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

課號：Psy5352　　教室： 普 101
識別碼：227U2810　　時間： 一 234

黃從仁


終於來到最後一堂課
!!!

1 Spiking Neuron

2 Spiking Neurons

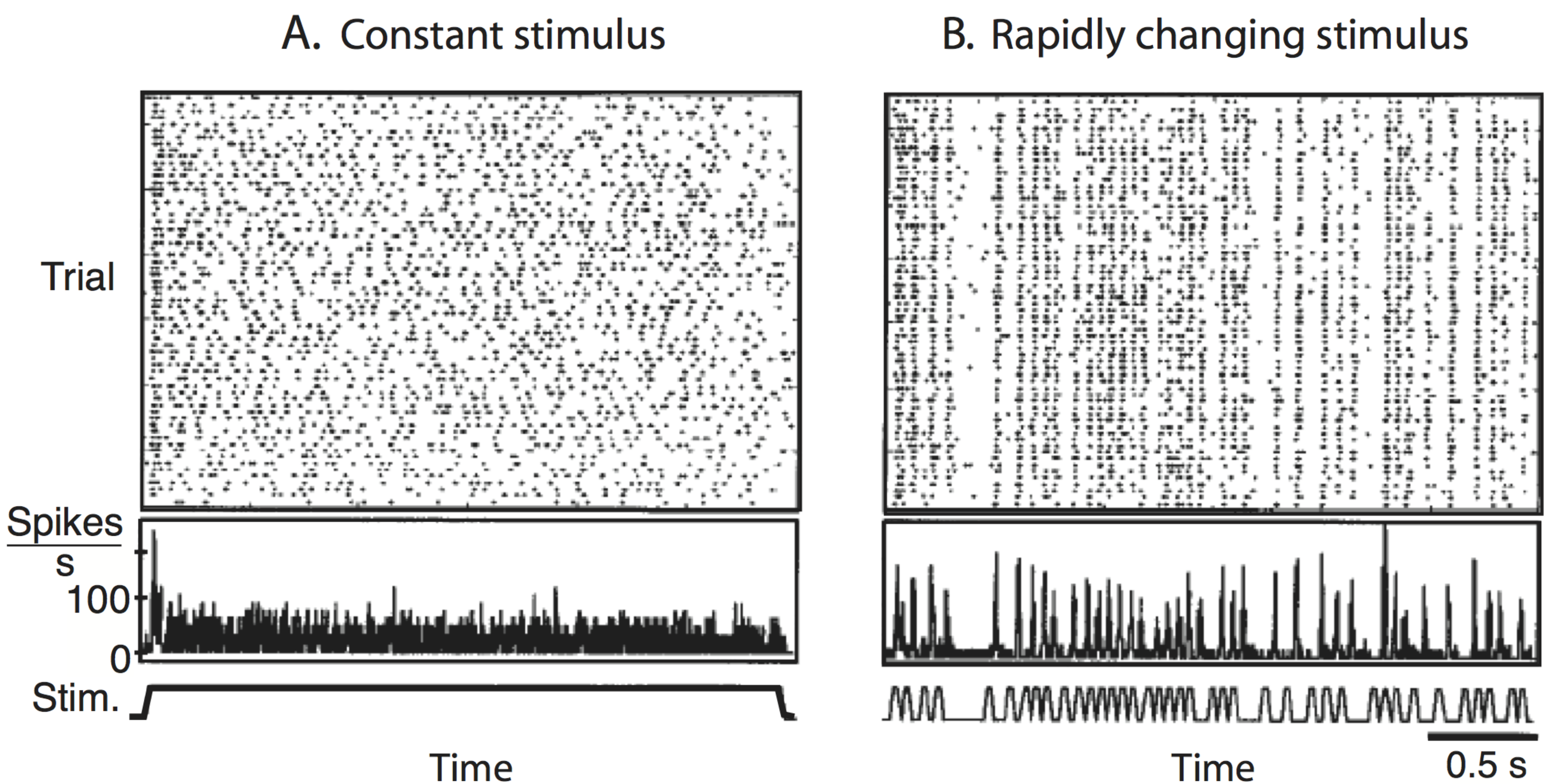
N Spiking Neurons

Rate-based Models

Closing Remarks

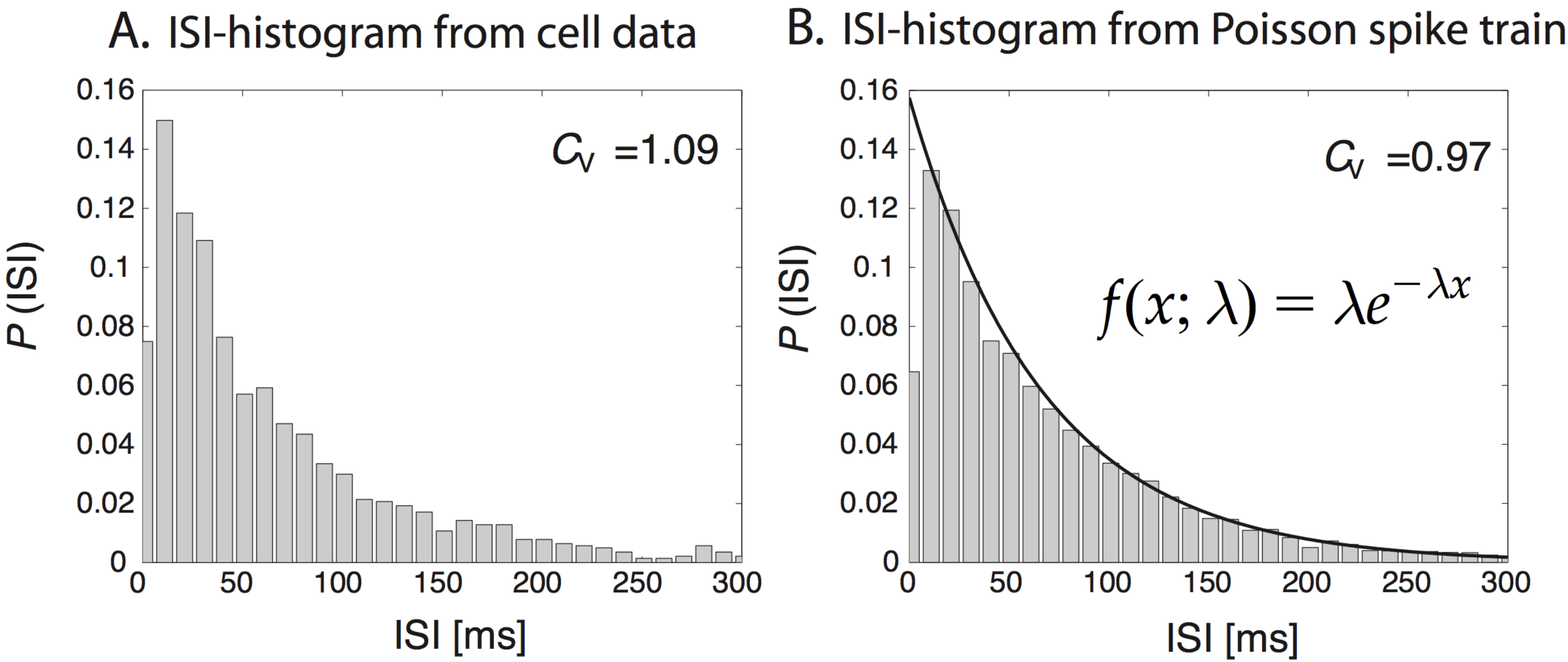
Spiking Variability (1/3)

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)

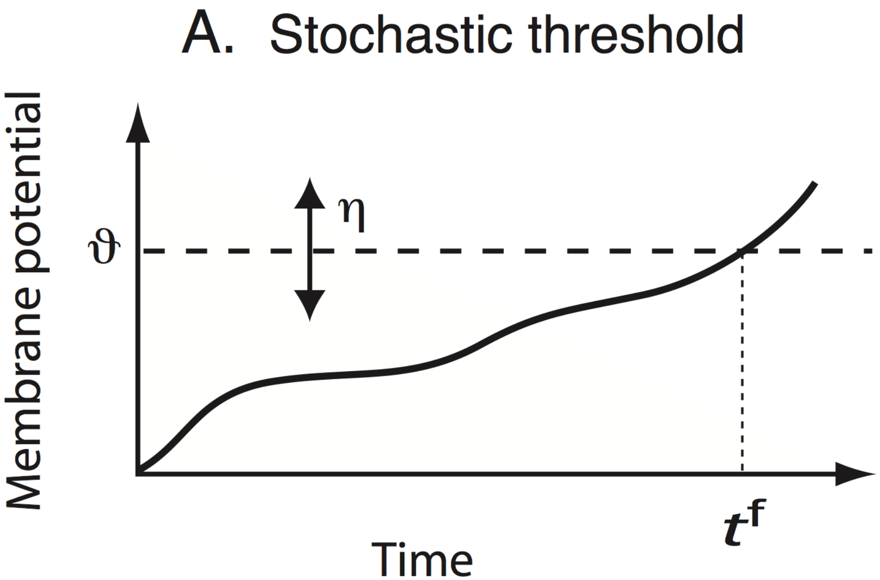
以下是指數分配 spike train 的 WHAT model

```
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)

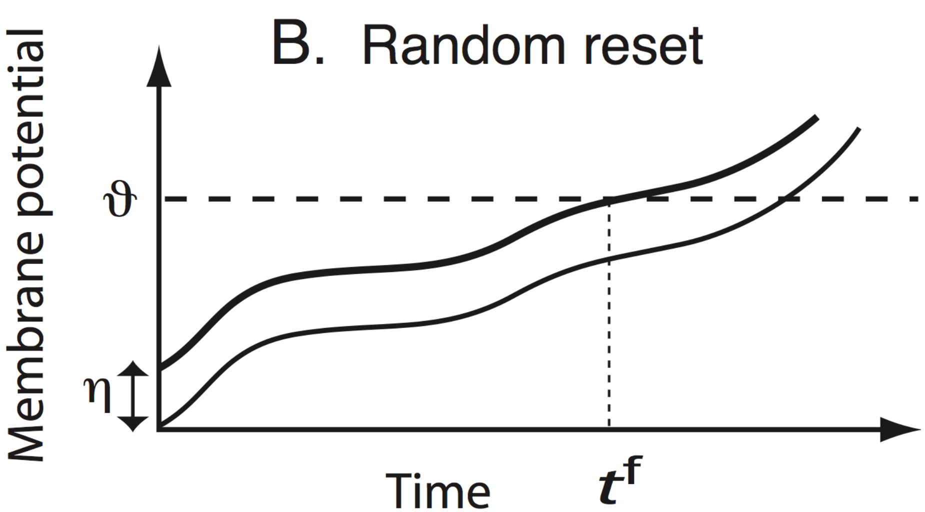
探索 IF 模型的三種隨機性可否產生 Poisson spikes?

