Independent Study Fall 2024: Pathways to Mathematical Systems Theory

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1 Objective

This three credit independent study course is designed to expose students to fundamental concepts in mathematical systems theory. The primary objective is to help students develop basic competence with the language and notation of discrete mathematics so that they can comfortably engage with classical and modern mathematical systems research grounded in discrete math. Students and the teacher will discuss papers on a weekly basis with a focus on comparing and contrasting ideas between readings, raising critiques, and determining which concepts and methods are most applicable to the student's general research objectives and Master's thesis.

2 Foundations

This section will focus on evaluating historical and modern approaches to mathematical systems theory. Students will develop a basic level of familiarity and comfort with with the ideas of classical mathematical systems theorists so that they are well-positioned to critically assess their merits and relevance for the student's own research.

Readings and discussions will focus on foundational questions such as:

How are general systems defined in mathematical terms? Are systems real, or constructions of the human mind? What are mathematical models, and why do humans create them? What are the unique benefits and limitations of classical mathematical systems theoretical approaches in modern systems science?

- Klir, G. J. (2001). Facets of Systems Science. (Ch.2) [1]

- Sayama, H. (2015). Introduction to the Modeling and Analysis of Complex Systems. (Ch. 2) [2]
- Zwick, M. (2023). Elements and Relations: Aspects of a Scientific Metaphysics (pp. 43-78, 123-141) [3]
- Joslyn, C. (1995). Semantic control systems [4]
- Bunge, M. (1979). Treatise on Basic Philosophy. Ontology II: A World of Systems (pp. 1-26) [5]
- Mobus, G. E., & Kalton, M. C. (2015). Systems Modeling. (pp. 645-660) [6]
- Drack, M., & Pouvreau, D. (2015). On the history of Ludwig von Bertalanffy's "General Systemology", and on its relationship to cybernetics – part III: Convergences and divergences. [7]

3 Applications

This section will shift the focus from foundational considerations and towards research applications. Students will develop sufficient comfort with the mathematical notation used in the readings to enable them to confidently assess and discuss the approaches, methodologies, and results.

Readings and discussions will focus on questions such as:

What makes mathematical approaches to systems science so effective? How does using the language of discrete mathematics benefit systems researchers? What sort of problems does the student want to address in their research, and which mathematical approaches and tools might be best suited to accomplish their goals?

- Joslyn, C. A. et al. (2020) Hypernetwork Science: From Multidimensional Networks to Computational Topology. [8]
- Joslyn, C. A. et al.(2017). Exchange Pattern Mining in the Bitcoin Transaction Directed Hypergraph. [9]
- Tasca, P., Liu, S., & Hayes, A. (2016). The Evolution of the Bitcoin Economy: Extracting and Analyzing the Network of Payment Relationships [10]
- Mobus, G.E. (2022). A Model of System and a Language to Represent It. (pp.188-211) [11]
- Mobus, G. E. (2022). The Process of Deep Systems Analysis. (pp. 249–261) [12]

4 Category Theory

This section will introduce a few basic concepts in category theory along with examples of applied research and explore how they relate to modern systems science.

Readings and discussions will focus on questions such as:

What is the relationship between the theories of sets, graphs, and categories? How can adopting category theoretical methods support the work of systems scientists? What challenges might arise when trying to adopt category theoretical methods?

- Cheng, E. (2022). The Joy of Abstraction. (Ch.8) [13]
- Lennox, J. B. (2024). Robert Rosen and Relational System Theory (pp. 1-38) [14]
- Zargham, M., & Shorish, J. (2023). Block Diagrams for Categorical Cybernetics [15]

5 Evaluation

To demonstrate understanding of material, students will:

- Engage in weekly discussions with the instructor.
- Submit a final report that places readings covered throughout the course into context. Students are expected to review and and reflect on what was useful, present their critiques, and to summarize and contextualize the significance of covered readings for their future progress

6 Supplemental Resources: Foundational Discrete Mathematics

The following textbooks will serve to aid students in their efforts to develop comfort with fundamental concepts of discrete math relevant for core methods in mathematical systems theory.

