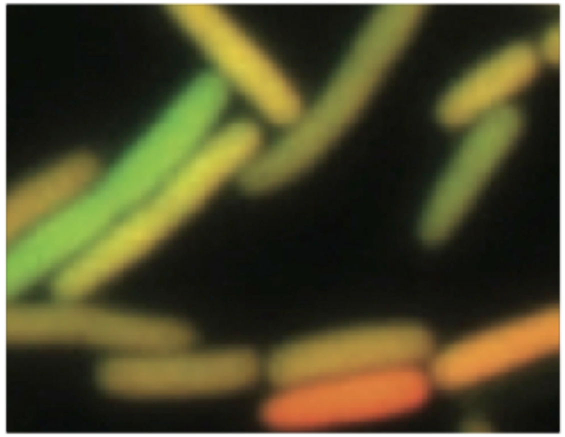
THOMAS SCHLEGEL

UNIVERSITY OF BRISTOL

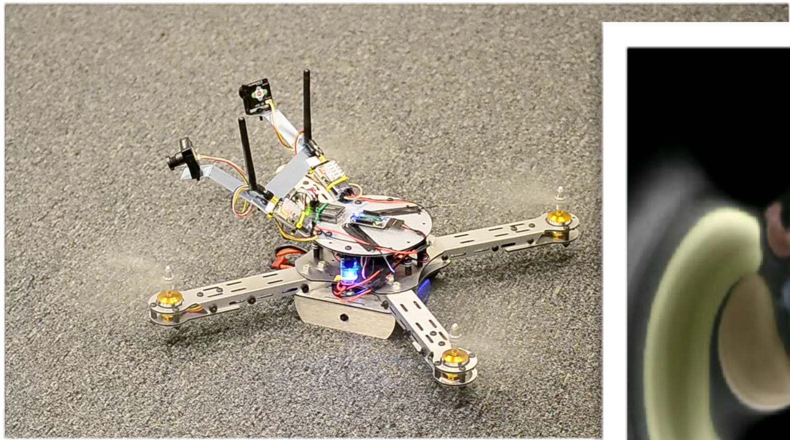


PETER SWAIN

# FROM HOUSE-HUNTING HONEYBEES TO NEURAL MODELS AND PSYCHOPHYSICS

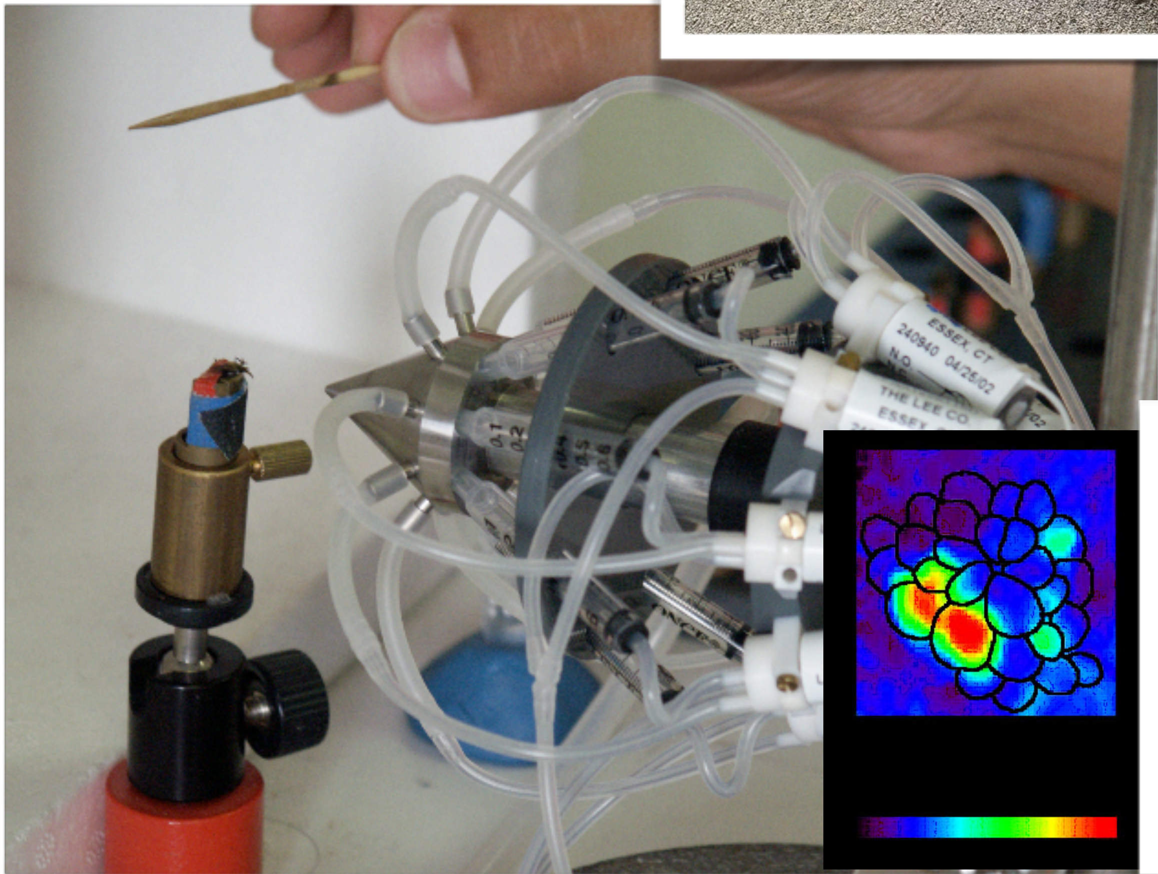
JAMES A. R. MARSHALL
DEPARTMENT OF COMPUTER SCIENCE AND KROTO RESEARCH INSTITUTE,
UNIVERSITY OF SHEFFIELD

