

CSE 6243

Advanced Topics in Machine Learning

Bo Dai
School of CSE, Georgia Tech

Course Introduction

Instructor



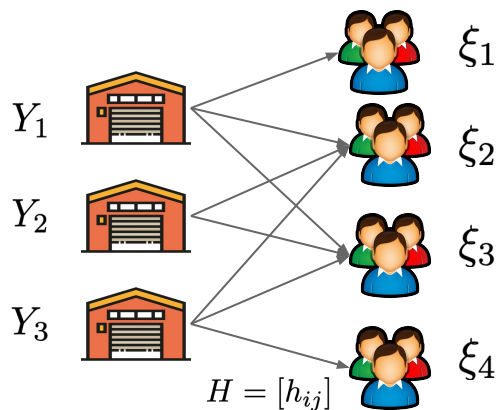
Bo Dai

Assistant Professor
School of Computational Science and Engineering

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Email: bodai@cc.gatech.edu
Homepage: <https://bo-dai.github.io>

Teaching:
CSE6243 Advanced Machine Learning <https://bo-dai.github.io/CSE6243-fall2023/>

Decision AI

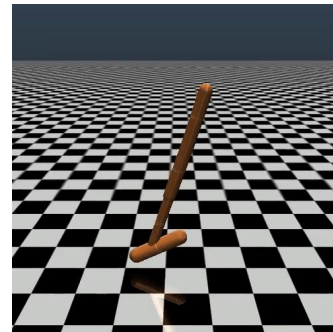


Order Fulfillment under Uncertainty

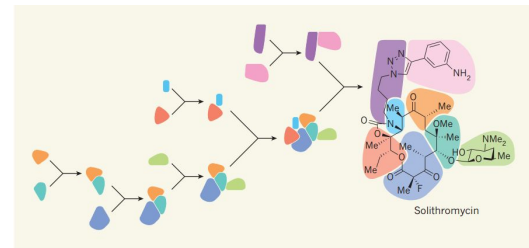


Stochastic Combinatorial Optimization

Searching/Decoding



Sequential Decision Making



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

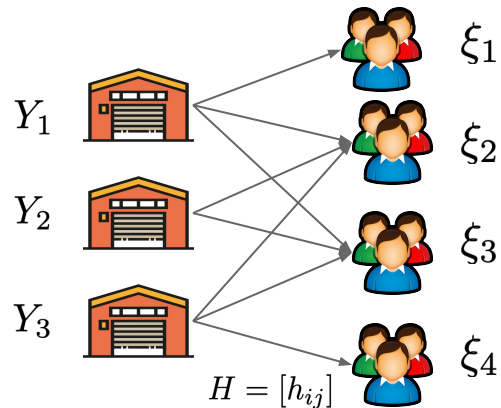
Decision AI

Learning-based methods to combat

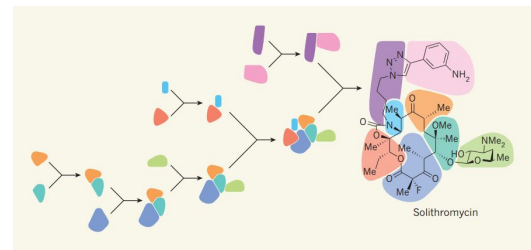
Combinatorial and Stochastic complexity

in decision-making process, focusing on

better decisions in Social and Physical science.



Reinforcement Learning, Generative Models, Optimization and Sampling



Teaching Assistant



Haotian Sun

Address: Coda East Wing

Email: haotian.sun@gatech.edu

Logistics

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

Location: [Scheller College of Business 203](#)

Discussion & HW submission: [Ed Discussion & Canvas](#)

Office Hour:

- Instructor: Monday, 4:00 - 5:00PM, CODA E1342A
- TA: Wednesday, 4:00 - 5:00PM, TBD, CODA C1306

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

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

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

Guest lectures from prestigious researchers

Advanced Sampling, Reinforcement Learning, and Foundation Models

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](#), [Bard](#), Claude.....
- Generative adversarial net
- Energy-based model
- Diffusion models : Midjourney, Stability AI, Imagen....

