Computational Neurodynamics

Topic 6
Competition

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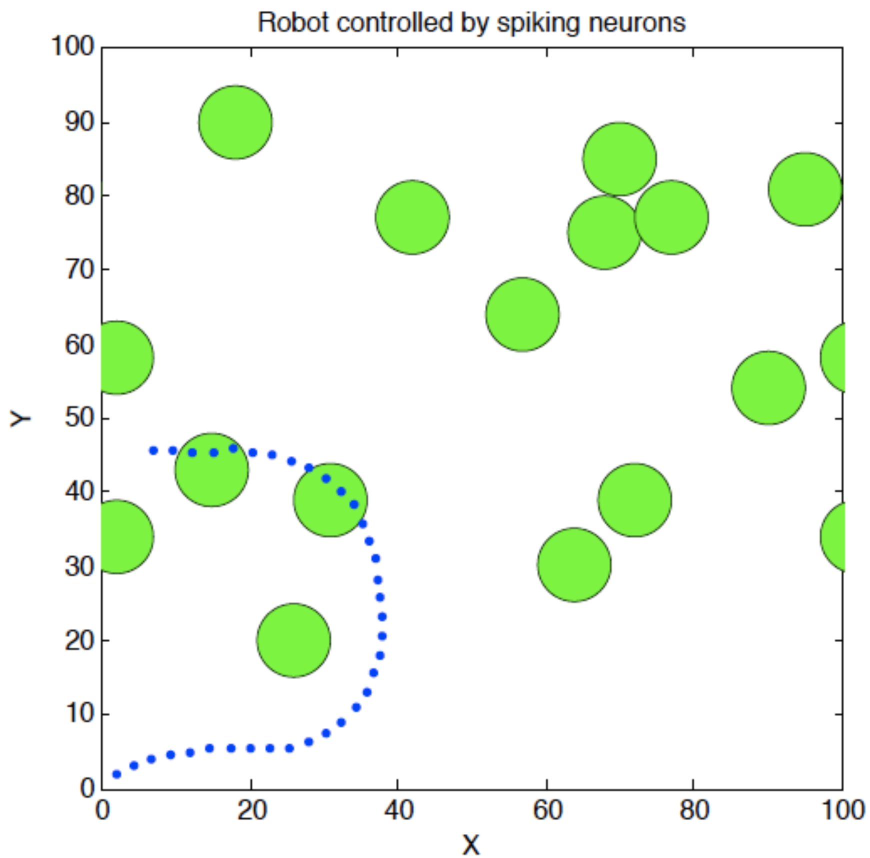
Overview

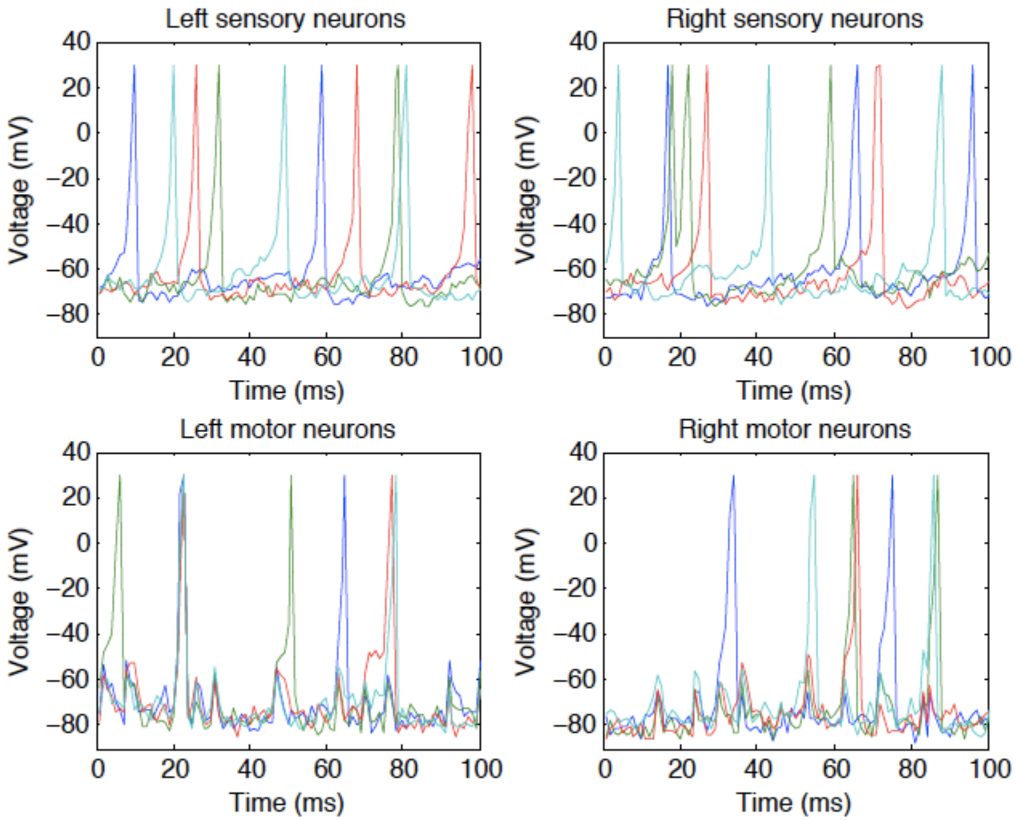
- The robot's dilemma
- Winner-takes-all mechanisms
- Periodic effects