# GREEN BRAIN




FU BERLIN

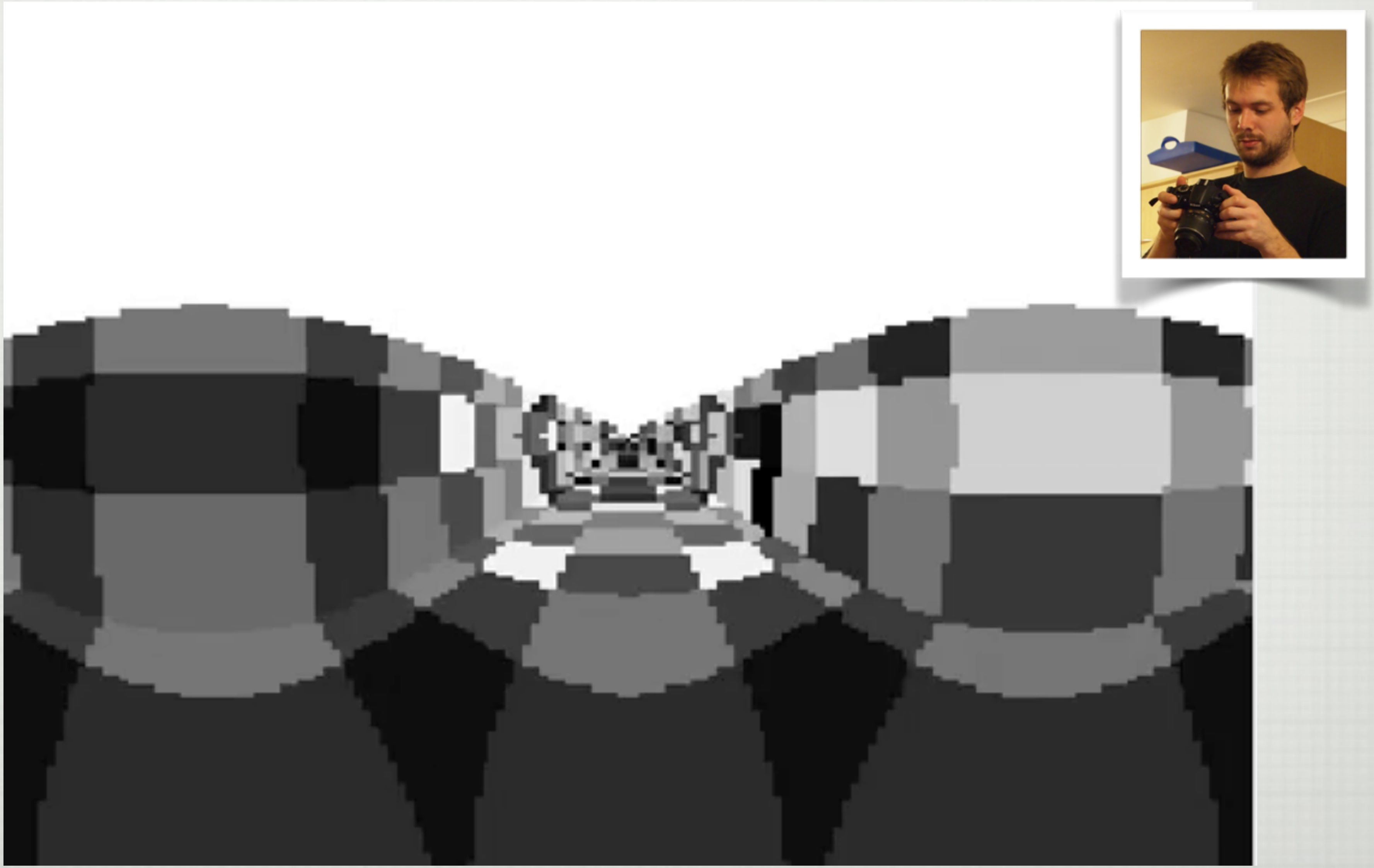
GREENBRAINPROJECT.CO.UK



UNIVERSITÉ PAUL SABATIER

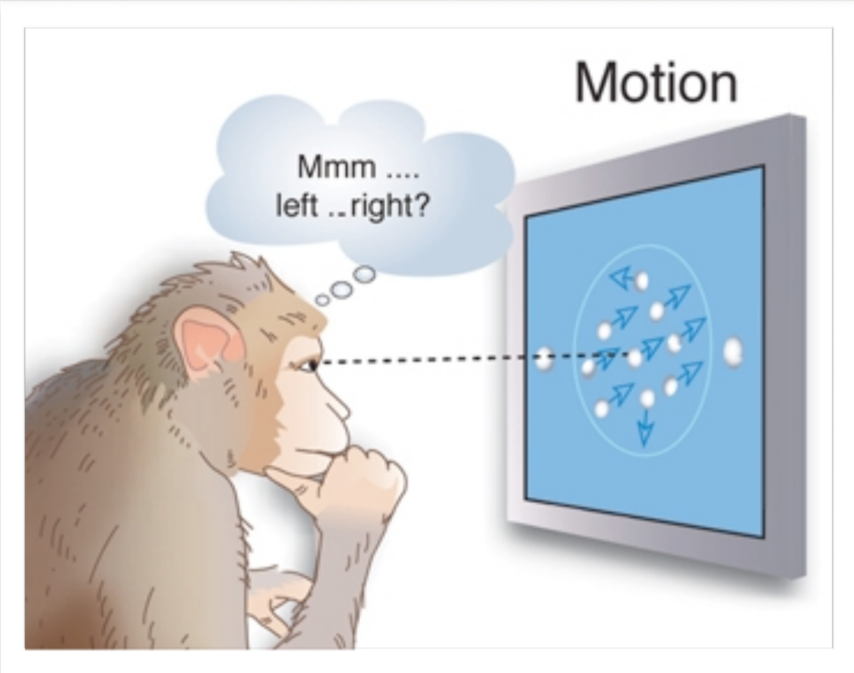

NVIDIA

# SIMULATING BEE VISION AND FLIGHT CONTROL

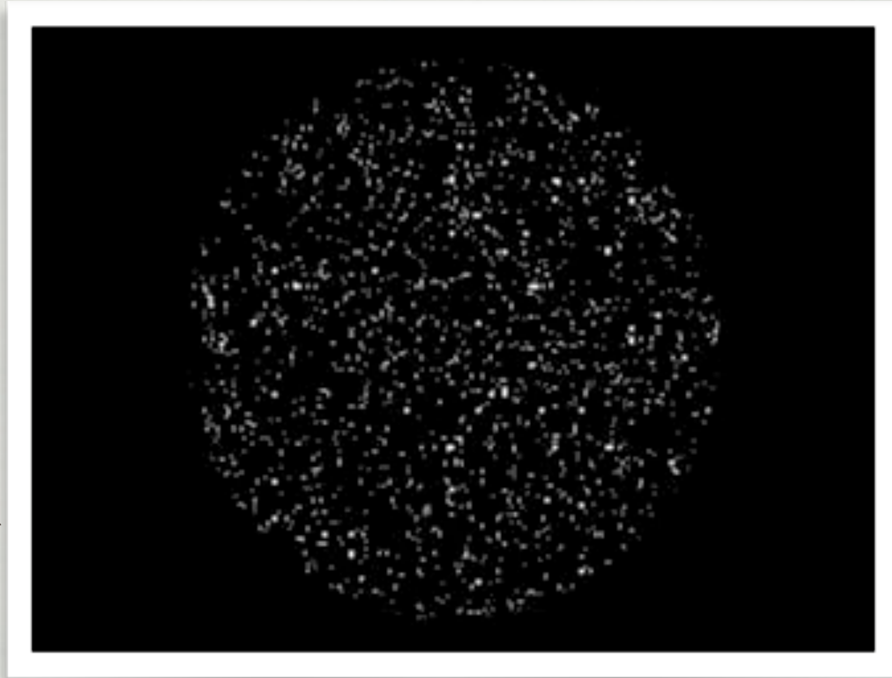


TOM SEELEY

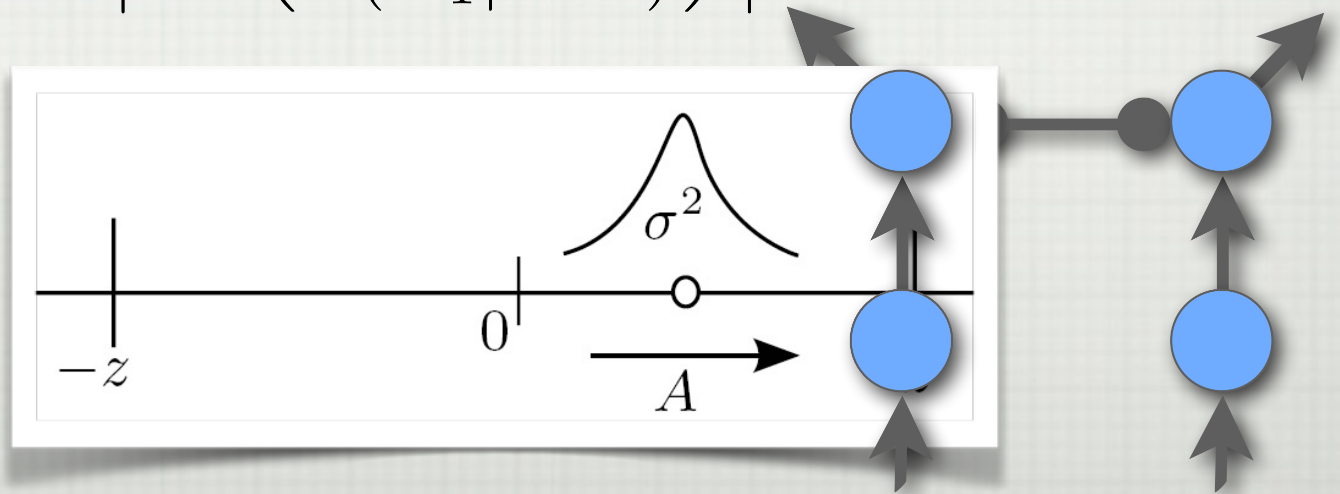
NATURE NEUROSCIENCE

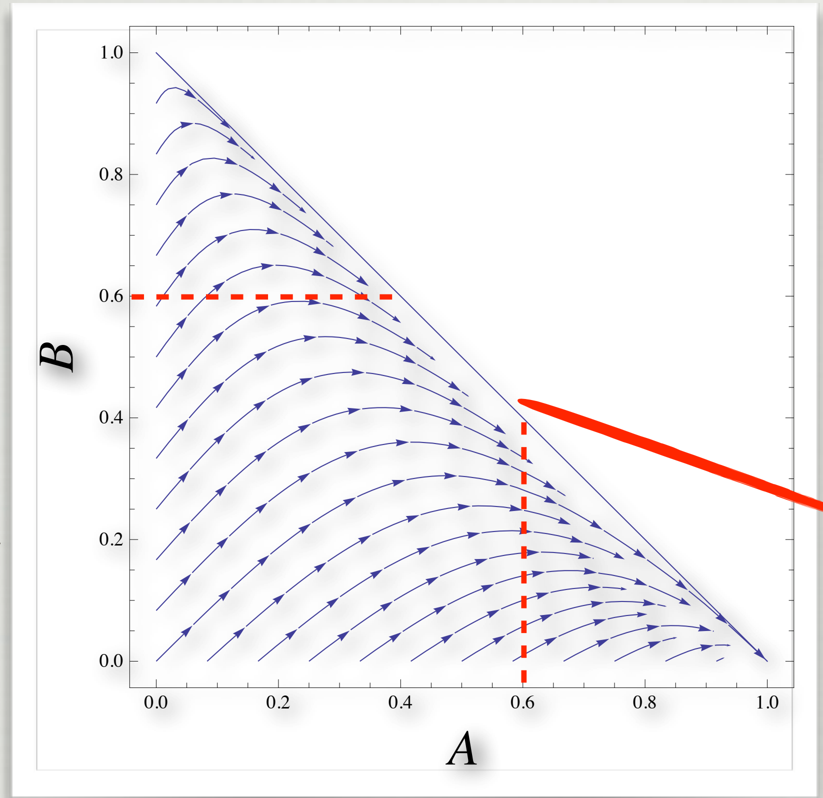



MONKEYBIZ.STANFORD.EDU



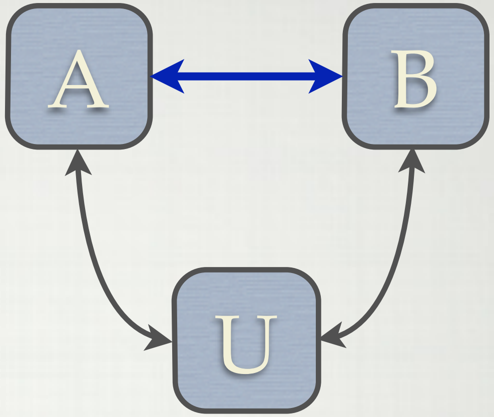
$$\left|\log\left(\frac{\mathrm{P}(H_0|\text{data})}{\mathrm{P}(H_1|\text{data})}\right)\right| > z$$






PATRICK HOGAN

KARL VON FRISCH

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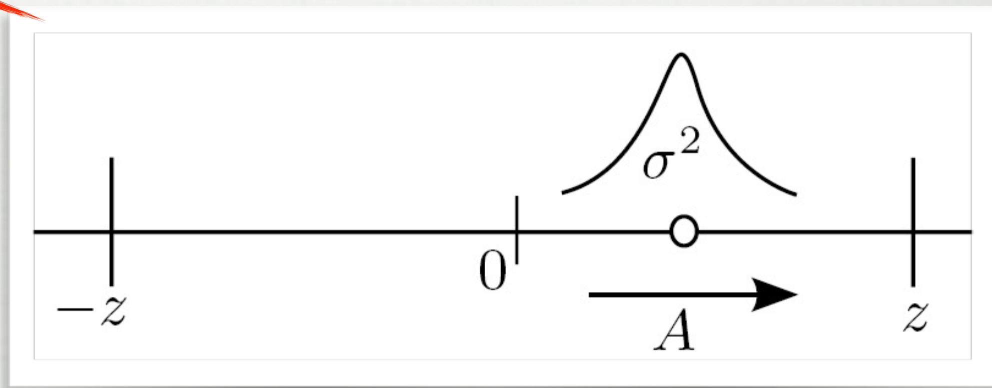


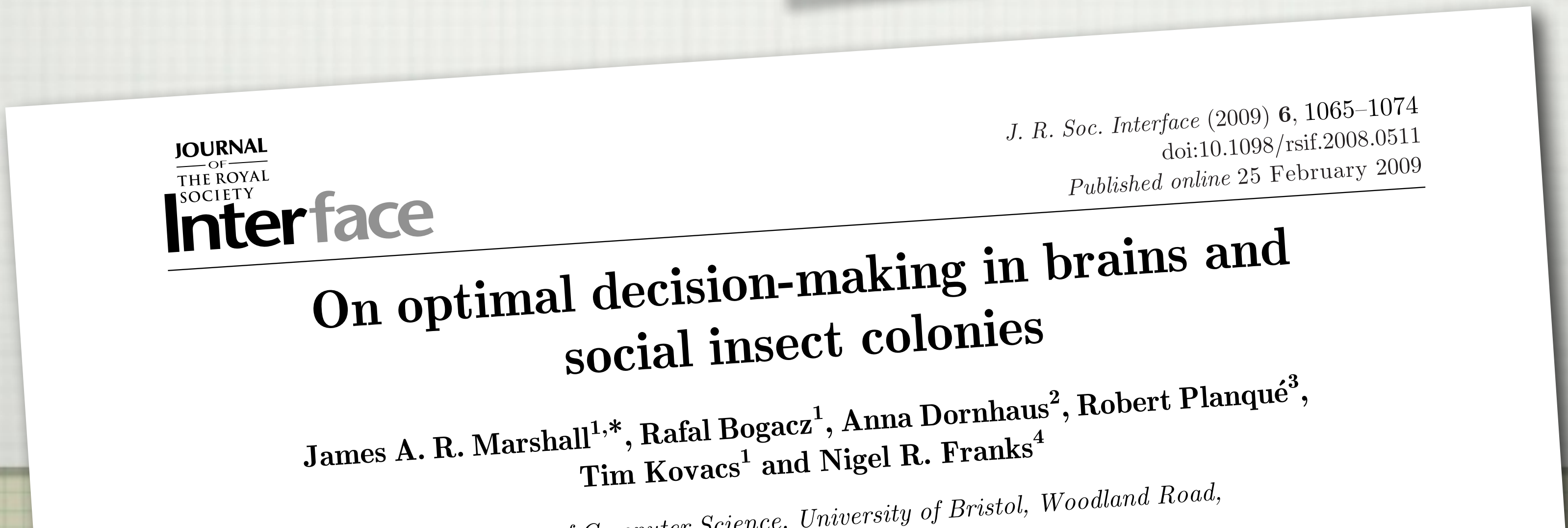

JOURNAL OF THE ROYAL SOCIETY Interface

J. R. Soc. Interface (2009) 6, 1065–1074
doi:10.1098/rsif.2008.0511
Published online 25 February 2009


# On optimal decision-making in brains and social insect colonies


James A. R. Marshall[1,*], Rafal Bogacz[1], Anna Dornhaus[2], Robert Planqué[3], Tim Kovacs[1] and Nigel R. Franks[4]

Computer Science, University of Bristol, Woodland Road,

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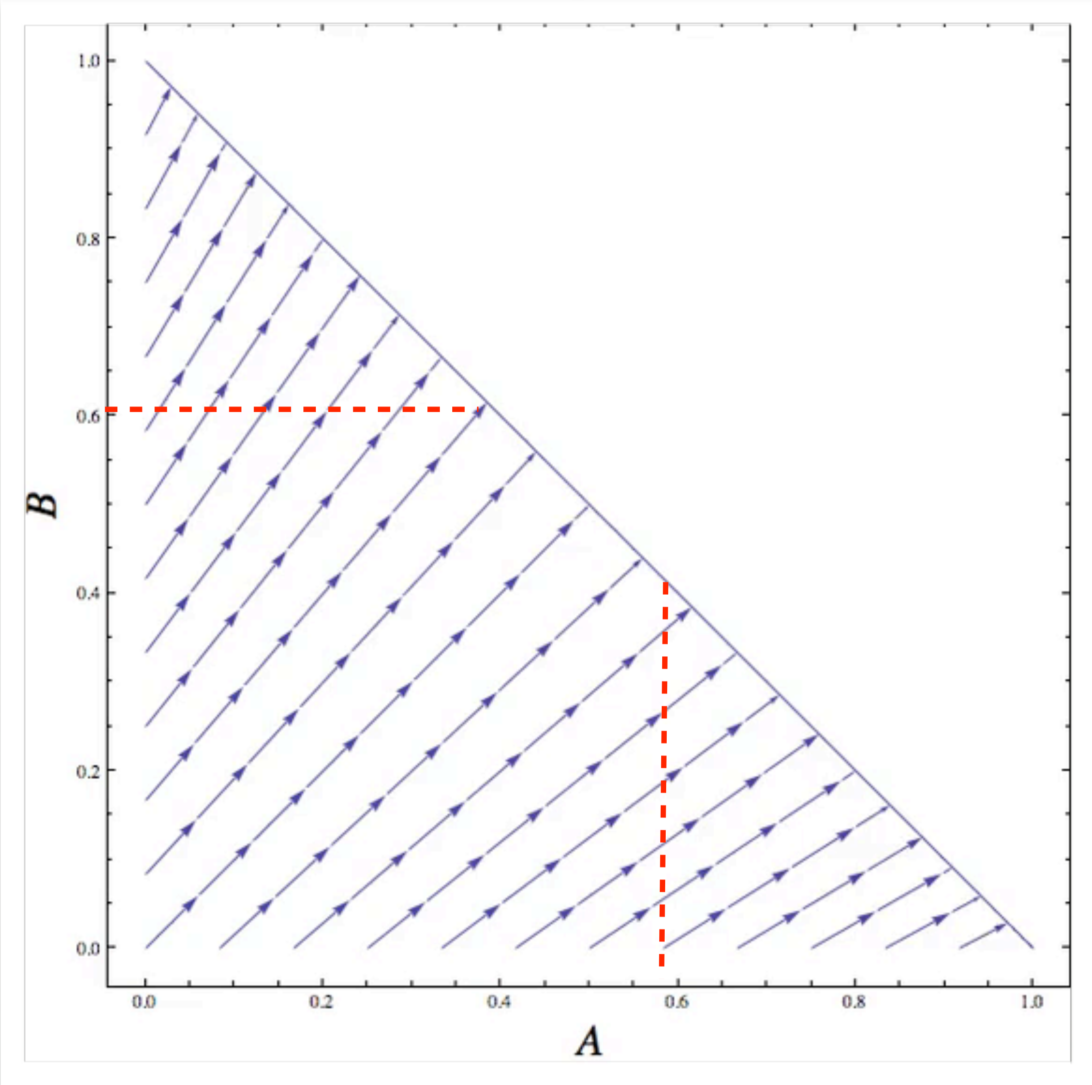
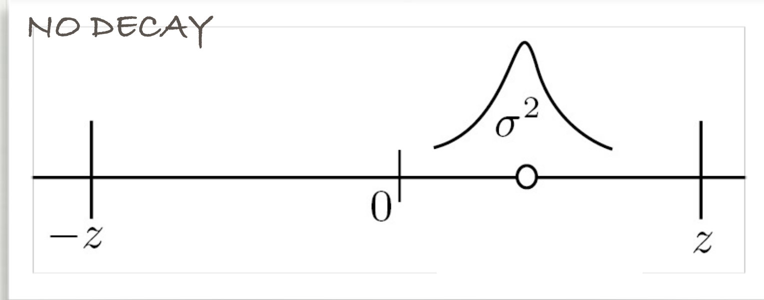
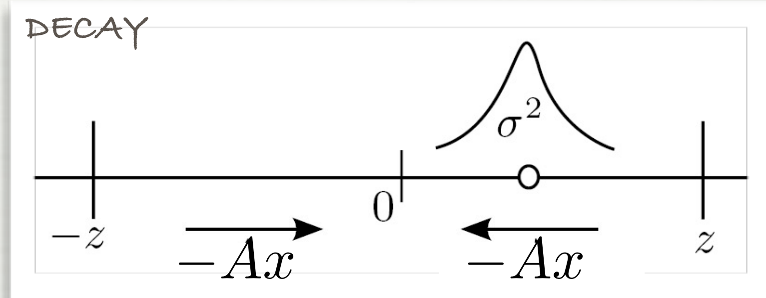
# EQUAL NESTSITE QUALITIES



