On a role for competitions in computational neuroscience

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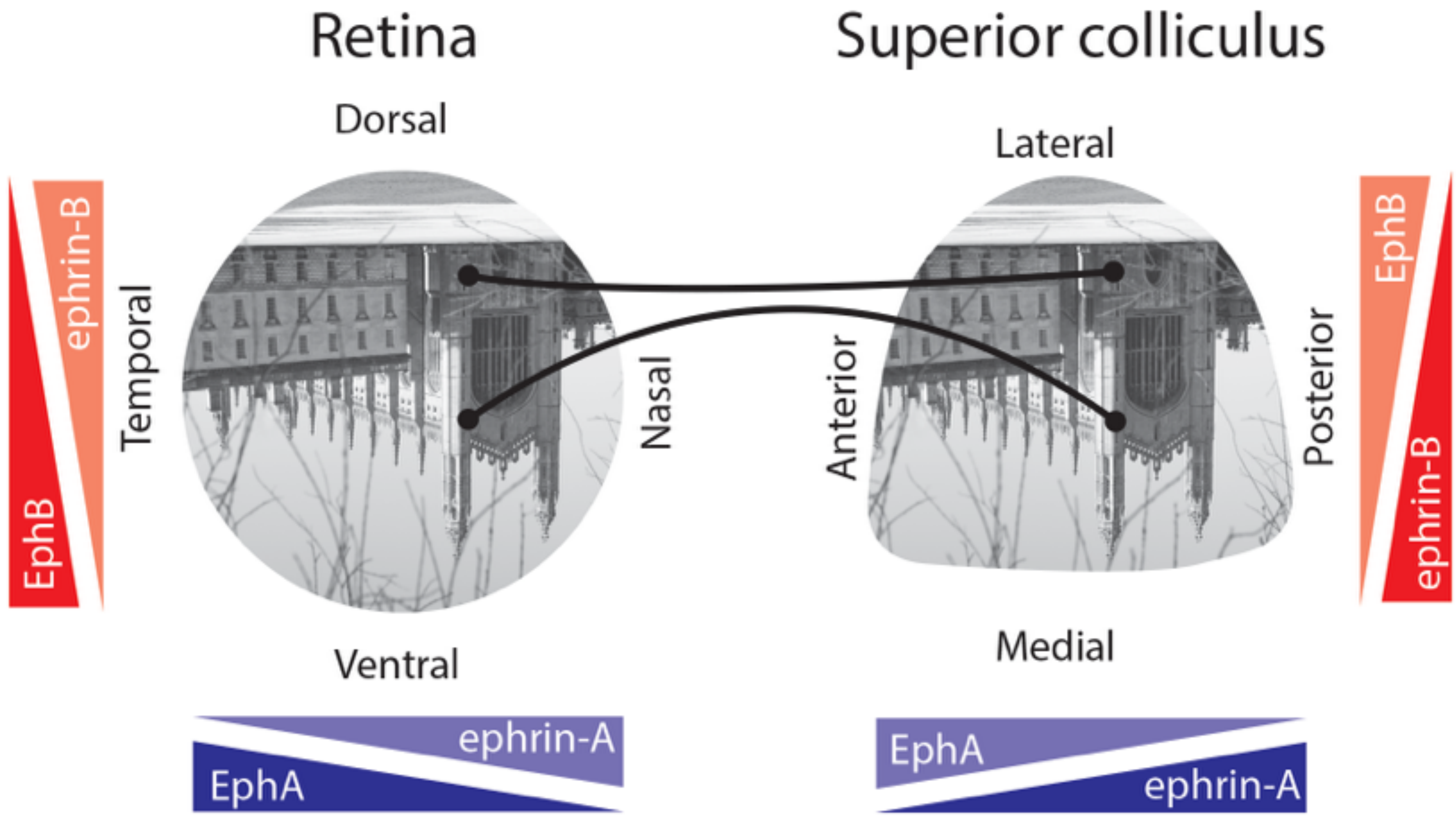
AINI 2016

Proc. R. Soc. Lond. B. **190**, 77–98 (1975)
Printed in Great Britain

On a role for competition in the formation of patterned neural connexions

By M. C. Prestige and D. J. Willshaw†



Retina
Superior colliculus
Dorsal
Ventral
Temporal
Nasal
Lateral
Medial
Anterior
Posterior
EphB
ephrin-B
EphB
ephrin-B
ephrin-A
EphA
EphA
ephrin-A

