神經與行為模型建構
(Neural & Behavioral Modeling)

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終於來到最後一堂課
!!!

1 Spiking Neuron

2 Spiking Neurons

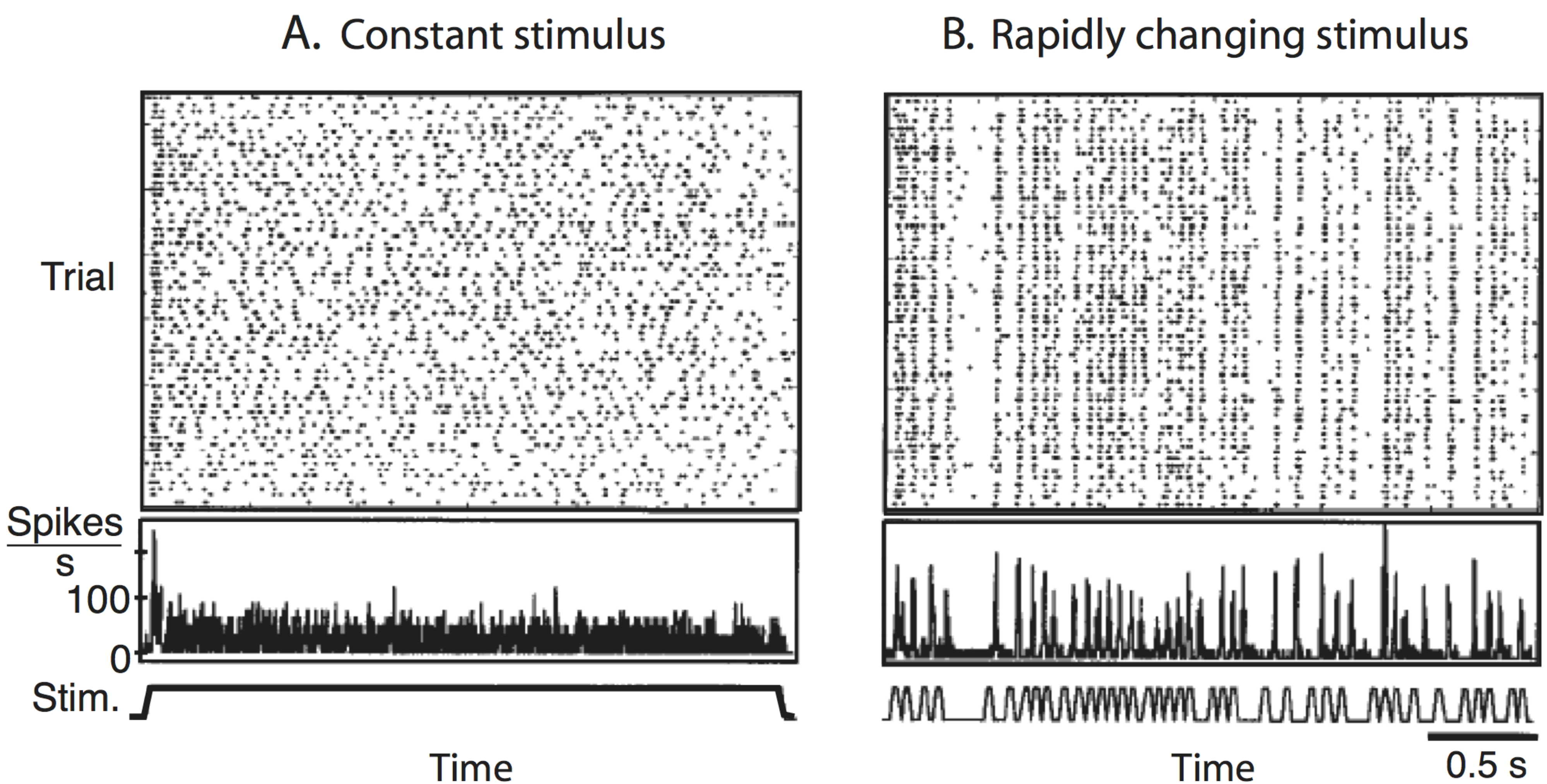
N Spiking Neurons

Rate-based Models

Closing Remarks

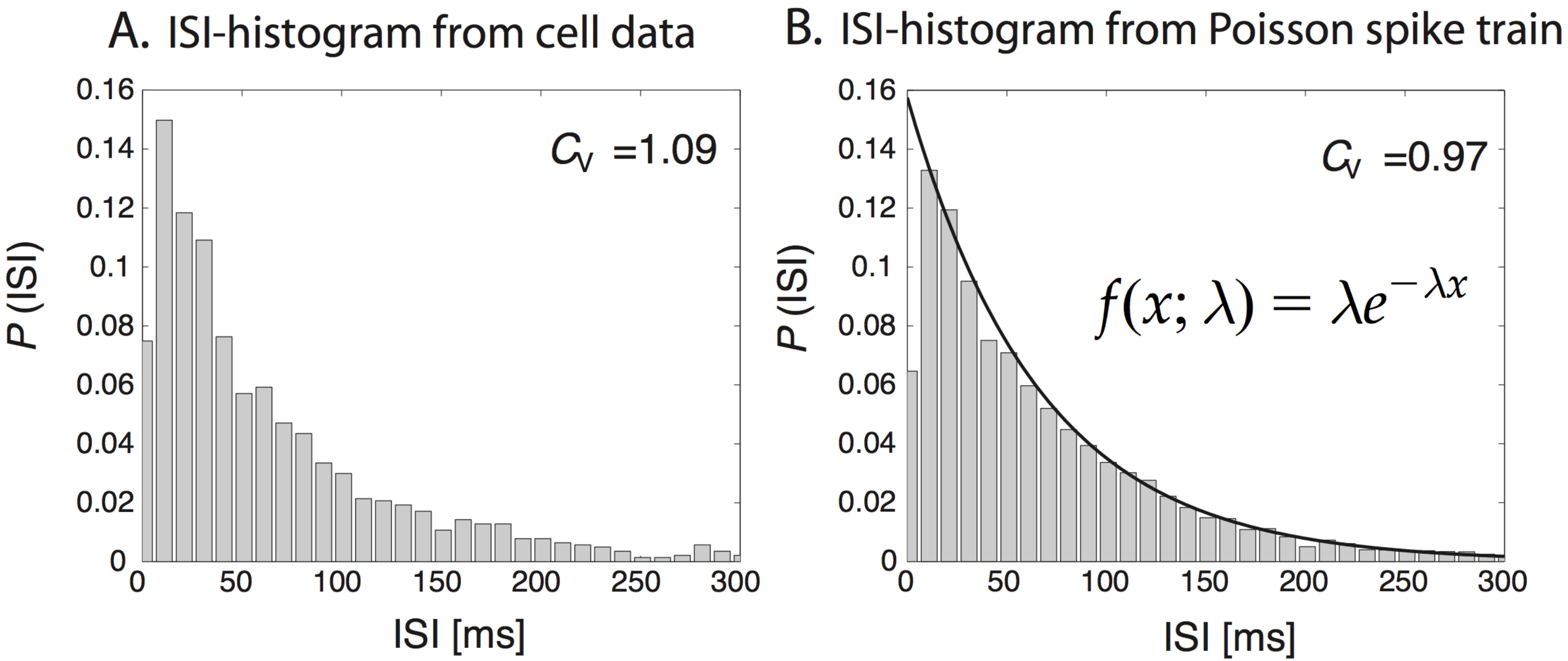
Spiking Variability (1/3)

神經元的反應時間不固定



Spiking Variability (2/3)

可看 interspike intervals (ISIs) 的變異係數 $C_V=\sigma/\mu$



ISIs 可用指數分配來描述：$C_V=\sigma/\mu=1$

# of spikes 可用Poisson分配來描述

Spiking Variability (3/3)

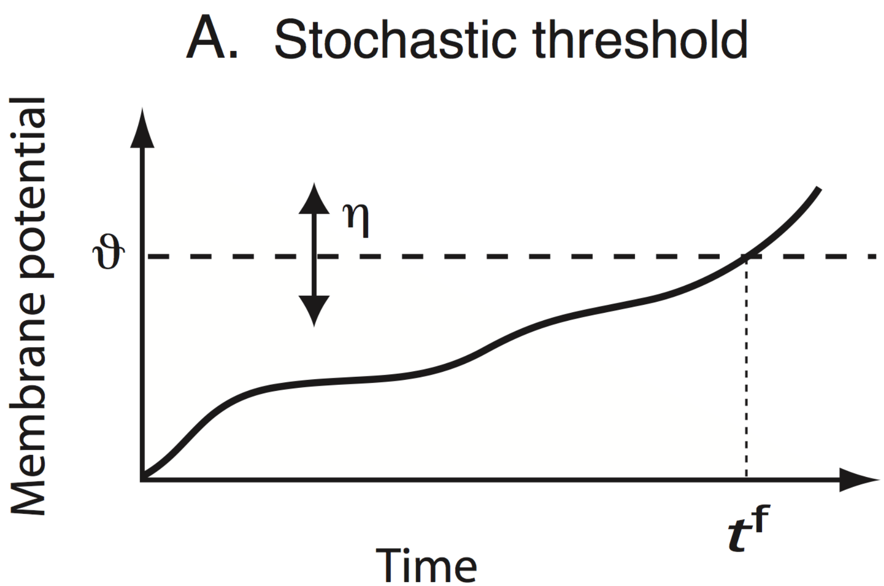
以下是指數分配 spike train 的 WHAT model

```
lmbda=20  # Firing rate [Hz]
Ns=1000  # of ISIs
isi=np.random.exponential(1/lmbda,1000)
#isi=np.log(1-np.random.rand(Ns))/lmbda
hist(isi,50); np.mean(isi)  # mean ISI [s]
cv=np.std(isi)/np.mean(isi)
```

什麼是產生指數分配 spike train 的 HOW model?