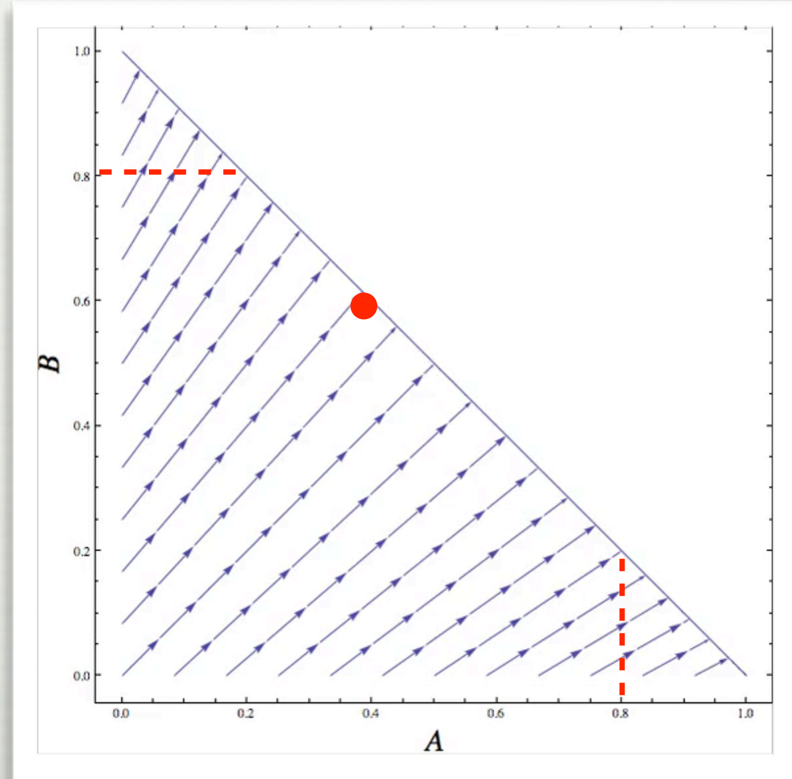




PATRICK HOGAN

# EXISTING NEURAL PROPOSALS

- ☐ COLLAPSING DECISION THRESHOLDS
- ☐ URGENCY SIGNAL
- ☐ TIME-DEPENDENT GAIN
- ☐ ASYMMETRIC INHIBITION



BEHAVIOR

# How Honeybees Break a Decision-Making Deadlock

During the search for a new nest site, use of an inhibitory signal enables honeybees to reach a decision.

**Jeremy E. Niven**

For a honeybee swarm of potentially thousands of individuals, choosing a home is a momentous decision. Failing to choose a single location may cause the swarm to split and the queen to be lost (*1*); choosing poorly may limit the swarm's growth or expose it to freezing temperatures during the winter (*2*). Studies over the past 60 years have shown that honeybee swarms use quorum sensing, a form of decentralized decision-making, to choose a suitable nest site, but many gaps remain in our understanding of this process. On page 108 in this issue, Seeley *et al*. (*3*) show that an inhibitory signal between bees advocating different locations allows them to make a decision even when potential nest sites are equally favorable.

Honeybee colonies reproduce through budding, whereby the queen and some workers leave the nest and bivouac on a branch. Some of the most experienced workers leave to locate suitable nest sites (*4*). Upon their return, these scouts advertise potential locations and their qualities by performing a waggle dance. During the dance, the scout walks straight across the bivouacking bees, making side-to-side waggles of her body. She then stops, turns left or right, and walks a semicircular return path to her starting point. The waggle run's duration and orientation encode the length and the angle of the outward flight, respectively, whereas the number of dance circuits encodes the quality of the potential nest site (*5*). Waggle dances recruit additional scouts to a site until a quorum number is reached and the swarm prepares to move to its new home (*2*).

Scouts advocating less attractive sites produce fewer dance circuits and make fewer trips to the site (*6*). Along with the recruitment of uncommitted scouts to more attractive sites, this was assumed to be sufficient to enable the bees to reach a quorum, thereby deciding which site to choose (*2*). However, foraging workers use an additional type of signal to communicate with other bees. Upon returning from a feeder that is crowded or where a predator is present, forager bees produce a brief vibrational signal that discourages other bees from producing waggle dances that advertise the location of that feeder (*7*). Hypothesizing that a similar signal may be used by house-hunting bees, Seeley *et al*. set out to observe scout behavior. They found that scouts received "stop" signals—head butts mainly to their head and thorax—from other bees during the return run of the waggle dance (see the figure). These stop signals occurred more frequently just before a scout stopped dancing.

The authors next established swarms on Appledore Island (Maine), which lacks natural nest sites, and gave them a choice of two identical nest boxes. Scouts visiting one box were marked with yellow paint; those visiting the other were marked with pink paint. Most of the bees giving "stop" signals during the decision selection process, dancing scouts with yellow paint received many more stop signals from scouts with pink paint and vice versa, showing that scouts from one site preferentially inhibit the dances of those advertising a competing site (see the figure, panel A). Once the scouts started implementing the decision, dancing scouts received stop signals from scouts that had visited either site. When swarms were given only one nest box, scouts received few stop signals during the decision phase but many during the implementation phase. This general inhibition of dancing during the implementation phase presumably ensures that all the bees are present when the swarm takes flight.

To demonstrate a role for the observed cross inhibition between scouts advertising competing sites, Seeley *et al*. constructed a series of computational models of the collective decision-making process, based on the interaction rules they had observed among the scouts. Models that incorporated no or indiscriminate stop signaling predicted that the scouts would reach a stable deadlock, failing to choose between two

**Cease and desist.** (**A**) Seeley *et al*. have found that during house hunting, scouts advertising one nest site preferentially inhibit scouts advertising another site during the decision-making process. Inhibition is conveyed by a "stop" signal, given mainly to the head and thorax of a scout during the return phase of the waggle dance. (**B**) Stop signals from scout bees inhibit other scouts, discouraging them from advertising a potential site. These

BEHAVIOR

# How Honeybees Break a Decision-Making Deadlock

During the search for a new nest site, use of an inhibitory signal enables honeybees to reach a decision.

THOMAS SCHLEGEL

School of Life Sciences, University of Sussex, Falmer, Brighton BN1 9QG, UK. E-mail: jen23@sussex.ac.uk

paint. Most of the bees giving "stop" signals had paint marks, showing they were scouts. During the decision phase of the nest-site

aging them from advertising a potential site. These inhibitory stop signals combine with recruitment of neutral scouts to produce a winning site.

SPONTANEOUS ACTIVATION

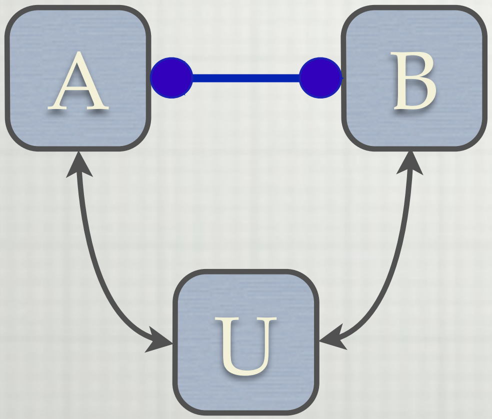
POSITIVE FEEDBACK

DECAY

CROSS-INHIBITION

$$\begin{cases} \mathrm{d}y_A := (y_U\gamma_A - y_A(\alpha_A - y_U\rho_A + y_B\sigma_B))\,\mathrm{d}t \\ \quad +k\sqrt{y_U^2 + y_A^2 + y_U^2 y_A^2}\,\mathrm{d}W_A \\ \mathrm{d}y_B := (y_U\gamma_B - y_B(\alpha_B - y_U\rho_B + y_A\sigma_A))\,\mathrm{d}t \\ \quad +k\sqrt{y_U^2 + y_B^2 + y_U^2 y_B^2}\,\mathrm{d}W_B \end{cases}$$

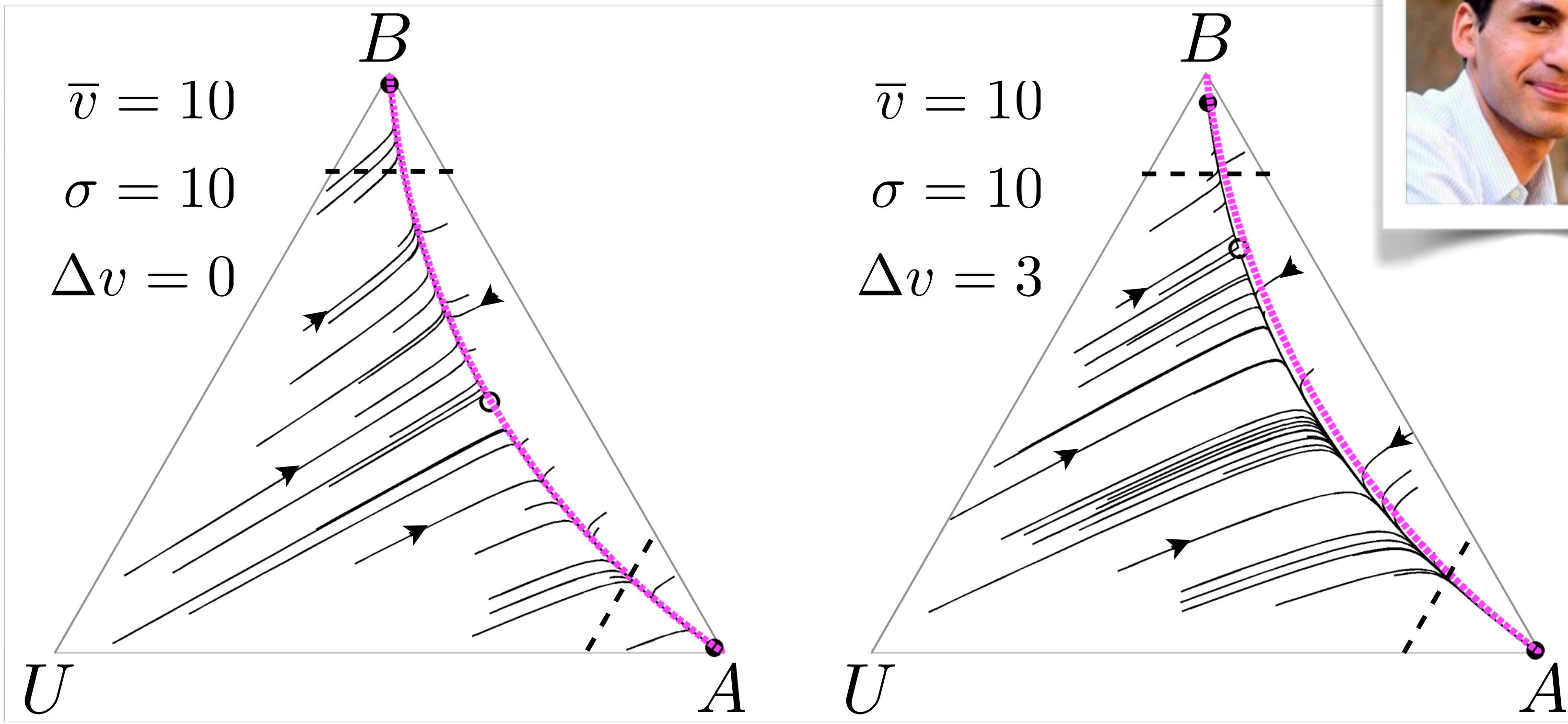
PAIS ET AL. (2013)




