Lecture 1: Probabilistic Model

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EE210: Probability and Introductory Random Processes
KAIST EE

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Roadmap

(1) Probabilistic Model
- Mathematical description of uncertain situations

(2) Sample Space, Event, Probability Law
- Elements of probability theory

(3) Probability Axioms
- 3 axioms for the completeness of a theory

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(2) Sample Space, Event, Probability Law

(3) Probability Axioms

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Modeling: Understand reality with a simple (mathematical) model

- Experiment
- Flip two coins

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◦ All outcomes	◦ $\{(H, H), (H, T), (T, H), (T, T)\}$

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  - Mathematical description of an uncertain situation
- Which model is good or bad?

Goal: Build up a probabilistic model. Hmm... How?

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Question: What are the conditions of Ω and $\mathbb{P}(\cdot)$ under which their induced probability model becomes "legitimate"?

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1. Sample Space Ω

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(not too concrete, not too abstract)

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   (b) The impact of the weather (rain or no rain) on the coin's behavior.

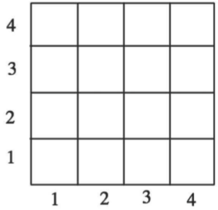
   $$\Longrightarrow \Omega = \{(H, R), (T, R), (H, NR), (T, NR)\},$$

   R(Rain), NR(No Rain).

Examples: Sample Space Ω

- *Discrete case:* Two rolls of a tetrahedral die

  - $\Omega = \{(1,1),(1,2),\dots,(4,4)\}$



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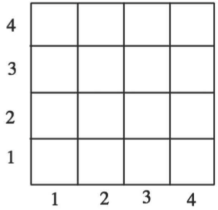
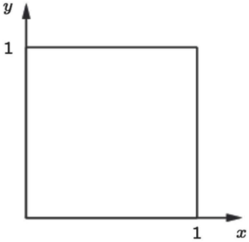


- *Continuous case:* Dropping a needle in a plain

  - $\Omega = \{(x,y) \in \mathbb{R}^2 \mid 0 \leq x, y \leq 1\}$



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2. Probability Law

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- Roll a dice. What is the probability of odd numbers?

  $\mathbb{P}(\{1, 3, 5\})$, where $\{1, 3, 5\} \subset \Omega$ is an event.

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- Need to construct $\mathbb{P}(\cdot)$ that naturally satisfies the intention of a probability theory designer just like you. What about the followings as starting points?

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  - many others

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- Note that coming up with the above axioms is far from trivial.

A1: Nonnegativity, A2: Normalization, A3: Finite additivity

Prove the following properties using the axioms: VIDEO PAUSE

1. For any event A, $\mathbb{P}(A) \leq 1$

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   $$\mathbb{P}(B) \overset{\text{A3}}{=} \mathbb{P}(A) + \mathbb{P}(B \setminus A) \overset{\text{A1}}{\geq} \mathbb{P}(A)$$

Probability Calculation Steps

1. Specify the sample space
2. Specify a probability law
   - from my earlier belief, from data, from expert's opinion
3. Identify an event of interest
4. Calculate

Toss a (biased) coin

1. $\Omega = \{H, T\}$
2. $\mathbb{P}(\{H\}) = 1/4$, $\mathbb{P}(\{T\}) = 3/4$,
3. probability of head or tail
4. $1/4$, $3/4$

Discrete but infinite sample space

- $\Omega = \{1, 2, 3, \ldots\}$, $\mathbb{P}(\{n\}) = \frac{1}{2^n}$, $n = 1, 2, \ldots$

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- $\mathbb{P}(\text{even numbers})$?

$$\begin{aligned}\mathbb{P}(\text{even}) &= \mathbb{P}(\{2, 4, 6, \ldots\}) \\ &= \frac{1}{2^2} + \frac{1}{2^4} + \frac{1}{2^6} + \cdots = 1/3\end{aligned}$$

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- Is the above right? If not, why?
  - Wrong: Finite additivity axiom does not allow this.

Probability Axioms Version 1

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Probability Axioms: Version 2

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A2. Normalization: $\mathbb{P}(\Omega) = 1$

A3. $\boxed{\text{Countable additivity:}}$ If $A_1, A_2, A_3, \ldots$ is an infite sequence of disjoint events, then $\mathbb{P}(A_1 \cup A_2 \cup \cdots) = \mathbb{P}(A_1) + \mathbb{P}(A_2) + \cdots$.

Interpretation of Probability Theory

- A narrow view: A branch of math
  - axioms $\rightarrow$ theorems
  - Mathematicians work very hard to find the smallest set of necessary axioms (just like atoms in physics)

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- Frequencies: $\mathbb{P}(H) = 1/2$
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- Beliefs: $\mathbb{P}(\text{He is reelected}) = 0.7$

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Questions?

You build up the very basics of a probabilistic model.

What else do we need to build up?

Review Questions

1) Please explain what a probabilistic model is and why we need it.
2) What is the mathematical definition of event?
3) What are the key elements of the probabilistic model?
4) Please list up the probability axioms and explain them.
5) Why do we need countable additivity in the probability axioms?