GENERAL ASSEMBLY

NAÏVE BAYES

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DATA SCIENCE PROCESS

1. Define problem.
2. Gather data.
3. Explore data.
4. Model with data.
5. Evaluate model.
6. Answer problem.

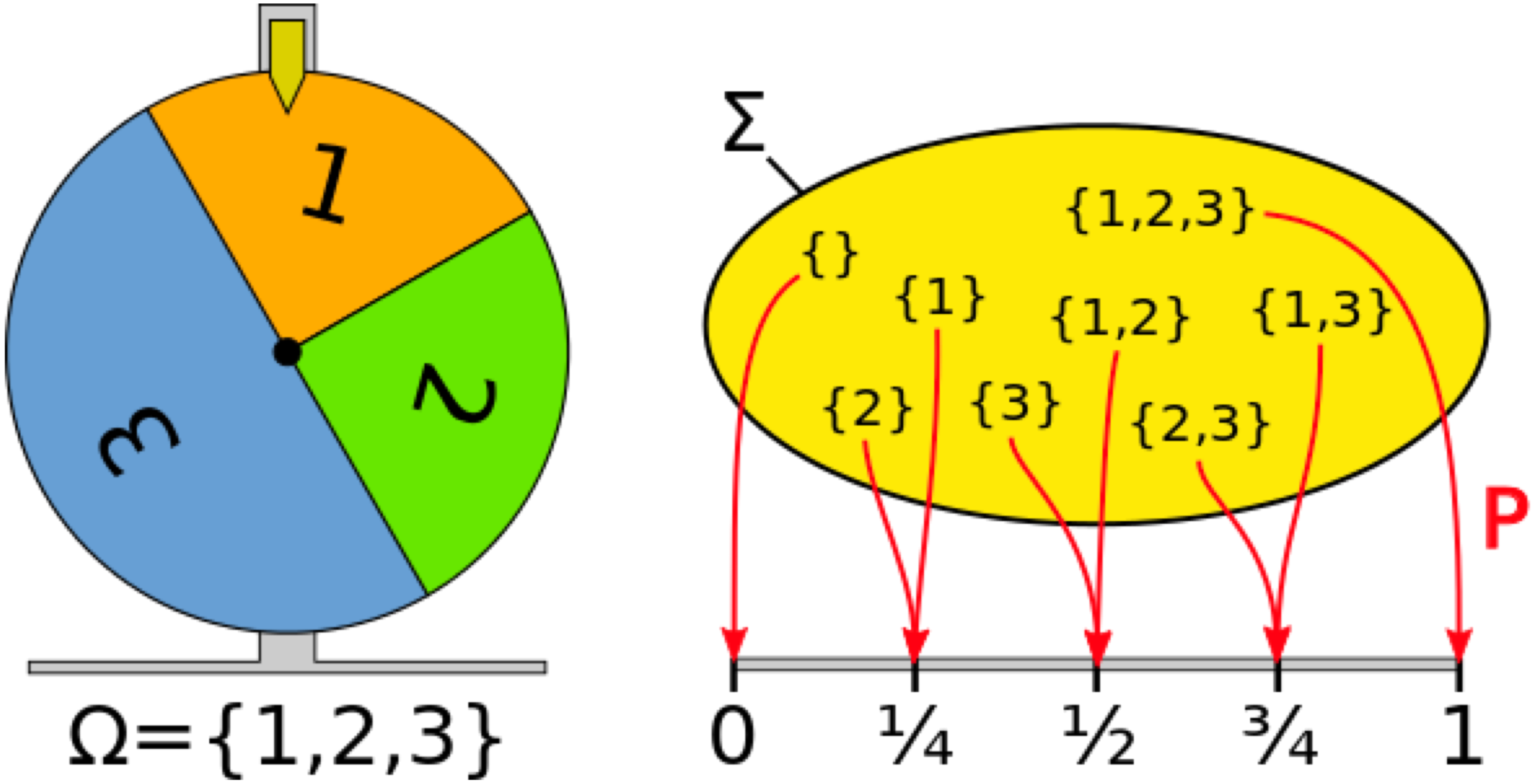
AGENDA

- Probability
- Bayes' Theorem
- Naïve Bayes

DEFINITIONS

- Experiment: A procedure that can be repeated infinitely many times and has a well-defined set of outcomes.
- Event: Any collection of outcomes of an experiment.
- Sample Space: The set of all possible outcomes of an experiment, denoted $\mathcal{S}$.