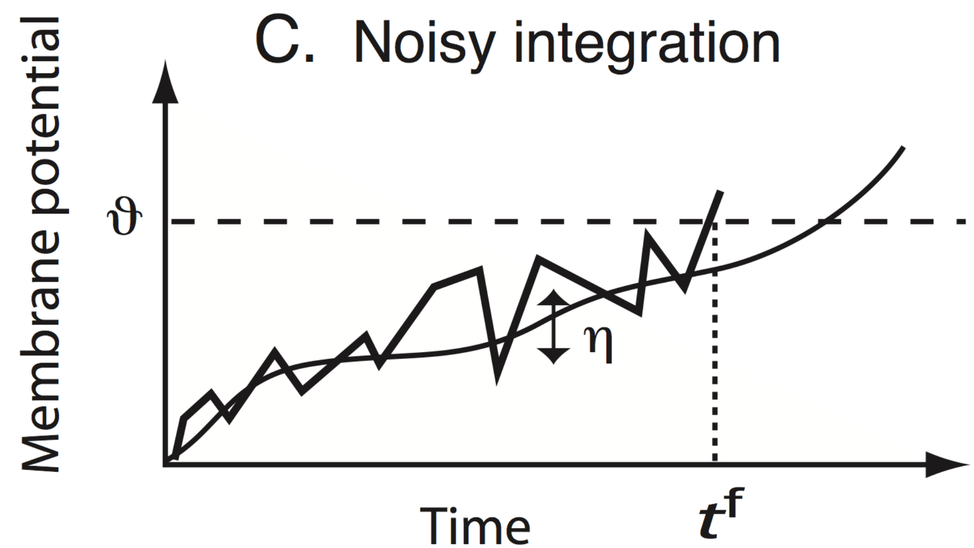


$$\vartheta \rightarrow \vartheta + \eta^{(1)}(t)$$

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

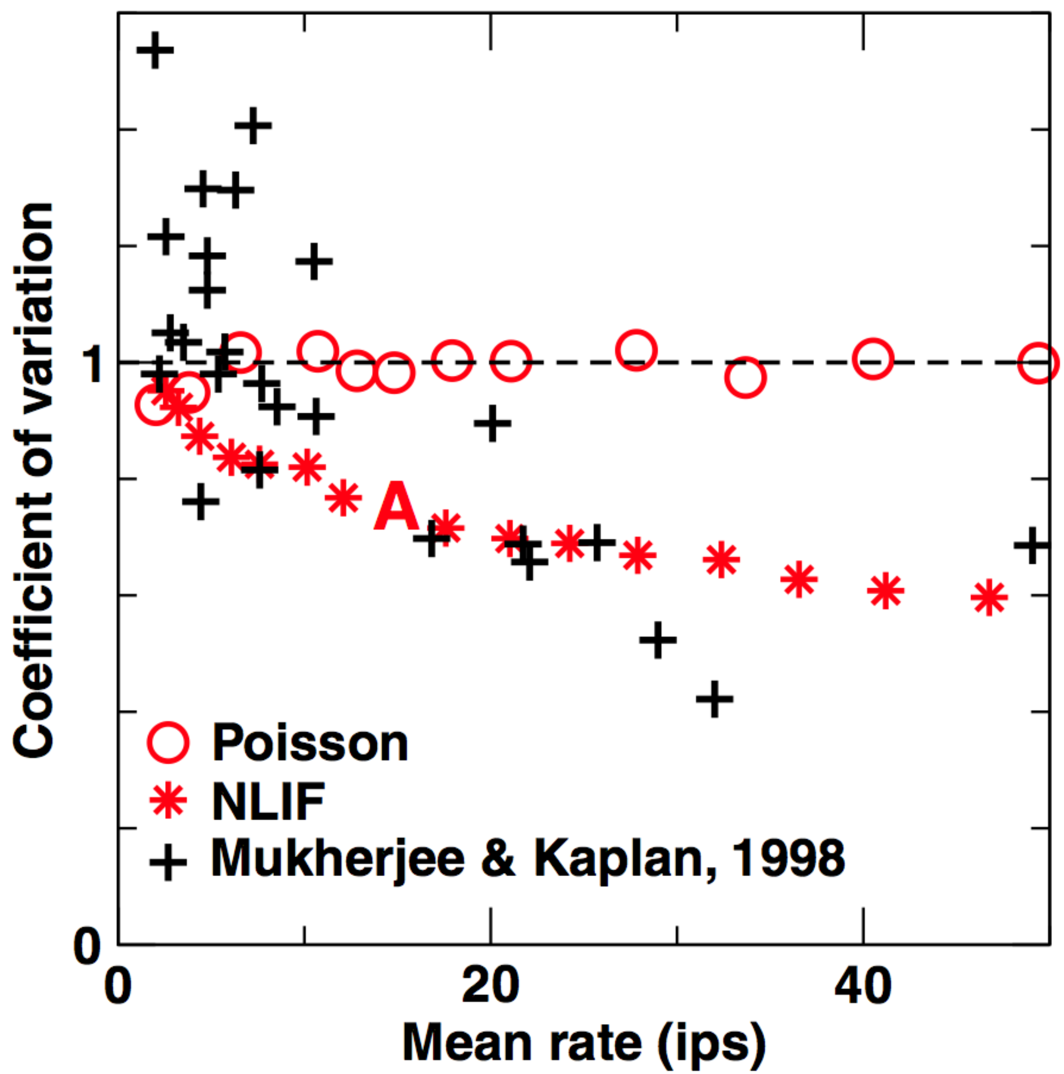
$$\tau_{\mathrm{m}} \frac{du}{dt} = -u + RI_{\mathrm{ext}} + \eta^{(3)}(t)$$





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

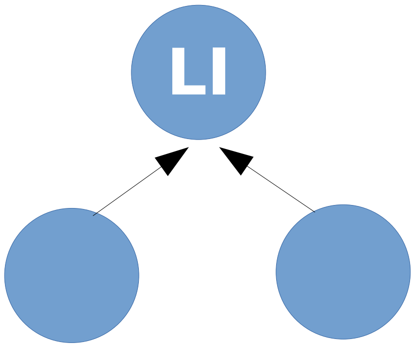
N Spiking Neurons

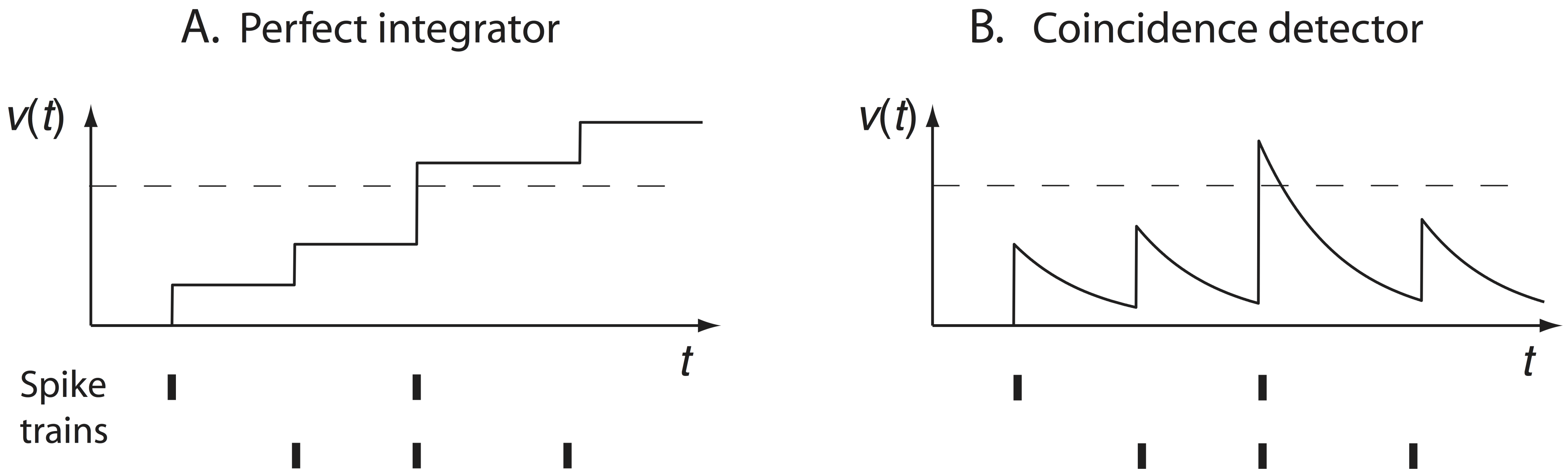
Rate-based Models

Closing Remarks

Coincidence Detector

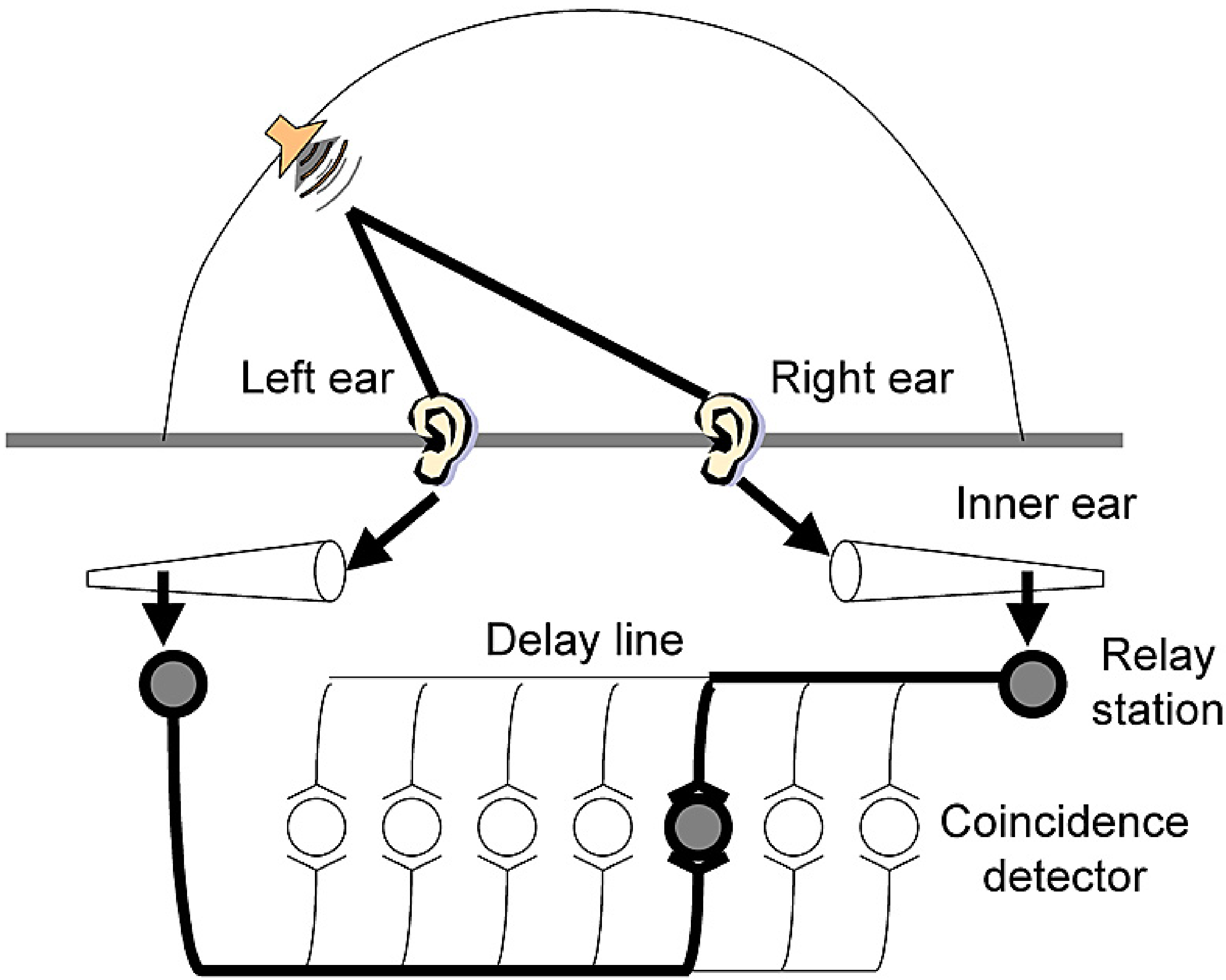
Leaky integrator 可粗略偵測同時性



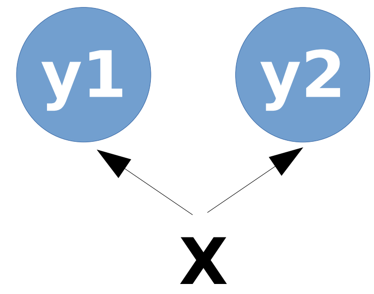


Jeffress Model

辨認音位時雙耳時間差 (ITD) 很重要



Two Leaky IF Neurons

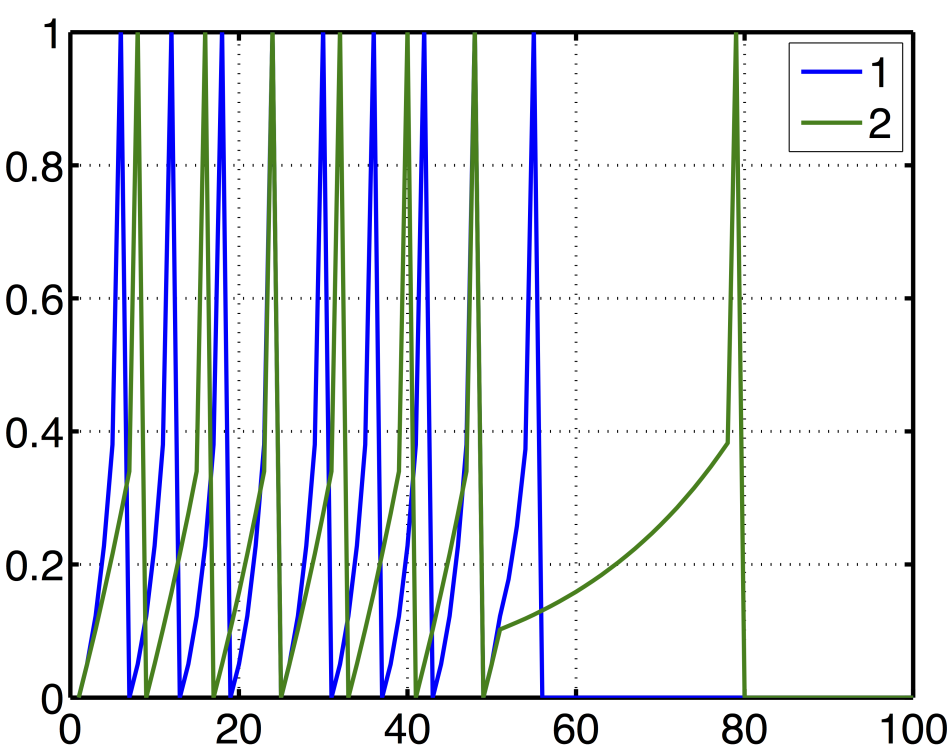



```
x=.5  # inputs to the two neurons
V=np.array([[0,0]])  # initial values of the two neurons
A=np.array([[.5,0],[0,.5]])  # Amm=decay of m
E=np.array([[0,0],[0,0]])  # Emn=excitation from n to m
I=np.array([[0,0],[0,0]])  # Imn=Inhibition from n to m
Vrst=0; Vthr=.4; Vspk=1; dt=0.1;
tspan=np.arange(0,10,dt)
