Coding

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This is a demo for illustrating the Poisson firing of visual cortical neurons in response to grating stimuli. The data is from Ecker et al., *Decorrelated Neuronal Firing in Cortical Microcircuits*, Science, 327, 584 (2010). http://bethgelab.org/datasets/v1gratings/

The RData file contains a list containing 8 preselected cells (>1 Hz firing rates, clear spikes) from a single experiment in given day. The fields of the list contain the following:

date date and time stamp when the session was recorded subject identifies the monkey used in the session conditions specifies the orientation and contrast used, selected for > 0.05 contamination contamination of the single units tetrode specifies the tetrode a single unit was recorded on; for tetrode grid layout, see supplementary material of Ecker et al. (2010) spikes contains binned spikes single units x conditions x time bins x repetitions times times aligned to bin centers

The experimental data is loaded from the `Data/Ecker/` folder - data_v1_binned_static_ses2.RData. First we load the data and see what it contains using the summary command:

```
load("./Ecker/data_v1_binned_static_ses2.RData")
summary(data)
```

```
##               Length Class  Mode
## date               1 -none- character
## subject            1 -none- character
## conditions        32 -none- list
## contamination      8 -none- numeric
## tetrode            8 -none- numeric
## spikes        276480 -none- numeric
## times             90 -none- numeric
```

The spikes field contains an array with the spikes recorded: cells x conditions x time bins x repetitions.

```
print(dim(data$spikes))
```

```
## [1]  8 16 90 24
```

We have 8 cells, 16 conditons, 90 time points and 24 repetitions. The stimuli are static gratings with different orientation and contrast levels shown for 500 ms. To see the different conditions we need to look the field conditions:

```
print(data$conditions)
```

```
##             [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10] [,11] [,12]
## contrast    1    10   1    10   1    10   1    10   1    10    1     10
## orientation 0    0    22.5 22.5 45   45   67.5 67.5 90   90    112.5 112.5
##             [,13] [,14] [,15] [,16]
## contrast    1     10    1     10
## orientation 135   135   157.5 157.5
```

There are two variables defining the condition: orientation and contrast. We have 8 orientations and 2 contrast levels. In the following we will plot the average response of the cells to the different stimuli.