本週作業 (1/2)

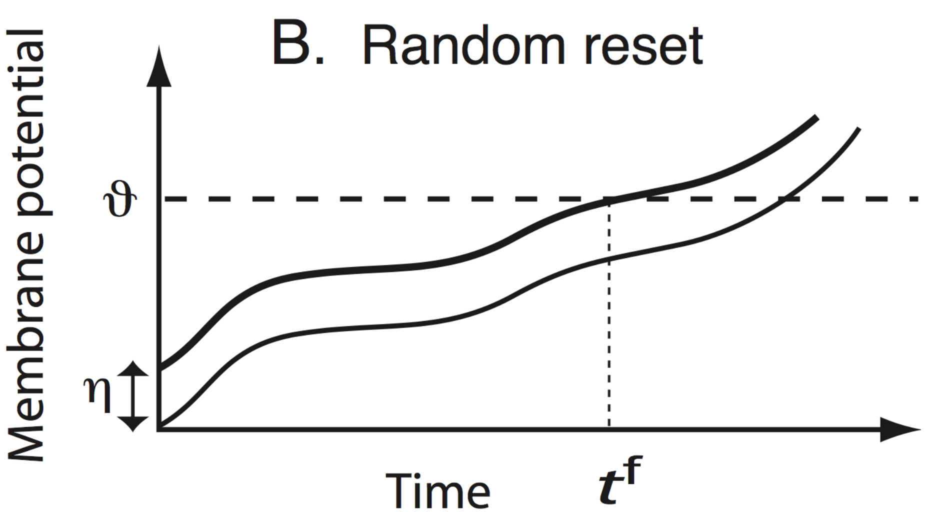
探索 IF 模型的三種隨機性可否產生 Poisson spikes?

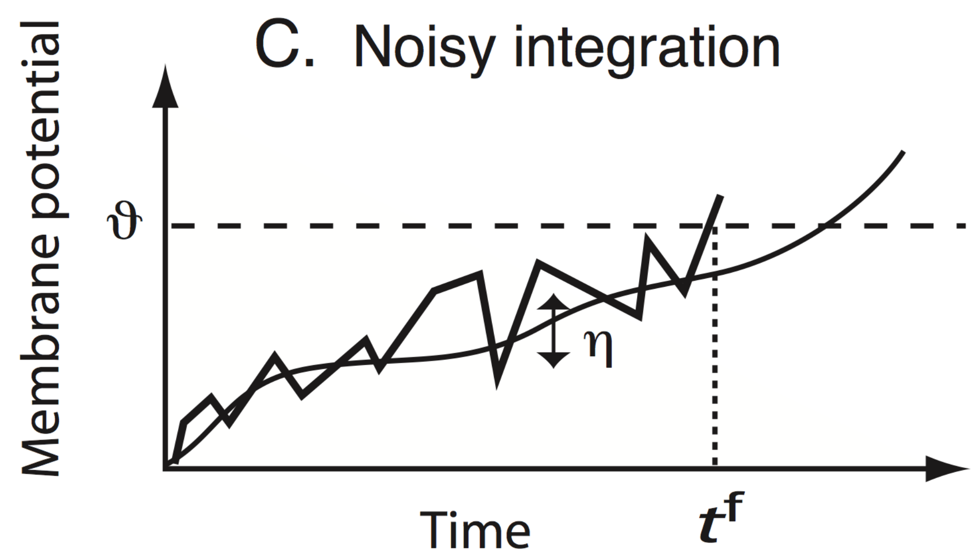


$$\vartheta \to \vartheta + \eta^{(1)}(t)$$

$$u^{\mathrm{res}} \to u^{\mathrm{res}} + \eta^{(2)}(t)$$

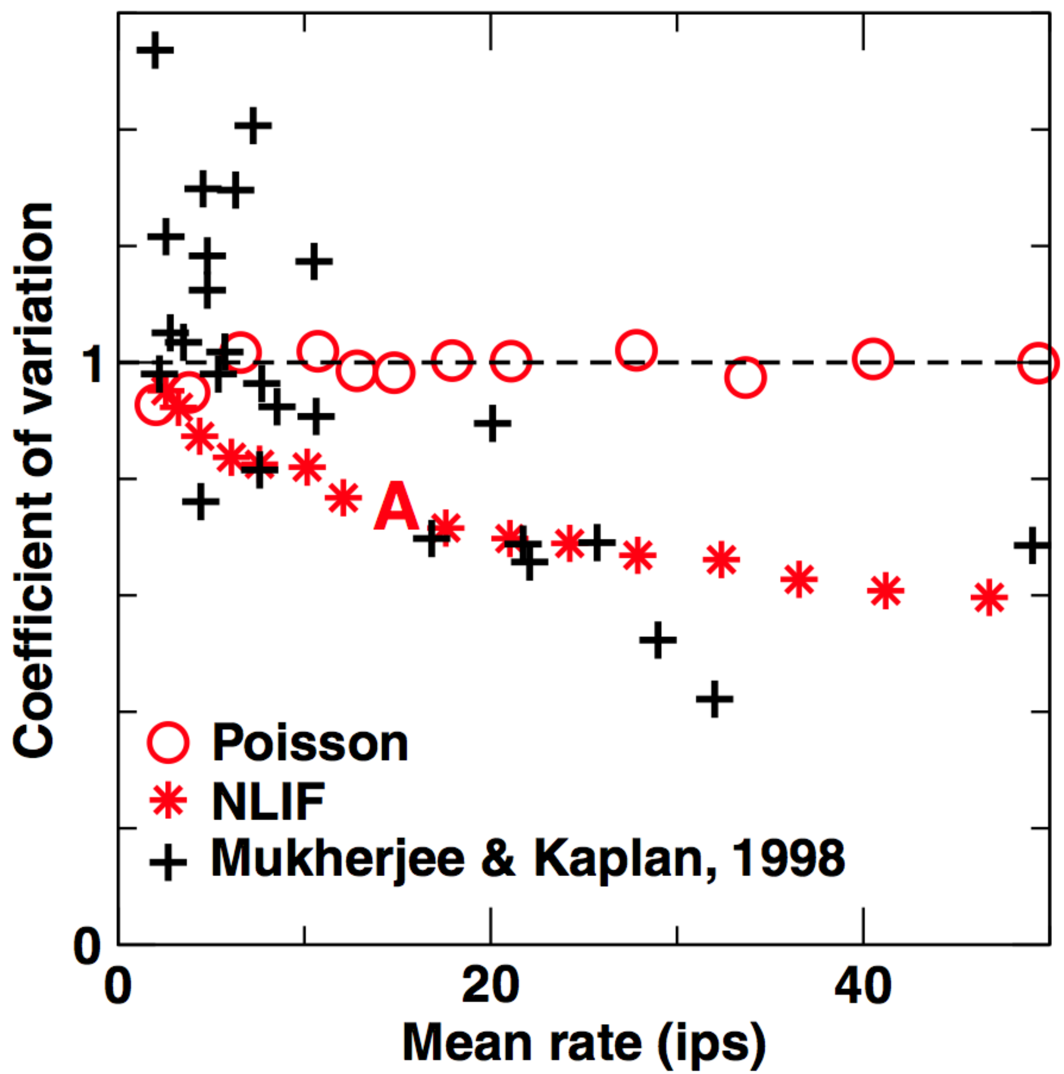
$$\tau_{\mathrm{m}} \frac{du}{dt} = -u + RI_{\mathrm{ext}} + \eta^{(3)}(t)$$





