CSE 6243

Advanced Topics in Machine Learning

Bo Dai
School of CSE, Georgia Tech

Course Introduction

Bo Dai

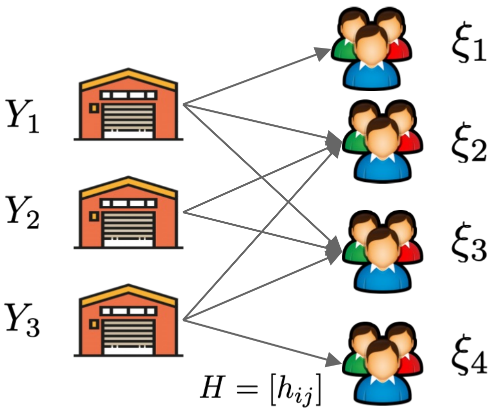
Assistant Professor
School of Computational Science and Engineering

Address: Coda E1342A
Email: bodai@cc.gatech.edu
Homepage: https://bo-dai.github.io

Teaching:
CSE6243 Advanced Machine Learning (Monday/Wednesday 5:00-06:15 pm)
https://bo-dai.github.io/CSE6243-fall2024/

Decision-Making Problem is Everywhere

Georgia Tech College of Computing
Computational Science and Engineering

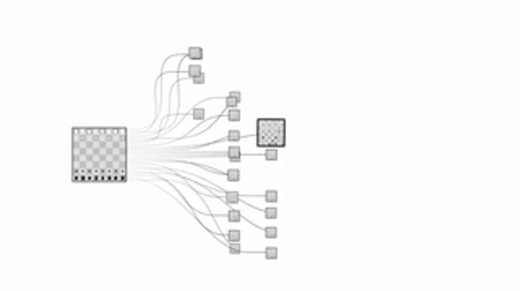


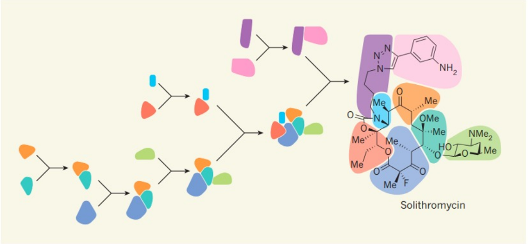
Order Fulfillment under Uncertainty

Path Planning

Searching/Decoding

Robotics



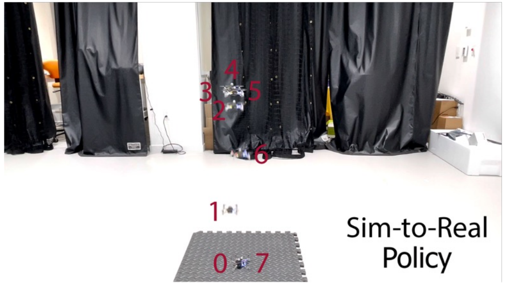


Drug Synthesis

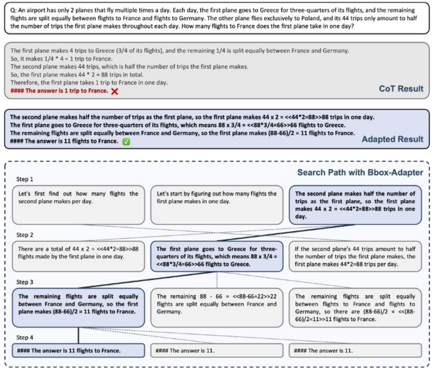
Practical decision-making and planning algorithms with computational and statistical efficiency

Foundation Model for Decision Making

Georgia Tech College of Computing
Computational Science and Engineering



Sim2Real [IROS 2024]