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']);
```

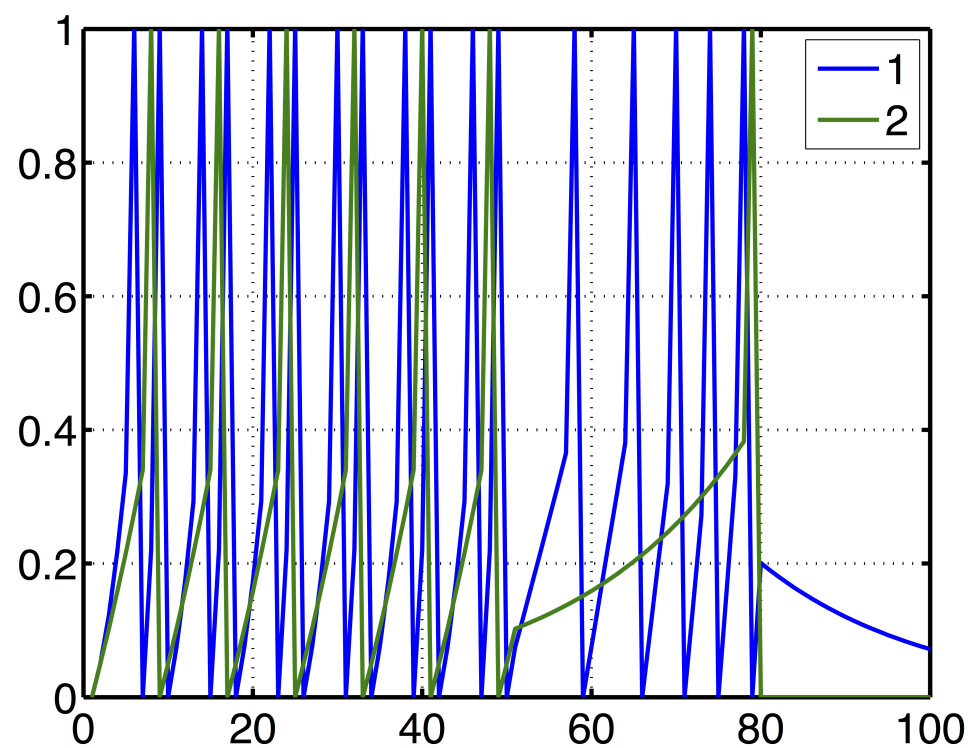
Effects of Excitations

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

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



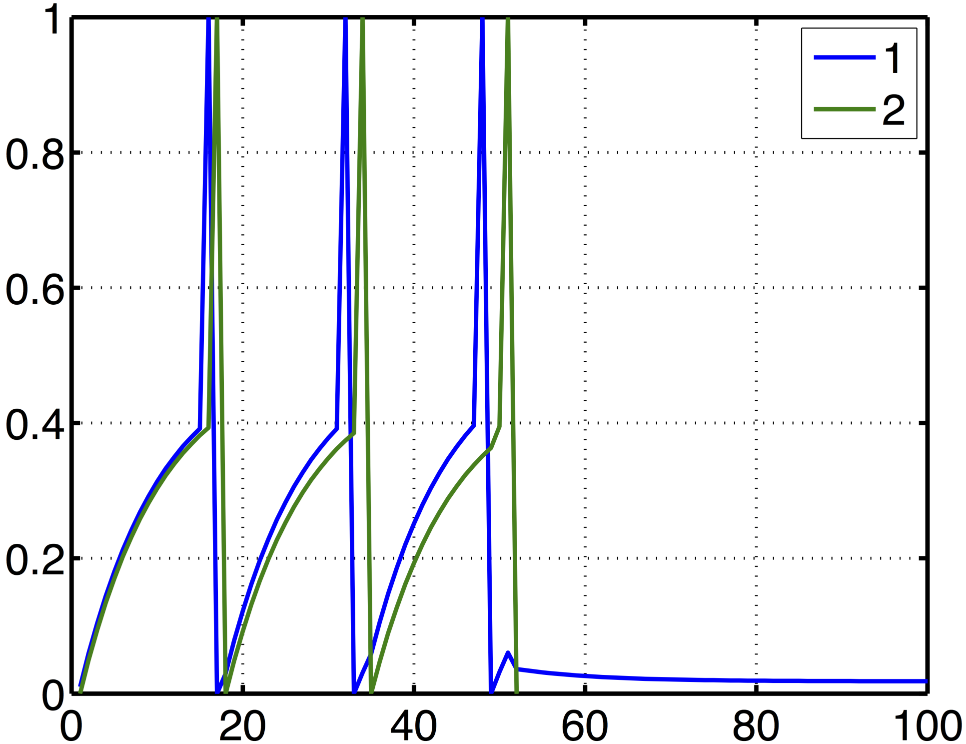
E=[[0,5],[0,1]]



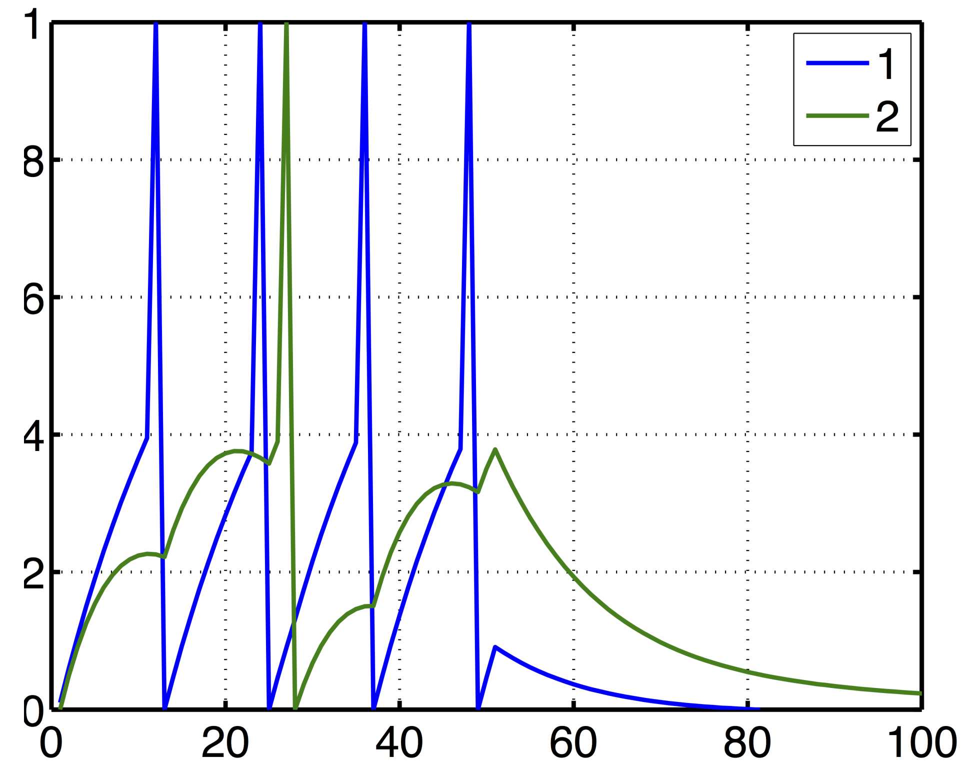
Effects of Mutual Inhibitions

兩顆 IF neurons 的活動會互相避開

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

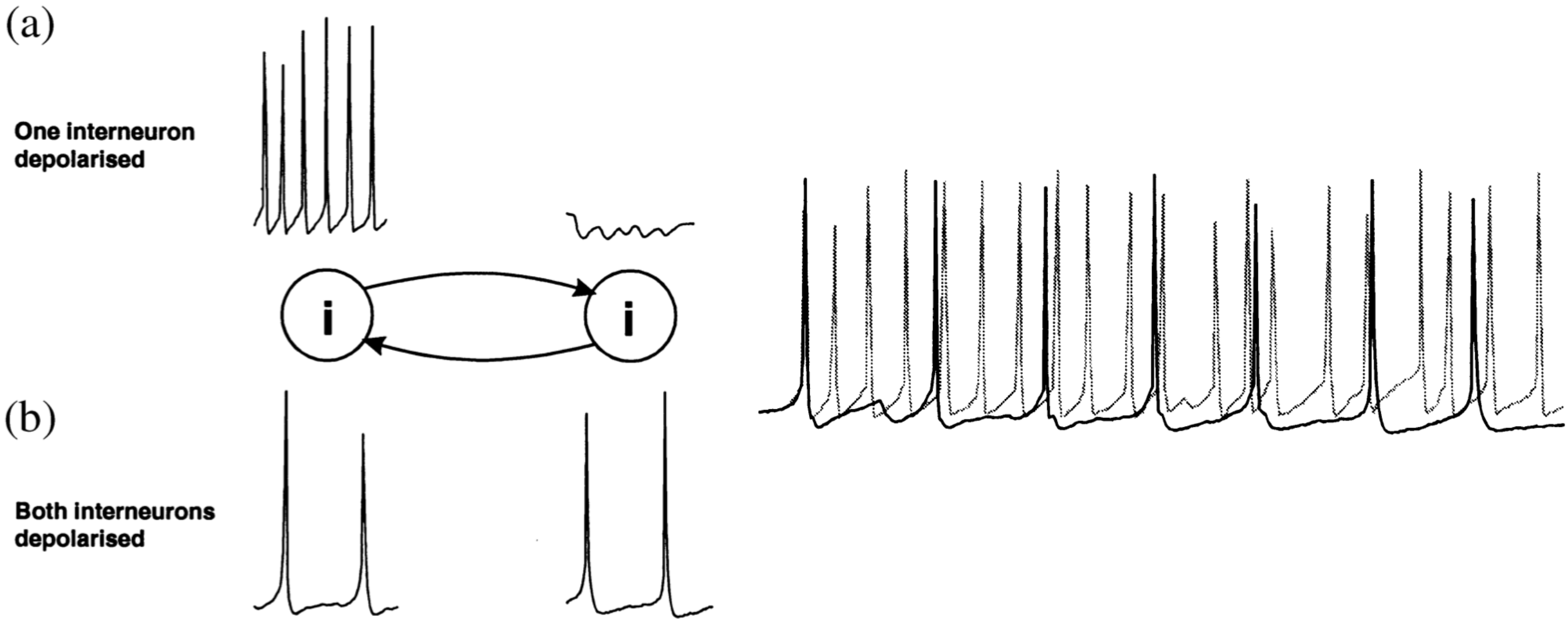


V=[[.01,0]]
I=[[0 .1],[1,0]]



Synchronization

可以有固定相差 (phase locking)



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

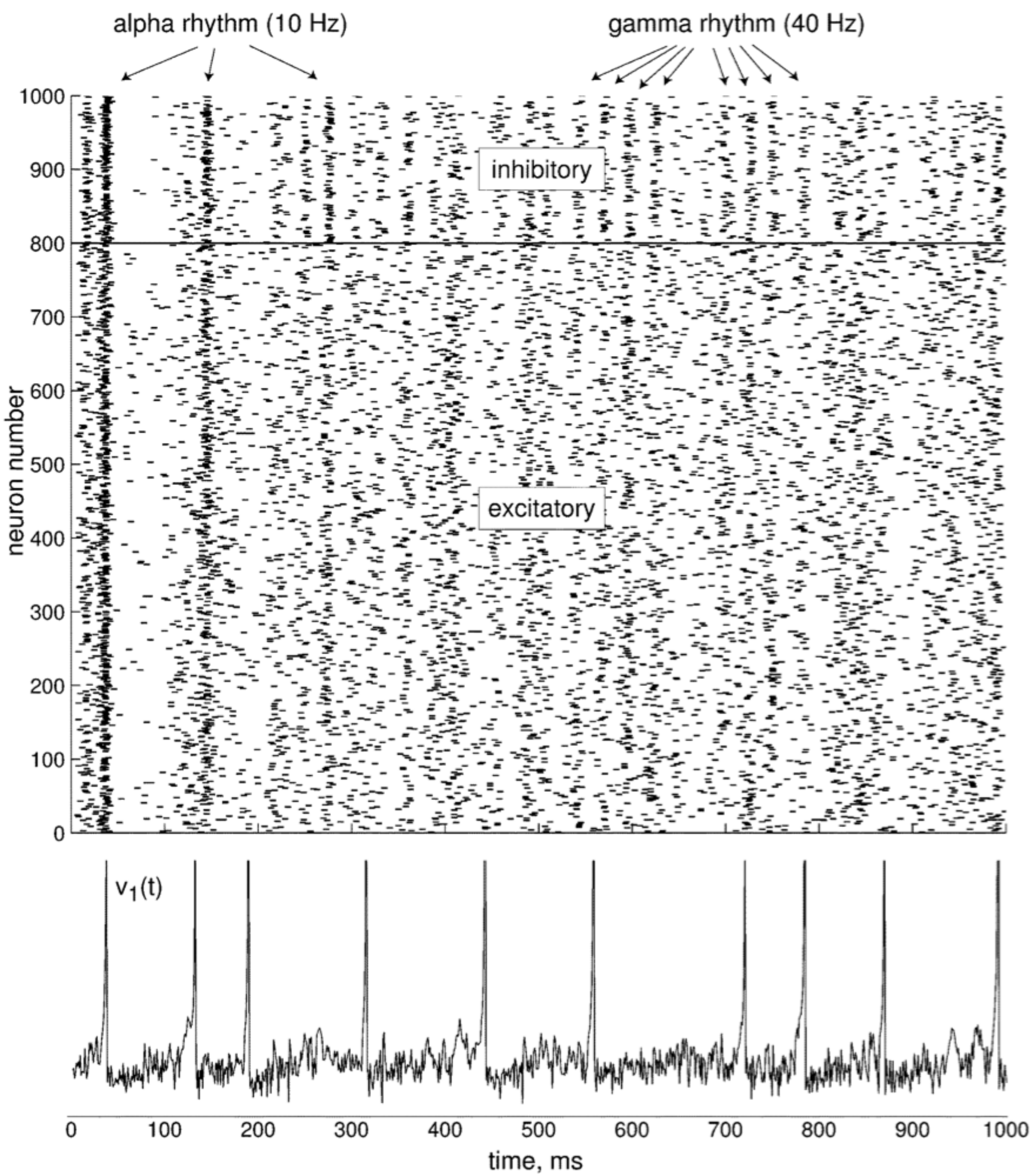
N Spiking Neurons

Rate-based Models

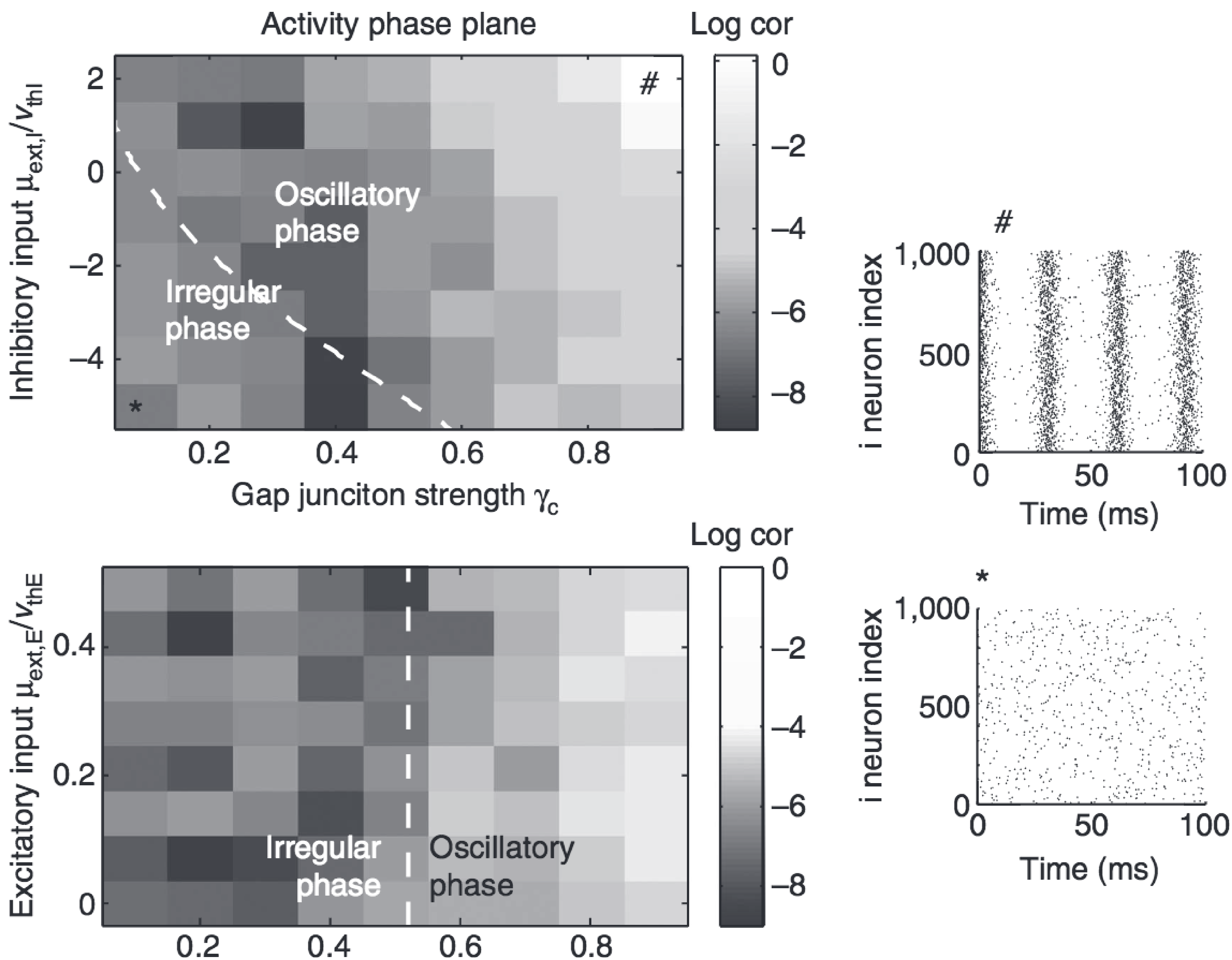
Closing Remarks

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



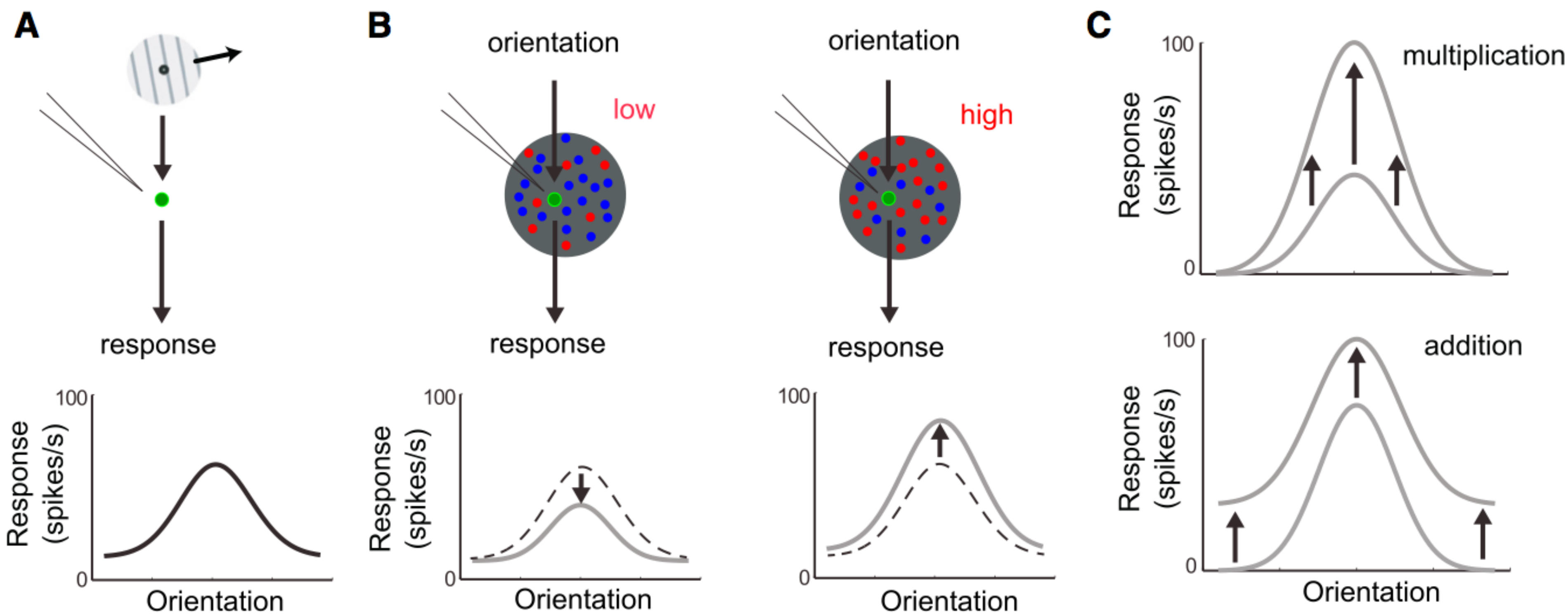
AdEx 模型的同步化



Activity phase plane
Log cor
0
–2
–4
–6
–8
#
Oscillatory phase
Irregular phase
*
Inhibitory input $\mu_{ext,I}/v_{thI}$
2
0
–2
–4
0.2
0.4
0.6
0.8
Gap junciton strength γ_c
#
1,000
500
0