PATRICK HOGAN

ADDITIVE WHITE NOISE

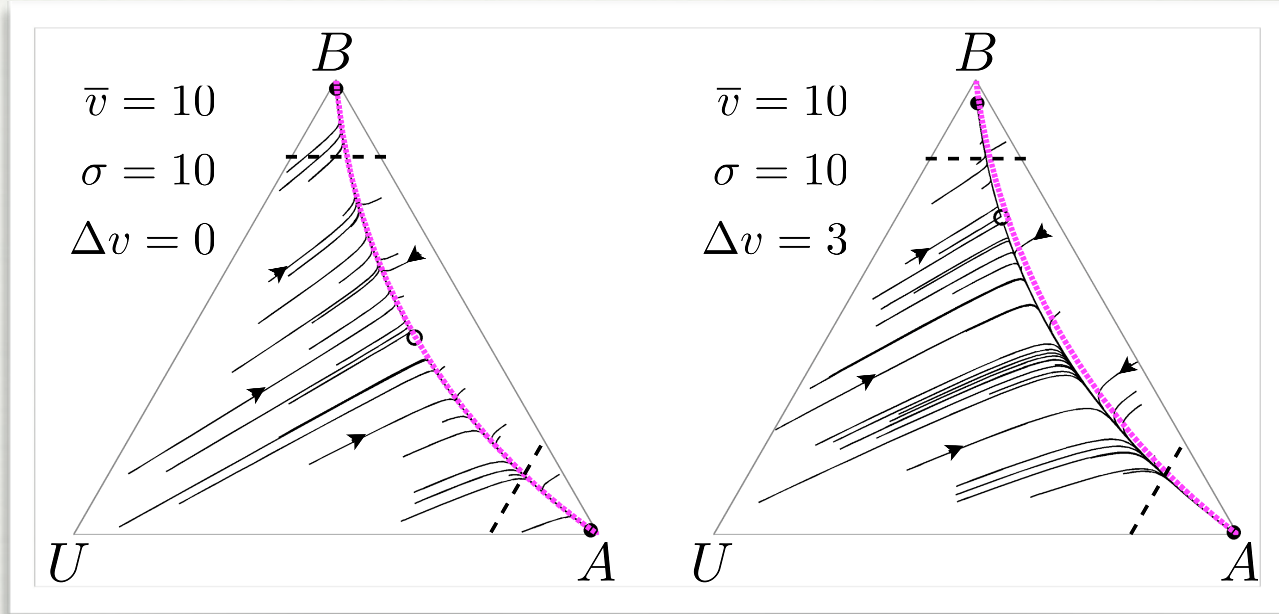
# SEPARATION OF TIMESCALES

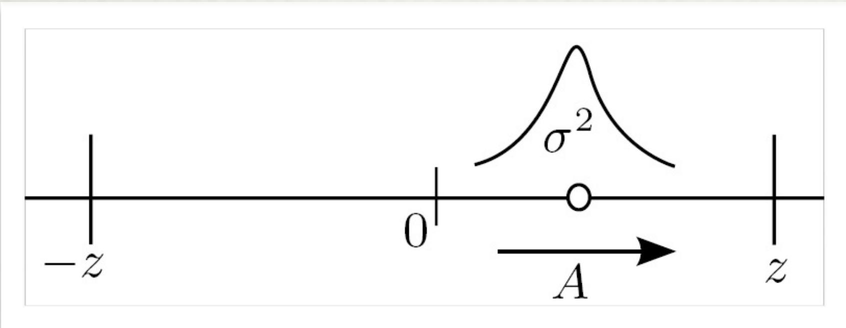


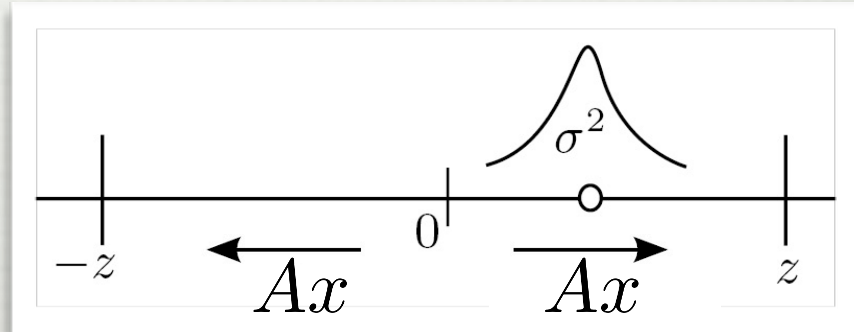

PAIS ET AL., 2013

$\overline{v}$ LARGE, $\dfrac{\Delta v}{\overline{v}}$ SMALL

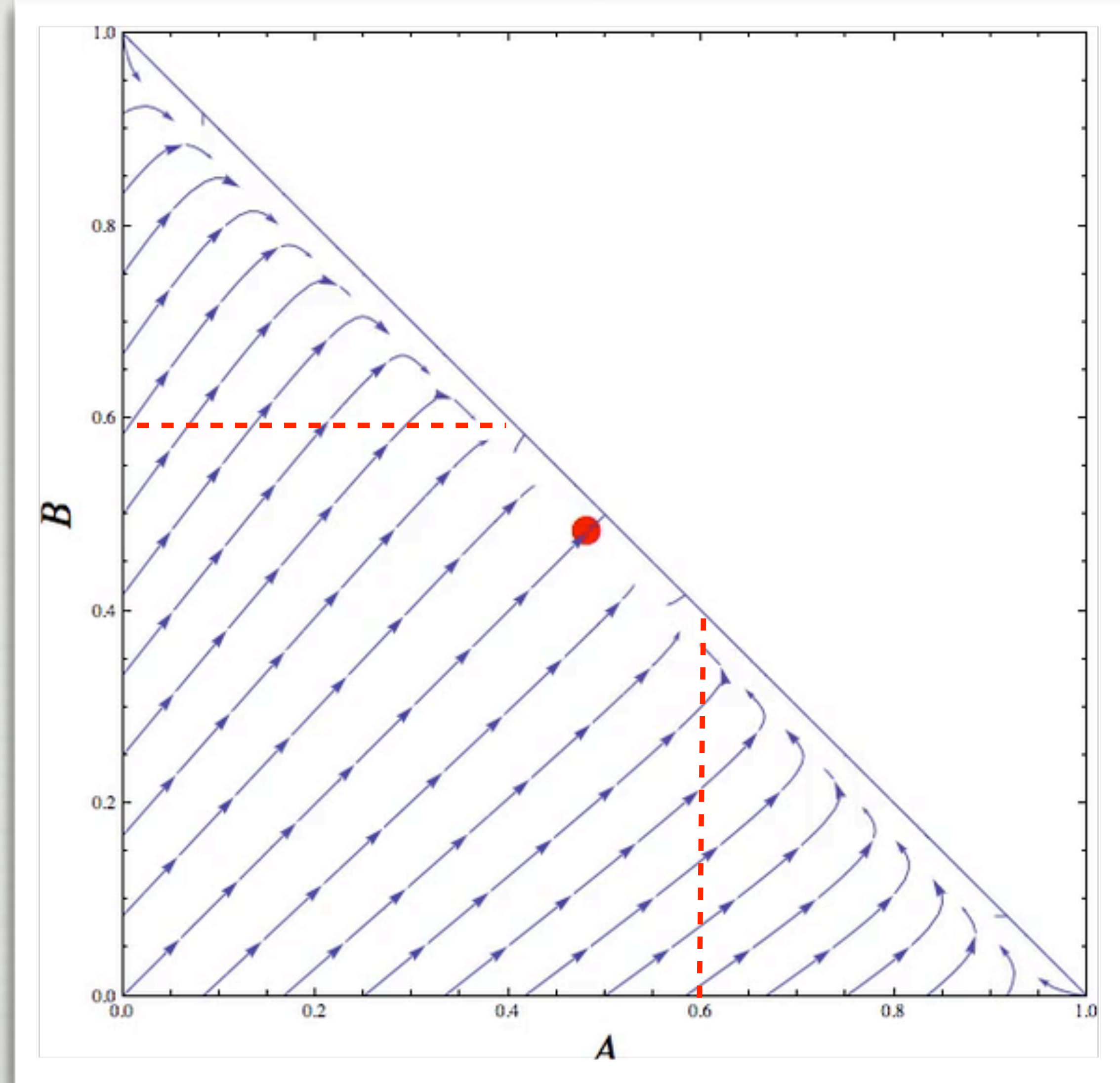
# SEPARATION OF TIMESCALES

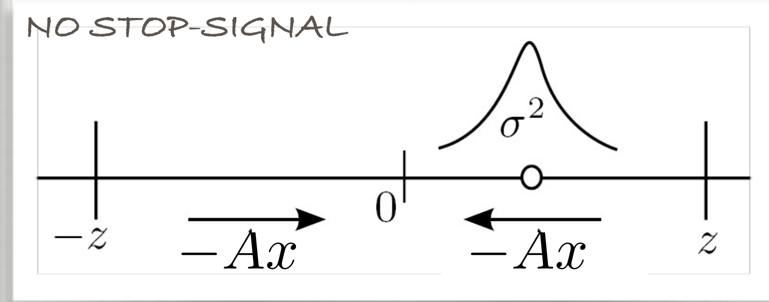


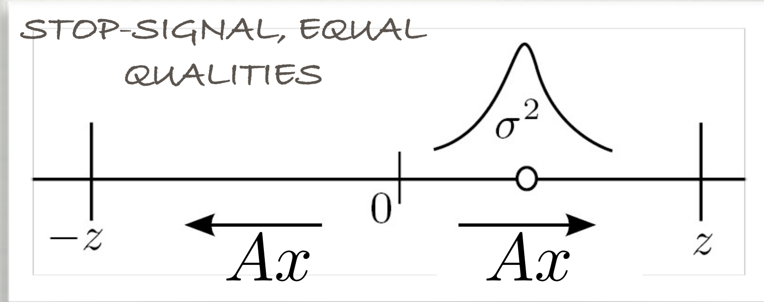