PROBABILITY BASICS



PROBABILITY RULES

- $P(\emptyset) = 0$
  - Note: $\emptyset$ indicates the "empty set," or the event containing zero outcomes from the experiment.

PROBABILITY RULES

- $P(A \cup B) = P(A) + P(B) - P(A \cap B)$
  - Venn diagrams can help to illustrate this – but remember that Venn diagrams are not proofs!
  - If A and B are disjoint, then $P(A \cap B) = 0 \Rightarrow P(A \cup B) = P(A) + P(B)$.

PROBABILITY RULES

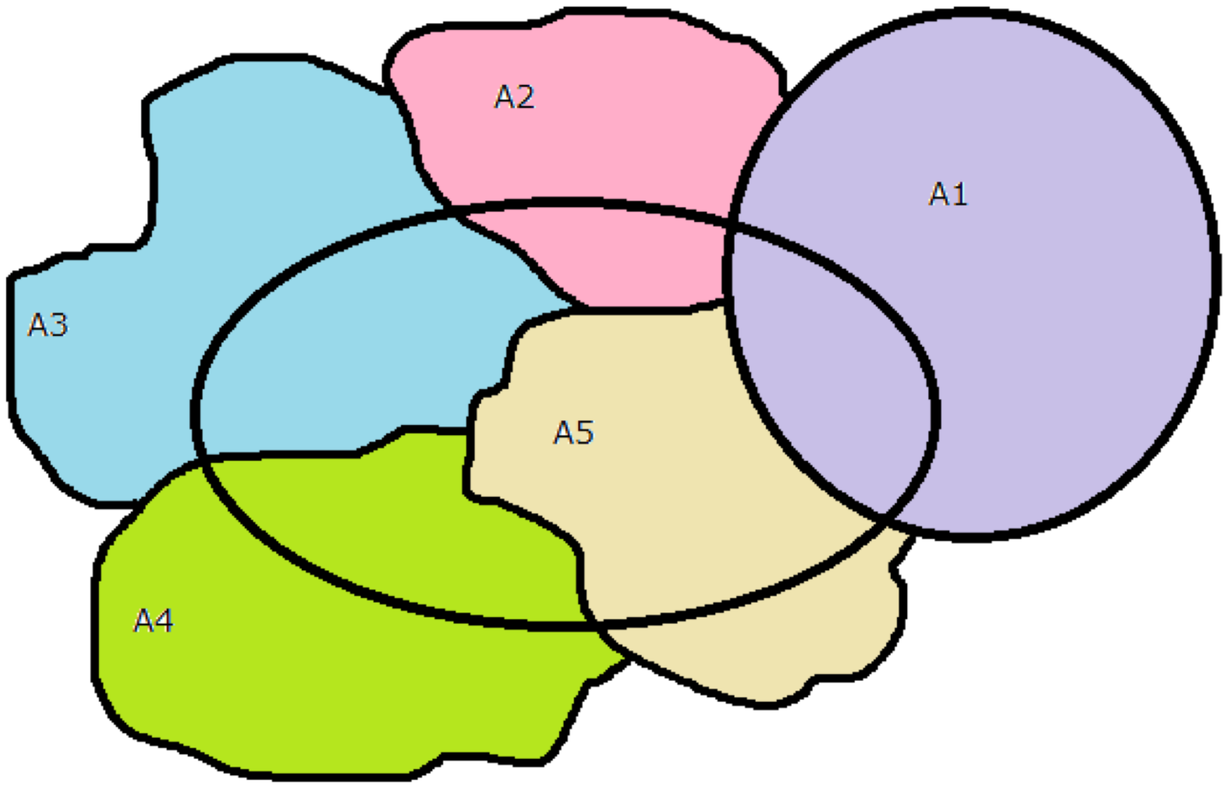
- $P(A|B) = \frac{P(A \cap B)}{P(B)}$
  - Note: $A|B$ means "A given B" or "A conditional on the fact that B happens."

PROBABILITY RULES

- $P(A \cap B) = P(A|B)P(B)$
  - We took the last rule, multiplied both sides of $P(B)$, and voila!

