Organization & Introduction

Probabilistic Decision Making VU – Practicals

(Reinforcement Learning KU)

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About Me

- PhD Student supervised by Prof. Peharz
- Computer Science background (Machine Learning)
- Research interests include
  - Probabilistic Machine Learning
  - Efficient Exact & Approximate Probabilistic Inference
  - Generative Models (Diffusion Models, Flows, . . .)
  - Probabilistic Circuits

What about You?

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At the end of this semester, you will

- Embrace probability theory as **optimal reasoning under uncertainty** 😍
- Be fluent in the **"language"** of probability 🗣️
  - Which allows you to easily understand & communicate many modern ML concepts
- Accept that probabilistic inference is **hard**, but not **hopeless** ❗
  - You know ways to model problems such that **inference is easy**
  - You know your way around **approximate inference** techniques
- Be able to interpret Machine Learning **through the lens of probability** 🤖

Organization

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- Attendence in the practicals **not mandatory**
- All practicals will be recorded (TUbe)
- 4 Assignment Sheets, worked on in groups of **at most 2** students
  - Submission via TeachCenter (PDF Report and Python Code)
  - Sufficient if **one team member** uploads submission
  - Cover Letter indicates group members
  - Groups can change during the semester
- If submission contains parts that are LLM-generated, or copied from different group
  - $\Longrightarrow$ **Plagiarism strike** for all parties involved (“invalid” grade) **!**

Assignment Sheets & Interviews

No	Assignment	Handout	Deadline	Points
1	Probability Spaces, σ-Algebras, Density Functions	24.10	14.11	20
2	Graphical Models, Basic Monte Carlo	14.11	05.12	25
3	MCMC, (Armortized) Variational Inference	05.12	09.01	35
4	Gaussian Processes, Reinforcement Learning	09.01	26.01	20

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- All deadlines are at 23:59 on the respective day
  - Strict deadlines, i.e., late submissions will be graded with 0 points
- After releasing the points for an assignment, we conduct **assignment interviews**
  - Random group of people invited to talk about **this assignment**
- Shortly after the PDM VU exam (Jan 28th), we conduct **final assignment interviews**
  - Random group of people invited to talk about **all assignments**
- Point deduction of up to 100% possible during assignment interviews

The assignment sheets will be a mix of

- Pen & Paper Exercises ✏️ 📖
  - Fundamental probability theory, inference, graphical models, ...
- Coding Exercises ⌨️
  - Using `python` and its ecosystem (`numpy`, `jax`, `numpyro`, ...) 🐍
  - **Algorithms/Tools**: Basic Monte Carlo, MCMC, Variational Inference, ...
  - **Applications**: Probabilistic Machine Learning (e.g., Bayesian Regression etc.)
  - Exploring **Probabilistic Programming** in `numpyro`

In the **(weekly) practical sessions**, I will

- Present and recap content **relevant for the assignment sheets**
- **Hand out** & discuss assignment sheets
- Answer **questions** regarding the assignments
- Apply the concepts from the lecture to **practical problems**

Probability Spaces

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- $\Omega \neq \emptyset$ is the **sample space**
- $\mathcal{F}$ is a σ-algebra on Ω
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Question 🤔

When is $\mathcal{F}$ called a σ-algebra on Ω ❓

σ-Algebra

Let $\Omega \neq \emptyset$ be a set and let $\mathcal{F} \subseteq \mathcal{P}(\Omega)$. Then $\mathcal{F}$ is called a **sigma-algebra** over Ω if

- $\Omega \in \mathcal{F}$
- $A \in \mathcal{F} \implies A^c := \Omega \setminus A \in \mathcal{F}$ (**closed under complement**)
- $A_1, A_2, \dots \in \mathcal{F} \implies \bigcup_{i \geq 1} A_i \in \mathcal{F}$ (**closed under countable union**)

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Corollary

- $\emptyset \in \mathcal{F}$
- $A_1, A_2, \dots \in \mathcal{F} \implies \bigcap_{i \geq 1} A_i \in \mathcal{F}$ (closed under countable intersection)

$$A_1, A_2, \dots \in \mathcal{F} \implies \bigcap_{i \geq 1} A_i \in \mathcal{F}$$

- Claim: This is true because **De Morgan's Law** tells us that

$$\bigcap_{i \geq 1} A_i = \left(\bigcup_{i \geq 1} A_i^c \right)^c$$

- ... which is clearly $\in \mathcal{F}$ if $A_1, A_2, \dots \in \mathcal{F}$

Proof

With $\omega \in \Omega$ and $A \subseteq \Omega$, we note that $\omega \in A \Leftrightarrow \omega \notin A^c$. Therefore, we have

$$\omega \in \bigcap_{i \geq 1} A_i \Leftrightarrow \forall i : \omega \in A_i \Leftrightarrow \forall i : \omega \notin A_i^c \Leftrightarrow \omega \notin \bigcup_{i \geq 1} A_i^c \Leftrightarrow \omega \in \left(\bigcup_{i \geq 1} A_i^c \right)^c$$

Quiz Time!

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Probability Measure

Let $(\Omega, \mathcal{F})$ be a *measurable space* (i.e., $\mathcal{F}$ is a σ-algebra on $\Omega \neq \emptyset$). Then

$$\mathbb{P} : \mathcal{F} \to [0, 1]$$

is called a **probability measure** if

- $\mathrm{P}(\Omega) = 1$
- if $A_1, A_2, \dots \in \mathcal{F}$ are **disjoint**, then $\mathcal{P}\left(\bigcup_{i \geq 1} A_i\right) = \sum_{i \geq 1} P(A_i)$

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Corollary

- $\mathbb{P}(\emptyset) = 0$
- $\mathbb{P}(A^c) = 1 - \mathbb{P}(A)$

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