Engineering Concentration in Machine Learning (ML)

Requirements and Instructions

bu.edu/eng/programs/machine-learning/

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BOSTON UNIVERSITY

Goals

Equip students with skills in:

1. **ML algorithms:**
   - select
   - adapt or optimize
   - design
   - assess performance
   - explore various application contexts

2. **ML software or hardware tools:** utilize, gain experience

3. **Data:** curate, visualize, or analyze data of various types

4. **Communication:** read and explain methods from ML literature

Overview

- **Concentration Declaration**
- **Coursework** (elective courses on website + slides 18—20)
  - **1 Required overview course** (2 choices; take only one):
    - **ENG EC 414:** Introduction to Machine Learning
    - **ENG EC 503:** Learning from Data
  - **2 Elective depth courses** (30 choices across 3 pillars):
    - **Pillar I:** Models, Learning, and Inference (7 choices)
    - **Pillar II:** Optimization, Algorithms, and Hardware (6 choices)
    - **Pillar III:** Applications (17 choices)
- **Required Experiential Component**
  - **Proposal + Summary + Slides + Self-Recorded Video Presentation**
  - **Options:** laboratory research, directed study, internship, senior design project/thesis, or ML course project from a fourth course.

Important Deadlines

- **Concentration declaration:** Last day of class, Junior Fall.

Experience	Proposal	Draft deliverables	Final deliverables
Senior Design Project or Senior Thesis	Oct 15	Apr 1	Apr 15
Summer Experience	May 30 (approved prior to start)	Sep 1	Sep 15
Others	At least 2 weeks before start	At most 2 weeks after completion **AND** before Dec 1 (Fall) or Apr 1 (Spring)	At most 4 weeks after completion **AND** before Dec 15 (Fall) or Apr 15 (Spring)

Concentration Declaration Requirements

- **Check:** You must have a **declared major** on record
- **Declare concentration** as early as possible, but not later than **the last day of class in the fall of junior year**
- **Download and complete** ML concentration declaration form from website
- **Propose** 3 courses and semesters you plan to take them:
  - 1 required
  - 2 electives
  - **no proposed course must be a required course for the major**
  - If a course project is proposed to satisfy the experiential component, then it must be from a course that is different from the above 3 proposed courses
- **Sign and date** the ML concentration declaration form **and submit** it to: engrec@bu.edu

Experiential Component Requirements

- **Options:** laboratory research, directed study, internship, senior design-project/thesis, or ML course project from a fourth course that is different from the 3 courses used to satisfy the course-requirements of the concentration
- **Required course:** must be completed **before** experience starts
- **Supervisor:** is needed, e.g., faculty member at a university or a researcher in industry. Supervisor must approve the proposal, summary, and presentation
- **Proposal:** must be approved by the Supervisor and Concentration Coordinator, and the Experiential Component Approval form must be submitted to the ENG Registrar's office.
- **Summary, Slides, Presentation Video:** must be submitted after completion of the experiential component. The summary, slides and video must be approved by the Supervisor and Concentration Coordinator.
- **Group projects:** individuals must **explicitly define** and **lead** their own **substantial efforts** directly related to **Machine Learning**
- **Note:** Experiential components cannot be double-counted across different concentrations.

Experiential Component: Confidentiality Issues

- Applies to internships, lab research experiences, startups, or any situation where the work may require participating in a nondisclosure agreement (NDA).

1. Students should, at the outset, be clear with their employers that the job experience will be used to satisfy the experiential requirement of the ML concentration.

2. Experiences involving confidentiality agreements or IP agreements are not exempt from the requirements of the proposal, summary, and presentation.

3. Students should plan for, and prepare the proposal, summary, and presentation to provide sufficient detail for evaluation.

4. The materials delivered to the concentration coordinator should be ‘sanitized’ to prevent disclosure of confidential details covered by an NDA; however, the materials must include sufficient detail to enable clear evaluation of the work and accomplishments that are relevant to the concentration.

5. The proposal and summary forms must include the signature of the supervisor acknowledging they have read the materials being submitted and they approve them.

Experiential Component: International Students

If you are an **international student** planning to use a **CPT-based internship** to complete the experiential component of the concentration, then you must successfully accomplish the following **before you can start your internship**:

- declare the concentration (see slide 5 for requirements),
- complete the required course for the concentration (EC 414 or EC 503),
- submit a proposal (see slides 9—13 for requirements),
- obtain the following approvals and authorizations:
  1. Proposal approval: from the concentration coordinator
  2. CPT approval: from the Assistant Director of the Career Development Office (reach out to the ENG Registrar's office for more information)
  3. ISSO authorization
- Each approval or authorization step requires some time. You must therefore alert your internship employers/supervisors to your situation and **choose a suitable start-date to ensure you have enough time to complete the above requirements**.

