

# Calculating probabilities of two events

FOUNDATIONS OF PROBABILITY IN PYTHON

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# Independence

Given that A and B are events in a random experiment, the conditions for independence of A and B are:

1. The order in which A and B occur does not affect their probabilities.
2. If A occurs, this does not affect the probability of B.
3. If B occurs, this does not affect the probability of A.

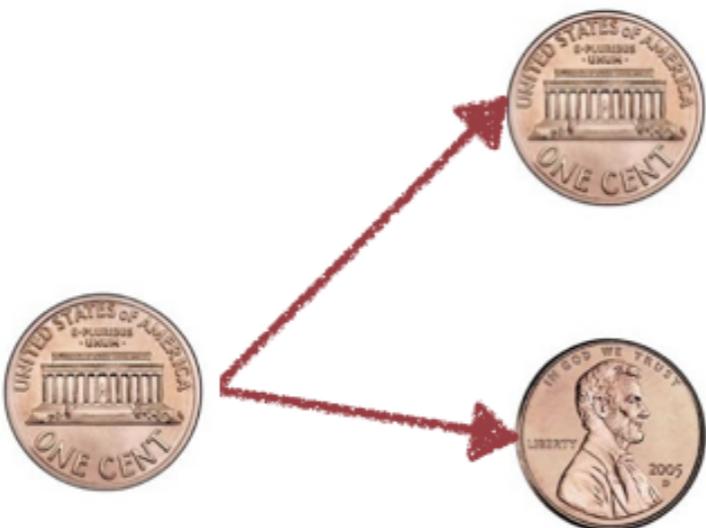


Fair coin

$$P(\text{tails}) = 0.5$$

$$P(\text{heads}) = 0.5$$

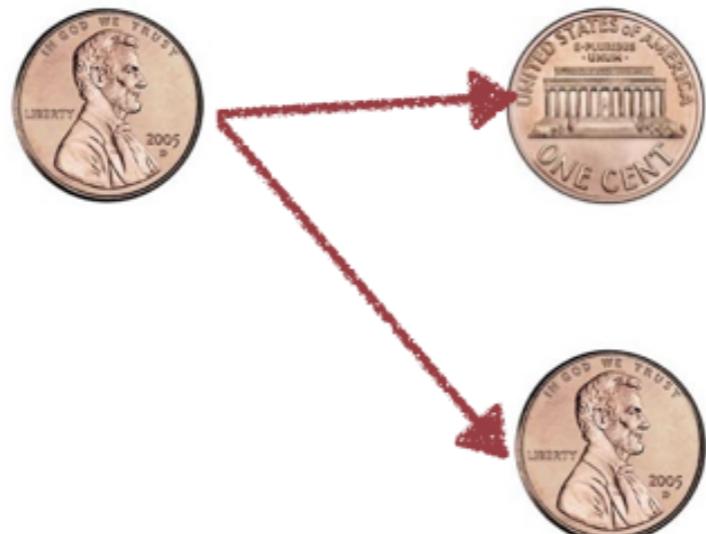
*First*



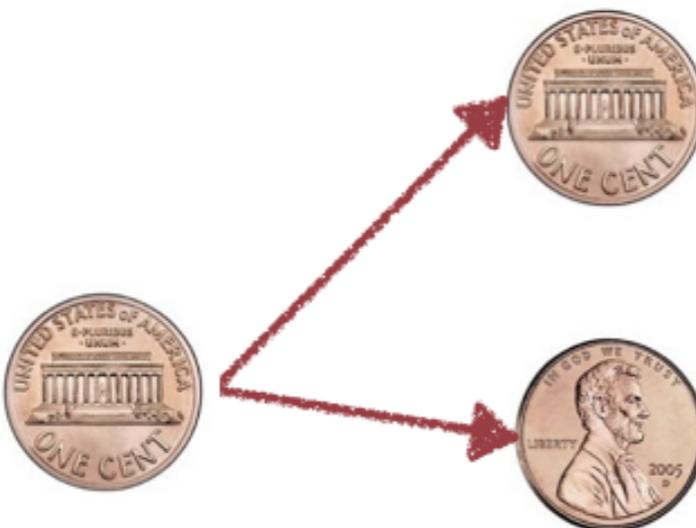
*Second*



*Outcome*



*First*



*Second*



*Outcome*

$$P(\text{heads and tails}) = ?$$

$$P(\text{tails and heads}) = ?$$

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$$P(\text{tails and tails}) = ?$$

$P(\text{heads} \text{ and } \text{tails}) = ?$

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$$P(A \text{ and } B) = P(A) P(B)$$

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$$P(\text{tails} \text{ and } \text{tails}) = P(\text{tails}) P(\text{tails})$$

$$P(A \text{ and } B) = P( A ) P( B )$$

$$P(\text{heads} \text{ and } \text{heads}) = P(\text{heads}) P(\text{heads}) = (0.5)(0.5) = 0.25$$

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# Measuring a sample

Generate a sample that represents 1000 throws of two fair coin flips

```
from scipy.stats import binom  
sample = binom.rvs(n=2, p=0.5, size=1000, random_state=1)
```

```
array([1, 1, 0, 1, 0, 0, 1, 1, 1, 1, 0, 2, 0, 1, 1, 1, 0, 0, 2, 2, ...])
```

Find repeated data

```
from scipy.stats import find_repeats  
find_repeats(sample)
```

```
RepeatedResults(values=array([0., 1., 2.]), counts=array([249, 497, 254]))
```



## Unfair coin

$$P(\text{Wheat Penny}) = 0.2$$

$$P(\text{Lincoln Penny}) = 0.8$$

$$P(A \text{ and } B) = P( A ) P( B )$$

$$P(\text{heads} \text{ and } \text{tails}) = P(\text{heads}) P(\text{tails}) = (0.2)(0.2) = 0.04$$

$$P(\text{heads} \text{ and } \text{heads}) = P(\text{heads}) P(\text{heads}) = (0.2)(0.8) = 0.16$$

$$P(\text{tails} \text{ and } \text{heads}) = P(\text{tails}) P(\text{heads}) = (0.8)(0.2) = 0.16$$

$$P(\text{tails} \text{ and } \text{tails}) = P(\text{tails}) P(\text{tails}) = (0.8)(0.8) = 0.64$$

# Measuring a biased sample

Using `biased_sample` data generated, calculate the relative frequency of each outcome

```
from scipy.stats import relfreq  
relfreq(biased_sample, numbins=3).frequency
```

```
array([0.039, 0.317, 0.644])
```

# Joint probability calculation

	Engine	Gear box
Fails	0.01	0.005
Works	0.99	0.995

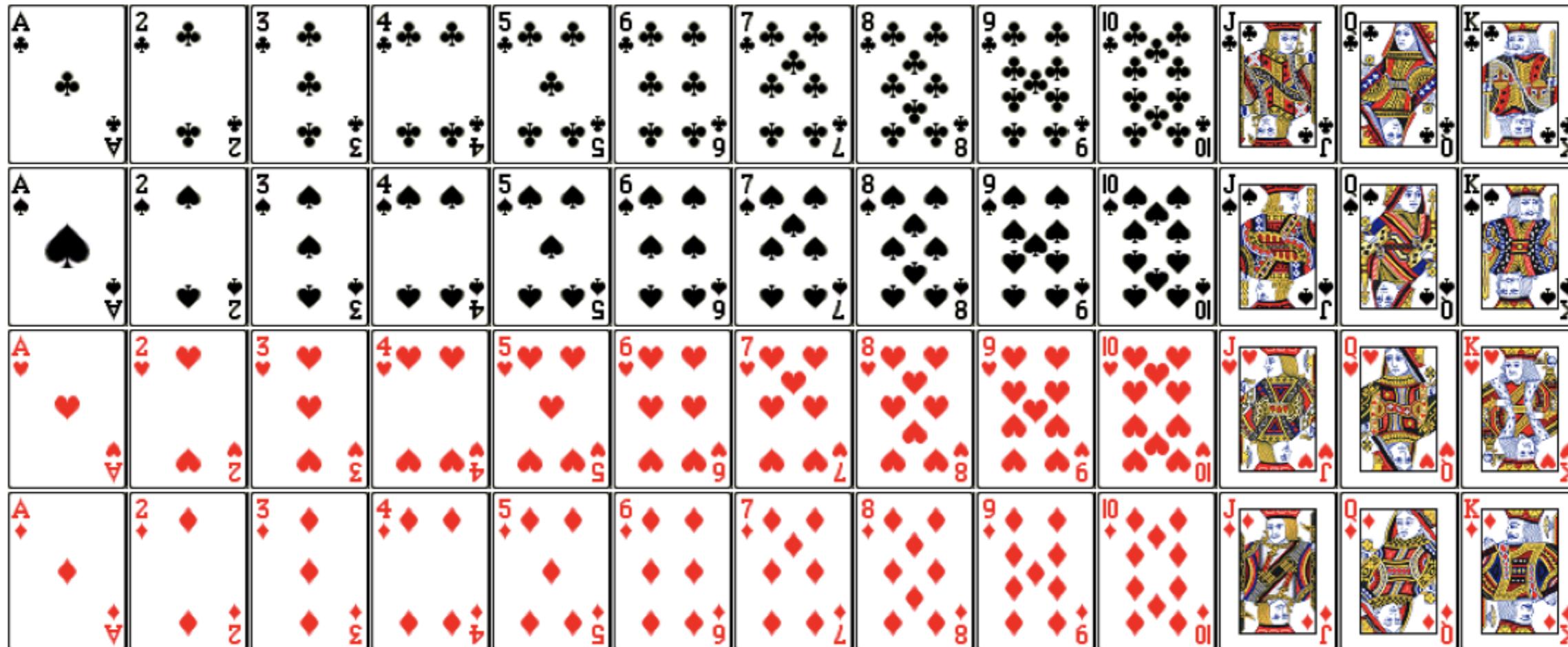
$P(\text{Engine fails and Gear box fails}) = ?$

```
P_Eng_fail = 0.01  
P_GearB_fail = 0.005  
P_both_fails = P_Eng_fail*P_GearB_fail  
print(P_both_fails)
```

0.00005

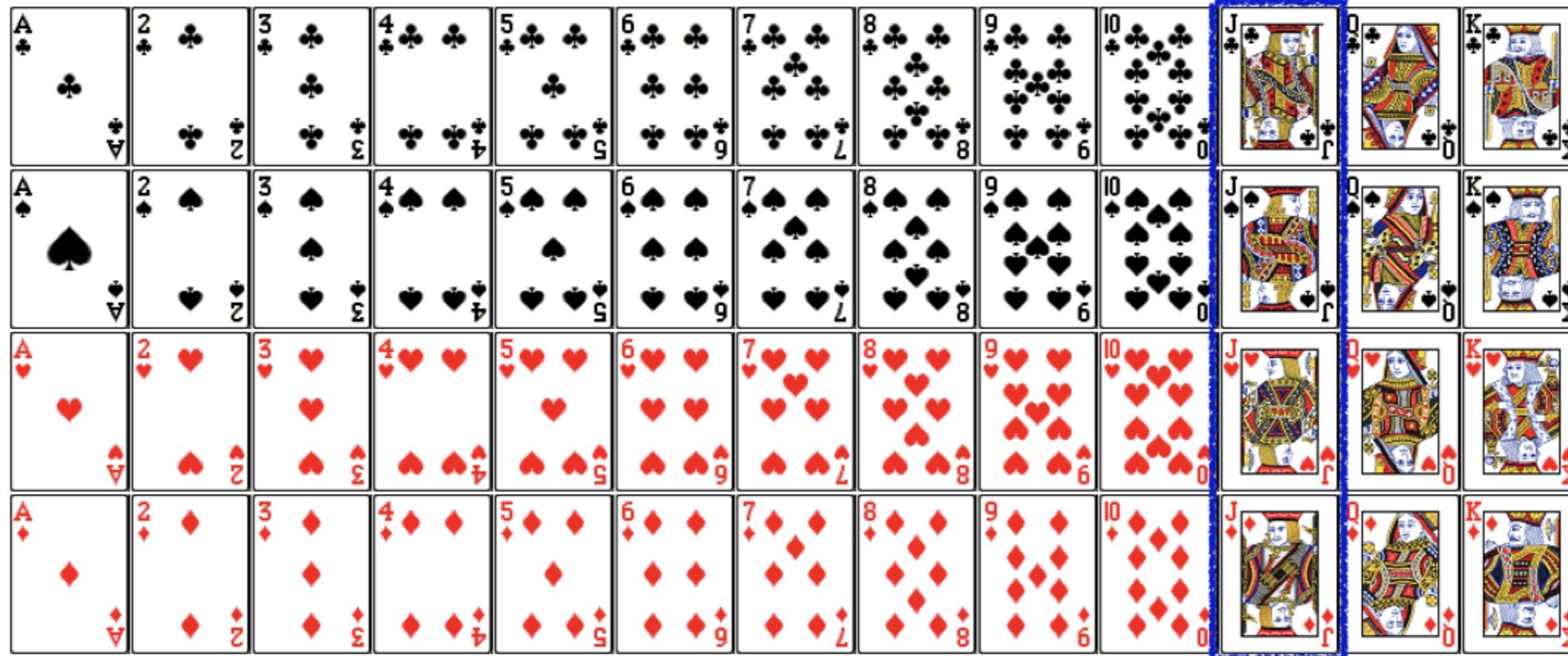
# $P(A \text{ or } B)$ with cards

$$P(\text{Jack or King}) = ?$$



# $P(A \text{ or } B)$ with cards (Cont.)

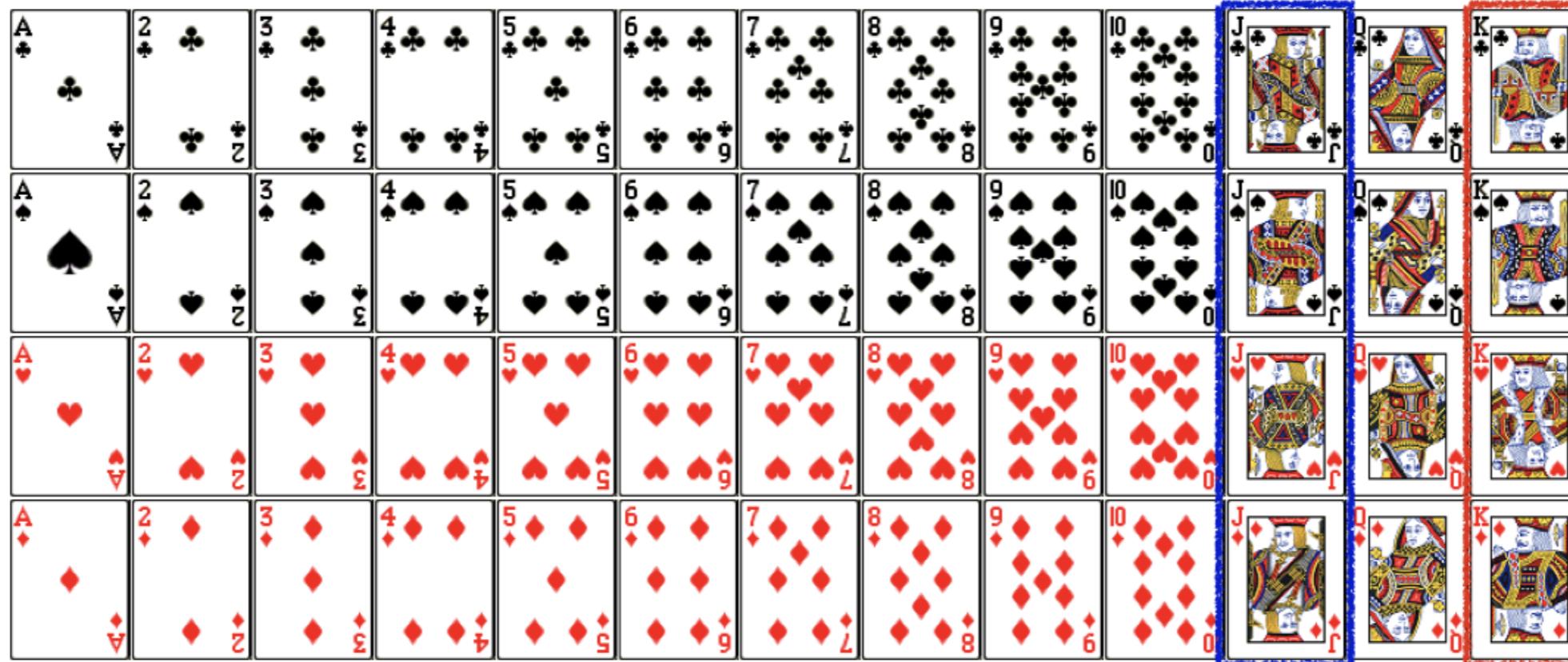
$$P(\text{Jack or King}) = P(\text{Jack}) + \dots$$



$$P(\text{Jack or King}) = \frac{4}{52} + \dots$$

# $P(A \text{ or } B)$ with cards (Cont.)

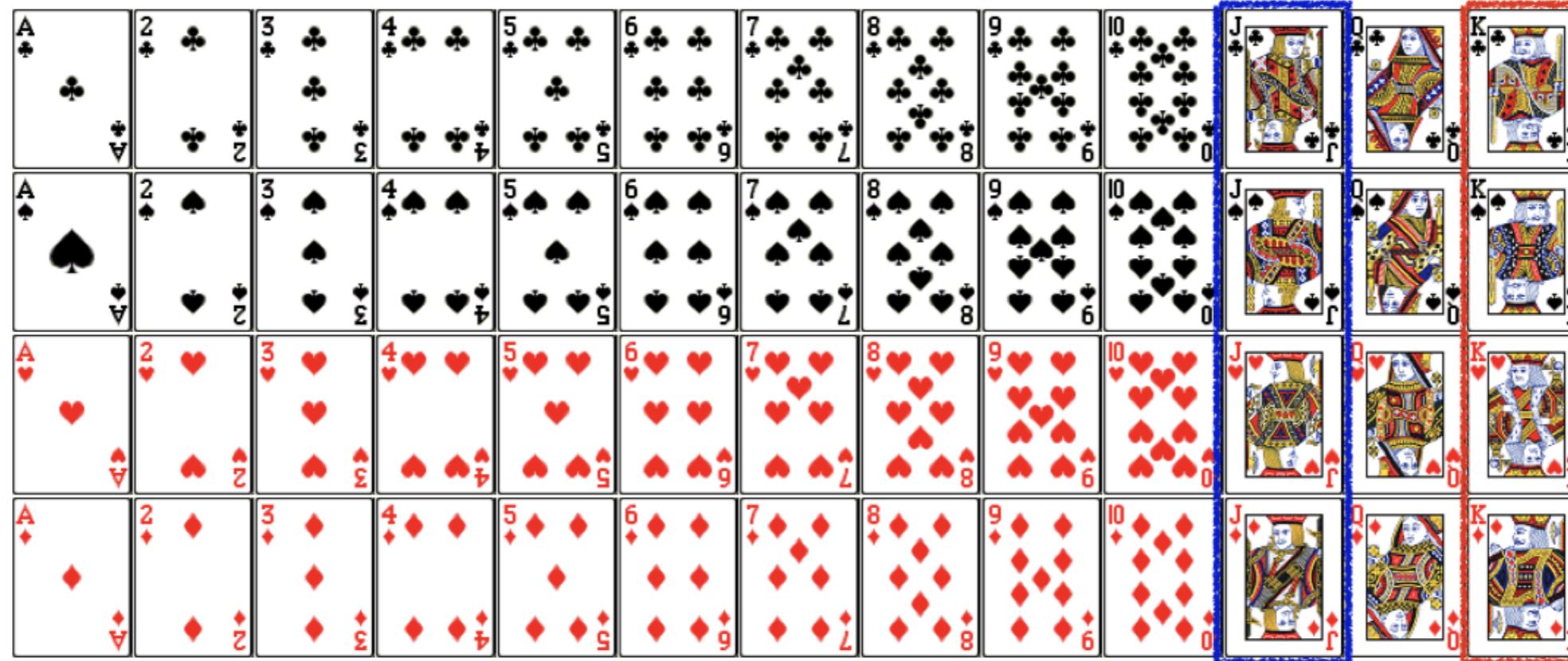
$$P(\text{Jack or King}) = P(\text{Jack}) + P(\text{King})$$



$$P(\text{Jack or King}) = \frac{4}{52} + \frac{4}{52}$$

# $P(A \text{ or } B)$ with cards (Cont.)

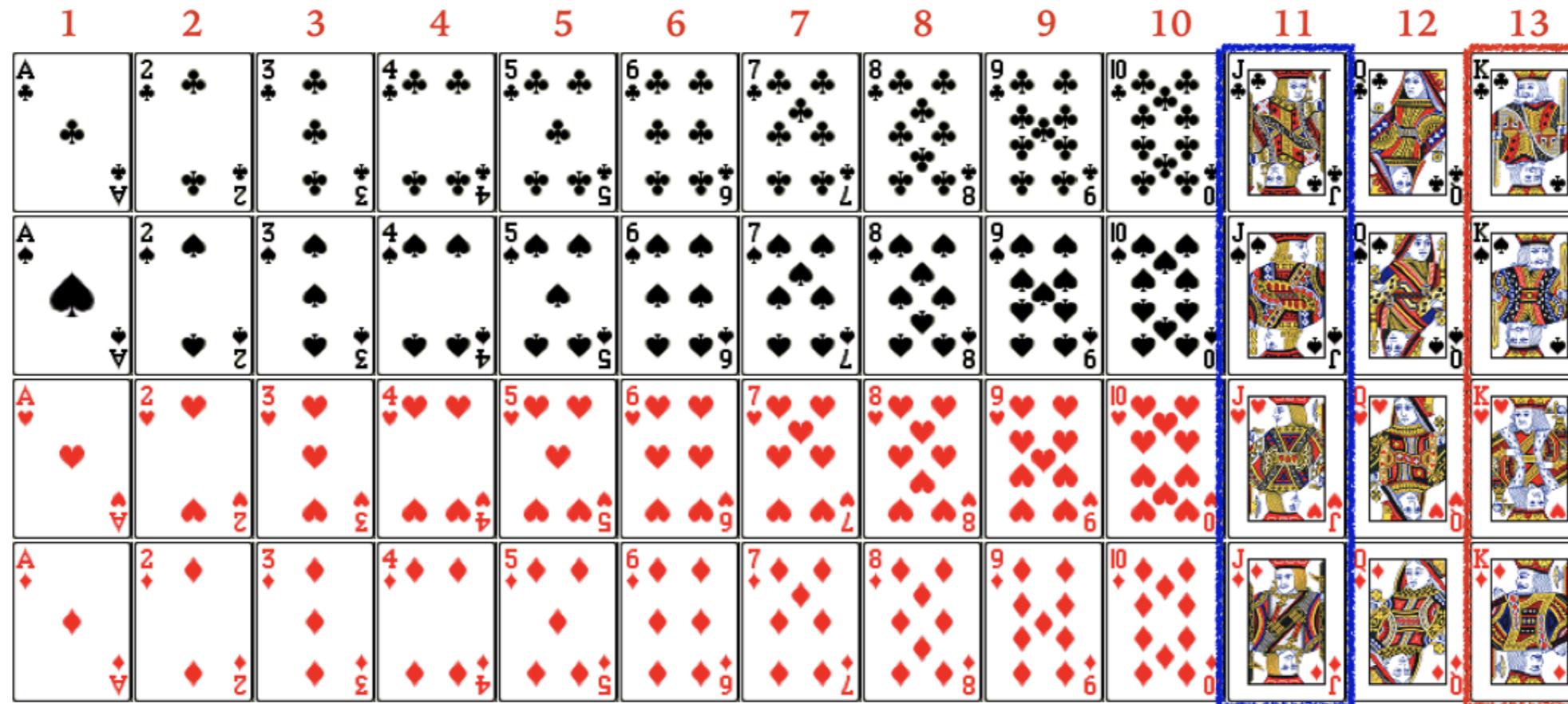
$$P(\text{Jack or King}) = P(\text{Jack}) + P(\text{King})$$



$$P(\text{Jack or King}) = \frac{4}{52} + \frac{4}{52} = \frac{8}{52} = \frac{2}{13}$$

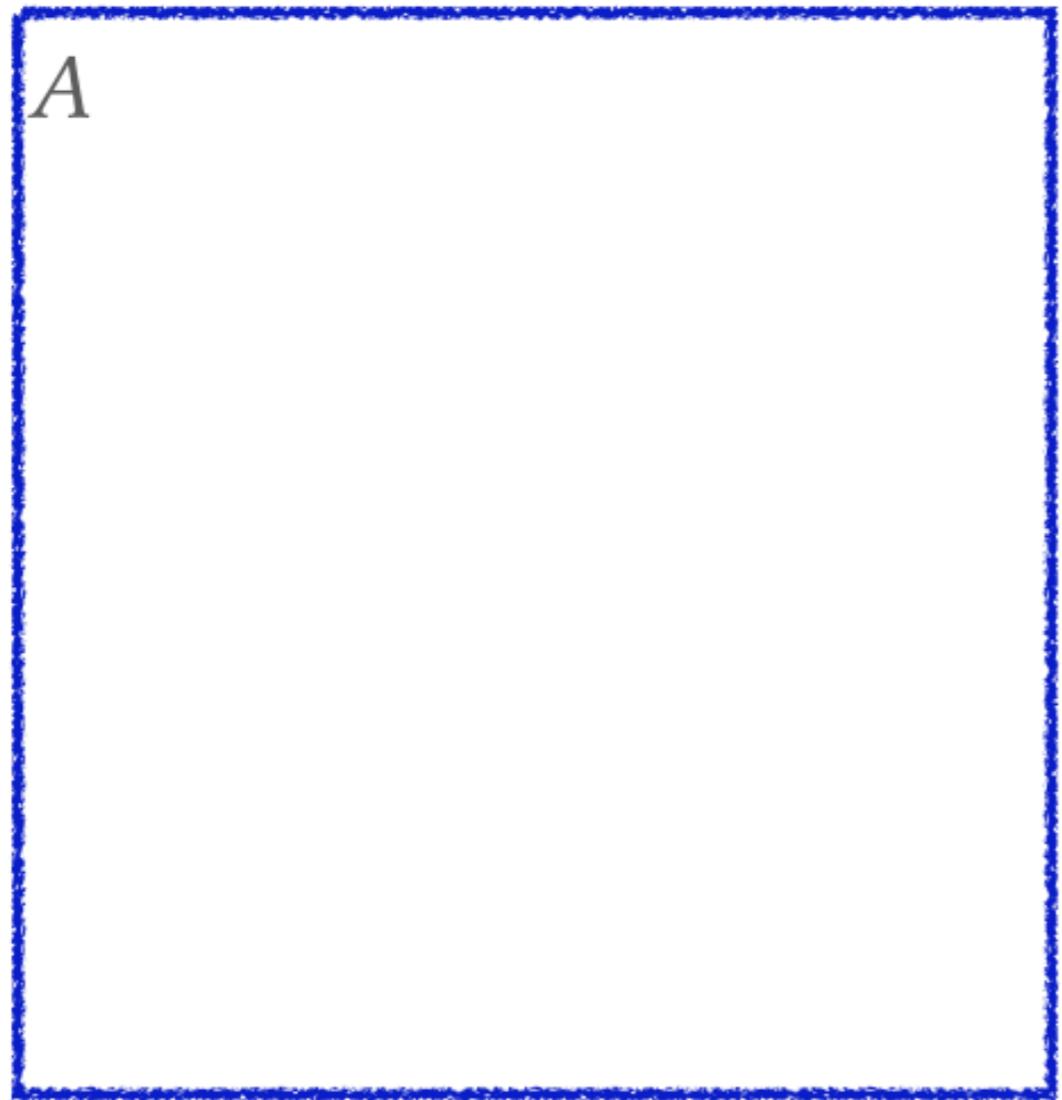
# $P(A \text{ or } B)$ with cards (Cont.)

$$P(\text{Jack or King}) = P(\text{Jack}) + P(\text{King})$$

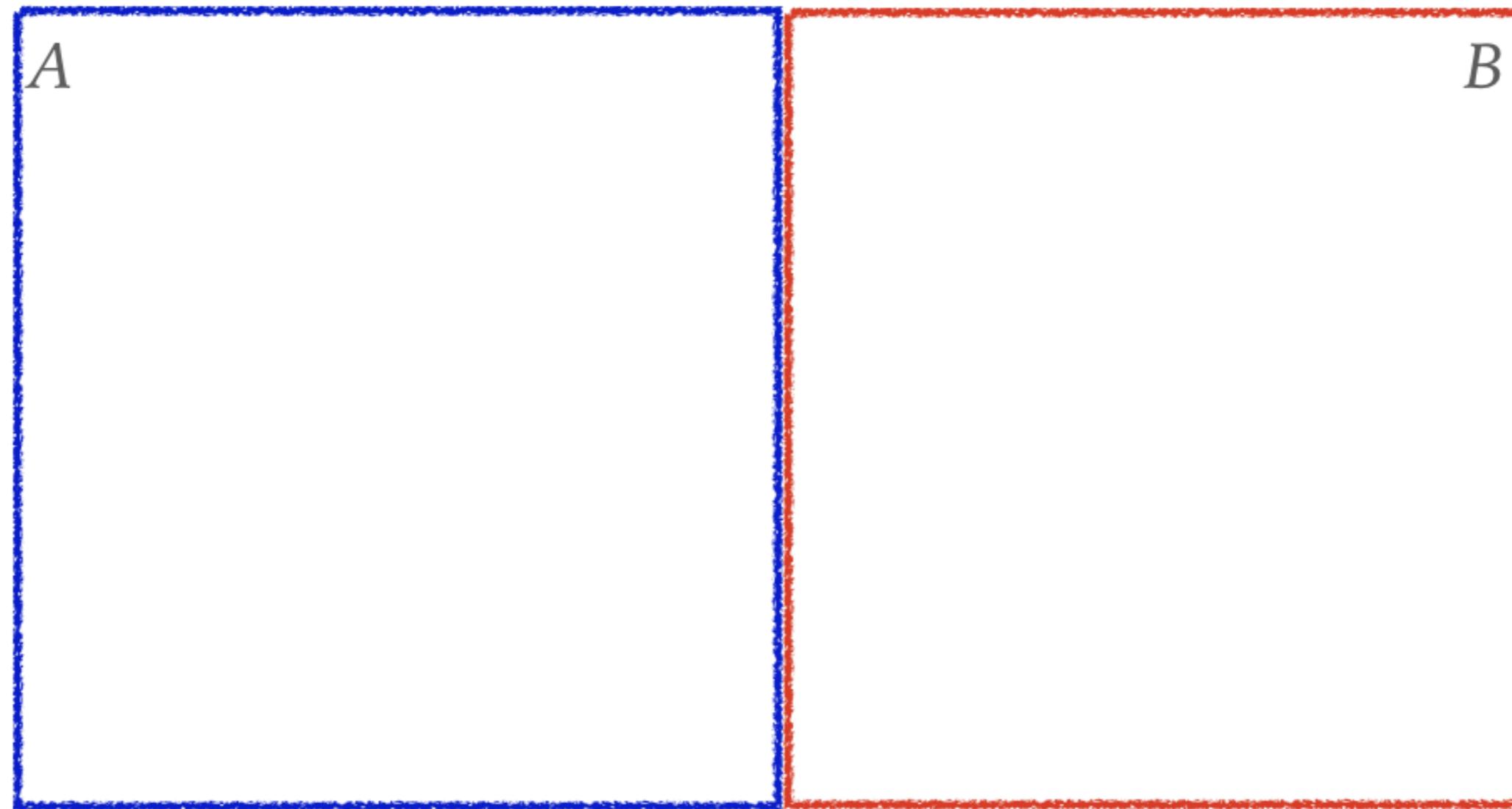


$$P(\text{Jack or King}) = \frac{4}{52} + \frac{4}{52} = \frac{8}{52} = \frac{2}{13}$$