i neuron index
0
50
100
Time (ms)
Log cor
0
–2
–4
–6
–8
Irregular phase
Oscillatory phase
Excitatory input $\mu_{ext,E}/v_{thE}$
0.4
0.2
0
0.2
0.4
0.6
0.8
*
1,000
500
0
i neuron index
0
50
100
Time (ms)

研究前沿 (1/2)

動全身則牽一髮：單一神經元受群體神經元的調控



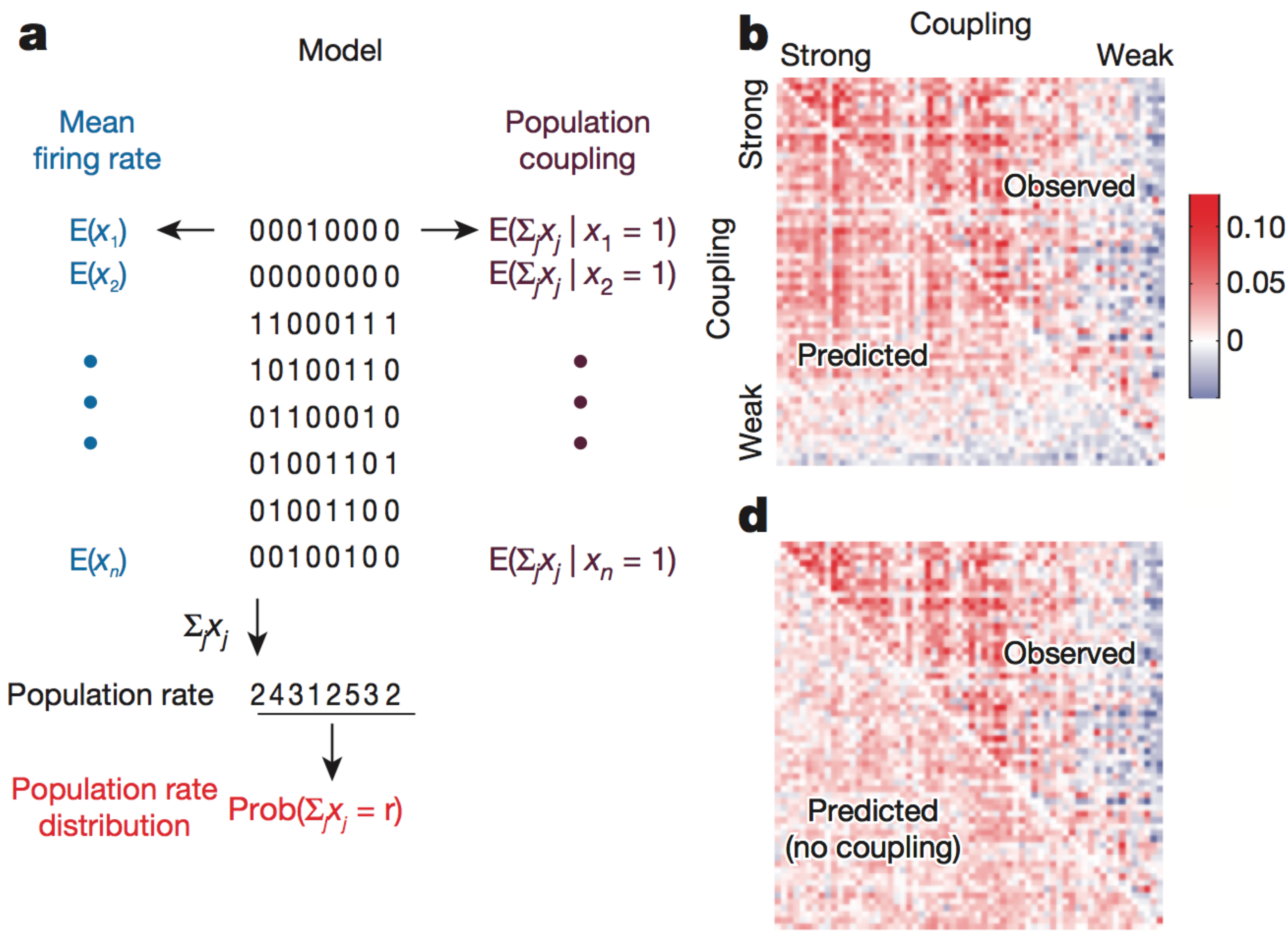
$$f_{c,i} = g_i d_{c,s(i)} + a_i h_c$$

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

2 Spiking Neurons

N Spiking Neurons

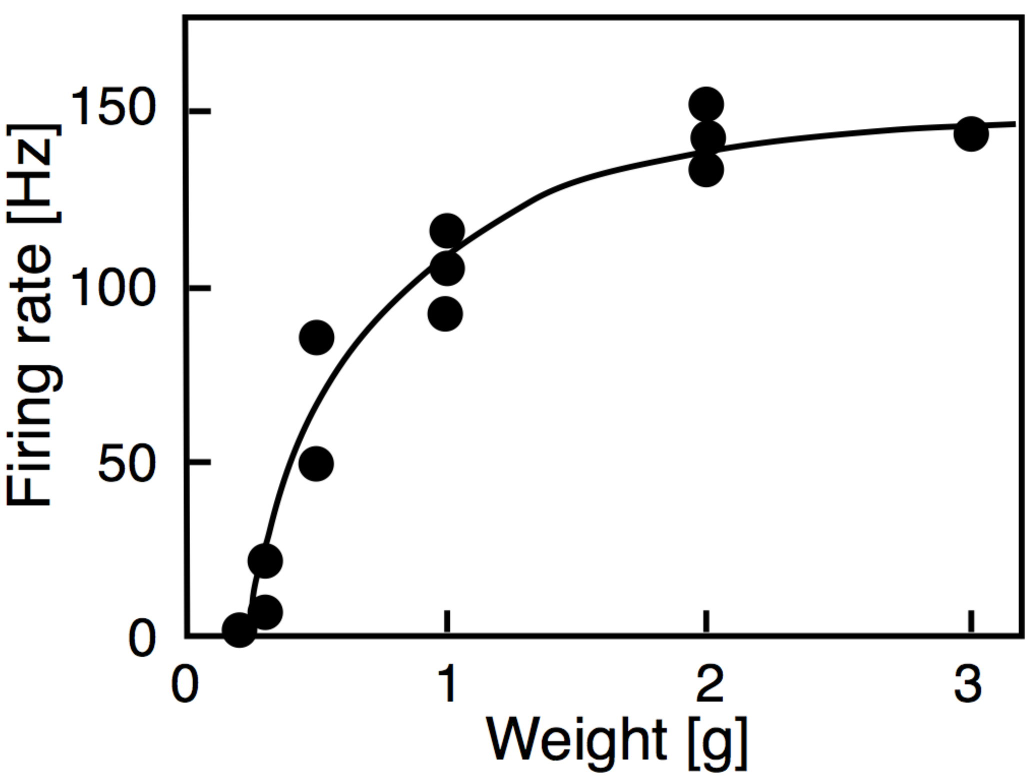
Rate-based Models

Closing Remarks

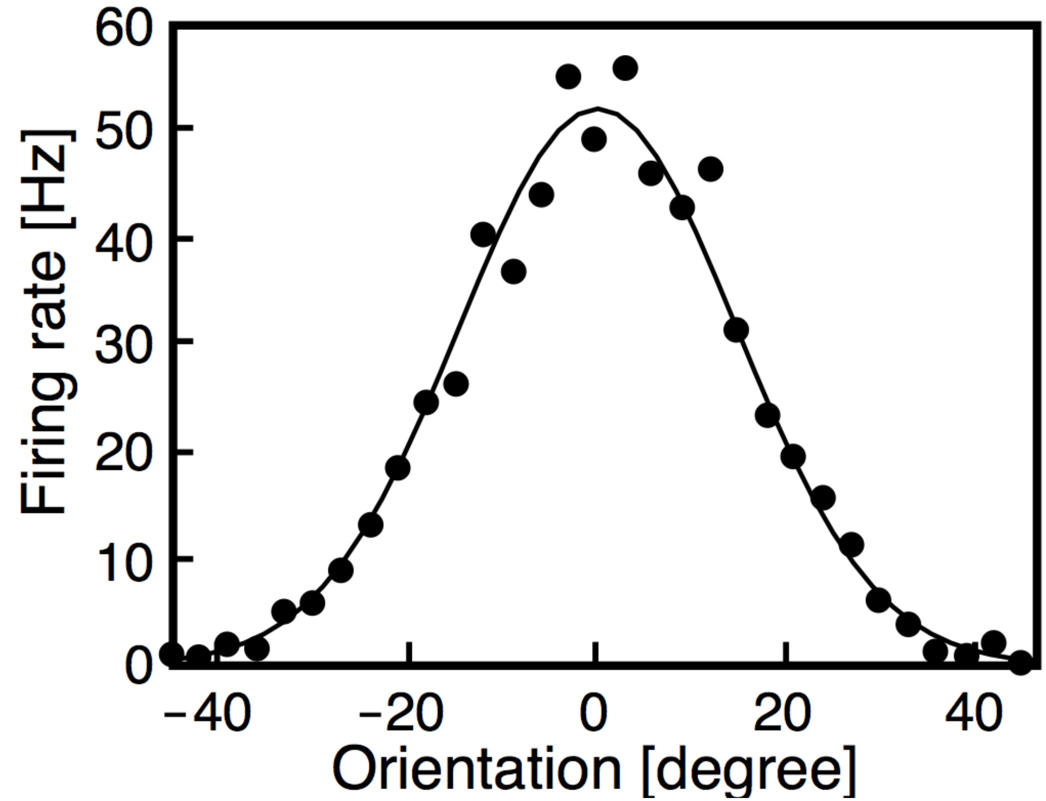
一顆神經元的 Rate Coding

Firing rate 表徵刺激或反應強度

Stretch receptor on frog muscle

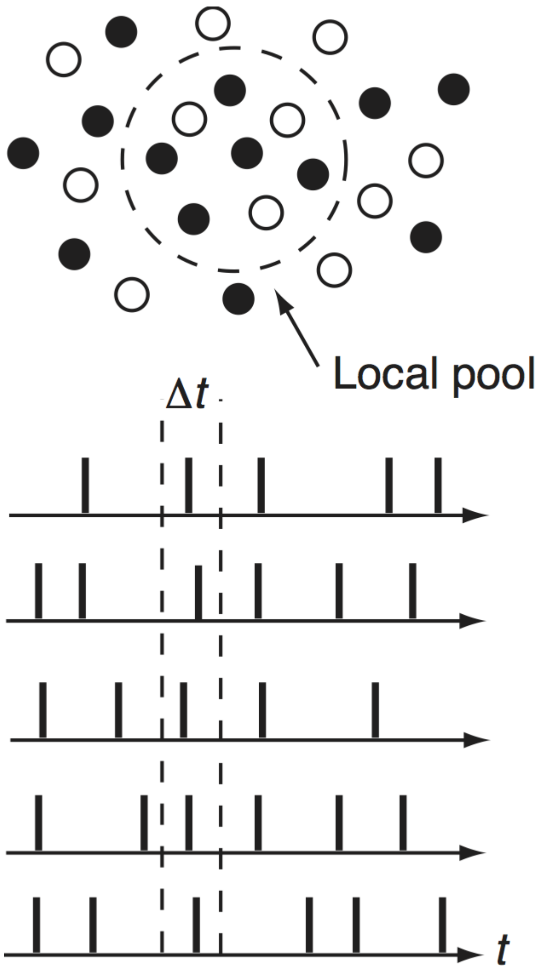


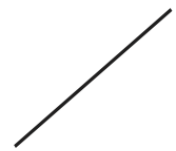
Tuning curve of V1 neuron in cat



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)

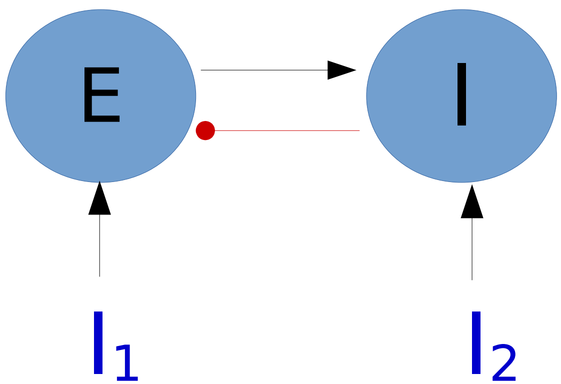
Bad additive inhibition !

$$s_E = W_{EE} * E \boxed{- W_{EI} * I} + h_E$$

$$s_I = W_{IE} * E \boxed{- W_{II} * I} + h_I.$$

$$\frac{dE}{dt} = -\alpha E + (1 - E) * \boxed{f(s_E)}$$