# STOP-SIGNAL: INCREASING SIGNAL, EQUAL QUALITIES

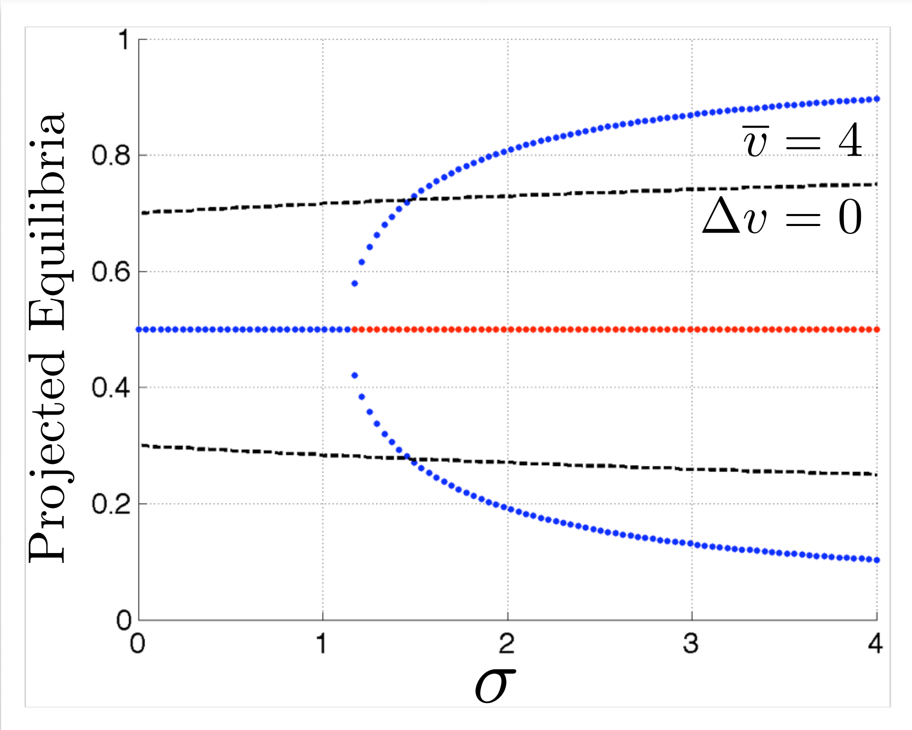


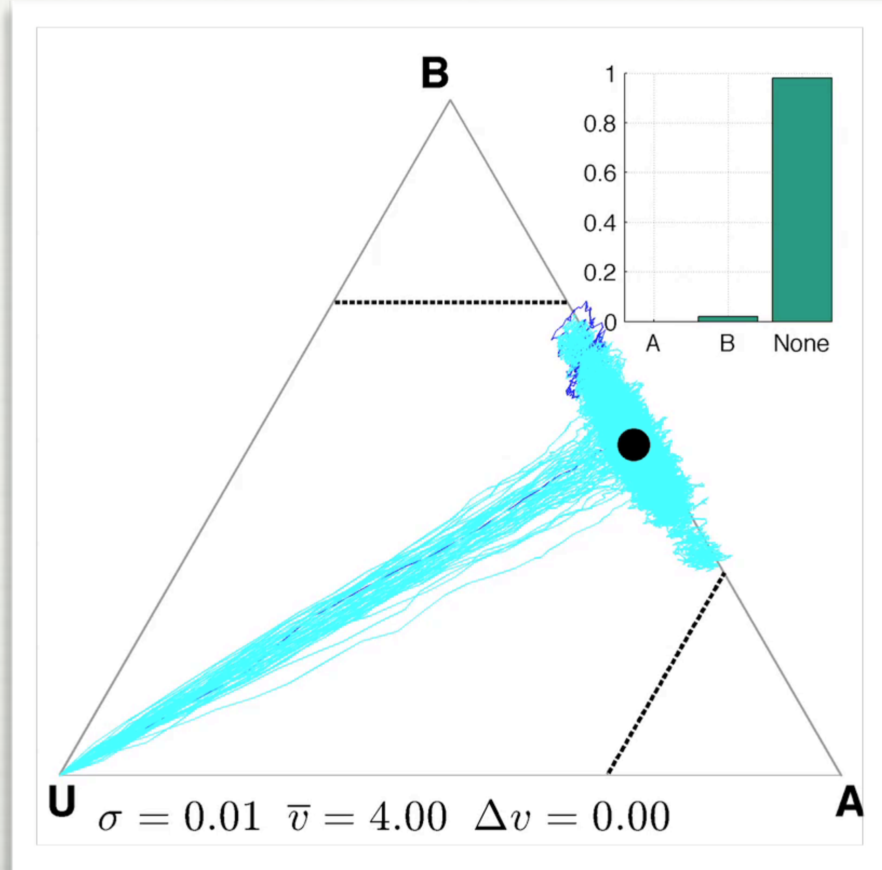




PATRICK HOGAN

# DEADLOCK BREAKING

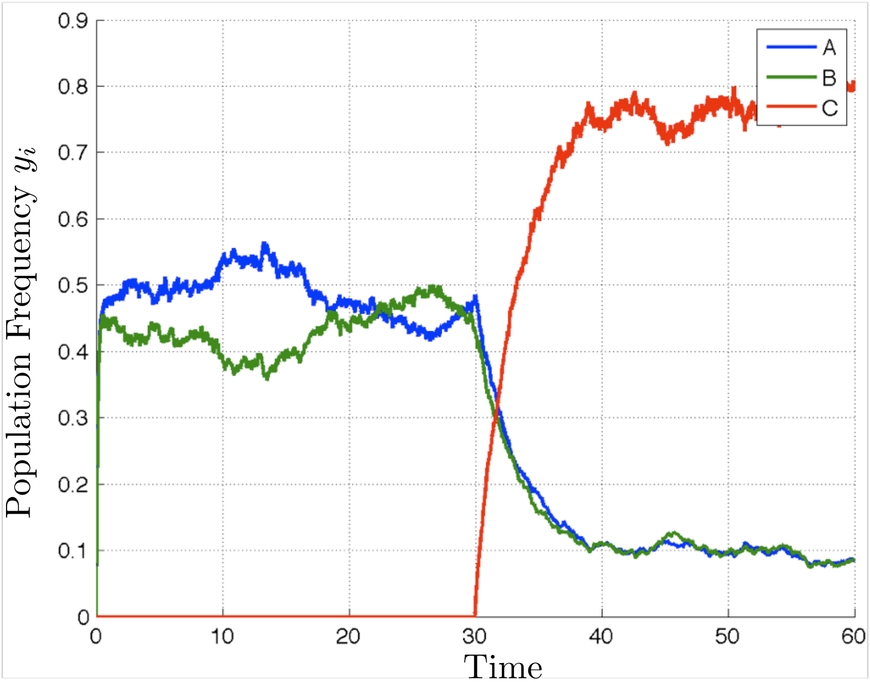


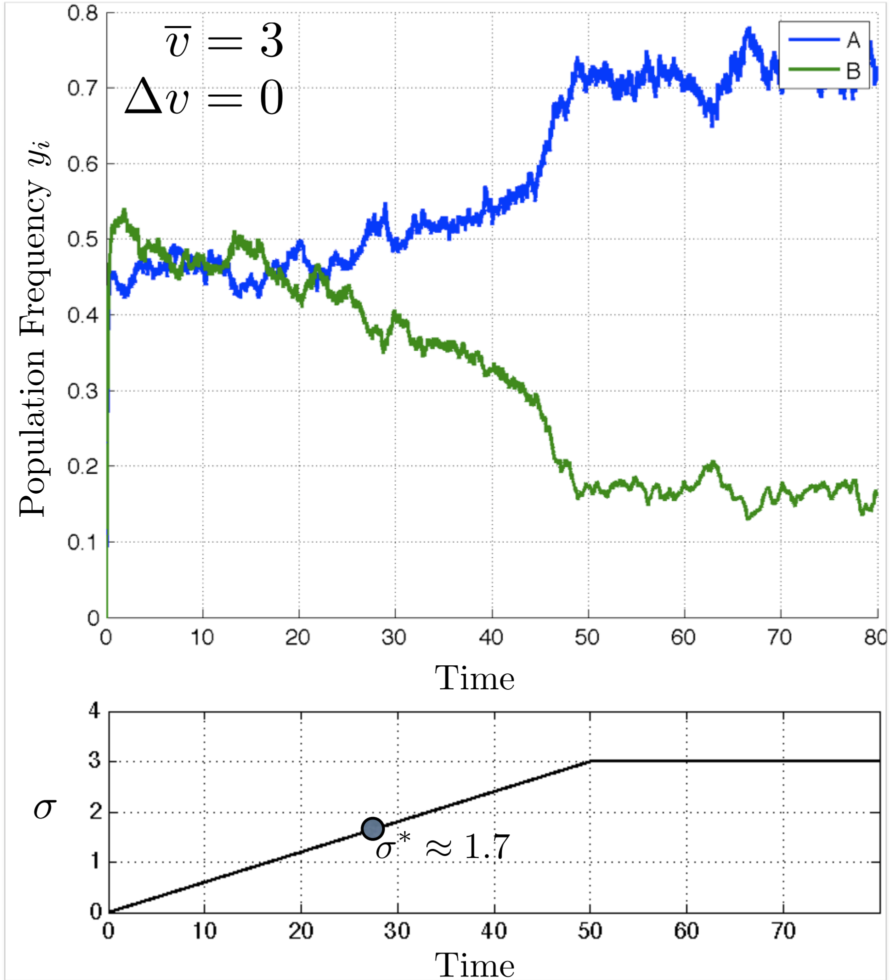




PAIS ET AL., 2013

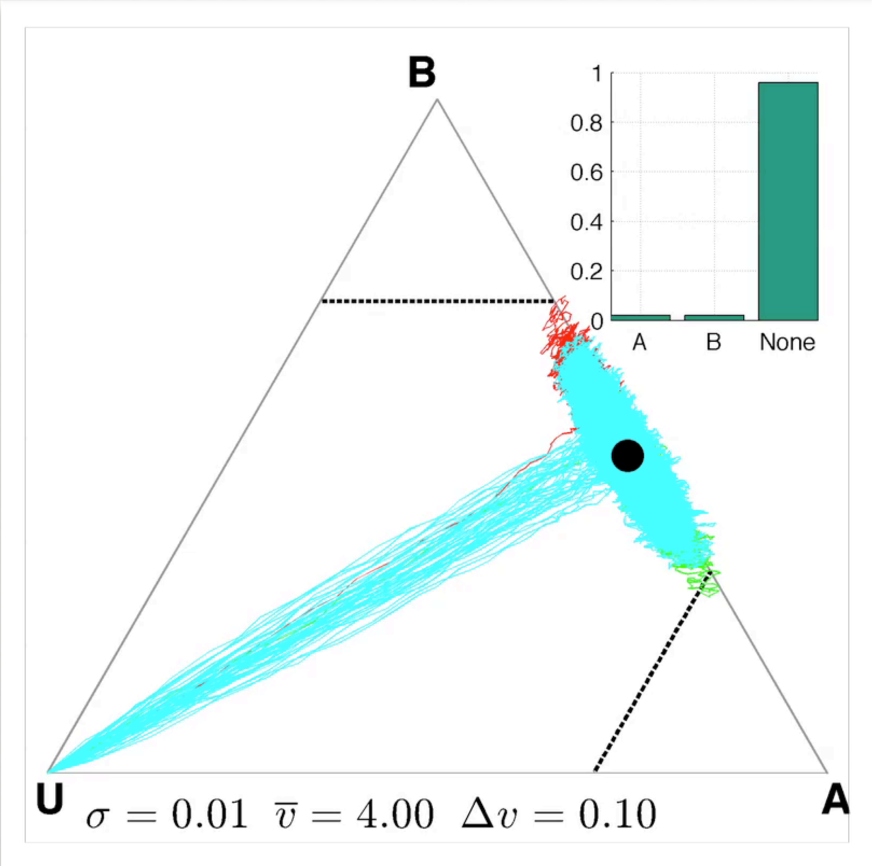
# VALUE-SENSITIVE COLLECTIVE DECISION-MAKING

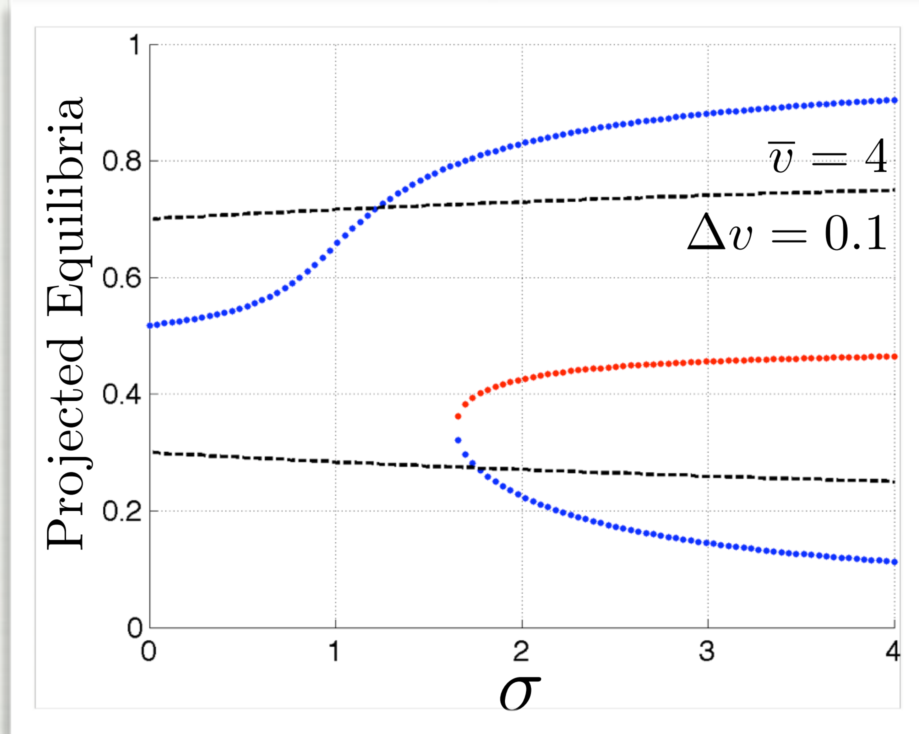
PAIS ET AL. (2013)