研究前沿

其實真正的神經反應也不是總是 Poisson spikes



(a) constant input

1 Spiking Neuron

2 Spiking Neurons

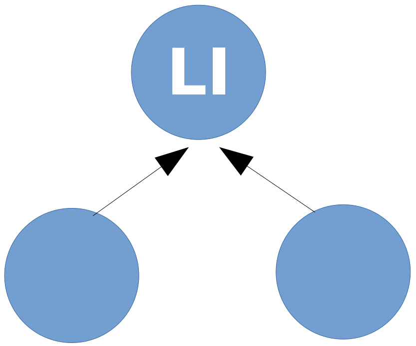
N Spiking Neurons

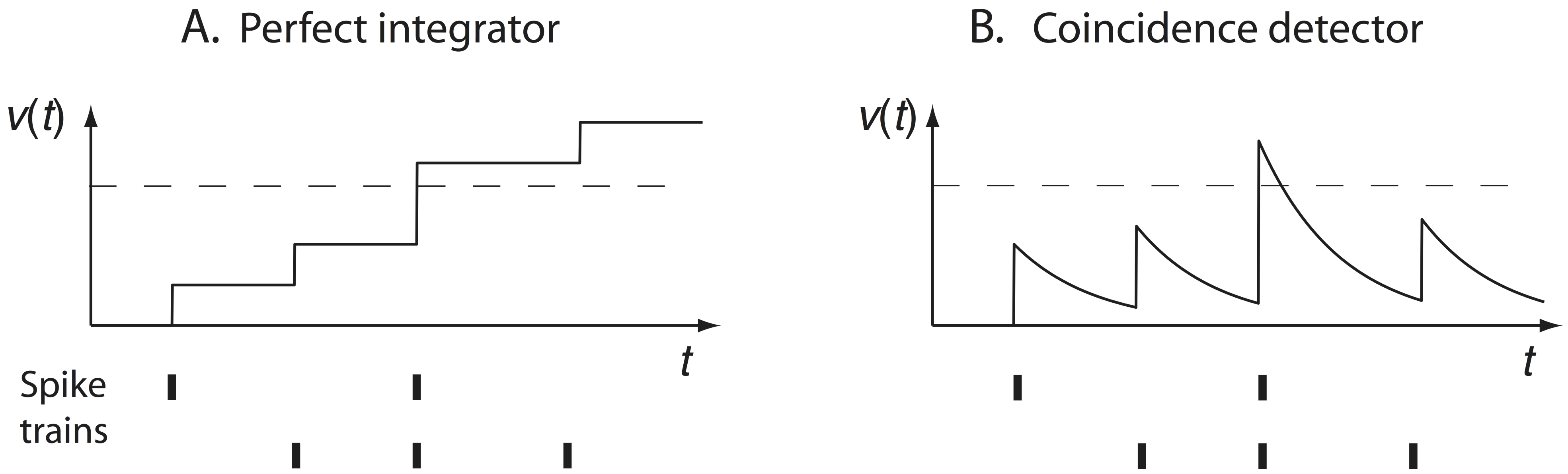
Rate-based Models

Closing Remarks

Coincidence Detector

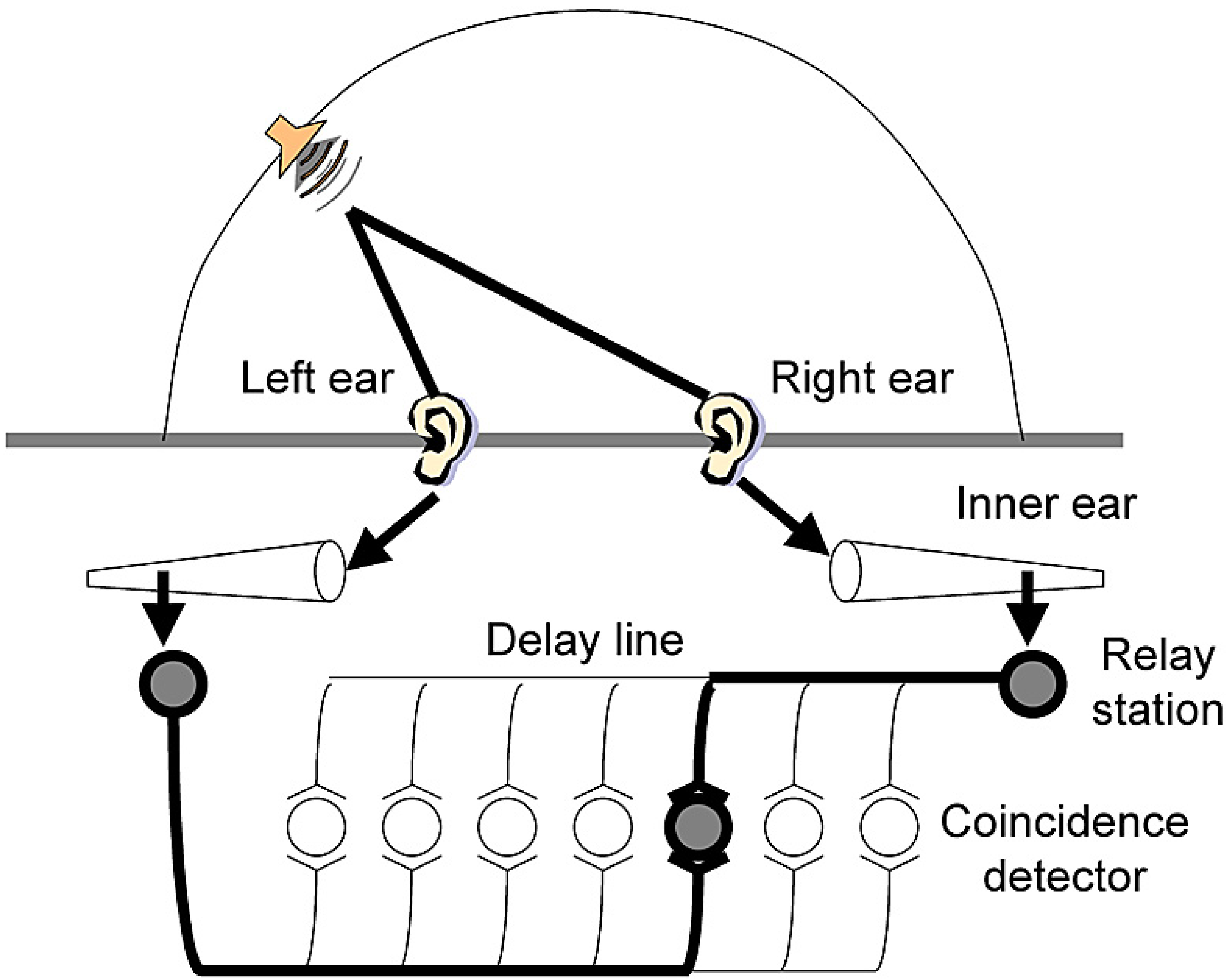
Leaky integrator 可粗略偵測同時性



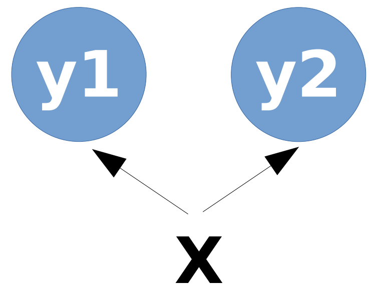


Jeffress Model

辨認音位時雙耳時間差 (ITD) 很重要



Two Leaky IF Neurons

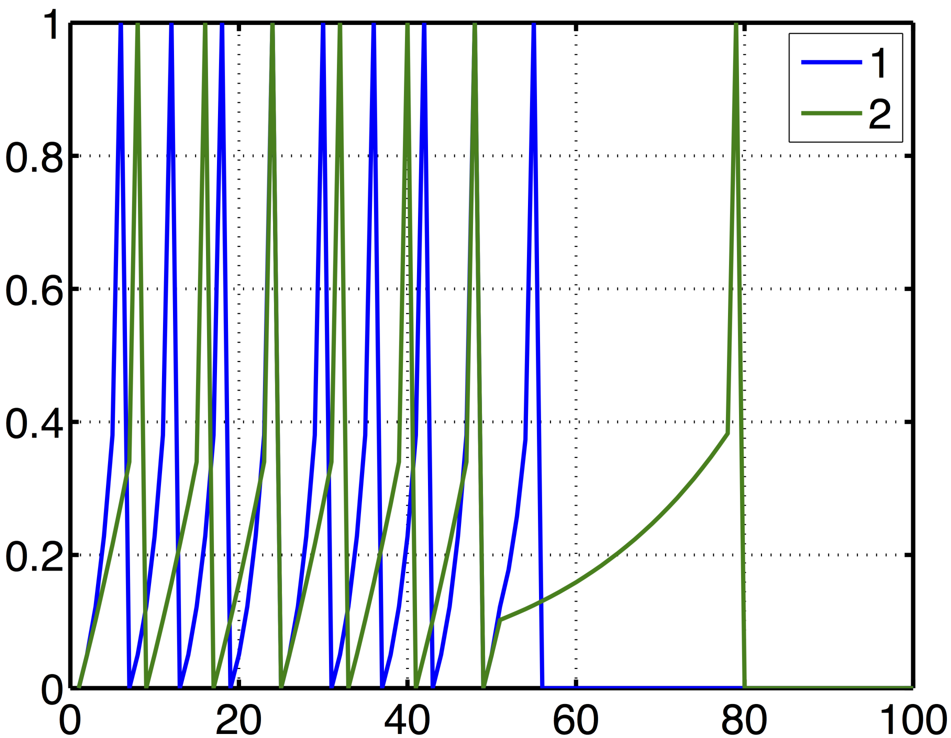



```
x=.5  # inputs to the two neurons
V=np.array([[0,0]])  # initial values of the two neurons
A=np.array([[.5,0],[0,.5]])  # Amm=decay of m
E=np.array([[0,0],[0,0]])  # Emn=excitation from n to m
I=np.array([[0,0],[0,0]])  # Imn=Inhibition from n to m
Vrst=0; Vthr=.4; Vspk=1; dt=0.1;
tspan=np.arange(0,10,dt)
for t in tspan:
 if t>5: x=0
 V1=V[-1]; s=V1>Vthr;
 V2=s*Vrst+(1-s)*(V1+dt*(-A.dot(V1)+E.dot(V1)-I.dot(V1)+x))
 V1=s*Vspk+(1-s)*V1
plot(V[:-1,:]); legend(['1','2']);
```