- Yeh, R., & Preparata, F. (1973). Introduction to Discrete Structures for Computer Science and Engineering. [16]
- Lipschutz, S. (1998). Schaum's Outline of Set Theory and Related Topics. [17]
- Strom, J., Astrom, K., & Akenine-Moller, T. (2020). Immersive Linear Algebra. [18]

The following Youtube video playlists provide additional coverage of fundamental concepts in discrete math.

- Block, T. (2024). Discrete Math (Sets, Logic, Proofs, Relations, Counting, Number Theory, Functions). [19]
- Block, T. (2015). Linear Algebra. [20]

Resources focused on exploring basic topics in discrete math using the Python programming language will serve to aid the student in using computational approaches to explore concepts covered in the course.

- Pinzon, K., & Roberts, J. (2024). Discrete Math. [21]
- Pinzon, K. (2023). Discrete Math with Python. [22]
- Raghuvanshi, Y., Mishra, Dr. D., & Dumka, P. (2022). Understanding Sets with the help of Python. [23]

References

[1] George J. Klir. *Facets of Systems Science*. Springer US, Boston, MA, 2001. ISBN 978-1-4613-5501-4 978-1-4615-1331-5. doi: 10.1007/978-1-4615-1331-5. URL `http://link.springer.com/10.1007/978-1-4615-1331-5`.

[2] Introduction to the Modeling and Analysis of Complex Systems, 2015. URL `https://open.umn.edu/opentextbooks/textbooks/233`. ISBN: 9781942341093.

[3] Martin Zwick. *Elements and Relations: Aspects of a Scientific Metaphysics*, volume 35 of *IFSR International Series in Systems Science and Systems Engineering*. Springer International Publishing, Cham, 2023. ISBN 978-3-030-99402-0 978-3-030-99403-7. doi: 10.1007/978-3-030-99403-7. URL `https://link.springer.com/10.1007/978-3-030-99403-7`.

[4] Cliff Joslyn. Semantic control systems. *World Futures*, 45(1-4):87–123, December 1995. ISSN 0260-4027, 1556-1844. doi: 10.1080/02604027.1995.9972555. URL `http://www.tandfonline.com/doi/full/10.1080/02604027.1995.9972555`.

[5] Mario Bunge. *Treatise on Basic Philosophy*. Springer Netherlands, Dordrecht, 1979. ISBN 978-90-277-0945-5 978-94-009-9392-1. doi: 10.1007/978-94-009-9392-1. URL `http://link.springer.com/10.1007/978-94-009-9392-1`.

[6] George E. Mobus and Michael C. Kalton. Systems Modeling. In George E. Mobus and Michael C. Kalton, editors, *Principles of Systems Science*,

pages 645–698. Springer, New York, NY, 2015. ISBN 978-1-4939-1920-8. doi: 10.1007/978-1-4939-1920-8_13. URL https://doi.org/10.1007/978-1-4939-1920-8_13.

[7] Manfred Drack and David Pouvreau. On the history of Ludwig von Bertalanffy's "General Systemology", and on its relationship to cybernetics – part III: convergences and divergences. *International Journal of General Systems*, 44(5):523–571, July 2015. ISSN 0308-1079. doi: 10.1080/03081079.2014.1000642. URL https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4610108/.

[8] Cliff A. Joslyn, Emilie Purvine, et al. Hypernetwork Science: From Multidimensional Networks to Computational Topology. In *Unifying Themes in Complex Systems X*, pages 377–392. Springer International Publishing, Cham, 2021. ISBN 978-3-030-67317-8 978-3-030-67318-5. doi: 10.1007/978-3-030-67318-5_25. URL https://link.springer.com/10.1007/978-3-030-67318-5_25. Series Title: Springer Proceedings in Complexity.