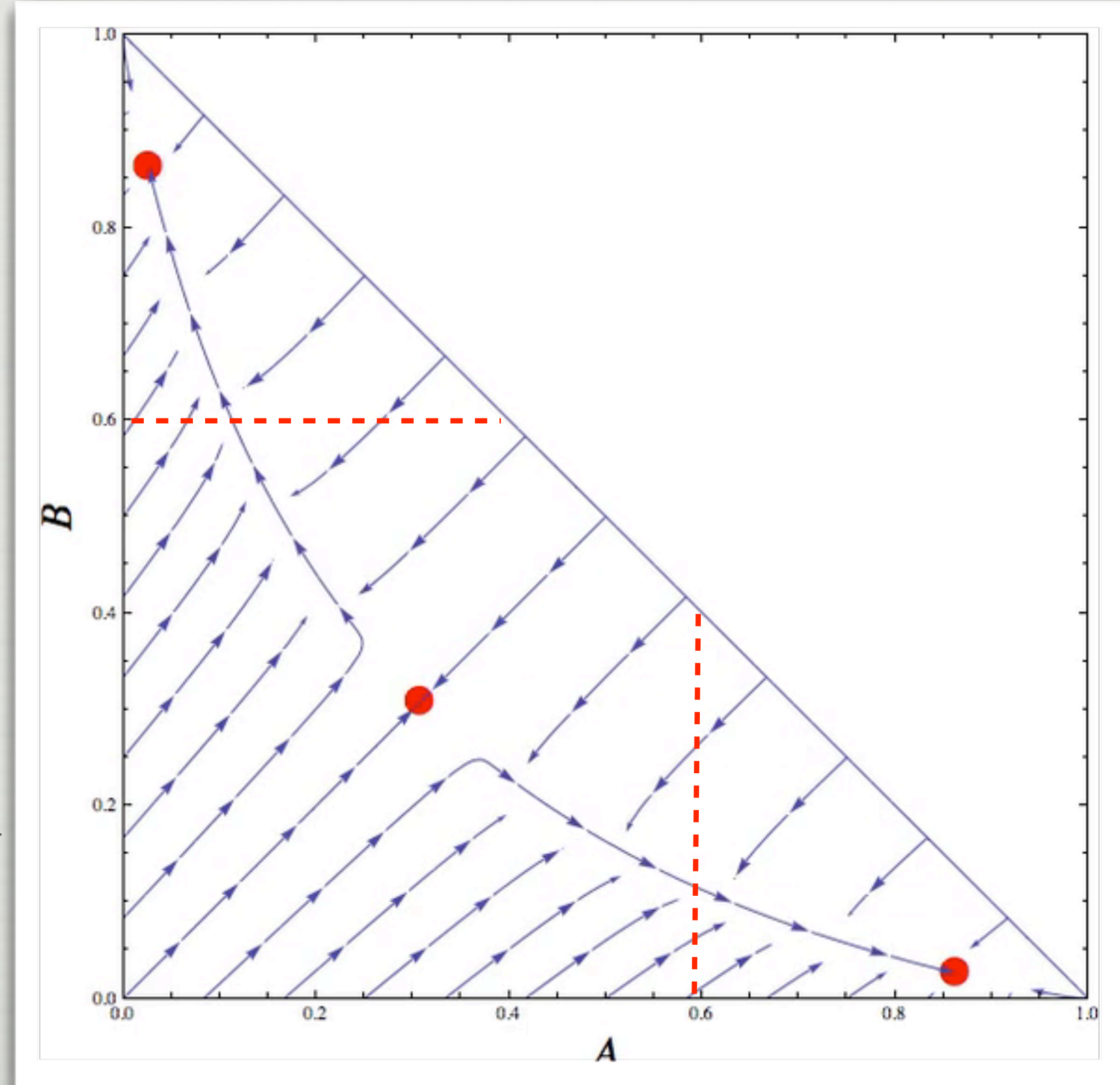
# AMPLIFICATION

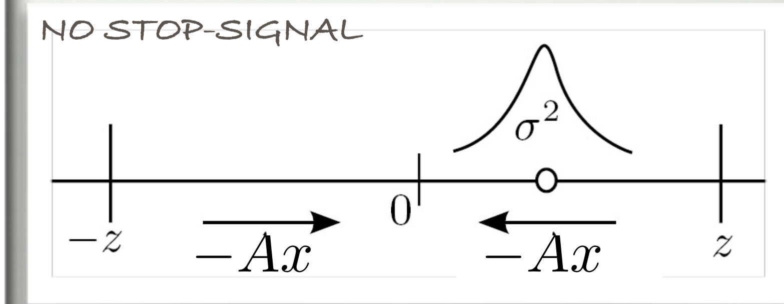


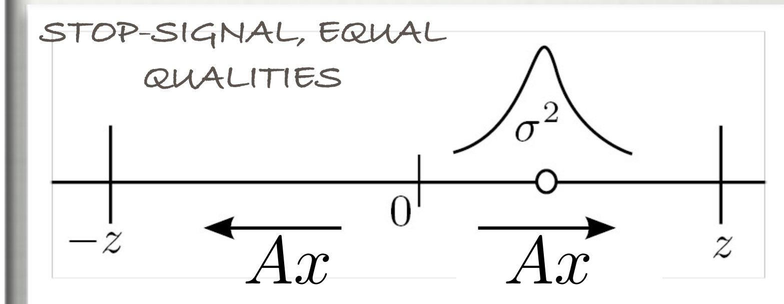



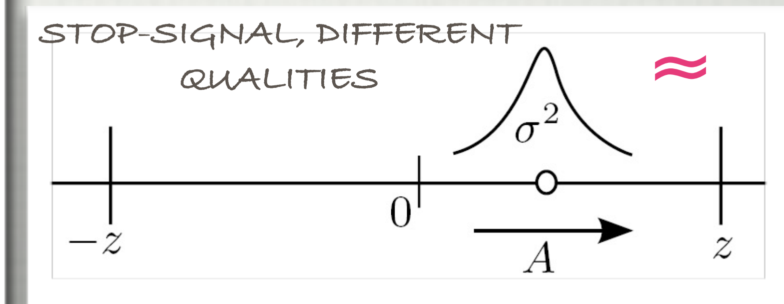

PAIS ET AL., 2013

# STOP-SIGNAL: INCREASING QUALITY DIFFERENCES



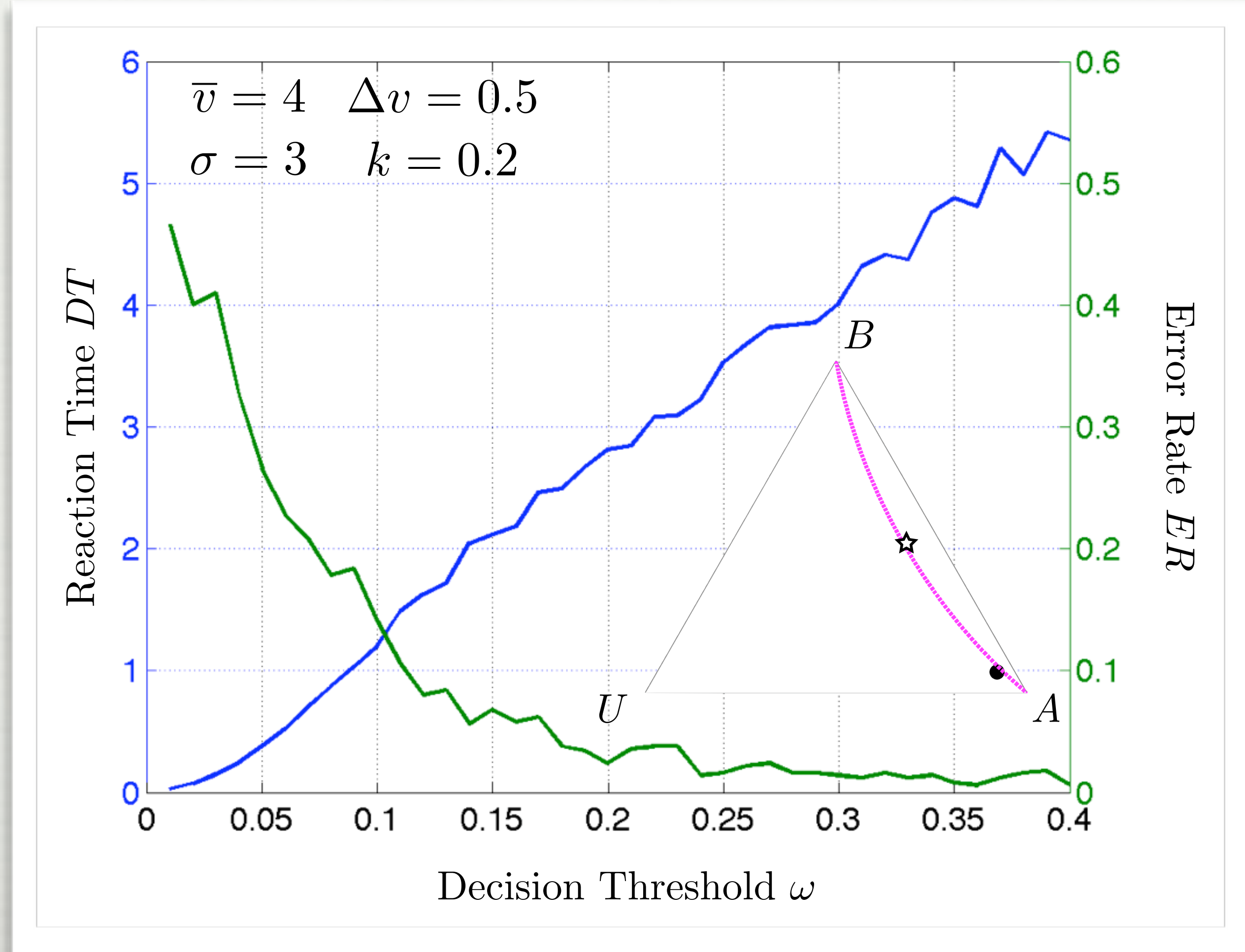



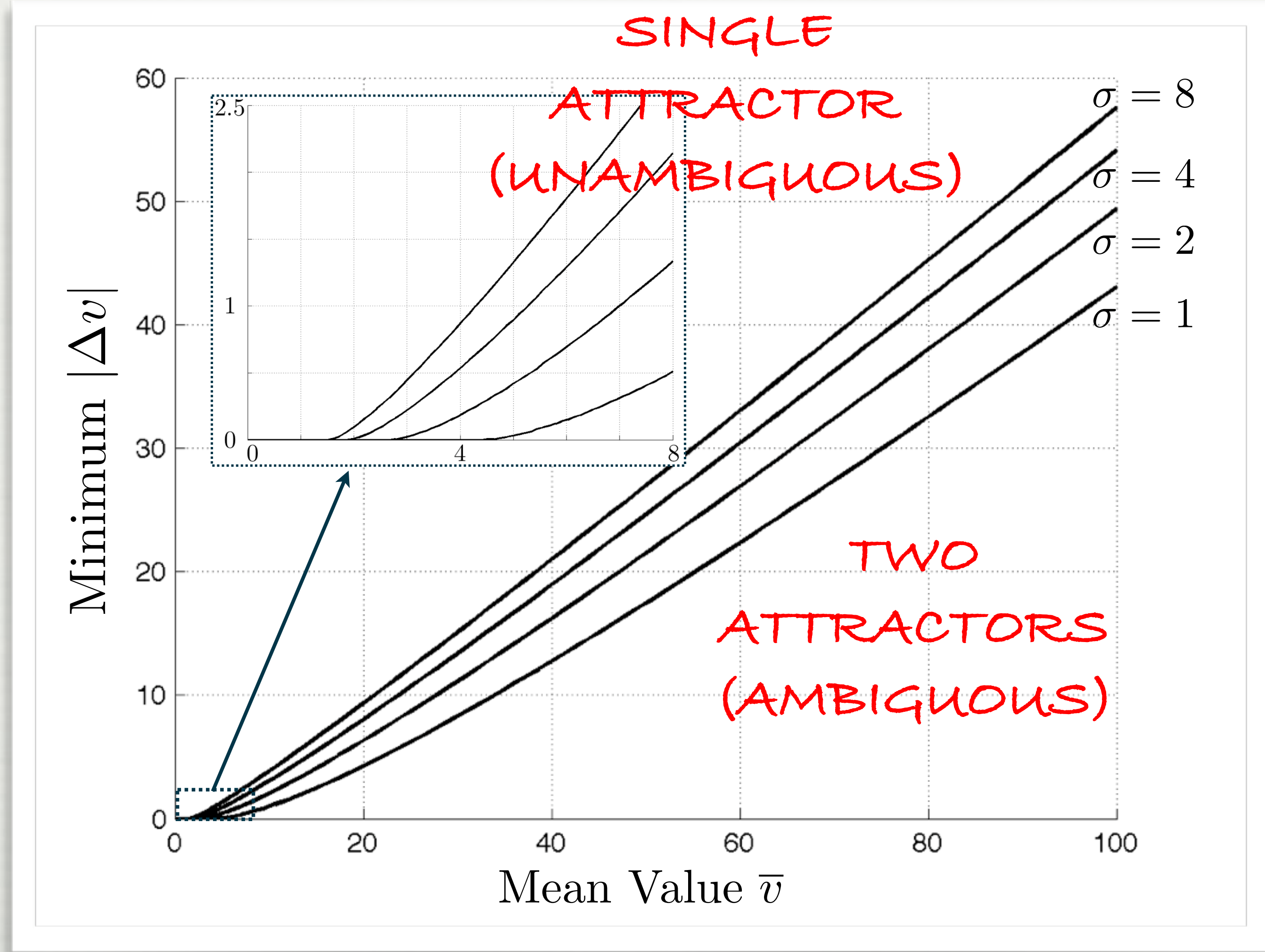

PATRICK HOGAN

# SPEED-ACCURACY TRADE-OFFS



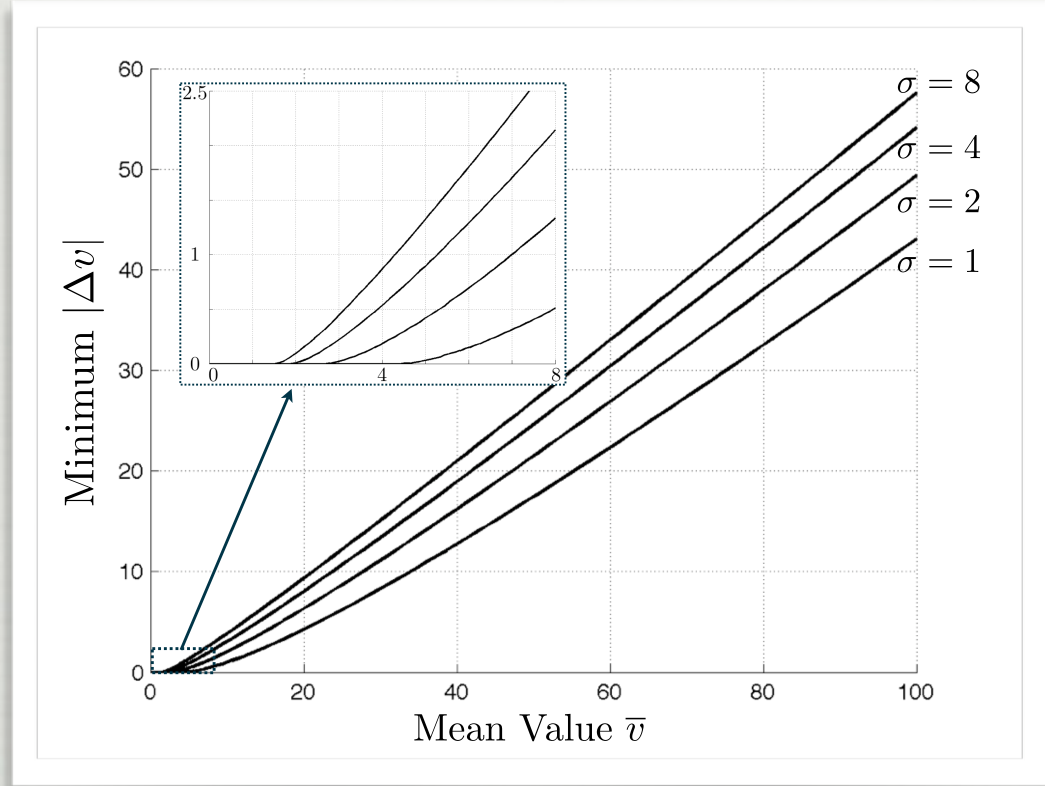

PAIS ET AL., 2013

# JUST-NOTICEABLE DIFFERENCES




PAIS ET AL., 2013

# JUST-NOTICEABLE DIFFERENCES




$$\frac{\Delta v}{\overline{v}} = K$$

$f(\sigma)$

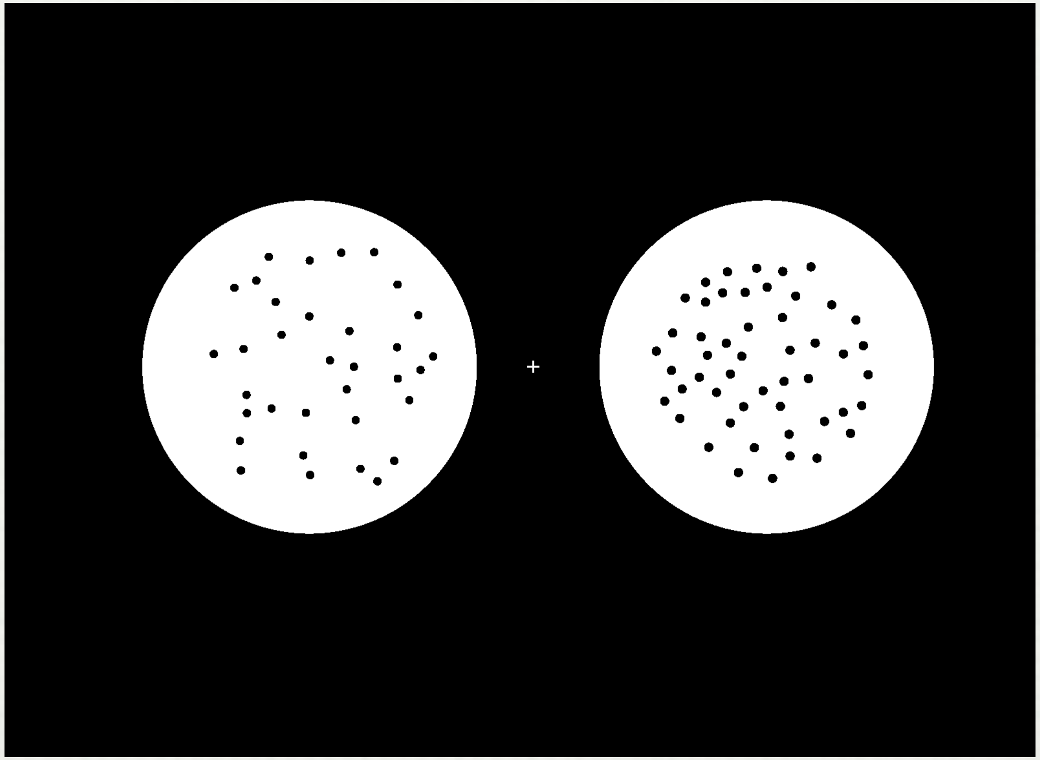
WEBER'S LAW


A
B
U
PATRICK HOGAN
ARTICLES
Salience driven value integration explains decision biases and preference reversal
Frontiers in Neuroscience
When Natural Selection Should Optimise Speed-Accuracy Trade-offs
Opinion
20 March 2014
Angelo Pirrone 1,2, Tom Stafford 1 and James A. R. Marshall 2,3,*
1 Department of Psychology, University of Sheffield, Sheffield, UNITED KINGDOM
2 Kroto Research Institute, University of Sheffield, Sheffield, UNITED KINGDOM
3 Department of Computer Science, University of Sheffield, Sheffield, UNITED KINGDOM
Correspondence*:
James A. R. Marshall
PSYCHOLOGICAL AND COGNITIVE SCIENCES

