Stimulus-dependent suppression of chaos in recurrent neural networks

Kanaka Rajan

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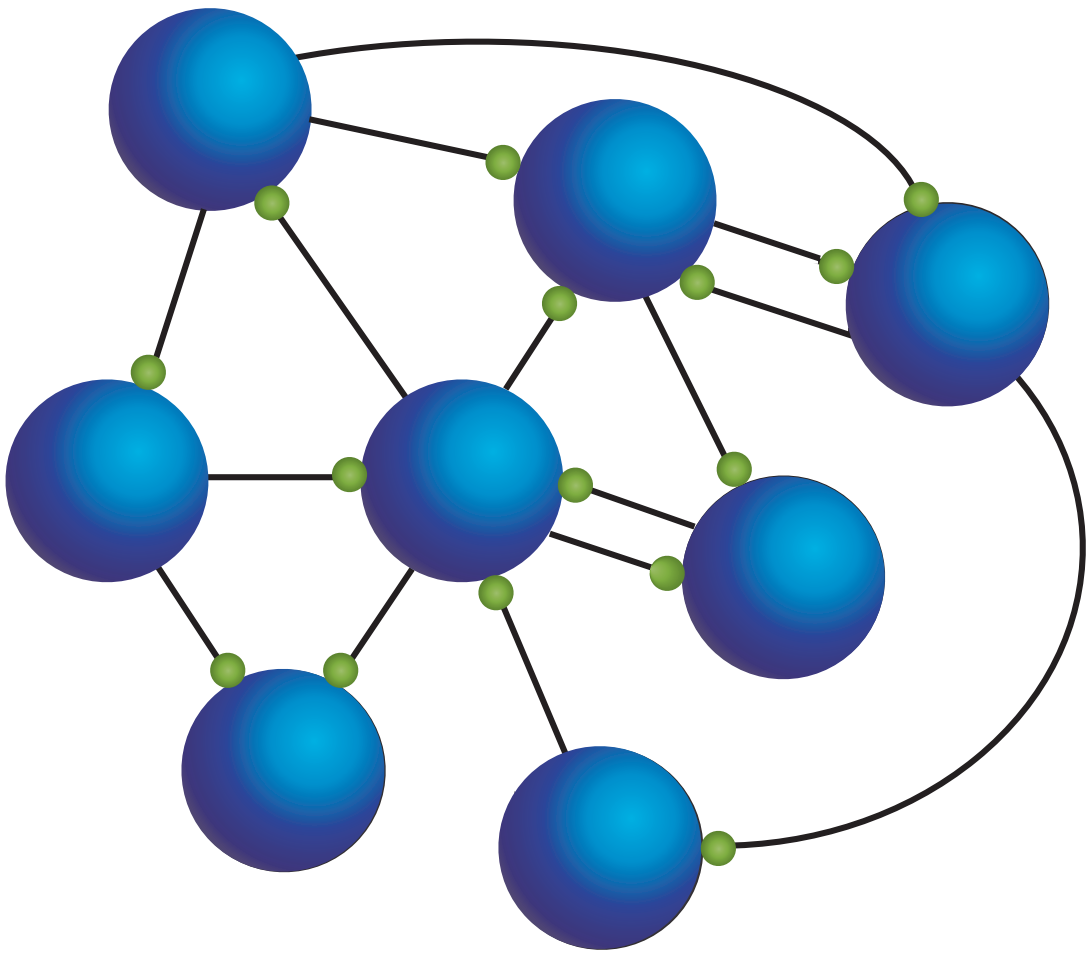
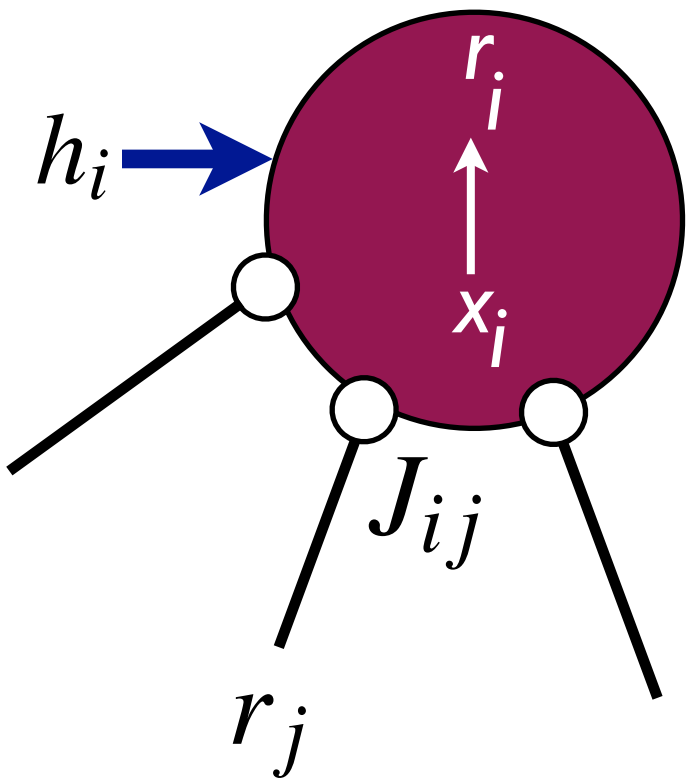
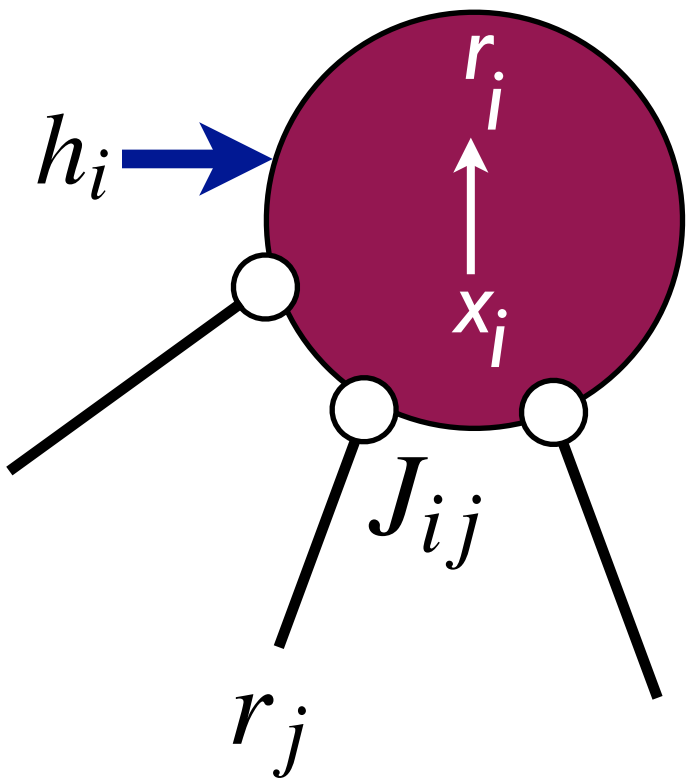



r_i
h_i
x_i
J_{ij}
r_j

$$\frac{dx_i}{dt} = -x_i + g\sum_{j=1}^{N} J_{ij} r_j + h_i$$

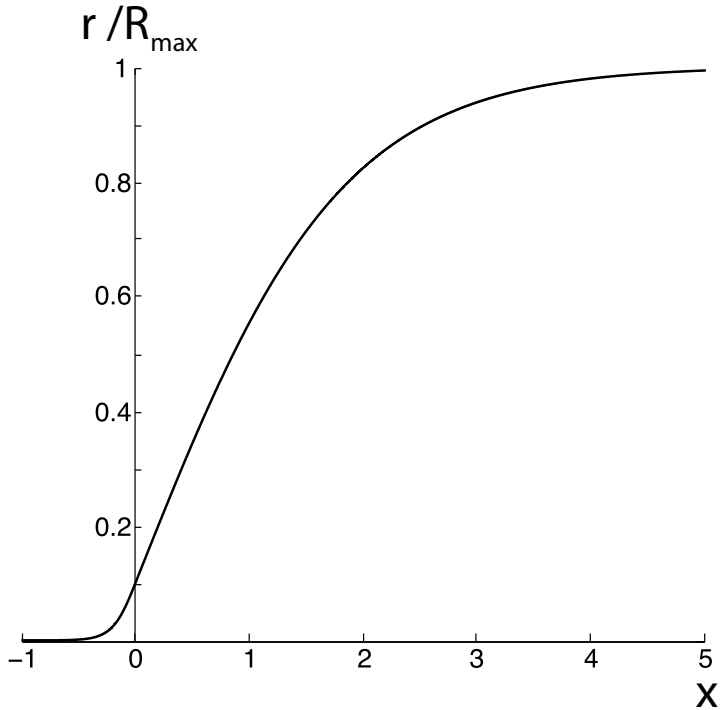


Synaptic weights

$$\langle J_{ij} \rangle_J = 0 \quad \text{and} \quad \langle J_{ij}^2 \rangle_J = \frac{1}{N}$$

Neuronal response function is nonlinear

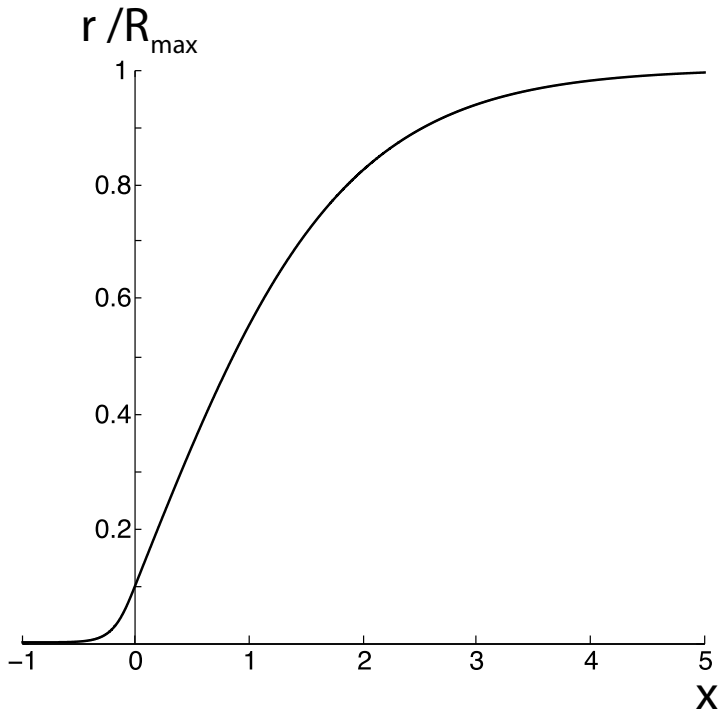
$$r_i = R_0 + \phi(x_i)$$



Neuronal response function is nonlinear

$$r_i = R_0 + \phi(x_i)$$

$$R_0 = 0.1 R_{\max}$$



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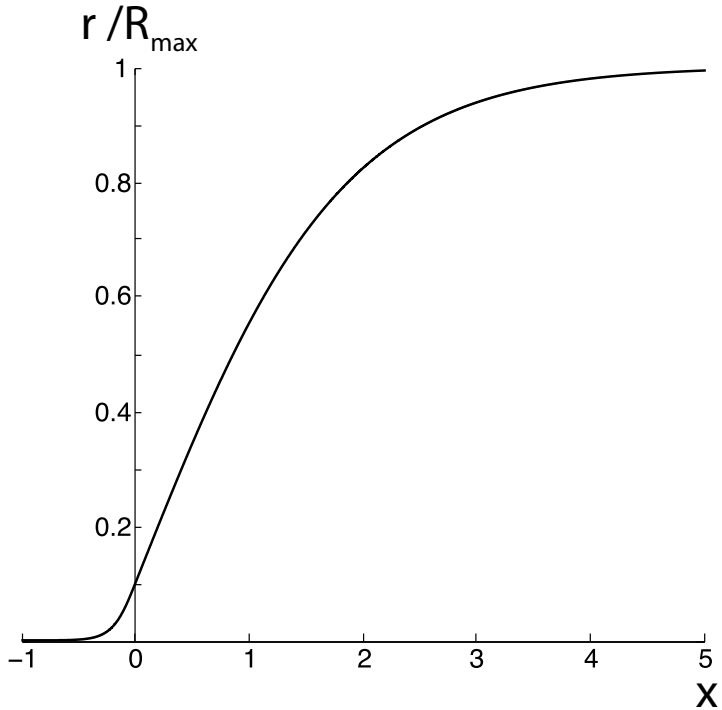
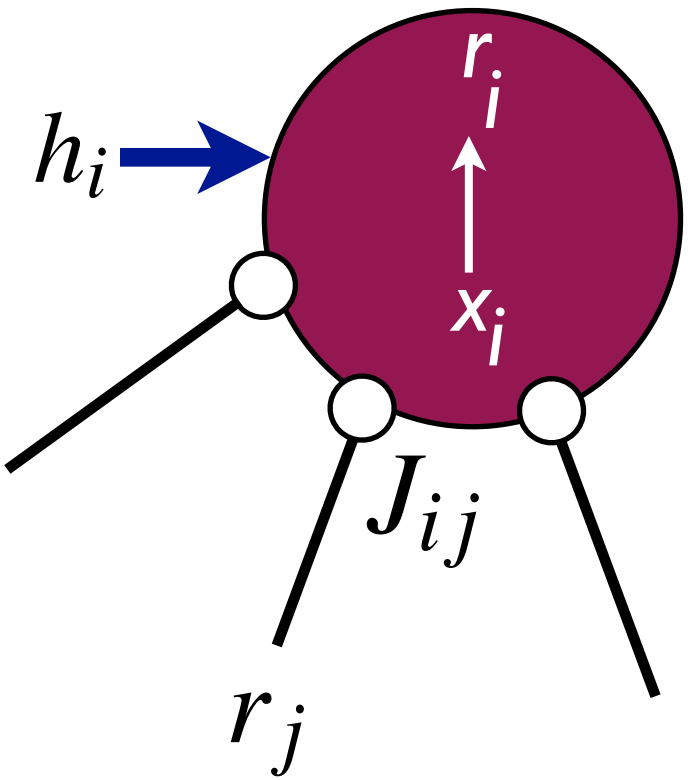


