Term Information

Effective Term	Spring 2023
Previous Value	*Spring 2022*

Course Change Information

What change is being proposed? (If more than one, what changes are being proposed?)

We are proposing that this course be part of the Theme - Number, Nature, and Mind

What is the rationale for the proposed change(s)?

The course content and goals align with those of the proposed GE category.

What are the programmatic implications of the proposed change(s)?

(e.g. program requirements to be added or removed, changes to be made in available resources, effect on other programs that use the course)?

None.

Is approval of the requrest contingent upon the approval of other course or curricular program request? No

Is this a request to withdraw the course? No

General Information

Course Bulletin Listing/Subject Area	Linguistics
Fiscal Unit/Academic Org	Linguistics - D0566
College/Academic Group	Arts and Sciences
Level/Career	Graduate, Undergraduate
Course Number/Catalog	5702
Course Title	Cognitive Models of Language
Transcript Abbreviation	Cognitive Models
Course Description	Models of human language processing and language parsing and interpretation; probabilistic models, issues in experimentation, and model implementation.
Semester Credit Hours/Units	Fixed: 3

Offering Information

Length Of Course	14 Week, 12 Week, 8 Week, 7 Week, 6 Week, 4 Week
Flexibly Scheduled Course	Never
Does any section of this course have a distance education component?	No
Grading Basis	Letter Grade
Repeatable	No
Course Components	Lecture
Grade Roster Component	Lecture
Credit Available by Exam	No
Admission Condition Course	No
Off Campus	Never
Campus of Offering	Columbus, Lima, Mansfield, Marion, Newark, Wooster
Previous Value	*Columbus*

Prerequisites and Exclusions

Prerequisites/Corequisites	Prereq: One of the following: 2000 or 2000H or 3701 or 3701H or any Ling course at the 4000 level or above, or Grad standing.
Previous Value	*Prereq: 2000, 2000H, 3701, or 3701H, or any Ling course at the 4000 level or above, or Grad standing.*
Exclusions	
Electronically Enforced	Yes

Cross-Listings

Cross-Listings

Subject/CIP Code

Subject/CIP Code	16.0102
Subsidy Level	Doctoral Course
Intended Rank	Junior, Senior, Masters, Doctoral

Requirement/Elective Designation

Number, Nature, Mind

The course is an elective (for this or other units) or is a service course for other units

Previous Value

The course is an elective (for this or other units) or is a service course for other units

Course Details

Course goals or learning objectives/outcomes

- Students will understand mathematical cognitive models explaining how language comprehension, production and acquisition work in the brain
- Students will understand how behavioral and neuro-imaging experimental evidence supports these models.

Content Topic List

- Probabilistic models of language processing
- Human language parsing and interpretation
- Information theory
- Issues in model implementation

Sought Concurrence No

Attachments

- 5702_Syllabus.txt: syllabus

  (Syllabus. Owner: McGory,Julia Tevis)
- 5702_Goals&LearningOutcomes.txt: GE Rationale

  (Other Supporting Documentation. Owner: McGory,Julia Tevis)
- 5702_syllabus.pdf: syllabus

  (Syllabus. Owner: Sims,Andrea Dorothy)

Comments

- - All campuses have been checked off

  - The intention is that any one of the listed courses is sufficient. The goal is also to be maximally inclusive regarding appropriate prereqs, in order to make sure the course is not restricted to majors. Interpretation of the prereqs as requiring three courses resulted from poor formatting on my part. The prepreqs have been rephrased to clarify. *(by Sims,Andrea Dorothy on 06/24/2022 08:33 AM)*
- - Please check off all campuses as the default position for the new GE is that courses should be available on every campus (per OAA policy). If your dept wants to appeal that, please upload a rationale.