# Probability of A or B

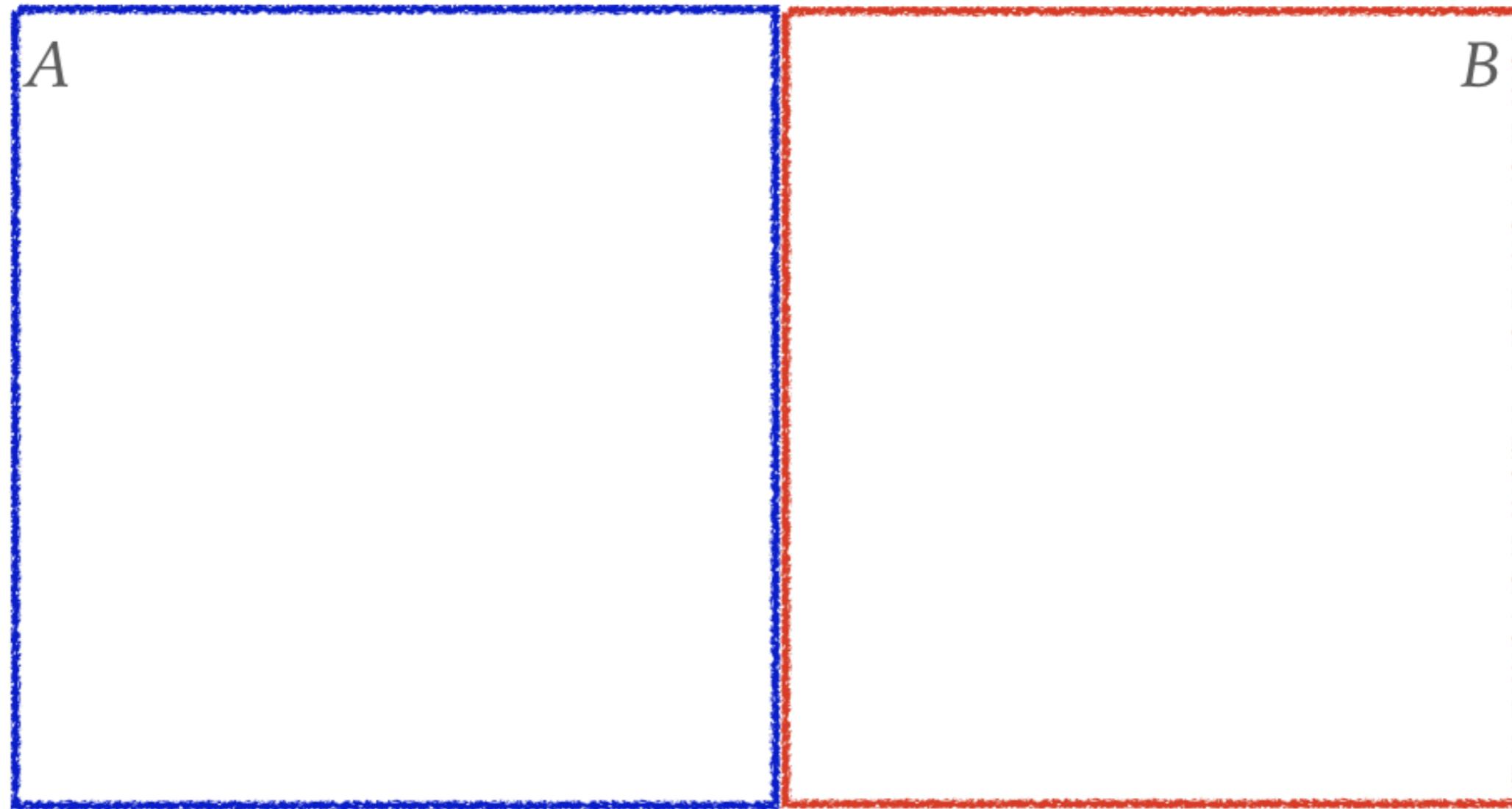


# Probability of A or B (Cont.)



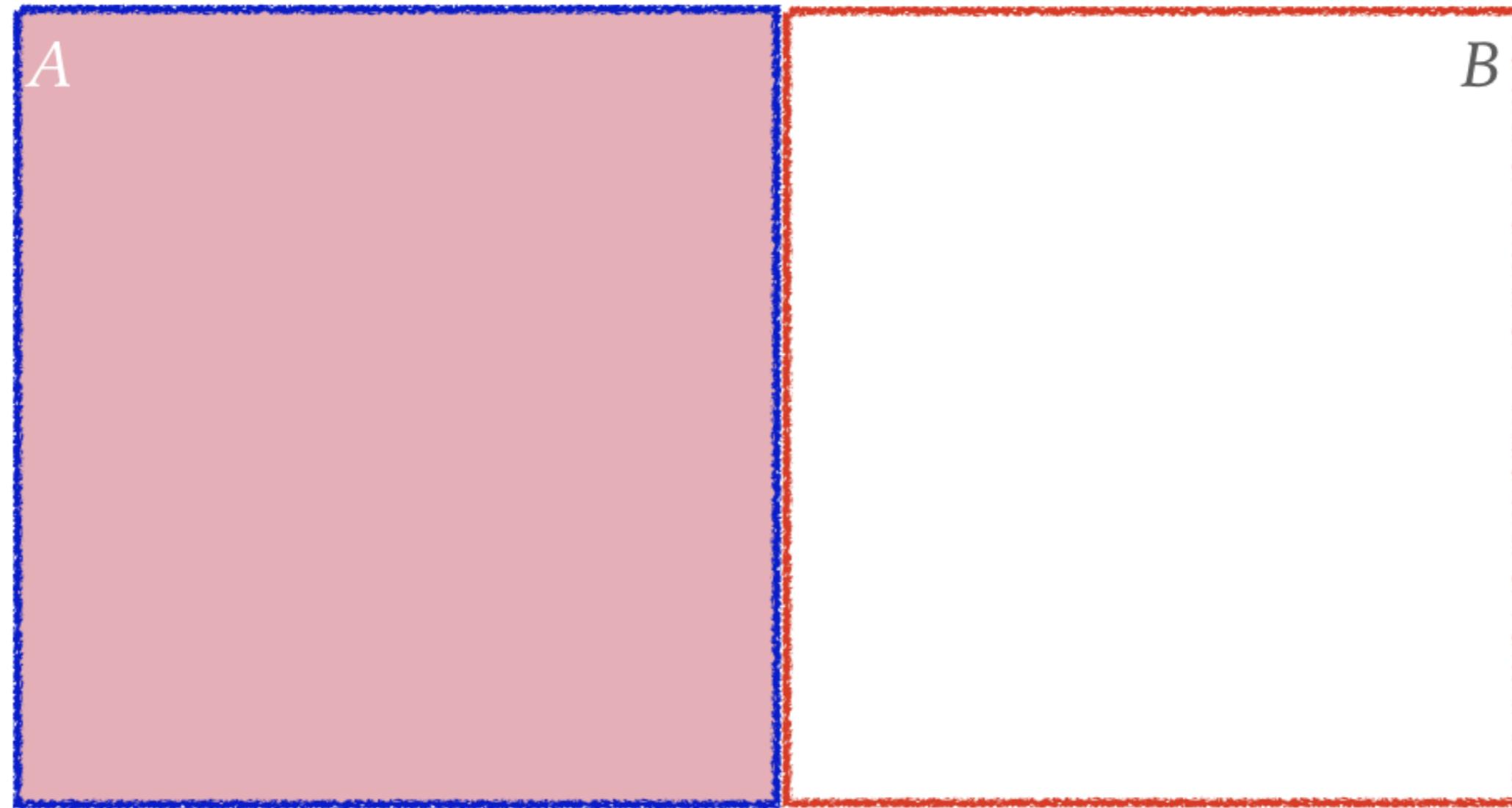
# Probability of A or B (Cont.)

$$P(A \text{ or } B) = ?$$



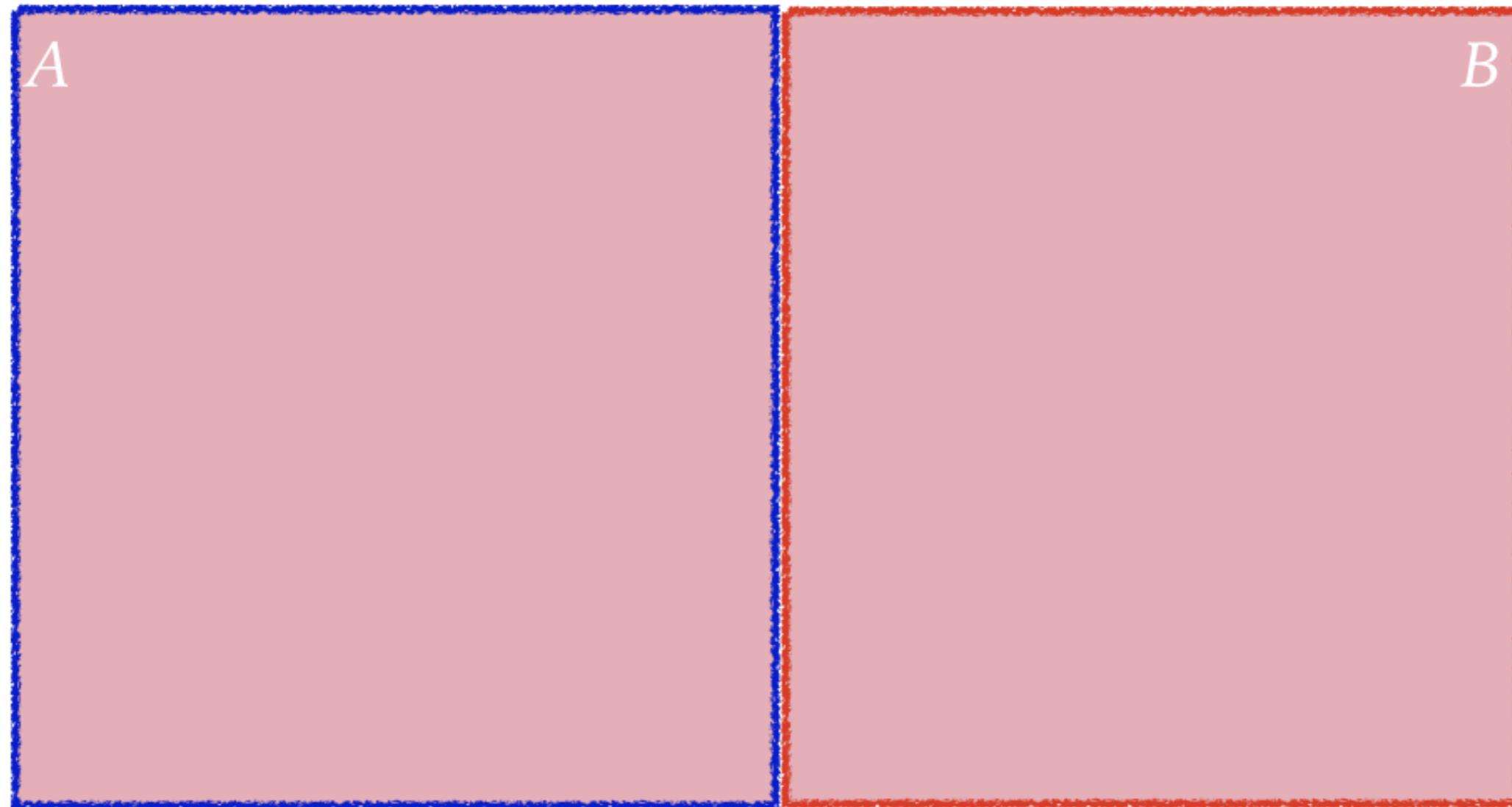
# Probability of A or B (Cont.)

$$P(A \text{ or } B) = P(A) + \dots$$



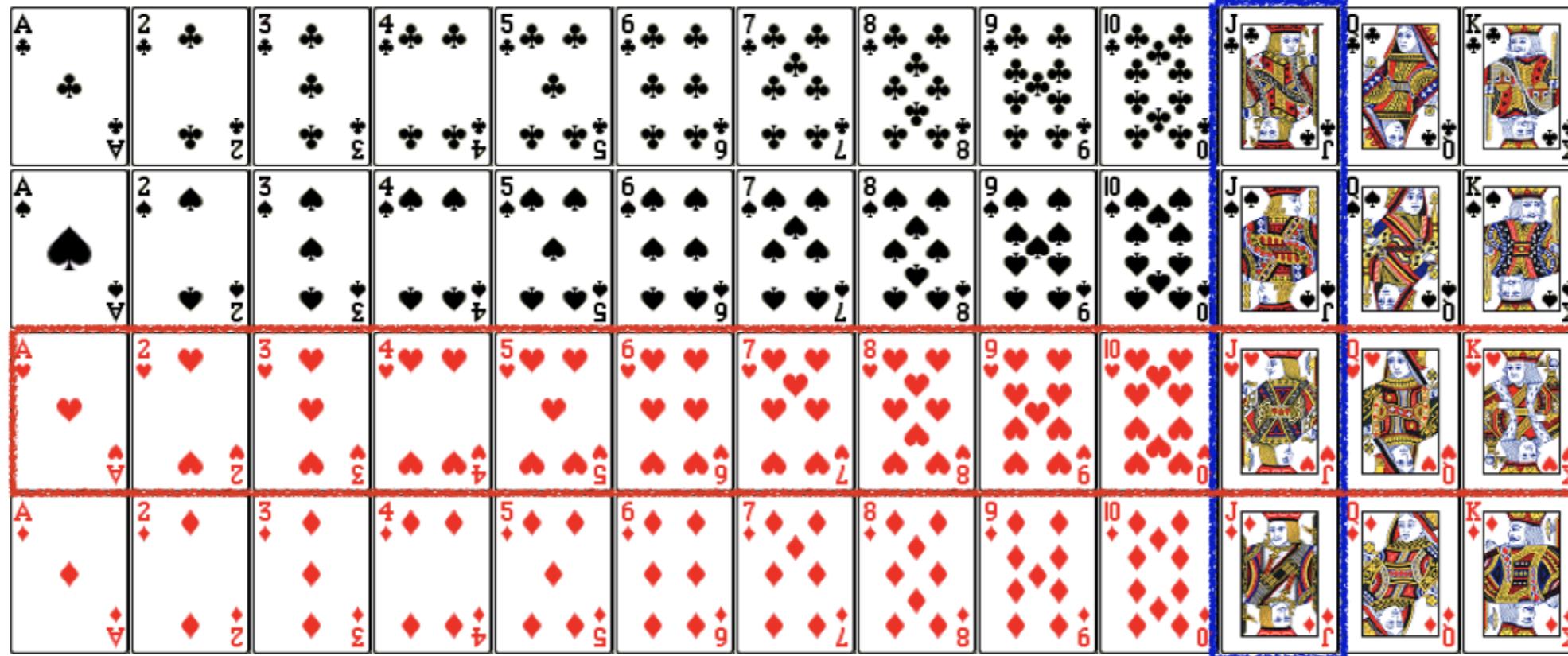
# Probability of A or B (Cont.)

$$P(A \text{ or } B) = P(A) + P(B)$$



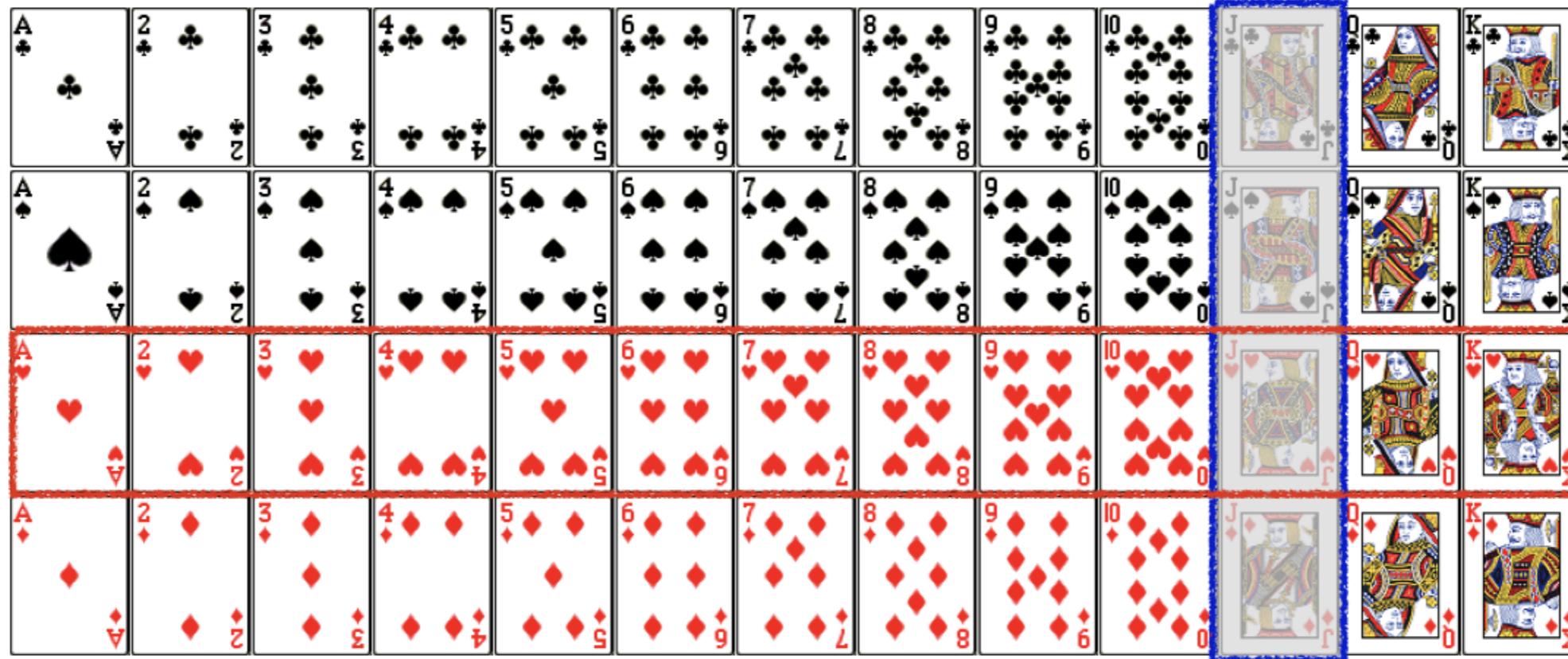
# $P(A \text{ or } B)$ with overlap

$$P(\text{Jack or Heart}) = ?$$



# $P(A \text{ or } B)$ with overlap (Cont.)

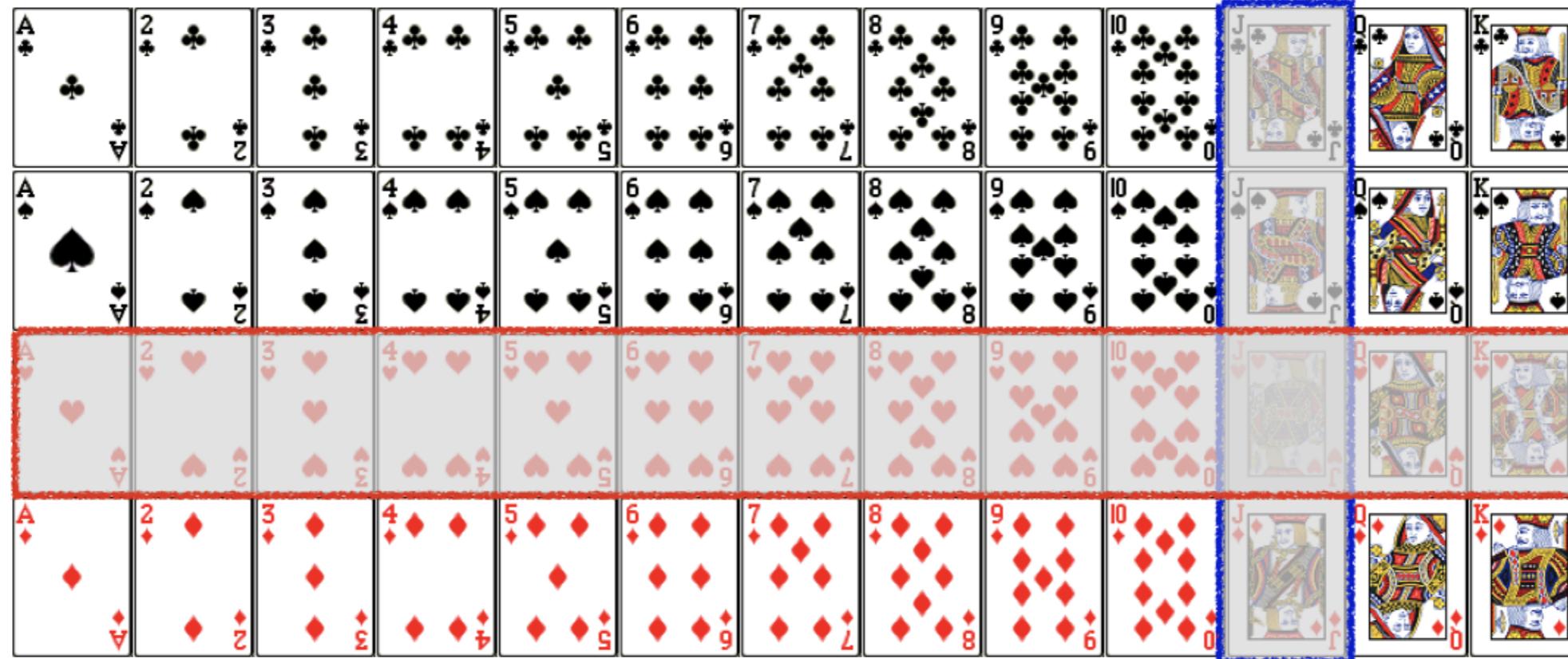
$$P(\text{Jack or Heart}) = P(\text{Jack}) + \dots$$



$$P(\text{Jack or Heart}) = \frac{4}{52} + \dots$$

# $P(A \text{ or } B)$ with overlap (Cont.)

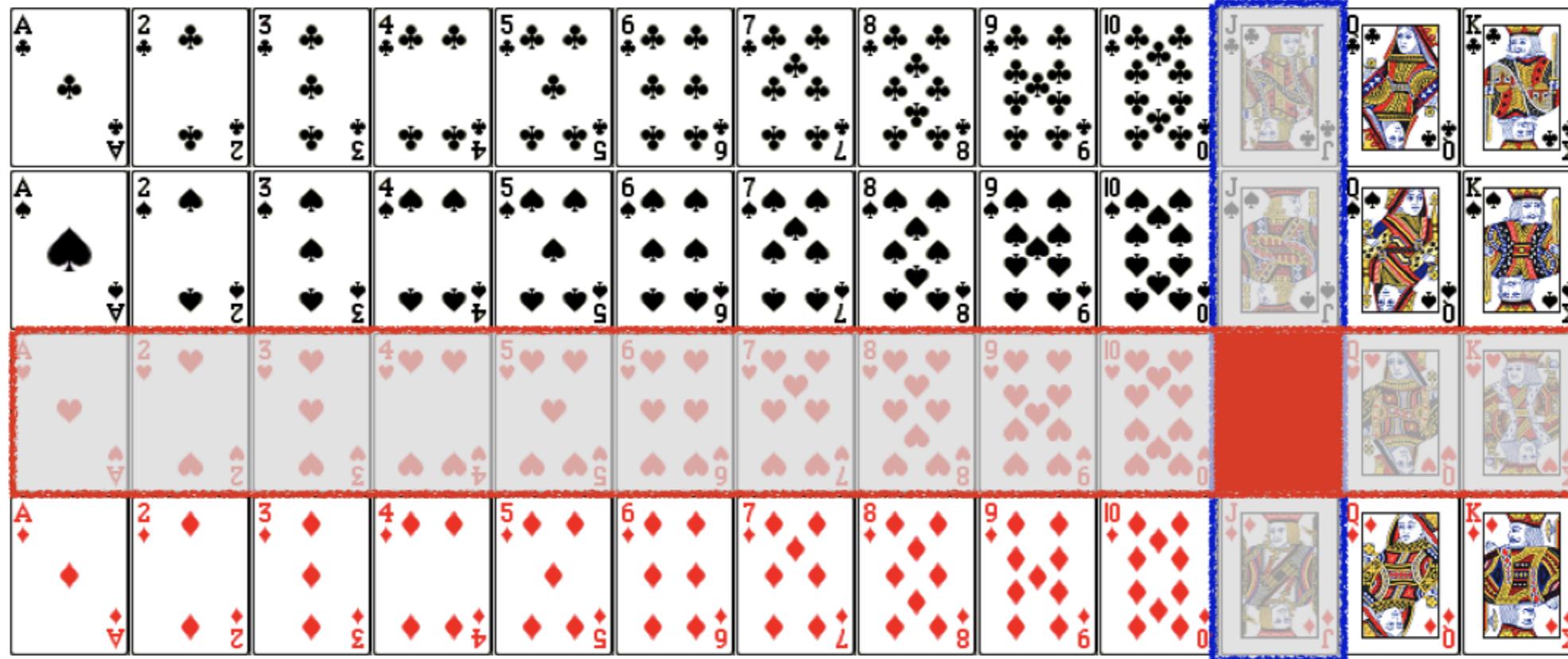
$$P(\text{Jack or Heart}) = P(\text{Jack}) + P(\text{Heart}) \dots$$



$$P(\text{Jack or Heart}) = \frac{4}{52} + \frac{13}{52} \dots$$

# $P(A \text{ or } B)$ with overlap (Cont.)

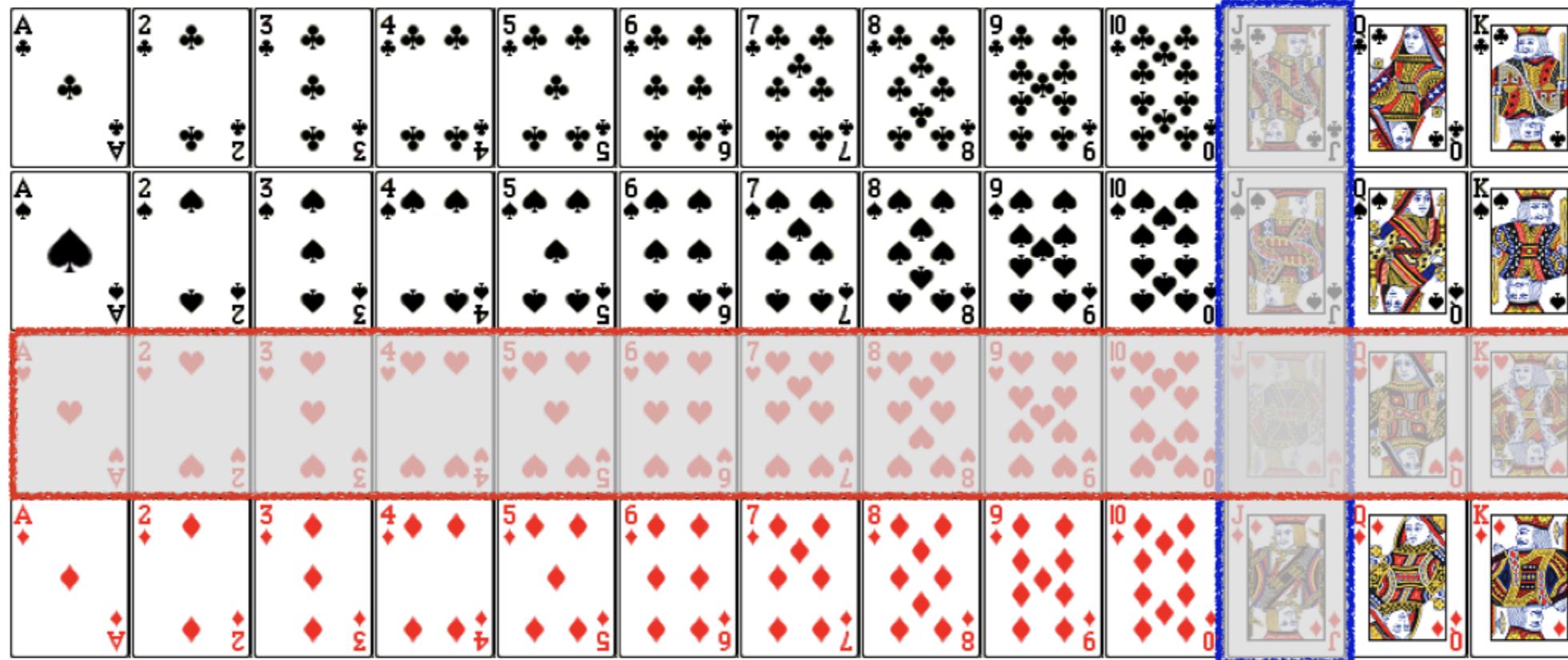
$$P(\text{Jack or Heart}) = P(\text{Jack}) + P(\text{Heart}) - P(\text{Jack and Heart})$$