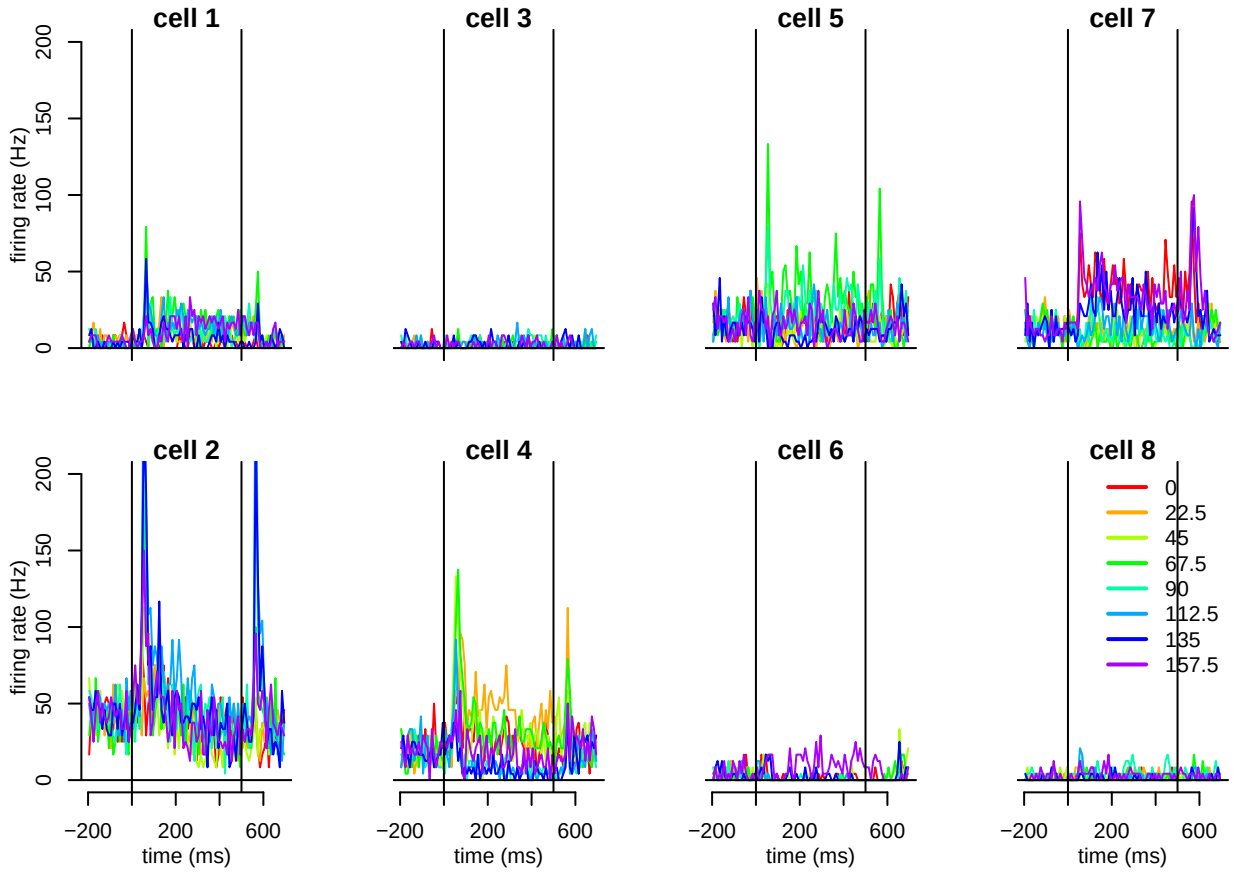
First, we extract contrast and orientation variables for plotting.

```
oris <- unlist(data$condition['orientation',])
contrasts <- unlist(data$condition['contrast',])
range.contrasts <- range(contrasts)
scaled.contrasts <- (contrasts - min(contrasts)) / (max(contrasts)-min(contrasts)) * 2 + 1/2
```

Next, we extract the firing rate - approximated as the average spike count - for each time point, only for high contrast trials. The start and the end of the stimulation period is indicated by the vertical lines.

```
n.cells <- dim(data$spikes)[1] # number of cells
n.conditions <- dim(data$spikes)[2] # number of conditions
L <- dim(data$spikes)[3] # length of recordings
par(mfcol=c(2,4)); par(mar=c(3,3,1,1)) # plotting subfigures
for (i.cell in 1:n.cells){
  title <- paste('cell', i.cell)
    rates <- matrix(0, L, n.conditions) # this is going to be the rate matrix for the cells
    for (i.condition in 1:n.conditions){
        sp <- data$spikes[i.cell,i.condition,,]
        rates[,i.condition] <- apply(sp, 1, mean)*100 # Hz
    }
    matplot(data$times, rates[,1:8*2], t="l", col=rainbow(9)[1:8], lty=1, lwd=1, axes=F, ylim=c(0, 200)
    abline(h=0)
    if ((i.cell %% 2) == 0){
      axis(1); mtext('time (ms)', 1, 2, cex=0.7)
    }
    if (i.cell < 3){
      axis(2); mtext('firing rate (Hz)', 2, 2, cex=0.7)
    }
    abline(v=c(0, 500))
    # readline(i.cell)
}

legend('topright', leg=unique(oris), col=rainbow(9)[1:8], lwd=2, lty=1, bty='n')
```