  - Please look at the number and types of prereqs for this course. A basic principle of the GE is that "All GE courses should be made available to undergraduates with a minimum of prerequisites and not be restricted to majors." What "minimum" means is, of course, at times up to debate & that's why we have faculty panels. And it is also obvious that a Themes course is likely to have more prereqs. However, here we have two Ling prereqs that also count to fulfill the SBS foundation (where in the new GE only one is needed) + a course at the 4000 level. Please take a hard look at the prereqs and see if these are truly necessary. (As such, the prereqs will likely be red flags for the panel--i.e a sign that the course is meant for majors/specialists in the field.) *(by Vankeerbergen,Bernadette Chantal on 06/23/2022 06:42 PM)*

Workflow Information

Status	User(s)	Date/Time	Step
Submitted	Sims,Andrea Dorothy	06/23/2022 11:16 AM	Submitted for Approval
Approved	Sims,Andrea Dorothy	06/23/2022 11:18 AM	Unit Approval
Revision Requested	Vankeerbergen,Bernadette Chantal	06/23/2022 06:43 PM	College Approval
Submitted	Sims,Andrea Dorothy	06/24/2022 08:34 AM	Submitted for Approval
Approved	Sims,Andrea Dorothy	06/24/2022 08:35 AM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	08/26/2022 10:36 AM	College Approval
Pending Approval	Cody,Emily Kathryn Jenkins,Mary Ellen Bigler Hanlin,Deborah Kay Hilty,Michael Vankeerbergen,Bernadette Chantal Steele,Rachel Lea	08/26/2022 10:36 AM	ASCCAO Approval

Linguistics 5702: Cognitive Models of Language
GE: Open Theme - Number, Nature, and Mind

This course covers formal mathematical cognitive models of how language comprehension, production and acquisition work in the brain, and behavioral and neuroimaging experimental evidence about these models.

GE: Open Theme: Number, Nature, and Mind

Prerequisites: LING2000 or LING2000H or LING3701 or LING3701H or any linguistics course 4000 or above, or graduate standing.

Instructor: William Schuler

Office: Oxley 210

Email: (my last name).77@osu.edu

Office hours: Tuesday and Thursday 2:30pm--3:30pm in the class Zoom room (using the link in the Carmen site) or by appointment (just email me)

Meeting time: Wednesday and Friday 11:10am-12:40pm in Baker Systems 130

Web site: https://www.asc.ohio-state.edu/schuler.77/courses/5702/index.html. The updated syllabus, assignments, slides, etc. will be posted here, so check it regularly.

Textbook (optional): "Language in Mind: An introduction to Psycholinguistics," Julie Sedivy. Sinauer Associates, 2014. ISBN 978-0-87-893598-7.

Goals:

1. Successful students will analyze the nature of mathematics and/or mathematical reasoning at a more advanced and in-depth level than in the Foundations component.

2. Successful students will integrate approaches to number, nature, and mind by making connections to their own experience of mathematical thinking and its application in the world, and by making connections to work they have done in previous classes and/or anticipate doing in the future.

3. Successful students will experience and examine mathematics as an abstract formal system accessible to mental manipulation and/or mathematics as a tool for describing and understanding the natural world or human cognition.

Expected Learning Outcomes (ELOs):

Successful students are able to:

1.1 Engage in critical and logical thinking about the nature and/or application of mathematical reasoning.

1.2 Engage in an advanced, in-depth, scholarly exploration of the philosophical and/or cognitive foundations of mathematics and/or the application of mathematics in understanding the natural world or human cognition.

2.1 Identify, describe, and synthesize approaches to or experiences of the role of mathematics and mathematical reasoning in different academic and non-academic contexts.

2.2 Demonstrate a developing sense of self as a learner through reflection, self- assessment, and creative work, building on prior experiences to respond to new and challenging contexts.

3.1 Analyze and describe how mathematics functions as an idealized system that enables logical proof and/or as a tool for describing and understanding the natural world or human cognition.

ELO 1.1 Engage in critical and logical thinking about the nature and/or application of mathematical reasoning:

Students will not only use formal mathematical models to make predictions in problem sets and in-class discussion, but they will also apply these models to understand the process of interpreting sentences in spoken natural languages like English as precise logical formulae in lambda calculus. In early units of the course, for example on natural logic, these predictions will be about the results of certain types of logical reasoning. Later units will use linear algebraic model of memory formation, as an outer product of cue and target vectors of neural activation, resulting in a matrix of synaptic weights between neurons, and will use cued association of these weight matrices, as an inner product of a synaptic weight matrix and a vector of neural activation. These experiences will expose students to the idea that formal mathematical reasoning is something that can be considered a cognitive process.

