Supplementary Figure 1

Examples of synchrony measures

Spike times were numerically generated to produce perfect synchrony (left column), two levels of spike time jitter (middle 2 columns) among 80 "cells" firing at 100 Hz, and a ring oscillator. These data were produced by manually generating a spike time raster, without any NEURON simulation. Jitter was introduced by adding a random offset to the time of every spike using the "randn" function in Matlab (standard normal distribution, multiple levels of standard deviation tested). Left: With 0 jitter, all cells fired synchronously (top) and the histogram of spike times (2.5 ms bins, bottom) shows that all 80 cells fired within the bin. Levels for F, R, and B at the bottom indicate the levels for perfect synchrony (100, 1, ~1). Middle left: A mild amount of jitter (standard deviation = 1) produces small asynchrony (top) and more than half of the cells fire within the 2.5 ms bins (bottom). F remains constant, while R and B both decrease slightly. Multiple levels of standard deviation were tested: whenever more than 50% of the cells fired within the 2.5 ms bins, R and/or B were > 0.2. Middle right: Higher levels of noise result in desynchronization of the network. In this case, standard deviation = 2.5 degrades the periodic signal significantly. F remains constant, since all cells are still firing the same number of times. The histogram shows that less than 50% of the cells fire synchronously, and R and B both drop below 0.2. Right: The ring oscillator consists of 100 cells with 1 ms delay between each cell. In this case, F indicates that each cell fires 10 times per second, and that the phase between the cells is somewhat consistent (R=0.32). The B, however, is actually below 0, because the synchrony is so poor between the cells. As predicted, B is -1/9 for N=100. This example illustrates how R and B provide different information. The close similarity between R and B in our results indicate that most bursting activity (high R) is also synchronous (high B).

Supplementary Figure 2

Comparison of β in the Driver and Neighbor networks

A: With baseline coupling, Neighbors begin to oscillate as their noise increases. They oscillate at the same frequency as the Drivers with much lower noise (noise present in the Drivers is indicated by the colored diagonal lines). Results are shown for 40 and 50 Hz Drivers in the left panel, 75 and 95 Hz Drivers in the right panel. In general, $\beta > 1000$ is good coherence. B: Same analysis with 0.001 μS gap junctions connecting Drivers to Neighbors. Results are similar, though the β for the Neighbors is consistently higher than in A, indicating better recruitment to oscillatory activity. C: Results for recurrent synapses. In this case, the oscillations begin with less noise, and the difference between the Drivers and Neighbors is smaller (lower difference in β between the two groups), showing even better recruitment. Stars: raw data shown in Fig. 7.

Supplementary Figure 3

Supplementary recruitment data

A: Spike rasters and power spectra for the Driver + Neighbor network with 95 Hz Drivers. F, R, and B from these data are marked in Fig. 4. With Drivers very active, the Neighbors are very suppressed (left, middle) until they receive 0.186 nA^2 noise (right). This suppression results in a low β value (Fig. 3, also note disparity between the red and green lines in the PSD at the bottom of the left and middle examples, indicating the Drivers themselves were altered) and high T-scores (Fig. 4). Thus, although the values for R and B are high in Fig. 4, recruitment is poor until the Neighbor noise nears 0.186 nA^2. B: F and B for the three coupling types (see Fig. 4, 6). These data show recruitment to both gamma (40 Hz) and fast gamma HFO (75 Hz) oscillations. F has a similar response for all Driver frequencies, and in each case earlier recruitment with recurrent synapses. B is qualitatively very similar to R in each case. Hash marks indicate that T-scores become very large when the Neighbors receive > 0.08 nA^2 noise with 40 Hz Drivers, as this is actually greater noise than the Drivers receive. All noise in nA^2.

Supplementary Figure 4

Comparison of F, R, and B between Drivers and Neighbors

In each plot, each measurement is calculated once for all 20 Neighbors and once for each of 4 groups of 20 Drivers. The Neighbor response is plotted alongside the mean response of the 4 Driver groups. The outputs with base, 0.001 μS gap junctions, and recurrent synapses are plotted as in Fig. 6. A: Response to 40 Hz Drivers. B: 75 Hz Drivers. C: 95 Hz Drivers. Note that the average Driver response is lower in this case when there are gap junctions, which is likely due to the altered input resistance of the Driver cells. The response to recurrent connections is also changed, but in that case it was due to increased inhibitory feedback because of recruited Neighbors (see. Fig. 7). This difference between gap junctions and recurrent synapses is clearly seen in the T-scores (Fig. 6).

