CNS-480/780 | COURSE OUTLINE

Computational Neuroscience and Supercomputing

Course code	CNS-480/780 (undergraduate section CNS-480; graduate section CNS-780)
Credit hours	3 (2 + 1): two lecture hours and one three-hour laboratory per week
Levels	BS (final year) | MS | PhD — one course, three levels of assessment
Prerequisites	Computational Neuroscience (or equivalent: spiking neuron models and networks); ordinary differential equations; programming in C, C++ or Python; introductory computer architecture is helpful.
Instructor	Dr. Asif Mehmood, Department of Computer Science
Contact	asifnazquaidian@gmail.com
Delivery	Lectures with live demonstrations, weekly laboratory on a workstation and an HPC cluster, graduate research project
Textbook	Computational Neuroscience and Supercomputing: Simulating brains at scale: neuron models, numerical methods, parallel and GPU computing, neuromorphic hardware and connectome-scale models (course textbook, October 2026), with the reference books below.

1 Course description

The brain has some 86 billion neurons and a hundred trillion synapses; simulating even a fraction of it is one of the grand challenges of scientific computing. This course teaches how large neural simulations are built and run. It reviews the neuron and synapse models used at scale and their computational cost, then develops the numerical methods of network simulation: time-driven and event-driven schemes, exact integration and spike-time precision. It introduces computer architecture for computational scientists (memory hierarchies, the roofline model) and parallel programming with MPI, OpenMP and GPUs, and applies them to the distribution of neurons and synapses, spike communication, memory scaling and load balance. It surveys the simulators and model-description standards of the field (NEURON, NEST, Brian, Arbor, GeNN, PyNN, NeuroML, SONATA), the efficient simulation of detailed multicompartment neurons, and the benchmark networks (Brunel, Potjans–Diesmann) used to compare platforms. The final part covers neuromorphic hardware, connectome-constrained and whole-brain models, and the performance engineering, energy and reproducibility questions of exascale neuroscience. Undergraduates learn to use and measure simulators; master's and doctoral students add performance modelling, parallel implementation and a research project.

2 Course learning outcomes (CLOs)

Outcomes are written at the cognitive levels of Bloom's revised taxonomy and mapped to the programme learning outcomes (PLOs) of the host programme (for computing degrees, the Seoul Accord graduate at-

CLO	Students will be able to…	Bloom level	PLO
CLO1	Explain the models, numerical schemes and data structures used in large-scale neural simulation and their computational costs.	C2 Understand	PLO1
CLO2	Implement and verify network simulations with appropriate integration schemes and measure their accuracy and performance.	C3 Apply	PLO2, PLO5
CLO3	Analyse the performance of neural simulations with roofline, Amdahl/Gustafson and communication models, and identify bottlenecks.	C4 Analyse	PLO2, PLO3
CLO4	Parallelise a spiking-network simulation with MPI, threads or GPUs and evaluate its strong and weak scaling.	C3 Apply	PLO2, PLO5
CLO5	Evaluate simulators, neuromorphic platforms and connectome-scale modelling strategies for a given scientific question, including energy and reproducibility.	C5 Evaluate	PLO3, PLO6
CLO6	Design, carry out and report an original large-scale simulation study with performance analysis and verification.	C6 Create	PLO4, PLO9

tributes used by NCEAC).

3 Weekly schedule

Sixteen weeks: fourteen teaching weeks, a mid-term week and a final-examination week. Each teaching week has two lecture hours and one three-hour computational laboratory.

Week	Topic (textbook chapter)	Laboratory	Assessment / CLO
1	Simulating the Brain: Scale, Questions and Machines (Ch. 1)	Measuring a simulation	Diagnostic quiz
2	Neuron and Synapse Models for Large-Scale Simulation (Ch. 2)	The cost of neuron models	Lab report 1 (CLO1, CLO2)
3	Numerical Integration of Spiking Networks (Ch. 3)	Exact integration and spike times	Problem set 1 (CLO2)
4	Computer Architecture for Computational Neuroscientists (Ch. 4)	Bandwidth, latency and the roofline	Lab report 2 (CLO3)
5	Parallel Programming: Threads, Message Passing and Scaling Laws (Ch. 5)	MPI basics with mpi4py	Problem set 2 (CLO3)
6	Distributed Simulation of Spiking Networks (Ch. 6)	A distributed LIF network with mpi4py	Lab report 3 (CLO4)
7	Memory, Connectivity Data Structures and Exascale Kernels (Ch. 7)	CSR connectivity and memory measurement	Quiz 1 (CLO1–CLO4); project proposal (graduate)
8	**Mid-term examination (Chapters 1–7)**	–	Mid-term (CLO1–CLO4)
9	GPU Computing for Neural Simulation (Ch. 8)	A spiking network on the GPU	Lab report 4 (CLO4)

