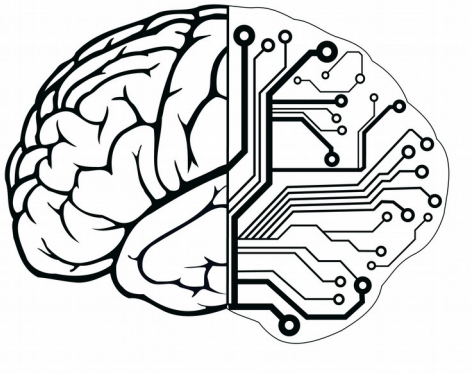
COM596
Brain-Inspired Artificial Intelligence

Course Outline
Winter 2021



Number of credits: 3

Instructor
Dr. Blake Aaron Richards – blake.richards@mcgill.ca

Teaching assistant
Raymond Chua – raymond.chua@mail.mcgill.ca

Prerequisites
There are no specific prerequisites for this course, but you will not do well in it if you do not have at least the following:

(1) Some basic **knowledge of how to code**, ideally in Python.

(2) Some basic **background in linear algebra, multivariate calculus, and statistics** (introductory undergrad classes are fine, but CEGEP/high-school maybe not).

If you do not have this background and you take this class anyway, you will likely be disappointed with your experience. Speak to me in the first week if you are unsure.

Lectures and location
Tuesdays and Thursdays from 10:05 AM to 11:25 AM in MAASS 112
Lectures will be 80 minutes, from 10:05 AM to 11:25 AM. **Attendance at lectures is not compulsory! For those students who do not wish to attend in person, recordings of the lectures will be made available on myCourses.** Note that due to the semi-online nature of classes this year, I will not give marks for in-class participation (I normally do), *but nonetheless, I hope you do ask questions and discuss in-class if you are there. Also, please prepare for class by doing the readings.*

Instructor office hours
Tuesdays and Thursdays from 1:00 PM to 2:00 PM *only on days with lectures*
Office hours will be done via Zoom
Joining Information:
https://mcgill.zoom.us/j/86206401202?pwd=dnRyclgrNlFVNU0vVTEwOE9vSXZhdz09
Meeting ID: 862 0640 1202
Passcode: 595739

TA office hours
By appointment, email Raymond to arrange a time if desired.

Course overview and learning outcomes/objectives

The brain is a sophisticated information processing device, capable of generating intelligent behaviour in a wide range of environments. In fact, despite all our advances in machine learning, it is still the most powerful, generalizable learning machine on Earth. The primary goal of the field of Artificial Intelligence (AI) is to make machines that can replicate the capabilities of the brain, and potentially at some point, exceed them.

Given this, it is unsurprising that a large number of AI researchers have sought inspiration from the brain in their work. In fact, the dominant paradigms for AI that exist today were all rooted, at some point in the past, in the use of neuroscience and psychology insights. This course will provide you with a historical overview of the influence of neuroscience and psychology ideas on AI. We will cover the earliest days of this interdisciplinary interaction, up through to today's state-of-the-art. You will learn both the basic brain facts required to understand the theory behind this work, as well as the mathematical details of the models. The specific learning objectives for the course are:

1. Students will understand broadly what computation is and what algorithms are. They will also understand how computations are implemented by algorithms, and in turn, how algorithms can be implemented by brain-like structures.
2. Students will become familiar with parallel distributed processing and neural network models, their advantages and disadvantages, and how they are used in AI.
3. Students will understand the core ideas of supervised learning, auto-associative memories, unsupervised learning, reinforcement learning, and their use in AI.
4. Students will understand the relationship between learning and optimization, and be able to identify at least two brain-inspired learning algorithms for neural networks.
5. Students will understand what an inductive bias is, this idea's place in the history of deep learning, and how it is related to neuroscience knowledge.
6. Students will be able to explain more sophisticated brain-inspired techniques, including convolution, attention, and memory augmentation.
7. Students will be able to program simple neural network models from scratch.
8. Students will be able to discuss scientific papers from the area of brain-inspired AI.

These objectives will provide the foundation for any future work in academia or industry related to neural information processing, brain machine interfaces or AI. There are many jobs in these areas at this point in history, and a lot of active research. Now is the right time to gain an education in this area!