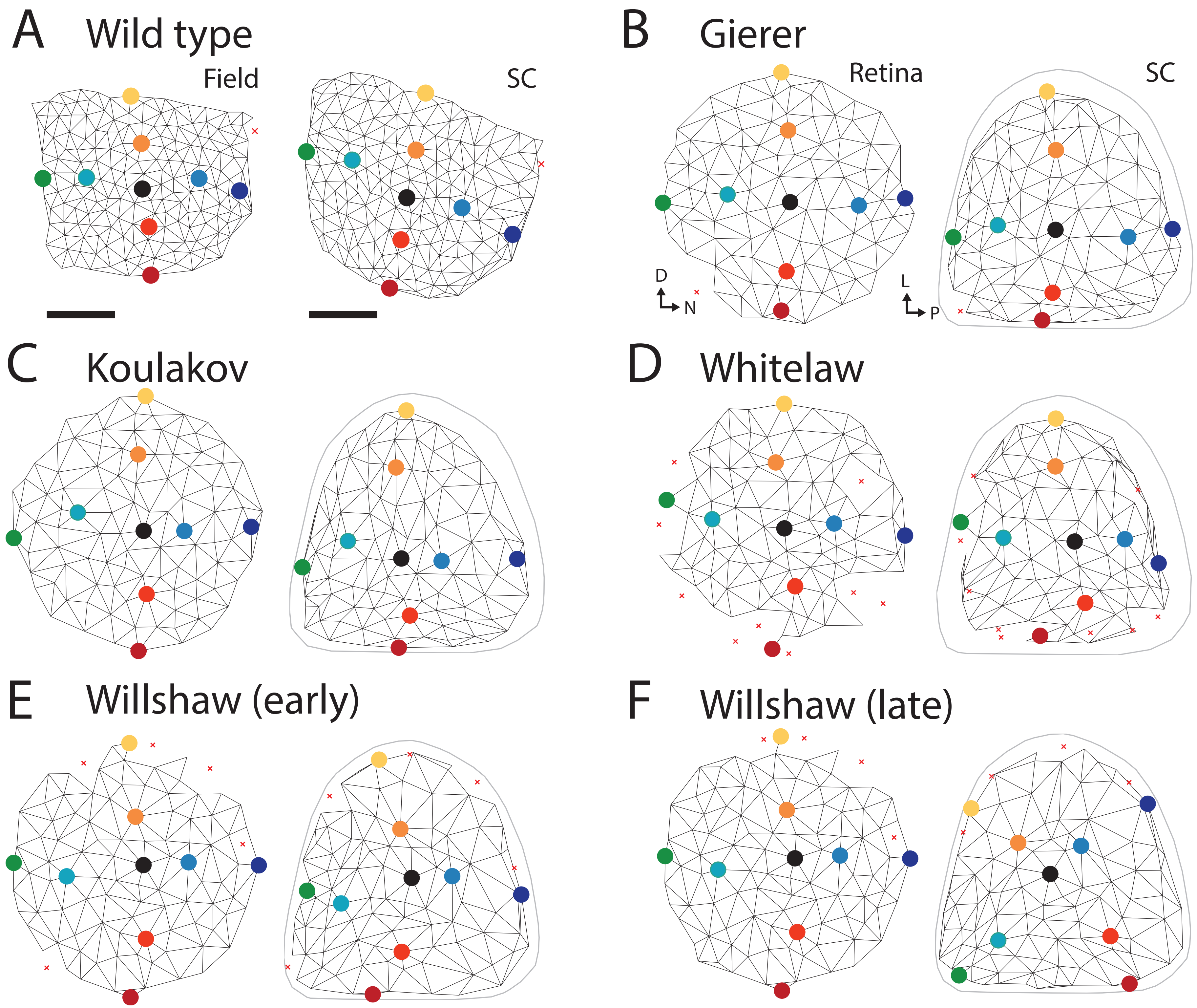
Which model works best?

- Marker induction (Willshaw, 2006)
- Activity and gradients (Whitelaw and Cowan, 1981)
- Gradients and competition (Gierer, 1983)
- Activity and gradients (Triplett, Koulakov et al. 2011)