$$\frac{dI}{dt} = -\alpha I + (1 - I) * \boxed{f(s_I)},$$



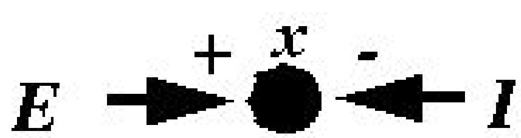
若爆掉則可被 activation/signal function 修正 !

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

1 Spiking Neuron

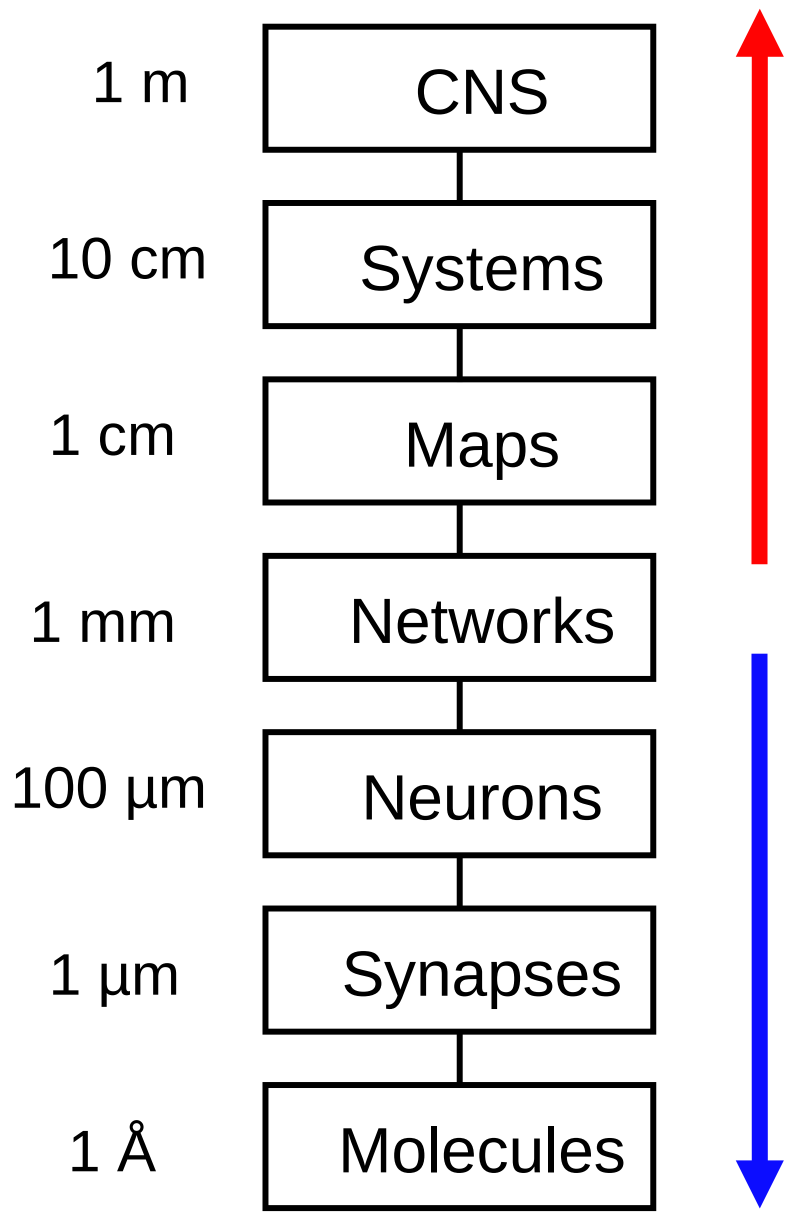
2 Spiking Neurons

N Spiking Neurons

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

Models across Scales

Correspondence Principle:

Molecules/Ion-Channels → Neurons → Networks → Behavior

Mechanistic

↓

Descriptive → Mechanistic

↓

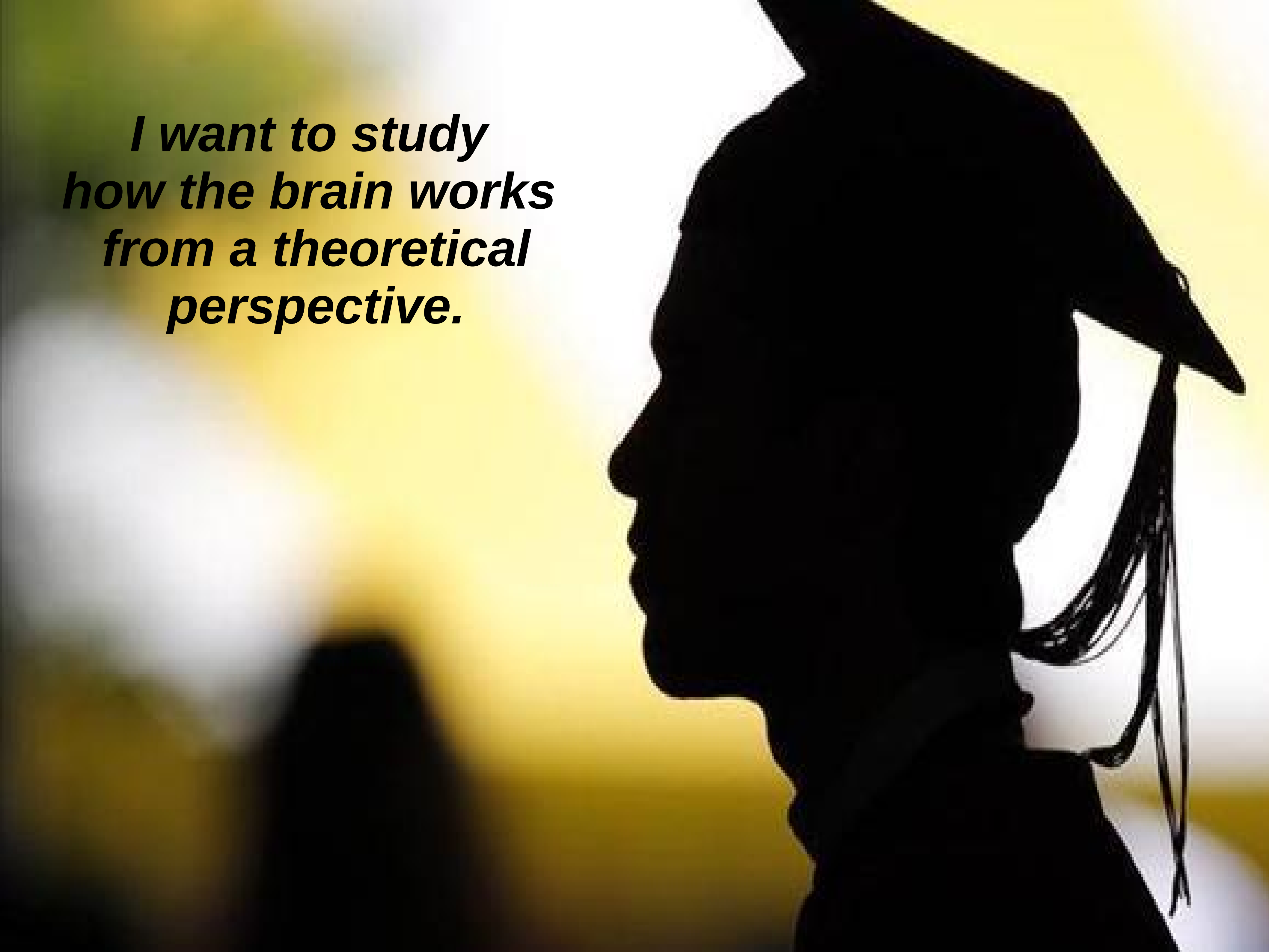
Descriptive → Mechanistic

↓

Descriptive → Mechanistic

Reviewing the Whole Semester

週次	日期	單元主題
第1週	9/5	Course Introduction: Models & modeling
第2週	9/12	Behavioral Modeling (1/2): System dynamics
第3週	9/19	Behavioral Modeling (2/2): Agent-based modeling
第4週	9/26	Computational Cognitive Science (1/2): Basics
第5週	10/3	Computational Cognitive Science (2/2): Advanced
第6週	10/10	國慶日放假
第7週	10/17	Computational Cognitive Neuroscience (1/3): Modeling principles & canonical neural computation
第8週	10/24	Computational Cognitive Neuroscience (2/3): Neural Networks