The Robot's Dilemma 1



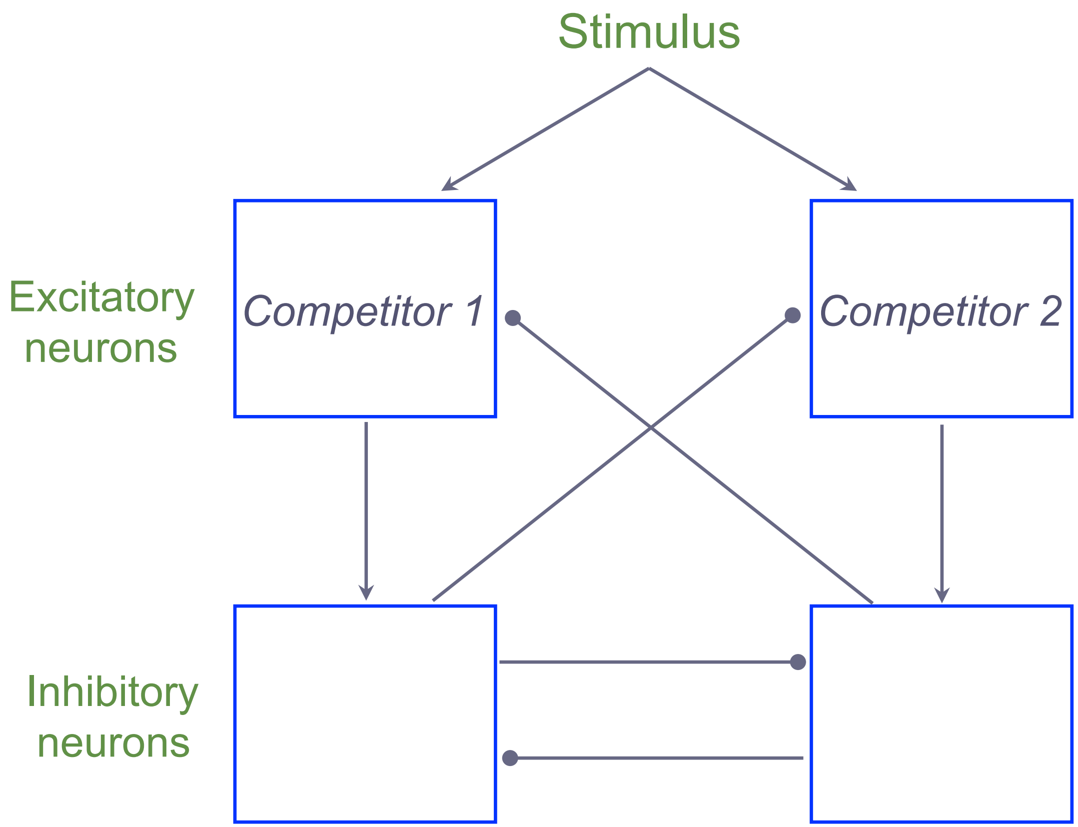
- In the situation here, there are two food sources ahead of the robot, one to the left and one to the right. It could turn towards either one
- If it is based on a simple Braitenberg controller, what will it do?

The Robot's Dilemma 2



- Both sets of sensory neurons are stimulated more or less equally. So both sets of motor neurons are stimulated more or less equally
- The robot speeds up, but it passes straight through the middle of the two food sources, missing both of them

Mutual Inhibition 1

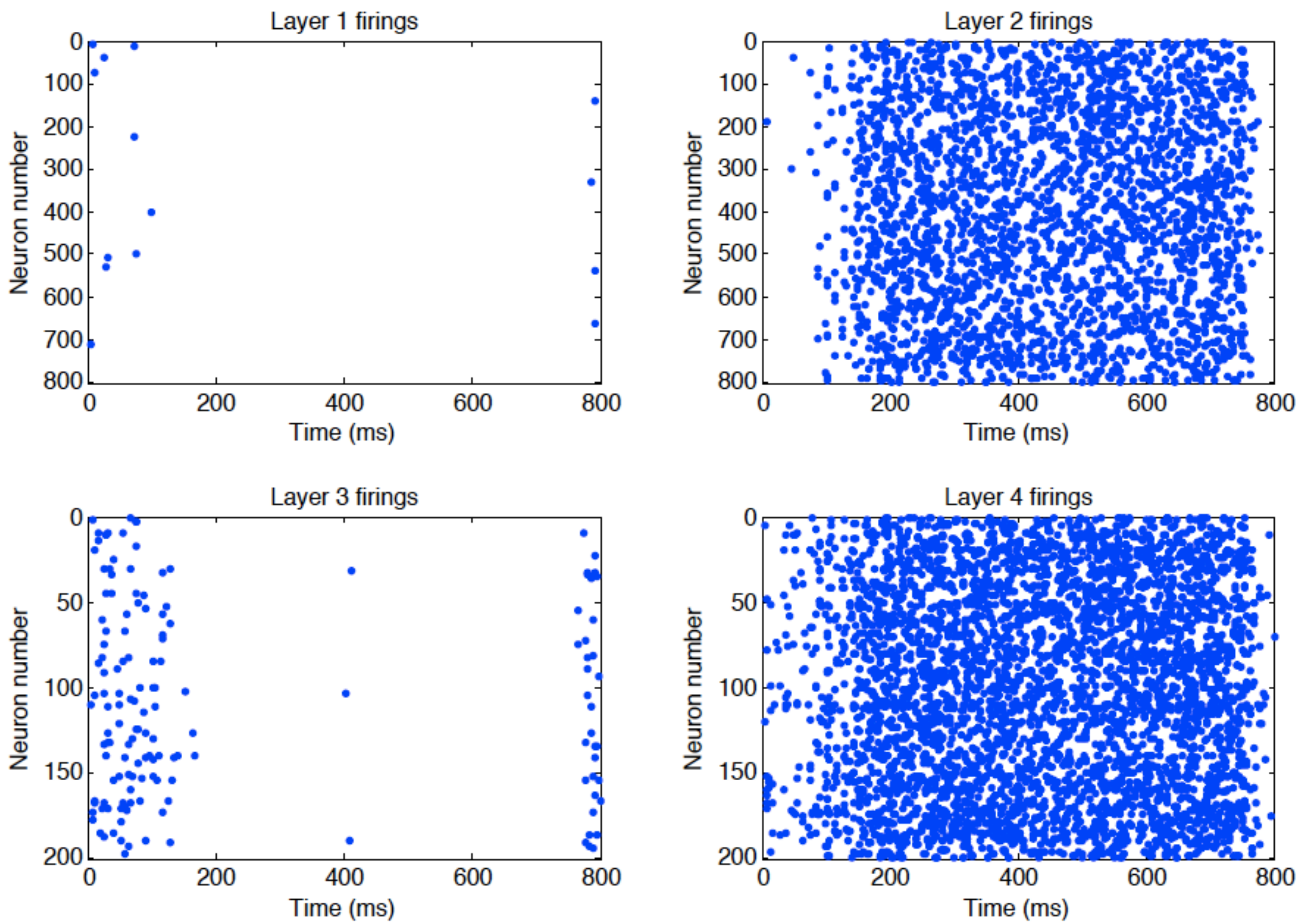


- This arrangement realises a winner-takes-all (WTA) competition between two rival responses to the same stimulus, using *mutual inhibition*
- Each competitor excites a matching inhibitory population, which inhibits its rival
- The configuration is *bistable* in the presence of a stimulus. In one stable state, the two populations on the left are active while the ones on the right are quiescent. The other stable state is the other way around
- The state in which both competitors are active is not stable