ELO 1.2 Engage in an advanced, in-depth, scholarly exploration of the philosophical and/or cognitive foundations of mathematics and/or the application of mathematics in understanding the natural world or human cognition:

The models explored in the background section about logical representations of complex ideas are some of the foundations of mathematics, philosophy, and cognitive science, including probability spaces (Andrey Kolmogorov), typed lambda calculus as a representation for complex ideas (Alonzo Church) and intensional logic as a representation of alternative possible world states (Rudolph Carnap). These are fundamental to formal inquiry about thinking, and likely to be broadly valuable across diverse areas of study.

ELO 2.1 Identify, describe, and synthesize approaches to or experiences of the role of mathematics and mathematical reasoning in different academic and non-academic contexts:

The subject matter invites students to think about language comprehension and complex idea formation in terms of millisecond-to-millisecond neural computations using a variety of mathematical models. The course studies processes that students may not have thought about in such a mechanistic way before, and as such gives students practice thinking of new phenomena as formal and measurable. The models used in the course draw on mathematical formalisms from a variety of different disciplines: decision theory arose in the study of economics, lambda calculus was developed in mathematics, Dirichlet distributions were developed in Bayesian statistics, and left-corner parsing was developed to organize compiler construction for programming languages in computer science.

ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts:

Students primarily interact with the models through problem sets in coursework, which challenge them to reflect on the basic workings of the formal tools taught in each unit of the course and apply them creatively to solve problem in the problem sets. The problem sets start by introducing basic operations like matrix multiplication, which may be review for some students, then build on these prior experiences to respond to new and challenging contexts by applying these standard tools to show, for example, how multiple ambiguous meanings may be propagated across several words as patterns of activation in sets of neurons in the brain. Other lectures and problem sets introduce probabilistic grammars, in which rules are assigned probabilities for expanding expressions like sentences or noun phrases into smaller expressions of other categories, then build on these prior experiences to respond to new and challenging contexts by using incremental operations on these probabilistic rules to predict reading times, and later by evaluating these probabilistic grammars during grammar acquisition based on the probability that these rules assign to sentences that the learner observes as stimuli.

ELO 3.1 Analyze and describe how mathematics functions as an idealized system that enables logical proof and/or as a tool for describing and understanding the natural world or human cognition:

The course material explores how a phenomenon like ambiguity (assigning multiple analyses to a single stimulus sentence) can be represented at different levels of detail using different mathematical models. For example, sentence processing can be modeled at a low (algorithmic) level using vectors of neural activations which may consist of several distinct patterns simultaneously superposed (added together) in the same vector, or at a higher (computational) level, as discrete distributions of partial analyses, each with a distinct probability. The fact that different models are needed to model different levels of detail shows students that the idealization of the simpler models is sometimes helpful in understanding cognitive phenomena, but for some applications a less idealized model is more appropriate, and decouples the phenomenon (ambiguity) from the mathematical tools used to describe it (matrix products or discrete distributions over complex data structures).

Course Content:

The course is divided into three sections:
1. a background section examining models of decision-making, logical reasoning, neural firing, and associative memory
2. a section examining models of language comprehension
3. a section examining models of language acquisition

1. Models examined in the background section include:
week 1: the Kolmogorov measure space model of probability
week 2: a decision theory model of action selection based on probabilistically-weighted estimates of utility
week 3: a typed lambda calculus model of how complex ideas can be represented in formal logic
week 4: intensional logic and natural logic models for reasoning about desired world states
week 5: the McCulloch-Pitts model of how neurons work, and how associations can be stored in synaptic efficiencies
week 6: a linear algebraic model of how distributed associative memory works, using patterns of activation among neurons
week 7: a graph theoretic model of how complex ideas can be implemented in distributed associative memory

2. Models examined in the section on language comprehension include:
week 8: a Fourier transform model of how sounds are mapped to patterns of activation in neurons
week 9-10: a left-corner parsing model of how words can be incrementally assembled into phrases and clauses
week 11: a probabilistic context-free grammar model for assigning probabilities to phrase and clause structures of sentences
week 12: the surprisal model of probabilistic complexity in sentence processing, as defined over probabilistic grammars

3. Models examined in the section on language acquisition include:
week 13: a gradient descent model of how generalization takes place in neurons
week 14-15: a Bayesian grammar acquisition model over probabilistic context-free grammars

There are no assigned readings. The course is taught from lecture notes which use a uniform notation for lambda calculus, probability and linear algebraic terms in all models, and include appropriate citations.