第9週	10/31	Computational Cognitive Neuroscience (3/3): Learning & Memory
第10週	11/7	Deep-learning Neural Networks (1/4): Fully-Connected Multilayer Perceptron (MLP)
第11週	11/24	Deep-learning Neural Networks (2/4): Convolutional Neural Network (CNN)
第12週	11/21	Deep-learning Neural Networks (3/4): Recurrent Neural Networks (RNN)
第13週	11/28	Deep-learning Neural Networks (4/4): Deep Reinforcement Learning (RL) & Advanced Networks
第14週	12/5	Computational Neuroscience (1/2): 1 spiking neuron
第15週	12/12	Computational Neuroscience (2/2): N spiking neuron
第16週	12/19	無期末考/課程



I want to study how the brain works from a theoretical perspective.

Heat Equation: Source Code

我大一 (1998) 寫的 Fortran 77 程式還健在

tren — tren@linux1:~/fortran — ssh — 71×16

```
[tren@linux1 fortran]$ ls -lt
total 68
-rwxr-xr-x 1 tren ra         14728 Jun 17 11:18 a.out
-rw-r--r-- 1 tren ra         15768 Jun 17 11:18 heat.o
-rw-r--r-- 1 tren csieguest   3107 Sep 11  2003 ran2.dat
-rw-r--r-- 1 tren csieguest    214 Sep 11  2003 ran2.f