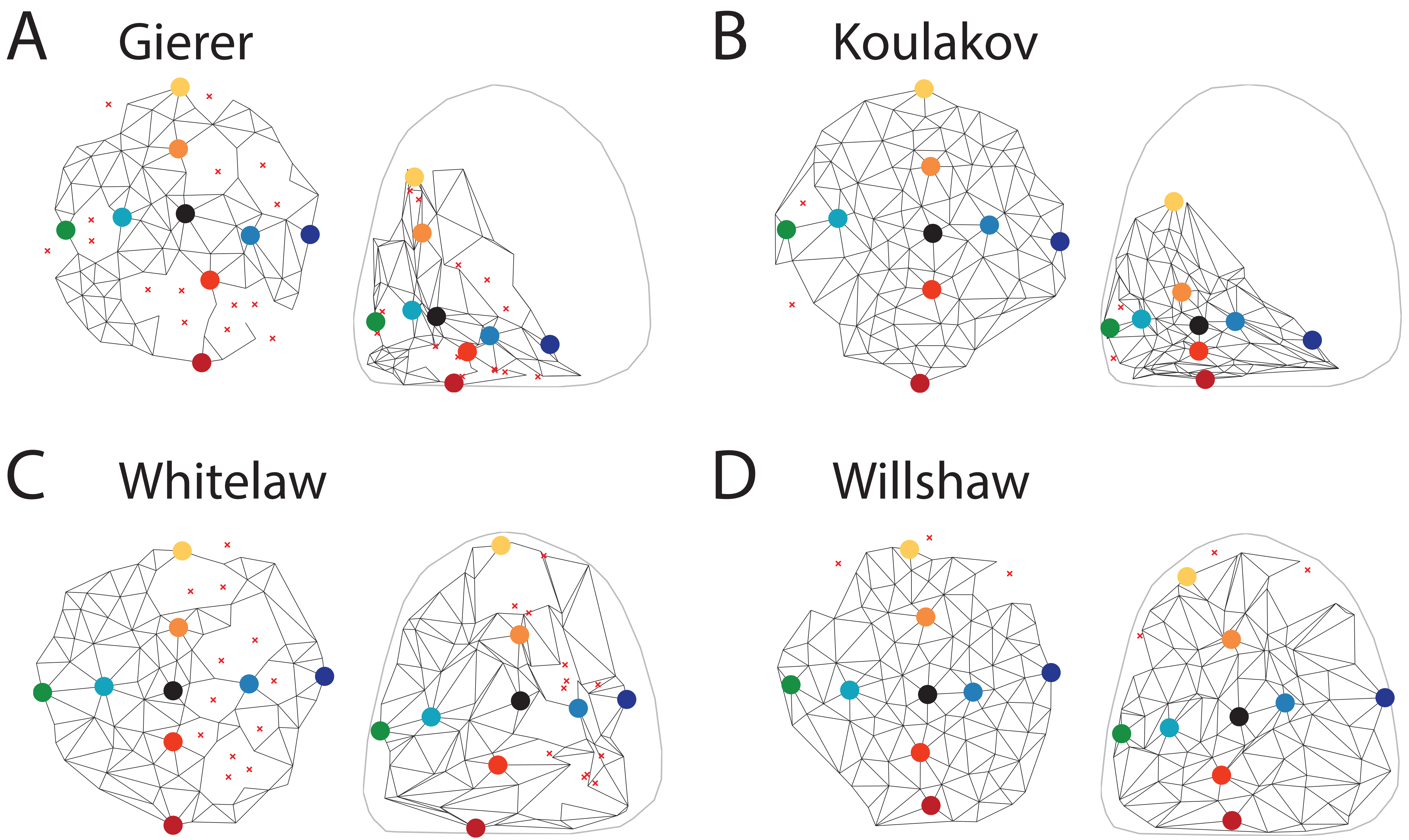
Rules of the game

- Model parameters optimised for one condition.
- Model evaluated on multiple experimental conditions.
- Where possible, experimental and simulated data analysed in same way (e.g. virtual anterograde injections).