# BEHAVIOURAL PREDICTIONS

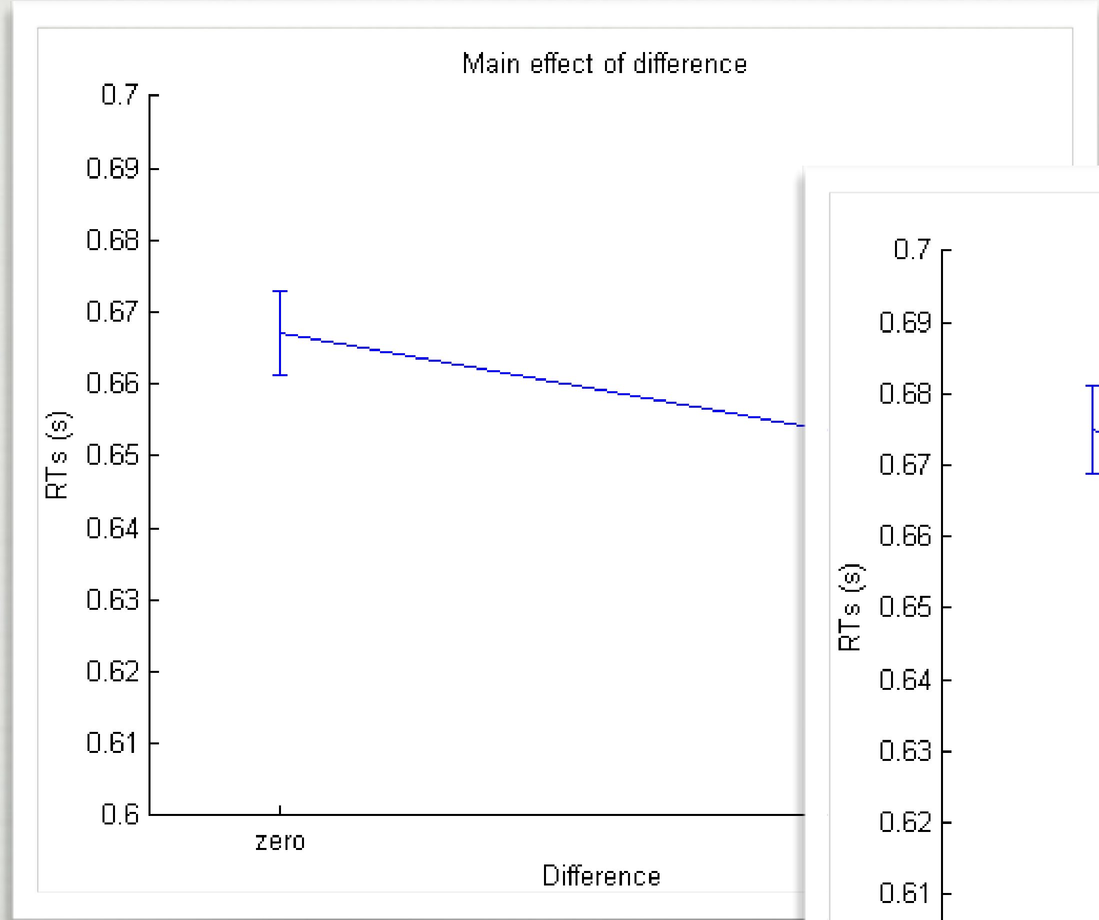
- DECISION-MAKERS IMPLEMENTING (SOMETHING LIKE) THIS MECHANISM SHOULD EXHIBIT:
  - WEBER'S LAW (STANDARD OBSERVATION)
  - SPEED-ACCURACY TRADE-OFFS (STANDARD OBS.)
  - REACTION-TIME SENSITIVITY TO ABSOLUTE VALUE
  - DECISION-MEMORY BASED ON PREVIOUS STIMULI VALUES

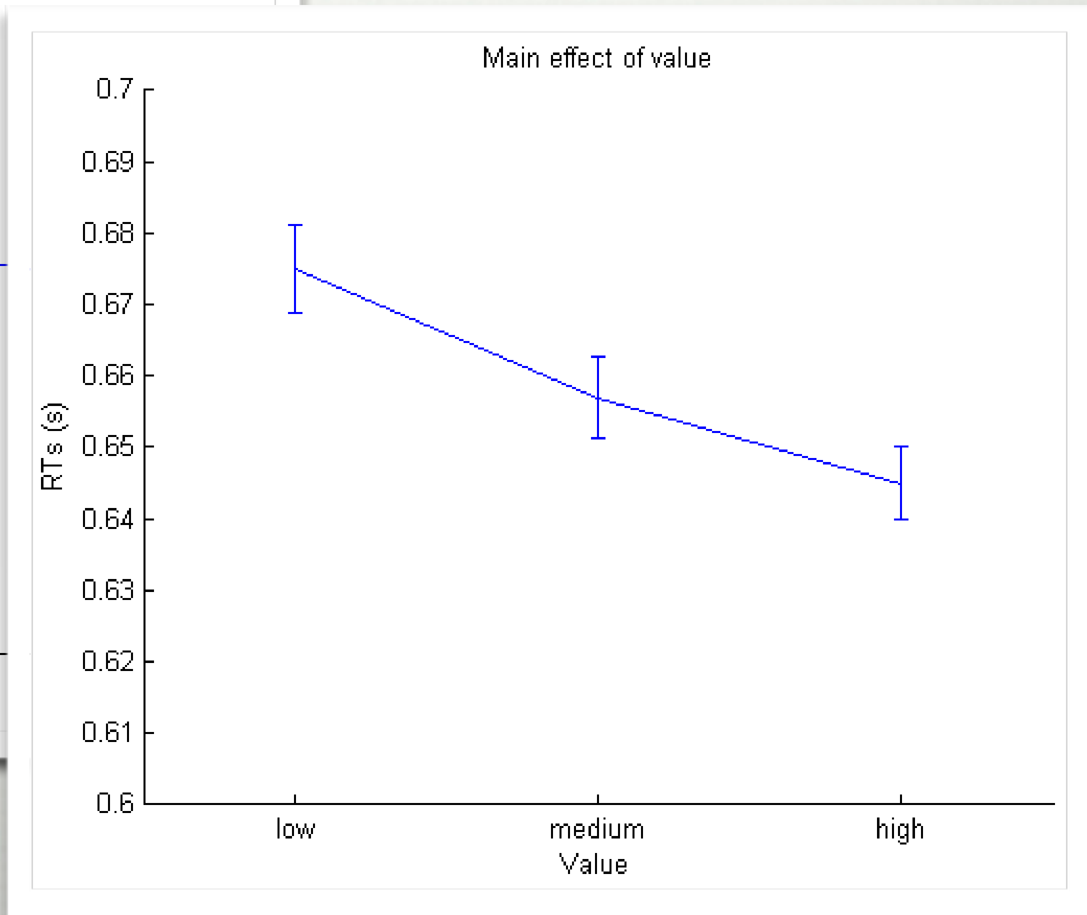
# VALUE-SENSITIVITY IN HUMANS



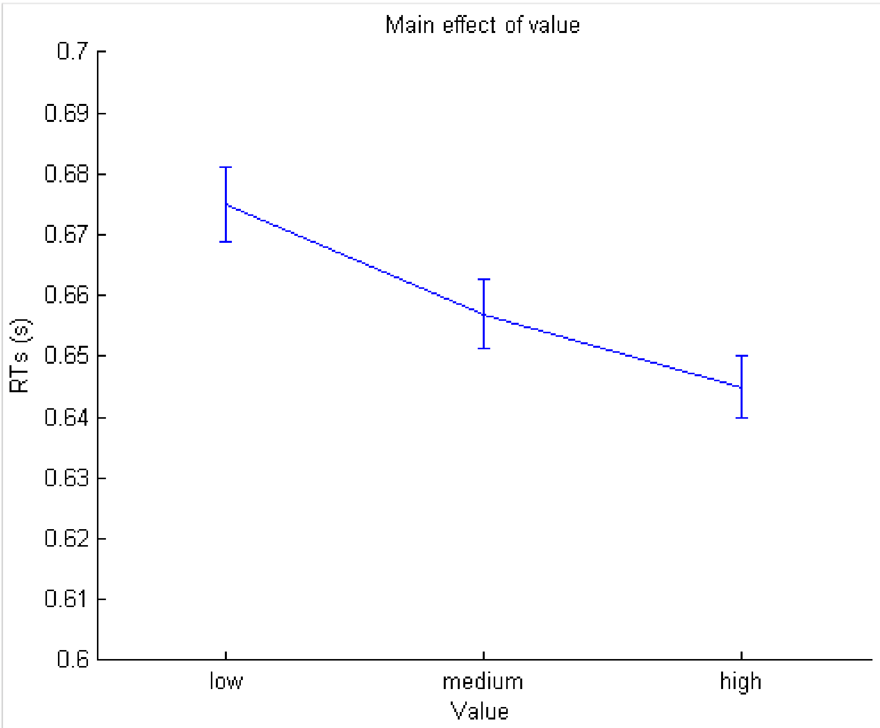
- TWO REWARD INSTRUCTIONS:
  - PERCEPTUAL: FIXED REWARD FOR CORRECT CHOICE, ZERO FOR INCORRECT
  - VALUE: REWARD PROPORTIONAL TO NUMBER OF DOTS