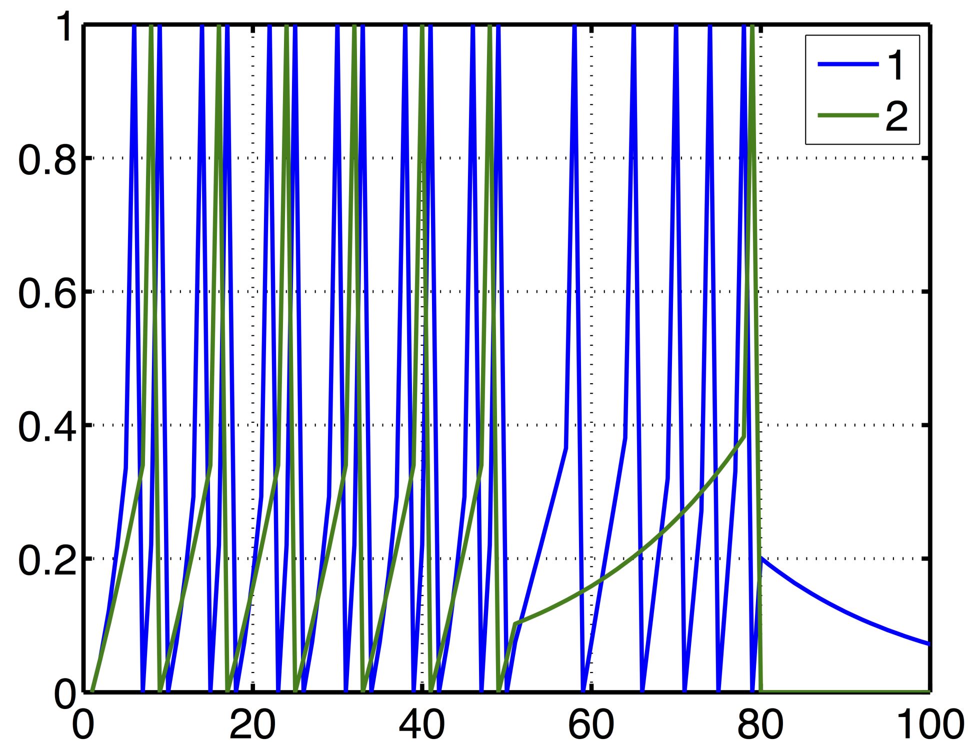
Effects of Excitations

拿掉 inputs 後 recurrent IF 神經元撐沒幾個 spikes

E=[[5,0],[0,1]]



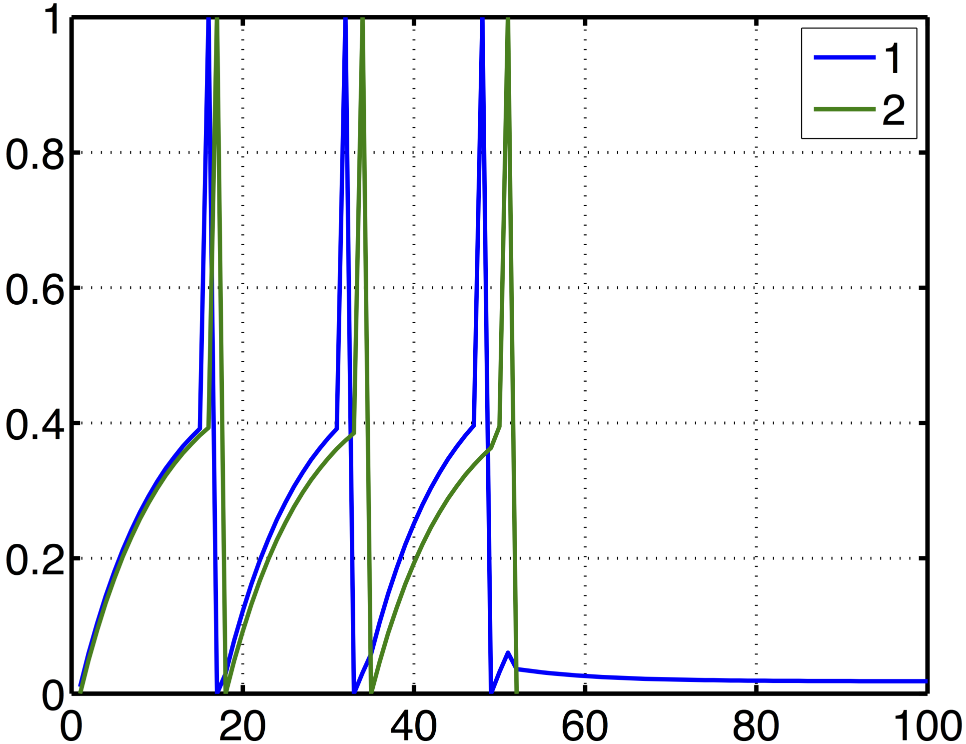
E=[[0,5],[0,1]]



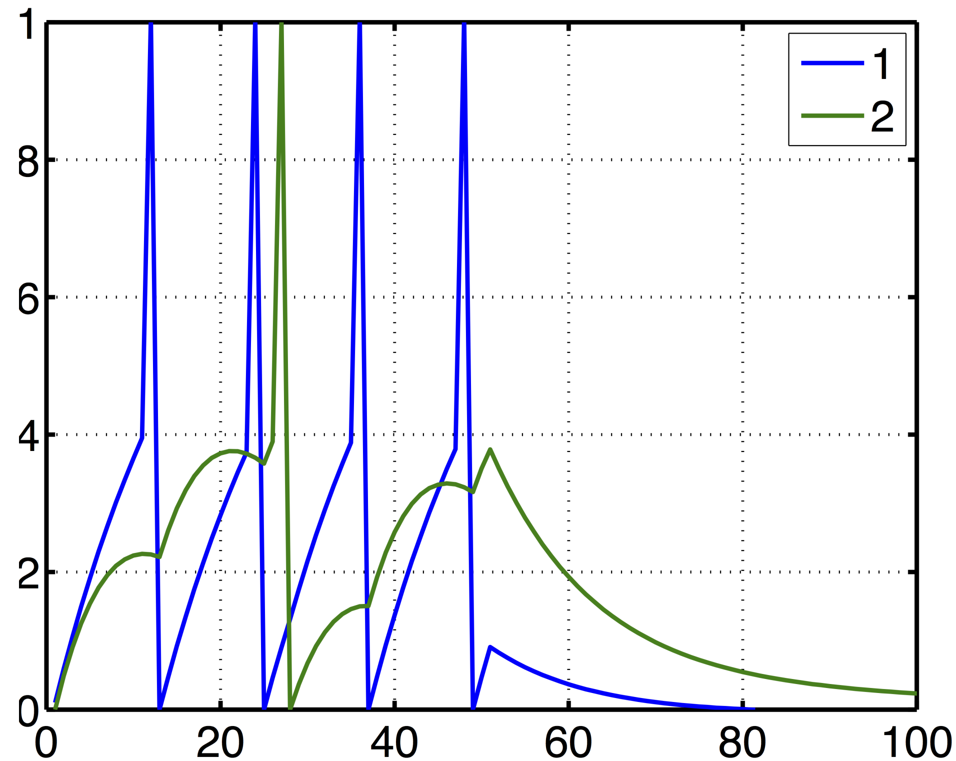
Effects of Mutual Inhibitions

兩顆 IF neurons 的活動會互相避開

V=[[.01, 0]]
I=[[0,.5],[.5, 0]]