Lattice analysis

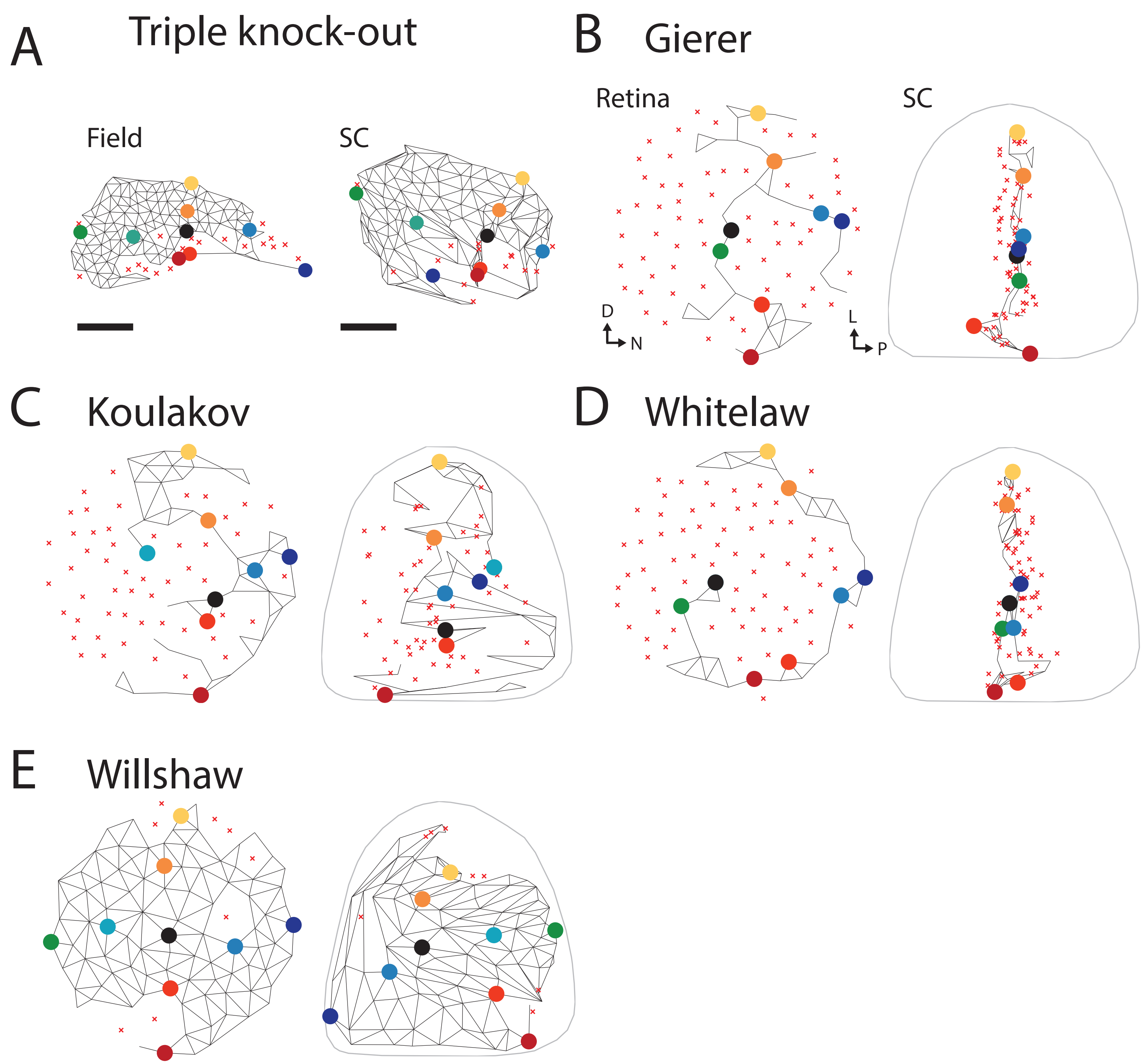


Math5 KO



(Triplett et al. 2011)

ephrin-A2/3/5 TKO



(Cang et al. 2008)