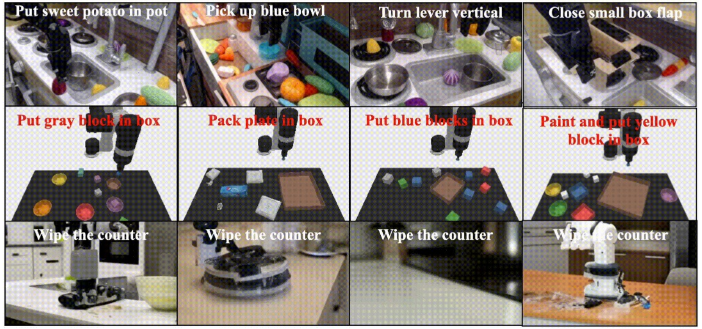
LLM Planning & Reasoning [ICML 2023 & 2024]

Foundation Models methods to complete

All tasks with Single interface

combating Computation and Sample complexity

in decision-making process, aiming for better Agent



Uni-Policy [NeurIPS 2023]

Reinforcement Learning, Representation, Generative Models, Optimization and Sampling

Teaching Assistant

Dmitry Shribak

Address: Coda East Wing
Email: shribak@gatech.edu

Logistics

Time: Monday/Wednesday 5:00-06:15 pm

Location: Molecular Sciences and Engr 1222

Discussion & HW submission: Ed Discussion & Canvas

Office Hour:

- Instructor: TBD
- TA: TBD

Prerequisite

- Graduate-level Machine Learning
  - Deep neural networks
  - Graphical models
  - Kernel methods…
- Probability and Statistics
  - Random variable, moment generating function
  - Bootstrap, delta method
  - MCMC sampling ...
- Numerical Linear Algebra & Optimization
  - Eigen decomposition, Singular value decomposition
  - Gram-Schmidt process
  - Convex function, duality…

Outline

Providing a unified view for different machine learning methods:

- Module I: Background Knowledge
- Module II: Generative Model
- Module III: Representation Learning
- Module IV: Reinforcement Learning

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WhiteBoard Derivation

Outline

- Module I: Background Knowledge
- Module II: Generative Model
- Module III: Representation Learning
- Module IV: Reinforcement Learning

Guest lectures from prestigious researchers

Reinforcement Learning, and Foundation Models

https://bo-dai.github.io/CSE6243-fall2024/

Textbooks

- Boyd & Vandenberghe. Convex Optimization. Cambridge University Press. 2003
- Bishop. Pattern Recognition and Machine Learning. Springer. 2006
- Mohri, Rostamizadeh, & Talwalkar. Foundations of Machine Learning. MIT Press. 2018
- Putman. Markov Decision Processes: Discrete Stochastic Dynamic Programming. John Wiley & Sons, Inc. 1994

The material of the class may go beyond these books

Module I: Background Knowledge

- Convex Optimization
  - Convex function
  - Duality
  - Stochastic gradient descent
- Probabilistic graphical model
  - Directed graphical models (Bayes Nets)
  - Undirected graphical models (Markov Random Fields)
- Sampling
  - Metropolis–Hastings algorithm
  - Gibbs sampling
  - Hamiltonian Monte-Carlo
- Revisit Neural Network

Module II: Generative Model

- Variational auto-encoder
- Autoregressive model
- Generative adversarial net
- Energy-based model
- Diffusion models

Module II: Generative ~~Model~~ AI

- Variational auto-encoder
- Autoregressive model : ChatGPT, Gemini, Claude.....
- Generative adversarial net
- Energy-based model
- Diffusion models : Midjourney, Stability AI, Imagen, Pika....

Module III: Representation Learning

- Representation Learning from EBM view
- Representation Learning from Spectral Decomposition view

Module IV: Reinforcement Learning

- Markov decision process
- Approximate dynamic programming
- Policy gradient
- Imitation learning
- (Offline RL, Exploration)...

Grading

- Participation (20%)
- Scribe Duties (40%)
- Final Project (40%)

Grading

- Participation (**20%**)
  - In-Class quiz **10%**
  - Completing mid-semester evaluation **4%**.
  - Machine Learning seminar **6%**

This is an in person class, no zoom link, except the guest lectures.