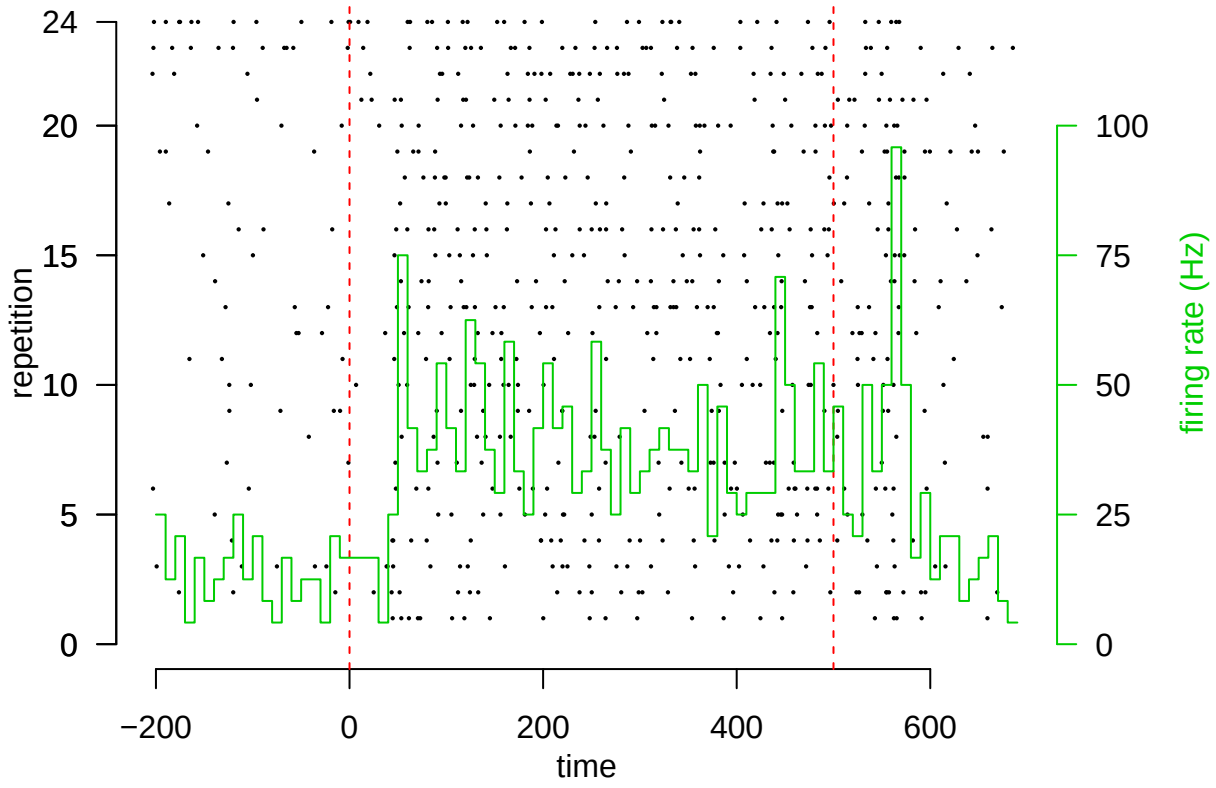


Nothe that

- cells respond differently to the stimuli - they differ in their firing rate, tuning and in the time course of the response
- some cells are tuned to orientation, others are not
- in many cells / stimuli there is a clear on and an off transient in the reponse
- the response to the stimulus is delayed by 50 ms - this is the time required for the signal to propagate from the retina to the visual cortex - 2 synapses in the retina, 1 in the thalamus (LGN) and 1 in the visual cortex

Now I select cell 7 which seems as an active cell showing stimulus-dependent responses. I will plot its activity - spike train - in each trial separately. Here I plot the second condition, which is 0 degrees orientation and 10 contrast. I also show the start and the end of the stimulus as well as the firing rate in Hz:

