# Bayesian Inference and Hypothesis Testing

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- So we can reverse the order of conditioning, i.e. relate to the probability of A given B to that of B given A.

# The cards problem

1. Print out a number of cards, with either [A|A], [A|B] or [B|B] on their sides.
2. If you have an A, what is the probability of an A on the other side?
3. Have the students perform the experiment with:
   3.1 Draw a random card.
   3.2 Count the number of people with A.
   3.3 What is the probability that somebody with an A on one side will have an A on the other?
   3.4 Half of the people should have an A?

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## The prior and posterior probabilities

| | | | | |
|---|---|---|---|---|
| A | A | 2/6 | A observed | 2/3 |
| A | B | 1/6 | A observed | 1/3 |
| B | A | 1/6 | | |
| B | B | 2/6 | | |

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- This is a purely subjective measure!

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- What is your belief now that the suspect is guilty?

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- What is your belief that the people with the positive test are guilty?

# Explanation

- Prior: $P(H_i)$.

$$
\begin{aligned}
P(D) &= P(D \cap H_0) + P(D \cap H_1) && (1) \\
&= P(D|H_0)P(H_0) + P(D|H_1)P(H_1) && (2)
\end{aligned}
$$

- Posterior: $P(H_0|D) = \frac{P(D|H_0)P(H_0)}{P(D|H_0)P(H_0)+P(D|H_1)P(H_1)}$
- Assuming $P(D|H_1) = 1$, and setting $P(H_0) = q$, this gives

$$P(H_0|D) = \frac{0.1q}{0.1q + 1 - q} = \frac{q}{10 - 9q}$$

- The posterior can always be updated with more data!

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- Posterior: $P(H_i|D) = P(D \cap H_i)/P(D) = P(D|H_i)P(H_i)/P(D)$
- Marginal probability:

$$\begin{aligned} P(D) &= P(D \cap H_0) + P(D \cap H_1) && (1) \\ &= P(D|H_0)P(H_0) + P(D|H_1)P(H_1) && (2) \end{aligned}$$

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# Python example

```
def get_posterior(prior, data, likelihood):
^^Imarginal = prior * likelihood[data][0] + (1 - prior) * l
^^Iposterior = prior * likelihood[data][0] / marginal
^^Ireturn posterior

import numpy as np
prior = 0.9 # Pr(H1)
likelihood = np.zeros([2, 2])
likelihood[0][0] = 0.9 # Pr(F|H0)
likelihood[1][0] = 0.1 # Pr(T|H0)
likelihood[0][1] = 0 # Pr(F|H1)
likelihood[1][1] = 1 # Pr(T|H1)
data = 1
return get_posterior(prior, data, likelihood)
```

# Types of hypothesis testing problems

## Simple Hypothesis Test

Example: DNA evidence, Covid tests

- Two hypothesese $H_0, H_1$
- $P(D|H_i)$ is defined for all $i$

## Multiple Hypotheses Test

Example: Model selection

- $H_i$: One of many mutually exclusive models
- $P(D|H_i)$ is defined for all $i$

## Null Hypothesis Test

Example: Are men's and women's heights the same?

- $H_0$: The 'null' hypothesis
- $P(D|H_0)$ is defined
- The alternative is undefined

# Pitfalls

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## Problem definition

- Defining the models $P(D|H_i)$ incorrectly.
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## The garden of many paths

- Having a huge hypothesis space
- Selecting the relevant hypothesis after seeing the data