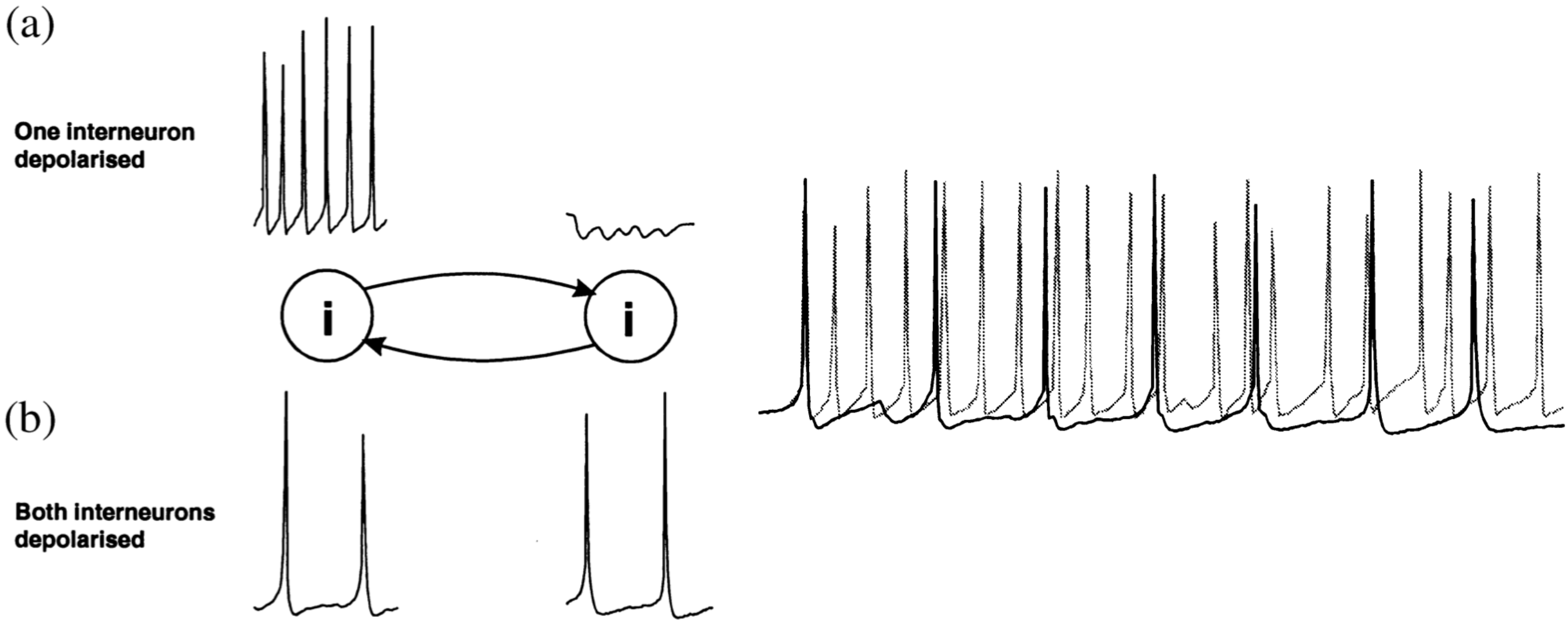


V=[[.01,0]]
I=[[0 .1],[1,0]]



Synchronization

可以有固定相差 (phase difference)



為何有不同的震盪頻帶：δ(1-4Hz), θ(4-8Hz), α(8-13Hz), β(13-30Hz), γ(30-70Hz)?

