Structure of Neuronal Correlation: Distance, Dynamics and Depth

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Zohary, Shadlen & Newsome (1994)

Averbeck, Latham & Pouget (2006)
Structure of neuronal correlation
Structure of neuronal correlation

• Distance
Structure of neuronal correlation

• Distance
  • Spatial extent
  • Tuning similarity
Structure of neuronal correlation

• Distance
  - Spatial extent
  - Tuning similarity

• Dynamics
Structure of neuronal correlation

• Distance
  Spatial extent
  Tuning similarity

• Dynamics
  Spontaneous vs Evoked
  Transition between states
Structure of neuronal correlation

- **Distance**
  - Spatial extent
  - Tuning similarity

- **Dynamics**
  - Spontaneous vs Evoked
  - Transition between states

- **Depth**
Structure of neuronal correlation

- **Distance**
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- **Depth**
  - Laminar variation
  - Correlation outside V1
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Methods

- Anesthetized macaque monkeys
- V1 array implants
- Stimulus with compromise parameters
Spatial scale of functional connections

Slow timescale

$r_{sc} = 0.30$

Response cell 1 (Z-score)

Response cell 2 (Z-score)
Spatial scale of functional connections

Slow timescale

Smith & Kohn (2008)
Spatial scale of functional connections

Slow timescale

Spike count correlation ($r_{sc}$)

Distance between electrodes (mm)

Percentage of pairs

$n=4490$

Smith & Kohn (2008)
Spatial scale of functional connections

Fast timescale

Smith & Kohn (2008)
Spatial scale of functional connections

Fast timescale

Area under CCG peak (+/- 10ms)

Distance between electrodes (mm)

n=4490

Smith & Kohn (2008)
Spatial scale of functional connections

Area under CCG peak (+/- 10ms)

Distance between electrodes (mm)

Spike count correlation ($r_{sc}$)

Distance between electrodes (mm)

Smith & Kohn (2008)
What about distances > 4 mm?

Smith & Kohn (2008)
What about distances > 4 mm?
What about distances > 4 mm?

Thomas recording
7-electrode microdrive

4 mm
Spatial scale of functional connections

Slow timescale (long distance)

Smith & Kohn (2008)
Dependence on tuning similarity ($r_{\text{signal}}$)

$r_{\text{signal}} \approx 1.0$

(range from -1 to 1)
Dependence on tuning similarity ($r_{\text{signal}}$)

$\approx -1.0$ (range from -1 to 1)
Dependence on tuning similarity ($r_{\text{signal}}$)

Normalized response

Orientation (degrees)

$\begin{align*}
  r_{\text{signal}} & \approx 0.2 \\
  \text{(range from -1 to 1)}
\end{align*}$
Dependence on tuning similarity ($r_{signal}$)

**Slow timescale**

- Distance between electrodes (mm)
- Orientation tuning similarity ($R_{signal}$)
- Spike count correlation ($r_{sc}$)

**Fast timescale**

- Distance between electrodes (mm)
- Orientation tuning similarity ($R_{signal}$)
- Area under CCG peak (+/- 10ms)

Smith & Kohn (2008)
Does this structure extend outside V1?
Does this structure extend outside V1?

- Awake animals
- V4 array implant
- Fixation task
- Same stimulus

Smith & Sommer (2010, SfN Abstract)
Spatial scale of functional connections

Slow timescale

Distance (mm)

$\rho_{sc}$

Monkey 1

Monkey 2

Smith & Sommer (2010, SfN Abstract)
Dependence on tuning similarity ($r_{signal}$)

Slow timescale

- **Monkey 1** (red line)
- **Monkey 2** (black line)

The graph shows the dependence of tuning similarity ($r_{signal}$) on $r_{signal}$ with data points and error bars for both monkeys. The x-axis represents $r_{signal}$ ranging from -1 to 1, while the y-axis shows the value of $r_{sc}$. The trend suggests a positive correlation between tuning similarity and $r_{signal}$.
Spike count correlation

Smith & Sommer (2010, SfN Abstract)
Spike count correlation

Synchrony

Distance (mm)

Spike count correlation

Synchrony

Smith & Sommer (2010, SfN Abstract)
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  - $r_{sc}$ extends over long distances; synchrony only short range

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  • $r_{sc}$ extends over long distances; synchrony only short range
  • at all distances, correlation higher with similar orientation preference

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Proportion of pairs

Spike count correlation ($r_{sc}$)

Evoked

$n = 4488$
7 implants

0.18

Smith & Kohn (2008)
Proportion of pairs

Spike count correlation ($r_{sc}$)