Summary

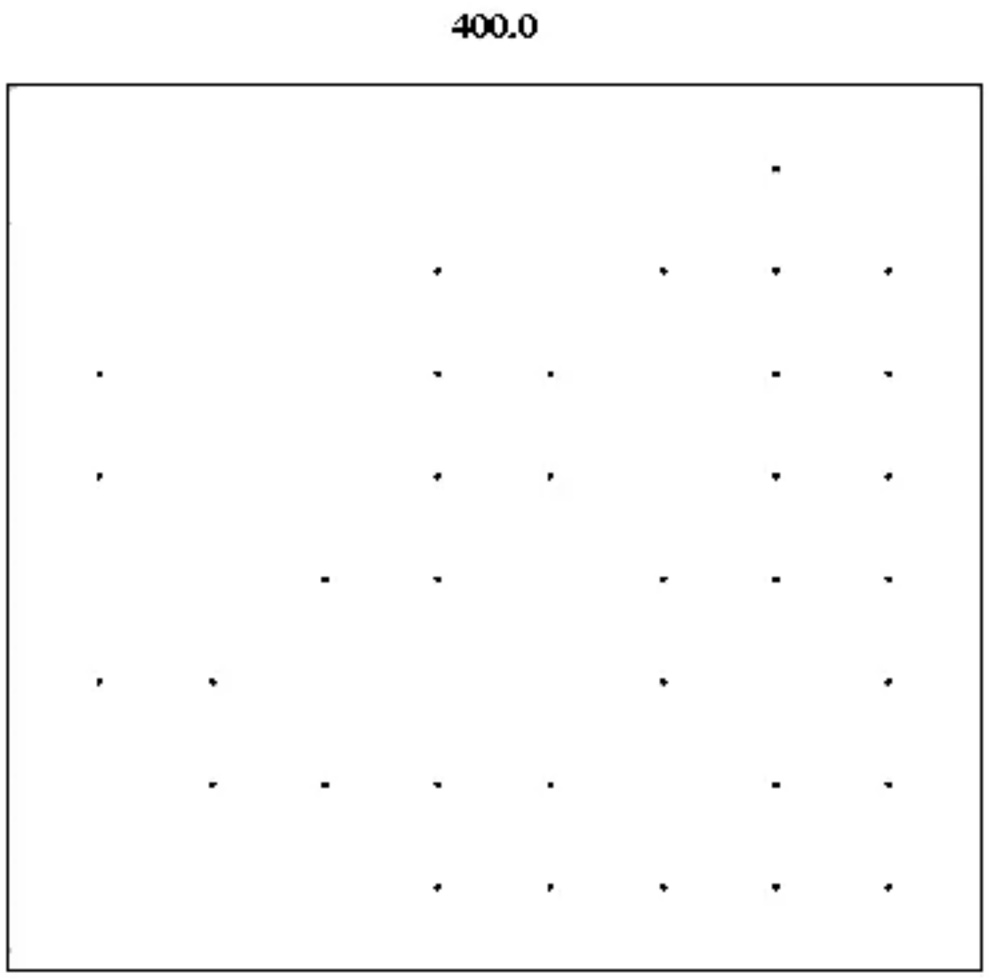
Genotype	Gierer	Koulakov	Whitelaw	Willshaw
Wild type	✓	✓	✓	* ✓
Isl2-EphA3$^{\mathrm{ki/ki}}$	Isl2^{+} misfit	Isl2^{+} misfit	* ✓	Isl2^{+} misfit
Isl2-EphA3$^{\mathrm{ki/+}}$	No collapse, Isl2^{+} misfit	* Isl2^{+} misfit	No collapse, Isl2^{+} misfit	No collapse, Isl2^{+} misfit
TKO (no gradient)	No patches	Patches but no global order	No patches	Global order but no polarity
TKO (weak gradient)	No patches	✓	No patches	Ordered map
Math5$^{-/-}$	* ✓	✓	Normal map	Normal map

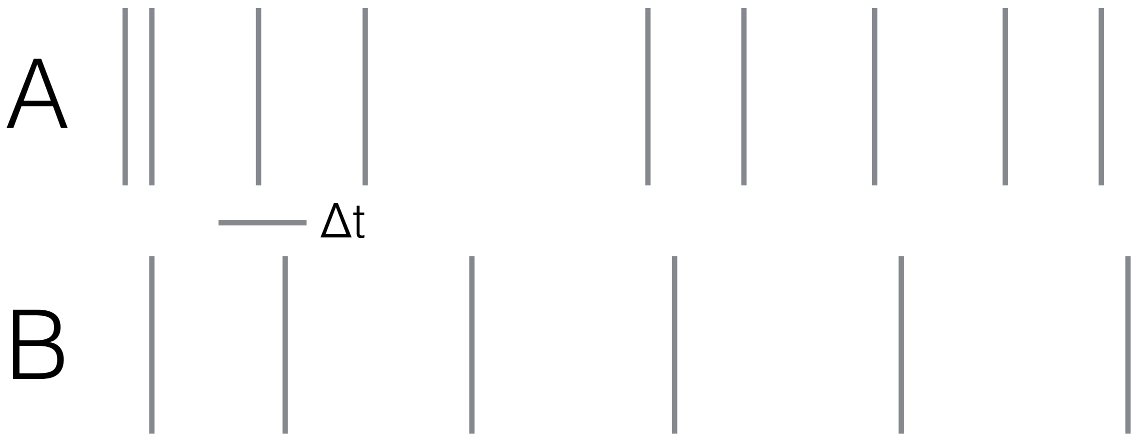
Asterisk (*) denotes which phenotype the model was optimized for.

Detecting correlations

Catherine Cutts (J Neurosci 2014)

Correlation index





$$c = \frac{N_{A,B[-\Delta t,+\Delta t]}T}{N_A N_B 2\Delta t}$$

(Wong et al. 1993; Demas et al. 2003)

Measuring correlation

Distance measures and cost functions

1 Victor and Purpura (1997)
2 ISI-distance (Kreuz et al., 2007a)
3 Hunter-Milton similarity (Hunter and Milton, 2003)
4 Van Rossum (2001)
5 SPIKE (Kreuz et al., 2013)

Cross-correlation based

6 Coincidence index (Pasquale et al., 2008)
7 Altered Coincidence index*
8 Cross correlation coefficient (Pasquale et al., 2008)
9 Schreiber et al. (2003) similarity coefficient
10 Altered Schreiber et al. similarity coefficient*
11 Kerschensteiner and Wong (2008) cross-correlation
12 Jimbo and Robinson index (Jimbo et al., 1999)