1 Spiking Neuron

2 Spiking Neurons

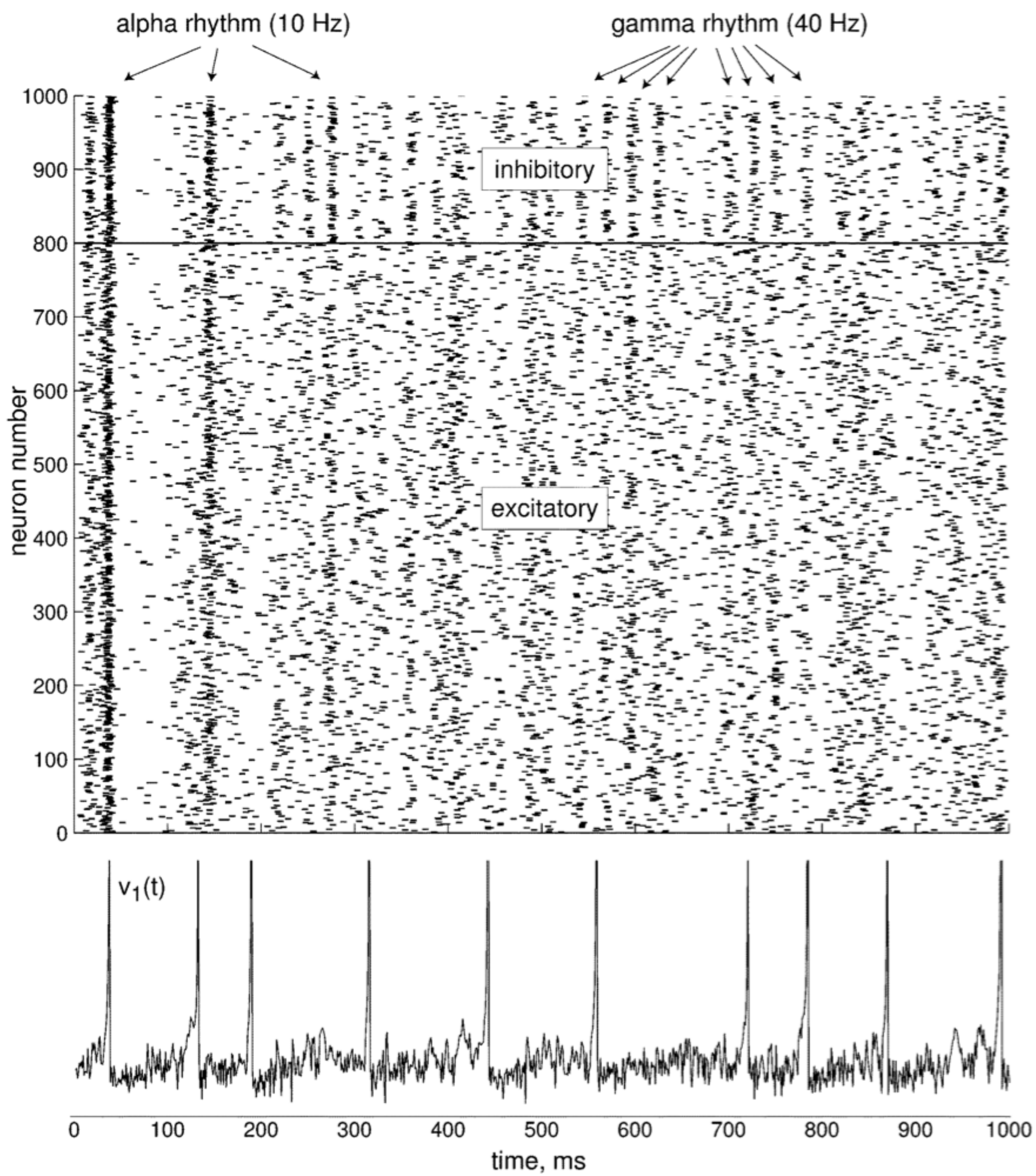
N Spiking Neurons

Rate-based Models

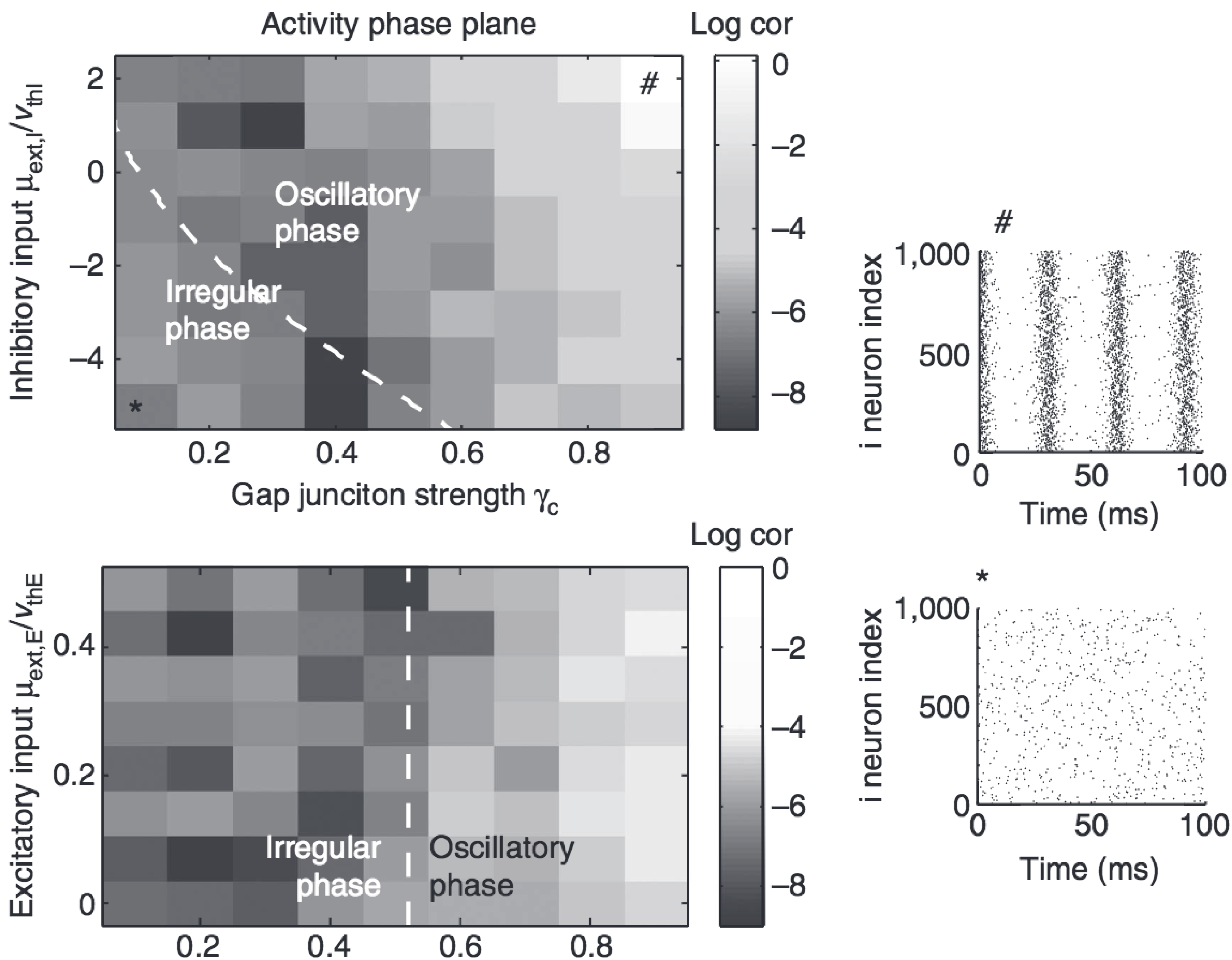
Closing Remarks

Izhikevich 模型的同步化

作業 (2/2): 探索修改哪些參數後模型就不會同步化



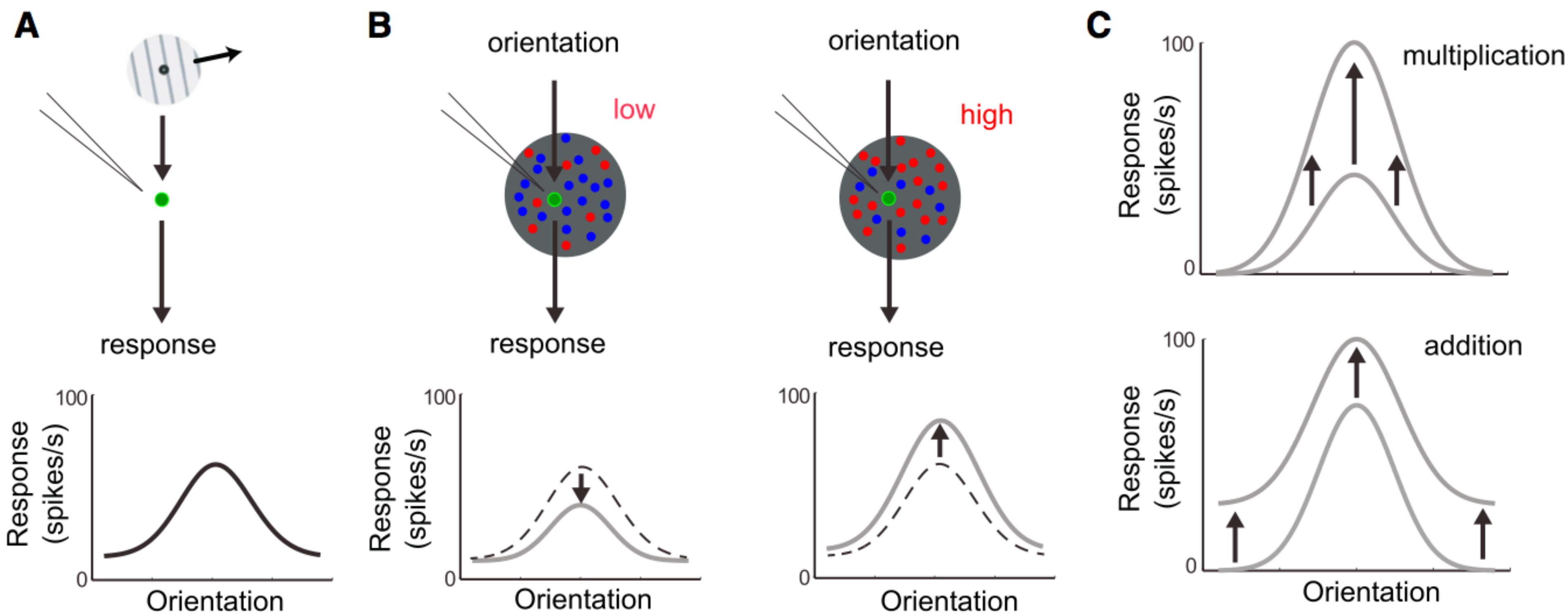
AdEx 模型的同步化



Activity phase plane
Log cor
Inhibitory input $\mu_{ext,I}/v_{thI}$
Gap junciton strength γ_c
Oscillatory phase
Irregular phase
#
*
i neuron index
Time (ms)
Log cor
Excitatory input $\mu_{ext,E}/v_{thE}$
Irregular phase
Oscillatory phase

研究最前沿 (1/2)

動全身則牽一髮：單一神經元受群體神經元的調控



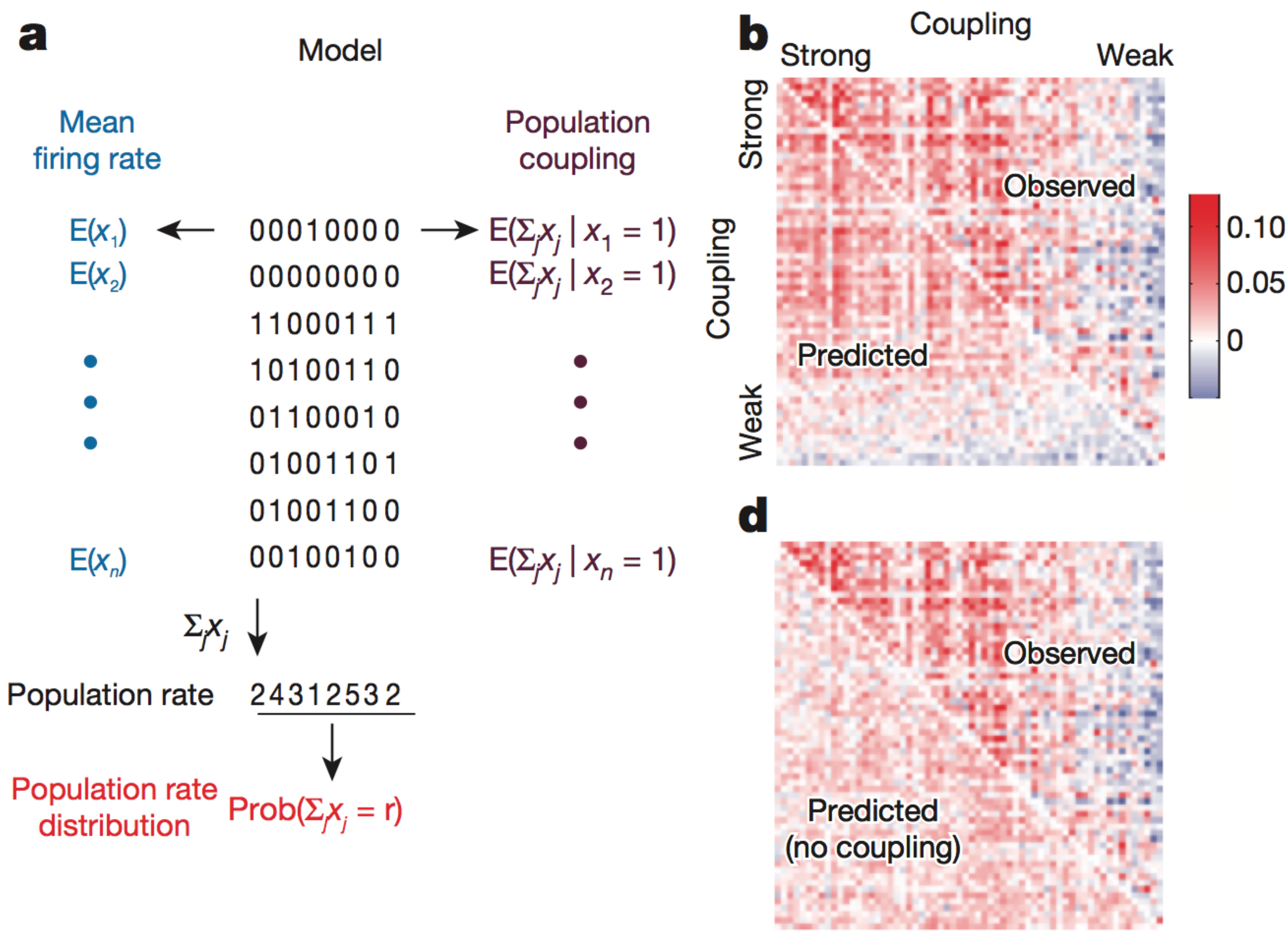
$$f_{c,i} = g_i d_{c,s(i)} + a_i h_c$$

d=tuning function; g=gain; a=additive term

g 與 a 是 trial i 的函數，還是也是 neuron c 的函數？

研究最前沿 (2/2)

N^2 個神經間相關可由其合群/主宰度預測 (N 個參數)