$$P(\text{Jack or Heart}) = \frac{4}{52} + \frac{13}{52} - \frac{1}{52}$$

# $P(A \text{ or } B)$ with overlap (Cont.)

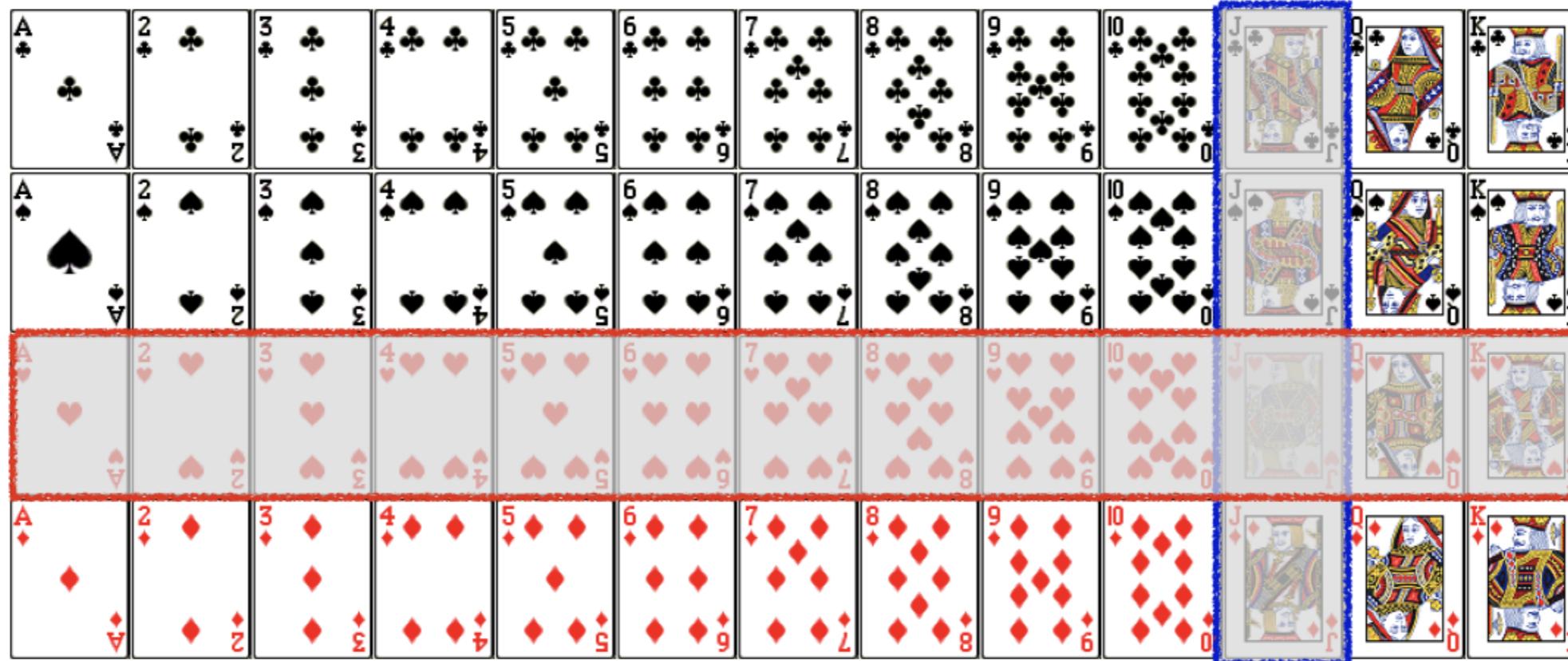
$$P(\text{Jack or Heart}) = P(\text{Jack}) + P(\text{Heart}) - P(\text{Jack and Heart})$$



$$P(\text{Jack or Heart}) = \frac{4}{52} + \frac{13}{52} - \frac{1}{52}$$

# $P(A \text{ or } B)$ with overlap (Cont.)

$$P(\text{Jack or Heart}) = P(\text{Jack}) + P(\text{Heart}) - P(\text{Jack and Heart})$$

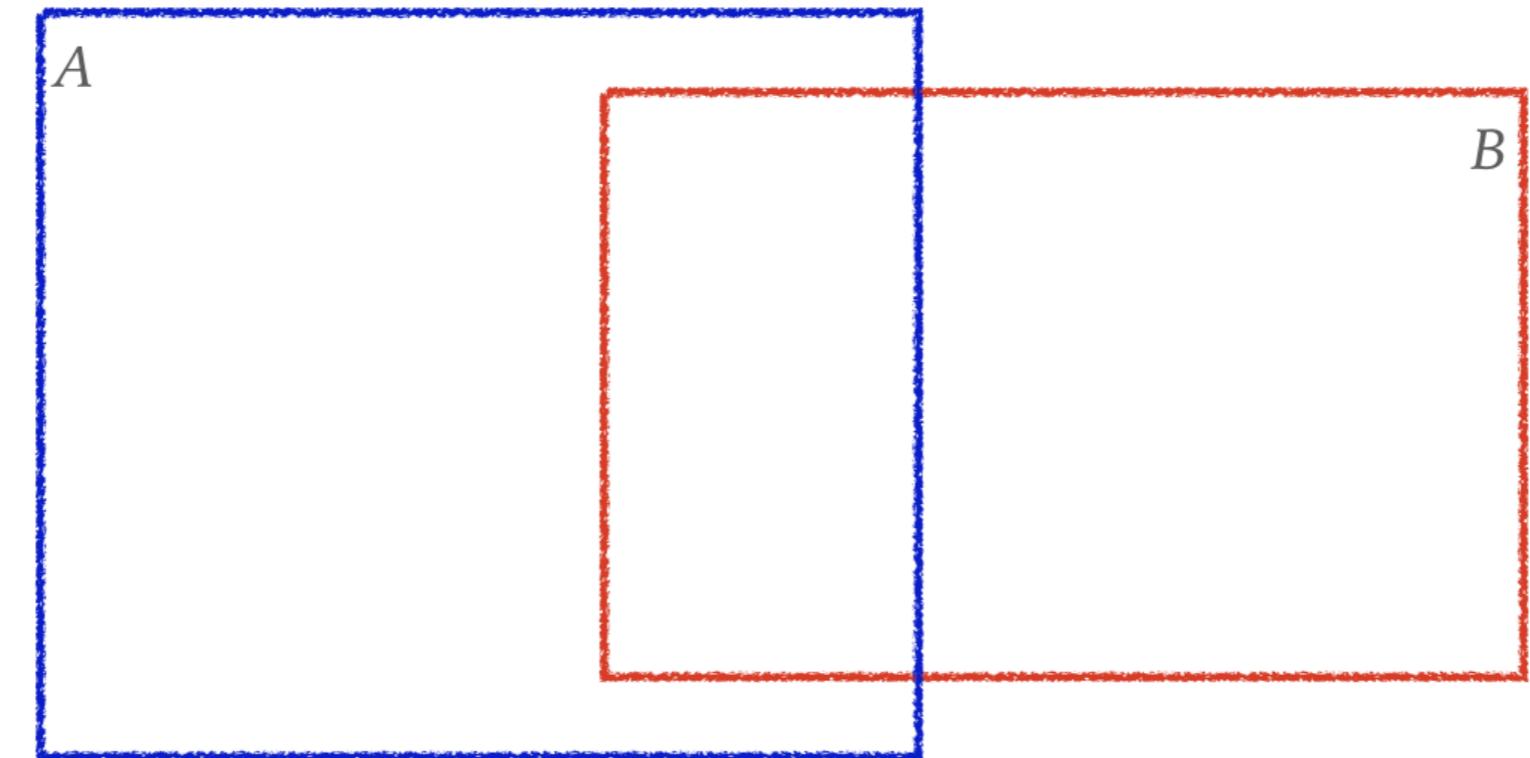


$$P(\text{Jack or Heart}) = \frac{4}{52} + \frac{13}{52} - \frac{1}{52} = \frac{16}{52} = \frac{4}{13}$$

# Diagram of $P(A \text{ or } B)$

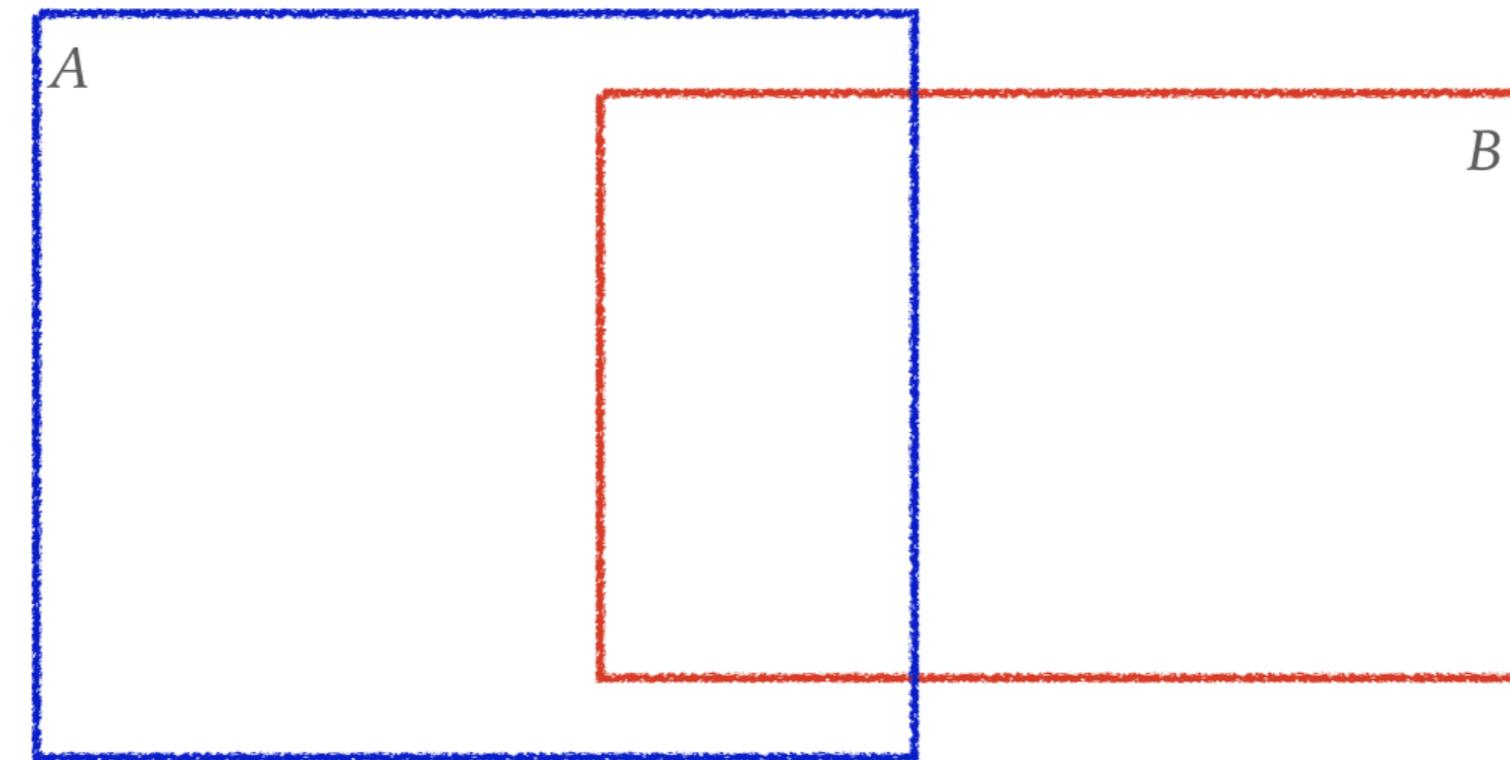


# Diagram of $P(A \text{ or } B)$ (Cont.)



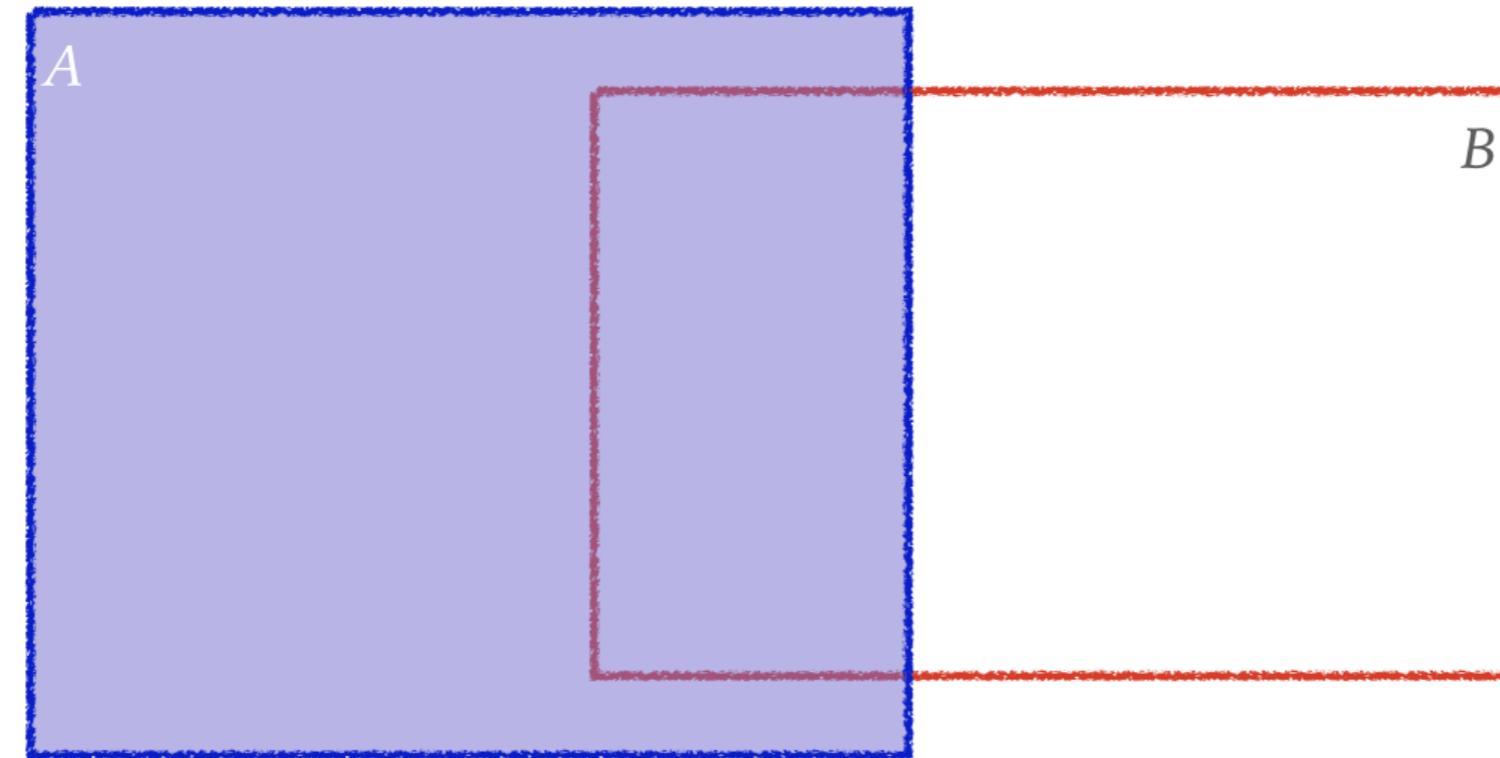
# Diagram of $P(A \text{ or } B)$ (Cont.)

$$P(A \text{ or } B) = ?$$



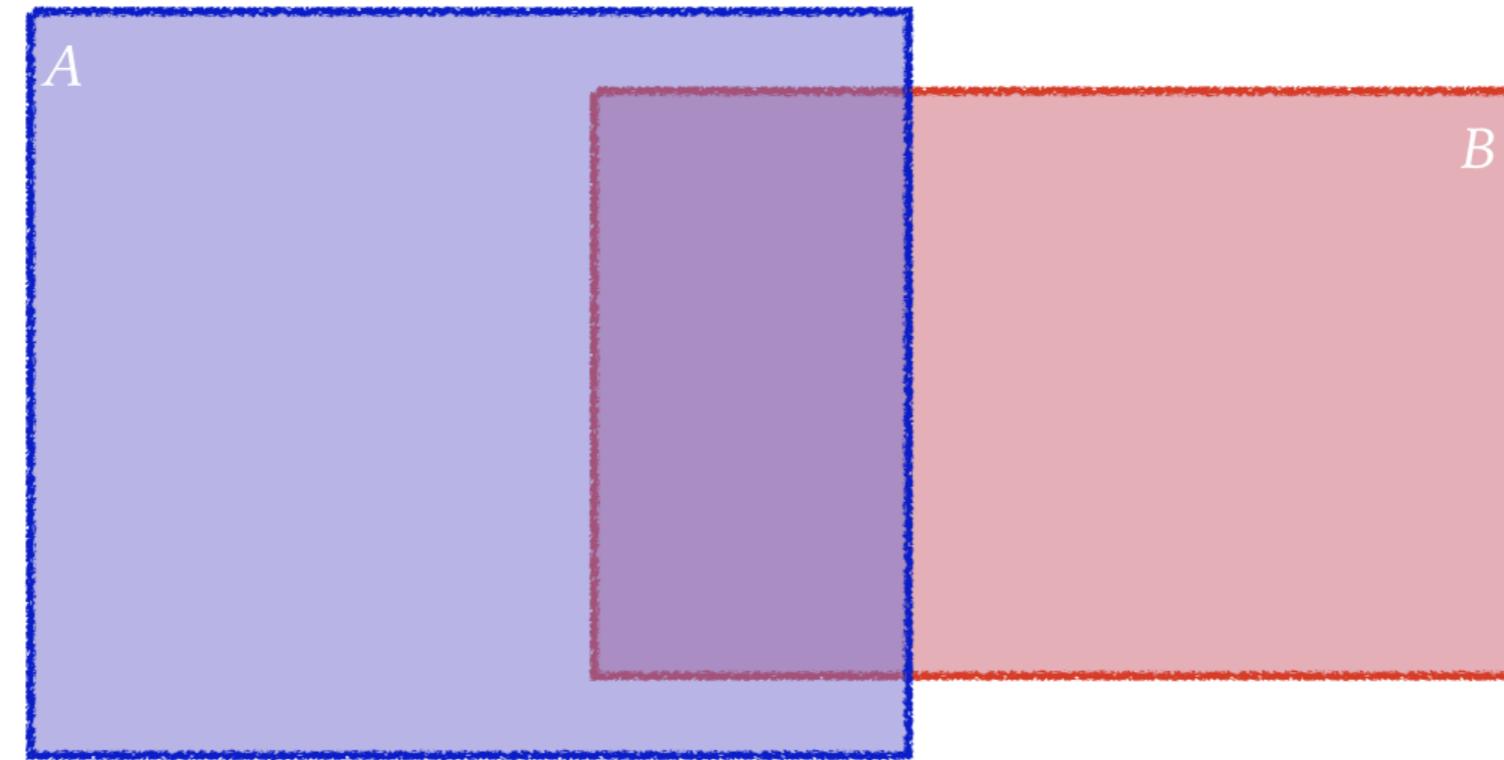
# Diagram of $P(A \text{ or } B)$ (Cont.)

$$P(A \text{ or } B) = P(A) + \dots$$



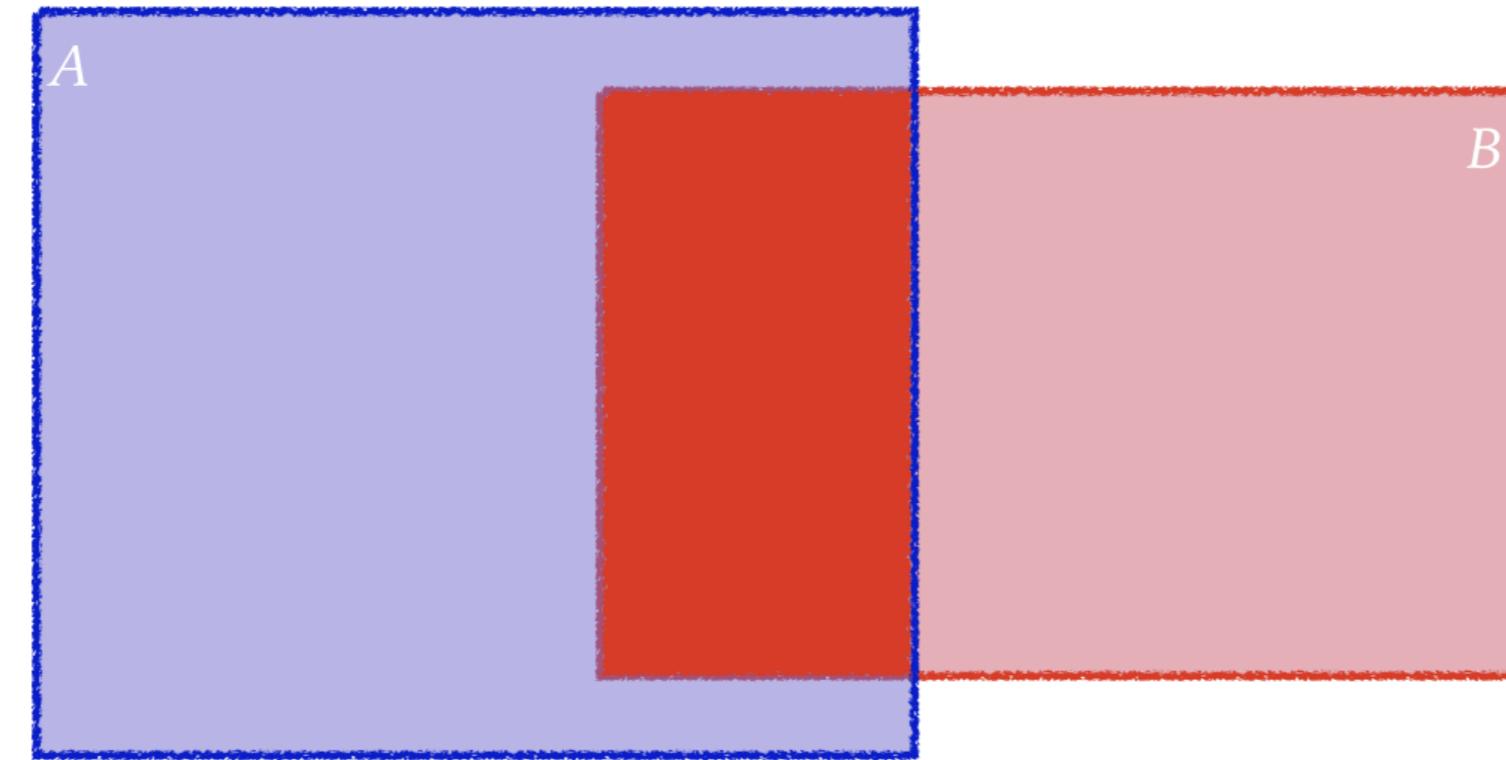
# Diagram of $P(A \text{ or } B)$ (Cont.)

$$P(A \text{ or } B) = P(A) + P(B) \dots$$



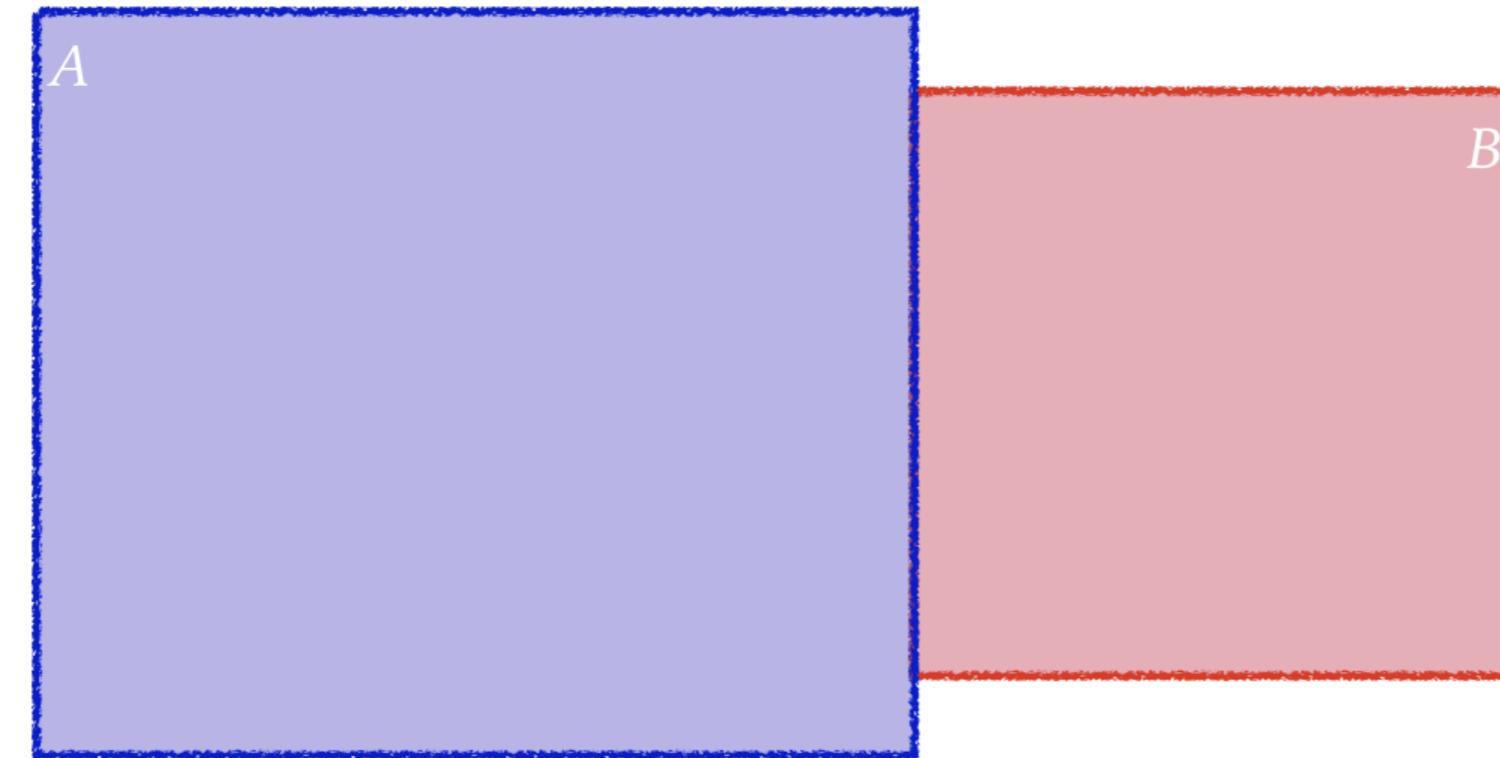
# Diagram of $P(A \text{ or } B)$ (Cont.)

$$P(A \text{ or } B) = P(A) + P(B) \dots$$



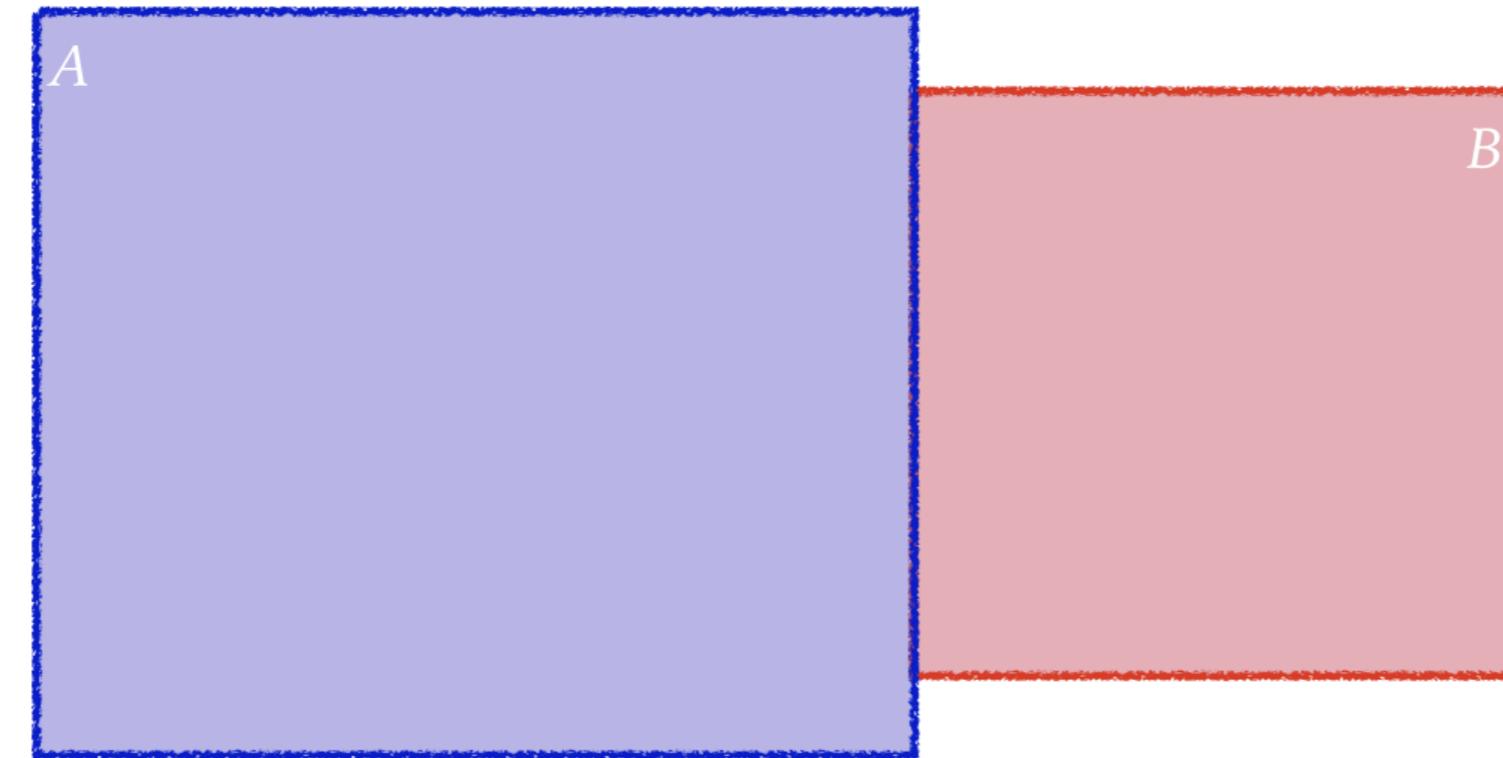
# Diagram of $P(A \text{ or } B)$ (Cont.)