# VALUE-SENSITIVITY IN HUMANS



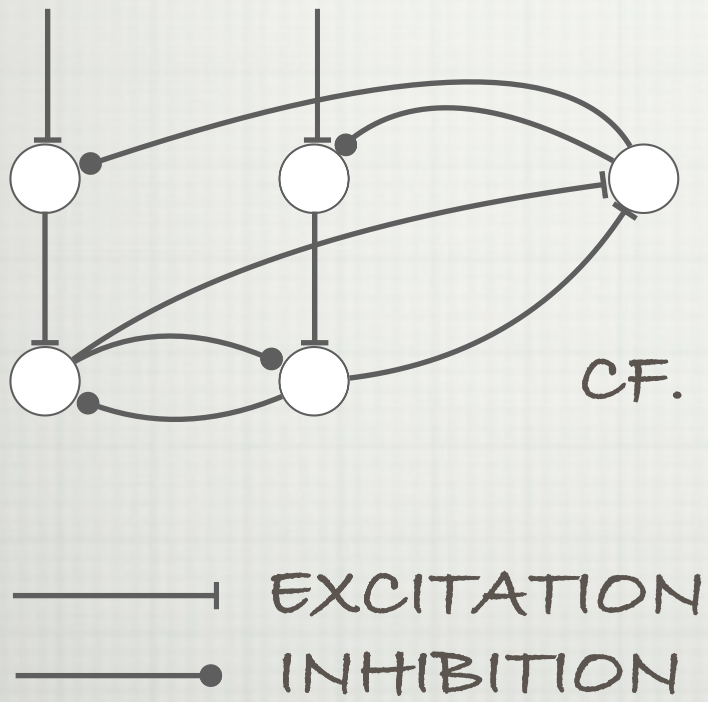



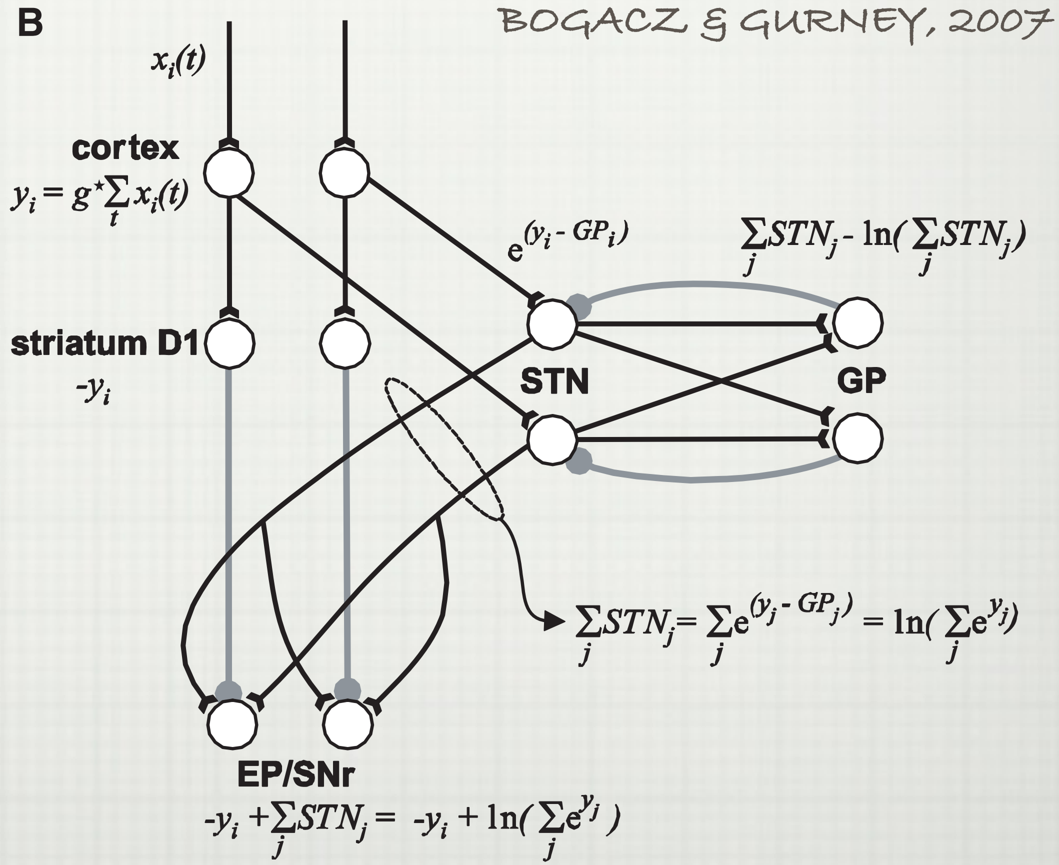
# VALUE-SENSITIVITY IN HUMANS



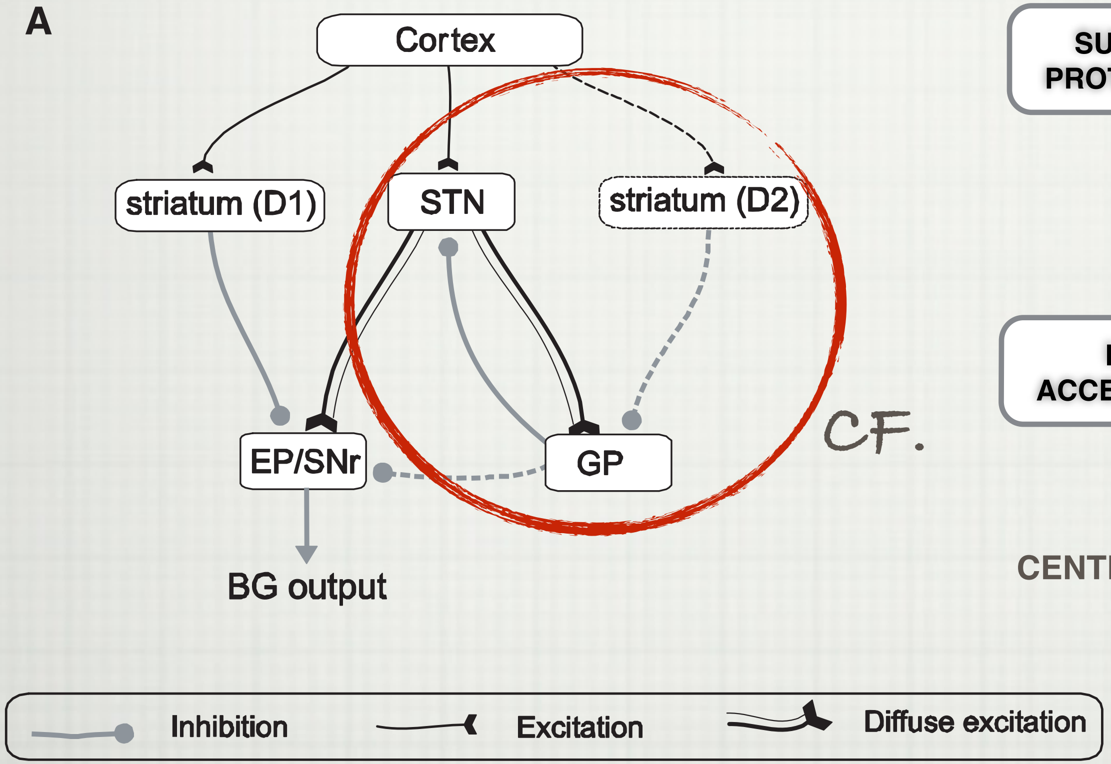

- INCONSISTENT WITH:
  - SIMPLE DRIFT-DIFFUSION MODEL
- CONSISTENT WITH:
  - STOP-SIGNAL MODEL
  - ACCUMULATOR MODELS
  - RACE/SEQUENTIAL CHOICE MODELS (E.G. KACELNIK ET AL.)

# LOOKING FOR IMPLEMENTATIONS OF VALUE-SENSITIVE DECISION-MAKING



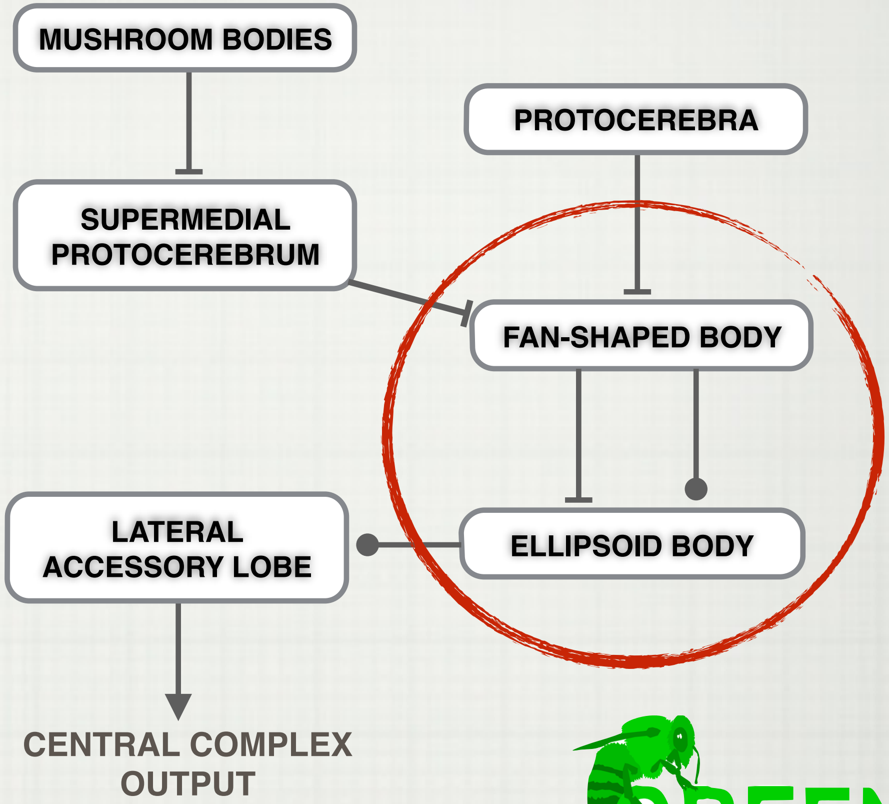
## VERTEBRATE




BOGACZ & GURNEY, 2007

CF.

## ARTHROPOD



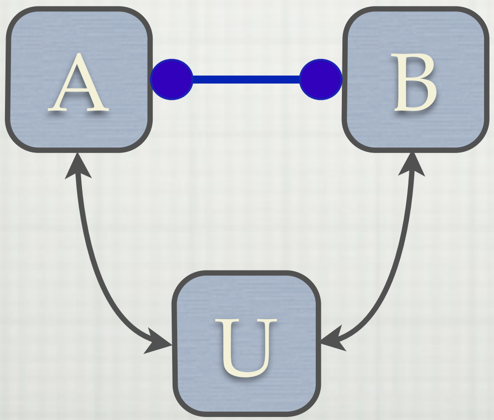

STRAUSFELD & HIRTH, 2013

GREEN BRAIN

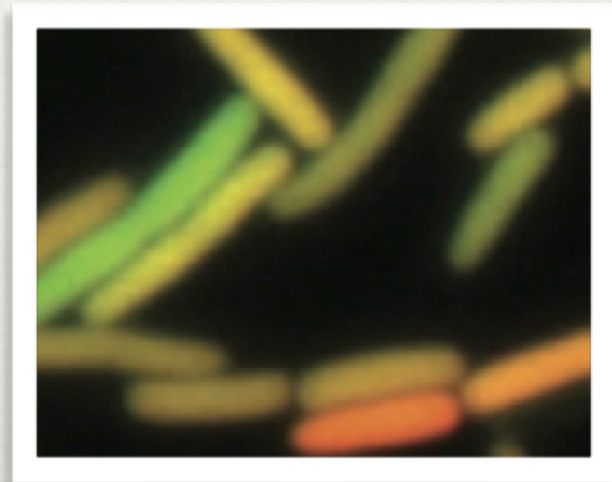
# LOOKING FOR IMPLEMENTATIONS OF VALUE-SENSITIVE DECISION-MAKING

$$
\begin{cases}
\mathrm{d}y_A & := & (y_U\gamma_A - y_A(\alpha_A - y_U\rho_A + y_B\sigma_B))\,\mathrm{d}t \\
& & +k\sqrt{y_U^2 + y_A^2 + y_U^2 y_A^2}\mathrm{d}W_A \\
\mathrm{d}y_B & := & (y_U\gamma_B - y_B(\alpha_B - y_U\rho_B + y_A\sigma_A))\,\mathrm{d}t \\
& & +k\sqrt{y_U^2 + y_B^2 + y_U^2 y_B^2}\mathrm{d}W_B
\end{cases}
$$

PAIS ET AL. (2013)



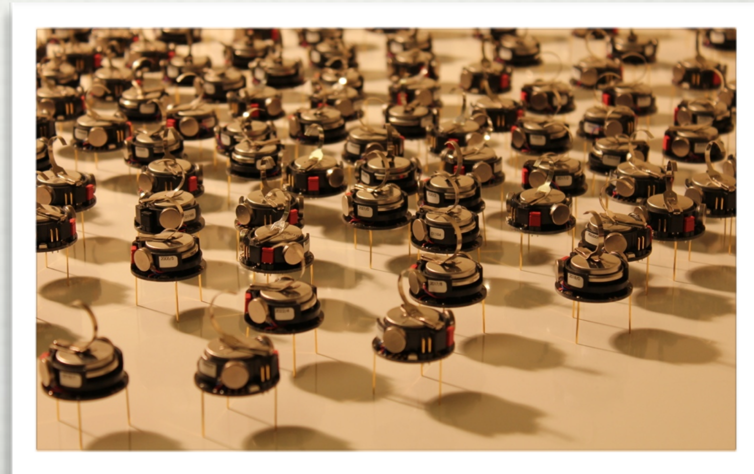

PATRICK HOGAN



PETER SWAIN

# PAYBACK FOR ENGINEERING?

- AS WELL AS DESIRABLE DECISION PROPERTIES, STOP-SIGNAL MODEL IMPLEMENTS ENERGY EFFICIENT DESIGION-MAKING
- SHOULD BE SUITABLE FOR CONTROLLER DESIGN FOR COLLECTIVE BEHAVIOUR



RODERICH GROSS

scentro

# ACKNOWLEDGEMENTS & REFERENCES

- THOMAS SCHLEGEL, TOM SEELEY AND KIRK VISSCHER (EXPERIMENTS)
- PATRICK HOGAN (STOP-SIGNAL MODEL)
- DARREN PAIS AND NAOMI LEONARD (DYNAMICAL SYSTEMS ANALYSES)
- ANGELO PIRRONE AND TOM STAFFORD (PSYCHOPHYSICS EXPERIMENTS)
- ALEX COPE (GREEN BRAIN MODELS)
- SEELEY ET AL. (2012) SCIENCE 335, 108-111
  - NIVEN (2012) SCIENCE 335, 43-44
- PAIS ET AL. (2013) PLOS ONE 8: E73216
- PIRRONE ET AL. (2014) FRONTIERS IN NEUROSCIENCE 08:73. DOI: 10.3389/FNINS.2014.00073
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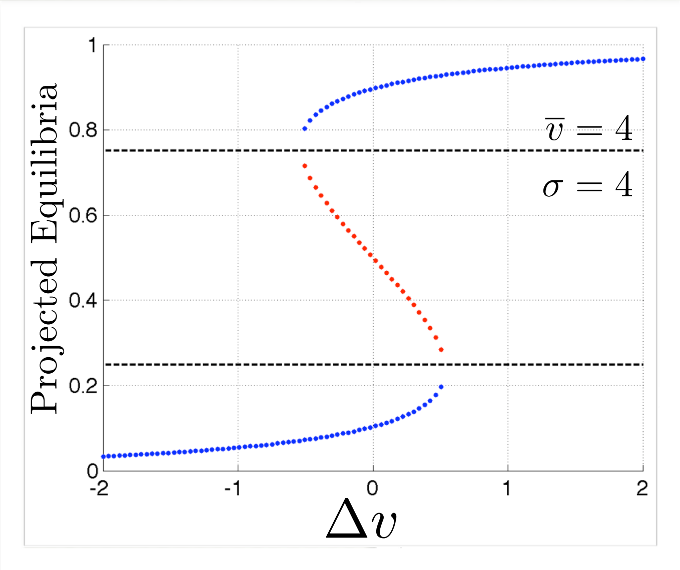
BBSRC

EPSRC

# HYSTERESIS




PAIS ET AL., 2013