Evoked
- $n = 4488$
- 7 implants
- $r_{sc} = 0.18$

Spontaneous
- $n = 2738$
- 6 implants
- $r_{sc} = 0.31$

Smith & Kohn (2008)
Proportion of pairs

Spike count correlation ($r_{sc}$)

**Evoked**

- $n = 4488$
- 7 implants
- $0.18$

**Spontaneous**

- $n = 2738$
- 6 implants
- $0.31$
Proportion of pairs

Spike count correlation ($r_{sc}$)

Evoked

1.28 s 1.5 s 1.28 s

Spontaneous

n = 4488 7 implants

n = 2738 6 implants

Spike count correlation ($r_{sc}$)
Proportion of pairs

Spike count correlation ($r_{sc}$)

Evoked

- $n = 4488$
- 7 implants

Spontaneous

- $n = 2738$
- 6 implants

Evoked

- 1.28 s
- 1.5 s
- 1.28 s

Spontaneous

- many seconds
- 1.28 s

Histograms show the proportion of pairs with different spike count correlations ($r_{sc}$) for evoked and spontaneous conditions.
Transition from evoked to spontaneous
Transition from evoked to spontaneous
Transition from evoked to spontaneous

1.28 s

10 s

1.28 s

100 ms

100 ms

100 ms
Transition from evoked to spontaneous

1.28 s

10 s

1.28 s

100 ms

100 ms

100 ms
Transition from evoked to spontaneous
Transition from evoked to spontaneous
Transition from evoked to spontaneous
Transition from evoked to spontaneous
n = 3367
3 implants
Time (seconds)

Firing rate (sp/s)

n = 3367
3 implants
Firing rate (sp/s)

Time (seconds)

n = 3367
3 implants
n = 3367
3 implants
n = 3367
3 implants
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• **Dynamics**
  - correlation is higher in spontaneous activity than evoked

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Structure of neuronal correlation

• Distance
  - \( r_{sc} \) extends over long distances; synchrony only short range
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• Dynamics
  - correlation is higher in spontaneous activity than evoked
  - sharply reduced at stimulus onset, returns slowly to higher levels at stimulus offset

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Dorsal

Anterior

Smith & Kohn (2009, SfN Abstract)
Figure 13: Nissl stain of the visual cortex reveals the different layers I through VI quite clearly.
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1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.05
0.10
0.15
0.20
0.25

Depth from first recorded spikes (mm)

Spike count correlation ($r_{sc}$)
Current Source Density

Smith & Kohn (2009, SfN Abstract)
Current Source Density

Smith & Kohn (2009, SfN Abstract)
Current Source Density

Depth

Source

Sink

Time (ms)

Depth (μm)

-1200
-800
-400
0
400
800

Spike count correlation ($r_{sc}$)

0 0.1 0.2

Average of 4 penetrations

Smith & Kohn (2009, SfN Abstract)
Depth (μm)

Frequency (Hz)

Smith & Kohn (2009, SfN Abstract)
Smith & Kohn (2009, SfN Abstract)
Are the input layers of V1 special?
V1-V2 CCGs

Recording depth (spacing of ~200 μm)

200 ms

0.1 %

Smith & Kohn (2009, SfN Abstract)
V1-V2 CCGs

Recording depth (spacing of ~200)

Example penetration

Spike count correlation ($r_{sc}$)

Smith & Kohn (2009, SfN Abstract)
Proportion of cases with sharp peaks in V1–V2 CCGs: 0.17 ± 0.01

Proportion of cases without sharp peaks in V1–V2 CCGs: 0.19 ± 0.01

Smith & Kohn (2009, SfN Abstract)
Proportion of cases

Spike count correlation ($r_{sc}$)

Input layers

Layers with sharp peaks in V1–V2 CCGs

$n = 6727$

$0.17 \pm 0.01$

Not input layers

Layers without sharp peaks in V1–V2 CCGs

$n = 2296$

$0.19 \pm 0.01$

Smith & Kohn (2009, SfN Abstract)
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• **Depth**
  - Correlation high in superficial & deep layers, near zero in input layers
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  - $r_{sc}$ extends over long distances; synchrony only short range
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  - correlation is higher in spontaneous activity than evoked
  - sharply reduced at stimulus onset, returns slowly to higher levels at stimulus offset

• **Depth**
  - Correlation high in superficial & deep layers, near zero in input layers
  - No evidence for such drastic layer differences in V2
Conclusions

• Correlation has different properties on different time scales
• Correlation depends on network state (spont vs. evoked)
• Correlation varies dramatically with layer in V1, but not V2
• Some principles of correlation are common across visual cortex

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Zohary, Shadlen & Newsome (1994)

Averbeck, Latham & Pouget (2006)