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$$



# Diagram of $P(A \text{ or } B)$ (Cont.)

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$$



# P(Jack or Heart) calculation in Python

```
P_Jack = 4/52  
P_Hearts = 13/52  
P_Jack_n_Hearts = 1/52  
P_Jack_or_Hearts = P_Jack + P_Hearts - P_Jack_n_Hearts  
print(P_Jack_or_Hearts)
```

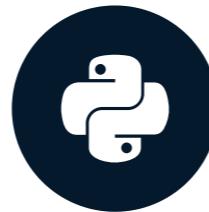
```
0.307692307692
```

# Let's calculate probabilities of two events

FOUNDATIONS OF PROBABILITY IN PYTHON

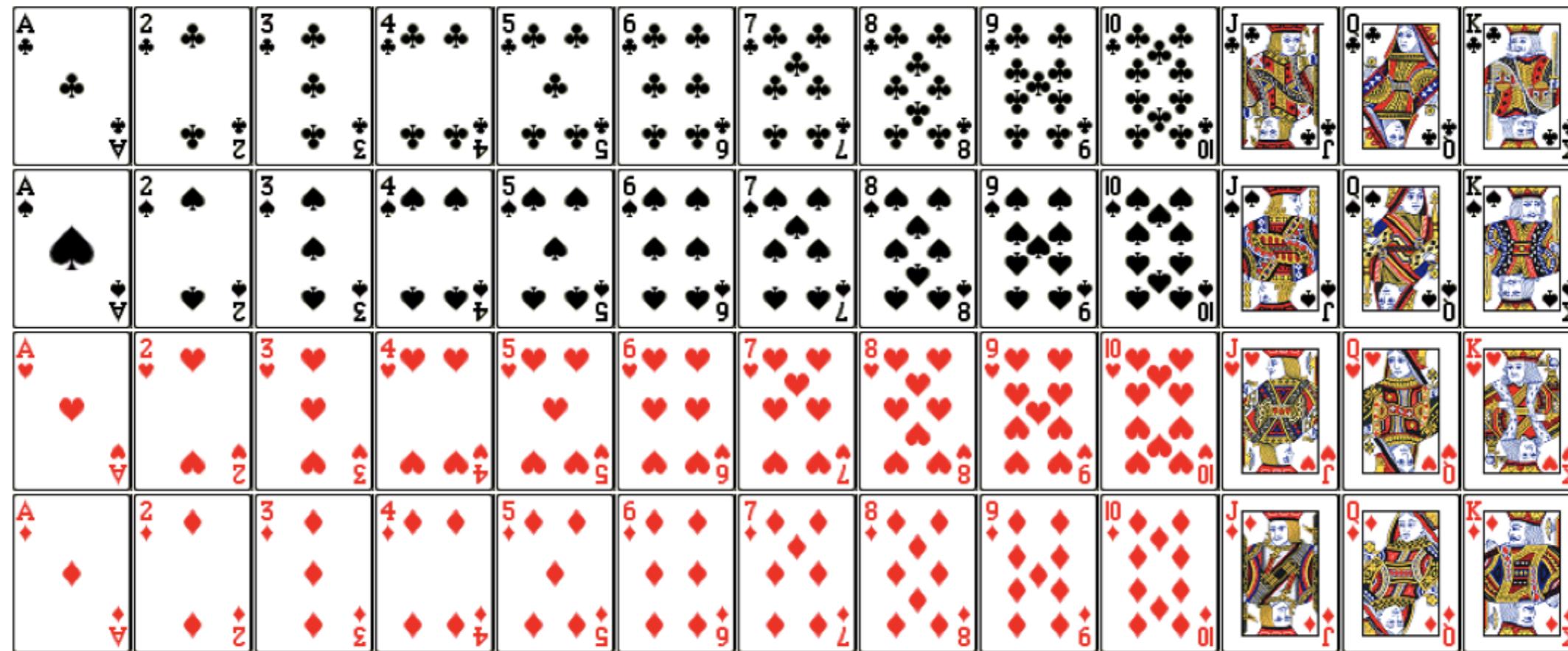
# Conditional probabilities

FOUNDATIONS OF PROBABILITY IN PYTHON

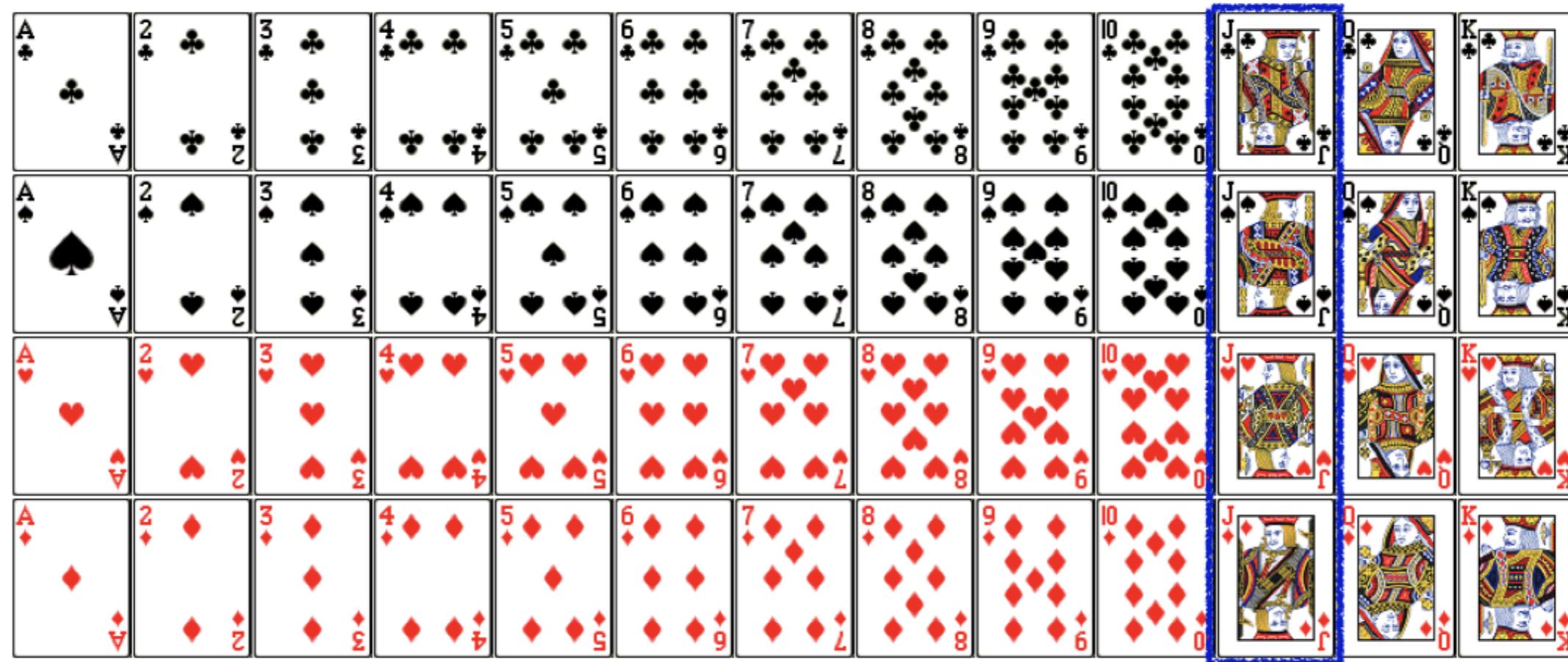


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# Dependent events

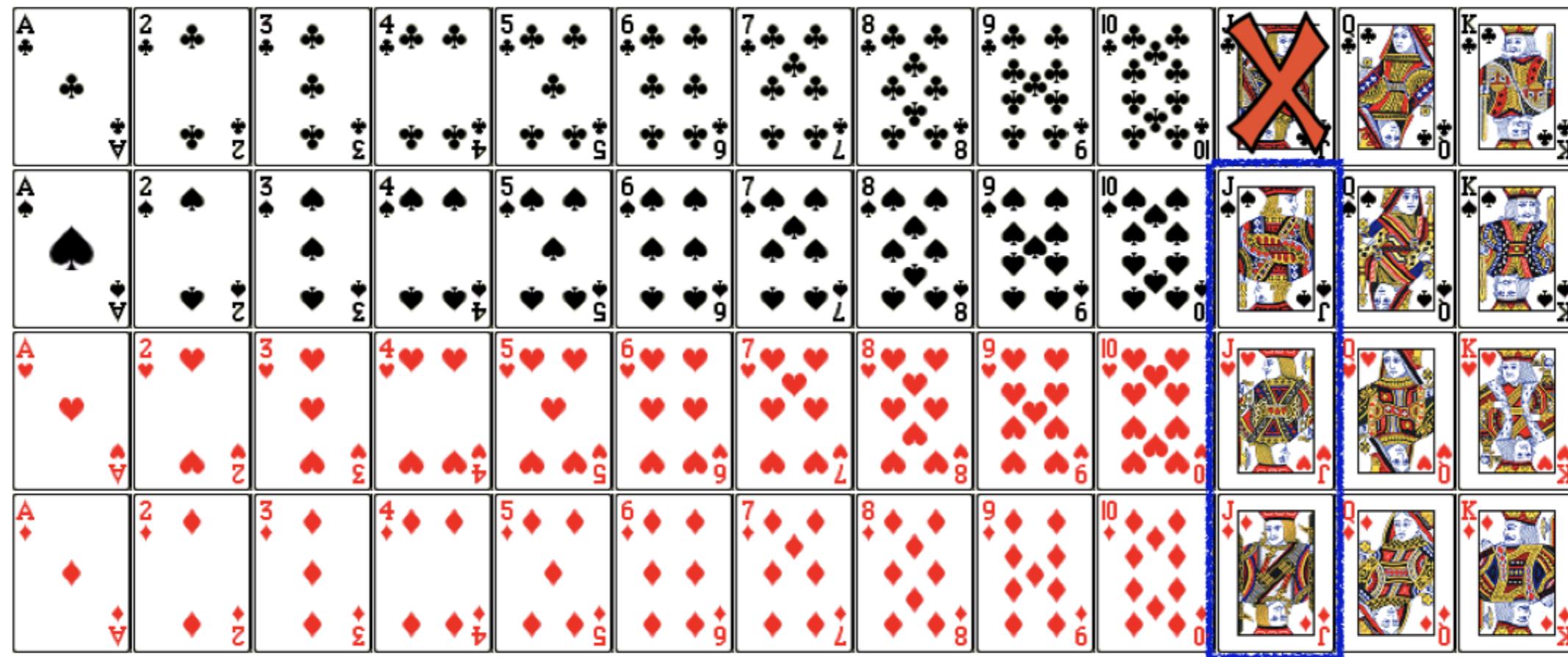


# Dependent events (Cont.)



$$P(\text{Jack}) = \frac{4}{52} \simeq 7.69\%$$

# Dependent events (Cont.)



$$P(\text{Jack}) = \frac{3}{51} \simeq 5.88\%$$

# Conditional probability formula

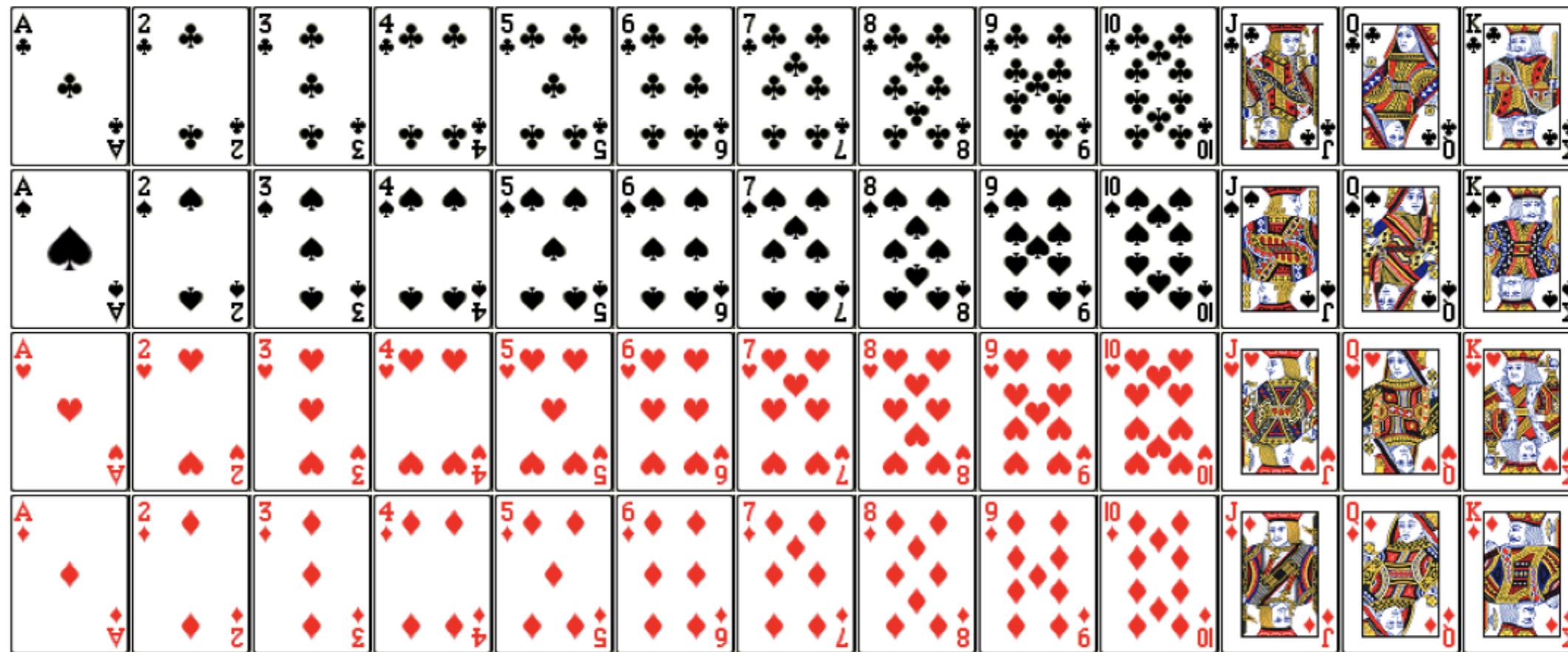
$$P(A \text{ and } B) = P(A)P(B)$$

# Conditional probability formula (Cont.)

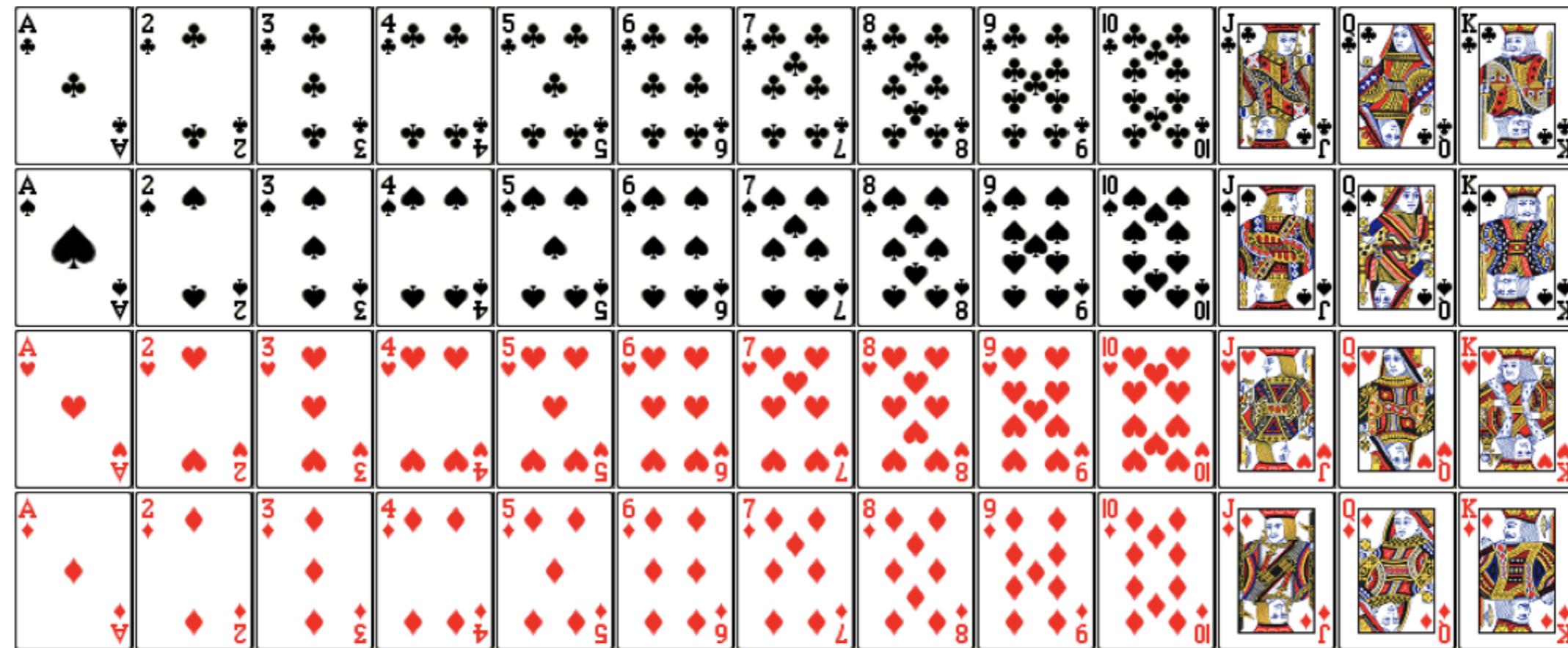
$$P(A \text{ and } B) = P(A)P(B|A)$$

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

# Conditional probability

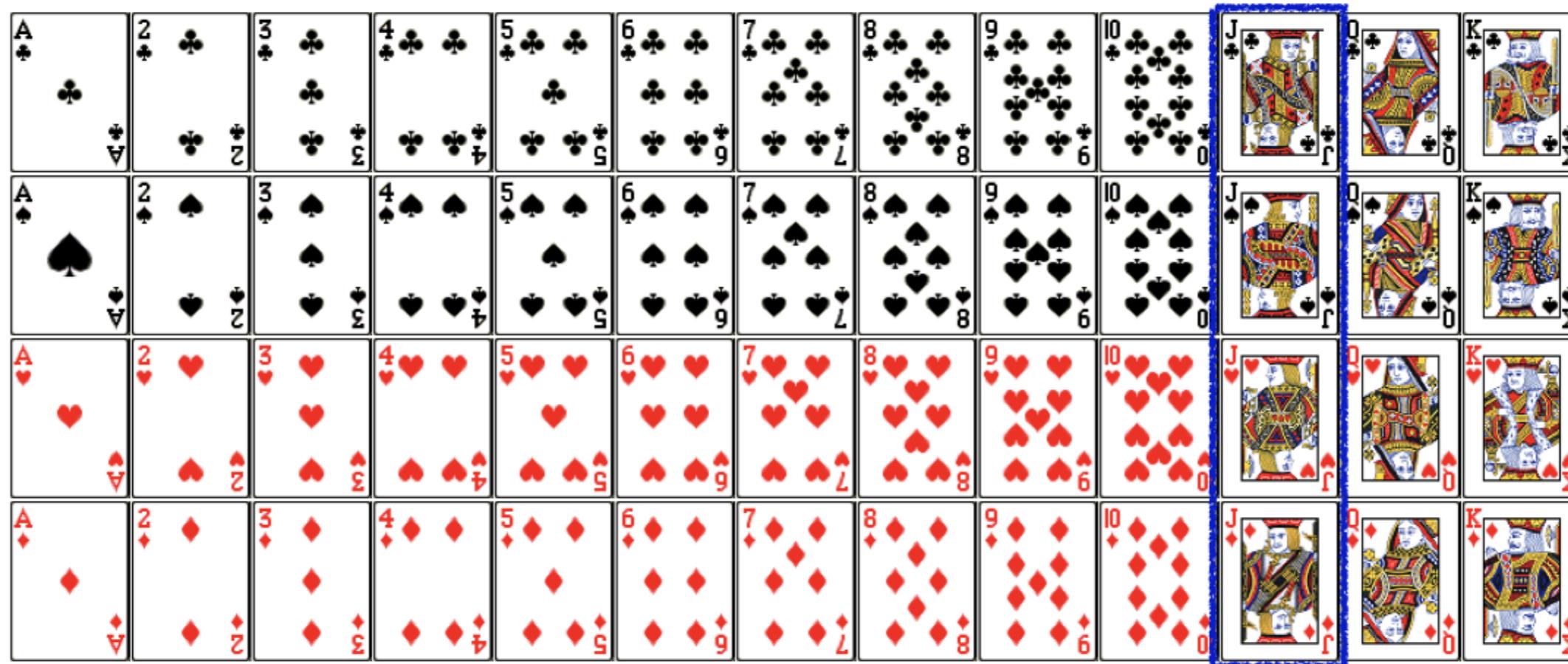


# Conditional probability (Cont.)



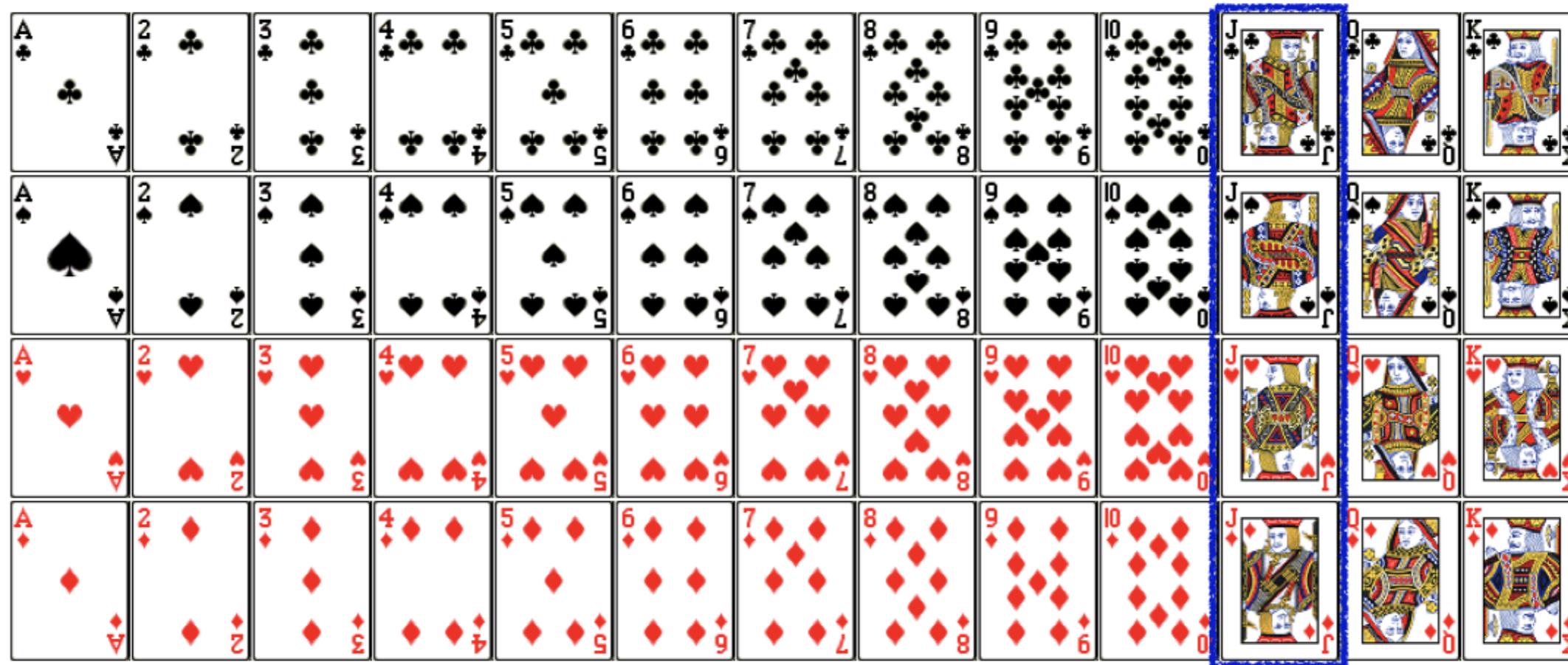
$$P(\text{Red}|\text{Jack}) = ?$$

# Conditional probability (Cont.)



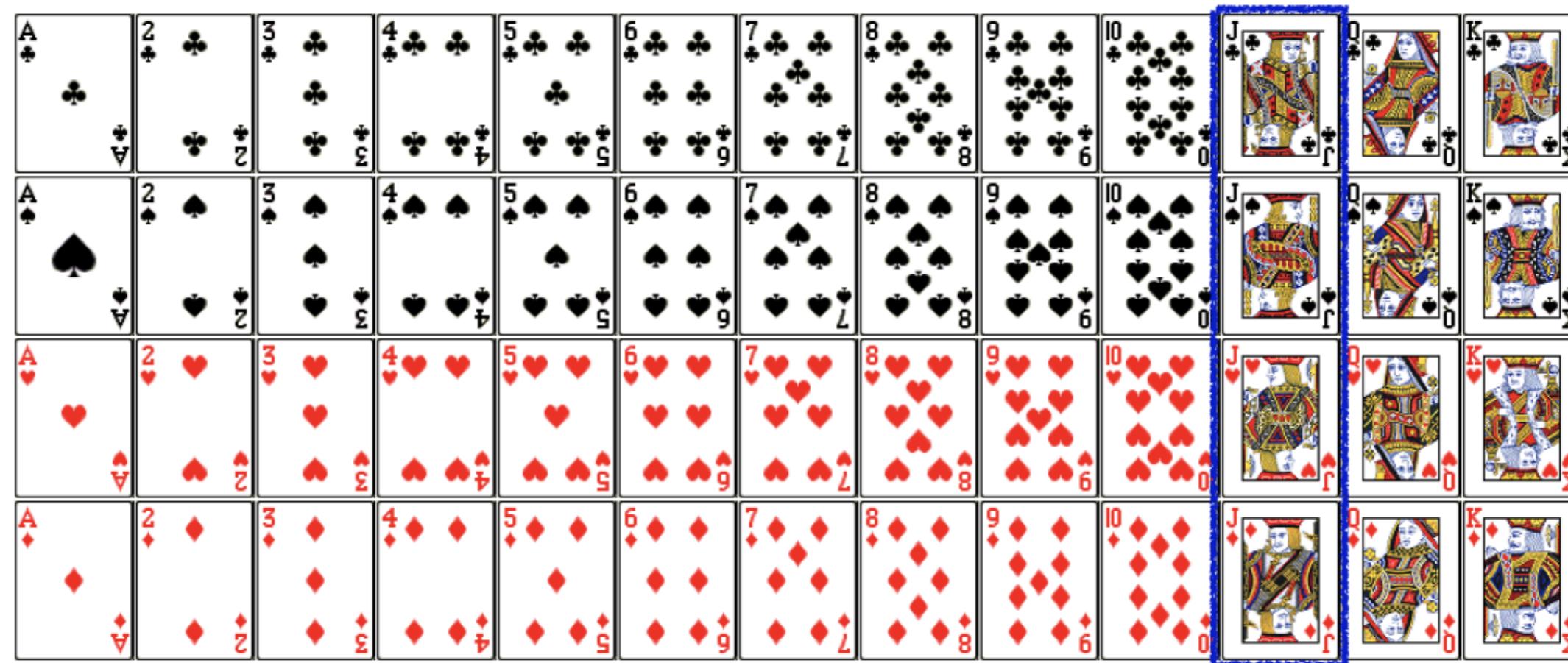
$$P(\text{Red}|\text{Jack}) = \frac{P(\text{Jack and Red})}{P(\text{Jack})}$$