Grading

- Scribe Duties (40%)
  - 2 students as a group
  - 24-26 lectures scribing with template
  - Submitted in 1 week on Canvas
  - Scribing slots https://docs.google.com/spreadsheets/d/11bQt7aMhygQ8gyrSXj8DZb3rrcy61k-KJSSynCQMRT8/edit?usp=sharing

Grading

- Final Project (40%)
  - 2-4 students as a group
  - **Proposal** : 2 pages excluding references (10%)
  - **Midway Report** : 3 pages excluding references (20%)
  - **Presentation** : oral presentation (20%)
  - **Final Report** : 5 pages excluding references (50%)
  - All write-ups should use the NeurIPS style

More details: https://bo-dai.github.io/CSE6243-fall2024/project/

What is Machine Learning?

Machine learning (**ML**) is an umbrella term for solving problems for which development of algorithms by human programmers would be cost-prohibitive, and instead the problems are solved by helping machines 'discover' their 'own' algorithms,[1] without needing to be explicitly told what to do by any human-developed algorithms.

-- Wikipedia

Machine learning is a branch of artificial intelligence (AI) that focuses on developing computer systems that can learn and adapt without explicit programming. Instead of following rigid rules, these systems learn from data and improve their performance over time.

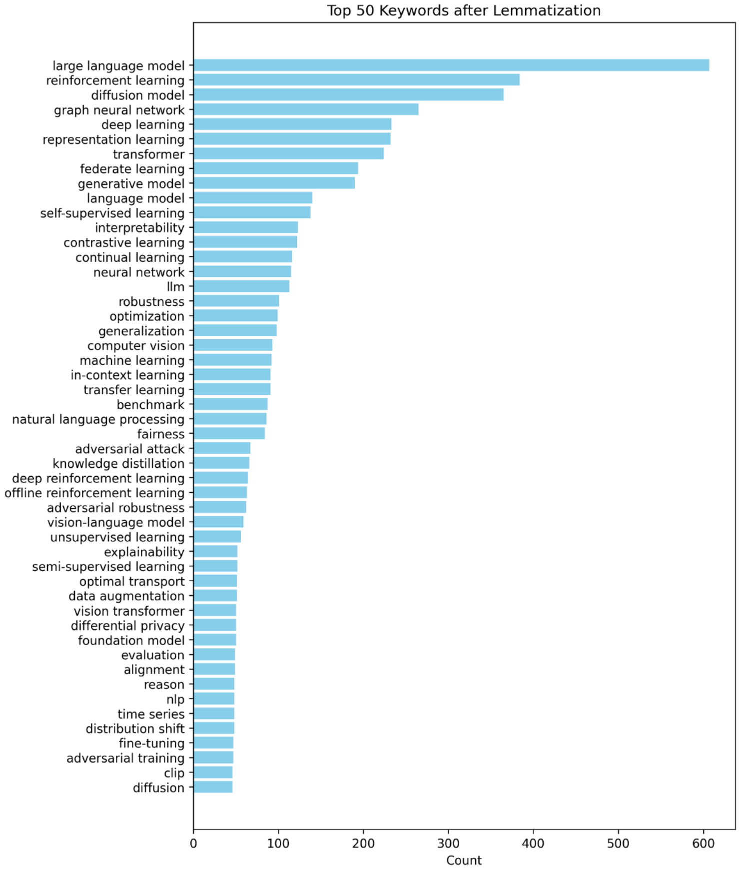
-- Gemini

Machine learning (ML) is a subset of artificial intelligence (AI) focused on the development of algorithms and statistical models that allow computers to learn from and make predictions or decisions based on data. Instead of being explicitly programmed to perform specific tasks, machine learning systems use data to identify patterns and improve their performance over time.