Credit hours and work expectations: This is a 3-credit-hour course. According to Ohio State policy, students should expect around 3 hours per week of time spent on direct instruction (instructor content and Carmen activities, for example) in addition to 6 hours of homework (reading and assignment preparation, for example) to receive a grade of (C) average.

Course requirements:

* Regular attendance and active participation (15% of grade): this will include participation in class or live Carmen Zoom meetings, if applicable.

*Completing six problem set assignments (85% of grade) (handed out about a week and a half before they are due, see schedule), handed in through Carmen. Late assignments are only accepted if extensions are requested and granted, and are penalized 20% on a per-question basis, so try to submit as many questions as possible on time.

Student participation requirements: Consistent engagement is expected. If any problems arise relative to attendance, please contact the instructor as soon as possible. Communication is important. You are encouraged to participate during class, ask questions, work on in-class problems in small groups, and share your experiences relative to the subjects and discussion that day.
Faculty feedback and response time:

Assignments: you can generally expect feedback within 7 days.

Email: I will reply to e-mails within 24 hours on school days.

Grading scale: OSU standard scheme

A	A-	B+	B	B-	C+	C	C-	D+	D
93%	90%	87%	83%	80%	77%	73%	70%	67%	60%

Students with Disabilities: The University strives to make all learning experiences as accessible as possible. If you anticipate or experience academic barriers based on your disability (including mental health, chronic or temporary medical conditions), please let me know immediately so that we can privately discuss options. To establish reasonable accommodations, I may request that you register with Student Life Disability Services. After registration, make arrangements with me as soon as possible to discuss your accommodations so that they may be implemented in a timely fashion. SLDS contact information: slds@osu.edu; 614-292-3307; slds.osu.edu; 098 Baker Hall, 113 W. 12th Avenue.

Academic Misconduct: It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term "academic misconduct" includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct http://studentlife.osu.edu/csc/.

Mental Health Services: As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities. The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Office of Student Life's Counseling and Consultation Service (CCS) by visiting ccs.osu.edu or calling 614-292-5766. CCS is located on the 4th Floor of the Younkin Success Center and 10th Floor of Lincoln Tower. You can reach an on call counselor when CCS is closed at 614-292-5766 and 24 hour emergency help is also available through the 24/7 National Suicide Prevention Hotline at 1-800-273-TALK or at suicidepreventionlifeline.org.

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Diversity: The Ohio State University affirms the importance and value of diversity in the student body. Our programs and curricula reflect our multicultural society and global economy and seek to provide opportunities for students to learn more about persons who are different from them. We are committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters sensitivity, understanding, and mutual respect among each member of our community; and encourages each individual to strive to reach their own potential. Discrimination against any individual based upon protected status, which is defined as age, color, disability, gender identity or expression, national origin, race, religion, sex, sexual orientation, or veteran status, is prohibited.

Linguistics 5702: Cognitive Models of Language

Syllabus

Instructor: William Schuler
Office: Oxley 210
Email: (my last name).77@osu.edu

Office hours: Tuesday and Thursday 2:30pm--3:30pm in the class Zoom room (using the link in the Carmen site) or by appointment (just email me)

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Web site: https://www.asc.ohio-state.edu/schuler.77/courses/5702/index.html. The updated syllabus, assignments, slides, etc. will be posted here, so check it regularly.

Course Description: This course covers formal mathematical cognitive models of how language comprehension, production and acquisition work in the brain, and behavioral and neuroimaging experimental evidence about these models.

Prerequisites: LING 2000, 2000H, 3701 or 3701H, or any linguistics course 4000 or above, or graduate standing.

Textbook (optional): "Language in Mind: An introduction to Psycholinguistics," Julie Sedivy. Sinauer Associates, 2014. ISBN 978-0-87-893598-7.

Course Goals:

1. Students will understand mathematical cognitive models explaining how language comprehension, production and acquisition work in the brain

2. Students will understand how behavioral and neuro-imaging experimental evidence supports these models.

GE Information: This course satisfies a General Education (GEN) requirement for the Themes: Number, Nature & Mind (NNM) category.

<u>NNM Goals:</u>

1. Successful students will analyze the nature of mathematics and/or mathematical reasoning at a more advanced and in-depth level than in the Foundations component.

2. Successful students will integrate approaches to number, nature, and mind by making connections to their own experience of mathematical thinking and its application in the world, and by making connections to work they have done in previous classes and/or anticipate doing in the future.