Fast Recovery: A Warning

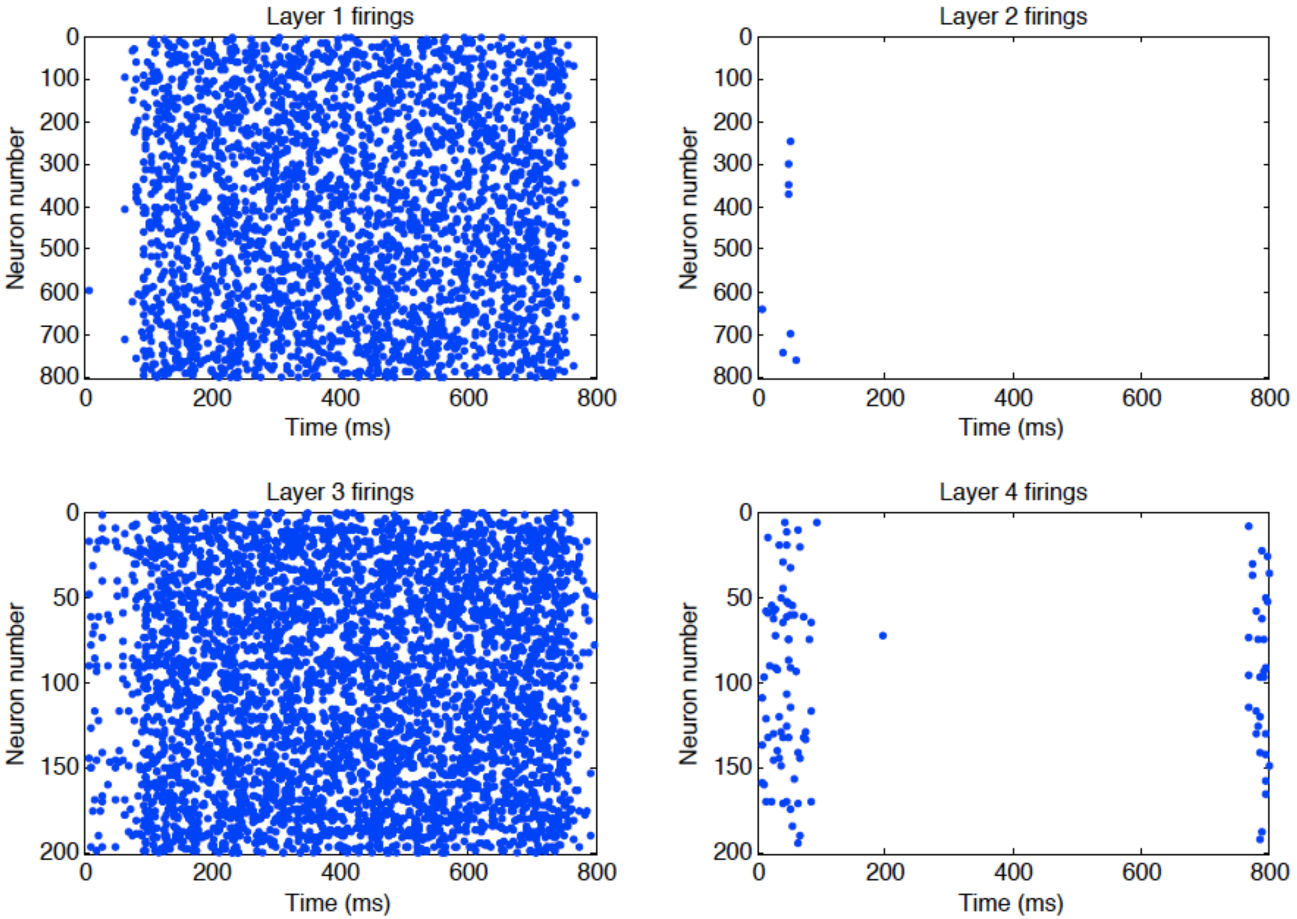
- In order to make this arrangement work, we will set the value of the a parameter in the Izhikevich model very high
- The effect of this is to make recovery after spiking unrealistically fast
- Without this move, WTA doesn't work as expected, for reasons we'll discuss shortly
  - Most spiking neuron models of WTA competition use simple integrate-and-fire neurons, which don't model the interplay of fast and slow dynamics
- So, even though it is widely used, it can be argued that the sort of WTA we'll be looking is biologically unrealistic

Competing Responses 1



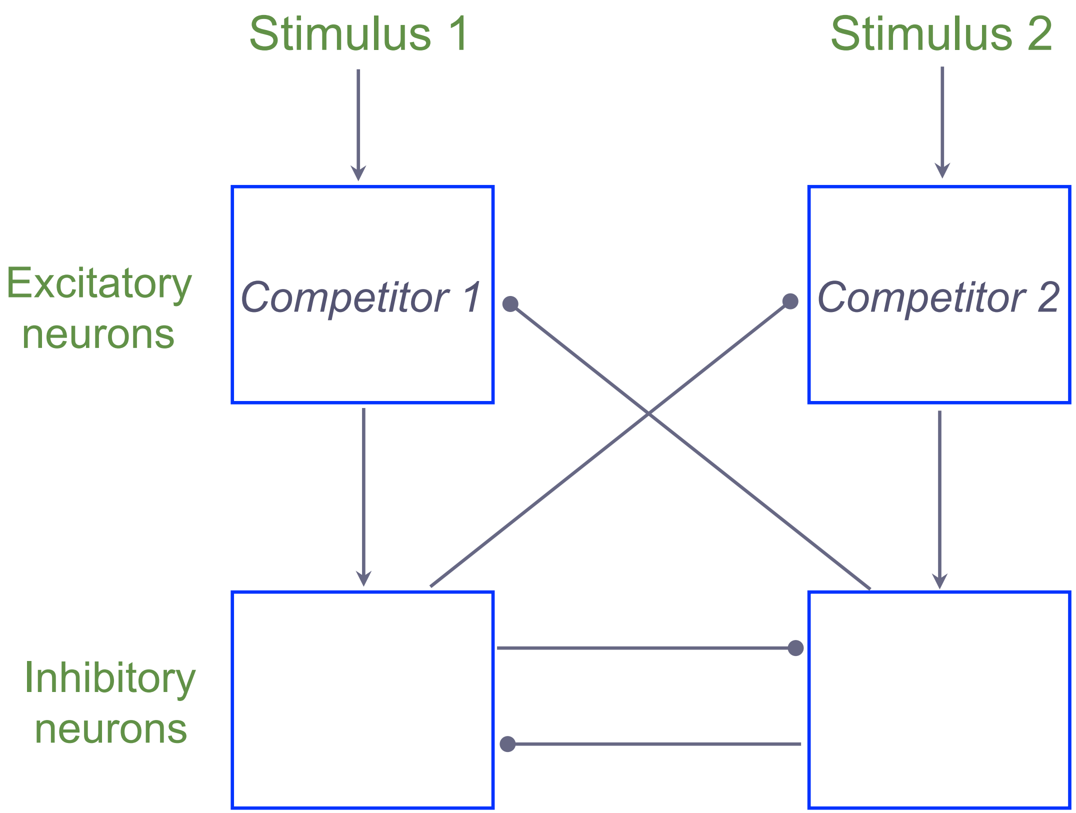
- For this mechanism to work with heterogenous neurons and a noisy stimulus, we need a large population
- Here we have 800 excitatory and 200 inhibitory
- This is the usual ratio of excitatory to inhibitory neurons (4:1)
- There is noisy input to the inhibitory layers. When the RHS starts to dominate, it shuts down the LHS altogether