ChatGPT

Personal Opinion

- Machine Learning is a subfield of AI
- Machine Learning focuses on a special type of algorithm design
    - These algorithms consume data, generates a model for prediction and decision


Top 50 Keywords after Lemmatization
large language model
reinforcement learning
diffusion model
graph neural network
deep learning
representation learning
transformer
federate learning
generative model
language model
self-supervised learning
interpretability
contrastive learning
continual learning
neural network
llm
robustness
optimization
generalization
computer vision
machine learning
in-context learning
transfer learning
benchmark
natural language processing
fairness
adversarial attack
knowledge distillation
deep reinforcement learning
offline reinforcement learning
adversarial robustness
vision-language model
unsupervised learning
explainability
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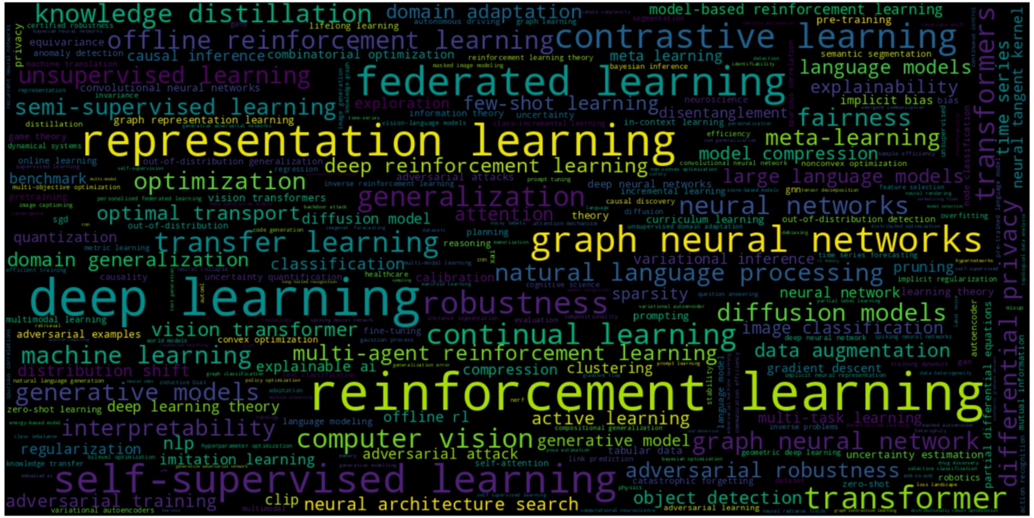
knowledge distillation
domain adaptation
model-based reinforcement learning
offline reinforcement learning
contrastive learning
transformers
unsupervised learning
federated learning
language models
explainability
semi-supervised learning
few-shot learning
fairness
representation learning
meta-learning
model compression
deep reinforcement learning
optimization
large language models
generalization
neural networks
optimal transport
diffusion model
attention
transfer learning
graph neural networks
domain generalization
classification
natural language processing
differential privacy
deep learning
robustness
sparsity
diffusion models
vision transformer
continual learning
image classification
machine learning
multi-agent reinforcement learning
data augmentation
distribution shift
explainable ai
clustering
generative models
reinforcement learning
deep learning theory
active learning
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self-supervised learning
adversarial training
clip
neural architecture search
object detection
transformer
causal inference
combinatorial optimization
meta learning
implicit bias
exploration
disentanglement
benchmark
quantization
variational inference
pruning
neural network
multi-task learning
offline rl
uncertainty estimation
gradient descent
compression
time series
neural tangent kernel

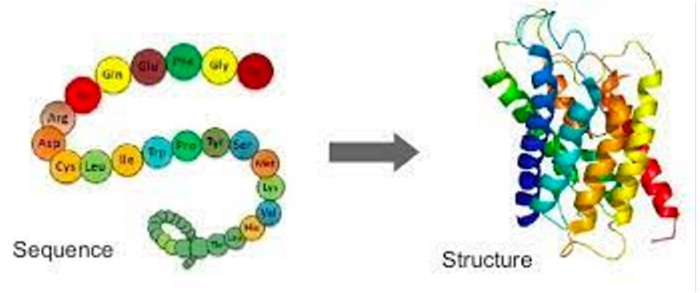
Machine Learning Paradigms

Supervised Learning $\mathcal{D} = \{(x_i, y_i)\}_{i=1}^{n} \in \mathcal{X} \times \mathcal{Y}$ $\quad \text{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \to \mathcal{Y}$

