**1.2 Spike Trains and Firing Rates**

**1.2神经冲动序列和发射速率**

Action potentials convey information through their timing.

动作电势通过他们的时机来传递消息。

Although action potentials can vary somewhat in duration, amplitude, and shape, they are typically treated in neural encoding studies as identical stereotyped events.

尽管神经冲动在持续时间、振幅、以及形状上有诸多区别，但在神经编码的研究中他们通常被当做完全相同的事件来处理。

If we ignore the brief duration of an action potential (about 1 ms), an action potential sequence can be characterized simply by a list of the times when spikes occurred.

如果我们忽略一个动作电势短暂的持续时间（约1ms），那么动作电势序列就能简单地用一系列动作电势发生的时间来代替。

For *n* spikes, we denote these times by *ti* with *i* =1*,*2*,...,n*.

对于n个神经冲动来说，我们用ti来代表其发生的时间，其中i=1,2,…,n。

The trial during which the spikes are recorded is taken to start at time zero and end at time *T*, so 0 ≤ *ti* ≤ *T* for all *i*.

在试验期间，时间从0开始到T停止，所以对所有的i都有0≤ti≤T。

The spike sequence can also be represented as a sum of infinitesimally narrow, idealized spikes in the form of *Dirac δ* functions (see the Mathematical Appendix),

神经冲动序列也能用*Diracδ*函数形式表示无穷窄并理想化的神经冲动的和表示（见数学附录）。

We call the neural response function and use it to re-express sums neural response

over spikes as integrals over time. For example, for any well-behaved function ,we can write

我们称为神经反应函数，并通过它以神经冲动对时间进行积分的形式来重新表示神经反应(的和)。对于一个性能良好的方程我们可以写出如下函数（1.2），

where the integral is over the duration of the trial. The equality follows from the basic defining equation for a *δ* function,

其中积分以整个试验的时间间隔为积分区间。

provided that the limits of the integral surround the point *t* (if they do not, the integral is zero).

若函数在点t处以外的积分处处为零，则根据 *δ* 函数的基本性质（1.3）等式成立。

Because the sequence of action potentials generated by a given stimulus typically varies from trial to trial, neuronal responses are typically treated probabilistically, and characterized, for example, by the probability that a spike occurs at a particular time during a trial.

因为通常一个特定刺激所产生的神经冲动序列每次试验都不同，所以神经反应通常以概率的方式来处理，例如一次试验中神经冲动在某个特定时间点发生的概率。

Spike times are continuous variables, and, as a result, the probability for a spike to occur at any precisely specified time is actually zero.

神经冲动时间是连续性随机变量，因此其在某个特定时间点发生的概率实际为0。

To get a nonzero value, we must ask for the probability that a spike occurs within a specified interval, for example the interval between times *t* and.

为了得到非零的值，我们必须寻找神经冲动发生在一个特定区间比如内的()内的概率。

For small , the probability of a spike falling in this interval is proportional to the size of the interval, .

对于很小的时间间隔，神经冲动在这个区间发生的概率是和的大小成正比的。

A similar relation holds for any continuous stochastic variable *z*.

这对于任何连续型随机变量z都成立。

The probability that *z* takes a value between *z* and , for small (strictly speaking, as →0) is equal to, where *p*[*z*] is called a probability density.

对于很小的（严格地说是趋于零）, z在区间上取值的概率等于，*p*[*z*]称为概率密度。

Throughout this book, we use the notation to denote probabilities and to denote probability densities.

在本书中，我们用表示概率，用表示概率密度。

We use the bracket notation,  generically for the probability of something occurring and also to denote a specific probability function.

*P*[ ]通常用来表示某事件发生的概率，不过也能用来表示某个特定的概率函数。

In the latter case, the notation  would be more appropriate, but switching between square brackets and parentheses is confusing, so the reader will have to use the context to distinguish between these cases.

在后面一种情况下，用其实更为合适，但是在方括号和小括号之间切换会让人疑惑，因此读者需要根据上下文来确定所表示的究竟是何意。

For the particular case of spike occurrences, we can write the probability that a spike occurs between times *t* and , for small as , where *p*[*t*] is the single spike probability density.

神经冲动发生这一特定事件，对很短的时间间隔，我们可以写出该事件在区间()上发生的概率为，其中为单个神经冲动发生的概率密度。

The probability density for the occurrence of a spike is, by definition, the firing rate of the cell, and we use the notation for this important quantity.

根据定义，单个神经冲动发生的概率密度为其细胞的发射速率，我们用来表示这一重要关系。

The firing rate at time *t*, can be estimated by determining the fraction of trials with a given stimulus on which a spike occurred between the times *t* and .

在时间点t，细胞的发射速率可以通过确定在时间间隔内一个给定的刺激引发的动作电势的试验分数来估计。

For sufficiently small and sufficiently large numbers of trials, this fraction provides a good estimate of r(t), as guaranteed by the law of large numbers.

对于足够小的的和足够大的试验次数，大数定律保证了这样的分数能提供对r(t)的良好估计。

The fraction of trials on which a spike occurs can be computed from the neural response function averaged over trials.

We use angle brackets, <>, to denote averages over trials that use the same stimulus, so that <*z*> for any quantity *z* is the sum of the values of *z* obtained from many trials involving the same stimulus, divided by the number of trials. The trial-averaged neural response function is thus denoted by <*ρ*(t)>. In any integral expression such as equation 1.2, the neural response function generates a contribution whenever a spike occurs. If instead, we use the trial-average response function in equation 1.2, this generates contributions proportional to the fraction of trials on which a spike occurred. Because of the relationship between this fraction and the firing rate, we find that