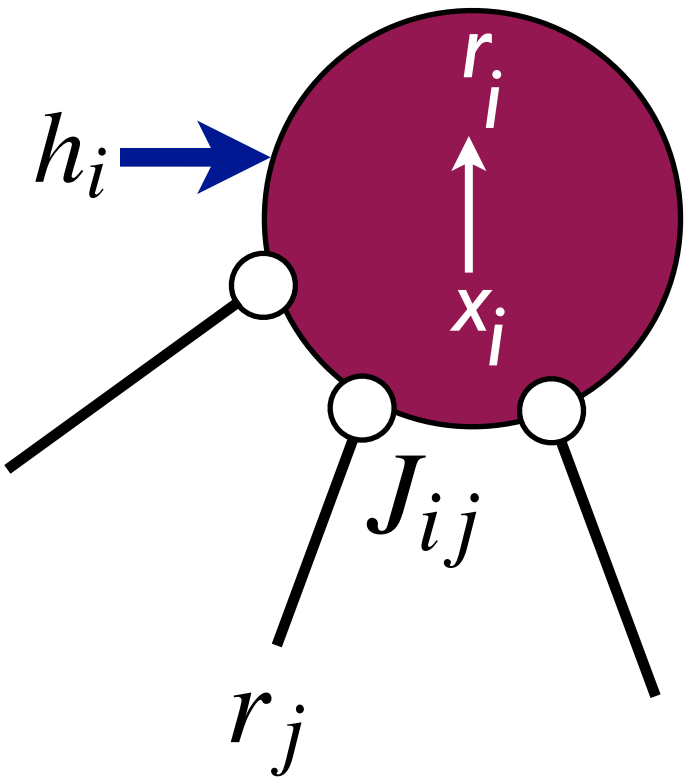
$$\underline{\phi}(x) = \begin{cases} R_0 \tanh\left(\frac{x}{R_0}\right) & if\ x \le 0 \\ (R_{\max} - R_0)\tanh\left(\frac{x}{R_{\max} - R_0}\right) if\ x > 0\,. \end{cases}$$

$$\frac{dx_i}{dt} = -x_i + g\sum_{j=1}^{N} J_{ij} r_j + h_i$$



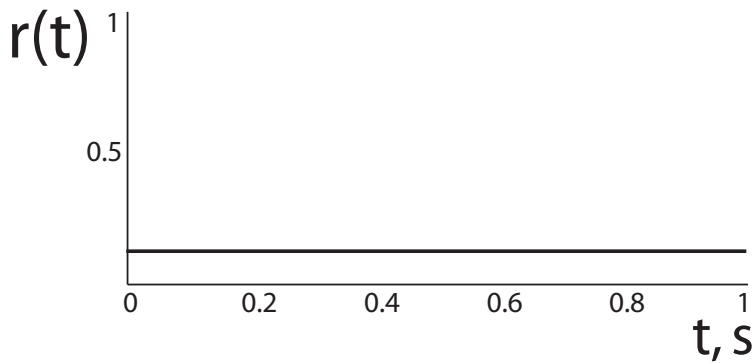
$$\frac{dx_i}{dt} = -x_i + g\sum_{j=1}^{N} J_{ij} r_j + h_i$$

scales synaptic variance



inactive

g = 0.9

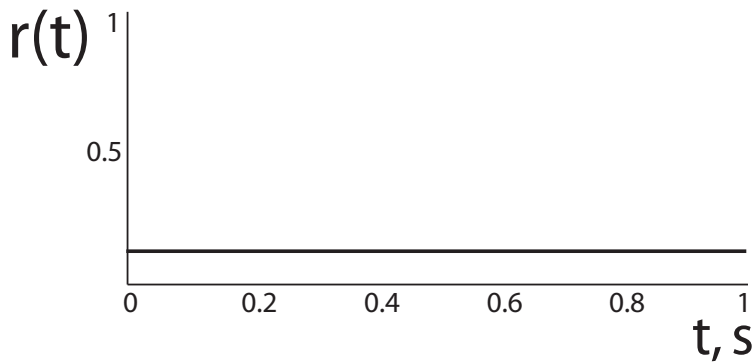


$N = 1000$

Sompolinsky, Crisanti & Sommer, 1988

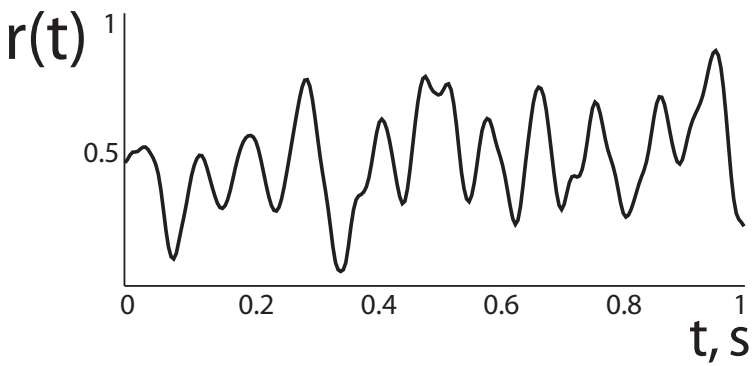
inactive

g = 0.9



spontaneously chaotic

g = 1.5



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Sompolinsky, Crisanti & Sommer, 1988

$$C(\tau) = \langle r(t) r(t+\tau) \rangle$$

inactive

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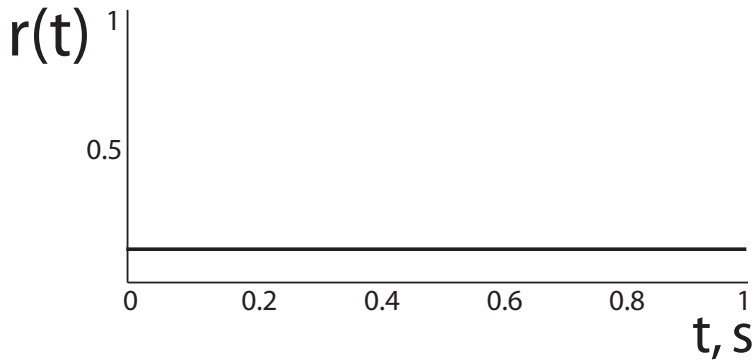

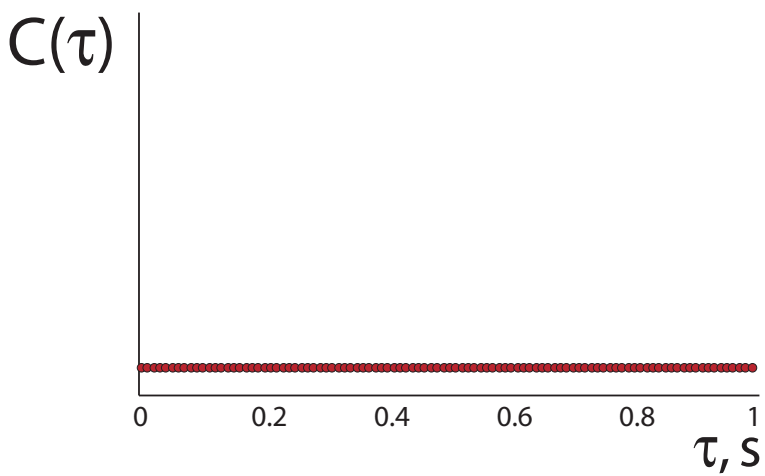

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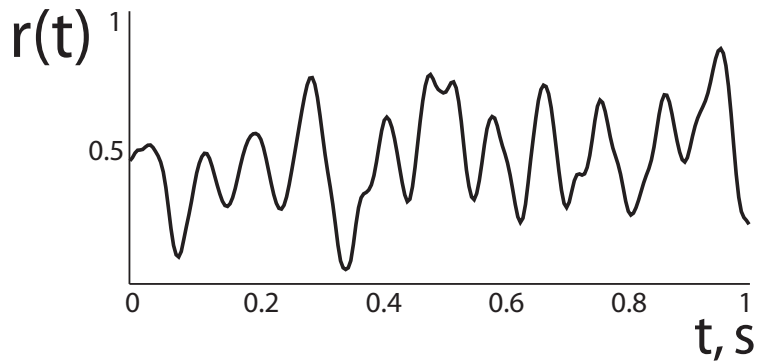
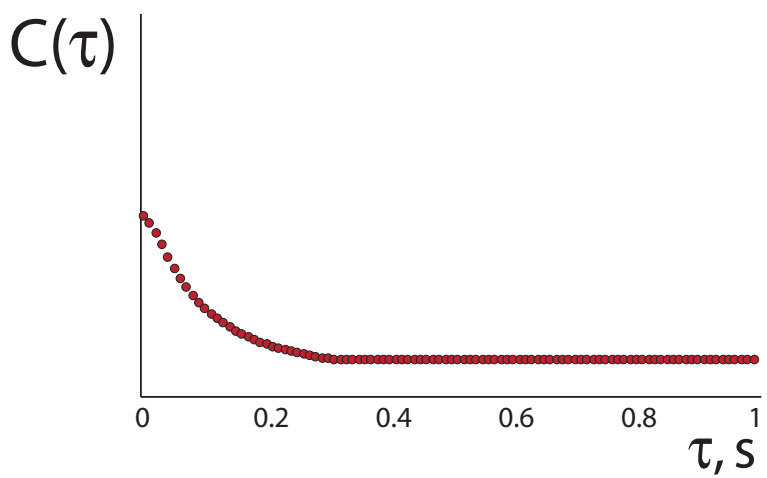
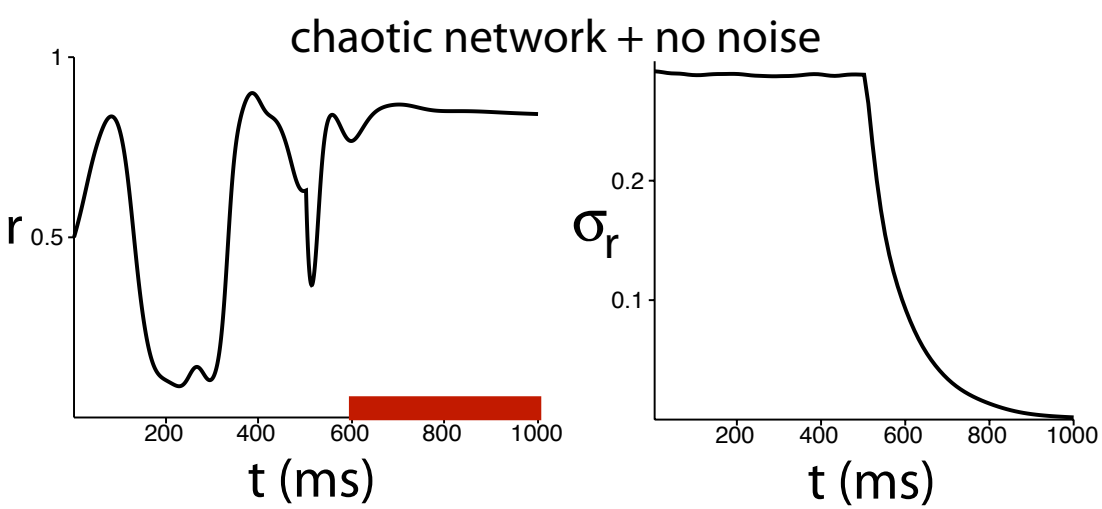