Unsupervised Learning $\mathcal{D} = \{x_i\}_{i=1}^{n} \in \mathcal{X}$ $\quad \text{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \to \mathcal{Z}$

Reinforcement Learning

Machine Learning Paradigms



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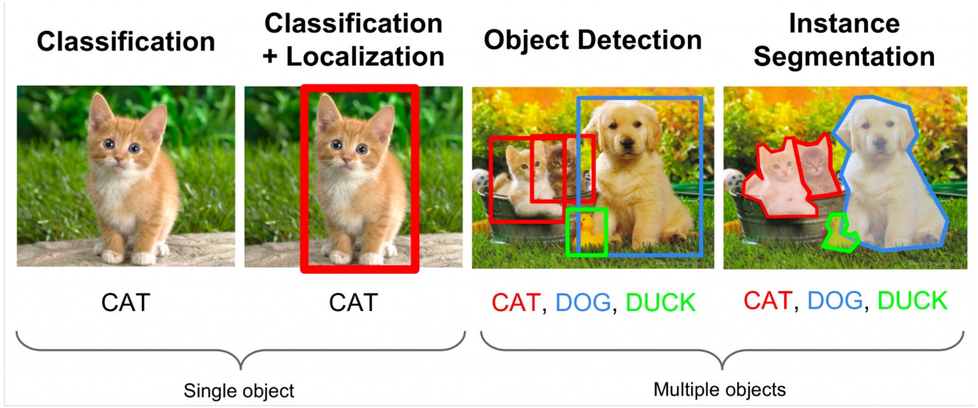
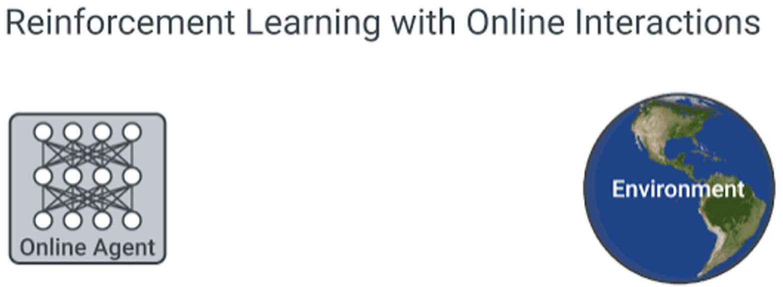


Machine Learning Paradigms

Passive Learning

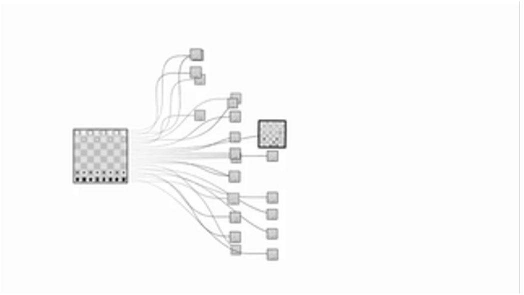
- Supervised Learning $\mathcal{D} = \{(x_i, y_i)\}_{i=1}^{n} \in \mathcal{X} \times \mathcal{Y}$ $\quad \mathrm{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \rightarrow \mathcal{Y}$
- Unsupervised Learning $\mathcal{D} = \{x_i\}_{i=1}^{n} \in \mathcal{X}$ $\quad \mathrm{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \rightarrow \mathcal{Z}$

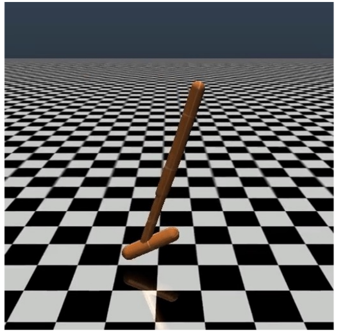
Reinforcement Learning



$$\mathrm{Alg}(\mathrm{Env}) \Rightarrow (\mathcal{D} = \{(s_i, a_i, r_i, s_i')\}_{i=1}^{T},\ \pi(\cdot|s) : \mathcal{S} \rightarrow \Delta(\mathcal{A}))$$