But, doing well in this course will require keeping up with the material and pushing yourself out of your comfort zone, especially if you are completely unfamiliar with neuroscience or psychology and have never programmed a neural network before. As well, the readings are probably different from what many students in computer science are used to. A few important tips:

- There are a fair number of readings (available for free on *myCourses*), at various levels of difficulty. You may not understand everything you read, but it is important that you understand the basic concepts. Discuss the readings with other students in the class. Discussion will help you to understand things you struggle with on your own.
- If you are struggling with any of the neuroscience or psychology concepts, come to office hours. I am here to help you understand these things.
- Get started on the programming assignments as soon as they are released, especially if you are new to programming neural networks.

Asking questions

Please ask questions! As many as possible! However, please post your out of class questions to *myCourses* so everyone can see the answer and the TA and I do not have to repeat ourselves. **We will not answer course content questions sent to us by email.** Only email questions to us if they are of a personal or specific-to-you administrative nature.

Course requirements and evaluation

The final grade is based on two assignments, a midterm test, a final exam, and a mark for participation in the post-lecture discussions. Here is the specific break-down:

Item	Percentage	Due date
Programming assignment 1	25%	February 22
Paper presentation video	20%	March 8
Programming assignment 2	25%	March 29
Essay assignment	30%	April 26

Programming assignments

As stated above, there will be two programming assignments. For both assignments, you will receive a backbone of Python code that you will use to build the models. The first assignment will have you program a Hopfield network for storing auto-associative memories. The second assignment will have you program an actor-critic network for a neuroscience inspired task. For both assignments you will **not** be allowed to use modern machine learning libraries that provide autograd capabilities. You will be doing it old school! In both assignments there will be a few questions to answer and some additional tasks for the graduate students.

Paper presentation video

In this assignment, groups of 3 students will be required to prepare a 20-minute presentation video on an article from the brain-inspired AI literature. A list of potential papers will be provided, but students may request other papers if they wish (though the choice must be approved by the instructor). The presentation must be done using slides, but you can make it using any recording device, editing software, etc. It could even just be a recording from your phone. The only requirement is that you submit a video in a standard video file format (e.g. avi, mp4, mov, etc.) by uploading it to myCourses. The presentation cannot be more than 20 minutes—you will lose marks if it is!!!! You are not required to show anyone's face in the video, only slides must be visible, but your voices must be audible. Also, it is important that

all 3 students participate and speak. In terms of instructions, the presentation can be structured as you wish, but it must answer the four following questions:

Q1) Background: What is the gap in AI capabilities that the paper is attempting to address, and what neuroscience insights are they using to do it?
Q2) Results: What data, model and/or analyses does the paper present, and how does it help us to fill the gap in AI capabilities?
Q3) Limitations: Does the paper completely fill the gap you identified, or does it leave it incomplete? If it is incomplete, how so?
Q4) Future directions: What new questions does the paper raise and what should other researchers do to address them?

The assignment will be marked out of **20 marks**, with the following breakdown:

- **4 marks** for success in addressing Q1 above
- **4 marks** for success in addressing Q2 above
- **3 marks** for success in addressing Q3 above
- **3 marks** for success in addressing Q4 above
- **6 marks** for clarity of the presentation

I will leave it up to you to pick your groups, and the paper you want to present. However, note that you must decide your group and paper by **February 12** and email me your decision. Anyone without a group and/or paper by this date will have them assigned.

Essay assignment
In your final assignment you will be tasked with writing a 4-page opinion piece. The piece is fairly open ended, but it must address the following question: *Which capabilities that animals/humans possess do current AI technologies not possess?* You must provide supporting evidence and ample citations to justify both aspects of your claim, i.e. you must provide some psychology or neuroscience evidence regarding the capabilities of humans or other animal species, and you must provide some evidence that current AI does not possess these capabilities. You should also finish by giving some speculative ideas as to potential means of endowing AI with this capability. The assignment is out of **30 marks**, and you will be marked as follows:

- How well do you describe the capability in question? **8 marks**
- Do you provide supporting evidence that humans/animals possess the capability? **7 marks**
- Do you supporting evidence that AI doesn't possess this capability? **7 marks**
- What are your ideas for how to endow AI with these capabilities? **4 marks**
- General clarity of writing. **4 marks**