Competing Responses 2



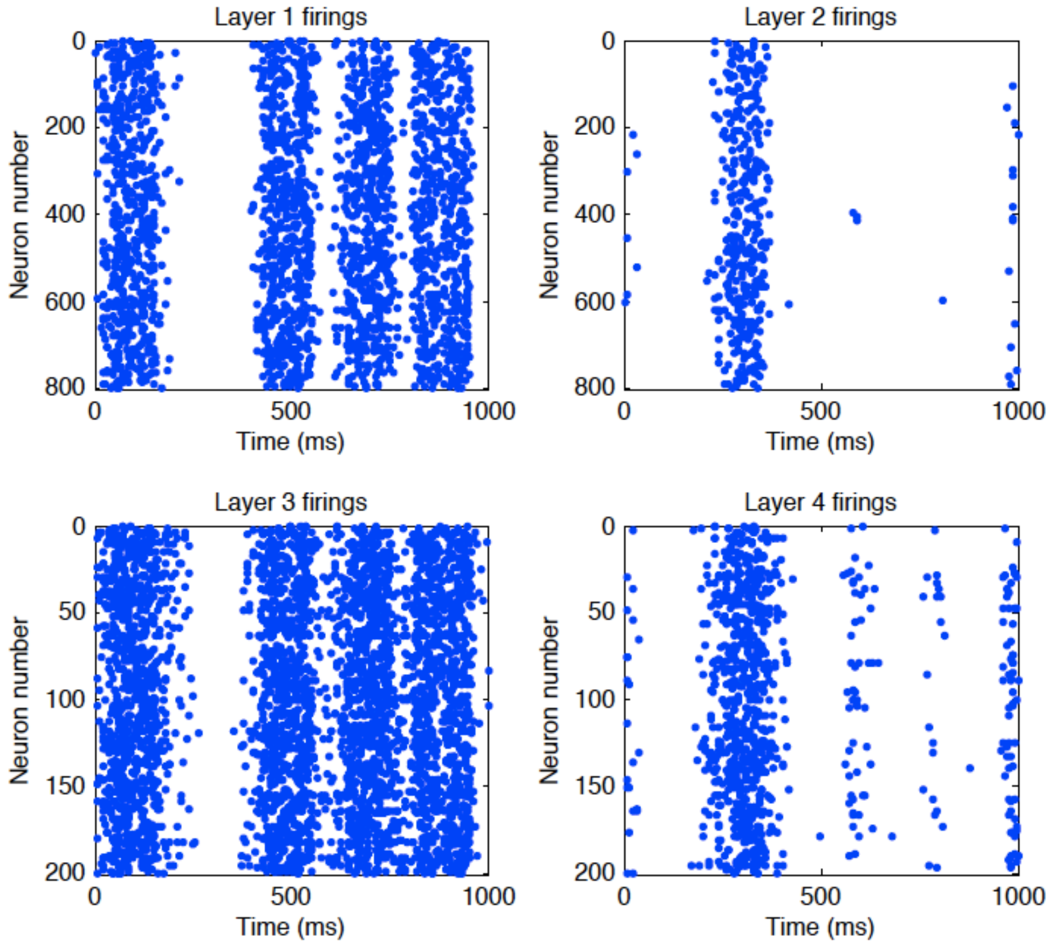
- Given the same stimulus, the WTA mechanism entails that each population wins 50% of the time
- The winner is determined by tiny random differences in the firing patterns at the start of the trial period
- As soon as the stimulus is withdrawn (at 750ms), activation dies away even in the winning population

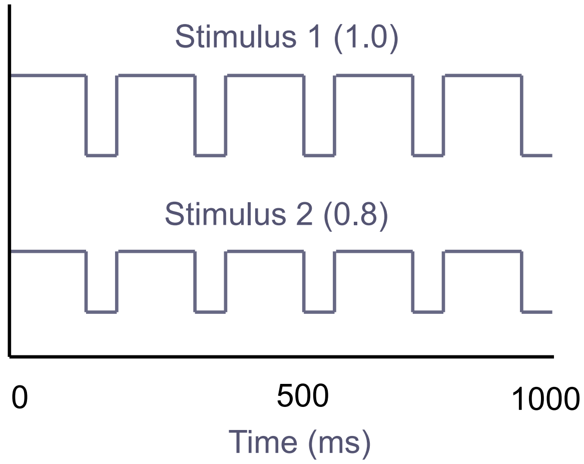
Mutual Inhibition 2



- The previous examples illustrate competing responses to the same stimulus
- Mutual inhibition can also be used to select a single response to different, competing stimuli
- We should expect the strongest stimulus to win most of the time