# Conditional probability (Cont.)



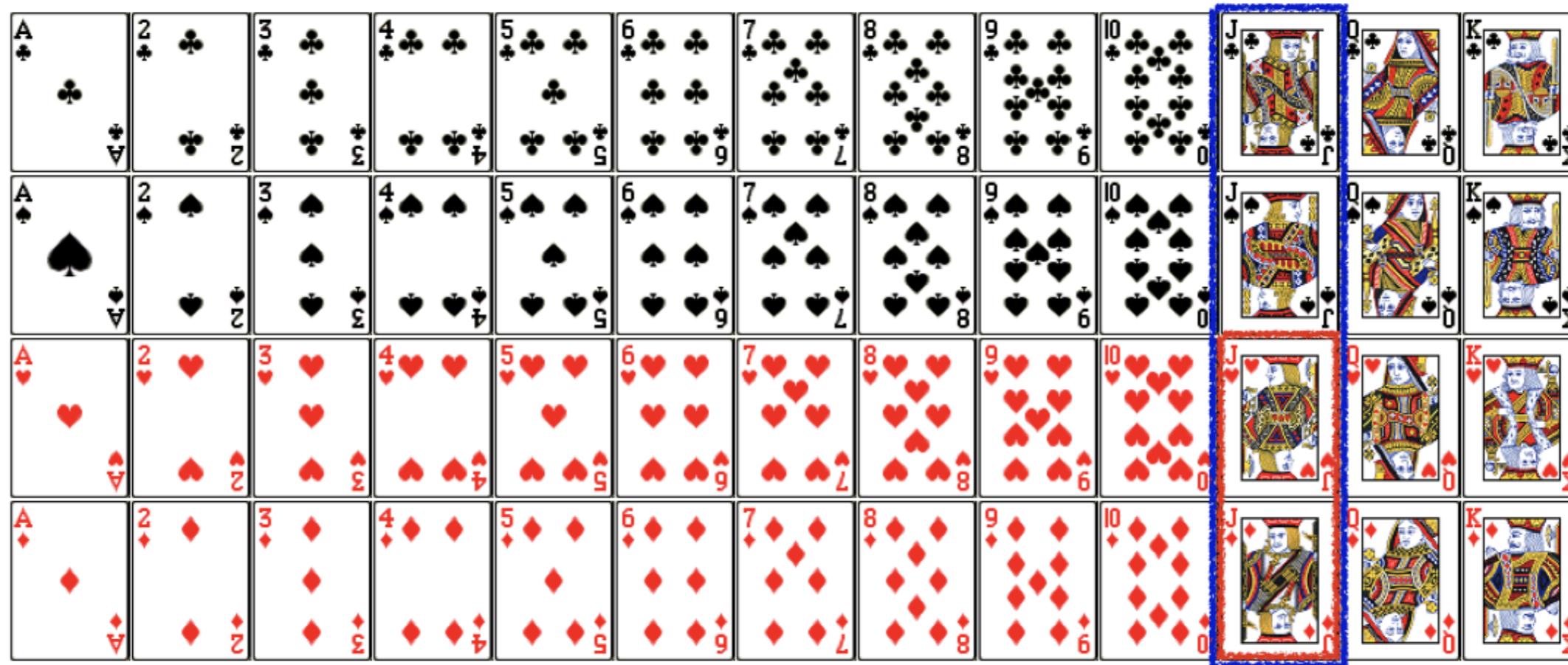
$$P(\text{Red}|\text{Jack}) = \frac{P(\text{Jack and Red})}{P(\text{Jack})}$$

# Conditional probability (Cont.)



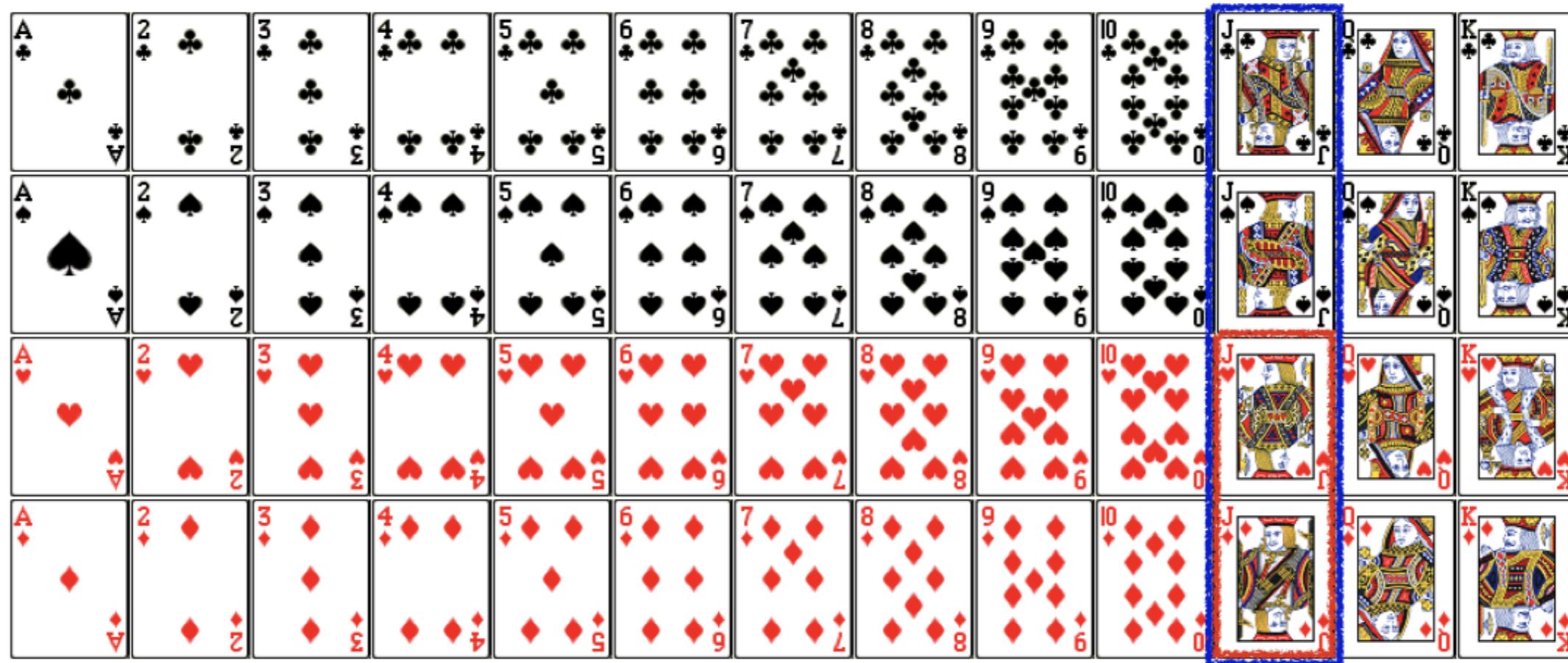
$$P(\text{Red}|\text{Jack}) = \frac{P(\text{Jack and Red})}{P(\text{Jack})} = \frac{X}{\frac{4}{52}}$$

# Conditional probability (Cont.)



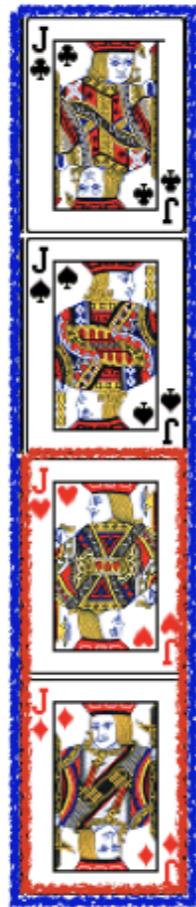
$$P(\text{Red}|\text{Jack}) = \frac{P(\text{Jack and Red})}{P(\text{Jack})} = \frac{\frac{2}{52}}{\frac{4}{52}}$$

# Conditional probability (Cont.)



$$P(\text{Red}|\text{Jack}) = \frac{P(\text{Jack and Red})}{P(\text{Jack})} = \frac{\frac{2}{52}}{\frac{4}{52}} = \frac{2}{4} = \frac{1}{2}$$

# Conditional probability (Cont.)



$$P(\text{Red}|\text{Jack}) = \frac{P(\text{Jack and Red})}{P(\text{Jack})} = \frac{\frac{2}{52}}{\frac{4}{52}} = \frac{2}{4} = \frac{1}{2}$$

# $P(\text{Red} \mid \text{Jack})$ calculation in Python

```
P_Jack = 4/52
```

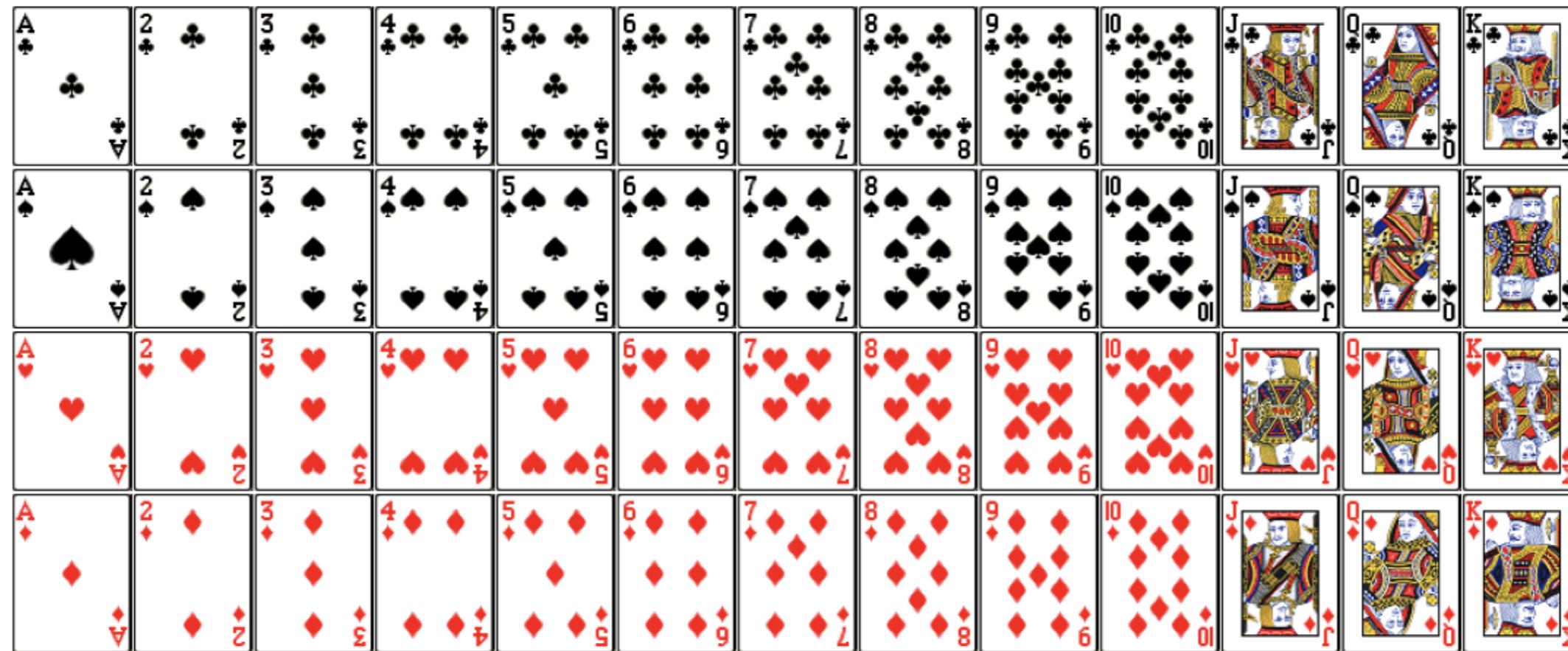
```
P_Jack_n_Red = 2/52
```

```
P_Red_given_Jack = P_Jack_n_Red / P_Jack
```

```
print(P_Red_given_Jack)
```

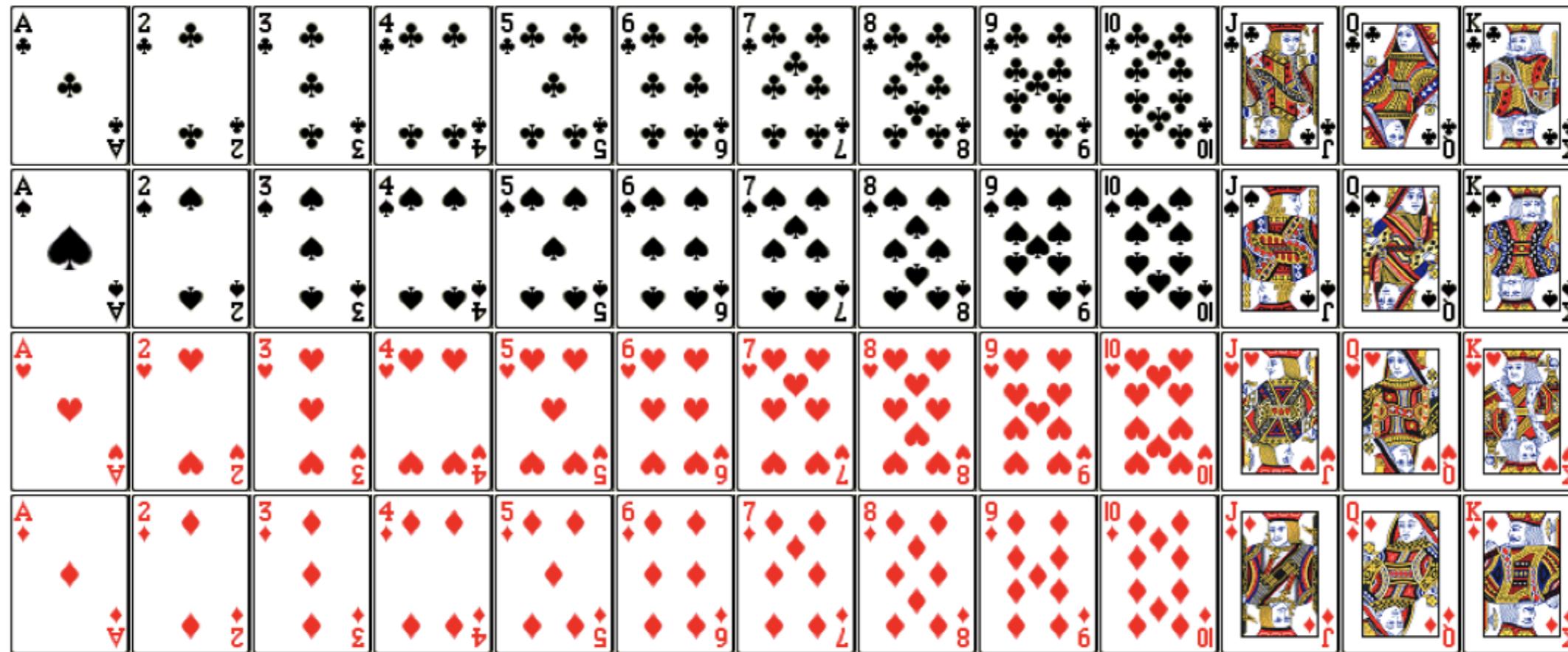
```
0.5
```

# Conditional probability



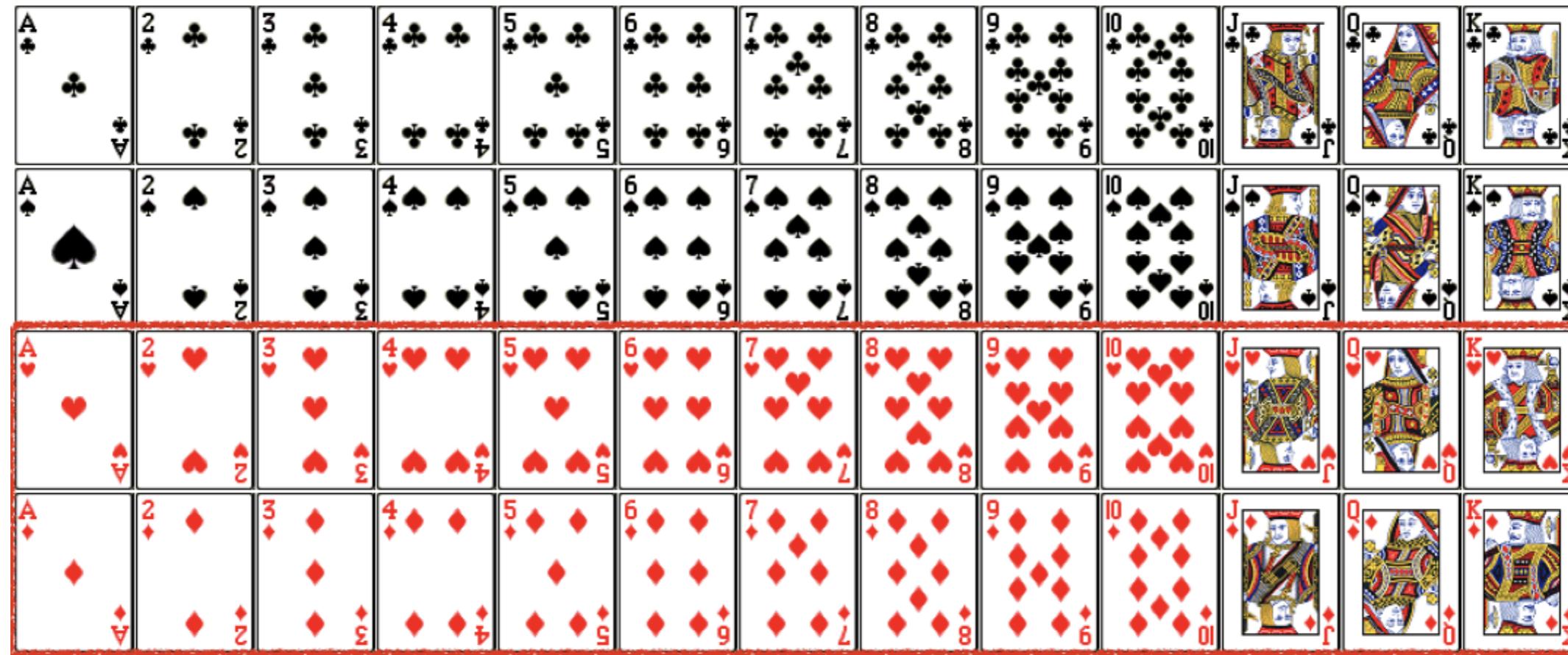
$$P(\text{Jack}|\text{Red}) = ?$$

# Conditional probability (Cont.)



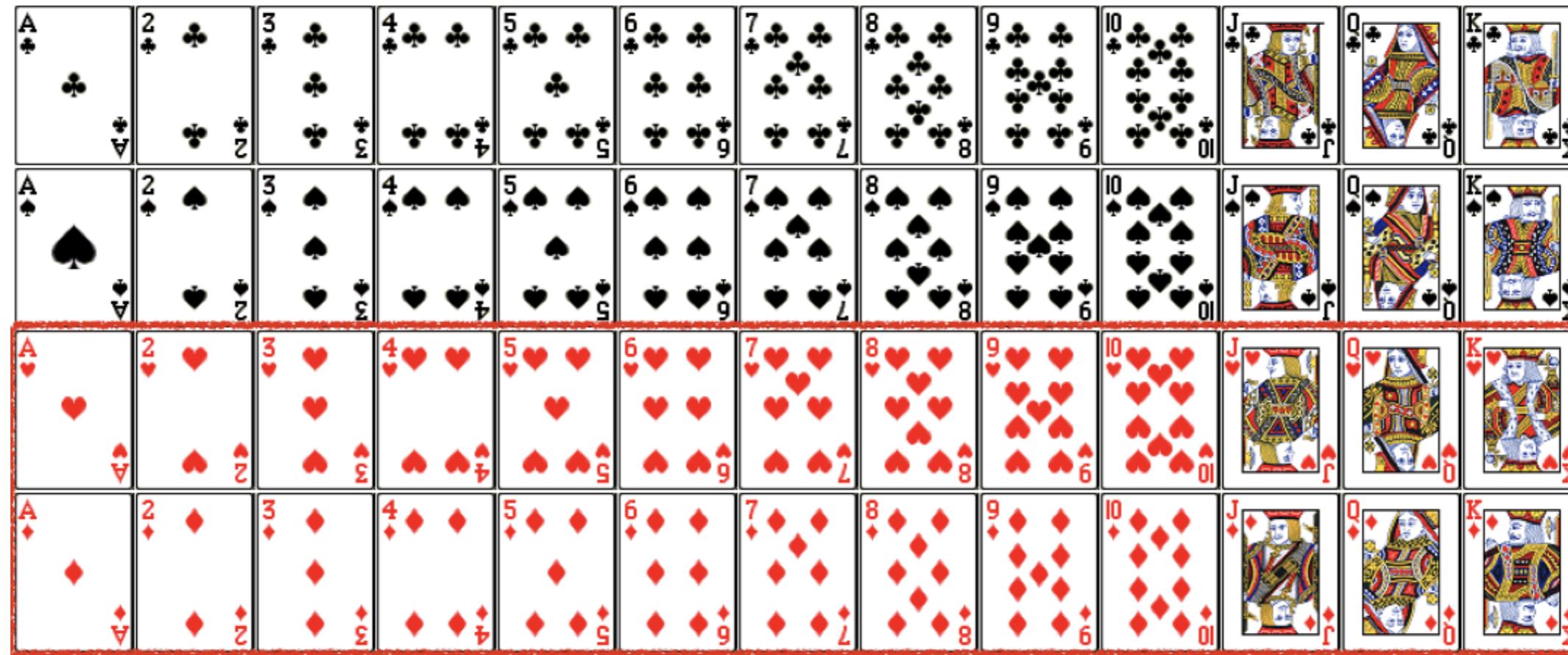
$$P(\text{Jack}|\text{Red}) = \frac{P(\text{Red and Jack})}{P(\text{Red})}$$

# Conditional probability (Cont.)



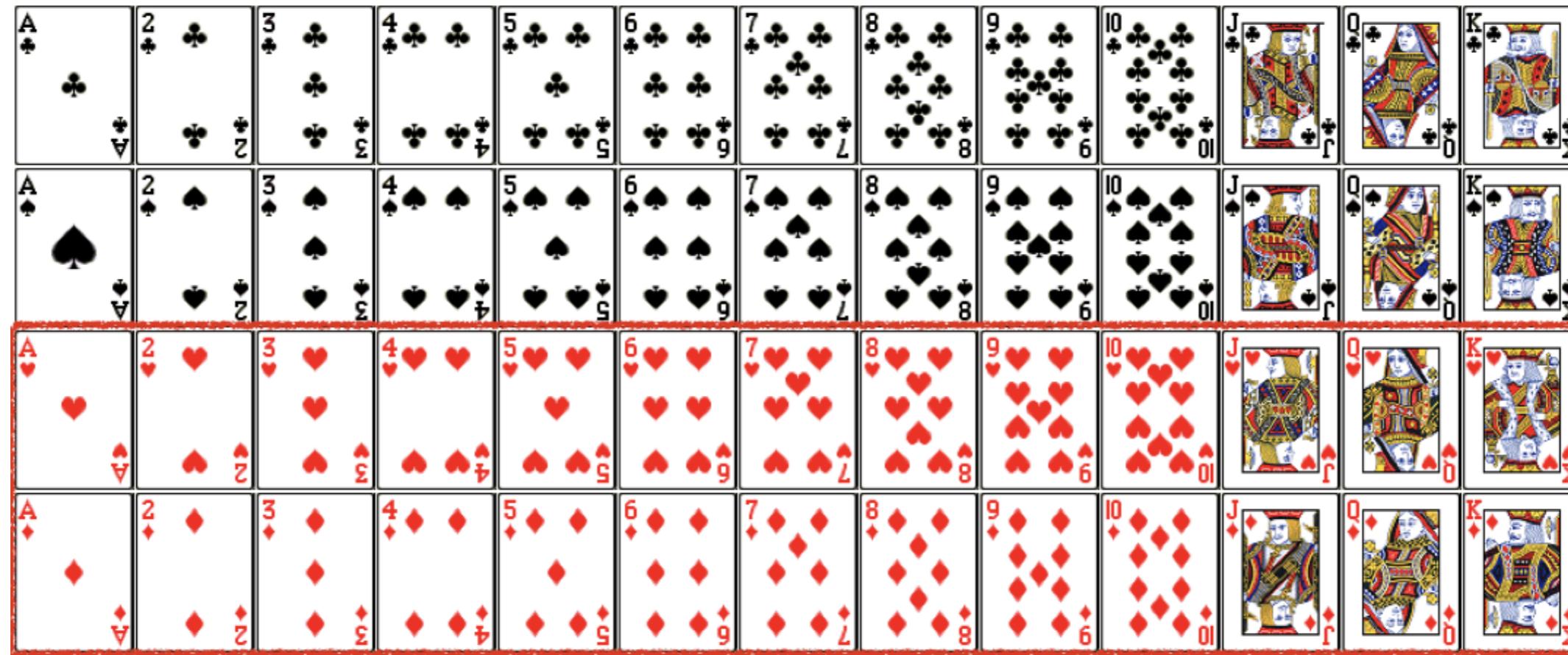
$$P(\text{Jack}|\text{Red}) = \frac{P(\text{Red and Jack})}{P(\text{Red})}$$

# Conditional probability (Cont.)



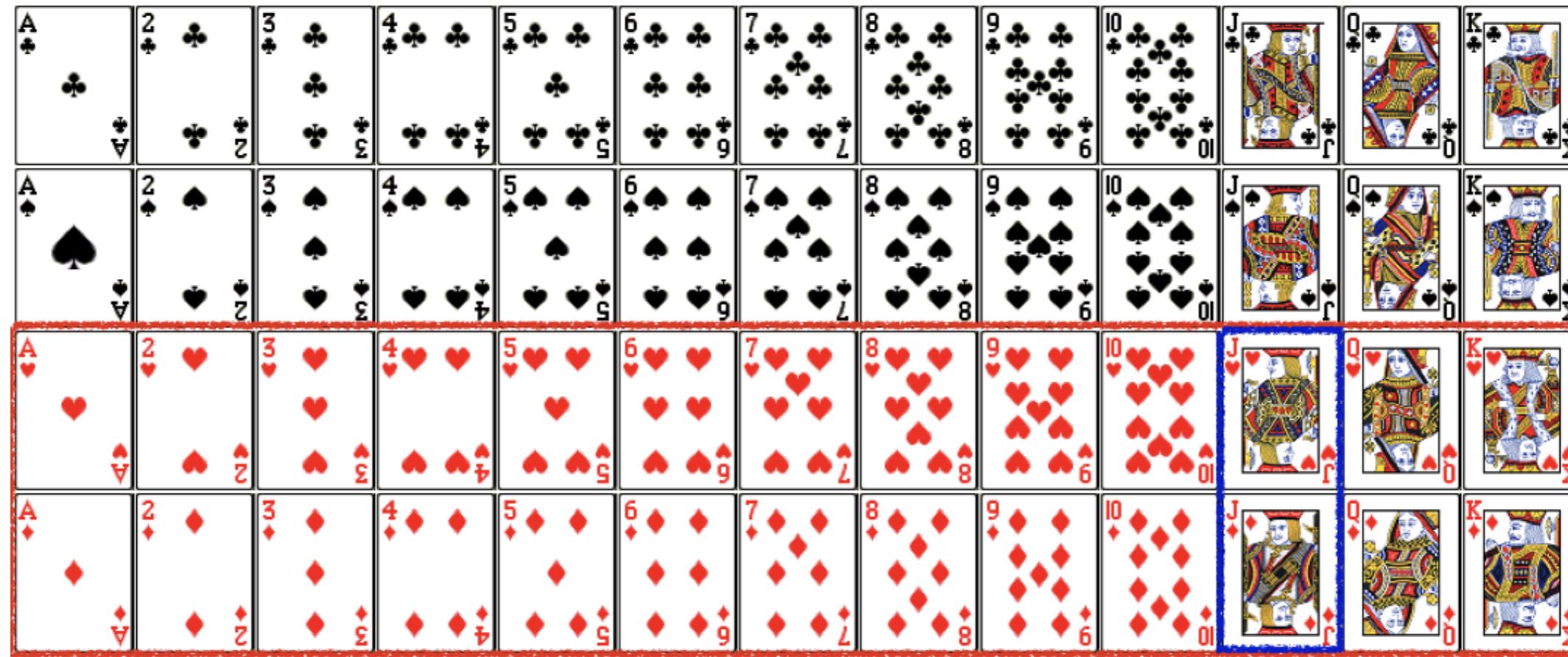
$$P(Jack|Red) = \frac{P(\\text{Red and Jack})}{P(\\text{Red})}$$

# Conditional probability (Cont.)



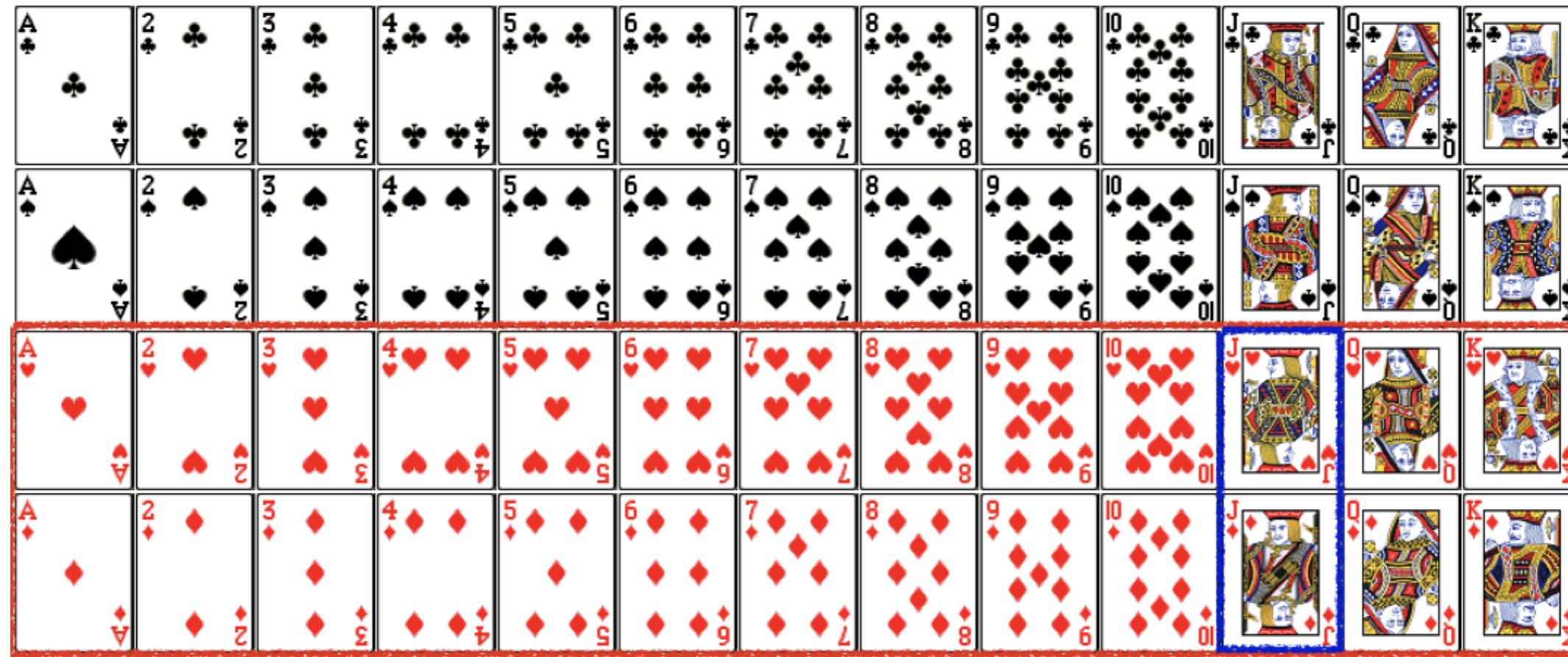
$$P(Jack|Red) = \frac{P(\\text{Red and Jack})}{P(\\text{Red})} = \frac{X}{\frac{26}{52}}$$