3. Successful students will experience and examine mathematics as an abstract formal system accessible to mental manipulation and/or mathematics as a tool for describing and understanding the natural world or human cognition.

NNM Expected Learning Outcomes (ELOs):

Successful students are able to:

ELO 1.1 Engage in critical and logical thinking about the nature and/or application of mathematical reasoning.

How this course meets this ELO: Students will not only use formal mathematical models to make predictions in problem sets and in-class discussion, but they will also apply these models to understand the process of interpreting sentences in spoken natural languages like English as precise logical formulae in lambda calculus. In early units of the course, for example on natural logic, these predictions will be about the results of certain types of logical reasoning. Later units will use linear algebraic model of memory formation, as an outer product of cue and target vectors of neural activation, resulting in a matrix of synaptic weights between neurons, and will use cued association of these weight matrices, as an inner product of a synaptic weight matrix and a vector of neural activation. These experiences will expose students to the idea that formal mathematical reasoning is something that can be considered a cognitive process.

ELO 1.2 Engage in an advanced, in-depth, scholarly exploration of the philosophical and/or cognitive foundations of mathematics and/or the application of mathematics in understanding the natural world or human cognition.

How this course meets this ELO: The models explored in the background section about logical representations of complex ideas are some of the foundations of mathematics, philosophy, and cognitive science, including probability spaces (Andrey Kolmogorov), typed lambda calculus as a representation for complex ideas (Alonzo Church) and intensional logic as a representation of alternative possible world states (Rudolph Carnap). These are fundamental to formal inquiry about thinking, and likely to be broadly valuable across diverse areas of study.

ELO 2.1 Identify, describe, and synthesize approaches to or experiences of the role of mathematics and mathematical reasoning in different academic and non-academic contexts.

How this course meets this ELO: The subject matter invites students to think about language comprehension and complex idea formation in terms of millisecond-to-millisecond neural computations using a variety of mathematical models. The course studies processes that students may not have thought about in such a mechanistic way before, and as such gives students practice thinking of new phenomena as formal and measurable. The models used in the course draw on mathematical formalisms from a variety of different disciplines: decision theory arose in the study of economics, lambda calculus was developed in mathematics, Dirichlet distributions were developed in Bayesian statistics, and left-corner parsing was developed to organize compiler construction for programming languages in computer science.

ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self- assessment, and creative work, building on prior experiences to respond to new and challenging contexts.

How this course meets this ELO: Students primarily interact with the models through problem sets in coursework, which challenge them to reflect on the basic workings of the formal tools taught in each unit of the course and apply them creatively to solve problem in the problem sets. The problem sets start by introducing basic operations like matrix multiplication, which may be review for some students, then build on these prior experiences to respond to new and challenging contexts by applying these standard tools to show, for example, how multiple ambiguous meanings may be propagated across several words as patterns of activation in sets of neurons in the brain. Other lectures and problem sets introduce probabilistic grammars, in which rules are assigned probabilities for expanding expressions like sentences or noun phrases into smaller expressions of other categories, then build on these prior experiences to respond to new and challenging contexts by using incremental operations on these probabilistic rules to predict reading times, and later by evaluating these probabilistic grammars during grammar acquisition based on the probability that these rules assign to sentences that the learner observes as stimuli.

ELO 3.1 Analyze and describe how mathematics functions as an idealized system that enables logical proof and/or as a tool for describing and understanding the natural world or human cognition.

How this course meets this ELO: The course material explores how a phenomenon like ambiguity (assigning multiple analyses to a single stimulus sentence) can be represented at different levels of detail using different mathematical models. For example, sentence processing can be modeled at a low (algorithmic) level using vectors of neural activations which may consist of several distinct patterns simultaneously superposed (added together) in the same vector, or at a higher (computational) level, as discrete distributions of partial analyses, each with a distinct probability. The fact that different models are needed to model different levels of detail shows students that the idealization of the simpler models is sometimes helpful in understanding cognitive phenomena, but for some applications a less idealized model is more appropriate, and decouples the phenomenon (ambiguity) from the mathematical tools used to describe it (matrix products or discrete distributions over complex data structures).