$N = 1000$

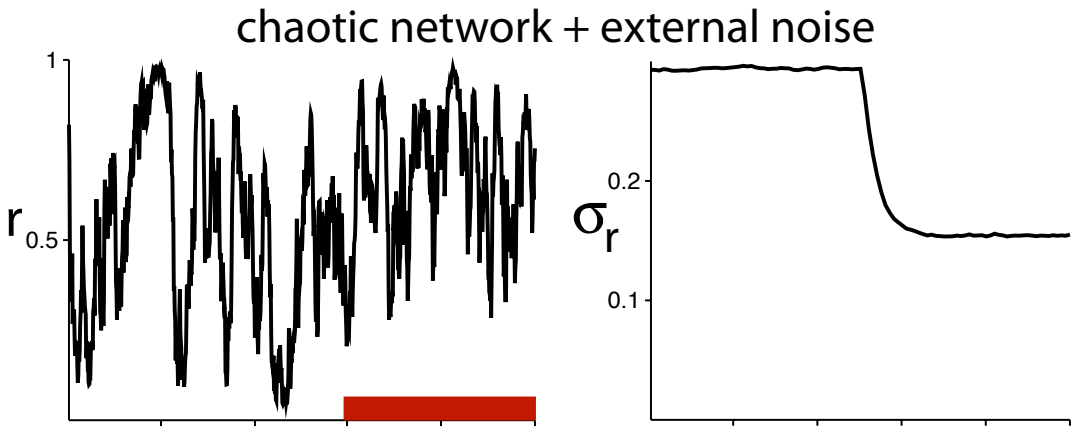
Sompolinsky, Crisanti & Sommer, 1988

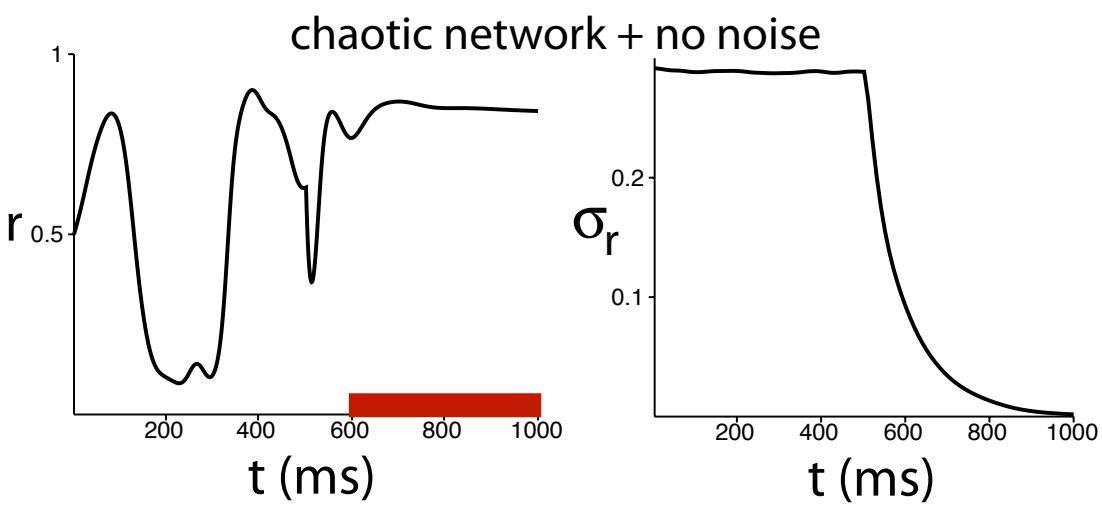
Drop in variability with constant input



Abbott, Rajan & Sompolinsky, 2010

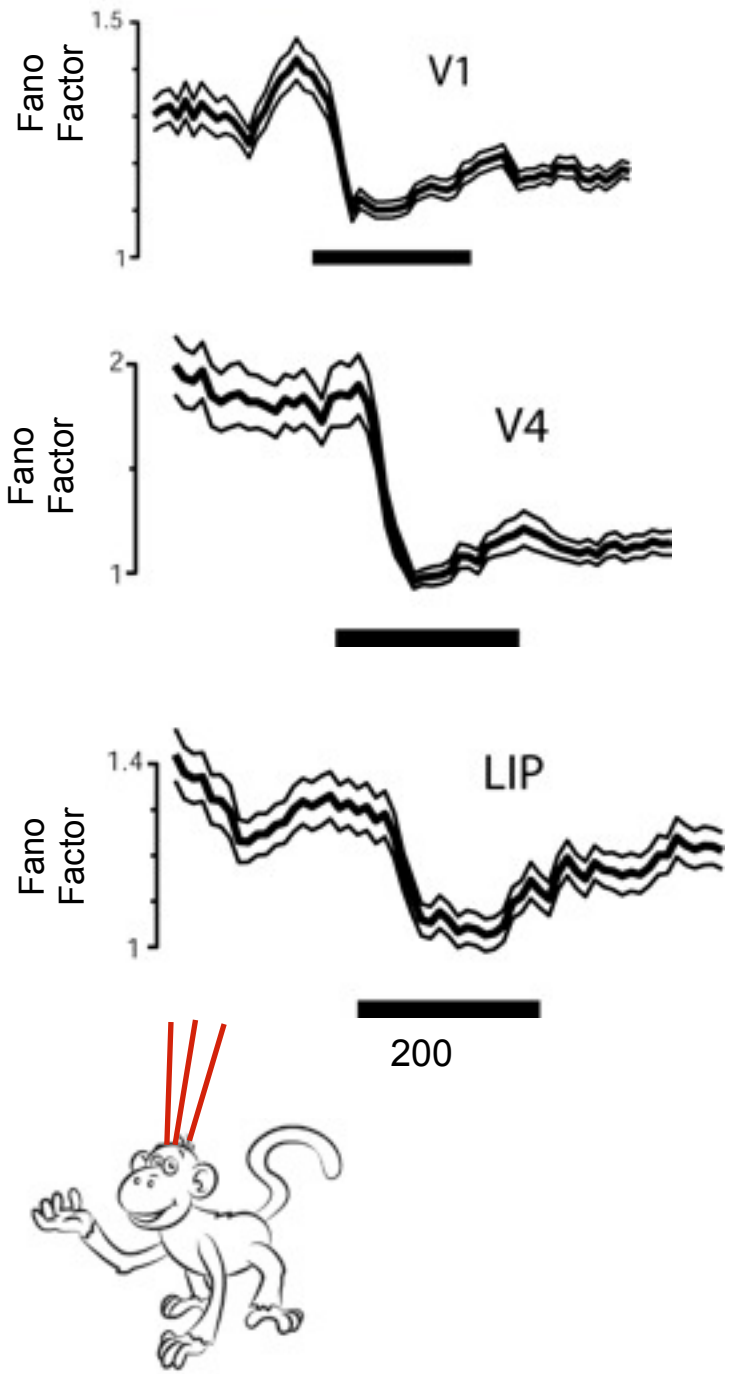
Drop in variability with constant input





Abbott, Rajan & Sompolinsky, 2010

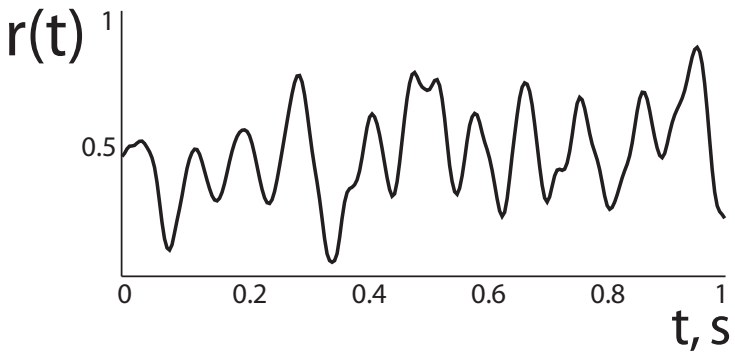
Experiments show evidence of input-dependent drop in response variability

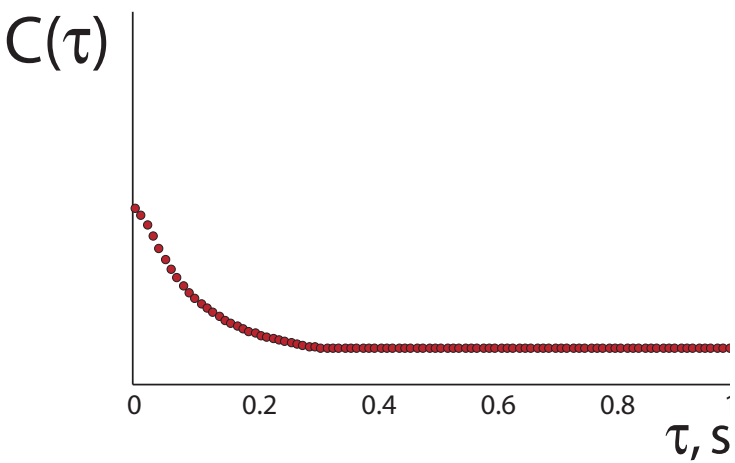


Churchland, Yu, Cunningham, Sugrue, Cohen, Corrado, Newsome, Clark, Hosseini, Scott, Bradley, Smith, Kohn, Movshon, Armstrong, Moore, Chang, Snyder, Ryu, Santhanam, Sahani & Shenoy, 2010

$$C(\tau) = \langle r(t) r(t+\tau) \rangle$$

I = 0



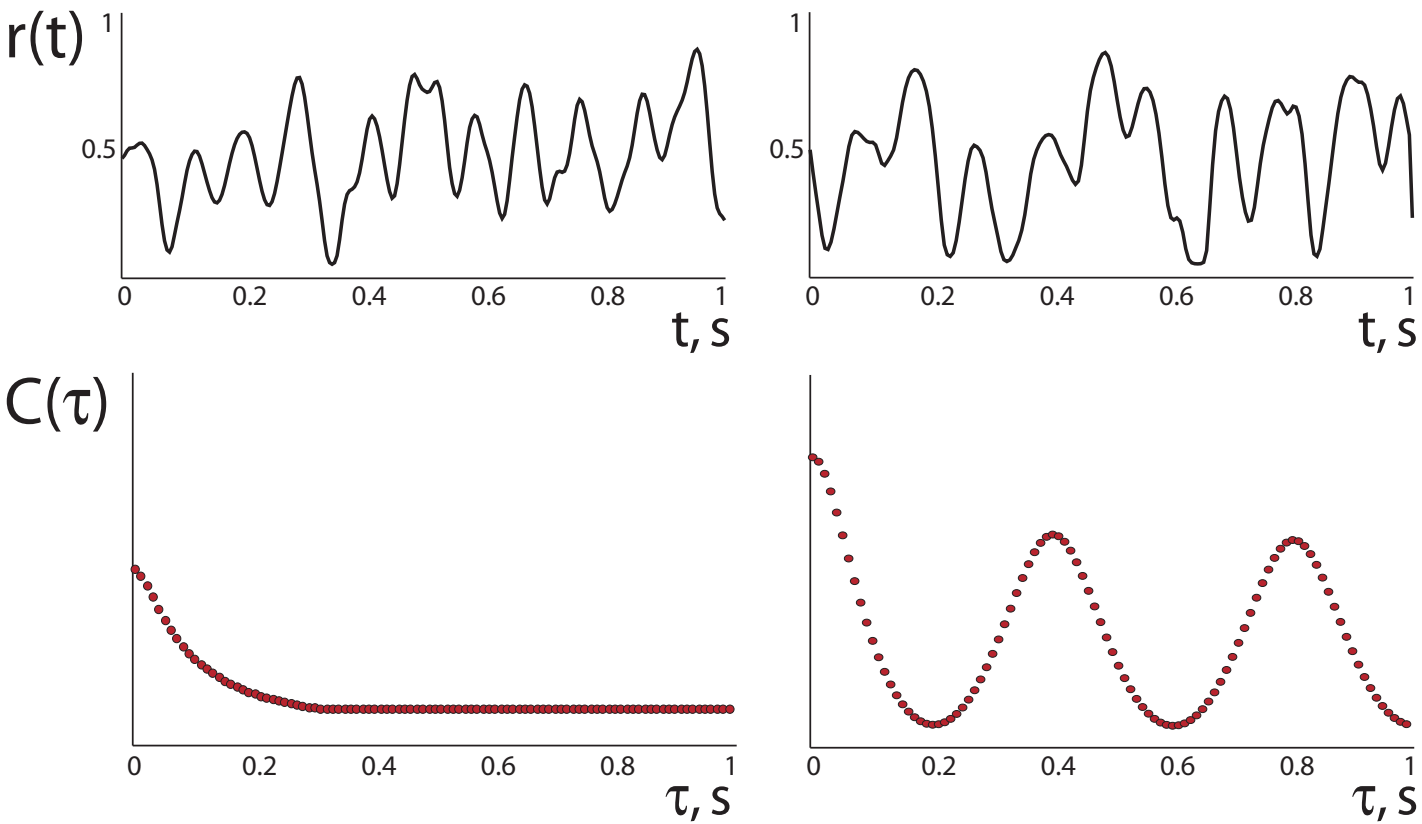


$N = 1000, g = 1.5, f = 2.5Hz$

Rajan, Abbott & Sompolinsky, 2010

$$C(\tau) = \langle r(t) r(t+\tau) \rangle$$

I = 0 **I < Icrit**



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Rajan, Abbott & Sompolinsky, 2010

