Understanding the world collectively

Gonzalo G. de Polavieja
Champalimaud Neuroscience Programme, Lisbon

www.polaviejalab.org

‘Proofs’ that there is collective intelligence in general

Condorcet jury model
Galton experiment
Collective error is always smaller

I will show they are NOT proofs, but each will give us a lesson of what is needed for collective intelligence

How do animals do it? A couple of lessons from animals

Can we enhance it with AI?

Condorcet (1785)

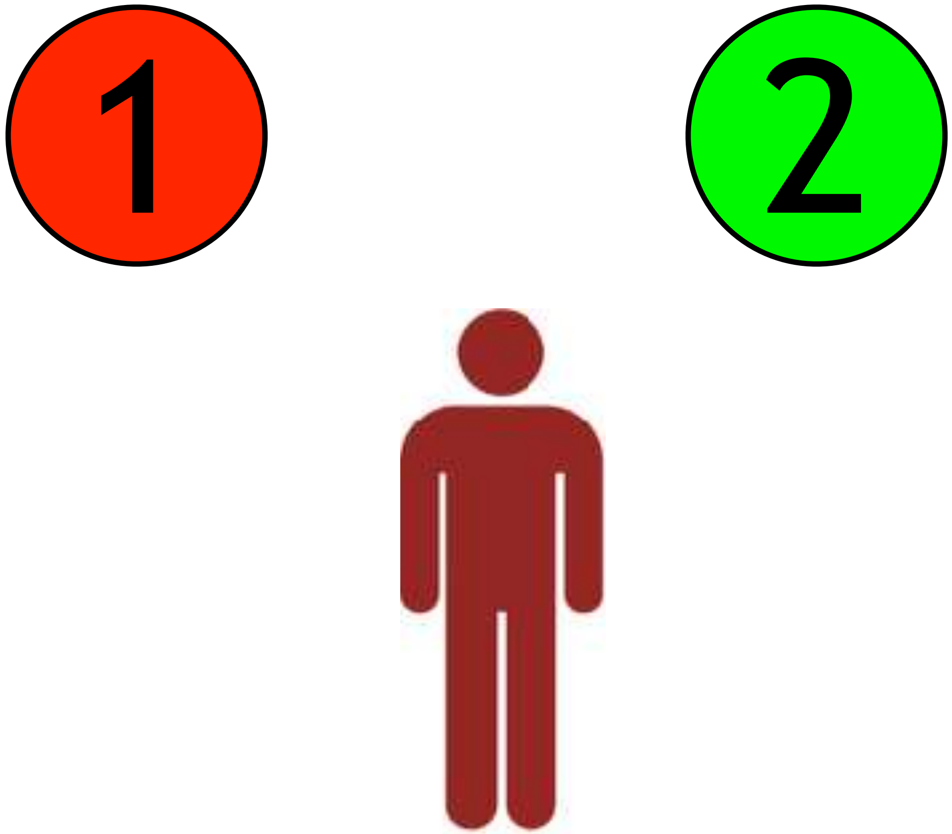
Marquis de Condorcet

Essay on the applicability of probability analysis to majority decisions

Condorcet (1785)