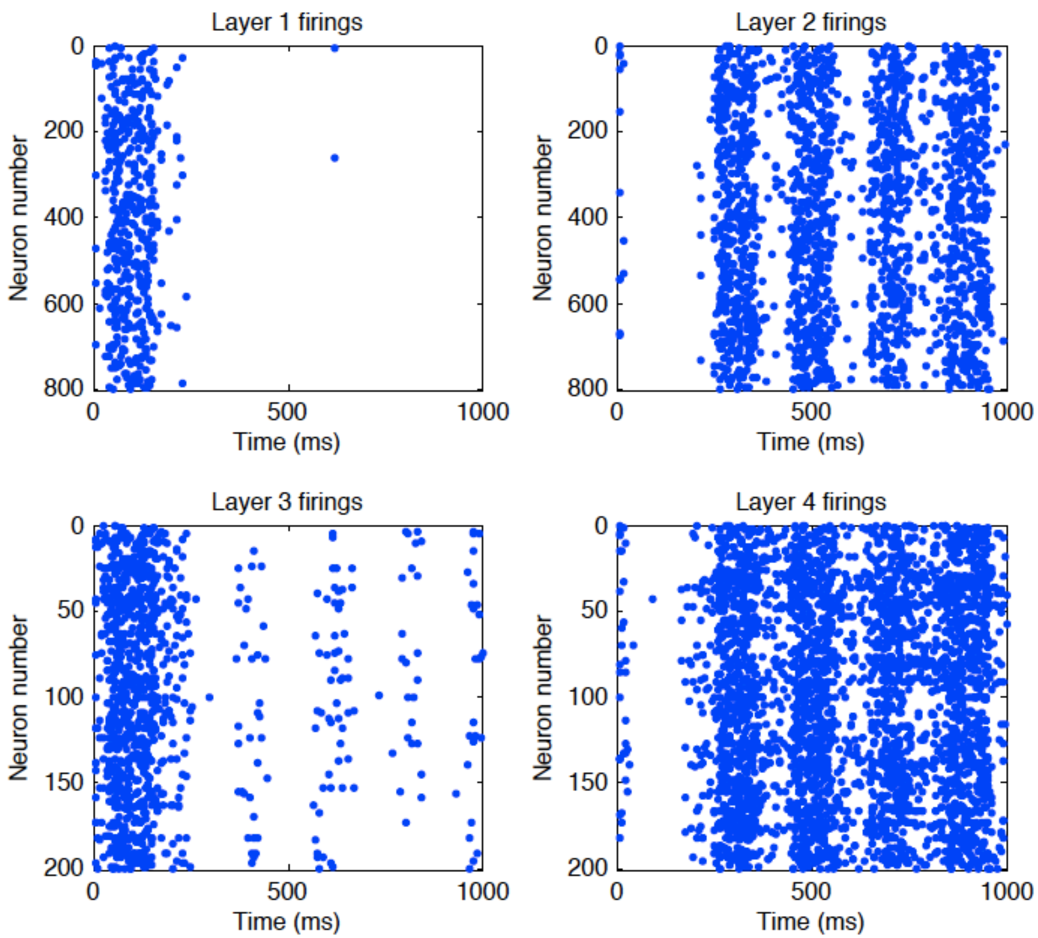
Competing Stimuli 1

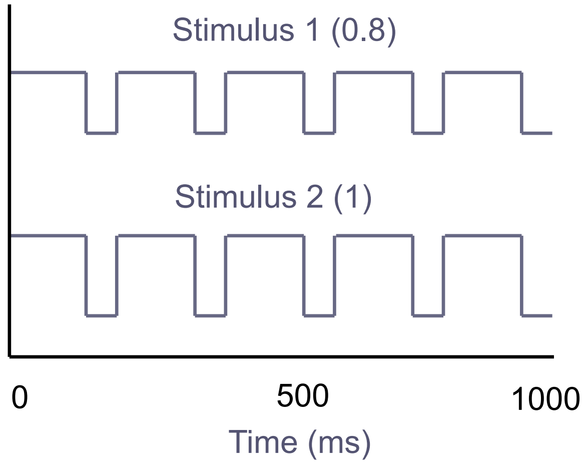




- To test this, we can deliver a series of 150ms stimuli followed by 50ms gaps
- One stimulus will be slightly stronger than the other
- As expected, the stronger one wins most of the time

Competing Stimuli 2





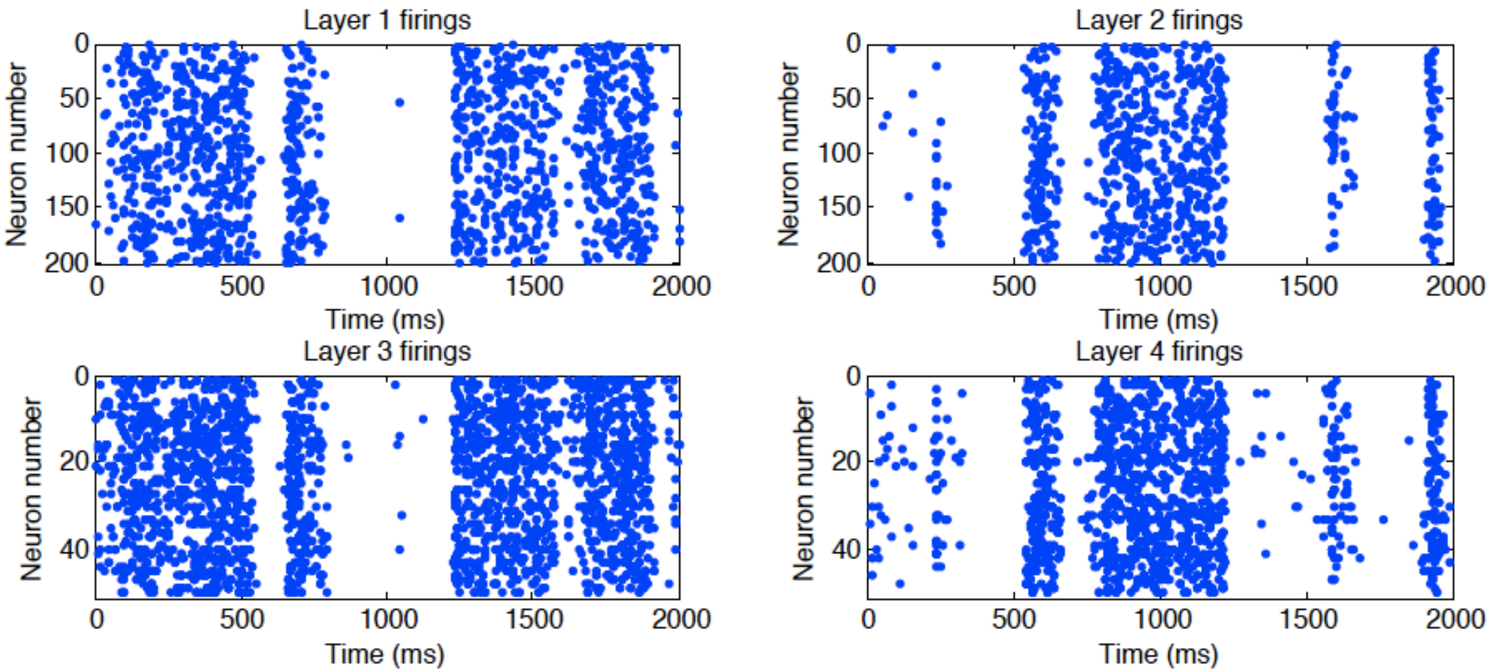
- To confirm the result, we flip the stimuli, so that Stimulus 2 is now the stronger one
- Again, the stronger stimulus wins most of the time