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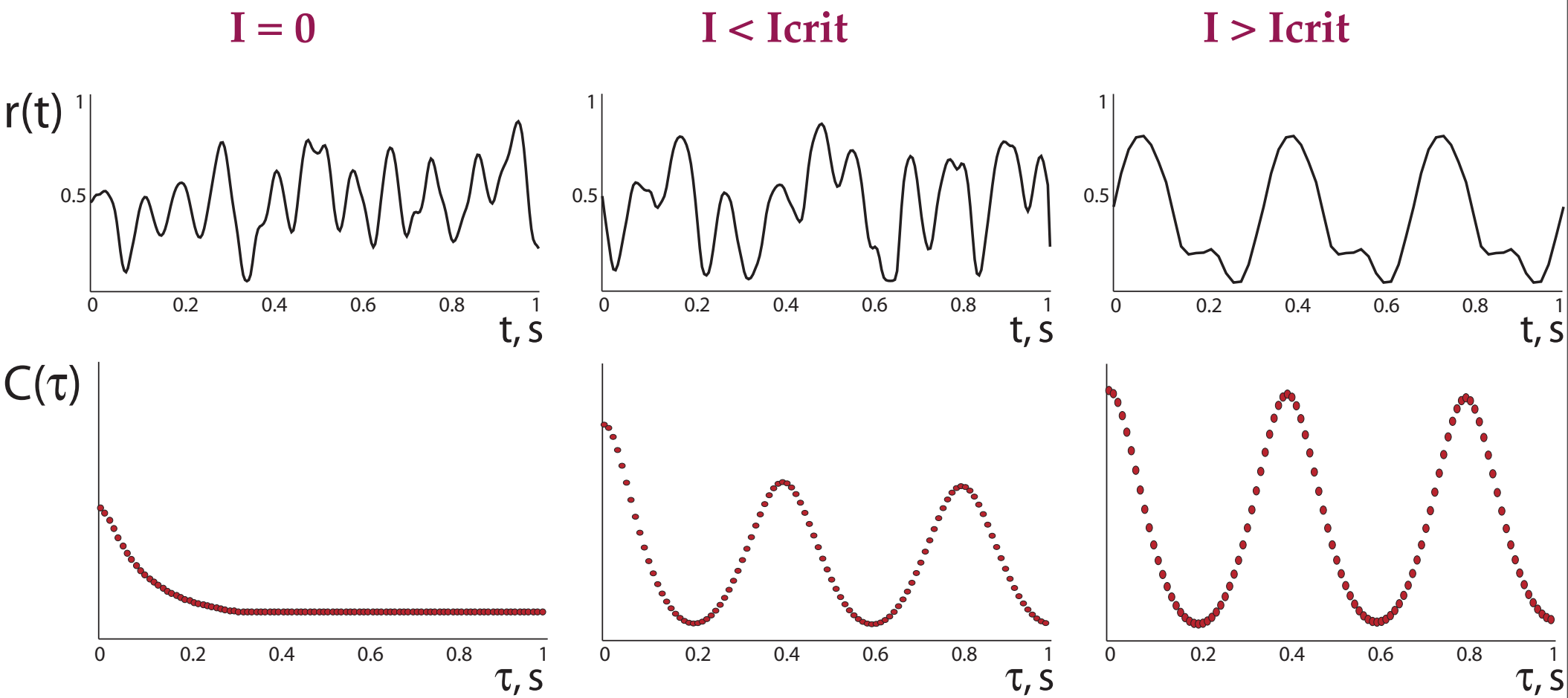

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Rajan, Abbott & Sompolinsky, 2010

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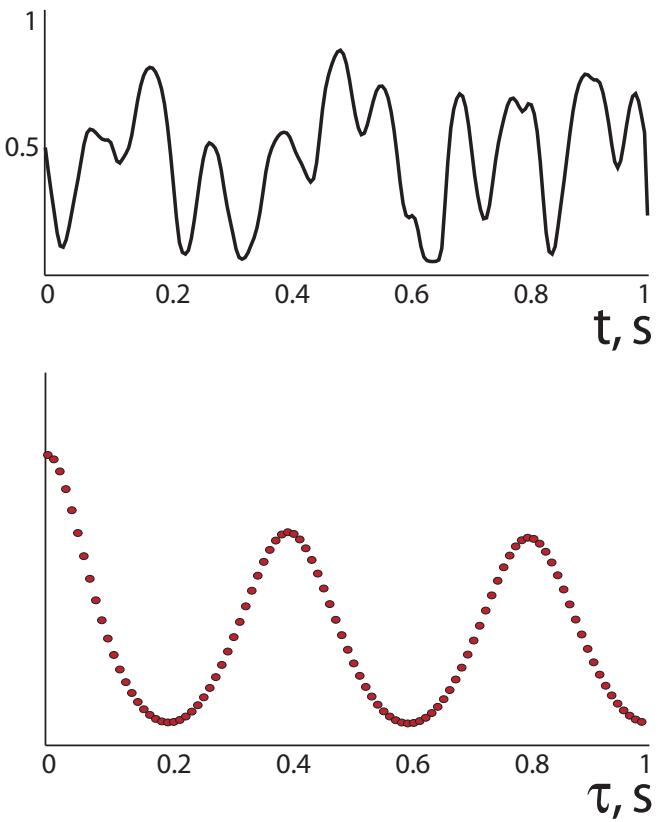
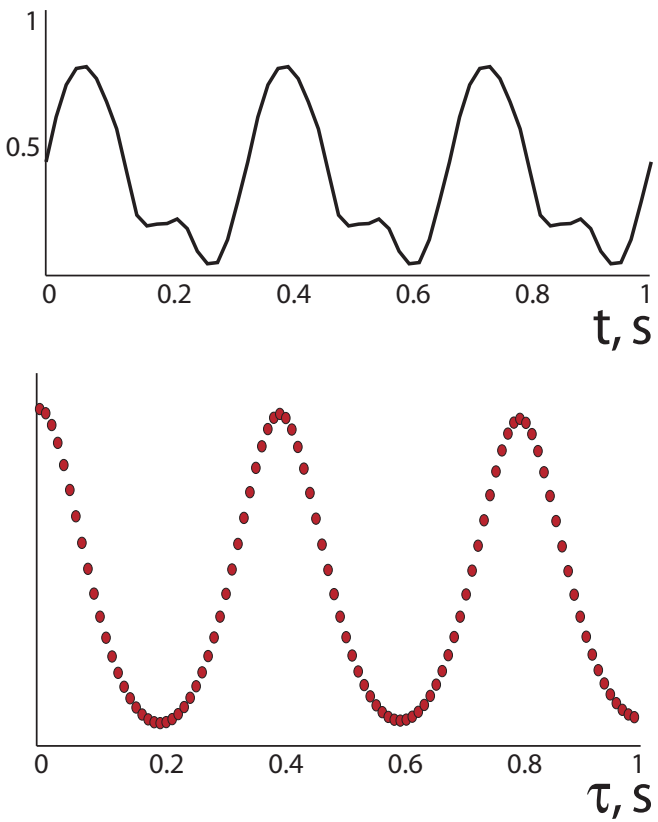