[9] Cliff A. Joslyn et al. Exchange Pattern Mining in the Bitcoin Transaction Directed Hypergraph. In Michael Brenner, Kurt Rohloff, Joseph Bonneau, Andrew Miller, Peter Y.A. Ryan, Vanessa Teague, Andrea Bracciali, Massimiliano Sala, Federico Pintore, and Markus Jakobsson, editors, *Financial Cryptography and Data Security*, volume 10323, pages 248–263. Springer International Publishing, Cham, 2017. ISBN 978-3-319-70277-3 978-3-319-70278-0. doi: 10.1007/978-3-319-70278-0_16. URL http://link.springer.com/10.1007/978-3-319-70278-0_16. Series Title: Lecture Notes in Computer Science.

[10] Paolo Tasca, Shaowen Liu, and Adam Hayes. The Evolution of the Bitcoin Economy: Extracting and Analyzing the Network of Payment Relationships, July 2016. URL https://papers.ssrn.com/abstract=2808762.

[11] George E. Mobus. A Model of System and a Language to Represent It. In George E. Mobus, editor, *Systems Science: Theory, Analysis, Modeling, and Design*, pages 177–225. Springer International Publishing, Cham, 2022. ISBN 978-3-030-93482-8. doi: 10.1007/978-3-030-93482-8_4. URL https://doi.org/10.1007/978-3-030-93482-8_4.

[12] George E. Mobus. The Process of Deep Systems Analysis. In George E. Mobus, editor, *Systems Science: Theory, Analysis, Modeling, and Design*, pages 249–321. Springer International Publishing, Cham, 2022. ISBN 978-3-030-93482-8. doi: 10.1007/978-3-030-93482-8_6. URL https://doi.org/10.1007/978-3-030-93482-8_6.

[13] Eugenia Cheng. The Joy of Abstraction. URL https://www.cambridge.org/core/books/joy-of-abstraction/00D9AFD3046A406CB85D1AFF5450E657.

[14] James Bryan Lennox. *Robert Rosen and Relational System Theory: An Overview*, volume 8 of *Anticipation Science*. Springer Nature Switzerland, Cham, 2024. ISBN 978-3-031-51115-8 978-3-031-51116-5. doi: 10.1007/978-3-031-51116-5. URL https://link.springer.com/10.1007/978-3-031-51116-5.

[15] Michael Zargham and Jamsheed Shorish. Block Diagrams for Categorical Cybernetics, April 2023. URL https://papers.ssrn.com/abstract=4569037.

[16] Raymond Yeh and Franco Preparata. Introduction to Discrete Structures for Computer Science and Engineering. *Addison-Wesley Longman Publishing Co., Inc. eBooks*, January 1973. URL https://www.academia.edu/110332183/Introduction_to_Discrete_Structures_for_Computer_Science_and_Engineering.

[17] Seymour Lipschutz. Schaum's Outline of Set Theory and Related Topics. URL https://www.mhprofessional.com/schaum-s-outline-of-set-theory-and-related-topics-9780070381599-usa.

[18] Jacob Strom, Kalle Astrom, and Tomas Akenine-Moller. Immersive Linear Algebra. URL https://immersivemath.com/ila/index.html#.

[19] Trevor Block. Discrete Math (Sets, Logic, Proofs, Relations, Counting, Number Theory, Functions), . URL http://www.youtube.com/playlist?list=PLDDGPdw7e6Ag1EIznZ-m-qXu4XX3A0cIz.

[20] Trevor Block. Linear Algebra, . URL https://www.youtube.com/playlist?list=PLDDGPdw7e6AjJacaEe9awozSaOou-NIx_.

[21] Kathy Pinzon and Joshua Roberts. Discrete Math. URL https://ggc-discrete-math.github.io/.

[22] Kathy Pinzon. Discrete Math with Python. URL https://www.youtube.com/playlist?list=PLAwz5xi38-_GjL8PHWujb2pzM8Ti4wteT.

[23] Yashasvini Raghuvanshi, Dr. Dhananjay Mishra, and Pankaj Dumka. Understanding Sets with the help of Python. 7:136–142, October 2022.