Machine Learning Paradigms





Reinforcement Learning

Reinforcement Learning with Online Interactions

$$\text{Alg}(\text{Env}) \Rightarrow (\mathcal{D} = \{(s_i, a_i, r_i, s_i')\}_{i=1}^{T},\ \pi(\cdot|s) : \mathcal{S} \to \Delta(\mathcal{A}))$$

Machine Learning Paradigms

Supervised Learning

Unsupervised Learning

Reinforcement Learning

$$\mathcal{D} = \{(x_i, y_i)\}_{i=1}^{n} \in \mathcal{X} \times \mathcal{Y} \quad \mathcal{D} = \{x_i\}_{i=1}^{n} \in \mathcal{X}$$

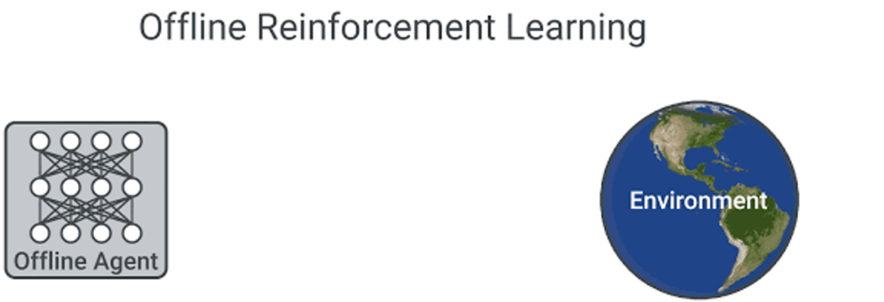
Semi Supervised Learning

Machine Learning Paradigms

Supervised Learning

Unsupervised Learning

Reinforcement Learning



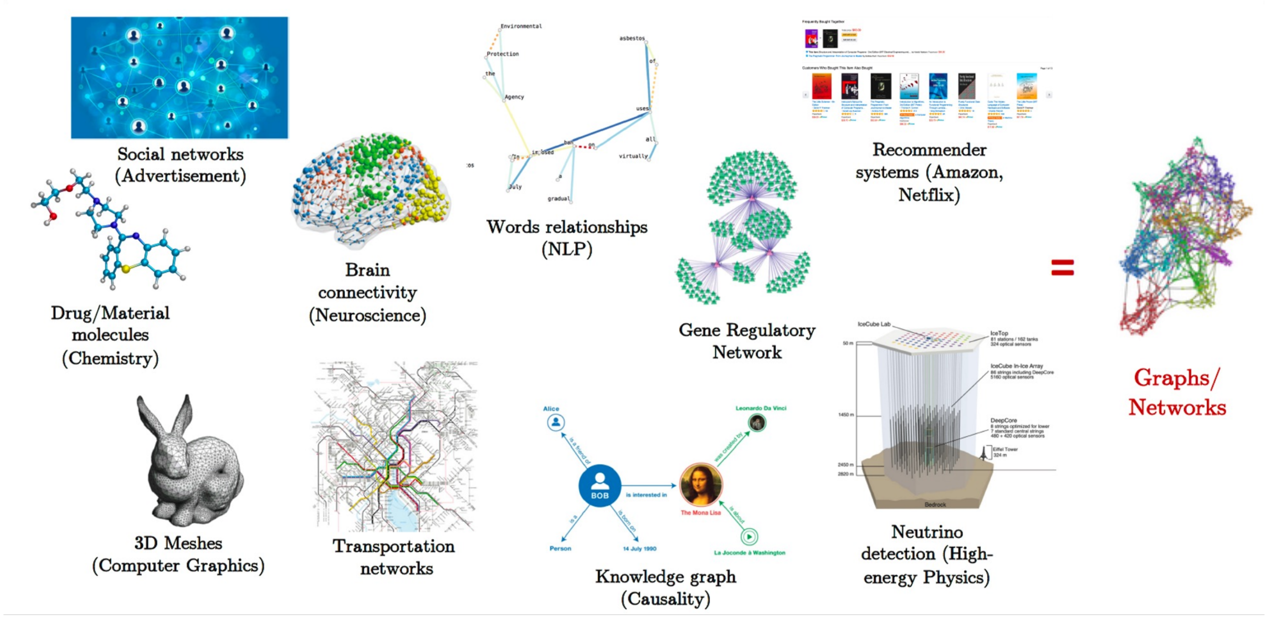
$$\mathcal{D} = \{(s_i, a_i, r_i, s_i')\}_{i=1}^{T} \qquad \mathrm{Alg}(\mathcal{D}) \Rightarrow \pi(\cdot|s) : \mathcal{S} \to \Delta(\mathcal{A})$$