Supplementary Figure 5

Recruitment to ripple oscillations

A: Ripples formed by strong (0.01 μS) inline gap junctions and loss of basket cells within Drivers. Neighbors maintain their basket cell connections and are connected to 20 Drivers via 0.005 μS gap junctions. I: Raw data for three noise levels. Varying noise to the Drivers (0.06, 0.08, and 0.186 nA^2) produced Driver oscillations at 82, 104 and 144 Hz. For each Driver frequency, a full range of noise was added to the Neighbors as in previous Figures. Left, middle: excellent recruitment to the Driver oscillation, as the Neighbors become much more active and synchronized with the HFO. Note that before noise is added, the Neighbors often oscillated loosely at slow gamma frequencies (cyan PSD lines) in response to the strong signal coming from the Drivers. Right: Even with very low amounts of noise, the Neighbors oscillated at harmonics of the Driver oscillation, in this case the addition of noise produces a strong oscillation at ¼ the Driver frequency. II: Recruitment data for gap junction ripples. Top: noise produces SR for all three HFO Driver frequencies. Middle: F increases to the Driver frequency asymptotically. The T-scores are quite high for noise < 0.186 nA^2 because the Neighbors oscillate slower. Bottom: R demonstrates very clearly when the Neighbors have become recruited to the HFO. Note that the strong subharmonic oscillation to 144 Hz at 0.008 noise is measured as excellent recruitment (R > 0.2, T-score << 10). Data from Fig. 8A have high cross-covariance but poor recruitment due to the slant artifact.

B: Ripples formed by 110 distributed recurrent synapses and loss of basket cells within Drivers. Neighbors maintain their basket cell connections and are connected to 20 Drivers via recurrent synapses. I: Raw data for two noise levels that produce 153 Hz and 180 Hz oscillations. In this case, the Drivers do not produce a stationary oscillation (see Fig. 8 and poor β evident in the broad peak in the green PSD lines). The Neighbors are still recruited to that irregular signal at certain noise levels. In both examples, the Neighbors also formed independent HFOs at lower frequencies (red line peaks at 120 Hz, 130 Hz) that were not present with either Driver input alone (blue line in PSD) or noise alone (black line). II: Recruitment occurs over a narrow range. Cross covariance is rarely > 0.5 when the Drivers oscillate at 153 and 180 Hz because the Neighbors tend to oscillate at 120 and 130 Hz in each case. With 135 Hz oscillations, this effect was not present and the cross-covariance produced SR despite low values of β (see Fig. 8B). F demonstrates that the Neighbors are oscillating at ripple frequencies in all three cases, and behave similar to the Drivers when noise is > 0.06 nA^2. R is very low because the Drivers themselves have low R due to their nonstationary oscillation; however, the Neighbors are still recruited quite well to that output, especially with 180 Hz Drivers (low T-scores).

C: IPSP ripples suppress epileptic oscillations. I: Raw data for very active Drivers (0.25 nA^2 noise) and ~ 200 Hz basket cell oscillations. Without the recurrent connections (left), Neighbors remained very suppressed until they received very high levels of noise. Recruitment was greatly improved when recurrent synapses were added, but the pyramidal cell oscillation was quite slow (55 Hz). Note that the Neighbors fire sparsely and randomly without the Driver input (black line). II. Cross covariance indicates that there is excellent recruitment when the Drivers oscillate and have recurrent connections. However, recruitment is very poor without recurrents and when the Drivers are less active (noise < 0.25 nA^2). All data except the light blue contain recurrent connections. F indicates that the oscillations are in the slow gamma range, and recruitment is poor except with recurrent synapses. R is very low for most noise levels because the cells are suppressed. When the cells are actively oscillating with 0.25 nA^2 noise, recruitment is excellent with recurrent synapses.