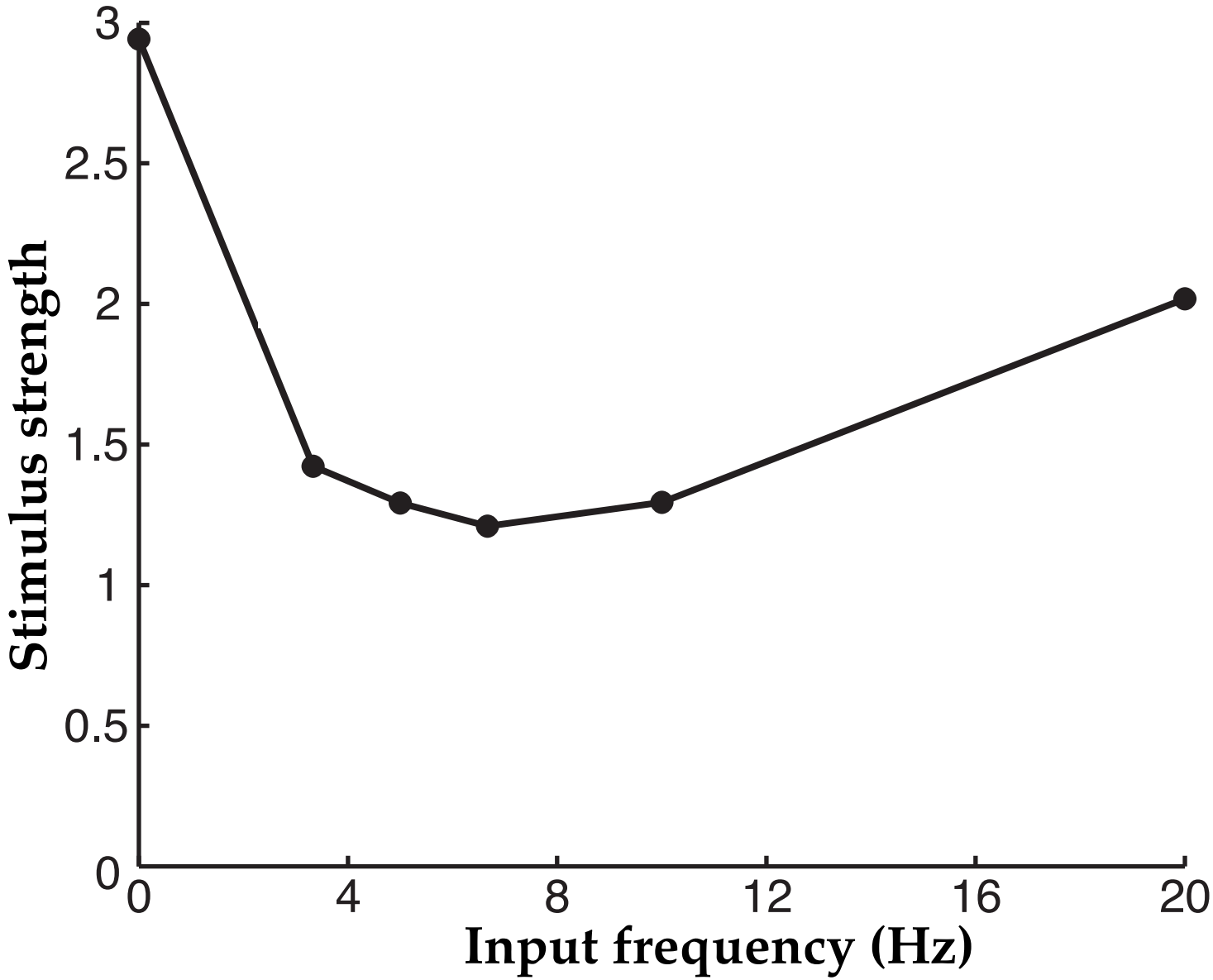
I > Icrit



$N = 1000, g = 1.5, f = 2.5Hz$

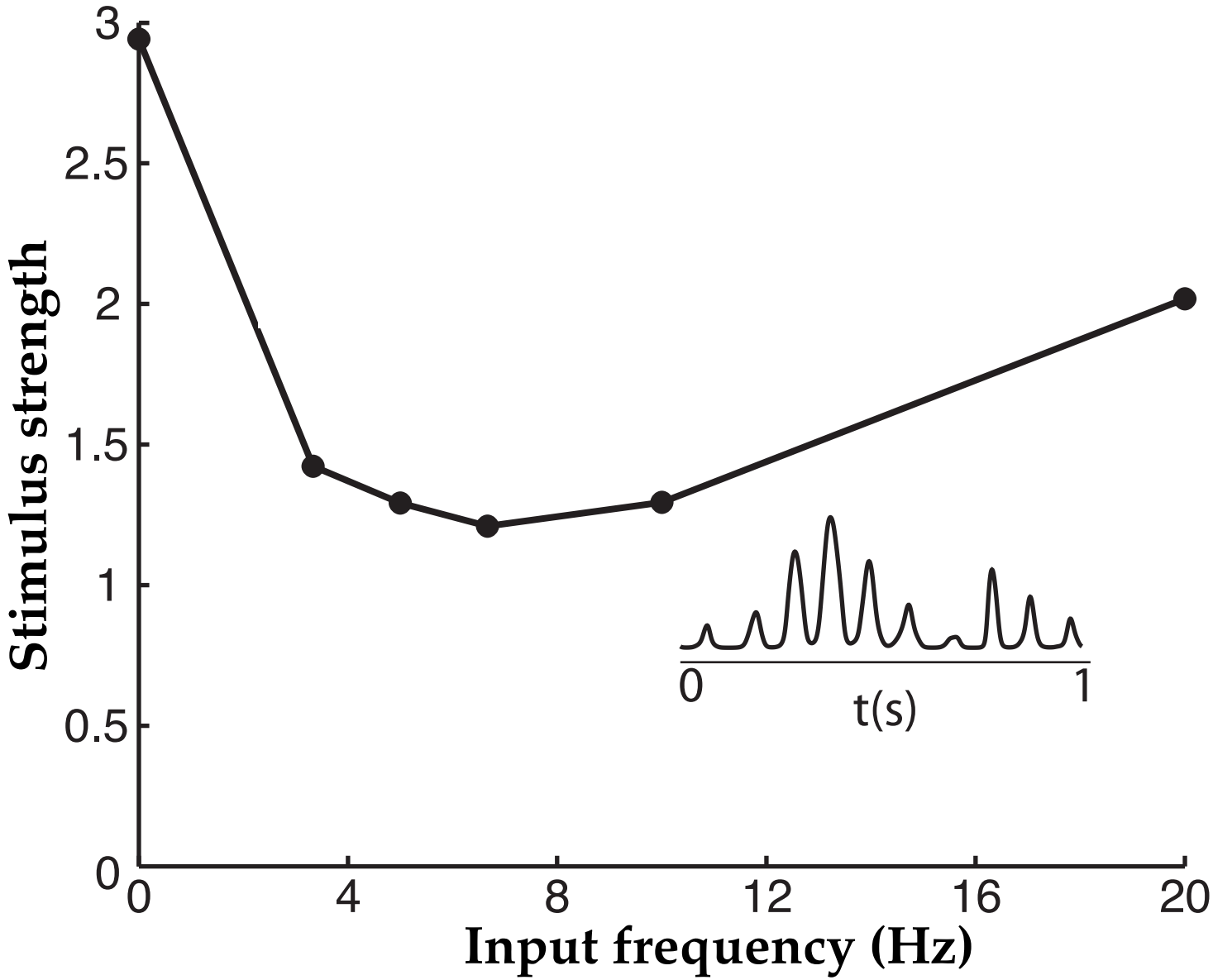
Rajan, Abbott & Sompolinsky, 2010

Phase transition between two types of dynamics



Abbott, Rajan & Sompolinsky, 2010
Rajan, Abbott & Sompolinsky, 2010 & 2011

Phase transition between two types of dynamics



Abbott, Rajan & Sompolinsky, 2010
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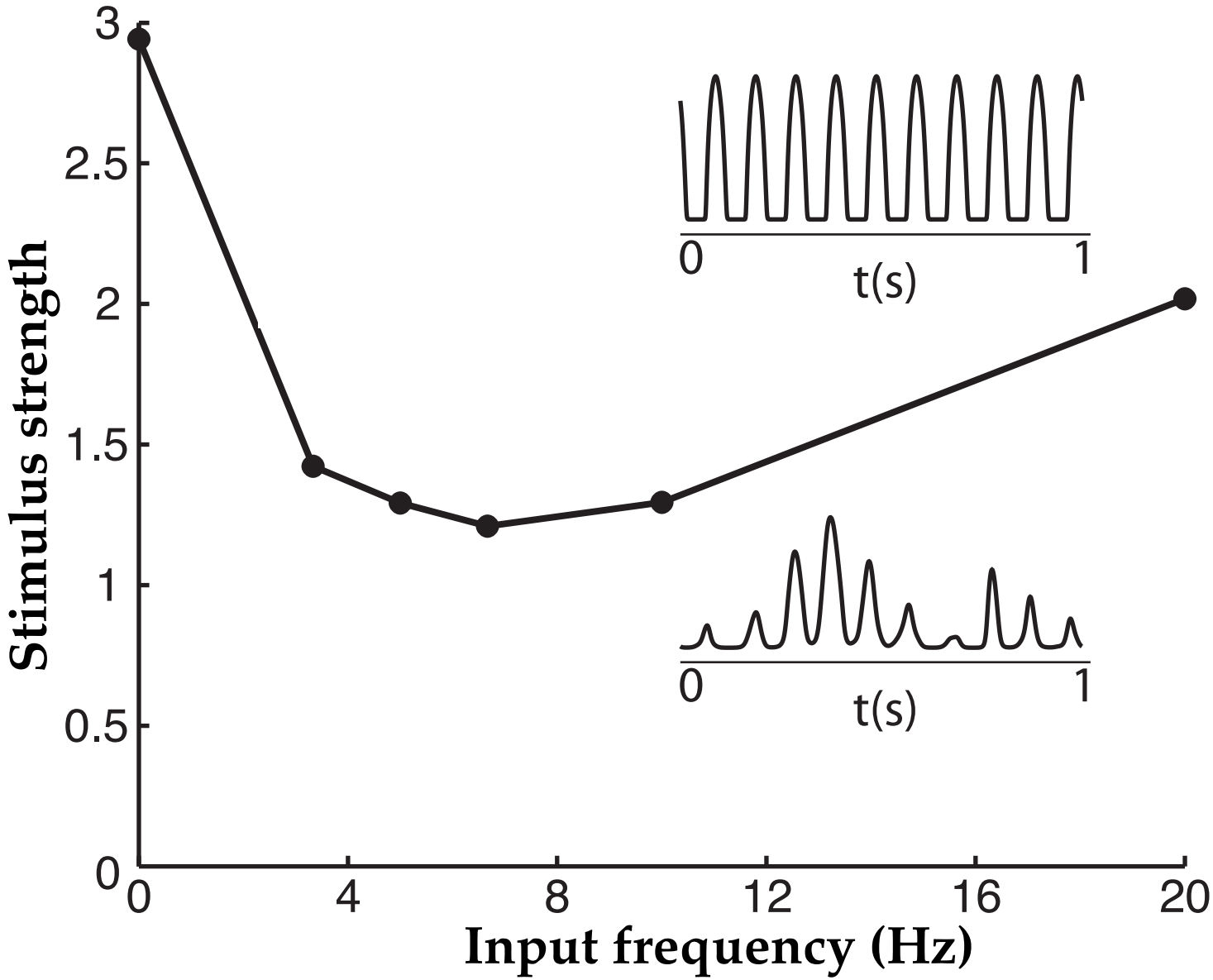

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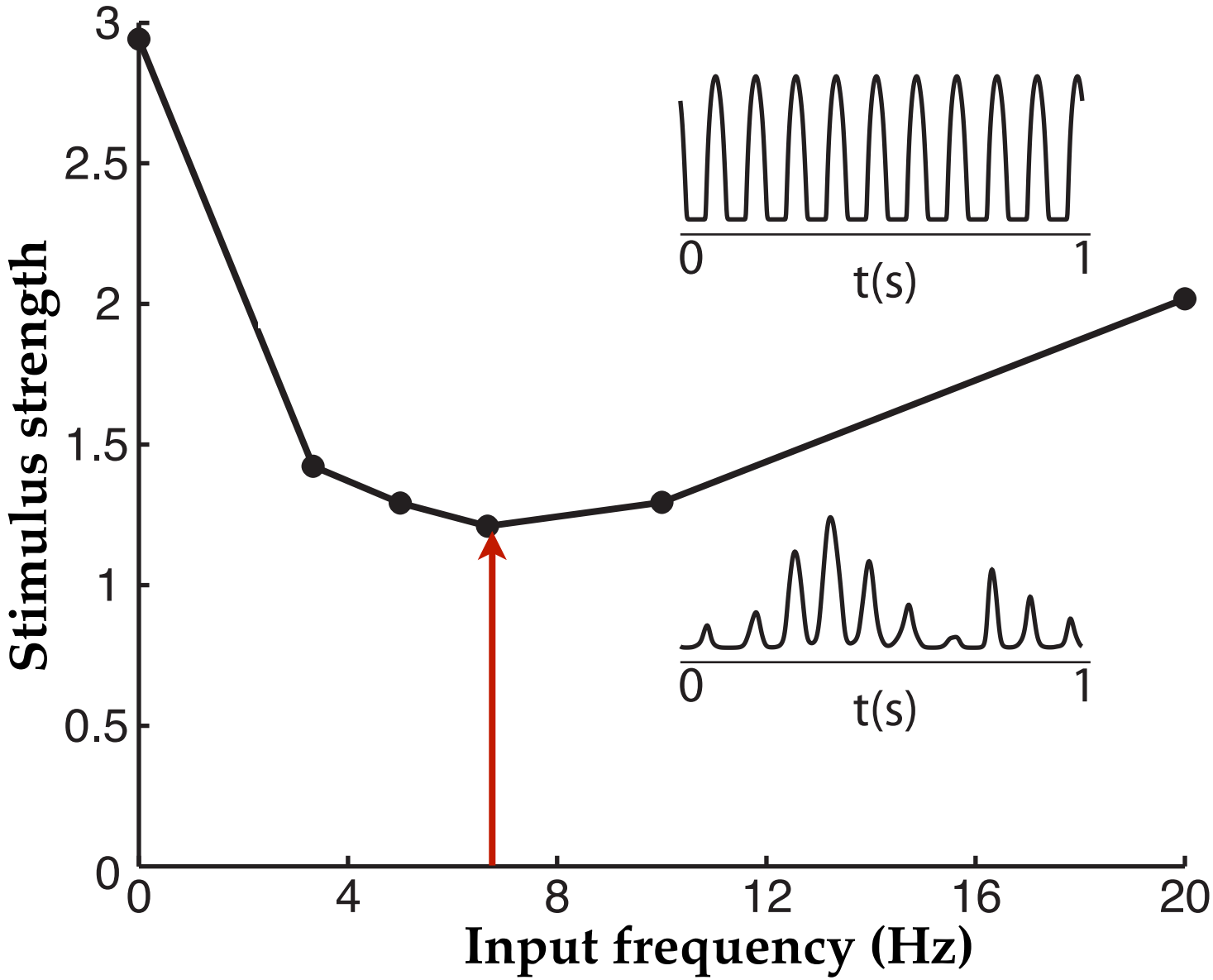
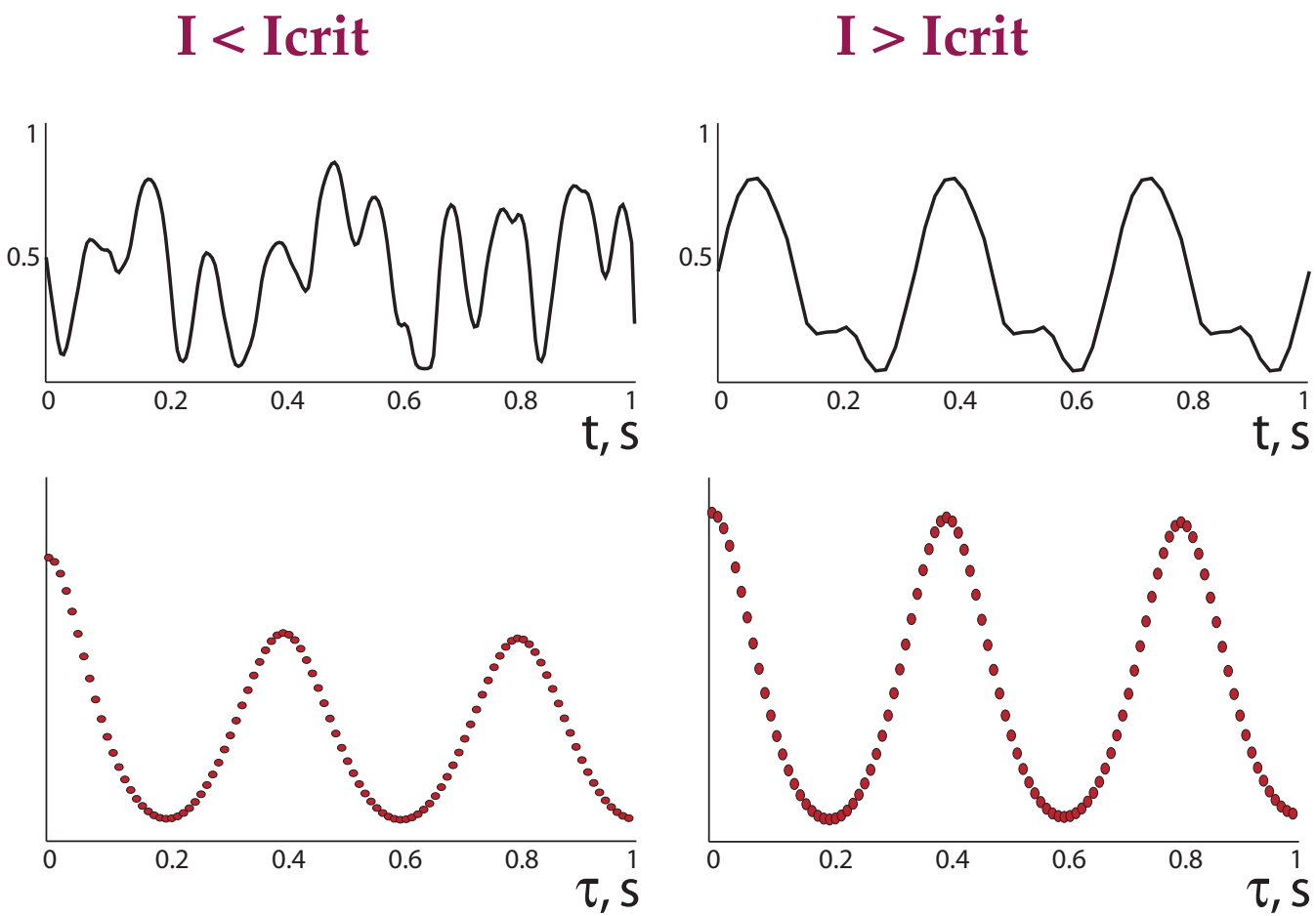