Incorrect option

Correct option

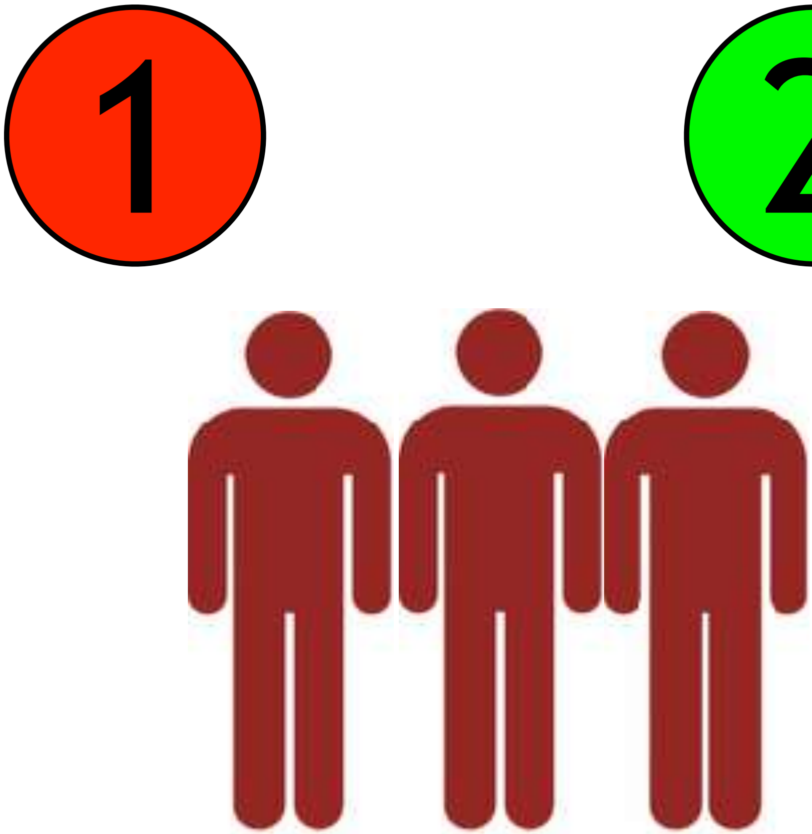


She chooses the right option
with probability ***p***

Condorcet (1785)

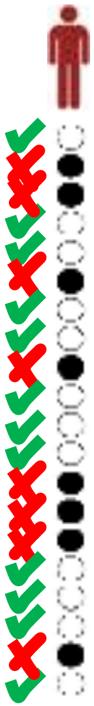
Incorrect option

Correct option

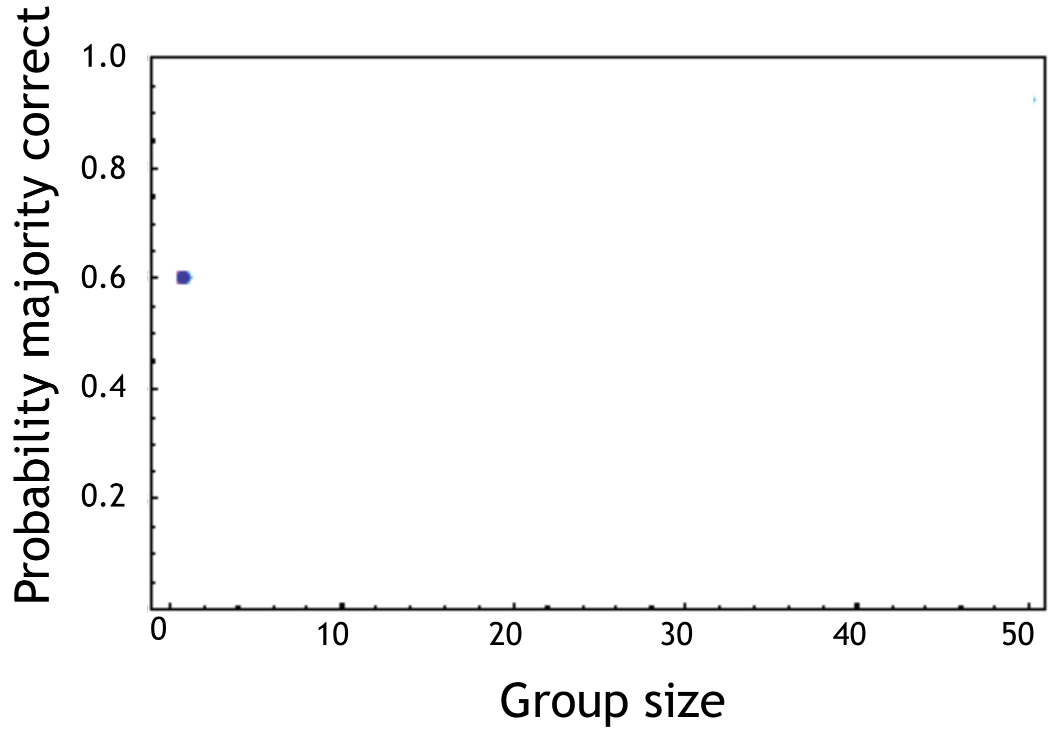


What is the probability that the majority (2 of them) chooses the correct option if each person does with probability p ?