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2. Models examined in the section on language comprehension include:
week 8: a Fourier transform model of how sounds are mapped to patterns of activation in neurons
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Diversity: The Ohio State University affirms the importance and value of diversity in the student body. Our programs and curricula reflect our multicultural society and global economy and seek to provide opportunities for students to learn more about persons who are different from them. We are committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters sensitivity, understanding, and mutual respect among each member of our community; and encourages each individual to strive to reach their own potential. Discrimination against any individual based upon protected status, which is defined as age, color, disability, gender identity or expression, national origin, race, religion, sex, sexual orientation, or veteran status, is prohibited.

As described in the course syllabus, Linguistics 5702 explores mathematical models of sentence processing and grammar acquisition at different representational levels. First, a background unit introduces lambda calculus and intensional logic as computational-level representations of complex ideas, introduces common linear algebraic models of neural activation and distributed associative memory as algorithmic-level representations of neural activity in the brain, and defines a mapping from the former logical forms to the latter cued associations. Then a unit on comprehension explores probabilistic context-free grammars as stochastic branching processes for dynamically resolving ambiguity during sentence processing. Finally a unit on acquisition explores Bayesian grammar induction models as explanations for how human language learners can acquire these probabilistic grammars from data that generally contains only positive examples.

The course lectures and problems sets expose students to basic mathematical tools, such as lambda calculus, probability spaces and matrix multiplication, that have been used to model a variety of phenomena across disciplines, and apply them to seemingly inscrutable phenomena of translating sentences into complex ideas. The use of multiple different mathematical models for different representational levels of cognitive phenomena decouples the phenomena to be modeled (e.g. ambiguity resolution in sentence processing) from the mathematical tools used to model it (linear algebra at the algorithmic level, and probabilistic grammars at the computational level), allowing students to appreciate how different formal tools offer different advantages as models of the same natural phenomena.

GE: Open Themes - Number, Nature, and Mind
Shared goals and ELOs:

GOAL 1: Successful students will analyze an important topic or idea at a more advanced and in-depth level than the foundations.

1.1 Engage in critical and logical thinking about the topic or idea of the theme:

Students will not only use formal mathematical models to make predictions in problem sets and in-class discussion, but they will also apply these models to understand the process of interpreting sentences in spoken natural languages like English as precise logical formulae in lambda calculus. In early units of the course, for example on natural logic, these predictions will be about the results of certain types of logical reasoning. Later units will use linear algebraic model of memory formation, as an outer product of cue and target vectors of neural activation, resulting in a matrix of synaptic weights between neurons, and will use cued association of these weight matrices, as an inner product of a synaptic weight matrix and a vector of neural activation. These experiences will expose students to the idea that formal mathematical reasoning is something that can be considered a cognitive process.

1.2 Engage in an advanced, in-depth, scholarly exploration of the topic or idea of the theme:

The models explored in the background section about logical representations of complex ideas are some of the foundations of mathematics, philosophy, and cognitive science, including probability spaces (Andrey Kolmogorov), typed lambda calculus as a representation for complex ideas (Alonzo Church) and intensional logic as a representation of alternative possible world states (Rudolph Carnap). These are fundamental to formal inquiry about thinking, and likely to be broadly valuable across diverse areas of study.

GOAL 2: Successful students will integrate approaches to the theme by making connections to out-of- classroom experiences with academic knowledge or across disciplines and/or to work they have done in previous classes and that they anticipate doing in future.

2.1 Identify, describe, and synthesize approaches or experiences as they apply to the theme:

The subject matter invites students to think about language comprehension and complex idea formation in terms of millisecond-to-millisecond neural computations using a variety of mathematical models. The course studies processes that students may not have thought about in such a mechanistic way before, and as such gives students practice thinking of new phenomena as formal and measurable. The models used in the course draw on mathematical formalisms from a variety of different disciplines: decision theory arose in the study of economics, lambda calculus was developed in mathematics, Dirichlet distributions were developed in Bayesian statistics, and left-corner parsing was developed to organize compiler construction for programming languages in computer science.

2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts:

Students primarily interact with the models through problem sets in coursework. The problem sets start by introducing basic operations like matrix multiplications, which may be review for some students, then apply these standard tools to show, for example, how multiple ambiguous meanings may be propagated across several words as patterns of activation in sets of neurons in the brain. Other lectures and problem sets introduce probabilistic grammars, in which rules are assigned probabilities for expanding expressions like sentences or noun phrases into smaller expressions of other categories, then use incremental operations on these probabilistic rules to predict reading times, and later evaluate these probabilistic grammars during grammar acquisition based on the probability that these rules assign to sentences that the learner observes as stimuli.