Abbott, Rajan & Sompolinsky, 2010
Rajan, Abbott & Sompolinsky, 2010 & 2011

Definition of signal and noise



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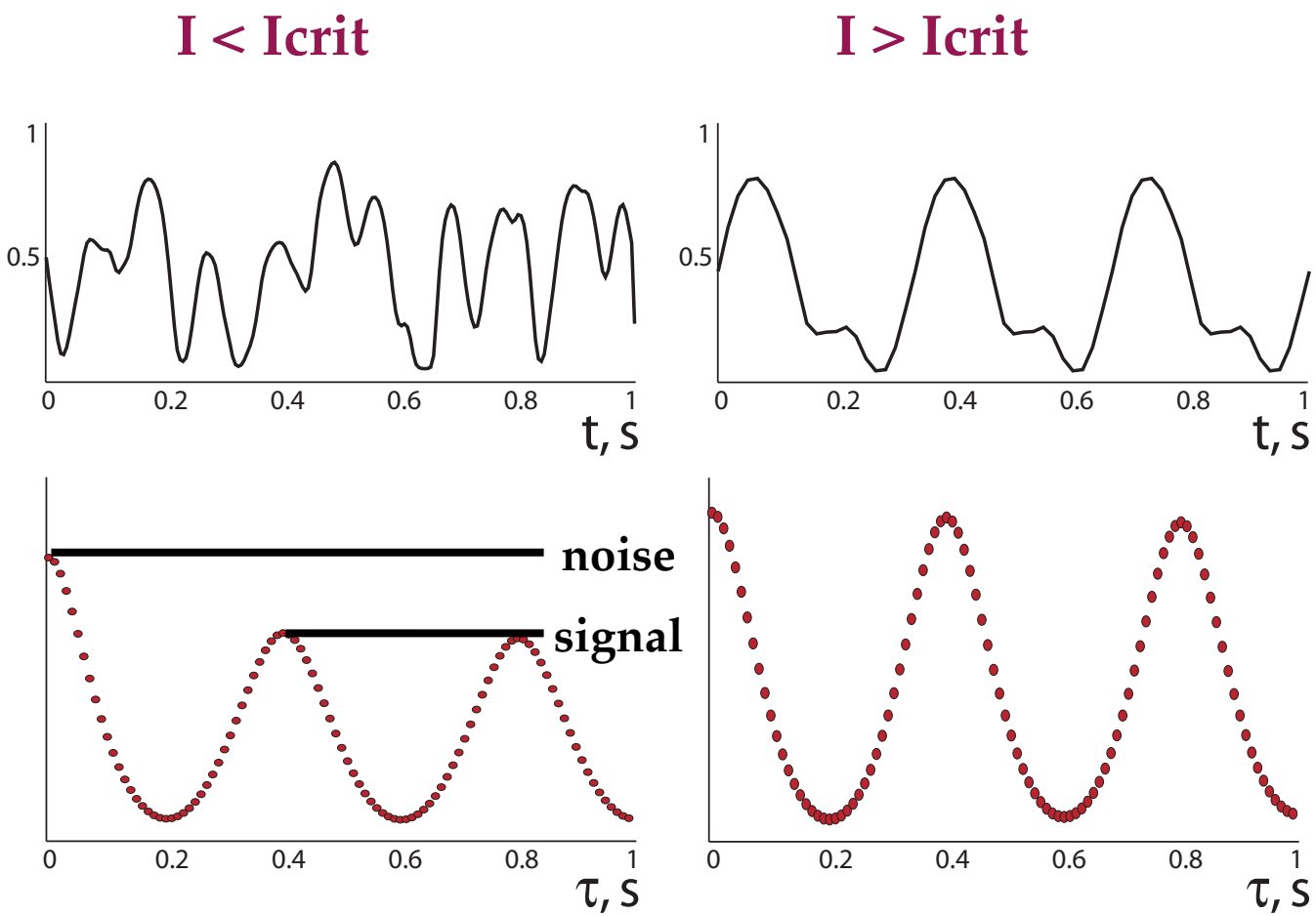
Rajan, Abbott & Sompolinsky, 2010

Definition of signal and noise



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Rajan, Abbott & Sompolinsky, 2010

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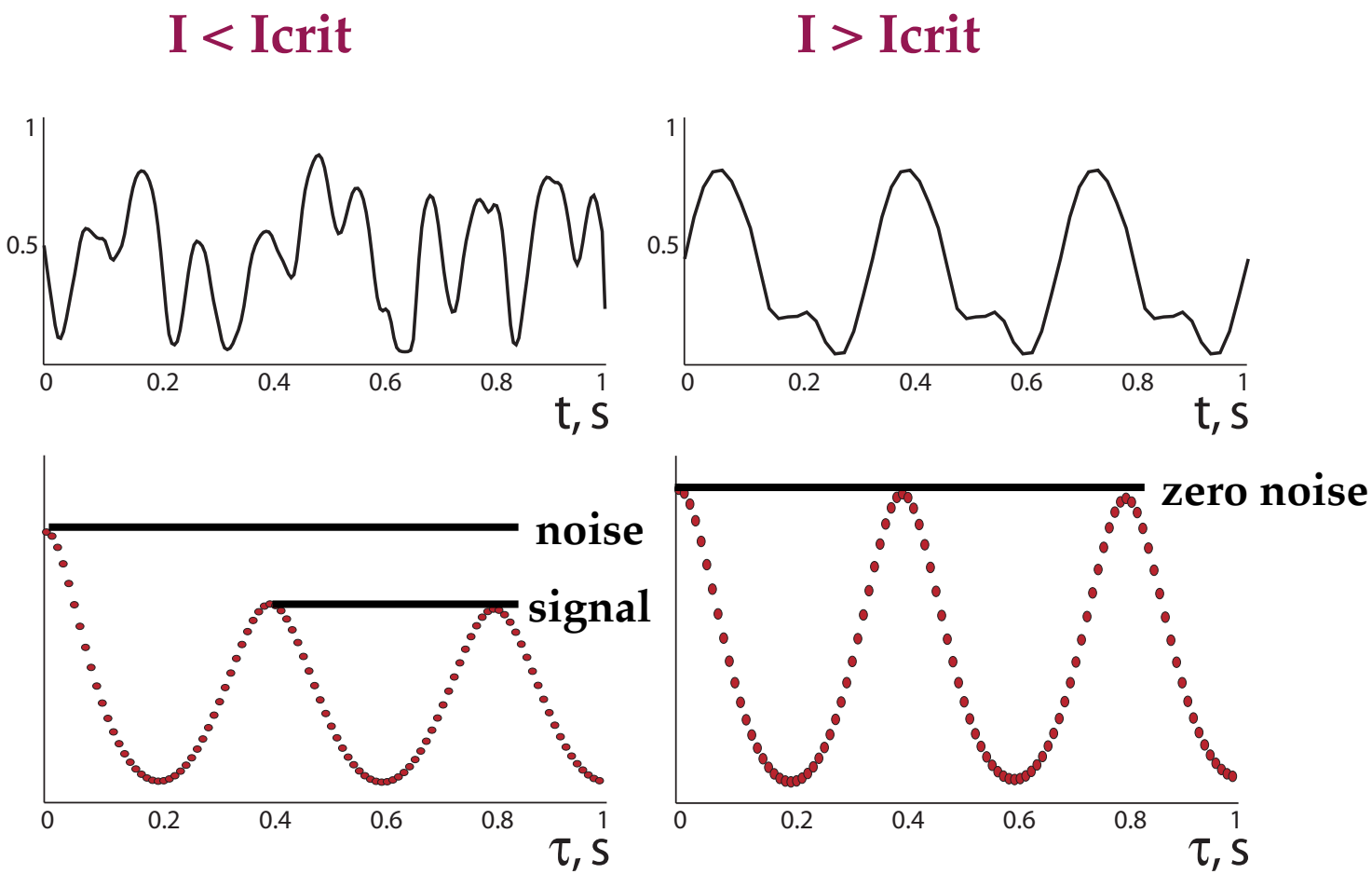
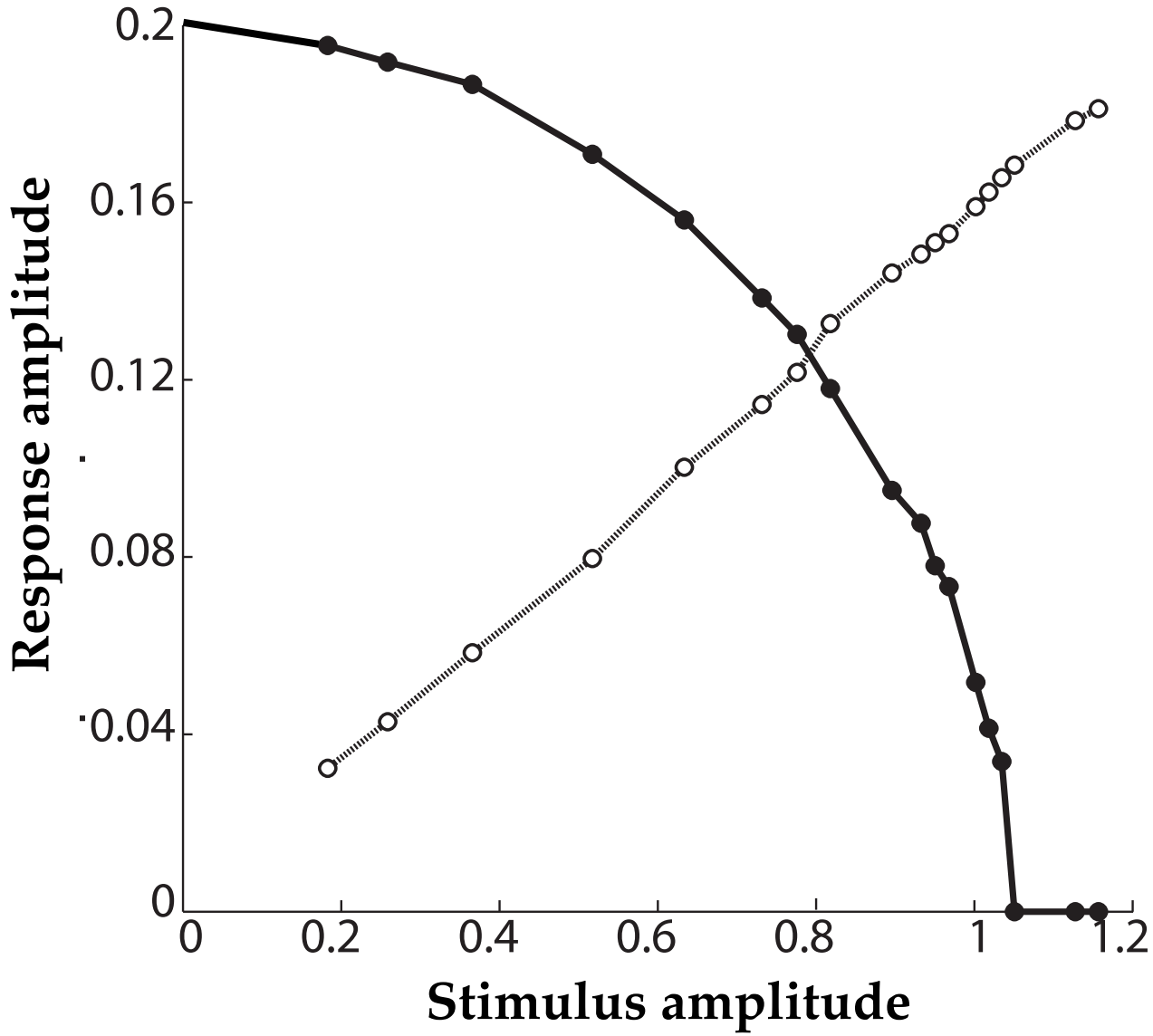


$N = 1000, g = 1.5, f = 2.5Hz$

Rajan, Abbott & Sompolinsky, 2010

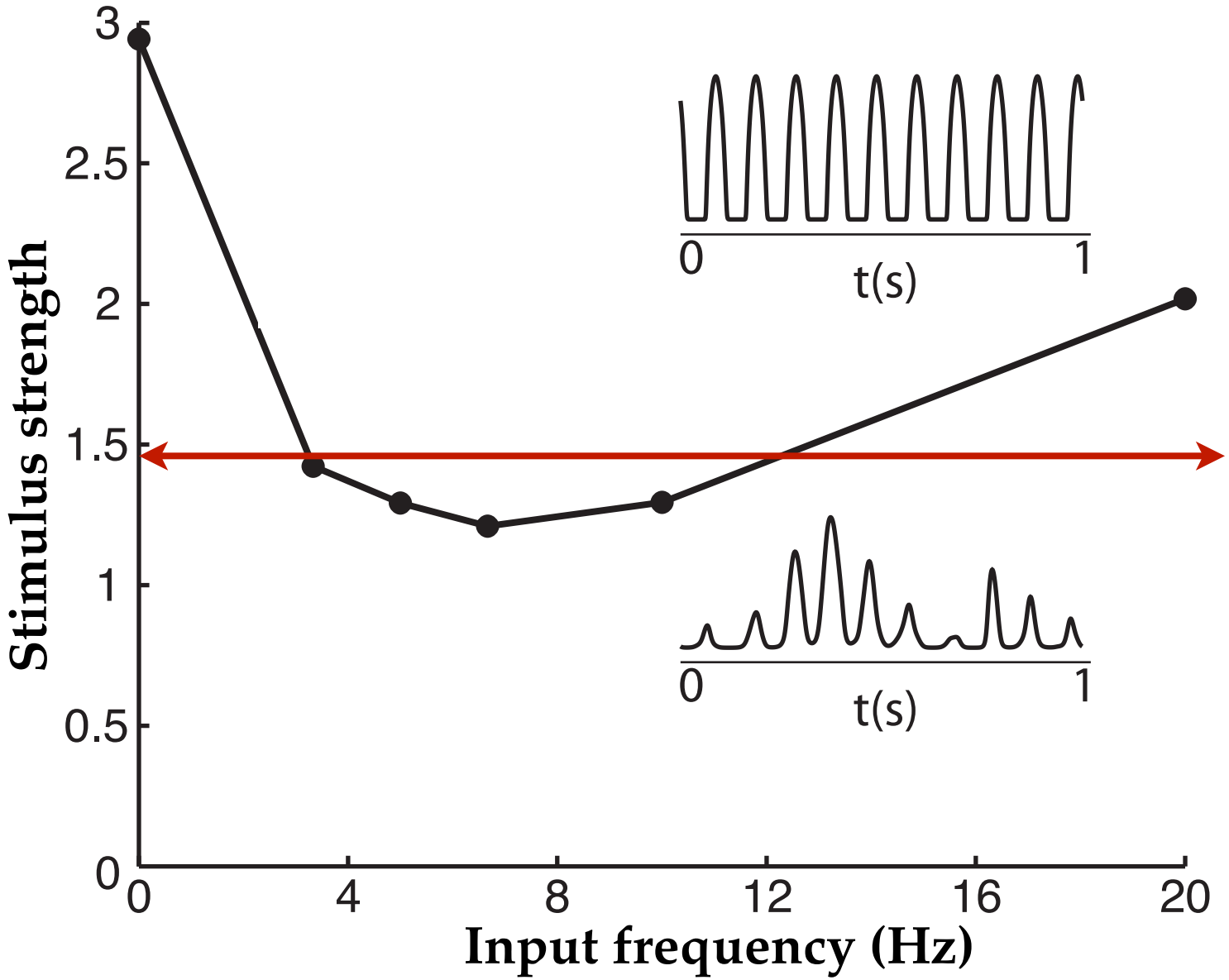
Noise drops to 0 as a function of stimulus strength