Experiential Component: Proposal

- **Submission + approval:** needed **before** experience (form on website)
- **Deadline:** see slide 4
- **Required course:** must be completed **before** experience
- **Experience Supervisor:** name + contact information + their approval
- If a course project is proposed, then it cannot be from the 3 courses used to satisfy the course-requirements of the concentration
- Proposed experience must:
  - Be **relevant** to ML: must connect to some **goals of concentration** (slide 2)
  - Have **substantial ML content involving data and ML algorithms**
- Group projects:
  - **substantial individual contribution to ML tasks** required
  - **individual proposal** required
  - discussion of **ML tasks and individual roles (lead vs support)** required
- Submit proposal-form (completed, signed & dated) + PDF document of proposal (see slides 10—13) to engrec@bu.edu

Experiential Component: Proposal

- **Drafts:** Students are highly encouraged to submit ***drafts*** to the Concentration Coordinator ***at least two weeks prior to the deadline*** in order to allow for the incorporation of feedback and satisfaction of all the requirements.
- **Document Type and Formatting:** The document must be typeset and submitted electronically in PDF format with 1 inch margins and a 12 pt serif font (Computer Modern or equivalent) and all figures and tables should have meaningful captions and should be integrated in the overall narrative to improve the understanding of the reader.
- **Page Limit:** The document should not exceed six pages (excluding References, Appendices, and Description of Individual Effort).
- **Focus:** The proposal should focus on describing the problem(s) under investigation, reviewing the literature, describing the proposed work (goals, ML problems, ML algorithms/models, datasets, data pre-processing, experiments to be performed, software/hardware tools to be used, code to be written), identifying key tasks with estimated completion times, formulating an evaluation plan, discussing division of labor, and including suitable figures, tables, and bibliographic references. ***The proposed work should identify ideal objectives (stretch goals) that you hope to achieve, and a fall-back plan (minimum deliverables), in case the ideal turns out to be unattainable***.
- **Structure:** The document must follow the structure outlined in the next 3 slides (use the bolded terms in the structure as section or subsection titles in your document):

Proposal Structure

Note: the Coordinator will evaluate the below components for approval.

1. **Heading:** “Machine Learning Concentration Experiential Component Proposal” + Title + Your name & major + Name(s), affiliation(s) and email(s) of supervisor(s) + Name(s), major(s) and email(s) of team member(s) (for a group project) + Date

2. **Introduction:** Discuss the broad problem **context** and **motivation** of your project topic. Discuss its importance, relevance, and potential applications. Crisply state the main **goals** of your project. Discuss any challenging aspects of your project or differences from standard problems in machine learning, if any.

3. **Prior Related Work:** Include a short description of the state of the art, including at least four or five sources, such as existing publications or patents that describe relevant problems or methods accompanied by bibliographic references. Be sure to distinguish between works that are only broadly related to the topic of your project and a smaller subset of key papers that are directly or closely related to your project. Your project does not need to be highly original, but discuss where it relies on existing work (e.g., the key papers), and where it differs. If your project is very specialized, you can expand your survey to include other relevant sources, such as publications that do not consider the same problem but nonetheless provide tools used in your project.

Proposal Structure

4. **Detailed Problem Description and Solution Methodology**: (multiple subsections):
   - i. **Learning and decision-making problems:** e.g., classification, regression, clustering, dimensionality reduction, etc. Clearly identify the features and labels (if any). Describe the problems precisely. If needed, use suitable mathematical language. Clearly identify the underlying constraints and assumptions: What is assumed to be known/given/available? What is unknown? What is to be learned; using what? What is to be predicted; using what? Are there any special constraints on what you are allowed to do or not do?
   - ii. **Learning and decision-making models/algorithms:** e.g., nearest-neighbor methods, logistic regression, kernel SVMs, kernel regression, boosting, random forests, multilayer perceptrons, deep learning models, etc. For non-standard models/algorithms include adequate details (key ideas, intuition, mathematical description, etc.) within the document and *pseudo-code* or *mathematical derivations* within an appendix. Identify which model/algorithms are your ***baselines*** for comparison.
   - iii. **Datasets:** provide details of synthetic or/and real datasets to train, fine tune, and test the models/algorithms (use at least 2 datasets – one could be a clean small-scale dataset and another a larger real-world dataset). This includes information about dataset sources and basic dataset properties, e.g., types of features and labels (quantitative, categorical, ordinal), number of samples with different labels, empirical distribution of features, basic statistics of quantitative features, e.g., mean, covariance, etc. Include these details within an appendix.
   - iv. **Data pre-processing:** discuss if your datasets are imbalanced, need feature normalization, have missing components, or outliers and methods to mitigate these issues.
   - v. **Software/hardware tools:** discuss any environments (e.g., Google Colab), software libraries (e.g., Keras, Tensorflow) or hardware (GPUs) required for your project.