1 Spiking Neuron

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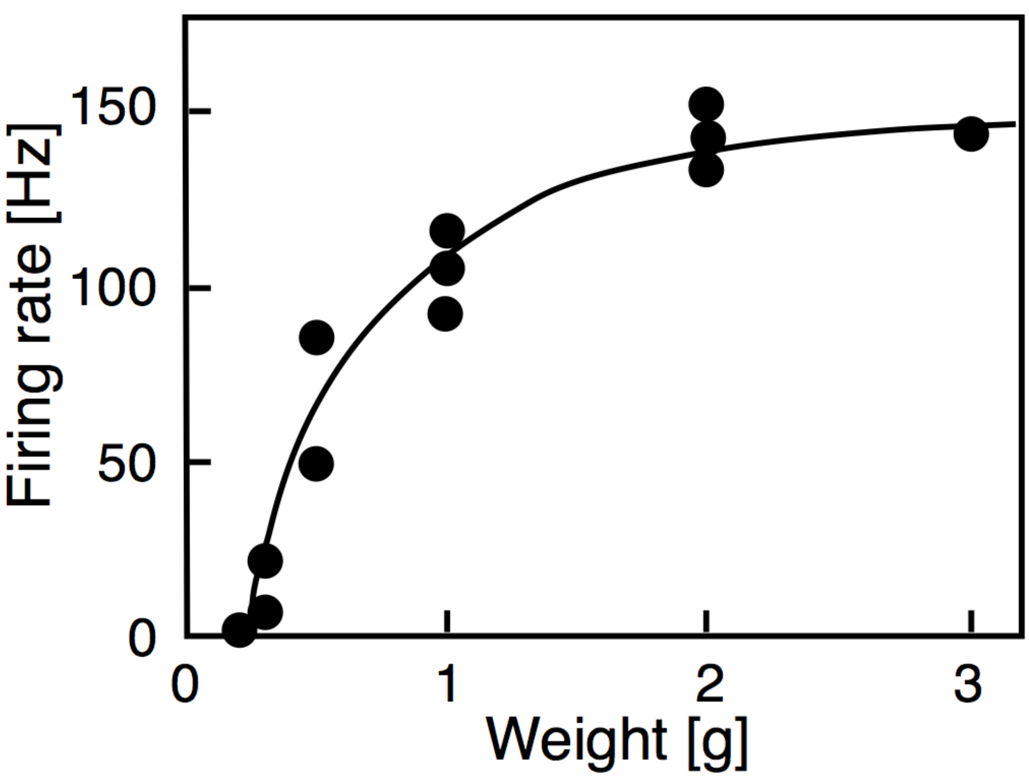
Rate-based Models

Closing Remarks

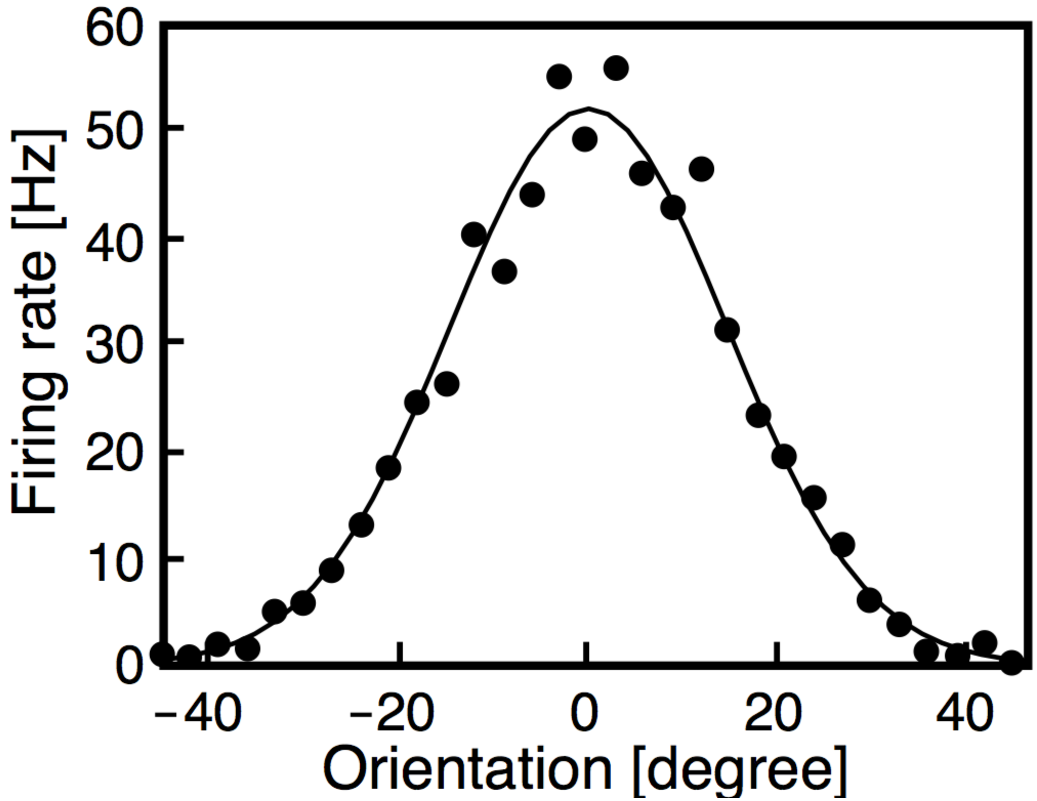
一顆神經元的 Rate Coding

Firing rate 表徵刺激或反應強度

Stretch receptor on frog muscle

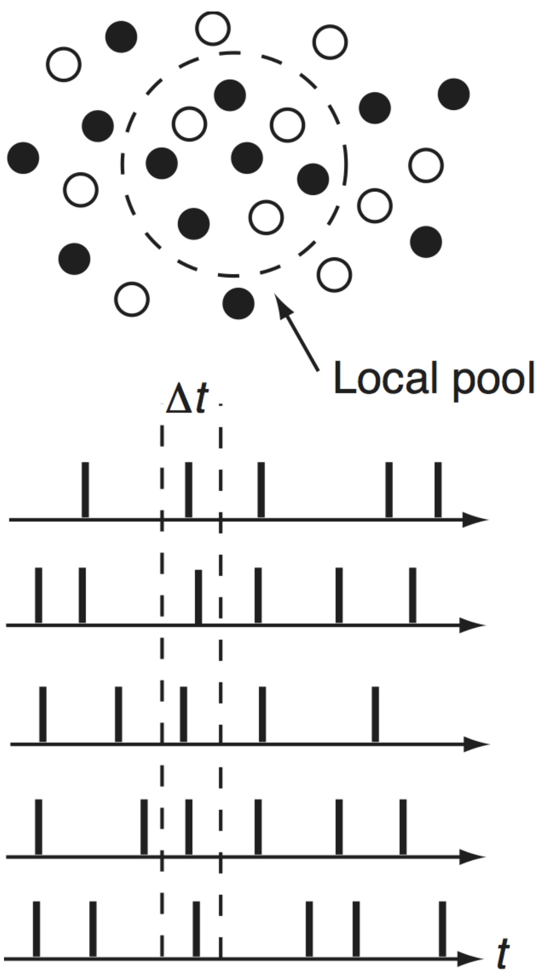


Tuning curve of V1 neuron in cat



多顆神經元的 Rate Coding

Firing rate 表徵刺激或反應強度：表徵形式多樣



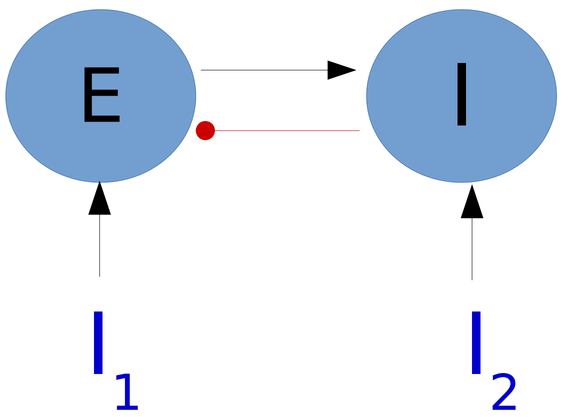
Type of function	Graphical represent.	Mathematical formula	MATLAB implementation
Linear		$g^{\text{lin}}(x) = x$	X
Step		$g^{\text{step}}(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{elsewhere} \end{cases}$	`floor(0.5*(1+sign(x)))`
Threshold-linear		$g^{\text{theta}}(x) = x\,\Theta(x)$	`x.*floor(0.5*(1+sign(x)))`
Sigmoid		$g^{\text{sig}}(x) = \frac{1}{1+\exp(-x)}$	`1./(1+exp(-x))`
Radial-basis		$g^{\text{gauss}}(x) = \exp(-x^2)$	`exp(-x.^2)`

Dynamics: Wilson-Cowan Eq.