-rw-r--r-- 1 tren csieguest   4224 Sep 11  2003 conf.f
-rw-r--r-- 1 tren csieguest   5009 Sep 11  2003 ranmar.f
-rw-r--r-- 1 tren csieguest   3104 Sep 11  2003 ran1.dat
-rw-r--r-- 1 tren csieguest    166 Sep 11  2003 ran1.f
-rw-r--r-- 1 tren csieguest   1758 Aug 26  2003 heat.f
[tren@linux1 fortran]$
```

Heat Equation: Executable File

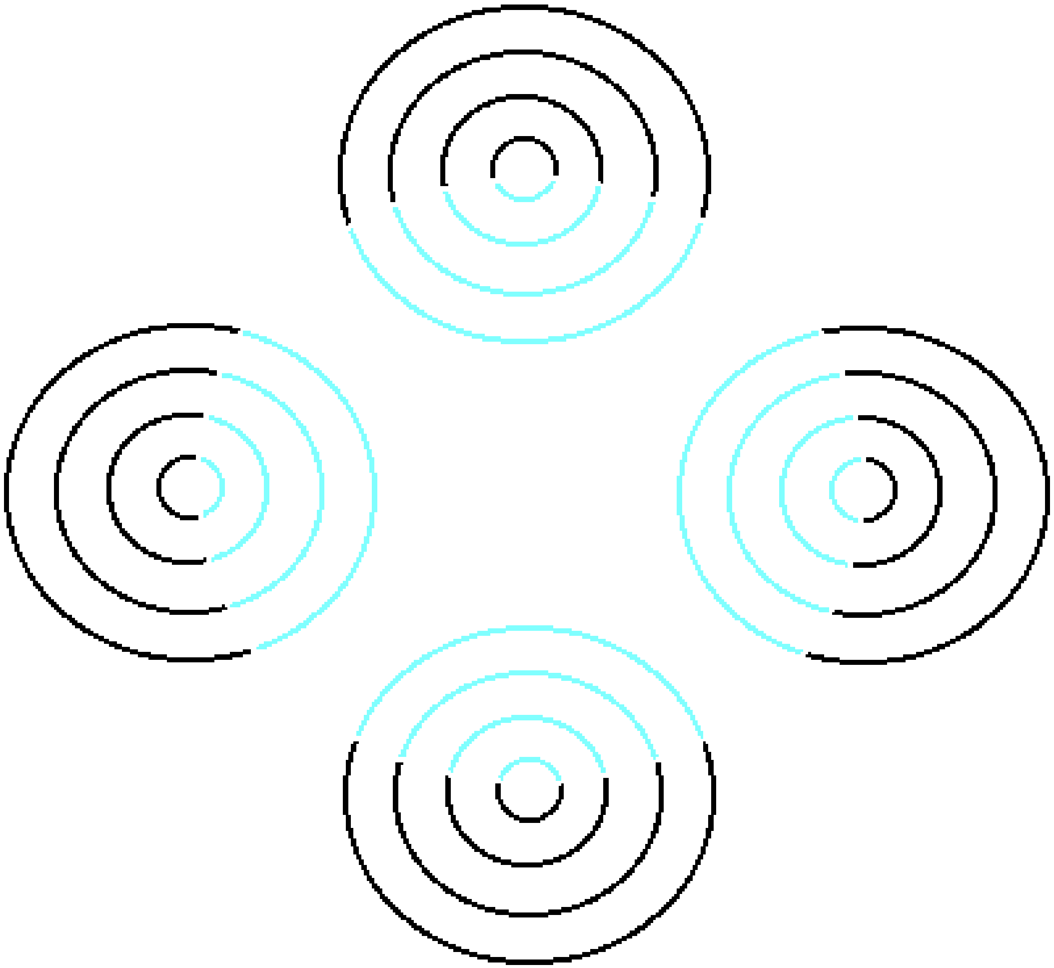
而且它還能跑！

tren — tren@linux1:~/fortran — ssh — 90×21

```
[tren@linux1 fortran]$ ./a.out
   -1  -1  -1  -1  -1  99  95  89  81  66  28  13   5   1  -1  -1  -1  -1  -1
   -1  -1  -1 100  96  91  85  78  69  55  35  22  13   7   3   0  -1  -1  -1
   -1  -1  99  94  89  83  77  70  61  50  37  26  18  11   7   3   0  -1  -1
   -1 100  94  88  83  77  70  63  55  46  36  28  20  14   9   6   3   0  -1
   -1  96  89  83  77  71  64  58  50  43  35  28  21  16  11   7   4   2  -1
   99  91  83  77  71  65  59  53  46  40  33  27  21  16  12   8   5   3   0
   95  85  77  70  64  59  53  48  42  37  31  26  21  16  12   9   6   3   1