Module III: Differentiable Programming

- Differentiable bilevel optimization as NNs
- Differentiable sampler as NNs
- Differentiable algorithms as NNs

Module IV: Reinforcement Learning

- Markov decision process
- Approximate dynamic programming
- Policy gradient
- Linear Programming-based planning
- (Offline RL, Exploration)...

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
- Amos. [Tutorial on amortized optimization](#).
- Putman. [Markov Decision Processes: Discrete Stochastic Dynamic Programming](#). John Wiley & Sons, Inc. 1994

The material of the class may go beyond these books

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/1TTlvcGLdT3sJgRes-8ml1eDk9EdnSPVISIP59FGVvU/edit?usp=sharing>

Grading

- Final Project (40%)
 - 3-4 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-fall2023/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 subfield of artificial intelligence (AI) that focuses on developing algorithms and models that enable computers to learn from and make predictions or decisions based on data, without being explicitly programmed. The goal of machine learning is to enable computers to improve their performance on a task by learning from experience.

-- ChatGPT

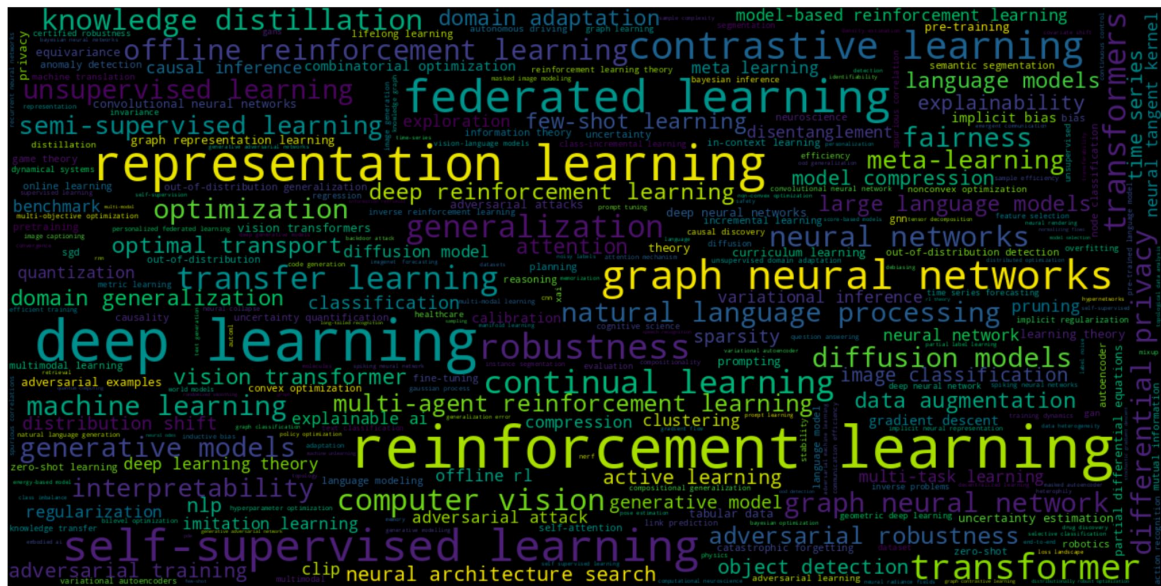
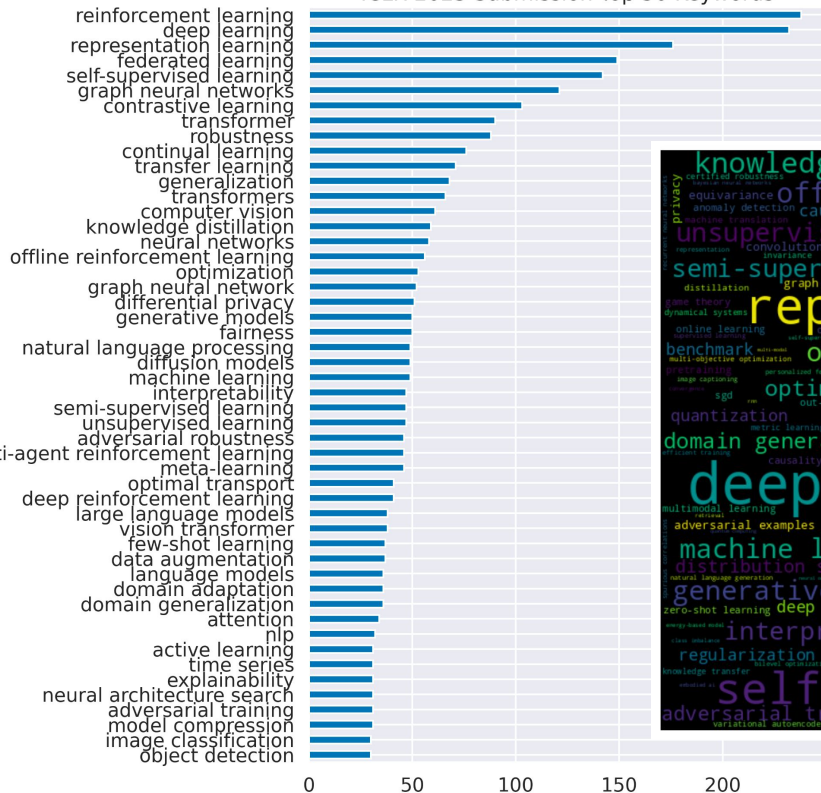
Machine learning is a type of artificial intelligence (AI) that allows software applications to become more accurate in predicting outcomes without being explicitly programmed to do so. Machine learning algorithms use historical data as input to predict new output values.

