

# Probability Formula Sheet

## Axioms

**Axiom 1:**  $0 \leq P[A]$

It states that the probability (mass) is nonnegative

**Axiom 2:**  $P[S] = 1$

It states that there is a fixed total amount of probability (mass), namely 1 unit.

**Axiom 3:** If  $A \cap B = \emptyset$ , then  $P[A \cup B] = P[A] + P[B]$

It states that the total probability (mass) in two disjoint objects is the sum of the individual probabilities (masses).

**Axiom 4:**

If  $A_1, A_2, \dots$  is a sequence of events such that  $A_i \cap A_j = \emptyset$  for all  $i \neq j$ , then

$$P\left[\bigcup_{k=1}^{\infty} A_k\right] = \sum_{k=1}^{\infty} P[A_k]$$

### Corollaries

$P[A^c] = 1 - P[A]$	$1 = P[S] = P[A^c] + P[A]$
$P[A] \leq 1$	$P[\emptyset] = 0$
$P[A \cup B] = P[A] + P[B] - P[A \cap B]$	If $A \subset B$ , then $P[A] \leq P[B]$
$P[A \cup B] \leq P[A] + P[B]$	

## Computing probabilities by counting methods

- Sampling with Replacement and with Ordering:

Number of distinct ordered  $k$ -tuples =  $n^k$

- Sampling without Replacement and with Ordering:

Number of distinct ordered  $k$ -tuples =  $n(n-1)\dots(n-k+1)$

Permutations of  $n$  Distinct Objects

Number of permutations of  $n$  objects =  $n(n-1)\dots(2)(1) \triangleq n!$  (We refer to  $n!$  as  $n$  factorial.)

- Sampling without Replacement and without Ordering

$$C_k^n \triangleq k! = n(n-1)\dots(n-k+1)$$

$$C_k^n = \frac{n(n-1)\dots(n-k+1)}{k!} = \frac{n!}{k!(n-k)!} \triangleq \binom{n}{k}$$

- Sampling with Replacement and without Ordering

$$\binom{n-1+k}{k} = \binom{n-1+k}{n-1}$$

## Conditional probability

$$P[A|B] = \frac{P[A \cap B]}{P[B]}$$

### Addition Rule:

$$P[A \cup B] = P[A] + P[B] - P[A \cap B]$$

If  $A$  &  $B$  are mutually exclusive then:  $P[A \cup B] = P[A] + P[B]$

### Multiplication Rule:

$$P[A \cap B] = P[A]P[B|A] = P[B]P[A|B]$$

If  $A$  &  $B$  are independent then:  $P[A \cap B] = P[A]P[B]$

## Probability Laws

### Total probability law:

$P[A] = P[A \cap B_1] + P[A \cap B_2] + \dots + P[A \cap B_n]$  OR

$P[A] = P[A|B_1]P[B_1] + P[A|B_2]P[B_2] + \dots + P[A|B_n]P[B_n]$  OR

$P[A] = P[A|B]P[B] + P[A|B^c]P[B^c]$

### Bayes' Law

$$P[B_i|A] = \frac{P[B_i \cap A]}{P[A]} = \frac{P[B_i \cap A]}{P[A]} = P[A|B_i] \frac{P[B_i]}{P[A]} = \frac{P[A|B_i]P[B_i]}{\sum_{k=1}^n P[A|B_k]P[B_k]}$$

### Probability definition:

$A$  &  $B$  are mutually exclusive if  $[A \cap B] = \emptyset$

$A$  &  $B$  are independent if  $P[A|B] = P[A]$  &  $P[B|A] = P[B]$  &  $P[A \cap B] = P[A]P[B]$

## Discrete Probability Distributions

### Expected value or mean of a discrete random variable $X$ :

$$m_x = E[X] = \sum_{x \in \mathcal{X}} x p_x(x) = \sum_k x_k p_x(x_k)$$

### Variance of the random variable $X$

$$\sigma_x^2 = \text{VAR}[X] = E[(X - m_x)^2] = \sum_k (x_k - m_x)^2 p_x(x_k) = E[X^2] - m_x^2$$

### Standard deviation of the random variable $X$ :

$$\sigma = \text{STD}[X] = \text{VAR}[X]^{1/2}$$



$X$	$X$ counts	$P_x$	Values of $x$	$E[X]$	$\text{VAR}[X]$
<b>Bernoulli</b>	Equals one if the event $A$ occurs, and zero otherwise.	$P_x = 1-p, P_1 = p$	0, 1	$p$	$p(1-p)$
<b>Binomial</b>	Number of successes in fixed $n$ trials.	$\binom{n}{k} p^k (1-p)^{n-k}$	0, 1, ..., $n$	$np$	$np(1-p)$
<b>Geometric</b>	Number of trials up through 1st success.	$p(1-p)^k, p(1-p)^{k-1}$	0, 1, ..., 1, 2, ...	$\frac{1-p}{p}, \frac{1}{p}$	$\frac{1-p}{p^2}$
<b>Uniform</b>	outcomes are equally likely	$\frac{1}{L}$	1, 2, ..., $L$	$\frac{L+1}{2}$	$\frac{L^2-1}{12}$
<b>Poisson</b>	number of events that occur in fixed time period	$\frac{\mu^k}{k!} e^{-\mu}, \mu > 0$	0, 1, 2, ...	$\mu$	$\mu$

# Probability Statistics Engineering Formula Sheets

**RJ Shavelson**



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