# Conditional probability (Cont.)



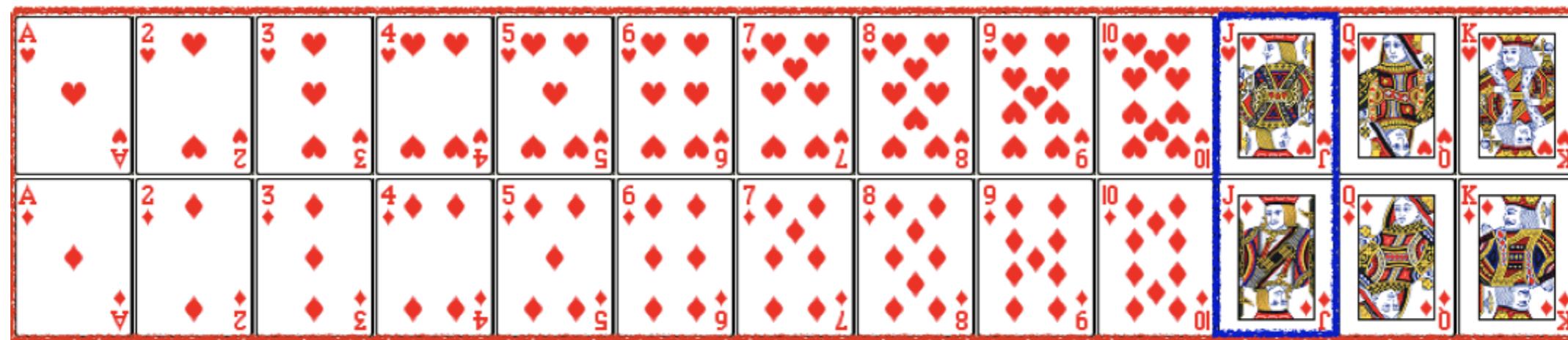
$$P(\text{Jack}|\text{Red}) = \frac{P(\text{Red and Jack})}{P(\text{Red})} = \frac{\frac{2}{52}}{\frac{26}{52}}$$

# Conditional probability (Cont.)



$$P(\text{Jack}|\text{Red}) = \frac{P(\text{Red and Jack})}{P(\text{Red})} = \frac{\frac{2}{52}}{\frac{26}{52}} = \frac{2}{26} = \frac{1}{13}$$

# Conditional probability (Cont.)



$$P(\text{Jack}|\text{Red}) = \frac{P(\text{Red and Jack})}{P(\text{Red})} = \frac{\frac{2}{52}}{\frac{26}{52}} = \frac{2}{26} = \frac{1}{13}$$

# $P(\text{Jack} \mid \text{Red})$ calculation in Python

```
P_Red = 26/52
```

```
P_Red_n_Jack = 2/52
```

```
P_Jack_given_Red = P_Red_n_Jack / P_Red
```

```
print(P_of_Jack_given_Red)
```

```
0.0769230769231
```

# **Let's condition events to calculate probabilities**

**FOUNDATIONS OF PROBABILITY IN PYTHON**

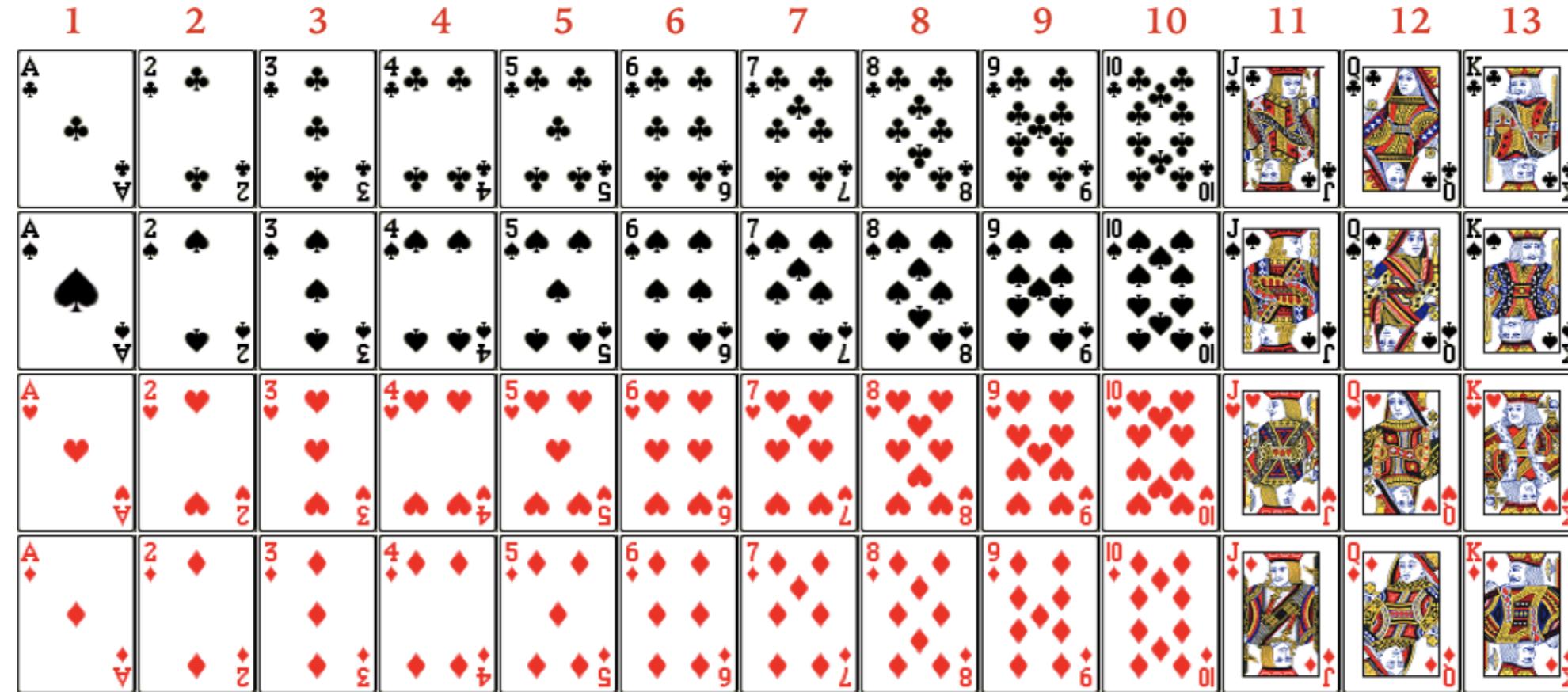
# Total probability law

## FOUNDATIONS OF PROBABILITY IN PYTHON

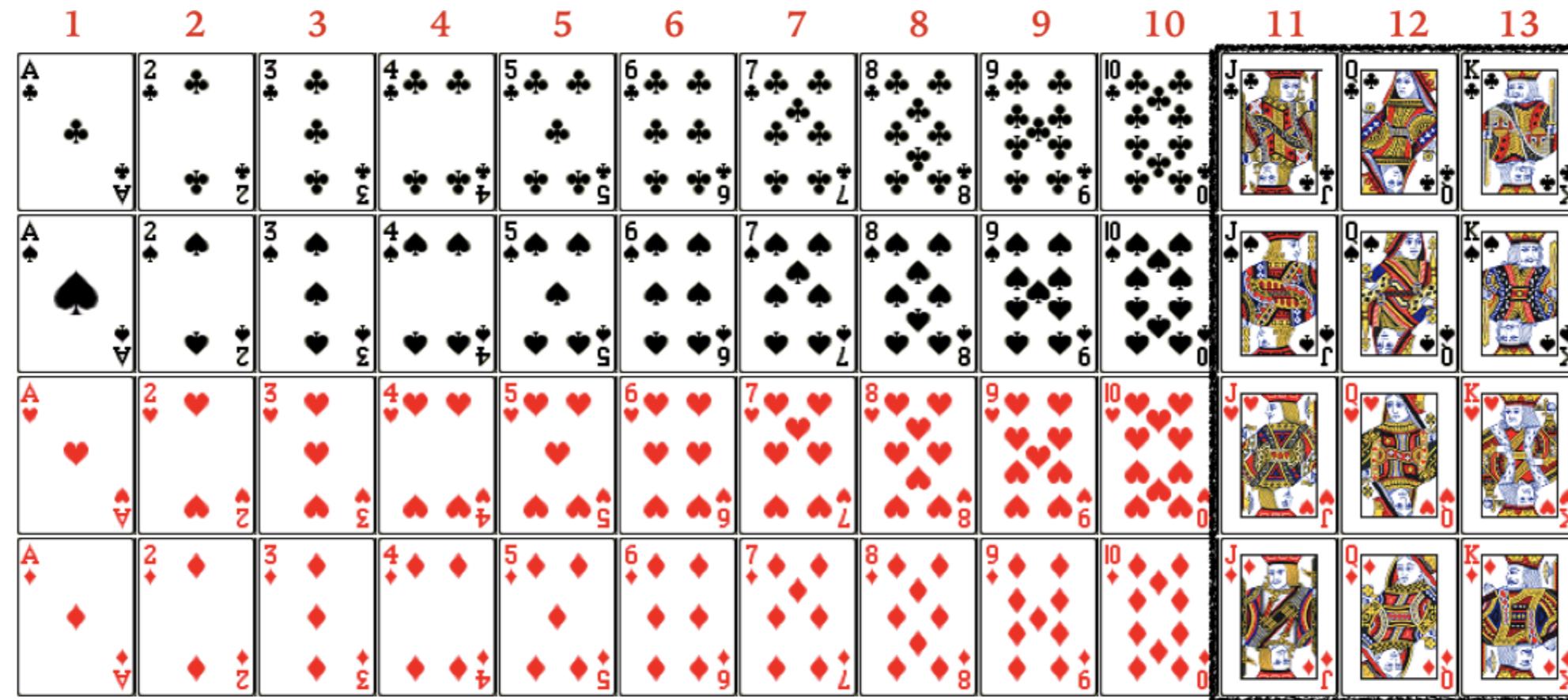


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# Deck of cards example

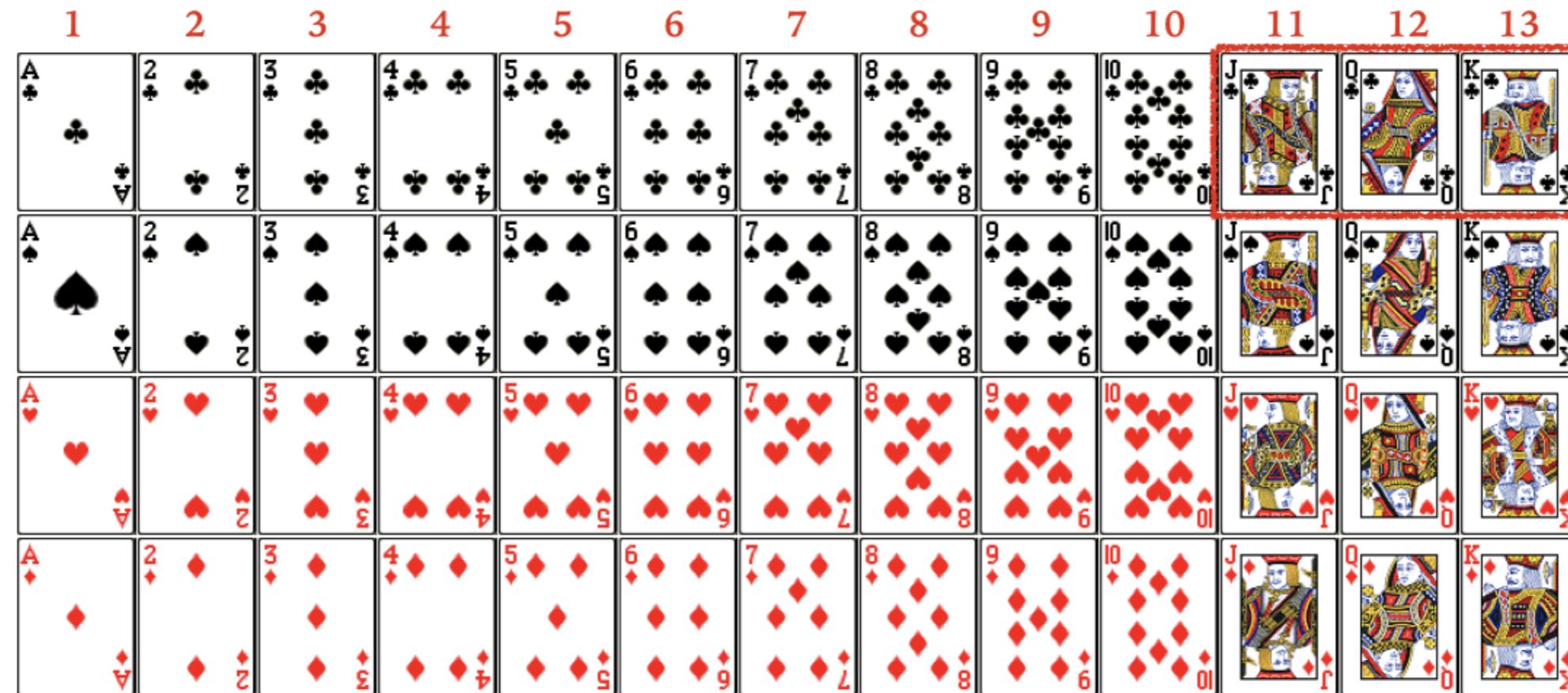


# Deck of cards example (Cont.)



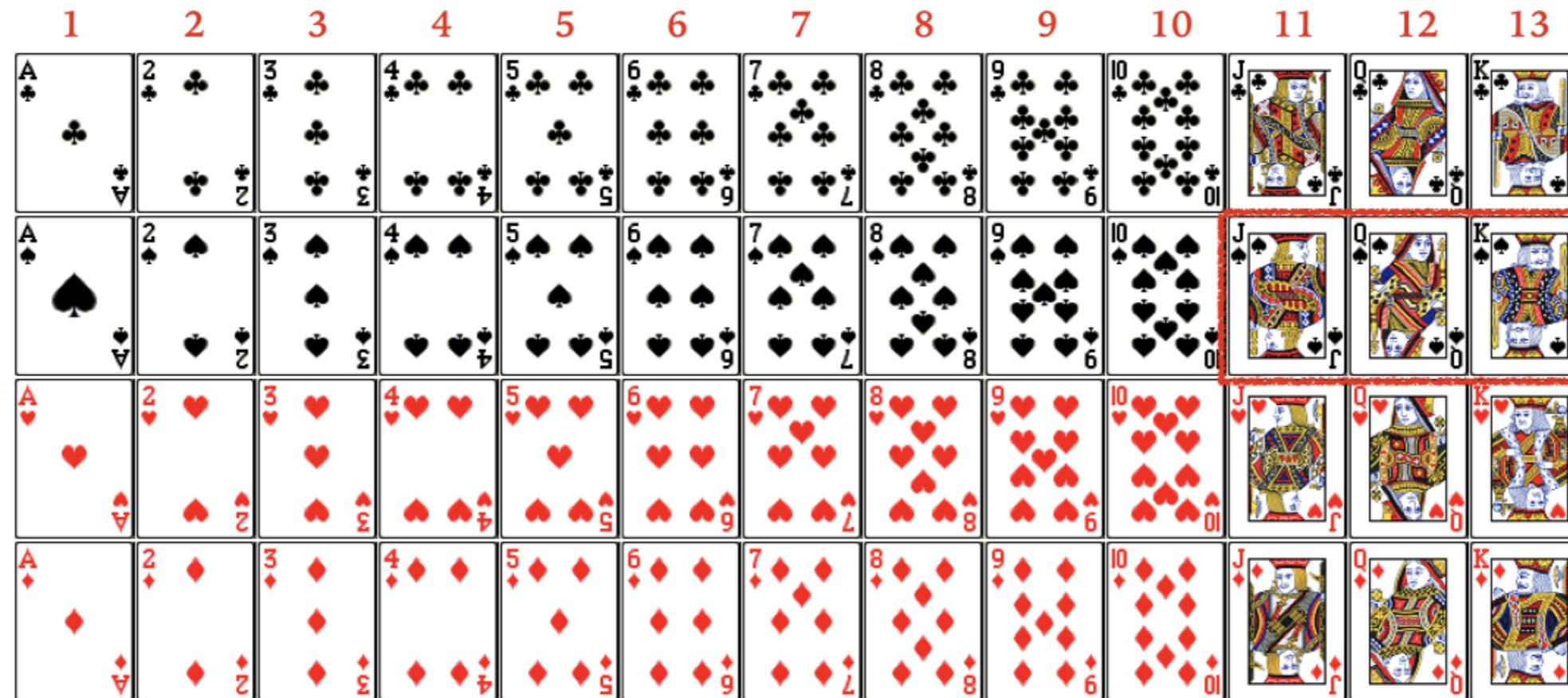
$$P(\text{Face card}) = ?$$

# Deck of cards example (Cont.)



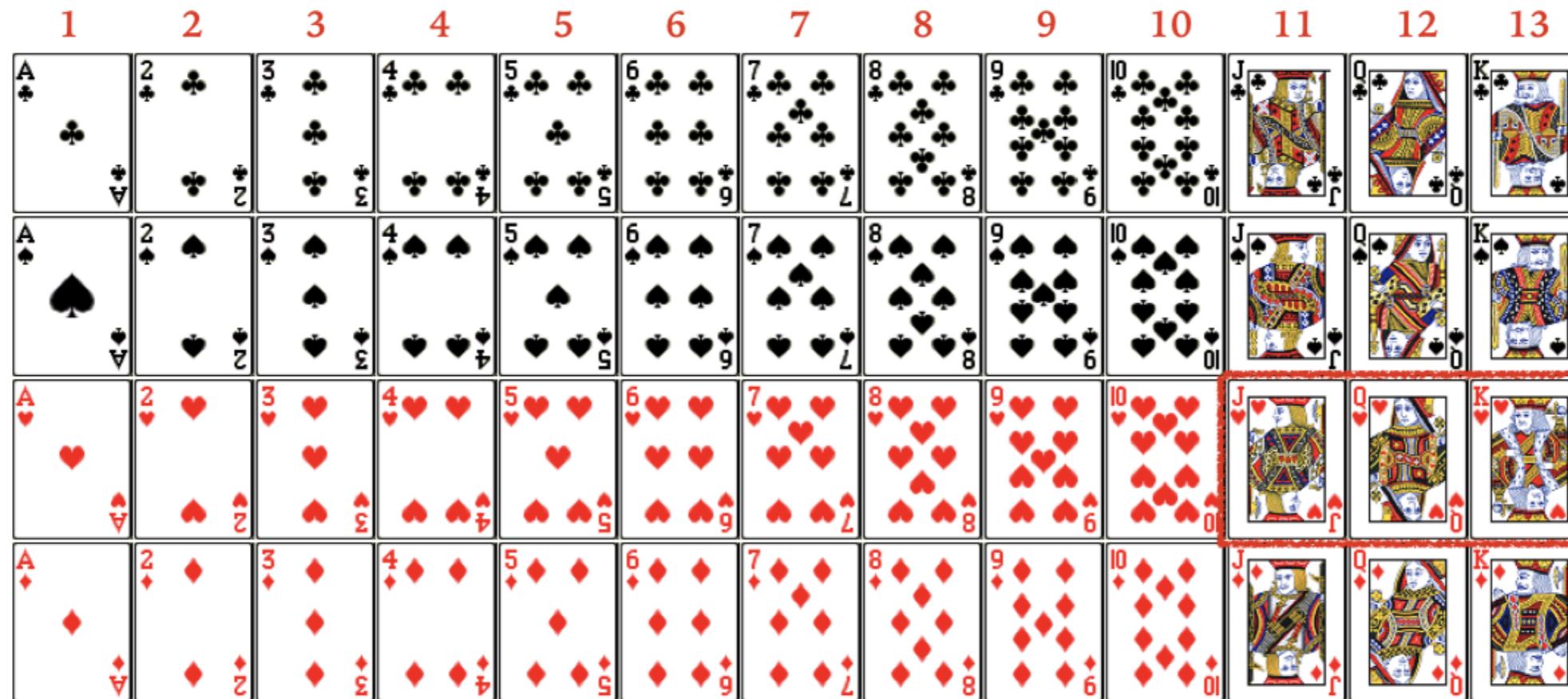
$$P(\text{Face card}) = P(\text{Club and Face card}) + \dots$$

# Deck of cards example (Cont.)



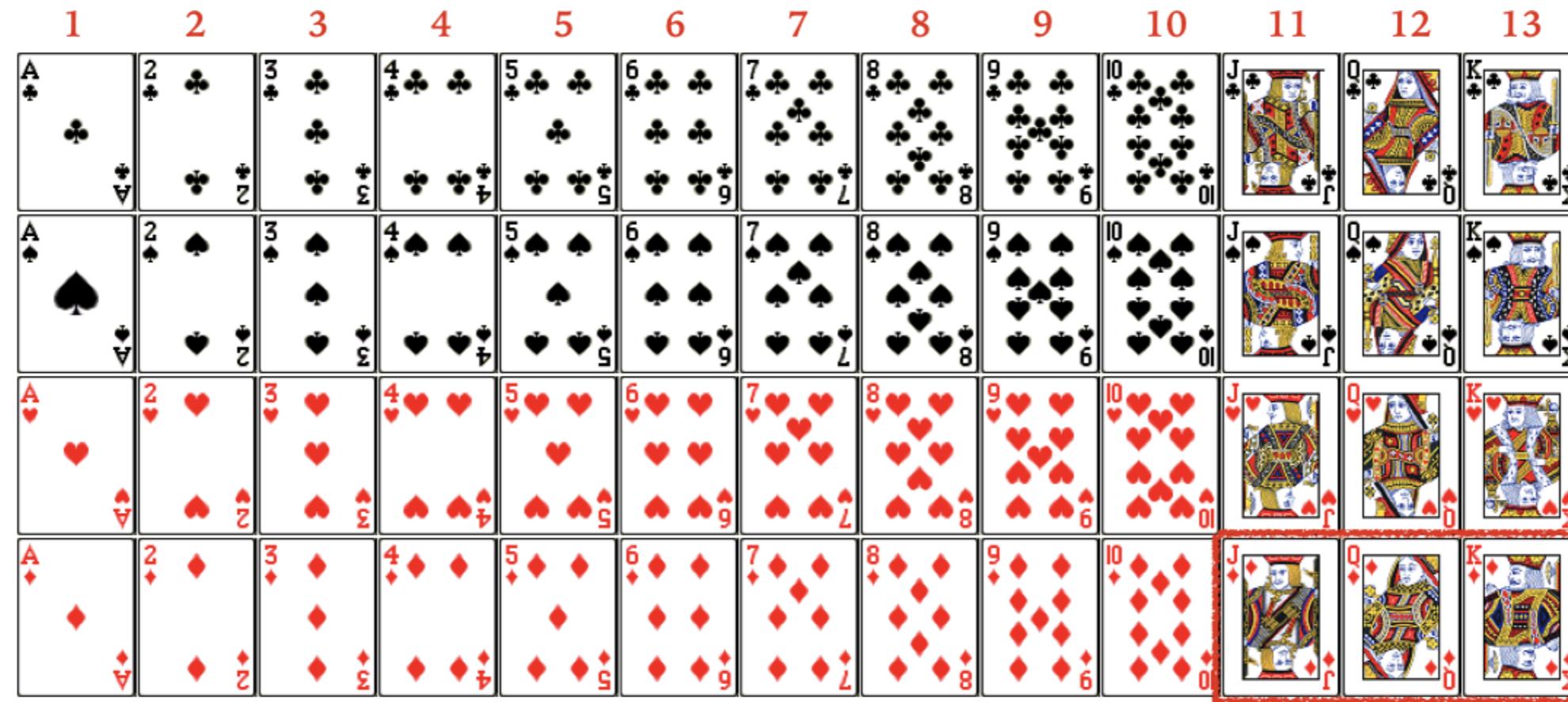
$$P(\text{Face card}) = P(\text{Club and Face card}) + P(\text{Spade and Face card}) + \dots$$

# Deck of cards example (Cont.)



$$P(\text{Face card}) = P(\text{Club and Face card}) + P(\text{Spade and Face card}) + \\ P(\text{Heart and Face card}) + \dots$$

# Deck of cards example (Cont.)



$$P(\text{Face card}) = P(\text{Club and Face card}) + P(\text{Spade and Face card}) + \\ P(\text{Heart and Face card}) + P(\text{Diamond and Face card})$$

# Face card example in Python

Total probability calculation, FC is Face card in the code

```
P_Club_n_FC = 3/52  
P_Spade_n_FC = 3/52  
P_Heart_n_FC = 3/52  
P_Diamond_n_FC = 3/52
```

```
P_Face_card = P_Club_n_FC + P_Spade_n_FC + P_Heart_n_FC + P_Diamond_n_FC  
print(P_Face_card)
```

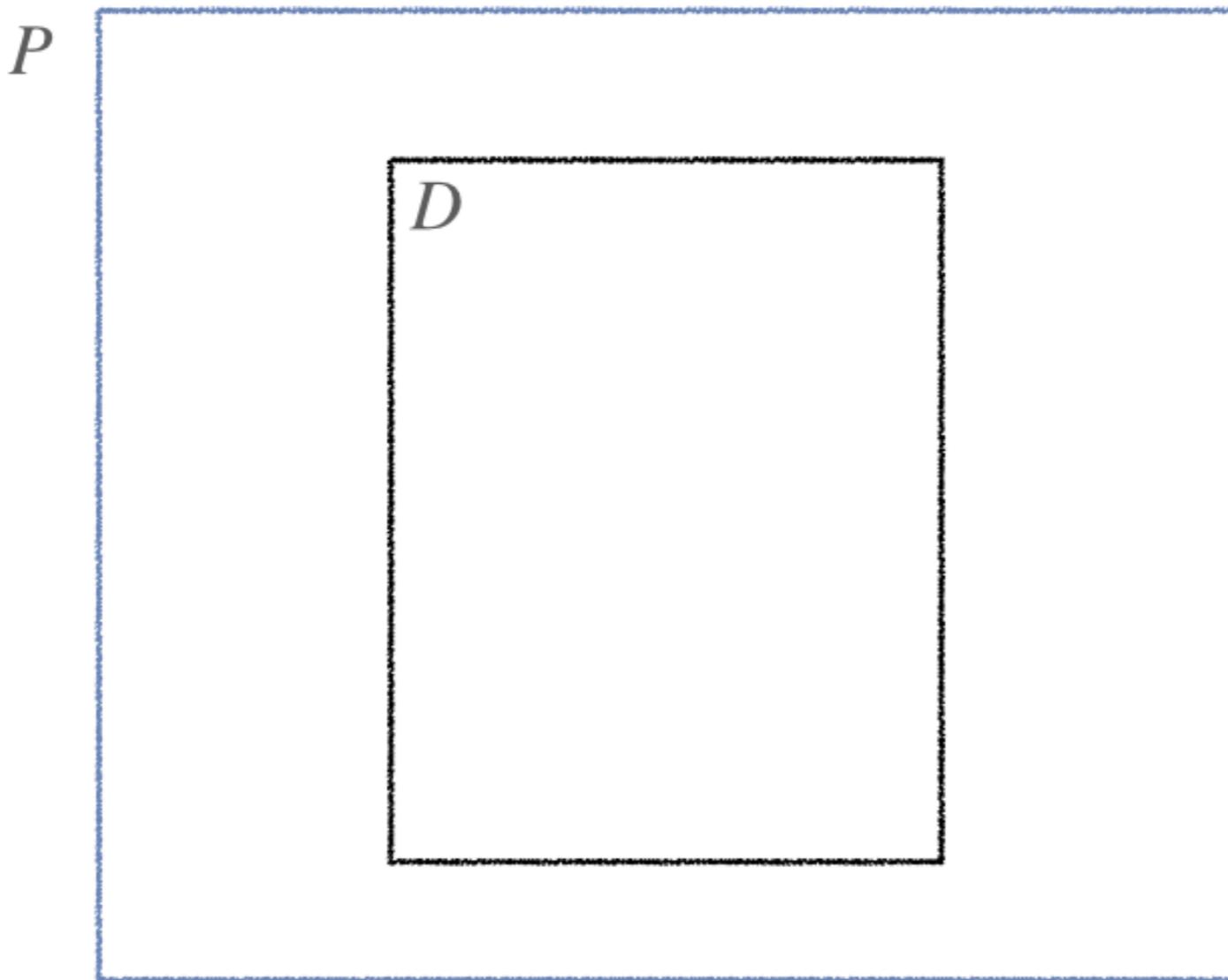
The probability of a face card is:

```
0.230769230769
```