Machine Learning Paradigms

Graph Learning

Passive Learning
- Supervised Learning
- Unsupervised Learning

Reinforcement Learning



Machine Learning Paradigms

Module I
Basic Knowledge

Supervised Learning

Unsupervised Learning

Reinforcement Learning

Module II
Generative Models

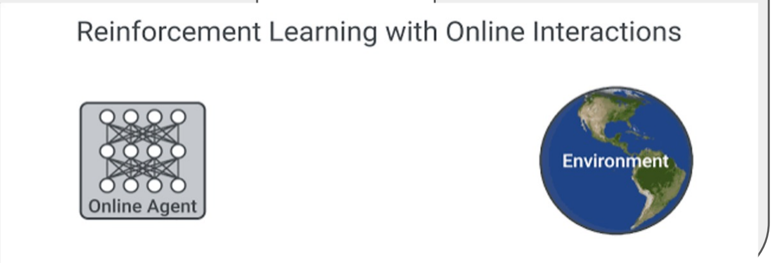
$$\mathcal{D} = \{(x_i, y_i)\}_{i=1}^{n} \in \mathcal{X} \times \mathcal{Y}$$

$$\mathcal{D} = \{x_i\}_{i=1}^{n} \in \mathcal{X}$$

Module III
Differentiable Programming

$$\mathrm{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \to \mathcal{Y}$$

$$\mathrm{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \to \mathcal{Z}$$



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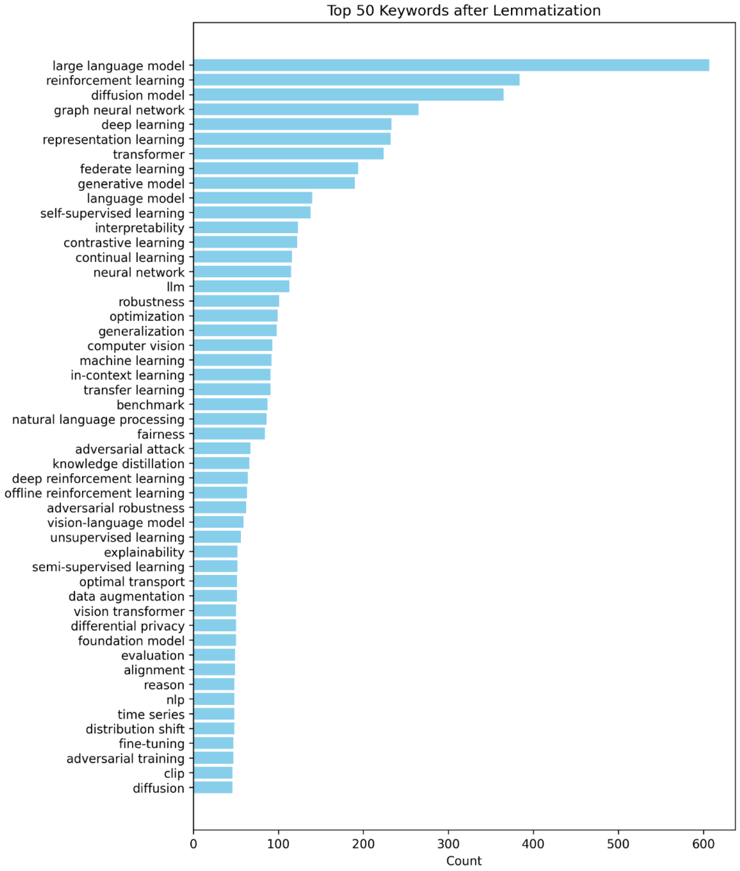
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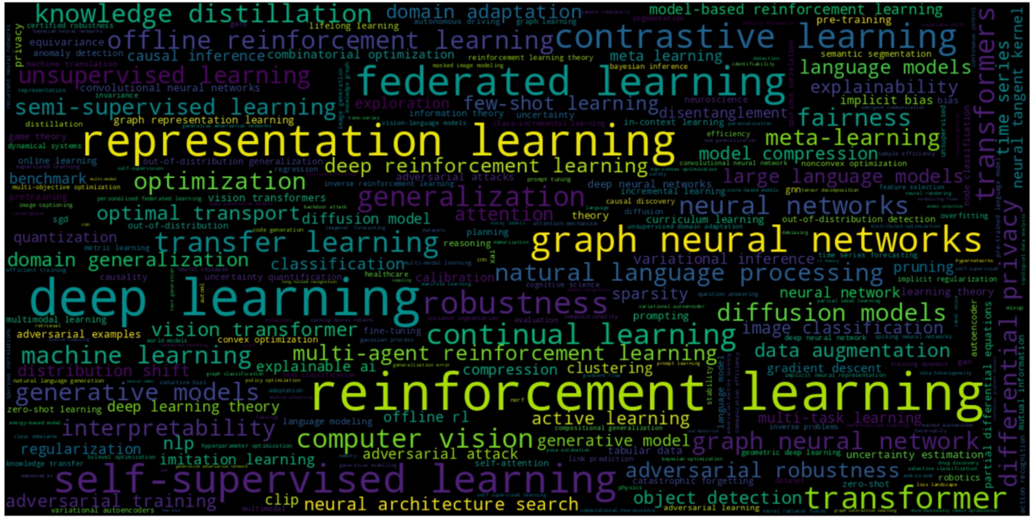