Statistical Effects 1

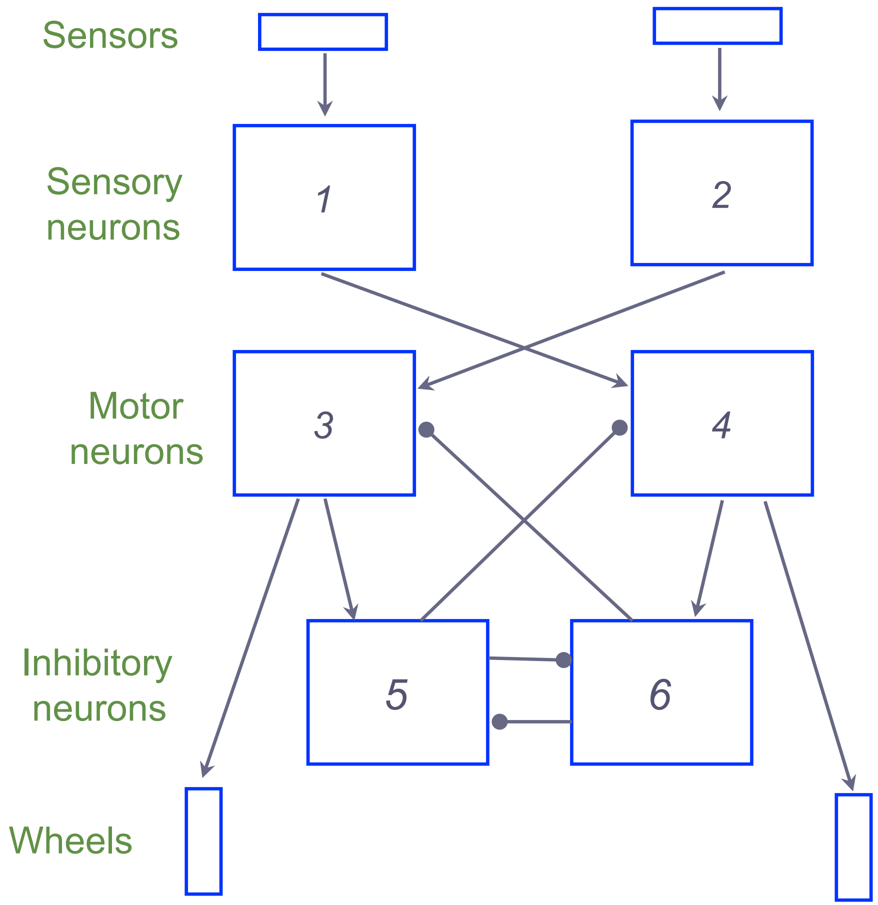
- If we reduce the number of neurons, neither competitor will dominate for long (whether we're talking about competing reponses or competing stimuli)
- This is because a sustained victory depends on there being enough ongoing inhibitory firing to shut out its rival
- But the firing is stochastic, so the amount of inhibition can vary
- The fewer neurons there are, the greater the variance in the mean firing rates
- So with fewer neurons, it will sometimes happen that the inhibitory firing dips far enough to allow activity in the rival to start, which can result in the winner swapping over

Statistical Effects 2

- This is what we see here (with constant identical input to both competitors). With just 200 neurons, there is irregular swapping between rivals, although at any one time there is a clearly dominant competitor