PROBABILITY RULES

- $P(B) = \sum_{i=1}^{n} P(B \cap A_i)$
  - "Law of Total Probability"



PROBABILITY RULES – SUMMARY

- $P(\emptyset) = 0$
- $P(A \cup B) = P(A) + P(B) - P(A \cap B)$
- $P(A|B) = \frac{P(A \cap B)}{P(B)}$
- $P(A \cap B) = P(A|B)P(B)$
- $P(B) = \sum_{i=1}^{n} P(B \cap A_i)$

BAYES' THEOREM

- Bayes' Theorem (Bayes' Rule) relates $P(A|B)$ to $P(B|A)$.

BREAKING DOWN BAYES' THEOREM

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

- $P(A)$ is the probability that A occurs given no supplemental information.
- $P(B|A)$ is the likelihood of seeing evidence (data) B assuming that A is true.
- $P(B)$ is the probability that B occurs given no supplemental information.
  - $P(B)$ what we scale $P(B|A)P(A)$ by to ensure we are only looking at A within the context of B occurring.

APPLYING BAYES' THEOREM TO SPAM CLASSIFICATION

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

APPLYING BAYES' THEOREM TO SPAM CLASSIFICATION

$$P(\text{spam}|\text{words in email}) = \frac{P(\text{words in email}|\text{spam})P(\text{spam})}{P(\text{words in email})}$$

APPLYING BAYES' THEOREM TO SPAM CLASSIFICATION

$$P(\text{spam}|\text{words}) = \frac{P(w_1|\text{spam})P(w_2|w_1 \cap \text{spam})P(w_3|w_2 \cap w_1 \cap \text{spam}) \cdots P(\text{spam})}{P(w_1)P(w_2|w_1)P(w_3|w_2 \cap w_1) \cdots}$$

- This gets **<u>really</u>** complicated. Can we simplify this?

NAÏVE BAYES

- The Naïve Bayes classification algorithm is a:
  - classification modeling technique
  - that relies on Bayes Theorem
  - that makes one simplifying *(and often unrealistic)* assumption

- <u>**We assume that our features are independent of one another.**</u>

APPLYING BAYES' THEOREM TO SPAM CLASSIFICATION

$$P(\text{spam}|\text{words}) = \frac{P(w_1|\text{spam})P(w_2|w_1 \cap \text{spam})P(w_3|w_2 \cap w_1 \cap \text{spam}) \cdots P(\text{spam})}{P(w_1)P(w_2|w_1)P(w_3|w_2 \cap w_1) \cdots}$$

$$P(\text{spam}|\text{words}) = \frac{P(w_1|\text{spam})P(w_2|\text{spam})P(w_3|\text{spam}) \cdots P(\text{spam})}{P(w_1)P(w_2)P(w_3) \cdots}$$

NAÏVE BAYES

- **Advantages** of making this assumption of feature independence:
    - Easier to calculate probabilities.
    - Empirically, our classifications are surprisingly accurate.

- **Disadvantages** of making this assumption of feature independence:
    - It's so incredibly unrealistic, especially in the case of text data.
    - While our classifications are accurate, our predicted probabilities are usually quite bad.

PROCESS OF NAÏVE BAYES

1. Decide which Naïve Bayes model to use.
   - BernoulliNB
   - MultinomialNB
   - GaussianNB

2. Decide what your priors will be.
   - Based on your data. *(default)*
   - Manually set.

3. `.fit()`, `.predict()`!

WHICH NAÏVE BAYES MODEL SHOULD I USE?

- BernoulliNB

- MultinomialNB

- GaussianNB

WHAT SHOULD MY PRIORS SHOULD BE?

$$P(\text{spam}|\text{words in email}) = \frac{P(\text{words in email}|\text{spam})P(\text{spam})}{P(\text{words in email})}$$

- Estimated from data.

- Manually set.

PROCESS OF NAÏVE BAYES

1. Decide which Naïve Bayes model to use.
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3. `.fit()`, `.predict()`!

WHERE DOES NAÏVE BAYES FIT IN OUR MENTAL SET OF MODELS?

INTERVIEW QUESTION

- Suppose we want to detect whether Amazon reviews are spam or ham. How would you do this?