   89  78  70  63  58  53  48  43  38  33  29  24  20  16  12   9   6   4   2
   81  69  61  55  50  46  42  38  34  30  26  22  18  15  12   9   6   4   2
   66  55  50  46  43  40  37  33  30  27  23  20  17  14  11   8   6   4   2
   28  35  37  36  35  33  31  29  26  23  21  18  15  12  10   8   5   3   2
   13  22  26  28  28  27  26  24  22  20  18  15  13  11   9   7   5   3   1
    5  13  18  20  21  21  21  20  18  17  15  13  11   9   8   6   4   2   1
    1   7  11  14  16  16  16  16  15  14  12  11   9   8   6   5   3   2   0
   -1   3   7   9  11  12  12  12  12  11  10   9   8   6   5   3   2   1  -1
   -1   0   3   6   7   8   9   9   9   8   8   7   6   5   3   2   1   0  -1
   -1  -1   0   3   4   5   6   6   6   6   5   5   4   3   2   1   0  -1  -1
   -1  -1  -1   0   2   3   3   4   4   4   3   3   2   2   1   0  -1  -1  -1
   -1  -1  -1  -1  -1   0   1   2   2   2   2   1   1   0  -1  -1  -1  -1  -1
[tren@linux1 fortran]$
```

Diffusion in BCS-FCS

我博一 (2004) 再次與擴散方程的相遇



你

“在下”

在下的 老師


你知道的太多了
You know too much


Game Over

全劇終