Synchrony not from cross-correlation

13 Correlation index (Wong et al., 1993)
14 Activity pair (Eytan et al., 2004)
15 Unitary events analysis (Grün et al., 2002)
16 Event synchronization (Kreuz et al., 2007b)*
17 Joris et al. (2006) correlation index

Information theory

18 Mutual information (Li, 1990)
19 Mutual information with smoothing*

Measures from shot-noise process

20 Coherence (at zero) (Eggermont, 2010)
21 Spike count correlation (Eggermont, 2010)
22 Smoothed spike count correlation (Kruskal et al., 2007)*
23 Spike count covariance (Eggermont, 2010)

Measures assuming a marked point process

24 Stoyan's K_{mm} function (Stoyan and Stoyan, 1994)
25 Isham's mark correlation function (Isham, 1985)
26 Ripley's K_{mm} function (Ripley, 1976)
27 Simpson (1949) index
28 Simpson (1949) index no correction
29 Stoyan's mark covariance function (Stoyan, 1984)
30 Mark variogram (Cressie, 1993)
31 Mark covariance function (Cressie, 1993)
32 Mark conditional expectation (E; Schlather et al., 2004)
33 Mark conditional variance (V; Schlather et al., 2004)
34 Mark conditional standard deviation (Schlather et al., 2004)

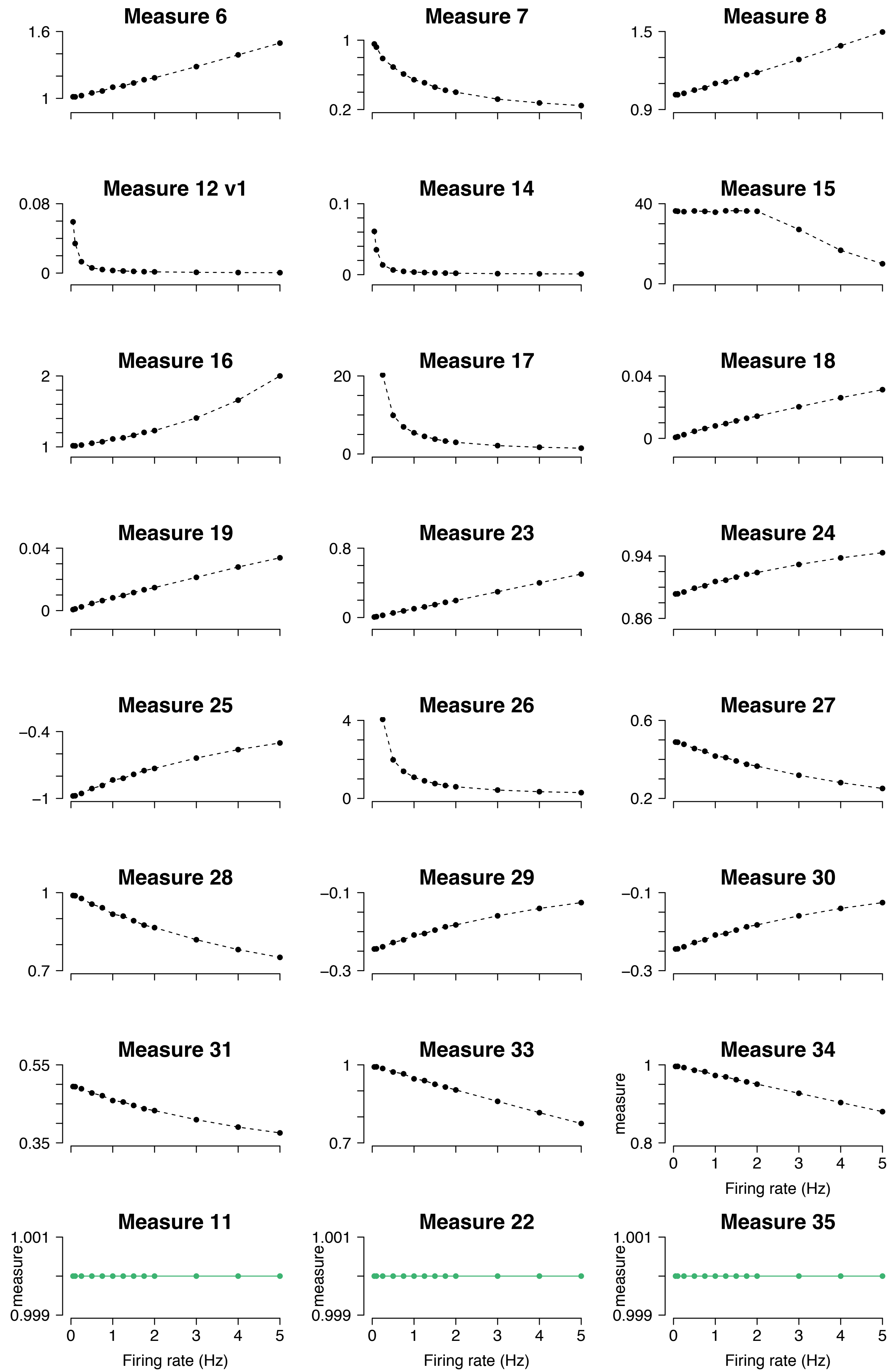
Which method is best?