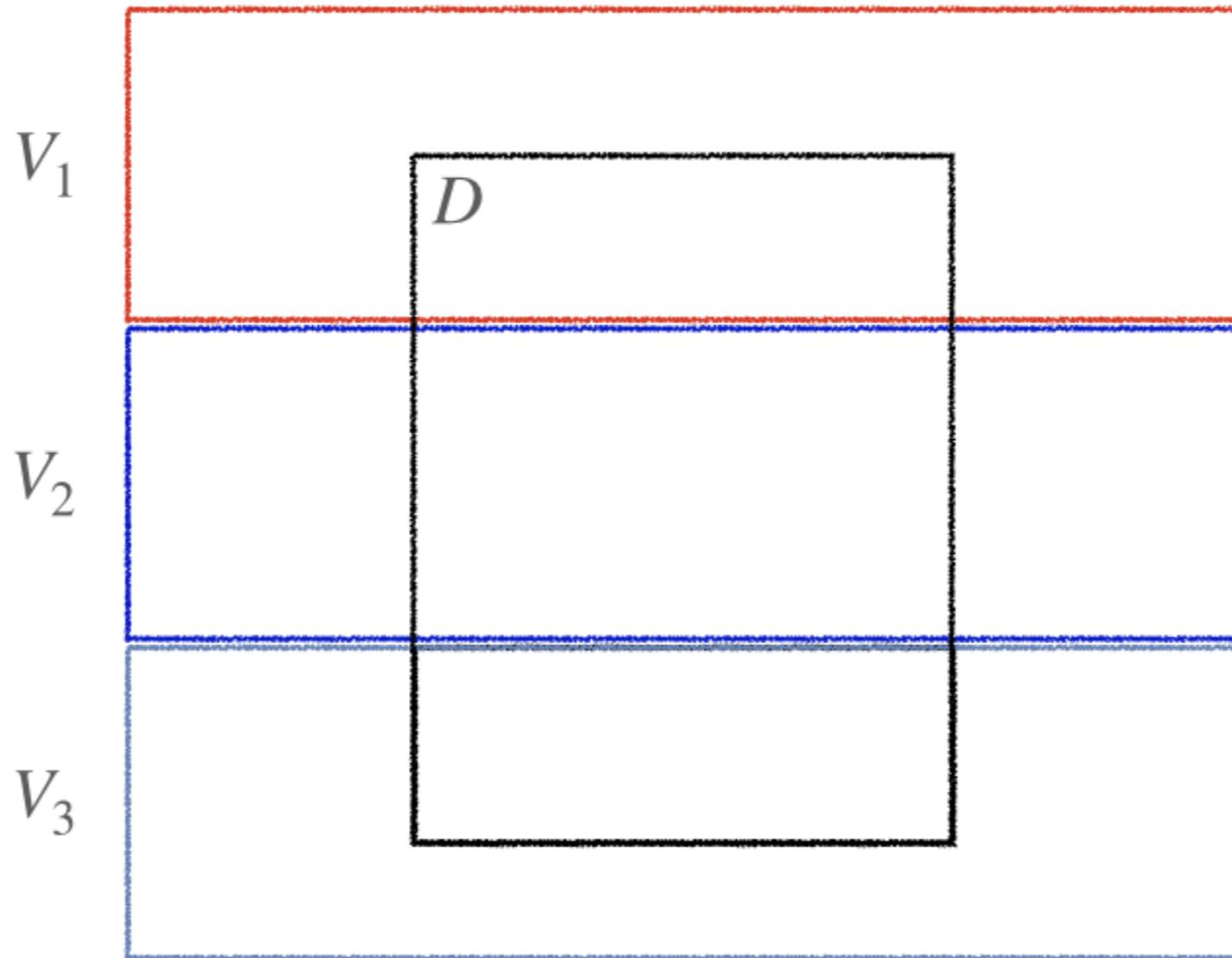
# Total probability



# Total probability (Cont.)

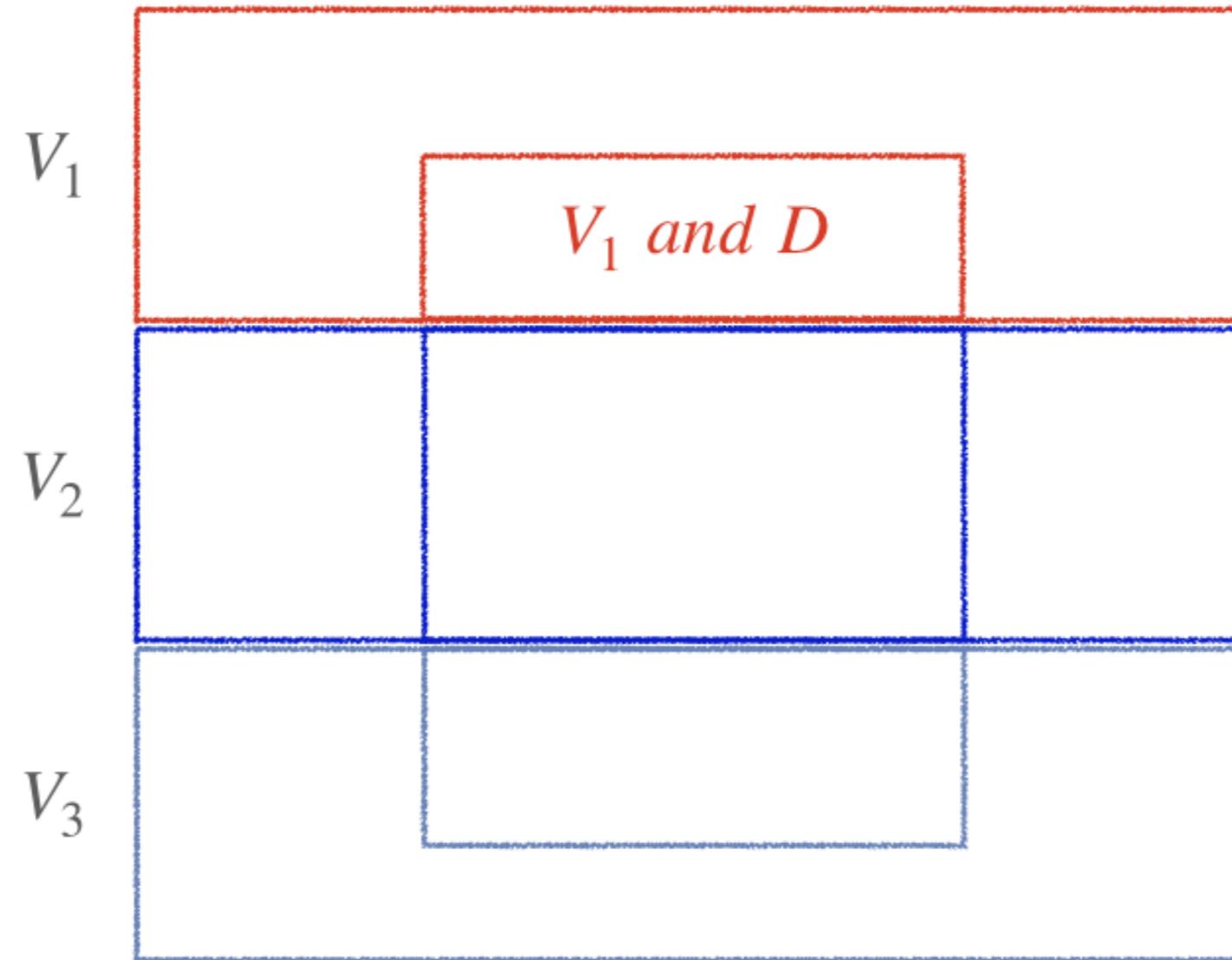


# Total probability (Cont.)



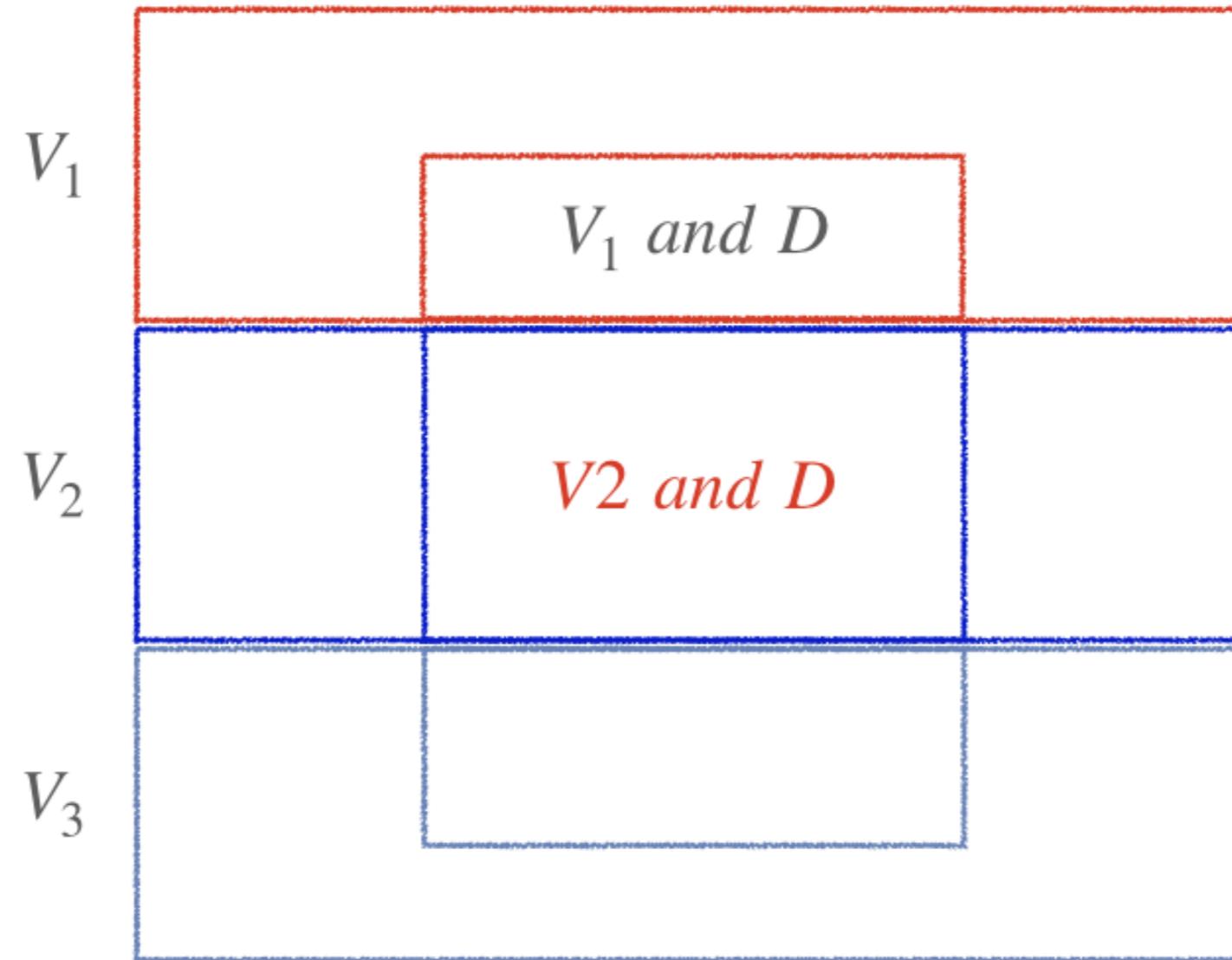
$$P(D) = ?$$

# Total probability (Cont.)



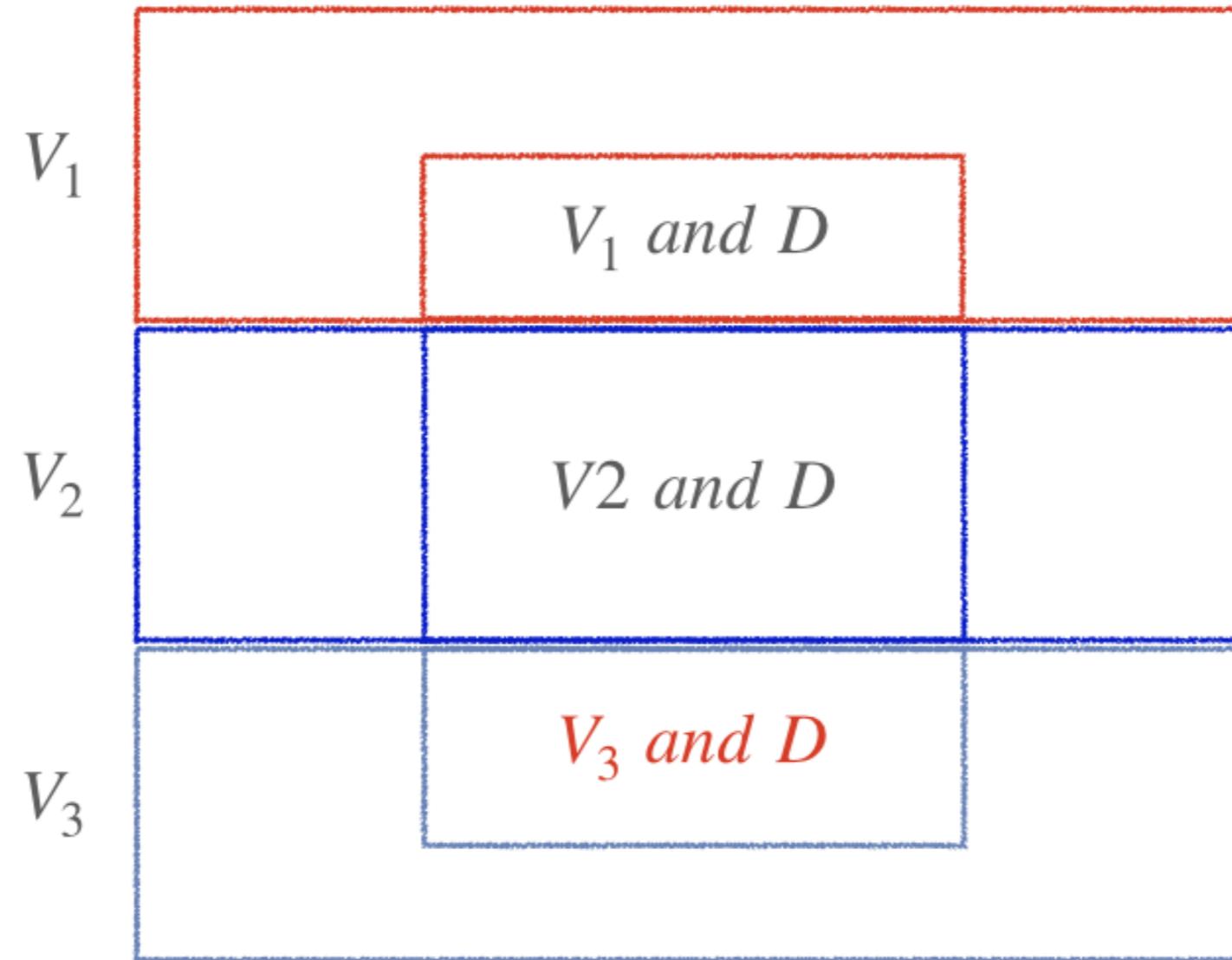
$$P(D) = P(V1 \text{ and } D) + \dots$$

# Total probability (Cont.)



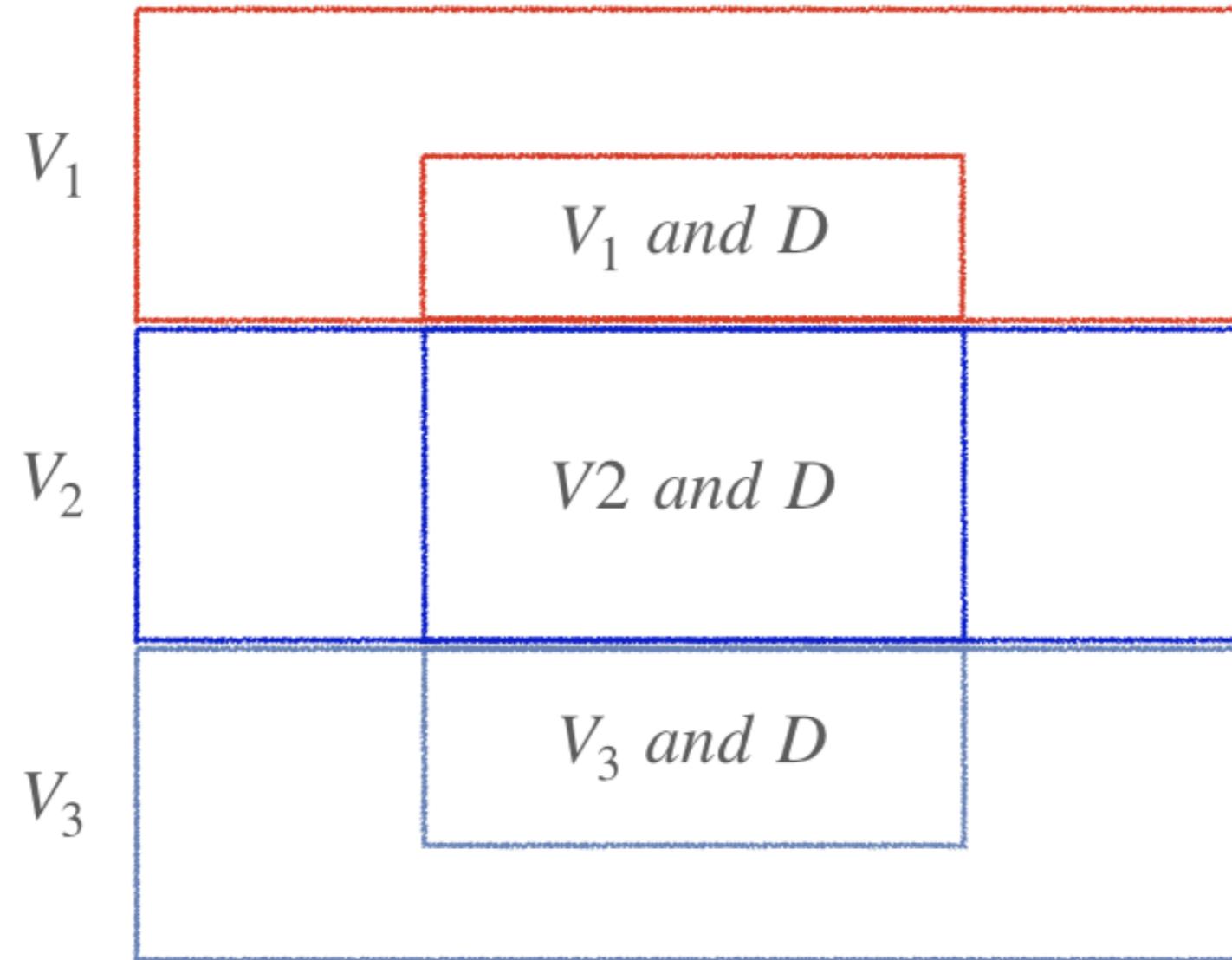
$$P(D) = P(V1 \text{ and } D) + P(V2 \text{ and } D) + \dots$$

# Total probability (Cont.)



$$P(D) = P(V1 \text{ and } D) + P(V2 \text{ and } D) + P(V3 \text{ and } D)$$

# Total probability (Cont.)



$$P(D) = P(V1)P(D|V1) + P(V2)P(D|V2) + P(V3)P(D|V3)$$

# Damaged parts example in Python

A certain electronic part is manufactured by three different vendors, V1, V2, and V3.

Half of the parts are produced by V1, and V2 and V3 each produce 25%. The probability of a part being damaged given that it was produced by V1 is 1%, while it's 2% for V2 and 3% for V3.

- What is the probability of a part being damaged?

# Damaged parts example in Python (Cont.)

- What is the probability of a part being damaged?

```
P_V1 = 0.5
```

```
P_V2 = 0.25
```

```
P_V3 = 0.25
```

```
P_D_g_V1 = 0.01
```

```
P_D_g_V2 = 0.02
```

```
P_D_g_V3 = 0.03
```

# Damaged parts example in Python (Cont.)

We apply the total probability formula

```
P_Damaged = P_V1 * P_D_g_V1 + P_V2 * P_D_g_V2 + P_V3 * P_D_g_V3  
print(P_Damaged)
```

The probability of being damaged is:

0.0175

# Let's start using the total probability law

FOUNDATIONS OF PROBABILITY IN PYTHON

# Bayes' rule

FOUNDATIONS OF PROBABILITY IN PYTHON



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$$P(A \text{ and } B) = P( A ) P( B )$$

$$P(\text{heads} \text{ and } \text{tails}) = P(\text{heads}) P(\text{tails}) = (0.2)(0.2) = 0.04$$

$$P(\text{heads} \text{ and } \text{heads}) = P(\text{heads}) P(\text{heads}) = (0.2)(0.8) = 0.16$$

$$P(\text{tails} \text{ and } \text{heads}) = P(\text{tails}) P(\text{heads}) = (0.8)(0.2) = 0.16$$

$$P(\text{tails} \text{ and } \text{tails}) = P(\text{tails}) P(\text{tails}) = (0.8)(0.8) = 0.64$$

# $P(A \text{ and } B)$ for independent events

$$P(A \text{ and } B) = P(A)P(B)$$

# $P(A \text{ and } B)$ for dependent events

$$P(A \text{ and } B) = P(A)P(B)$$

$$P(A \text{ and } B) = P(A)P(B|A)$$

# $P(A \text{ and } B)$ for dependent events (Cont.)

$$P(A \text{ and } B) = P(A)P(B)$$

$$P(A \text{ and } B) = P(A)P(B|A)$$

$$P(B \text{ and } A) = P(B)P(A|B)$$

# $P(A \text{ and } B)$ is equal to $P(B \text{ and } A)$

$$P(A \text{ and } B) = P(A)P(B)$$

$$P(A \text{ and } B) = P(A)P(B|A)$$

$$P(B \text{ and } A) = P(B)P(A|B)$$

# $P(A \text{ and } B)$ is equal to $P(B \text{ and } A)$ (Cont.)

$$P(A \text{ and } B) = P(A)P(B)$$

$$P(A \text{ and } B) = P(A)P(B|A)$$

$$P(B \text{ and } A) = P(B)P(A|B)$$

$$P(A)P(B|A) = P(A \text{ and } B) = P(B \text{ and } A) = P(B)P(A|B)$$

# Bayes' relation

$$P(A \text{ and } B) = P(A)P(B)$$

$$P(A \text{ and } B) = P(A)P(B|A)$$

$$P(B \text{ and } A) = P(B)P(A|B)$$

$$P(A)P(B|A) = P(A \text{ and } B) = P(B \text{ and } A) = P(B)P(A|B)$$

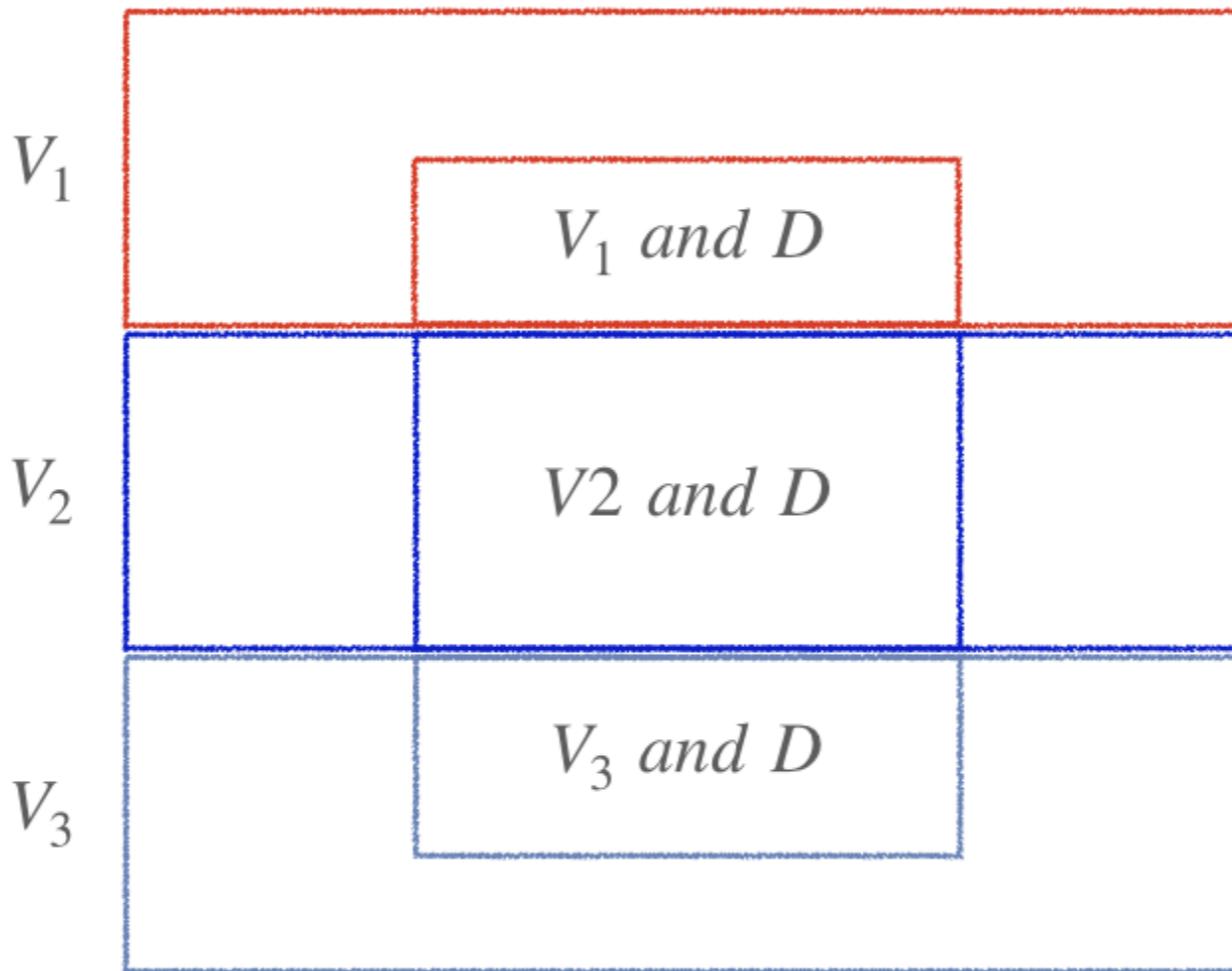
$$P(A)P(B|A) = P(B)P(A|B)$$

# Bayes' rule

$$P(A)P(B|A) = P(B)P(A|B)$$

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

# Total probability



$$P(D) = P(V_1 \text{ and } D) + P(V_2 \text{ and } D) + P(V_3 \text{ and } D)$$

# Total probability (Cont.)

$$P(D) = P(V_1 \text{ and } D) + P(V_2 \text{ and } D) + P(V_3 \text{ and } D)$$

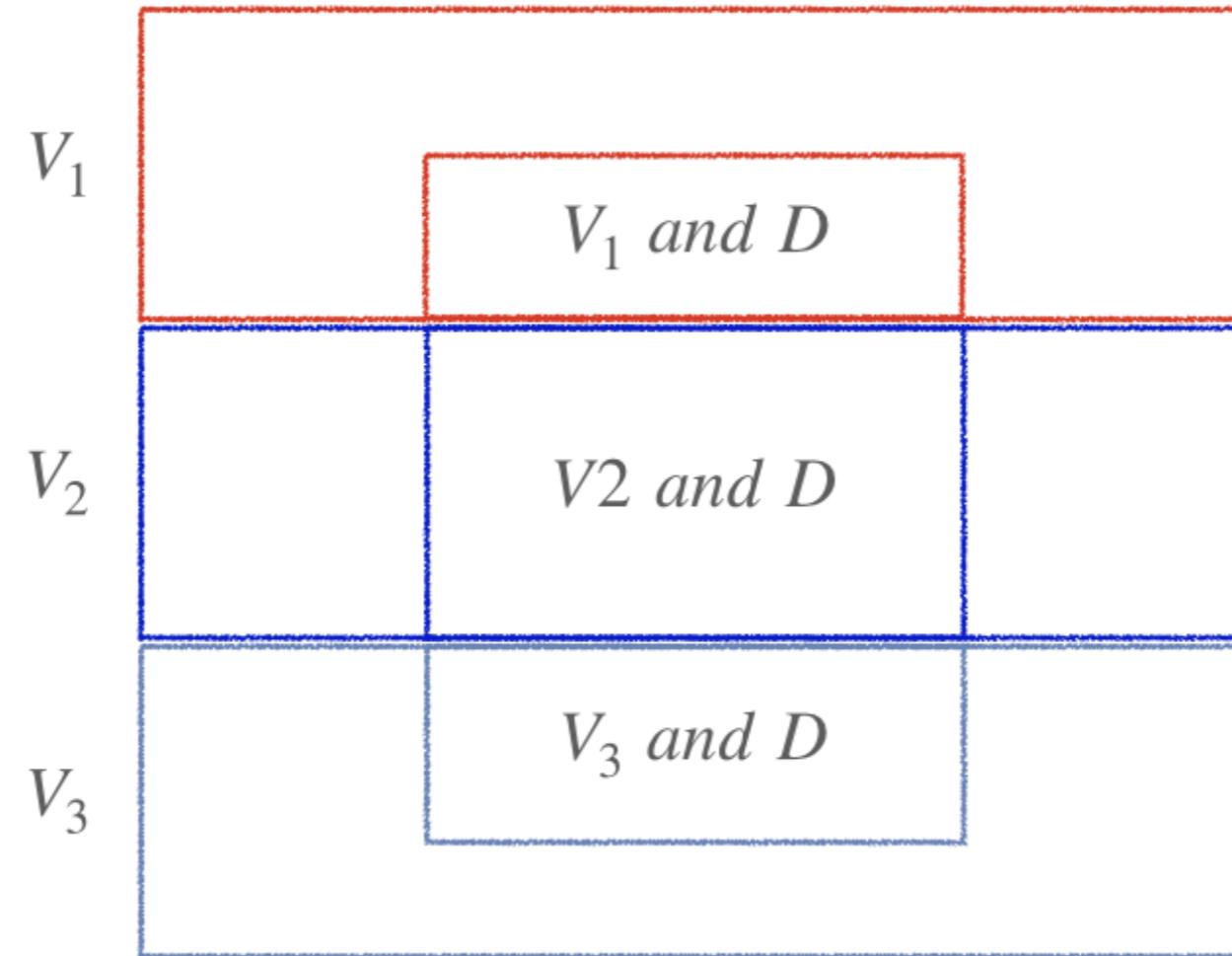
$$P(V_1 \text{ and } D) = P(V_1)P(D|V_1)$$

$$P(V_2 \text{ and } D) = P(V_2)P(D|V_2)$$

$$P(V_3 \text{ and } D) = P(V_3)P(D|V_3)$$

$$P(D) = P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)$$

# Total probability (Cont.)



$$P(D) = P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)$$

# Bayes' formula

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

# Bayes' formula (Cont.)

- Bayes' formula:

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

- The probability of a part being from vendor i, given that it is damaged:

$$P(V_i|D) = \frac{P(V_i)P(D|V_i)}{P(D)}$$

# Bayes' formula (Cont.)

- Bayes' formula:

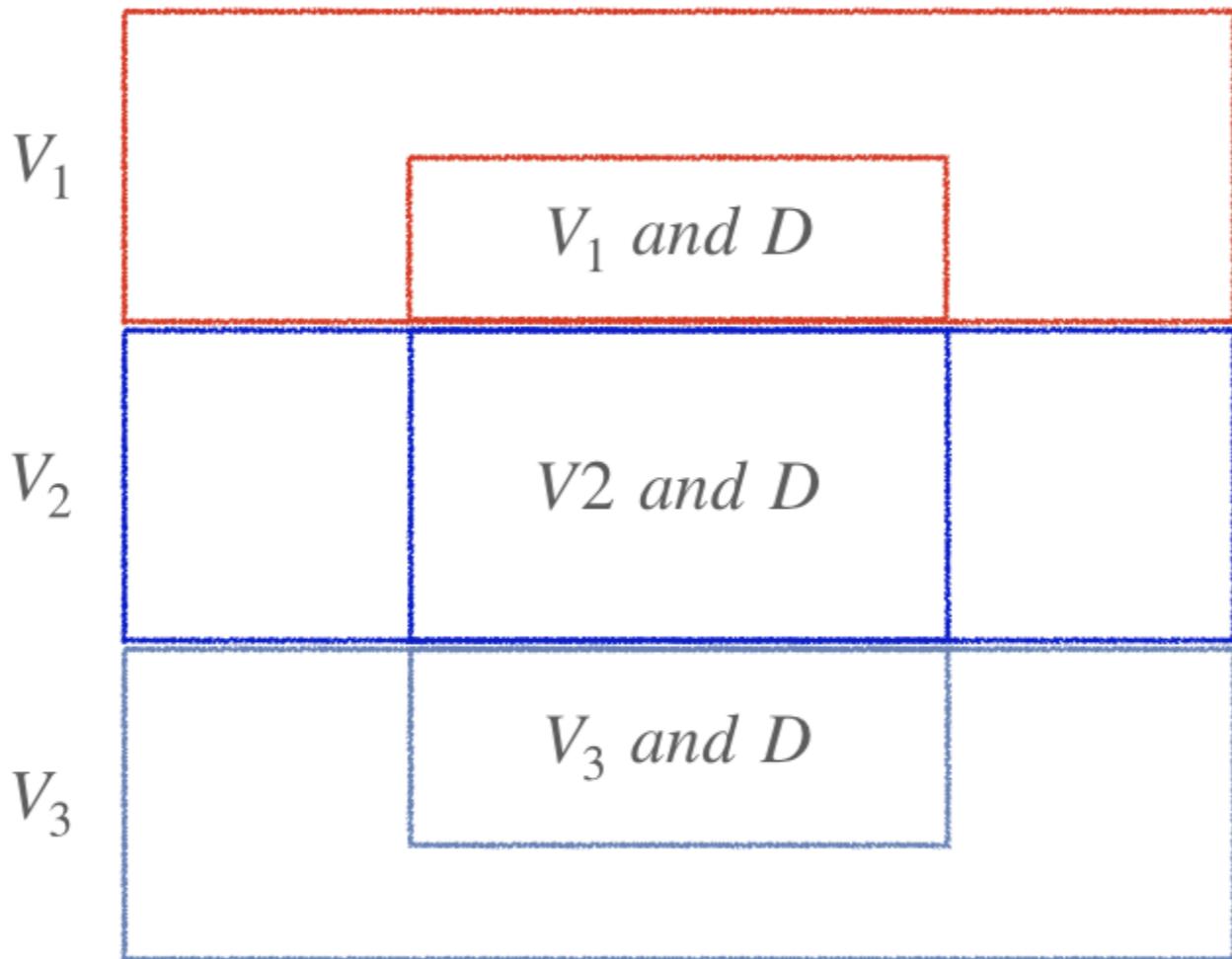
$$P(A|B) = \frac{P(A)P(B|A)}{P(B)}$$

- The probability of a part being from vendor i, given that it is damaged:

$$P(V_i|D) = \frac{P(V_i)P(D|V_i)}{P(D)}$$

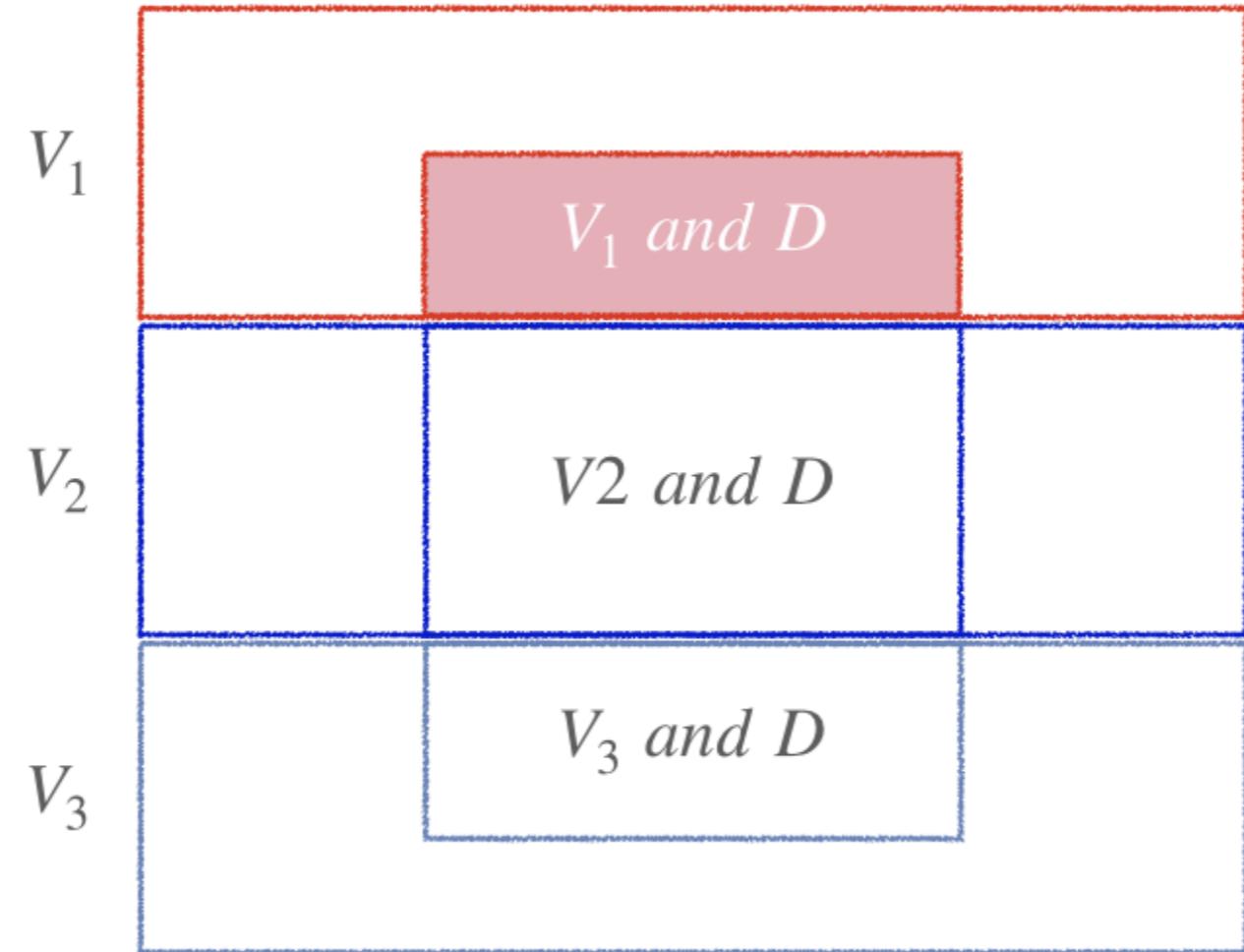
$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule



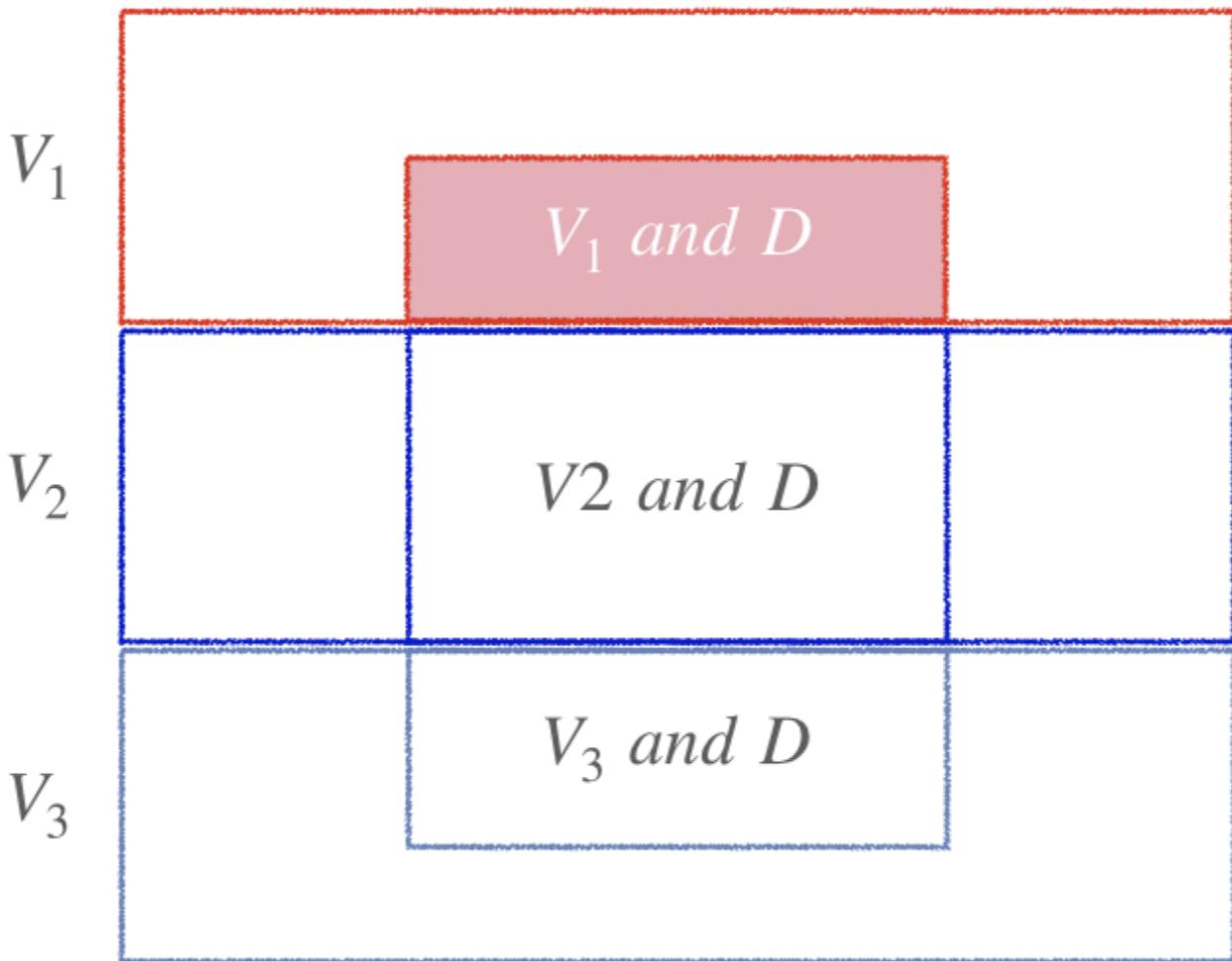
$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule (Cont.)



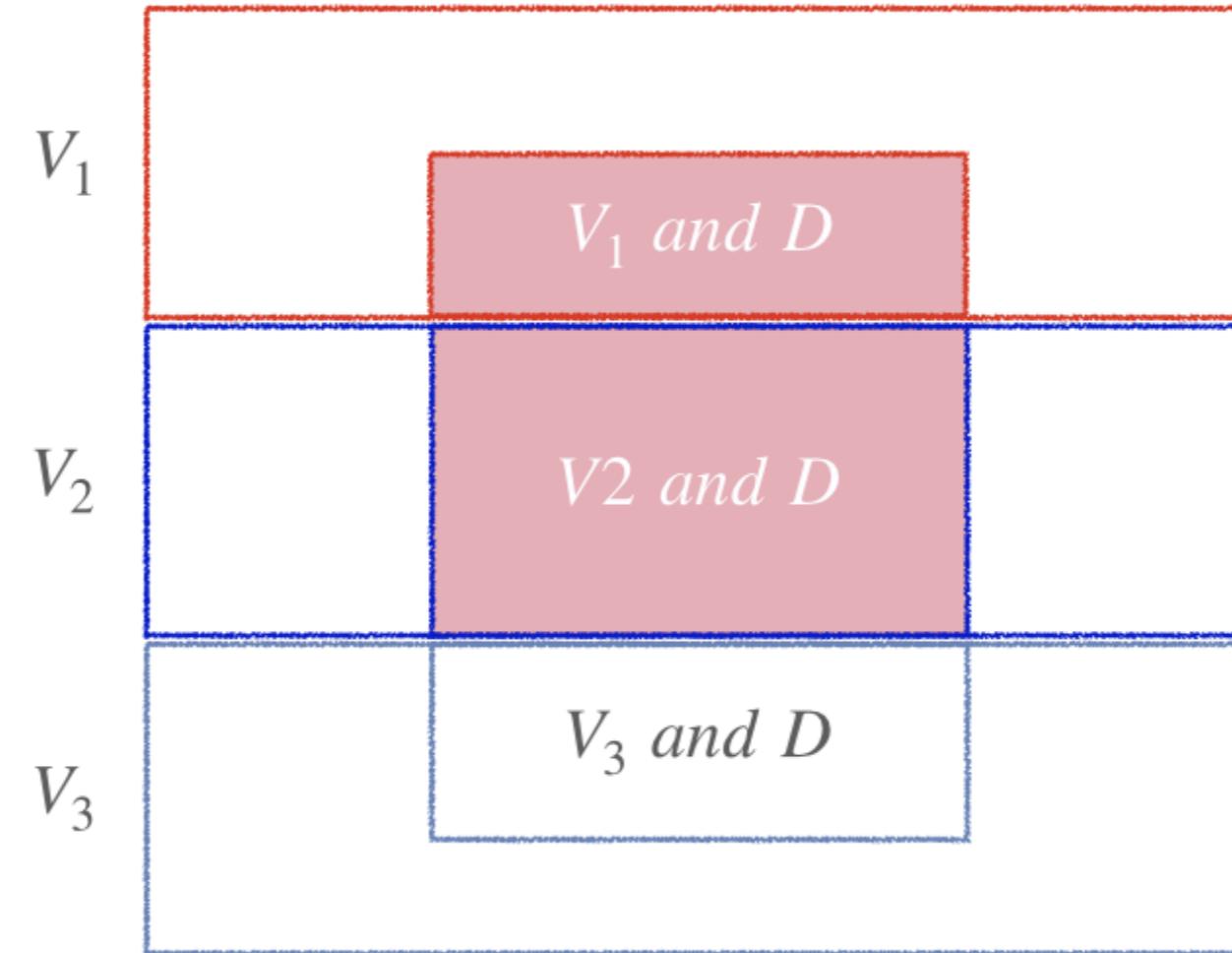
$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule (Cont.)



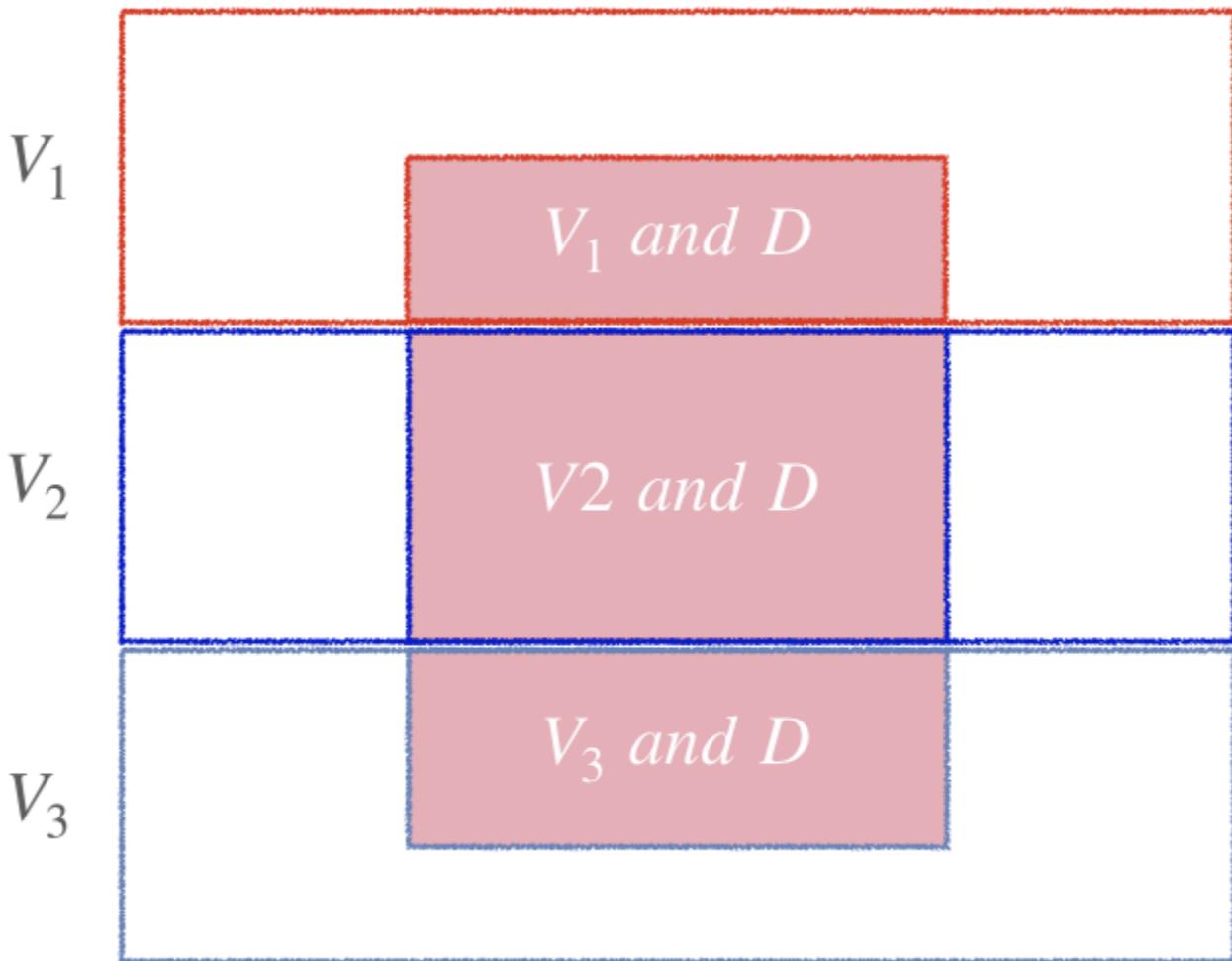
$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule (Cont.)



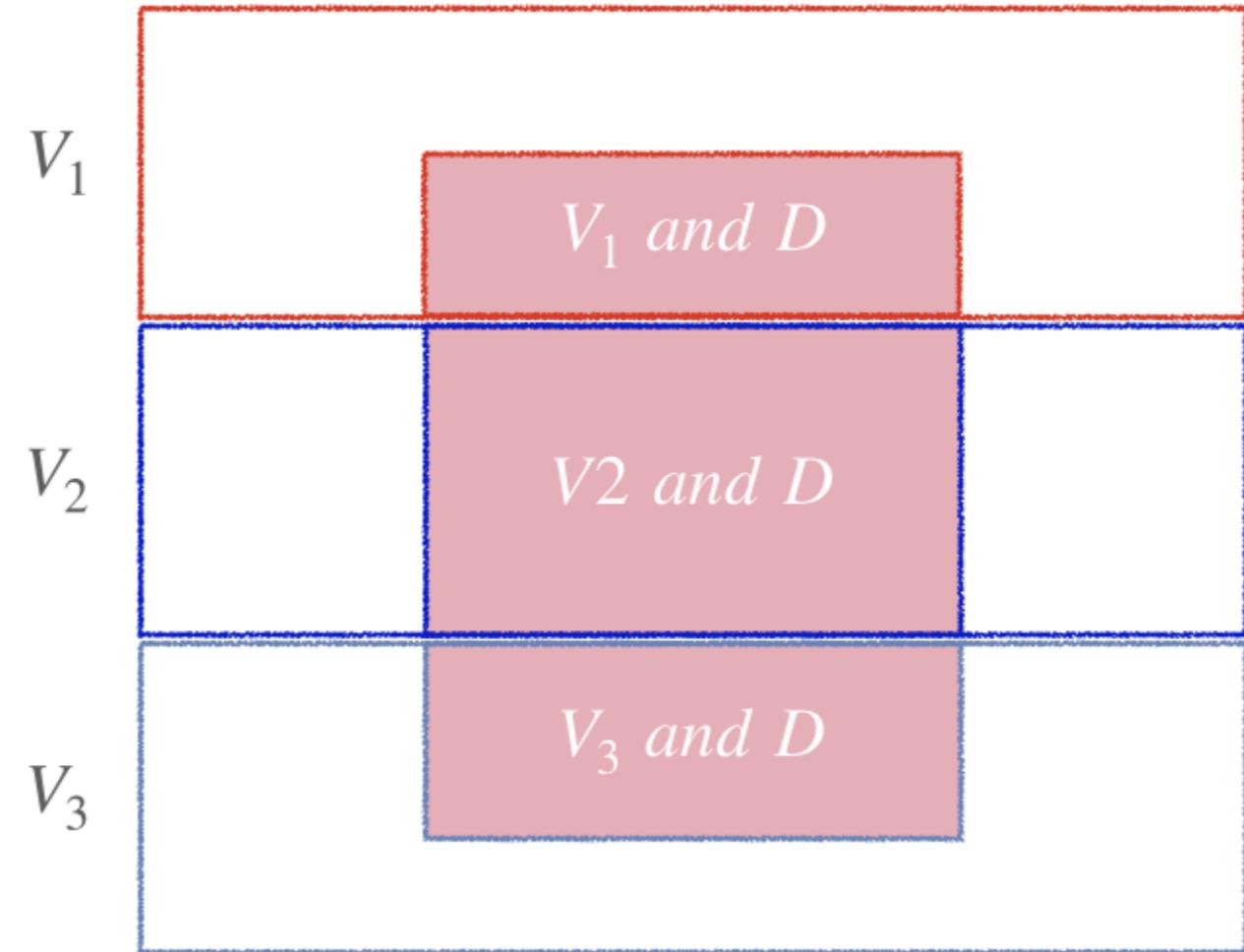
$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule (Cont.)



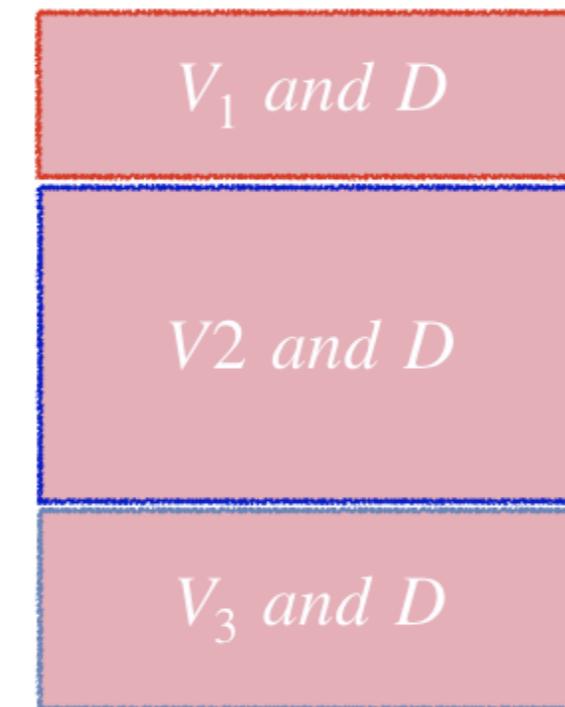
$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule (Cont.)



$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Visual representation of Bayes' rule (Cont.)



$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

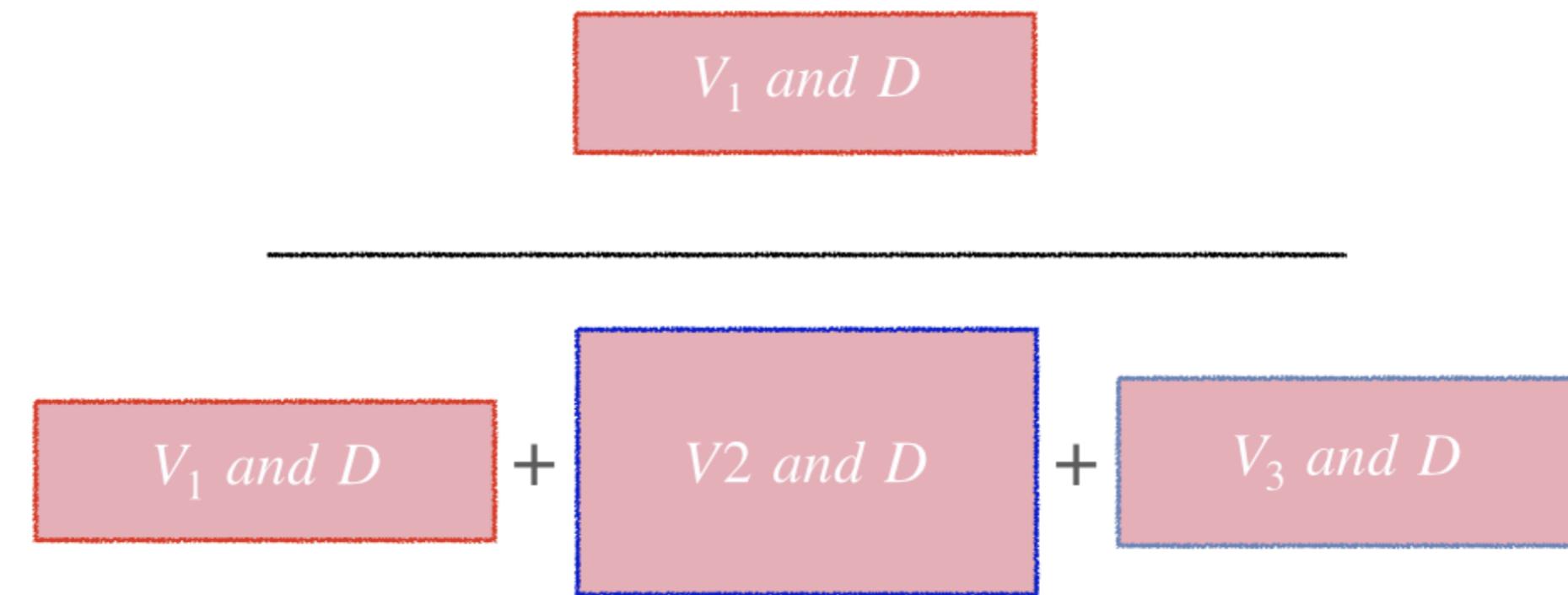
# Visual representation of Bayes' rule (Cont.)

*V<sub>1</sub> and D*

...

$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{\dots}$$

# Visual representation of Bayes' rule (Cont.)



$$P(V_1|D) = \frac{P(V_1)P(D|V_1)}{P(V_1)P(D|V_1) + P(V_2)P(D|V_2) + P(V_3)P(D|V_3)}$$

# Factories and parts example in Python

A certain electronic part is manufactured by three different vendors, V1, V2, and V3.

Half of the parts are produced by V1, and V2 and V3 each produce 25%. The probability of a part being damaged given that it was produced by V1 is 1%, while it's 2% for V2 and 3% for V3.

- Given that the part is damaged, what is the probability that it was manufactured by V1?

# Factories and parts example in Python (Cont.)

- Given that the part is damaged, get the probability that it was manufactured by V1.

```
P_V1 = 0.5
```

```
P_V2 = 0.25
```

```
P_V3 = 0.25
```

```
P_D_g_V1 = 0.01
```

```
P_D_g_V2 = 0.02
```

```
P_D_g_V3 = 0.03
```

```
P_Damaged = P_V1 * P_D_g_V1 + P_V2 * P_D_g_V2 + P_V3 * P_D_g_V3
```

# Factories and parts example in Python (Cont.)

```
P_V1_g_D = (P_V1 * P_D_g_V1) / P_Damaged # P(V1|D) calculation  
print(P_V1_g_D)
```

A randomly selected part which is damaged is manufactured by V1 with probability:

```
0.285714285714
```

# Let's exercise with Bayes

FOUNDATIONS OF PROBABILITY IN PYTHON