Probability Formula Sheet *Maria N.*

Axioms

Axiom 1: $\quad 0 \le P[A]$

It states that the probability (mass) is nonnegative

Axiom 2: $\quad P[S] = 1$

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

Axiom 3: $\quad$ 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:

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

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

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

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 = $n(n-1)\ldots(n-k+1)$

Permutations of n Distinct Objects

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

- **Sampling without Replacement and without Ordering**

$$C_k^n \, k! = n(n-1)\ldots(n-k+1)$$

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

- **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:

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

$P[A] = P[A|B_1]P[B_1] + P[A|B_2]P[B_2] + \cdots + P[A|B_n]P[B_n]$ 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 $[A \cap B] = 0$

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:

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

Variance of the random variable X

$$\sigma_X^2 = VAR[X] = E[(X - m_x)^2] = \sum_k (x_k - m_X)^2 p_X(x_k)$$
$$= E[X^2] - m_X^2$$

Standard deviation of the random variable X:

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

X	X counts	Px		Values of x		E[X]		VAR[X]
Bernoulli	Equals one if the event A occurs, and zero otherwise.	$p_0 = 1 - p$, $p_1 = p$		0, 1		p		$P(1-p)$
Binomial	Numbers of successes in fixed n trials	$\binom{n}{k} p^k (1-p)^{n-k}$		0, 1, …, n		np		$np(1-p)$
Geometric	Number of trials up through 1st success	$p(1-p)^k$	$p(1-p)^{k-1}$	0, 1, …	1, 2, …	$\frac{1-p}{p}$	$\frac{1}{p}$	$\frac{1-p}{p^2}$
Uniform	outcomes are equally likely	$\frac{1}{L}$		1, 2, …, L		$\frac{L+1}{2}$		$\frac{L^2-1}{12}$
Poisson	number of events that occur in fixed time period	$\frac{a^k}{k!} e^{-a}$, $a > 0$		0, 1, 2		a		a

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Daniel Zwillinger

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