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regularization
nlp
clip
benchmark

Machine Learning Paradigms

Module I
Basic
Knowledge

Module II
Generative
Models

Module III
Representation
Learning

Supervised Learning

$$\mathcal{D} = \{(x_i, y_i)\}_{i=1}^n \in \mathcal{X} \times \mathcal{Y}$$

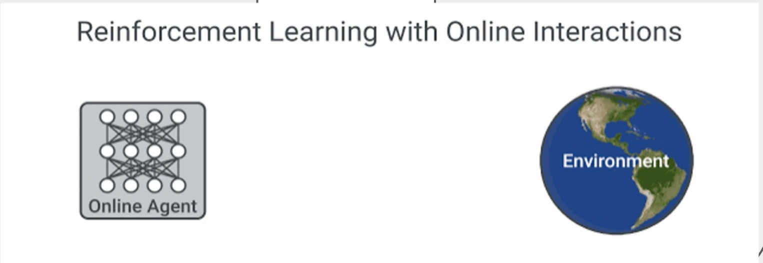
$$\mathrm{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \to \mathcal{Y}$$

Unsupervised Learning

$$\mathcal{D} = \{x_i\}_{i=1}^n \in \mathcal{X}$$

$$\mathrm{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \to \mathcal{Z}$$

Modele IV
Reinforcement Learning



$$\mathrm{Alg}(\mathrm{Env}) \Rightarrow (\mathcal{D} = \{(s_i, a_i, r_i, s_i')\}_{i=1}^T,\ \pi(\cdot|s) : \mathcal{S} \to \Delta(\mathcal{A}))$$

Tentative Schedule

https://bo-dai.github.io/CSE6243-fall2024/lectures/

Q&A