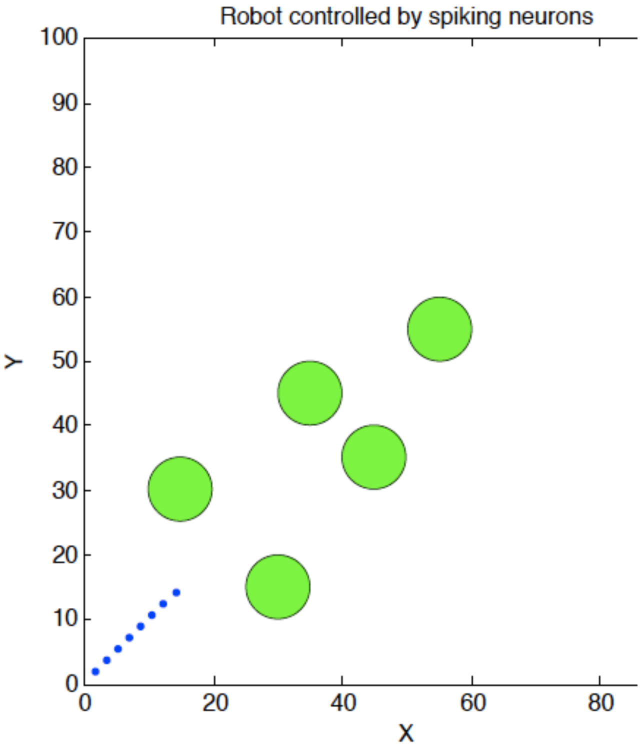


Action Selection 1

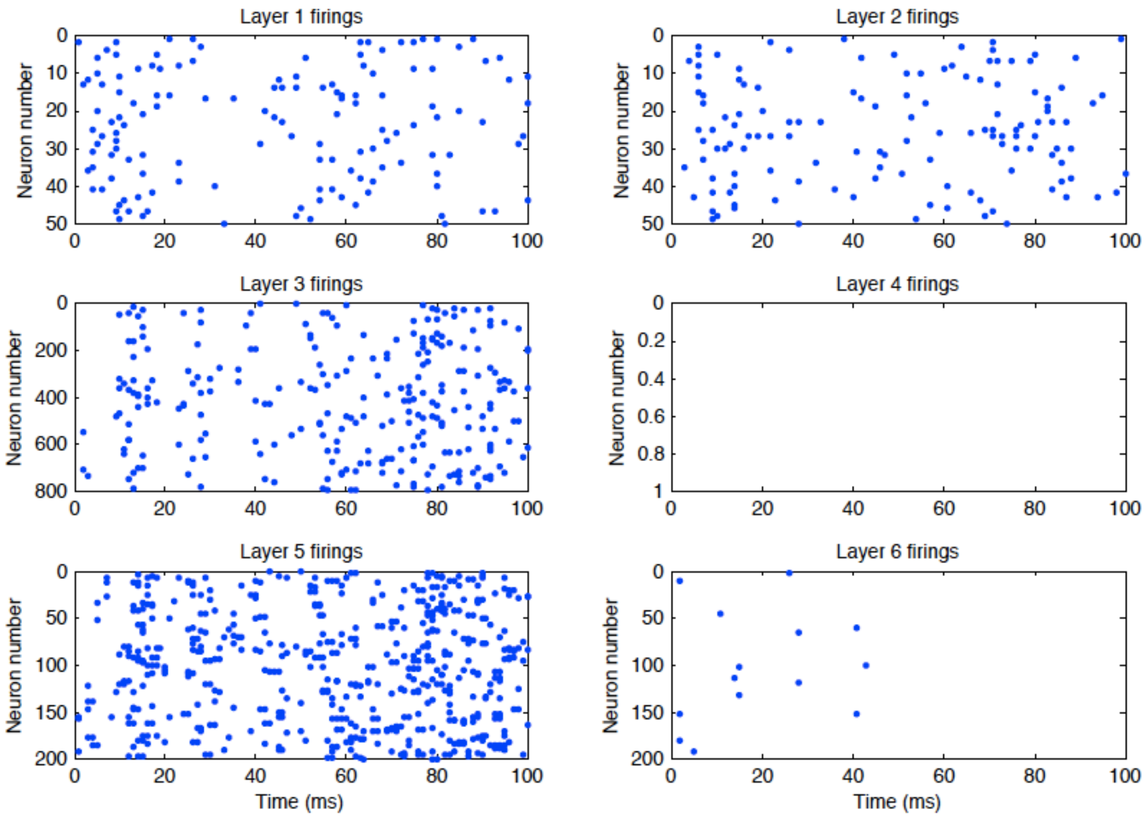


- We can now address the robot's dilemma using a winner-takes-all mechanism for action selection
- The arrangement is the basically the same as for the Braitenberg vehicle
- But mutual inhibition between the motor areas ensures that, when presented with equal but opposing stimuli, the robot will select one over the other, and commit to one direction to turn