Proposal Structure

5. **Experiments:** Describe experiments on synthetic or/and real data. This includes details of the training, fine-tuning/cross-validation, and testing methodology (training, cross-validation and testing folds, loss functions, mini-batch sizes, epochs/ iterations/ stopping-criteria, learning-rate schedules, optimizers). Discuss any experiments related to sensitivity to initialization or other algorithm parameters (called `ablation studies') and impact of real-world degradations like class imbalance, missing data, outliers, high data dimensionality or predictor-complexity relative to the size of the training set.
6. **Tasks and timeline:** propose a sequence of **key** tasks and their estimated completion times
7. **Evaluation plan:** Provide performance metrics (use more than one) and criteria to decide what would be deemed success or failure. This should be based on measurable goals stated using absolute targets or as relative improvements with respect to the status quo (baseline), e.g., “The project will be deemed a success if our proposed methods improve the F1 score of the prior method by 5% points.”
8. **Key figures and tables:** as appropriate (within 6-page limit)
9. **Bibliographic references:** Include the list of references used.
10. **Appendices:** describe detailed dataset properties, pseudo-code of non-standard methods, mathematical derivations, and *additional* figures or tables if some *finer points* need to be made.
11. **Individual contribution:** Required only if the proposed work is part of a group project. Discuss key ML tasks and individual efforts of all team members (identify lead and supporting roles). If multiple students in the group are using the same project as a concentration experiential component, include a table with the names and the leading roles for each student; each student should be responsible for at least one substantial ML task that has little overlap with the others.

Experiential Component: Summary & Presentation

- Must be submitted and approved **after** completion of experience (form on website)
- **Deadline:** see slide 4
- Must include **supervisor's approval** via signature on summary form
- **Deliverables:** Submit the following to engrec@bu.edu
  - Copy of Experiential Component Proposal
  - Summary Approval Form (completed, signed & dated)
  - PDF document of Summary (see slide 15)
  - PDF document of presentation slides (see slides 16, 17)
  - Link to a self-recoded video of your presentation placed on your BU Google Drive (**include link in PDF document of presentation slides**)
- **Drafts:** Students are highly encouraged to submit ***drafts*** of the summary to the Concentration Coordinator ***at least two weeks prior to the deadline*** in order to allow for the incorporation of feedback and satisfaction of all the requirements.
- **Group project report and presentation requirements:** an ***individual report and presentation*** is required; substantial ***individual*** contribution to ***ML tasks*** is required; ***discussion of ML tasks and individual roles*** (lead vs support) required.

Experiential Component: Summary

- **Note:** the Coordinator will evaluate the below components for approval.
- **Document Type, Formatting, Page Limit, and Structure:** The Summary should *follow the same requirements as the proposal*. See slides 10—13.
- **Work Performed:** Please provide specific details on the work actually performed and completed, highlighting the challenges you encountered and the implemented solutions.
- **Evaluation:** For the evaluation part, the report should include training and testing performance metrics obtained by baseline methods (which could be from prior work) and the methods that you implemented and compare them. In particular,
  - Report the ***average values*** of performance metrics together with ***error bars*** on the training set (at the end of training and fine-tuning/cross-validation) and on the test sets (across test folds).
  - Use suitable figures and tables to aid comparison of results across different methods and experimental settings.
  - Discuss if your results are consistent with your understanding, i.e., are they expected or unexpected? Can you explain them? Do they make sense?
  - Discuss pros and cons (if any) of different methods.
  - Discuss any results related to sensitivity to initialization or other algorithm parameters and impact of real-world degradations like class imbalance, missing data, outliers, high data dimensionality or predictor complexity relative to the size of the training set.
  - When feasible, discuss and compare the time/memory complexities of the models/algorithms you have explored.
- **Conclusion:** Describe what you have learned from the project and (***optionally***) what further improvements are possible.