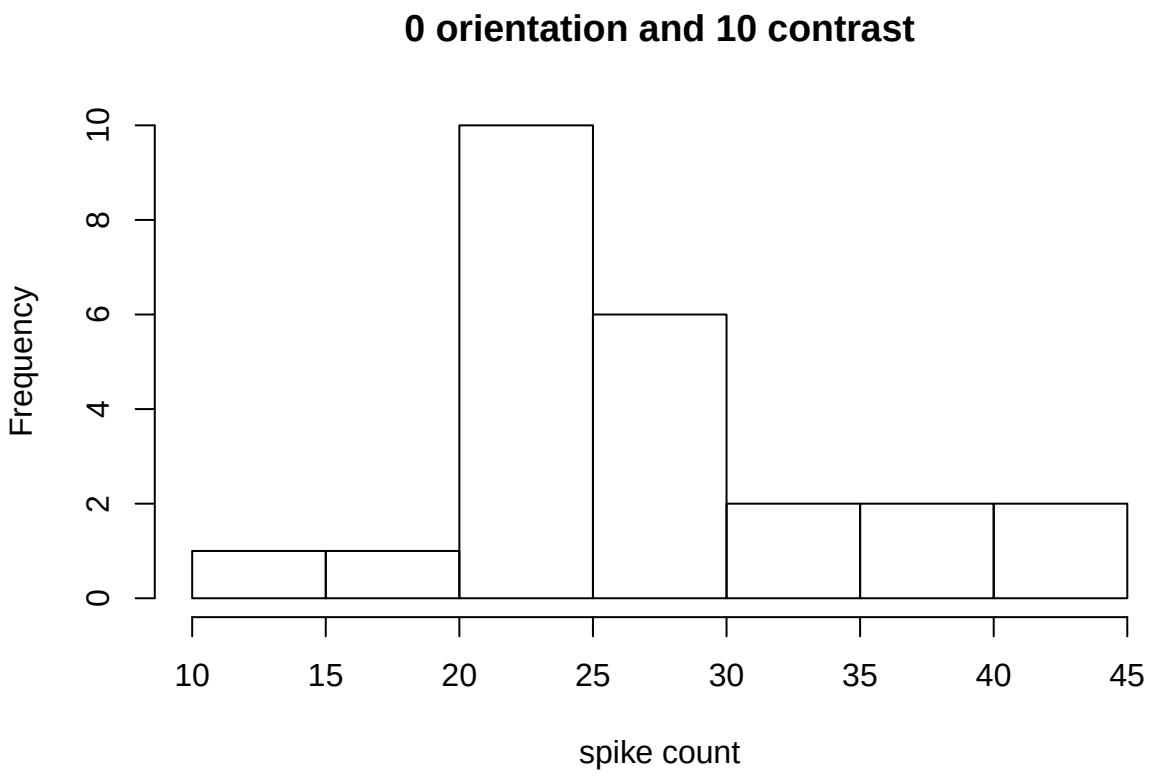
```
source("./Ecker/plot_raster.R")
par(mar=c(4,4,1,4))
cell <- data$spikes[7,,] # 16 conditions, 90 time points and 24 repetitions
plot.raster(cell[2,,], data$times)
abline(v=c(0, 500),, col=2, lty=2)
lines(data$times - 5, rowMeans(cell[2,,]) * 100 / 5, t='s', col=3)
axis(4, c(0, 5, 10, 15, 20), c(0, 5, 10, 15, 20)*5, col=3, las=2)
axis(2, c(0, 5, 10, 15, 20, 24), c(0, 5, 10, 15, 20, 24), las=2)
mtext('firing rate (Hz)', 4, col=3, 3)
```



There are a few important points to note:

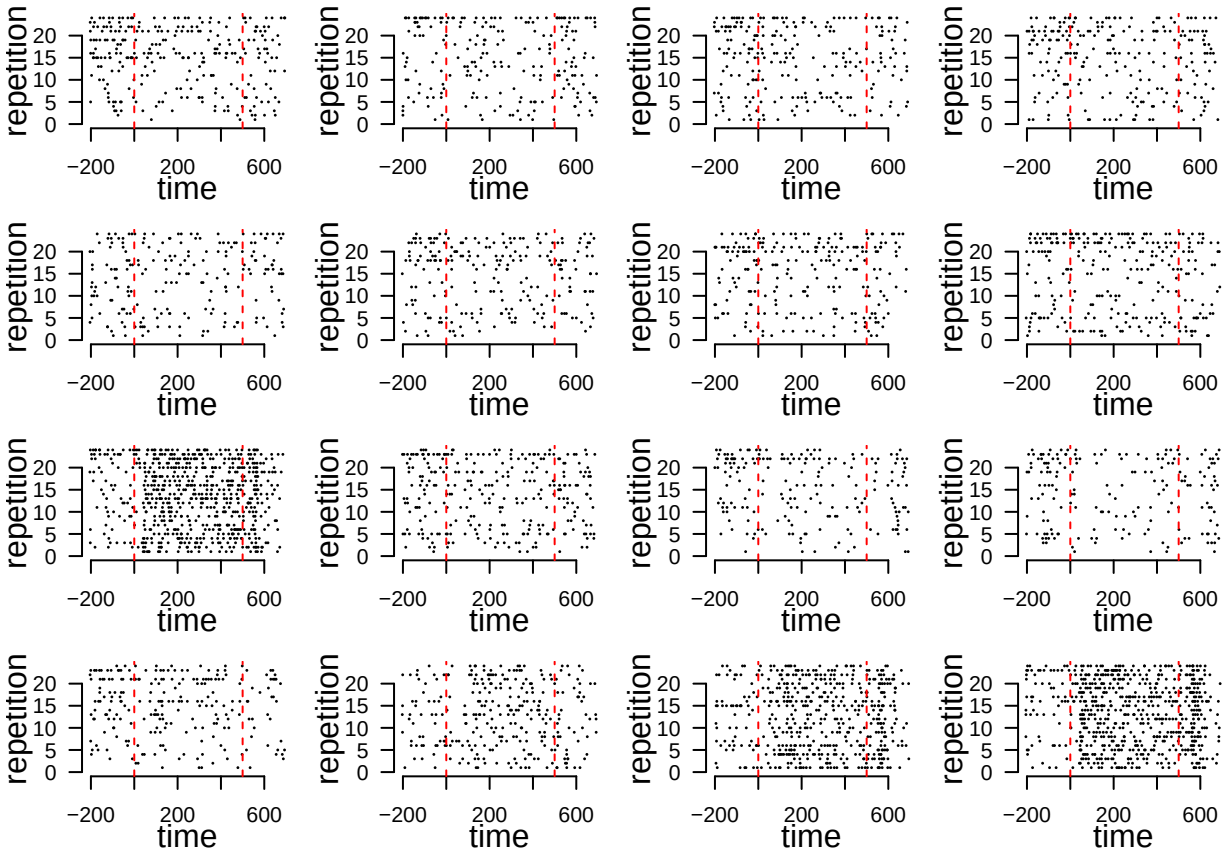
- the spiking is variable - the number of spikes in any given trial is different, and varies between 14 and 42, even though the stimulus is identical in each of these trials.
- there is activity before and after the stimulus is on

```
hist(colSums(cell[2,,]), xlab='spike count', main='0 orientation and 10 contrast')
```



Now let's see the response to all different conditions - 8 orientations at different 2 contrast levels. First two rows are the low contrast, below are the high contrast stimuli:

```
par(mfrow=c(4,4)); par(mar=c(3,3,1,1))
for (i in seq(1, 15, by=2)){
  plot.raster(cell[i,,], data$times)
  abline(v=c(0, 500), col=2, lty=2)
}
for (i in seq(2, 16, by=2)){
  plot.raster(cell[i,,], data$times)
  abline(v=c(0, 500), col=2, lty=2)
}
```



Homework

In this homework we will estimate the amount of variability of this cell in each of the 16 different conditions and examine how well it is captured by a Poisson distribution. Since the true firing rates are likely to change continuously during the stimulus presentation, we will analyse the variability of the spike counts over an entire 900 ms long trial. We will use the fact that for inhomogenous Poisson processes (PPs with changing rate) the spike count variability is equal to the mean spike count - so their ratio, called the Fano factor, is 1. Sometimes we will restrict ourselves to a smaller interval before, during or after the stimulus presentation. You need the following R functions to complete this exercise: apply(), mean(), var().

- First calculate the spike count on each of the 24 trials in each of the 16 conditions. This gives you 16*24 spike counts. [2p]
- Then calculate the mean and the variance of the spike count across trials for each of the 16 stimulus conditions (16 means and 16 variances) [2p]
- Finally compute the Fano factor by dividing the variances with the means. (https://en.wikipedia.org/wiki/Fano_factor, 16 numbers). [2p]
- Is the variability you observe consistent with Poisson firing? [4p]
- Repeat the same analysis now focusing on a short period (200 ms) before or after the stimulus onset. [2p]
- What do you observe? Is the variability you observe now more or less consistent with Poisson firing? [4p]

- What are the possible causes of the deviations from Poisson assumptions? What are the most important factors that can increase or decrease the variance relative to the Poisson variability? [4p]