Theme-specific goals and ELOs:

GOAL 1: Successful students will analyze the nature of mathematics and/or mathematical reasoning at a more advanced and in-depth level than in the Foundations component.

ELO 1.1 Engage in critical and logical thinking about the nature and/or application of mathematical reasoning:

Students will not only use formal mathematical models to make predictions in problem sets and in-class discussion, but they will also apply these models to understand the process of interpreting sentences in spoken natural languages like English as precise logical formulae in lambda calculus. In early units of the course, for example on natural logic, these predictions will be about the results of certain types of logical reasoning. Later units will use linear algebraic model of memory formation, as an outer product of cue and target vectors of neural activation, resulting in a matrix of synaptic weights between neurons, and will use cued association of these weight matrices, as an inner product of a synaptic weight matrix and a vector of neural activation. These experiences will expose students to the idea that formal mathematical reasoning is something that can be considered a cognitive process.

ELO 1.2 Engage in an advanced, in-depth, scholarly exploration of the philosophical and/or cognitive foundations of mathematics and/or the application of mathematics in understanding the natural world or human cognition:

The models explored in the background section about logical representations of complex ideas are some of the foundations of mathematics, philosophy, and cognitive science, including probability spaces (Andrey Kolmogorov), typed lambda calculus as a representation for complex ideas (Alonzo Church) and intensional logic as a representation of alternative possible world states (Rudolph Carnap). These are fundamental to formal inquiry about thinking, and likely to be broadly valuable across diverse areas of study.

GOAL 2: Successful students will integrate approaches to number, nature, and mind by making connections to their own experience of mathematical thinking and its application in the world, and by making connections to work they have done in previous classes and/or anticipate doing in the future.

ELO 2.1 Identify, describe, and synthesize approaches to or experiences of the role of mathematics and mathematical reasoning in different academic and non-academic contexts:

The subject matter invites students to think about language comprehension and complex idea formation in terms of millisecond-to-millisecond neural computations using a variety of mathematical models. The course studies processes that students may not have thought about in such a mechanistic way before, and as such gives students practice thinking of new phenomena as formal and measurable. The models used in the course draw on mathematical formalisms from a variety of different disciplines: decision theory arose in the study of economics, lambda calculus was developed in mathematics, Dirichlet distributions were developed in Bayesian statistics, and left-corner parsing was developed to organize compiler construction for programming languages in computer science.

ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts:

Students primarily interact with the models through problem sets in coursework, which challenge them to reflect on the basic workings of the formal tools taught in each unit of the course and apply them creatively to solve problem in the problem sets. The problem sets start by introducing basic operations like matrix multiplication, which may be review for some students, then build on these prior experiences to respond to new and challenging contexts by applying these standard tools to show, for example, how multiple ambiguous meanings may be propagated across several words as patterns of activation in sets of neurons in the brain. Other lectures and problem sets introduce probabilistic grammars, in which rules are assigned probabilities for expanding expressions like sentences or noun phrases into smaller expressions of other categories, then build on these prior experiences to respond to new and challenging contexts by using incremental operations on these probabilistic rules to predict reading times, and later by evaluating these probabilistic grammars during grammar acquisition based on the probability that these rules assign to sentences that the learner observes as stimuli.

GOAL 3: Successful students will experience and examine mathematics as an abstract formal system accessible to mental manipulation and/or mathematics as a tool for describing and understanding the natural world or human cognition.

ELO 3.1 Analyze and describe how mathematics functions as an idealized system that enables logical proof and/or as a tool for describing and understanding the natural world or human cognition:

The course material explores how a phenomenon like ambiguity (assigning multiple analyses to a single stimulus sentence) can be represented at different levels of detail using different mathematical models. For example, sentence processing can be modeled at a low (algorithmic) level using vectors of neural activations which may consist of several distinct patterns simultaneously superposed (added together) in the same vector, or at a higher (computational) level, as discrete distributions of partial analyses, each with a distinct probability. The fact that different models are needed to model different levels of detail shows students that the idealization of the simpler models is sometimes helpful in understanding cognitive phenomena, but for some applications a less idealized model is more appropriate, and decouples the phenomenon (ambiguity) from the mathematical tools used to describe it (matrix products or discrete distributions over complex data structures).