○ signal

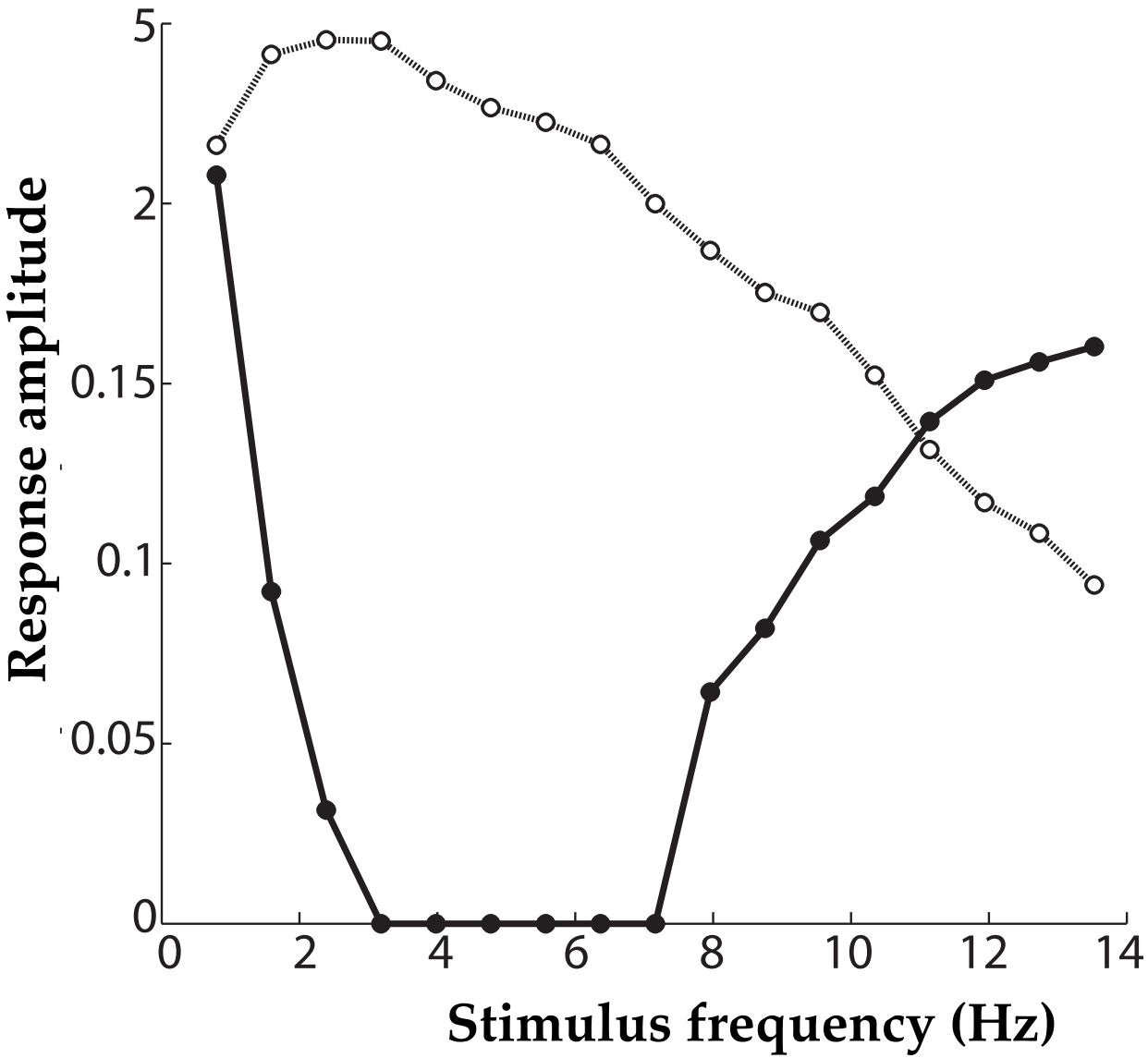
● noise

Phase transition between two types of dynamics



Abbott, Rajan & Sompolinsky, 2010
Rajan, Abbott & Sompolinsky, 2010 & 2011

Noise has a more interesting dependence on frequency



○ signal

● noise

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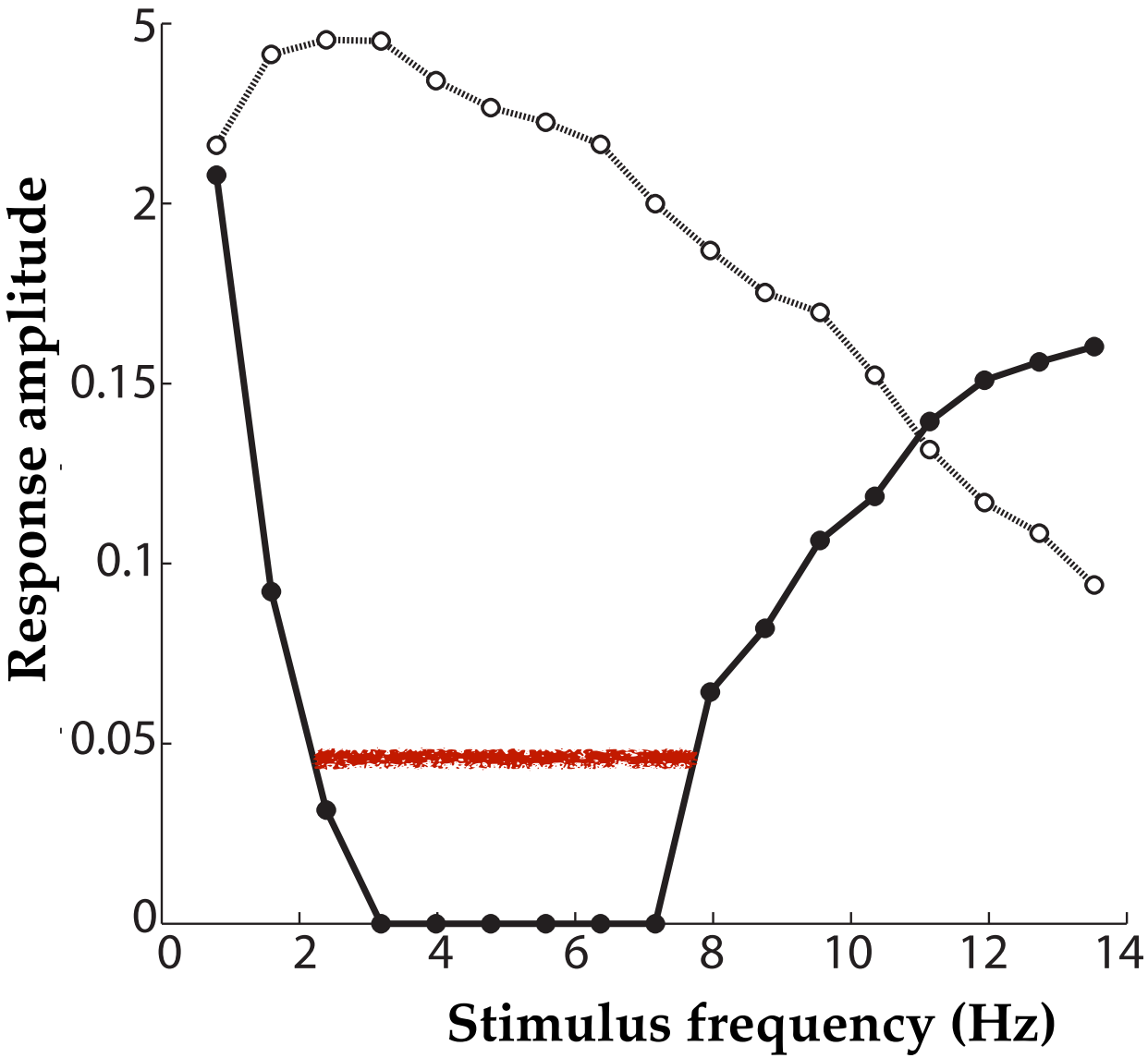
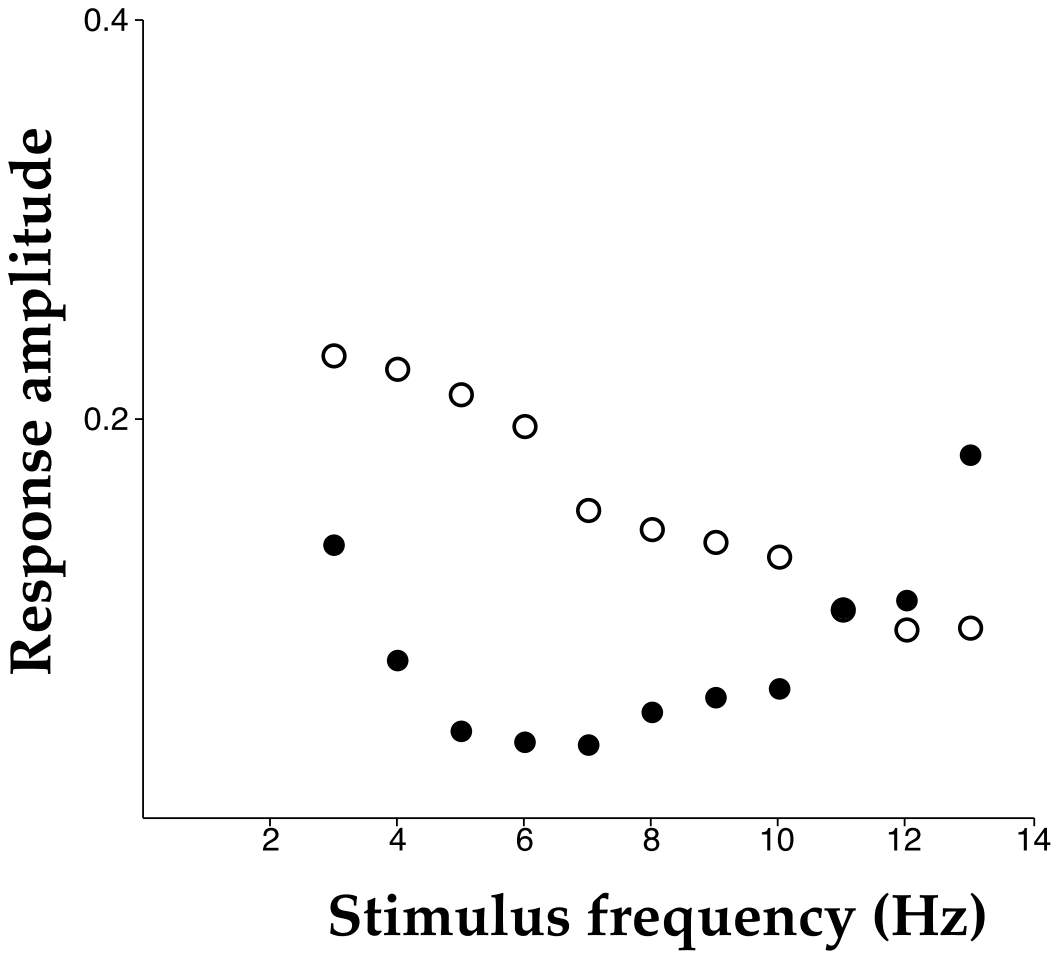


○ signal

● noise

What of the additional stochastic noise sources in real circuits?



