of language. *IRE Transactions on Information Theory*, 2(3), 113–124.

  – Newell, A., Shaw, J. C., and Simon, H. A. (1958). Elements of a theory of human problem solving. *Psychological Review*, 65(3), 151–166.

  – Chomsky, N. (1959). Review of B. F. Skinner, *Verbal Behavior*. *Language*, 35(1), 26–58.

  – Miller, G. A. (2003). The cognitive revolution: A historical perspective. *Trends in Cognitive Sciences*, 7(3), 141–144.

- **Session 2** Number cognition + Lab 1

  Required reading:

  – Pica, P., Lemer, C., Izard, V., and Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigene group. *Science*, 306(5695), 499–503.

  Technical reference:

  – Chapters 1-3 in *Stats*.

  *Optional readings:*

  – Wynn, K. (1998). Psychological foundations of number: Numerical competence in human infants. *Trends in Cognitive Sciences*, 2(8), 296–303.

  – Feigenson, L., Dehaene, S., and Spelke, E. (2004). Core systems of number. *Trends in Cognitive Sciences*, 8(7), 307–314.

  – Izard, V., and Dehaene, S. (2008). Calibrating the mental number line. *Cognition*, 106(3), 1221–1247.

  – Göbel, S. M., Shaki, S., and Fischer, M. H. (2011). The cultural number line: A review of cultural and linguistic influences on the development of number processing. *Journal of Cross-Cultural Psychology*, 42(4), 543–565.

  – Leibovich, T., Katzin, N., Harel, M., and Henik, A. (2017). From "sense of number" to "sense of magnitude": The role of continuous magnitudes in numerical cognition. *Behavioral and Brain Sciences*, 40, e164.


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- **Session 3** Object recognition + Lab 2

  Required reading:

  – Shepard, R. N., and Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171(3972), 701–703.

  Technical reference:

  – Chapter 4 in *Stats*.

  *Optional readings:*

  – Marr, D. and Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, 200(1140), 269–294.

  – Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, 94(2), 115–147.

  – Riesenhuber, M., and Poggio, T. (1999). Hierarchical models of object recognition in cortex. *Nature Neuroscience*, 2(11), 1019–1025.

  – Bar, M. (2004). Visual objects in context. *Nature Reviews Neuroscience*, 5(8), 617–629.

  – Peissig, J. J. and Tarr, M. J. (2007). Visual object recognition: Do we know more now than we did 20 years ago?. *Annual Review of Psychology*, 58(1), 75–96.

  – Krizhevsky, A., Sutskever, I., and Hinton, G. E. (2012). Imagenet classification with deep convolutional neural networks. In *Advances in Neural Information Processing Systems*, 25.

- **Session 4** Category + Lab 3

  Required reading:

  – Eleanor, R. (1978) Principles of Categorization, in Rosch, E. and Lloyd, B. B. (eds), *Cognition and Categorization*. Lawrence Erlbaum, 27–48.

  Technical reference:

  – Chapter 7 in *Stats*.

  *Optional readings:*

  – Rosch, E. (1975). Cognitive representations of semantic categories. Journal of Experimental Psychology: General, 104(3), 192–233.

  – Rosch, E., & Mervis, C. B. (1975). Family resemblances: Studies in the internal structure of categories. Cognitive Psychology, 7(4), 573–605.

  – Tversky, A. (1977). Features of similarity. *Psychological Review*, 84(4), 327–352.

  – Shepard, R. N. (1980). Multidimensional scaling, tree-fitting, and clustering. *Science*, 210(4468), 390–398.

  – Medin, D. L., Goldstone, R. L. and Gentner, D. (1993). Respects for similarity. *Psychological Review*, 100(2), 254–278.


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– Tenenbaum, J. B., & Griffiths, T. L. (2001). Generalization, similarity, and Bayesian inference. *Behavioral and Brain Sciences*, 24(4), 629–640.