- 34 measures in literature + 1 from us => 35.
- Phase 1: six necessary properties:

1. Symmetric
2. Robust to variations in firing rate
3. Robust to amount of data
4. Bounded [-1, +1]
5. Robust to variations in bin width (Δt)

Twenty-one measures rejected as they depend on firing rate.

(autocorrelation of Poisson trains)



Phase 2: Desirable properties

Desirable properties:

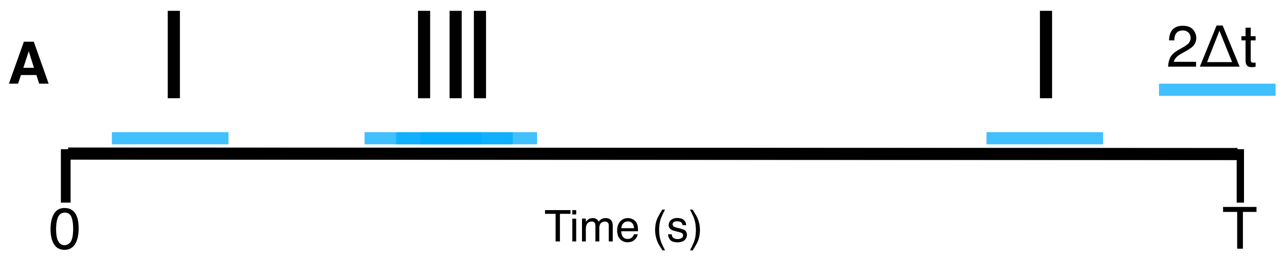
- D1: Ignore periods when both neurons are inactive.
- D2: minimal assumptions on structure.
- D3: aside from Δt, minimise number of parameters

Four methods:

- Kerschensteiner and Wong correlation (D1, D2)
- Tiling coefficient (D1, D2, D3)
- Spike count correlation (D2, D3)
- Kruskal et al. binless correlation measure (D1?, D2, D3)

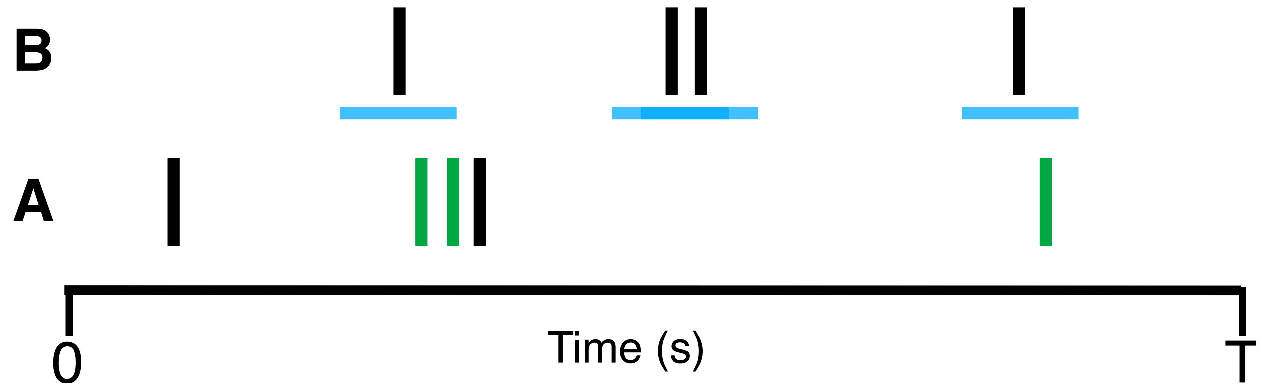
Tiling coefficient - TC

T_A: the proportion of total recording time which lies within ±Δt of any spike from A. **T_B** calculated similarly.