○ signal

● noise

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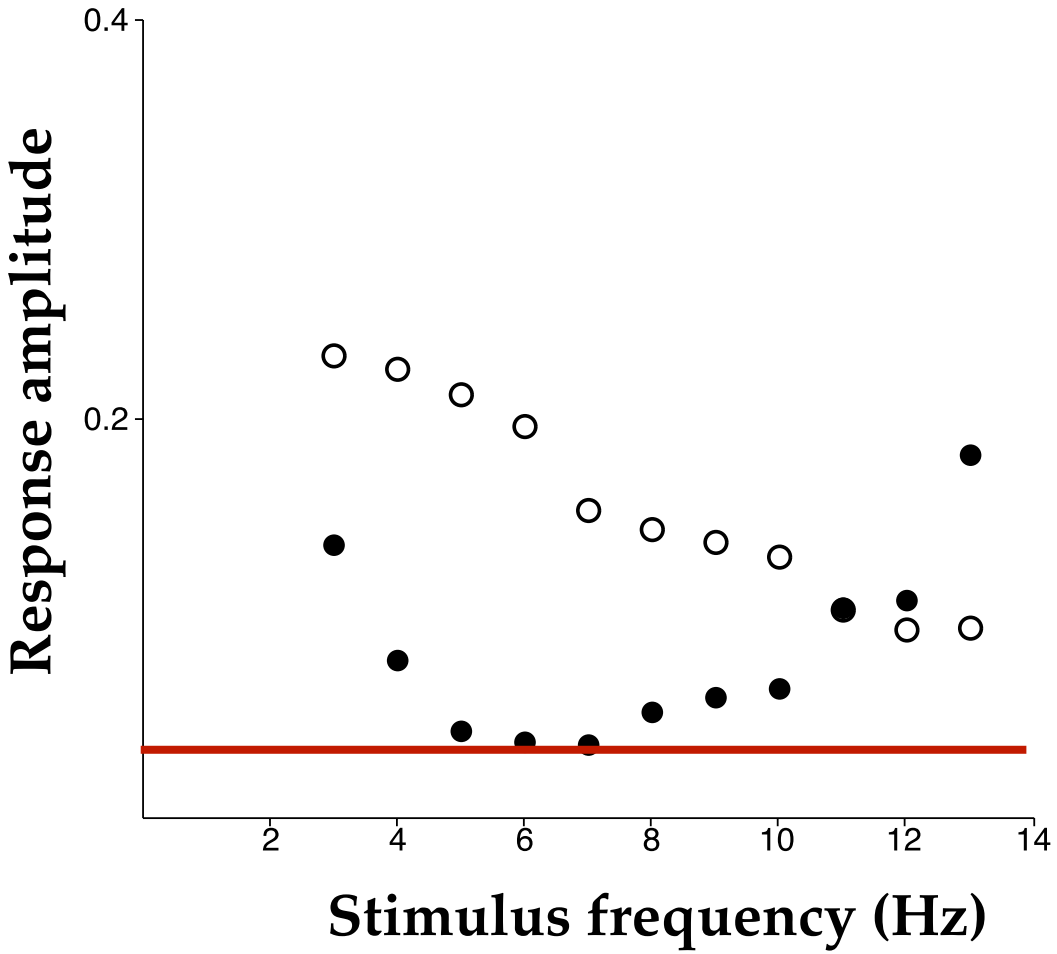

○ signal

● noise

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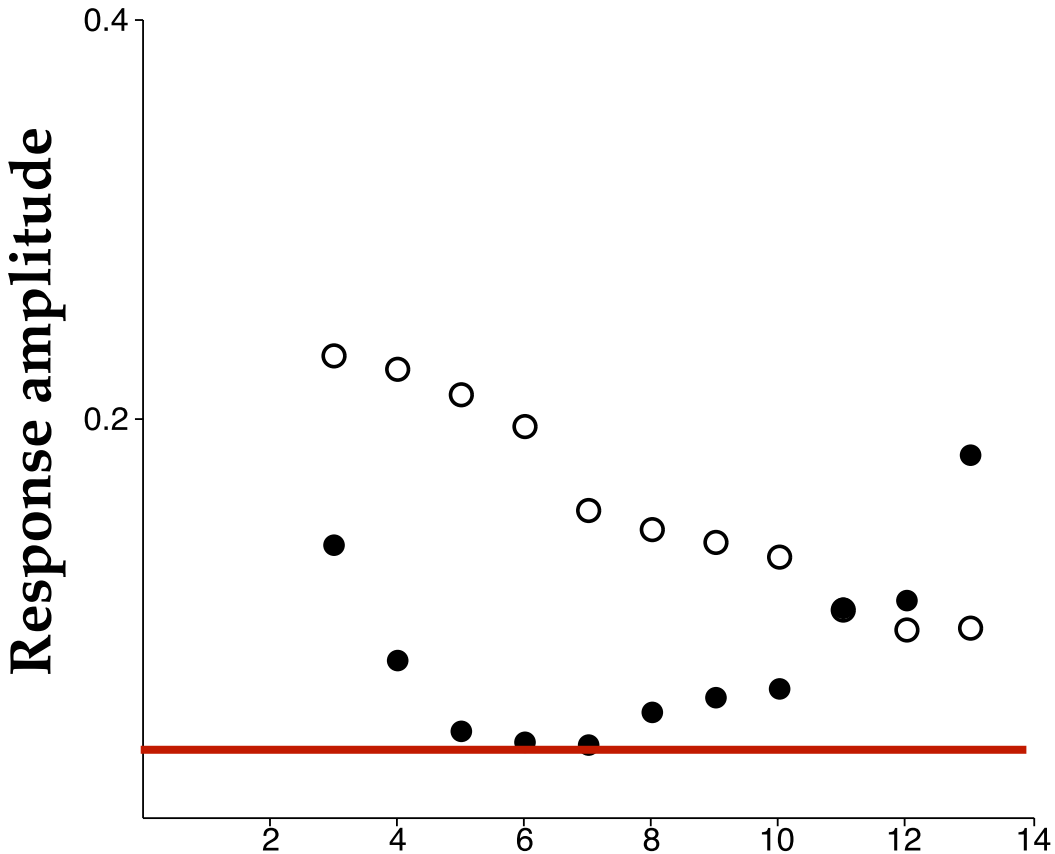

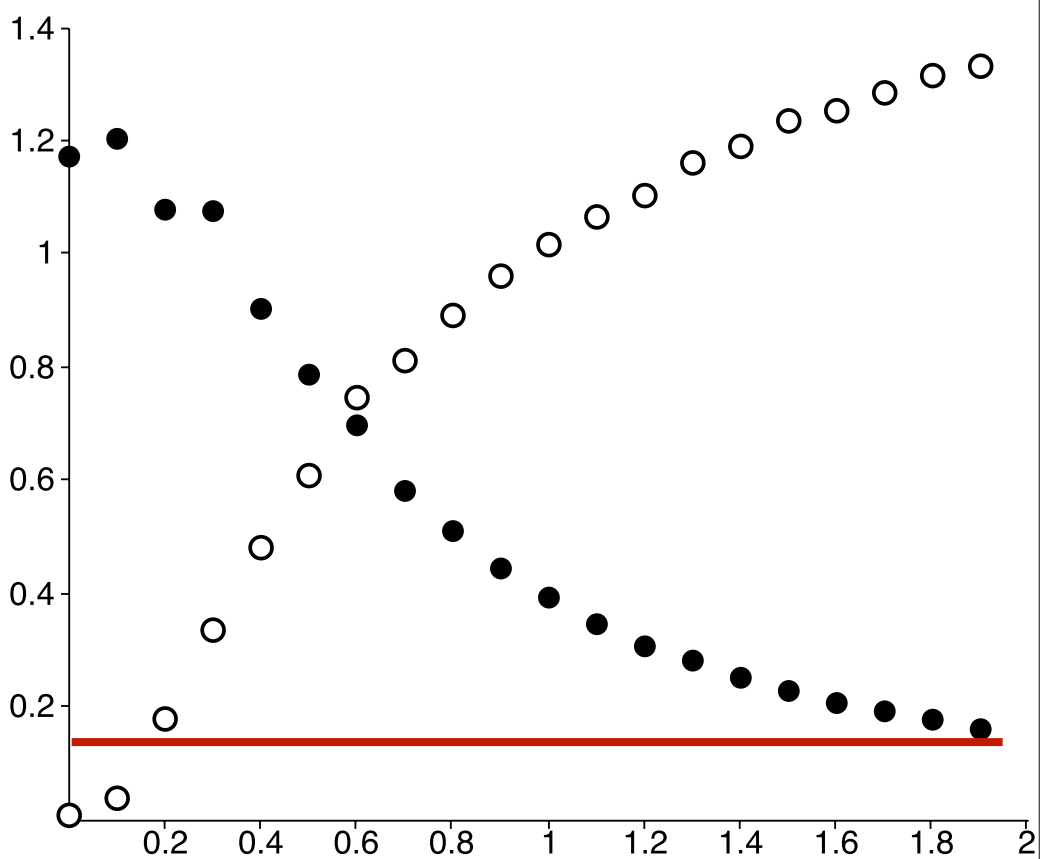

signal

noise

Conclusions

External stimulus actively suppresses intrinsic noise in chaotic networks

This suppression is most effective at intermediate frequencies

Thank you

L F Abbott, Columbia University
Haim Sompolinsky, Hebrew University & Harvard University

and for insights, advice and experimental direction

Mark Churchland & Krishna Shenoy, Stanford University

Support : Swartz Foundation and the Lewis-Sigler Institute

Spontaneous activity starts at 1 and is chaotic

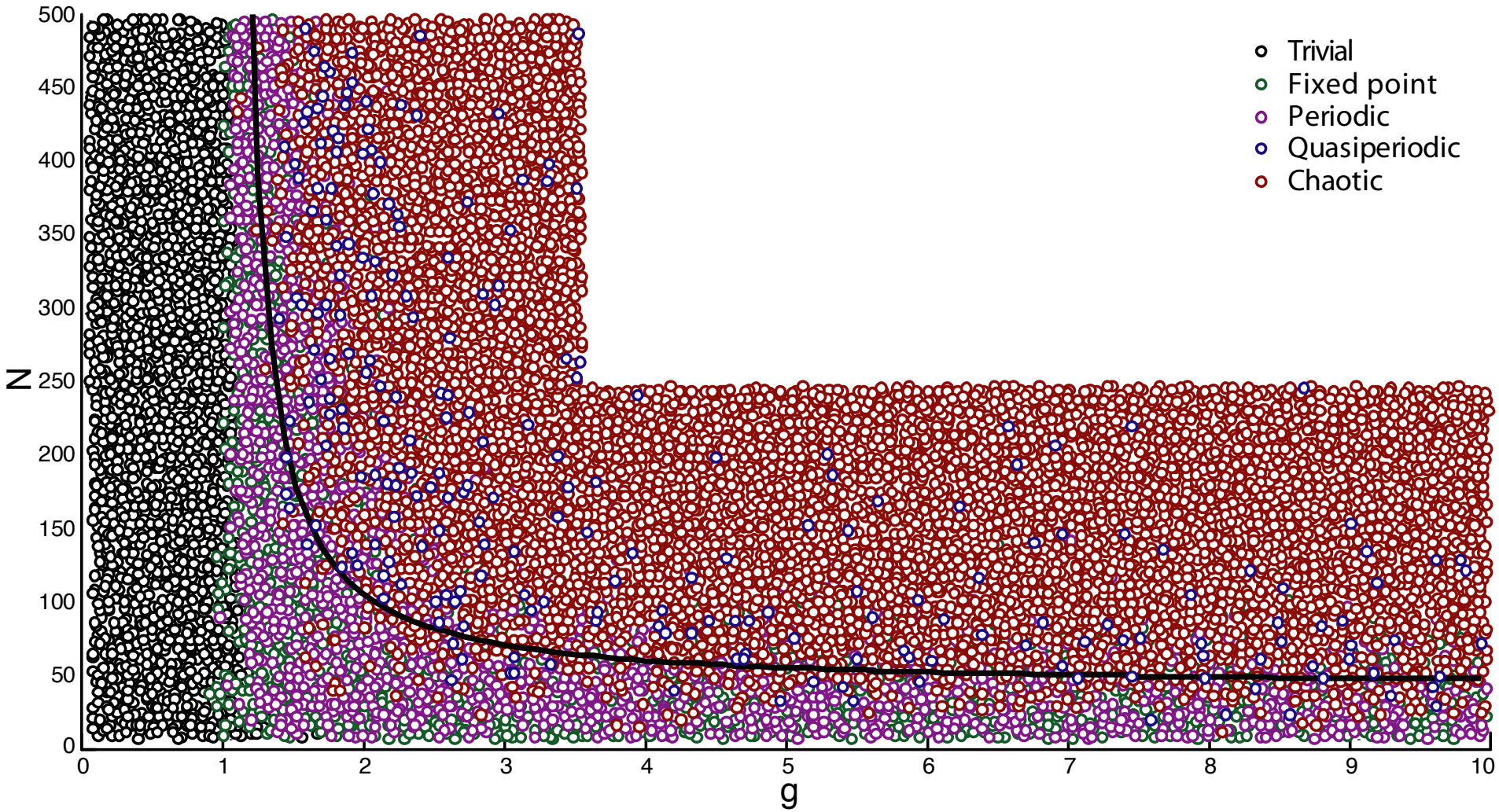

Figure: Avi Ziskind

Sompolinsky, Crisanti & Sommers, 1988