Indian Institute of Technology Kanpur

Department of Cognitive Science

Proposal for a New Course

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1. Course No: **CGS410**
2. Course Title: **Language in the Mind and Machines**
3. Per Week Lectures: **3** (L), Tutorial: **0** (T), Laboratory: **0** (P), Additional Hours[0-2]: **0** (A), Credits (3*L): **09** Duration of Course: **Full Semester**
4. Proposing Department/IDP: **Cognitive Science (CGS)**

   Other Departments/IDPs which may be interested in the proposed course: **All Departments**

   Other faculty members interested in teaching the proposed course:

5. Proposing Instructor(s): **Dr. Himanshu Yadav**

6. Course Description:

A) Objectives

Humans possess an amazingly complex communication system that allows them to transmit any message using a linear stream of auditory/visual symbols in real time. We know this system as language. How did human language evolve? How does it work in the mind? **Language in the Mind and Machines** is an introductory course on the study of language from a cognitive perspective. The course is designed to expose students to fundamental questions in language science, e.g., how language came into existence, how it evolved, and how is it processed in the mind and machines, and provide them with a set of tools and methods to investigate these questions. The students will learn fresh perspectives on language: Language as a complex adaptive system of symbols and Language as a cognitive function. The focus will be on the universals of human language, variation across languages, origin and evolution of language, processing of language in the mind and Large Language Models. The course will attract students from all study backgrounds to take up challenging and interesting problems in the study of language and solve them using novel mathematical and computational techniques. This course will have a considerable focus on regular hands-on assignments which would target interesting open problems in language science and will end with a course project to be done using Python/R. **The course is targeted at all engineering and science disciplines who wish to understand language and solve some outstanding research problems in the study of language and the mind.**

B) Content

(40 Lectures; each of 50 minutes duration)

Sr No.	Broad Topic	Topics	No. of Lectures
Theme I: Language as a complex adaptive system			
1	Language as a system of symbols	(a) Origin of language (b) Form and Function (c) The structure of symbols (d) A topological space of language structures (e) Universals of structures (f) Variation in structures	6
2	The generative engine behind language	(a) *Grammar* (b) The space of structures licensed by *grammar* (c) The *grammar*-granted space vs. the observed space of structures (d) Limitations of a theory of *grammar* (e) What shapes the language beyond *grammar*	5
3	Language evolves in response to cognitive and communicative pressures	(a) Language as a complex adaptive system (b) Cross-linguistic variation in topological space of structures (c) Rarity of certain structures (d) Language adapts to its environment: the communication channel between lan- guage users (e) Which language structures survive? (f) Properties of the communication chan- nel that drives language evolution (g) A new line of inquiry into the origin and evolution of human language	7
Theme II: Language as a cognitive function			
4	Encoding and decoding of language	(a) Language needs encoding and decoding (b) Encoding mechanism in the mind (c) Decoding mechanism in the mind (d) Linguistic illusions (e) Observations about the human syntac- tic parser	5
5	Working memory and language processing	(a) Enter working memory (b) Dependency locality theory (c) Cue-based retrieval theory (d) Limitations of working memory-based theories	4
6	Top-down prediction and language processing	(a) Predictive processing (b) Prediction of upcoming linguistic information (c) Information-theoric models of sentence processing (d) Open questions in sentence processing research	4
Theme III: Language in the transformer-based neural networks			
7	Performance of the large language models	(a) Introduction to LLMs (b) Learning in LLMs vs humans (c) Topological space of structures learned by the LLMs (d) Do LLMs learn *grammar*? (e) Cue-based retrieval and attentional mechanism in LLMs (f) Language, thought, and LLMs	6
8	Language evolution in humans vs machines	(a) Architectural constraints of LLMs vs. human mind (b) Language evolution in a society of LLMs (c) Interpretable AI	3

C) Pre-requisites

Basic programming in Python (loops and conditionals, functions, classes);
High-school mathematics (functions, equations, sets)

D) Short summary for including in the Courses of StudyBooklet:

Language in the Mind and Machines is an introductory course on the study of language designed to provide two fresh perspectives on language: Language as a complex adaptive system and Language as a cognitive function. This course will expose students to fundamental questions in language science including how language originated, how it evolved, and how it is processed in the mind and machines, and provide them with a set of computational and empirical tools to investigate these questions. The content of this course will invite students from all study backgrounds to take up challenging and interesting problems in the study of language and solve them using novel mathemat- ical and computational techniques. This course will have a considerable focus on regular hands-on assignments which will target some interesting open problems and will end with a course project to be done using Python/R.

7. Recommended Books (Reference Books)

[1] Hawkins, John A. *A performance theory of order and constituency.* Cambridge University Press, 1994.

[2] Hawkins, John A. *Efficiency and Complexity in Grammars.* Oxford University Press, USA, 2004.

[3] Vasishth, Shravan, and Felix Engelmann. *Sentence comprehension as a cognitive process: A computational approach.* Cambridge University Press, 2021.

[4] Ferrer i Cancho, Ramon, and Ricard V. Solé. *Least effort and the origins of scaling in human language.* Proceedings of the National Academy of Sciences. 100.3 (2003): 788-791.

[5] Ferrer i Cancho, Ramon. *Euclidean distance between syntactically linked words.* Physical Review. 70.5 (2004): 056135.

[6] Futrell, Richard, Kyle Mahowald, and Edward Gibson. *Large-scale evidence of dependency length minimization in 37 languages.* Proceedings of the National Academy of Sciences 112.33 (2015): 10336-10341.

[7] Hahn, Michael, and Yang Xu. *Crosslinguistic word order variation reflects evolutionary pressures of dependency and information locality.* Proceedings of the National Academy of Sciences 119.24 (2022): e2122604119.

[8] Gibson, Edward. *The dependency locality theory: A distance-based theory of linguistic complex- ity.* Image, language, brain/MIT Press (2000).

[9] Lewis, Richard L., and Shravan Vasishth. *An activation-based model of sentence processing as skilled memory retrieval.* Dictionary of World Philosophy. Routledge, 2013. 375-419.

[10] Futrell, Richard, Edward Gibson, and Roger P. Levy. *Lossy-context surprisal: An information- theoretic model of memory effects in sentence processing.* Cognitive science 44.3 (2020): e12814.

[11] Piantadosi, Steven. *Modern language models refute Chomsky's approach to language*. Language Science Press. 2023.

[12] Voita, Elena, et al. *Analyzing Multi-Head Self-Attention: Specialized Heads Do the Heavy Lift- ing, the Rest Can Be Pruned.* Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics. 2019.

8. Any other remarks:

Hands on assignments and a mini project to be implemented in Python/R will form an important part of the grading scheme for this course.

Dated: October 2, 2024 **Proposer:** Himanshu Yadav

DPGC Convener (CGS):

The course is approved / not approved

Chairman, SUGC/SPGC