-- Google Bard

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

ICLR 2023 Submission Top 50 Keywords



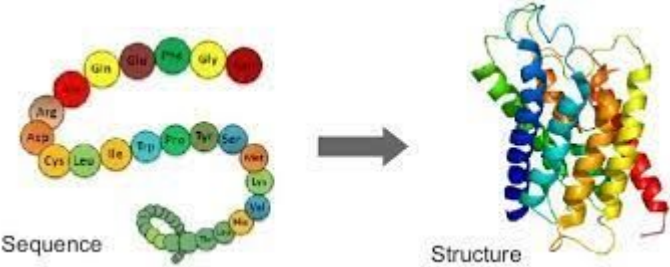
Machine Learning Paradigms

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

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

Reinforcement Learning

Machine Learning Paradigms





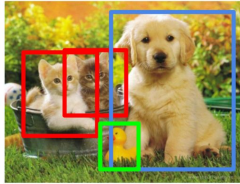

Supervised Learning

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

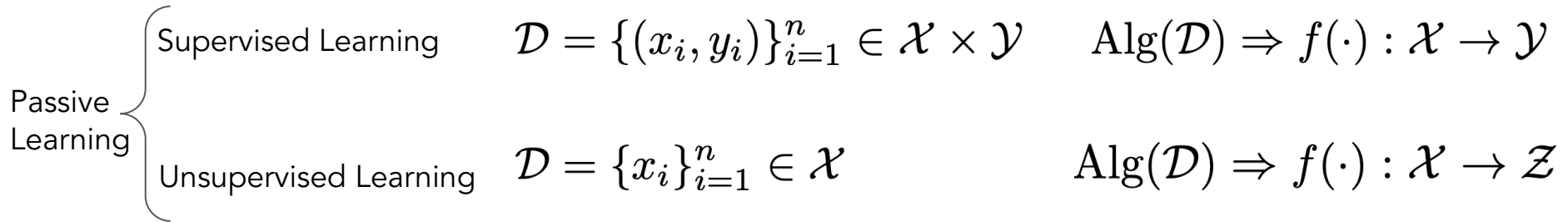
Unsupervised Learning

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



| Classification | Classification + Localization | Object Detection | Instance Segmentation |
|---|--|---|---|
|  |  |  |  |
| CAT | CAT | CAT, DOG, DUCK | CAT, DOG, DUCK |
| Single object | | Multiple objects | |