Experiential Component: Presentation

- **Presentation slides:**
  - **Limit:** not more than 10 slides (excluding animations)
  - **Structure:** follow Summary structure, but could cover different, complementary content.
  - **Submit:** a **PDF file** of your slides together with your Summary
- **Video recording of slide presentation:**
  - **Self-recorded video:** of your **slide presentation**
  - **Video duration:** not more than 5 minutes
  - **Presenter visibility:** video should show the presentation content together with the student presenting (suggested solution: use a screen recording in Zoom with the participant video panel visible).
  - **Share:** Place the video file in **your** BU Google Drive and include a **link** to it in the PDF document of your slides (**on the first slide**)

Presentation content and delivery tips:

- **Structure and Content:** This should be similar to the Summary, but do not aim to duplicate it exactly or be too detailed. Crisply convey to an audience of your peers, the main problems and methods studied in your project, the context, motivation, and significance of the problems being studied, and the key experiments and results. The discussion of related work can be much shorter than in the Summary and you need not present detailed mathematical derivations (unless it is crucial to your project). Aim for a clear, well-organized presentation highlighting any "cool" aspects.
- **Minimize text; use visuals:** Use ***simple*** (not overly complex) figures, diagrams, animations, images, videos, and short bullet lists as much as possible. Keep the amount of text on the slides to a minimum. Use ***short phrases*** occupying only 1 or 2 lines instead of long, grammatically correct, complete sentences.
- **Math:** Carefully choose which equations (if any) you want to display. Do not blindly dump many equations from the Summary into your presentation. Any symbol that you display must be explained at some level otherwise it need not be displayed at all. Aim to provide an intuitive explanation or interpretation of the underlying mathematics if you include math in your slides.
- **Make an outline** of the main points that you want to convey *before* preparing the presentation. Practice a "dry run" in front of your friends. If you find yourself out of time or having to run through the presentation, it means that you need to prioritize and select the main points better.
- **Stay under the given time limit:** In the industry, if a limit is specified and it is significantly exceeded, it will create a negative impression on co-workers and the management.
- **Presenter is crucial, not slides:** The most important part of a presentation is the presenter speaking; the slides are just a visual support to stress the most important points. You want your audience to ***listen*** to you rather than spend time reading slides.

Elective Courses

Taking courses across multiple pillars will add to the breadth and diversity of knowledge, whereas taking several courses from one pillar will provide depth within that pillar.

- **Pillar I: Models, Learning, and Inference**
  - ENG EC 418 – Introduction to Reinforcement Learning
  - ENG EC 523 / CAS CS 523 – Deep Learning
  - ENG BE 500 (Dunlop): Deep learning for BME images and signals
  - ENG EC 500 (Venkataraman): Foundations of Probabilistic Machine Learning
  - ENG BE 559: Foundations of BME data science and ML
  - ENG EC 505 – Stochastic Processes and Inference
  - ENG EC 517 – Introduction to Information Theory

Elective Courses

Taking courses across multiple pillars will add to the breadth and diversity of knowledge, whereas taking several courses from one pillar will provide depth within that pillar.

- **Pillar II: Optimization, Algorithms, and Hardware**
  - ENG EC 525 – Optimization for Machine Learning
  - ENG EC 504 – Advanced Data Structures and Algorithms
  - ENG EC 524 – Optimization Theory and Methods
  - ENG EC 526 – Parallel Algorithms for High Performance Computing
  - ENG EC 527 – High Performance Programming with Multicore and GPUs
  - ENG EC 528 – Cloud Computing

Elective Courses

- **Pillar III: Applications**
  - ENG BE 403 – Biomedical Signals and Controls
  - ENG BE 500 – AI and Systems Biology
  - ENG BE 500 (Dunlop) – Deep Learning for Biomedical Images and Signals
  - ENG BE/EC 519 Speech Processing by Humans and Machines
  - ENG BE 562 – Computational Biology: Machine Learning Fundamentals
  - ENG BE 570 – Introduction to Computational Vision
  - ENG ME 404 – Dynamics and Control of Mechanical Systems
  - ENG ME 416 – Introduction to Robotics
  - ENG EK 505 – Introduction to Robotics and Autonomous Systems
  - ENG ME 570 – Robot Motion Planning
  - ENG EC 401 – Signals and Systems
  - ENG EC 402 – Control Systems
  - ENG EC 415 – Software Radios
  - ENG EC 516 – Digital Signal Processing
  - ENG EC 518 – Robot Learning
  - ENG EC 500 (Batmangheligh): Medical Image Analysis using AI tools
  - ENG EC 520 – Digital Image Processing and Communication

Questions?

- Administrative:

  ENG Registrar's office
  engrec@bu.edu

- Other:

  ML Concentration Coordinator
  Prof. Prakash Ishwar pi@bu.edu