兩群神經元 ： 刺激性 (E) 和抑制性 (I)

Bad additive inhibition !

$$
\begin{aligned}
s_E &= W_{EE} * E - W_{EI} * I + h_E \\
s_I &= W_{IE} * E - W_{II} * I + h_I .
\end{aligned}
$$



$$
\begin{aligned}
\frac{dE}{dt} &= -\alpha E + (1 - E) * f(s_E) \\
\frac{dI}{dt} &= -\alpha I + (1 - I) * f(s_I),
\end{aligned}
$$

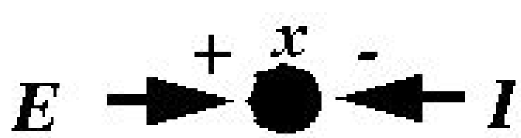
若爆掉則可被 activation/signal function 修正 !

Additive Eq. vs. Shunting Eq.

Additive Eq: dy/dt=-Ay+E-I

平衡時 dy/dt=0 ⇒ y_∞=(E-I)/A

用減的抑制會有下界問題

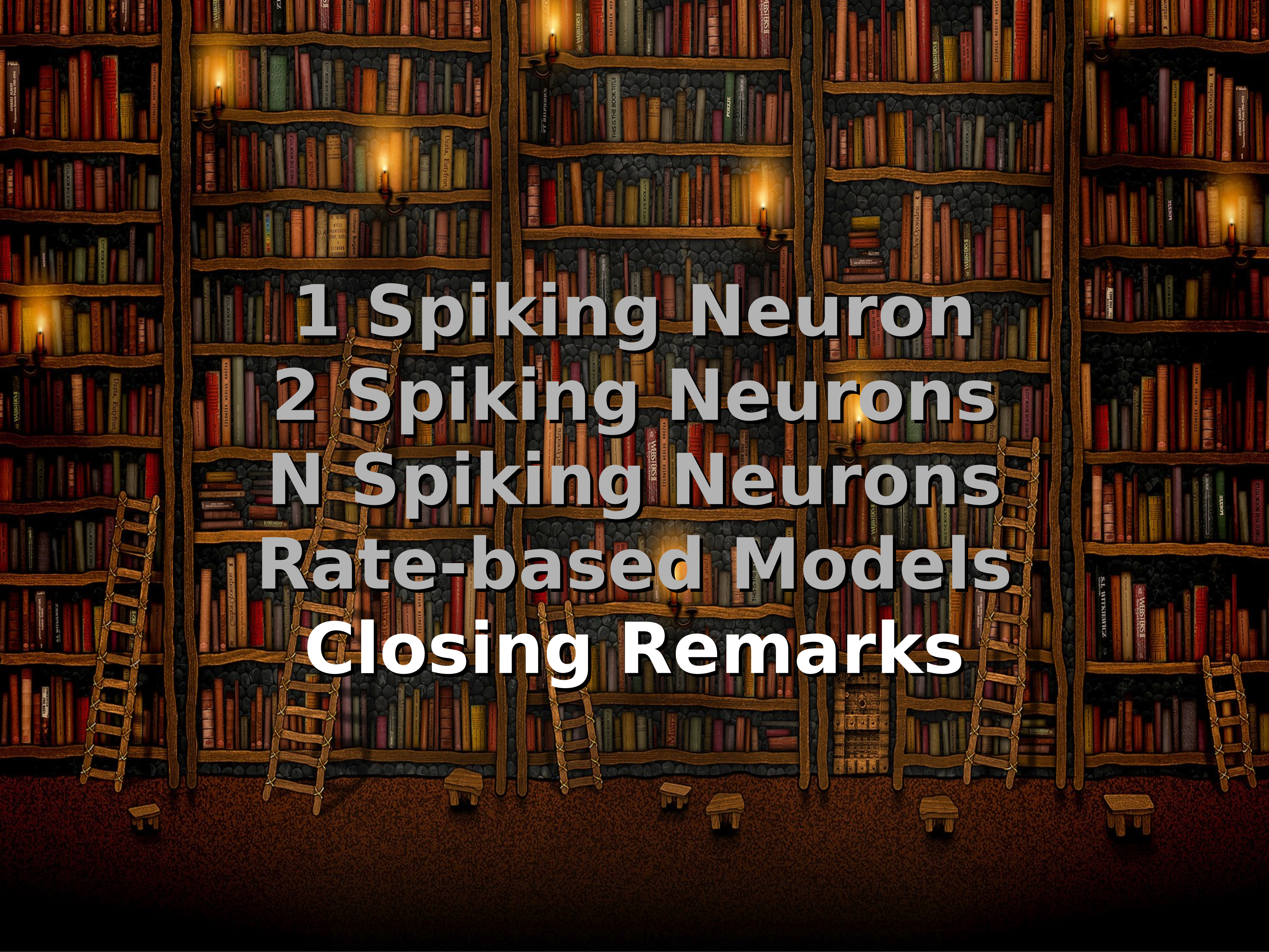


$$\frac{dx}{dt} = \underbrace{-Ax}_{\text{decay term}} + \underbrace{\underbrace{(B-x)}\,[E]^{+}}_{\substack{\text{shunting}\\ \text{excitation term}}} - \underbrace{\underbrace{x}\,[I]^{-}}_{\substack{\text{shunting}\\ \text{inhibition term}}}$$

Shunting Eq: dy/dt=-Ay+(1-y)*E-y*I

平衡時 dy/dt=0 ⇒ y_∞=E/(A+E+I)

用除的抑制是 normalization



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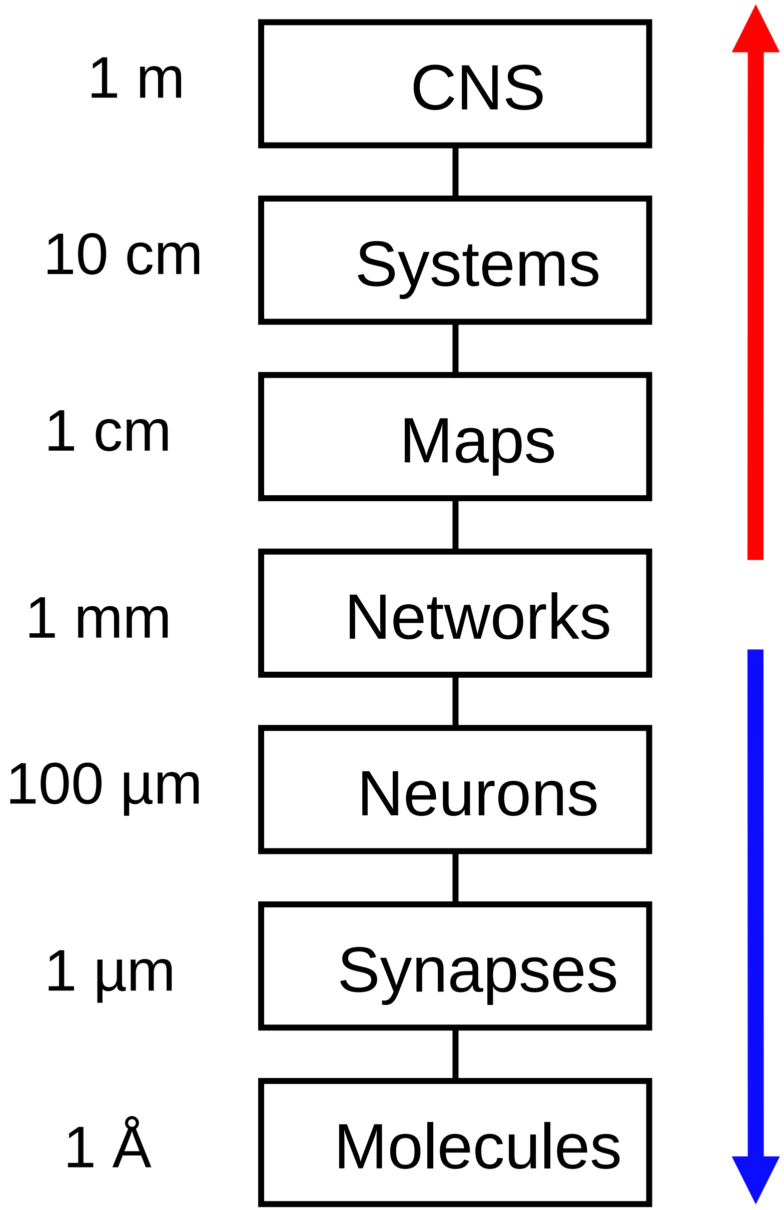
Rate-based Models

Closing Remarks

Research Scales



Computational Cognitive Science

Bayesian perception
Diffusion models

Computational Cognitive Neuroscience

Connectivity analysis
Neural networks

Computational Neuroscience

Neural coding
Neuronal models

Computational Neuroscience

Pros

Offering good insights about neural processes

Providing specific testable predictions

Cons

Modeling neural correlates rather than behavior

Often not characterizing inter-cortical dynamics

Game Over

Models across Scales

Correspondence Principle:

Molecules/Ion-Channels→Neurons→Networks→Behavior

Mechanistic
↓
Descriptive→Mechanistic
↓
Descriptive→Mechanistic
↓
Descriptive→Mechanistic


你知道的太多了
You know too much

全劇終