Machine Learning Paradigms



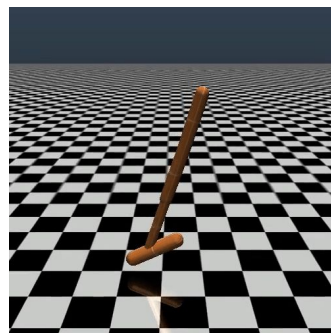
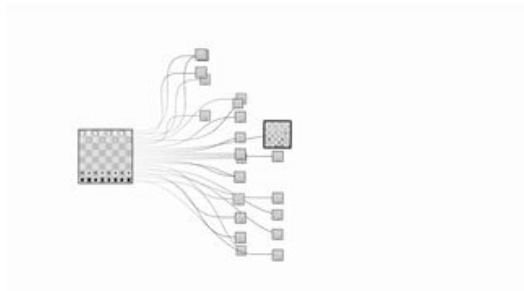
Reinforcement Learning with Online Interactions

Reinforcement Learning



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

Machine Learning Paradigms



Reinforcement Learning

Reinforcement Learning with Online Interactions



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

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

Offline Reinforcement Learning



$$\mathcal{D} = \{(s_i, a_i, r_i, s'_i)\}_{i=1}^T$$

$$\text{Alg}(\mathcal{D}) \Rightarrow \pi(\cdot|s) : \mathcal{S} \rightarrow \Delta(\mathcal{A})$$

Machine Learning Paradigms

Graph Learning

Passive Learning

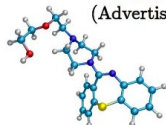
Supervised Learning

Unsupervised Learning

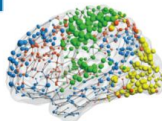
Reinforcement Learning



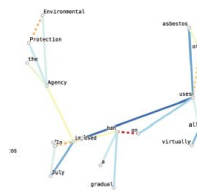
Social networks
(Advertisement)



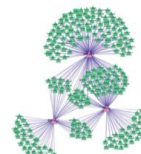
Drug/Material
molecules
(Chemistry)



Brain
connectivity
(Neuroscience)



Words relationships
(NLP)



Gene Regulatory
Network



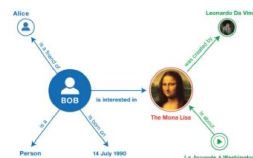
Recommender
systems (Amazon,
Netflix)



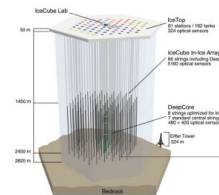
3D Meshes
(Computer Graphics)



Transportation
networks



Knowledge graph
(Causality)