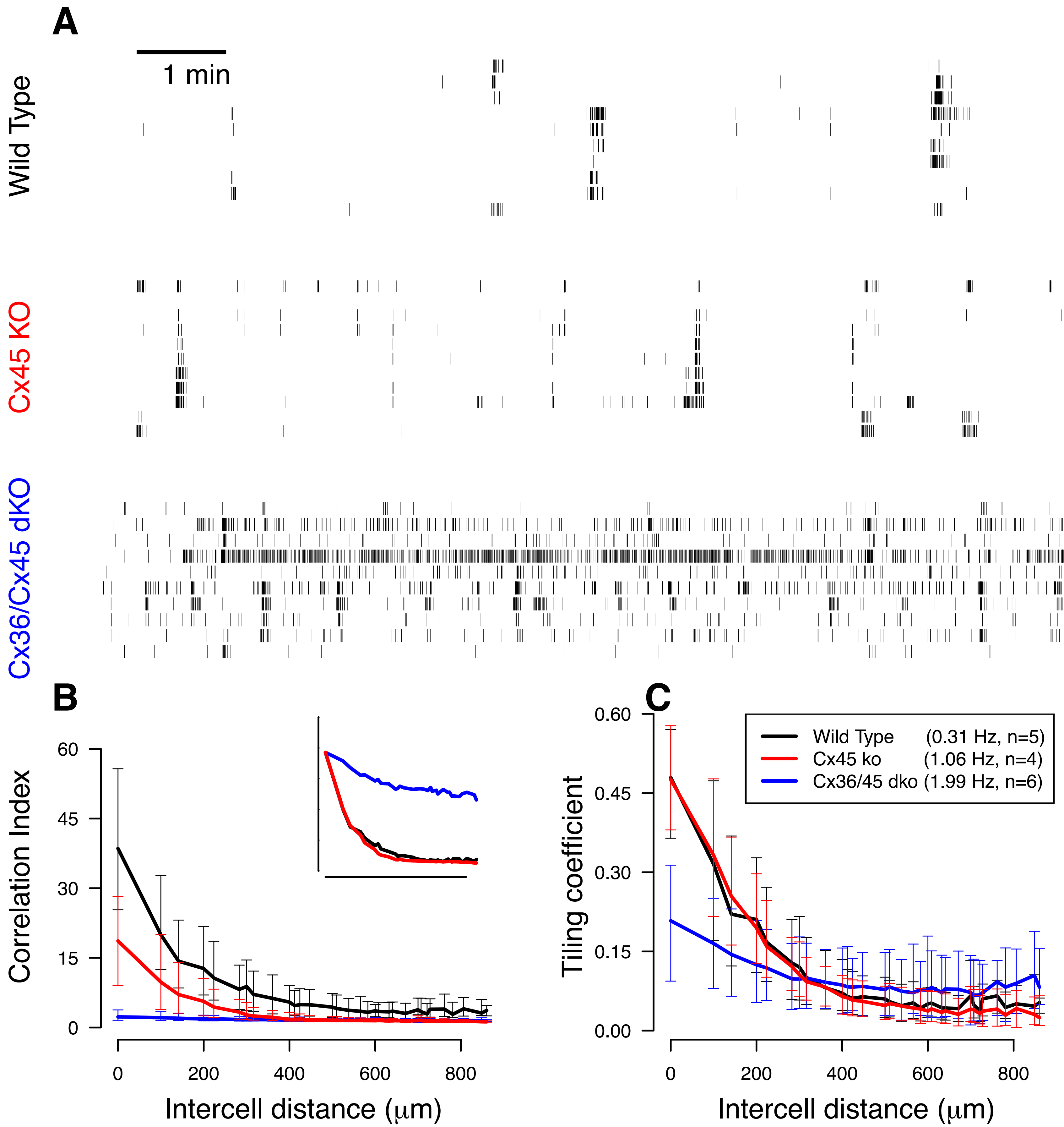
T_A is given by the fraction of the total recording time (black) which is covered (tiled) by blue bars. Here T_A is 1/3.

P_A: the proportion of spikes from A which lie within ±Δt of any spike from B. **P_B** calculated similarly.



P_A is the number of green spikes in A (3) divided by the total number of spikes in A (5). Here P_A is 3/5.

$$TC = \frac{1}{2}\left(\frac{P_A - T_B}{1 - P_A T_B} + \frac{P_B - T_A}{1 - P_B T_A}\right)$$



(Blankenship et al. 2011)

Summary

- Competitions can help frame problems in interesting ways and remove a source of bias.
- No model can account for all experimental data on mouse retinocollicular map formation.
- We now have better ways to detect correlated activity (tiling coefficient) and bursts.

Acknowledgments

Funding: EPSRC, Wellcome Trust, USIAS, BBSRC

Map formation: JJJ Hjorth, CS Cutts, DC Sterratt, DJ Willshaw

Correlations: CS Cutts

Data/code: http://damtp.cam.ac.uk/user/eglen