Week	Topic (textbook chapter)	Laboratory	Assessment / CLO
10	Simulators, Model Description Languages and Reproducibility (Ch. 9)	One model, two simulators	Problem set 3 (CLO5)
11	Simulating Morphologically Detailed Neurons at Scale (Ch. 10)	The Hines algorithm	Lab report 5 (CLO2, CLO3)
12	Benchmark Networks: From Brunel to the Cortical Microcircuit (Ch. 11)	The Brunel network	Lab report 6 (CLO2, CLO4)
13	Neuromorphic Computing (Ch. 12)	Simulating hardware constraints	Quiz 2 (CLO3, CLO5)
14	Connectome-Constrained and Whole-Brain Models (Ch. 13)	Simulating a wiring diagram	Paper review (CLO5)
15	Performance Engineering, Energy and the Exascale Future (Ch. 14)	The course project workflow	Project presentations (CLO6)
16	**Final examination (all chapters)**	–	Final (CLO1–CLO5); project report (CLO6)

4 Assessment

Undergraduate (BS) and graduate (MS/PhD) students attend the same lectures but are assessed differently: graduate students complete the advanced (MS) and research (PhD) exercises and a research project.

BS students

Problem sets (3)	10%
Quizzes (2)	10%
Laboratory reports (6)	25%
Mid-term examination	20%
Final examination	35%

MS and PhD students

Problem sets with MS/PhD problems	10%
Laboratory reports (6)	15%
Critical review of two research papers	10%
Mid-term examination	15%
Research project (proposal, presentation, report)	25%
Final examination	25%

Graduate research project

Graduate students choose a project in week 7 and present it in week 15. A project answers a scientific or computational question with a large simulation and a performance analysis. Examples: strong and weak scaling of a Brunel network implemented with MPI on the departmental cluster, compared with a performance model; a GPU implementation of spike delivery with pre- and postsynaptic parallelism; the effect of the integration scheme and time step on the statistics of a balanced network; porting the Potjans–Diesmann microcircuit between two simulators through PyNN or SONATA and quantifying the agreement of firing statistics; simulating a connectome-constrained Drosophila circuit and testing a behavioural prediction. Deliverables: a two-page proposal, a 15-minute presentation and a report in journal format (6–8 pages) with reproducible code, a verification section and a performance section. PhD reports must state a hypothesis and compare with the literature.

Grading rubric for laboratory reports and projects

Criterion	Excellent (4)	Satisfactory (2–3)	Needs work (0–1)
Model and method	Correct equations, algorithms and parameters, justified choices	Minor errors that do not change conclusions	Wrong model or unexplained method
Code and results	Runs, reproducible, figures labelled with units, baselines and error bars	Runs with small gaps	Does not run or results missing
Interpretation	Links results to theory, physiology or the literature	Describes results without depth	No interpretation
Communication	Clear structure, correct references	Understandable, some gaps	Unclear or unreferenced

5 Reading list

Course textbook

Computational Neuroscience and Supercomputing: Simulating brains at scale: neuron models, numerical methods, parallel and GPU computing, neuromorphic hardware and connectome-scale models. Dr. Asif Mehmood, October 2026.

Reference books and papers

1. R. Brette *et al.*, Simulation of networks of spiking neurons: a review of tools and strategies, *J. Comput. Neurosci.* 23:349–398, 2007.
2. N. T. Carnevale and M. L. Hines, *The NEURON Book*. Cambridge University Press, 2006.
3. J. L. Hennessy and D. A. Patterson, *Computer Architecture: A Quantitative Approach*, 6th ed. Morgan Kaufmann, 2019.
4. W. Gropp, E. Lusk and A. Skjellum, *Using MPI*, 3rd ed. MIT Press, 2014; W.-m. W. Hwu, D. B. Kirk and I. El Hajj, *Programming Massively Parallel Processors*, 4th ed. Morgan Kaufmann, 2022.
5. E. M. Izhikevich, *Dynamical Systems in Neuroscience*. MIT Press, 2007; W. Gerstner *et al.*, *Neuronal Dynamics*. Cambridge University Press, 2014.
6. A. C. Guyton and J. E. Hall, *Textbook of Medical Physiology*, 11th ed. Elsevier Saunders, 2006 (Chapters 45–46: organisation of the nervous system and synapses).
7. Primary papers: Morrison *et al.* (2005), Kunkel *et al.* (2014), Jordan *et al.* (2018), Potjans & Diesmann (2014), van Albada *et al.* (2018), Knight & Nowotny (2018), Markram *et al.* (2015), Billeh *et al.* (2020), Dorkenwald *et al.* (2024), Shiu *et al.* (2024).

6 Course policies

- Attendance of at least 80% of lectures and laboratories is required to sit the final examination.

- Laboratory reports are individual work; code may be discussed but must be written and understood by the student; all sources, including AI assistants, must be acknowledged.
- Every performance claim must state the hardware, software versions, problem size and number of repetitions; every simulation result must include a verification check.
- Cluster accounts are for course work only and must be used according to the centre’s acceptable-use policy; jobs must be submitted through the batch system.
- Late submissions lose 10% per day and are not accepted after five days without a documented reason. Plagiarism is handled according to the institution’s policy and the HEC plagiarism policy.