- **Session 5** Categorization + Lab 4

  Required reading:

  – Goldstone, R. L., Kersten, A., & Carvalho, P. F. (2003). Concepts and categorization. In Healy, A.F. and Proctor, R.W. (eds), *Comprehensive handbook of psychology, Volume 4: Experimental psychology*. Wiley, 599–621.

  *Optional readings:*

  – Reed, S. K. (1972). Pattern recognition and categorization. Cognitive Psychology, 3, 382–407.

  – Rosch, E. (1973). Natural categories. *Cognitive Psychology*, 4(3), 328–350.

  – Medin, D. L., and Smith, E. E. (1984). Concepts and concept formation. *Annual Review of Psychology*, 35(1), 113–138.

  – Nosofsky, R. M. (1986). Attention, similarity, and the identification-categorization relationship. *Journal of Experimental Psychology: General*, 115(1), 39–57.

  – Anderson, J. R. (1991). The adaptive nature of human categorization. *Psychological review*, 98(3), 409–429.

  – Roads, B. D. and Love, B. C. (2024). Modeling similarity and psychological space. *Annual Review of Psychology*, 75(1), 215–240.

- **Session 6** Words + Lab 5 + Guidelines for topic research

  Required reading:

  – Chapter 2 in Zipf, G. K. (1949). *Human behavior and the principle of least effort*. Addison-Wesley Press.

  Technical reference:

  – Nichols, T. E., and Holmes, A. P. (2001). Nonparametric permutation tests for functional neuroimaging: A primer with examples. *Human Brain Mapping*, 15(1), 1–25.

  *Optional readings:*

  – Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27, 379—423 and 623—656.

  – Brown, R. (1958). How shall a thing be called? *Psychological Review*, 65(1), 14–21.

  – Hockett, C. F. (1960). The origin of speech. *Scientific American*, 203(3), 88–97.

  – Piantadosi, S. T. (2014). Zipf's word frequency law in natural language: A critical review and future directions. *Psychonomic Bulletin & Review*, 21, 1112–1130.


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- Pleyer, M., Perlman, M., Lupyan, G., de Reus, K., and Raviv, L. (2025). The 'design features' of language revisited. *Trends in Cognitive Sciences*, 30(7), 611–631.

- **Session 7** Project description and requirements + Formation of project groups

  Background readings on color naming across languages:

  - Berlin, B., and Kay, P. (1969). *Basic color terms: Their universality and evolution*. University of California Press.
  - Regier, T., Kay, P., and Cook, R. S. (2005). Focal colors are universal after all. *Proceedings of the National Academy of Sciences*, 102(23), 8386–8391.
  - Regier, T., Kay, P., and Khetarpal, N. (2007). Color naming reflects optimal partitions of color space. *Proceedings of the National Academy of Sciences*, 104(4), 1436–1441.
  - Lindsey, D. T., and Brown, A. M. (2009). World Color Survey color naming reveals universal motifs and their within-language diversity. *Proceedings of the National Academy of Sciences*, 106(47), 19785–19790.
  - Abbott, J. T., Griffiths, T. L,., and Regier, T. (2016). Focal colors across languages are representative members of colors categories. *Proceedings of the National Academy of Sciences*, 113(40), 11178-11183.
  - Gibson, E., Futrell, R., Jara-Ettinger, J., Mahowald, K., Bergen, L., Ratnasingam, S., ... and Conway, B. R. (2017). Color naming across languages reflects color use. *Proceedings of the National Academy of Sciences*, 114(40), 10785–10790.
  - Zaslavsky, N., Kemp, C., Regier, T., and Tishby, N. (2018). Efficient compression in color naming and its evolution. *Proceedings of the National Academy of Sciences*, 115(31), 7937–7942.
  - Twomey, C. R., Roberts, G., Brainard, D. H., and Plotkin, J. B. (2021) What we talk about when we talk about colors. *Proceedings of the National Academy of Sciences*, 118(39), e2109237118.