Action Selection 2



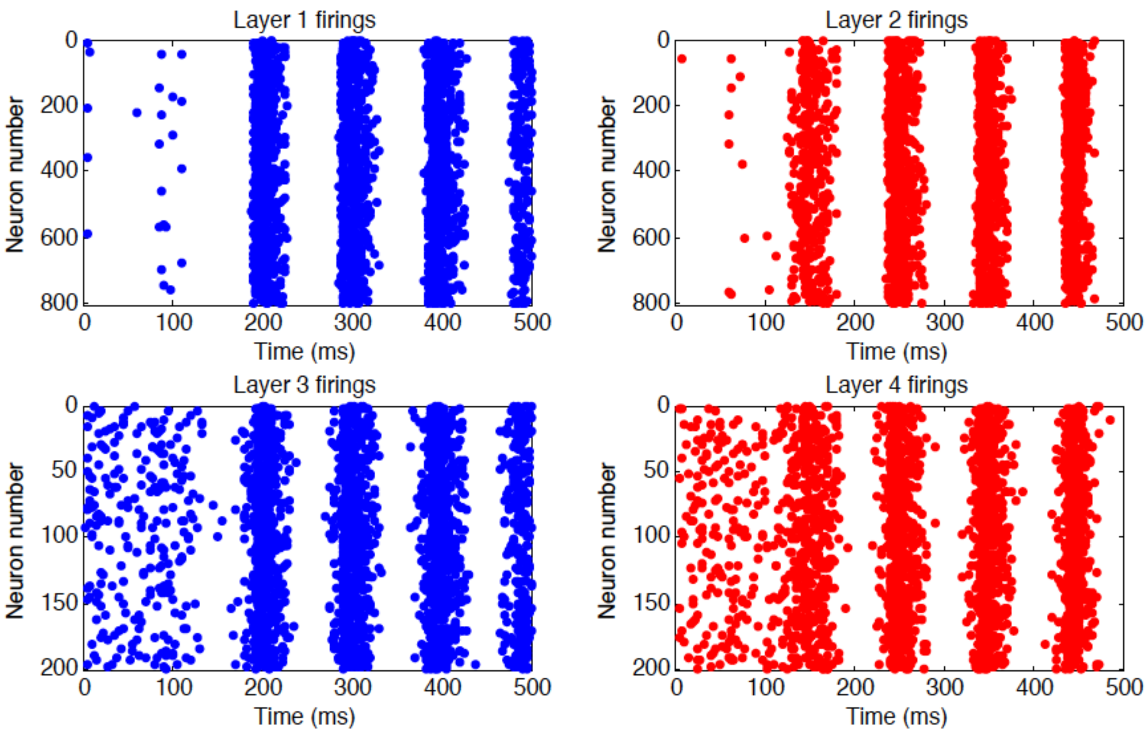
A dilemma for the robot



The left motor neurons are the winners

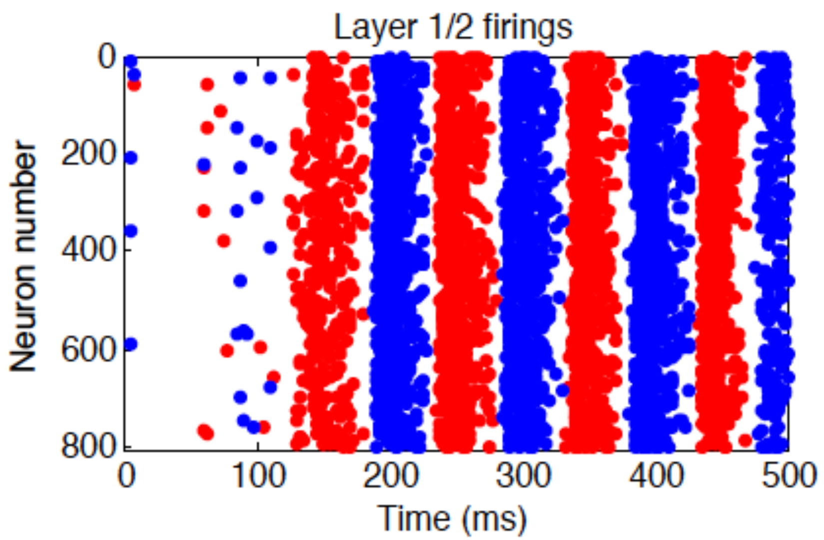
Periodic Effects 1

- Recall that, to obtain the WTA effect, the parameter a in the Izhikevich neuron model was set high. So what happens if we retain the usual a values for excitatory and inhibitory neurons?



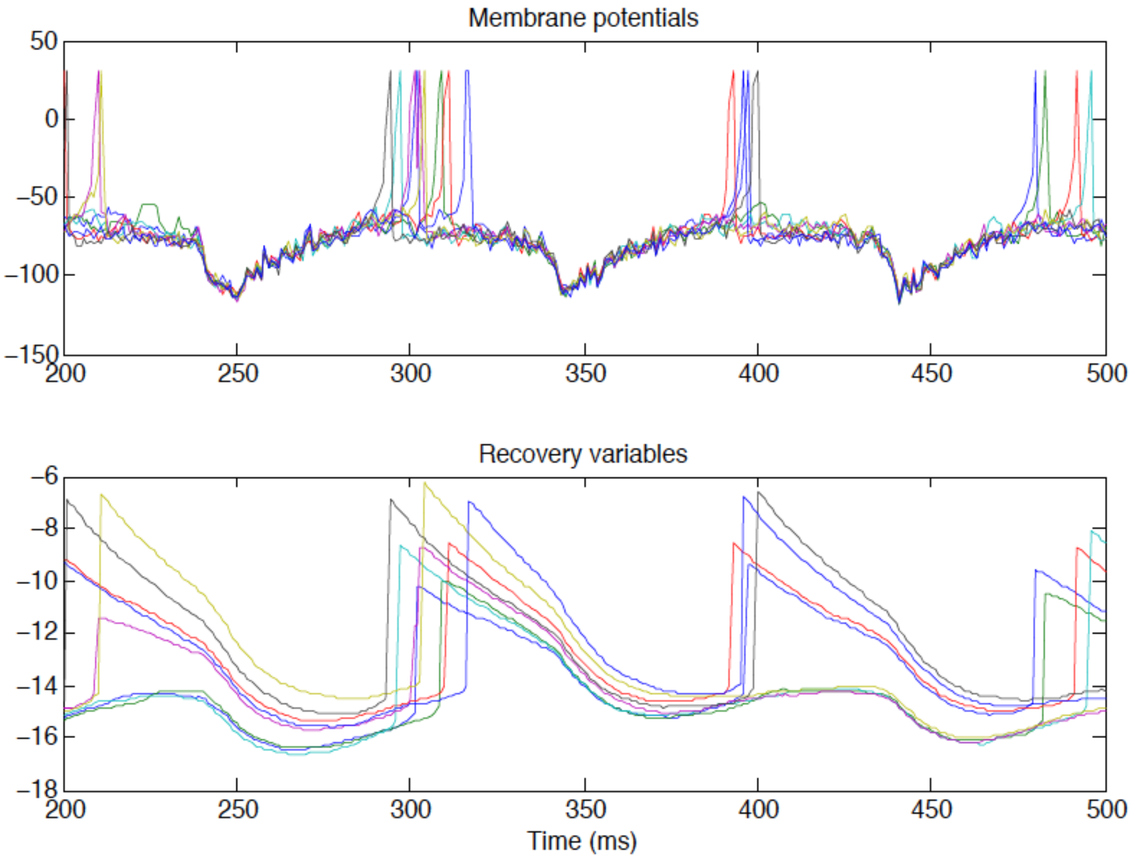
Periodic Effects 2

- Then neither competitor can be an outright winner, because of the slow dynamics of the recovery variable u. This promotes *oscillation*, a phenomenon we will study in detail later in the course
- However, because of the competitive arrangement of the populations, when one competitor is in a trough, the other can become active. The result is that they end up exactly 180º out of phase with each other



- Here we see raster plots of the excitatory populations of the two competitors overlaid on each other
- They are clearly exactly interleaved (180º out of phase)

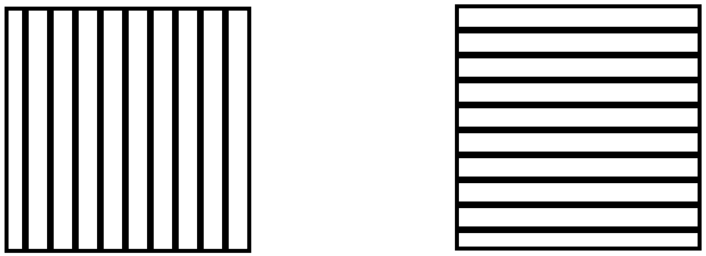
Slow Recovery



- Why does this periodic phenomenon occur?
- It occurs because of the increase in u after spiking. This prevents a neuron from spiking again until u has drifted back down
- After a period of time, so many neurons in the currently active population are recovering that it can no longer inhibit its rival
- The plots on the left show this for eight representative neurons

Binocular Rivalry

- Competition is a basic feature of cortical dynamics. We've seen a motor example, but there are also examples on the sensory side
- Binocular rivalry is a classic example, which involves competition between the visual areas of the left and right hemispeheres
- Different images are presented to the left and right eyes



- You might expect subjects to report seeing an overlay of the two images (a criss-cross pattern)
- But most report that one or other image is dominant, and that the dominant image spontaneous switches from one to the other