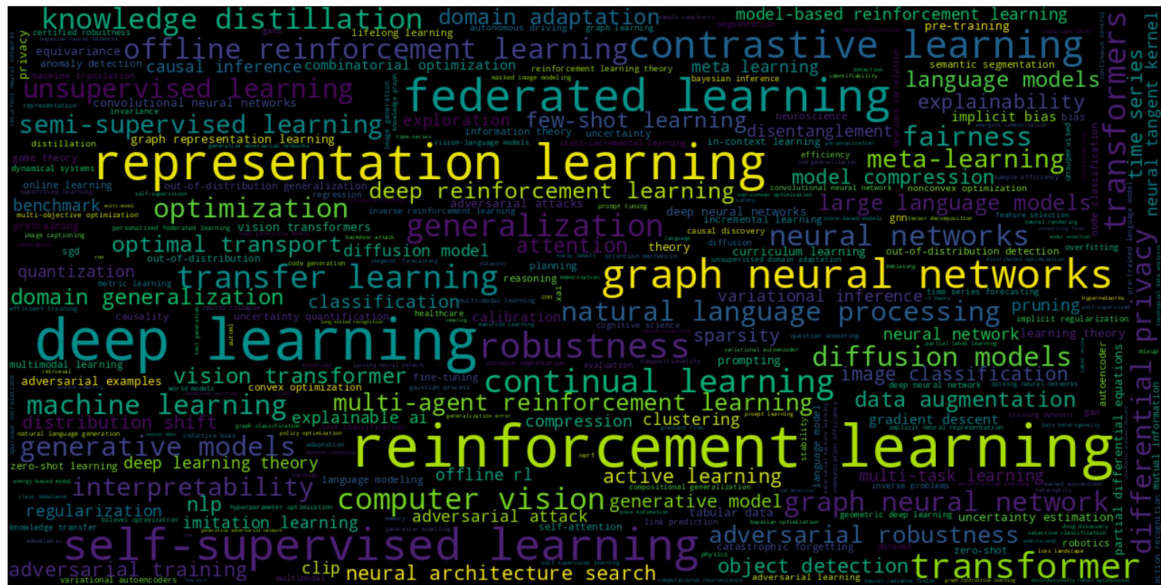
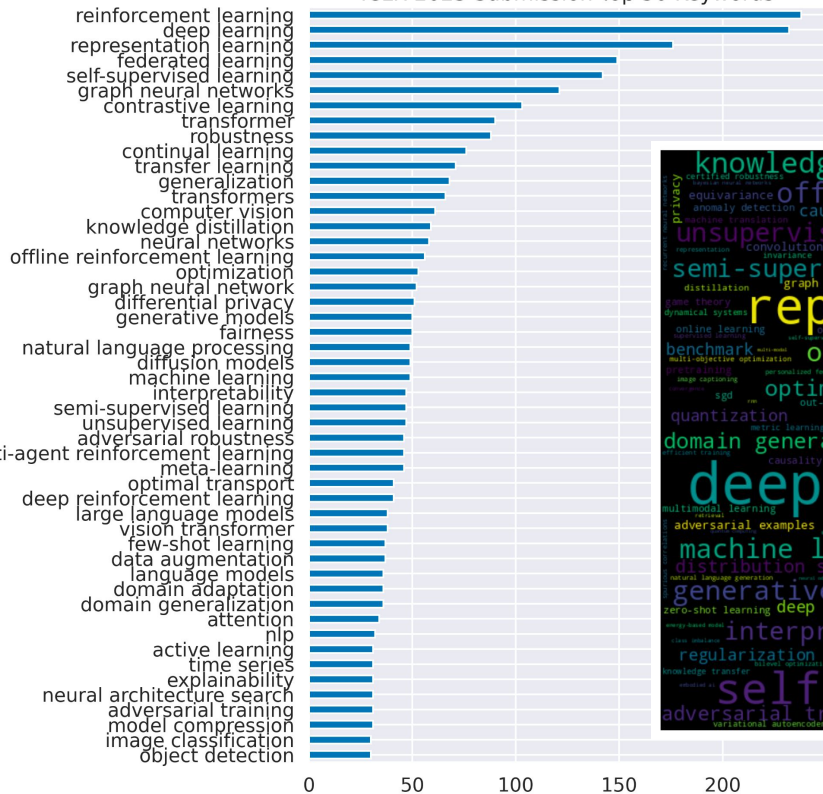
Neutrino
detection (High-
energy Physics)

=



Graphs/
Networks

ICLR 2023 Submission Top 50 Keywords



Machine Learning Paradigms

Module I Basic Knowledge

Supervised Learning

Unsupervised Learning

Reinforcement Learning

Module II Generative Models

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

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

Reinforcement Learning with Online Interactions



Module III Differentiable Programming

$$\text{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \rightarrow \mathcal{Y}$$

$$\text{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \rightarrow \mathcal{Z}$$



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

Machine Learning Paradigms

Module I
Basic
Knowledge

Supervised Learning

Unsupervised Learning

Module III
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

$$\text{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \rightarrow \mathcal{Y}$$

$$\text{Alg}(\mathcal{D}) \Rightarrow f(\cdot) : \mathcal{X} \rightarrow \mathcal{Z}$$

Reinforcement Learning with Online Interactions



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

Q&A