  Background readings on word meaning and colexification across languages:

  - François, A. (2008). Semantic maps and the typology of colexification. From polysemy to semantic change: Towards a typology of lexical semantic associations, 106, 163.
  - Kemp, C., Xu, Y., and Regier, T. (2018). Semantic typology and efficient communication. *Annual Review of Linguistics*, 4, 109–128.
  - Xu, Y., Duong, K., Malt, B.C., Jiang, S., and Srinivasan, M. (2020) Conceptual relations predict colexification across languages. *Cognition*, 201, 104280.
  - Brochhagen, T., and Boleda, G. (2022) When do languages use the same word for different meanings? The Goldilocks principle in colexification. *Cognition*, 226, 105179.

- **Session 8** Spatial language and cognition


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Required reading:

- Majid, A., Bowerman, M., Kita, S., Haun, D. B., and Levinson, S. C. (2004). Can language restructure cognition? The case for space. *Trends in Cognitive Sciences*, 8(3), 108–114.

Optional readings:

- Landau, B. and Jackendoff, R. (1993). "What" and "where" in spatial language and spatial cognition. *Behavioral and Brain Sciences*, 16(2), 217–238.
- Levinson, S. C. (1996). Language and space. *Annual Review of Anthropology*, 25(1), 353–382.
- Bowerman, M. and Choi, S. (2003). Space under construction: Language-specific spatial categorization in first language acquisition. *Language in mind: Advances in the study of language and thought*, 3, 87–427.
- Levinson, S., Meira, S., and The Language and Cognition Group. (2003). 'Natural concepts' in the spatial topological domain-adpositional meanings in crosslinguistic perspective: An exercise in semantic typology. *Language*, 79(3), 485–516.
- Carstensen, A., Xu, J., Smith, C. T., and Regier, T. (2015). Language evolution in the lab tends toward informative communication. In Proceedings of the Annual Meeting of the Cognitive Science Society.

- **Session 9** Diversity and cognition + Student presentation of topic research

Required reading:

- Evans, N. and Levinson, S. C. (2009). The myth of language universals: Language diversity and its importance for cognitive science. *Behavioral and Brain Sciences*, 32(5), 429–448.

*Optional readings:*

- Tomasello, M., Carpenter, M., Call, J., Behne, T., and Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, 28(5), 675–691.
- Henrich, J., Heine, S. J., and Norenzayan, A. (2010). The weirdest people in the world?. *Behavioral and Brain Sciences*, 33, 61–83.
- Blasi, D. E., Henrich, J., Adamou, E., Kemmerer, D., and Majid, A. (2022). Over-reliance on English hinders cognitive science. *Trends in Cognitive Sciences*, 26(12), 1153–1170.
- Blasi, D. E., Hamilton, M. J., Gray, R. D., and Bowern, C. L. (2026). The rise and fall of language diversity through the Holocene. *Science*, 393(6809), 387-391.

- **Session 10** Cognitive bias

Required reading:

- Tversky, A., and Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185(4157), 1124–1131.


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Optional readings:

- Bertrand, M. and Mullainathan, S. (2004). Are Emily and Greg more employable than Lakisha and Jamal? A field experiment on labor market discrimination. *American Economic Review*, 94(4), 991–1013.
- Chater, N., Oaksford, M., Hahn, U., and Heit, E. (2010). Bayesian models of cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, 1(6), 811–823.
- Haselton, M. G., Nettle, D., and Andrews, P. W. (2015). The evolution of cognitive bias. In *The handbook of evolutionary psychology*, 724–746.

- **Session 11** Summary + Guidelines for project presentation and report writing

  *Optional readings:*

  - Newell, A. (1973). You can't play 20 questions with nature and win: Projective comments on the papers of this symposium. In *Visual information processing: Proceedings of the eighth annual Carnegie symposium on cognition*, 283–305.
  - Binz, M., Akata, E., Bethge, M., Brändle, F., Callaway, F., Coda-Forno, J., ..., and Schulz, E. (2025). A foundation model to predict and capture human cognition. *Nature*, 644(8078), 1002–1009.

- **Session 12** Student project presentation


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