Lecture and readings schedule

Week	Dates	Subject	Required readings
1	Jan 7	What is artificial intelligence?	Turing (1950) Richards (2018)
2	Jan 12, 14	Parallel distributed processing 1	PDP Chapter 1 Marr & Poggio (1976)
3	Jan 19, 21	Parallel distributed processing 2	PDP Chapter 2 PDP Chapter 3
4	Jan 26, 28	Gradient descent and backpropagation-of-error	PDP Chapter 8
5	Feb 2, 4	Auto-associative memories and Hopfield networks	Hopfield (1982) Hopfield (1984)
6	Feb 9, 11	Unsupervised learning 1: competitive learning	Rumelhart and Zipser (1985)
7	Feb 16, 18	NO CLASS: NSERC PANEL	NA
8	Feb 23, 25	Unsupervised learning 2: Boltzmann and Helmholtz machines	PDP Chapter 8 Dayan (1995)
9	Mar 9, 11	The neuroscience roots of reinforcement learning	Sutton & Barto (1981) RL Chapters 1 & 6
10	Mar 16, 18	Deep learning and inductive biases	Bengio and LeCun (2007)
11	Mar 23, 25	Cortex-inspired visual processing	Fukushima (1980) George et al. (2020)
12	Mar 30, Apr 1	Attention and its links to memory	Xu et al. (2015), Vaswani et al. (2017) Ramasauer et al. (2020)
13	Apr 6, 8	Towards conscious machines?	Bengio (2019) Mashour (2020)
14	Apr 13	Class summary and review	NA

Language of submissions

In accord with McGill University's Charter of Students' Rights, students in this course have the right to submit in English or in French any written work that is to be graded. This does not apply to courses in which acquiring proficiency in a language is one of the objectives.

Conformément à la Charte des droits de l'étudiant de l'Université McGill, chaque étudiant a le droit de soumettre en français ou en anglais tout travail écrit devant être noté (sauf dans le cas des cours dont l'un des objets est la maîtrise d'une langue).

Academic integrity

McGill University values academic integrity. Therefore, all students must understand the meaning and consequences of cheating, plagiarism and other academic offences under the Code of Student Conduct and Disciplinary Procedures" (see McGill's guide to academic honesty for more information).

L'université McGill attache une haute importance à l'honnêteté académique. Il incombe par conséquent à tous les étudiants de comprendre ce que l'on entend par tricherie, plagiat et autres infractions académiques, ainsi que les conséquences que peuvent avoir de telles actions, selon le Code de conduite de l'étudiant et des procédures disciplinaires (pour de plus amples renseignements, veuillez consulter le guide pour l'honnêteté académique de McGill).

Additional statements regarding evaluation

The University Student Assessment Policy exists to ensure fair and equitable academic assessment for all students and to protect students from excessive workloads. All students and instructors are encouraged to review this Policy, which addresses multiple aspects and methods of student assessment, e.g. the timing of evaluation due dates and weighting of final examinations.

Note that to support academic integrity, your assignments may be submitted to text-matching or other appropriate software (e.g., formula-, equation-, and graph-matching).

Accessibility

As the instructor of this course I endeavor to provide an inclusive learning environment. However, if you experience barriers to learning in this course, do not hesitate to discuss them with me and the Office for Students with Disabilities, 514-398-6009.

Course evaluations

End-of-course evaluations are one of the ways that McGill works towards maintaining and improving the quality of courses and the student's learning experience. You will be notified by e-mail when the evaluations are available. Please note that a minimum number of responses must be received for results to be available to students.

Land acknowledgement statement

McGill University is on land which has long served as a site of meeting and exchange amongst Indigenous peoples, including the Haudenosaunee and Anishinabeg nations. We acknowledge and thank the diverse Indigenous people whose footsteps have marked this territory on which peoples of the world now gather.

L'Université McGill est sur un emplacement qui a longtemps servi de lieu de rencontre et d'échange entre les peuples autochtones, y compris les nations Haudenosaunee et Anishinabeg. Nous reconnaissons et remercions les divers peuples autochtones dont les pas ont marqué ce territoire sur lequel les peuples du monde entier se réunissent maintenant.

Note: *In the event of extraordinary circumstances beyond the University's control, the content and/or evaluation scheme in this course is subject to change.*