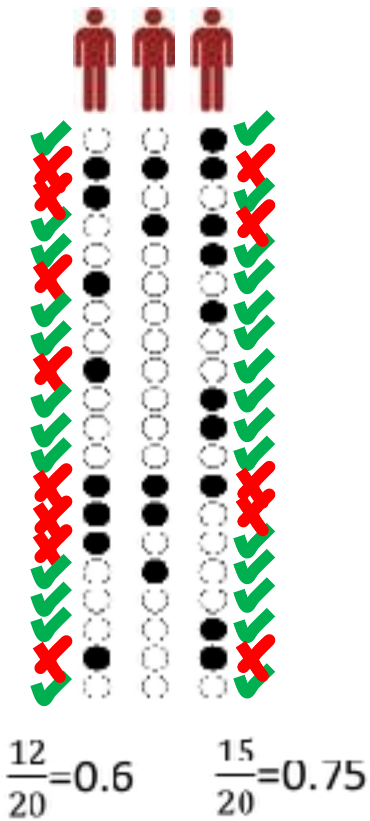
Condorcet (1785)

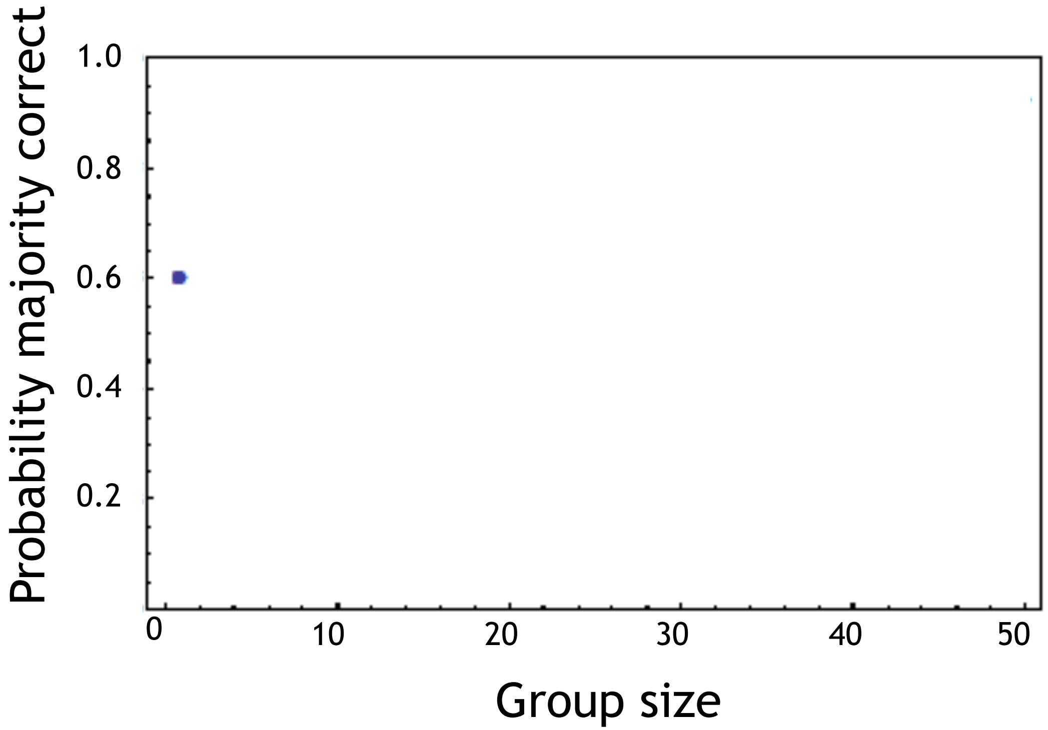


$\frac{12}{20}$=0.6

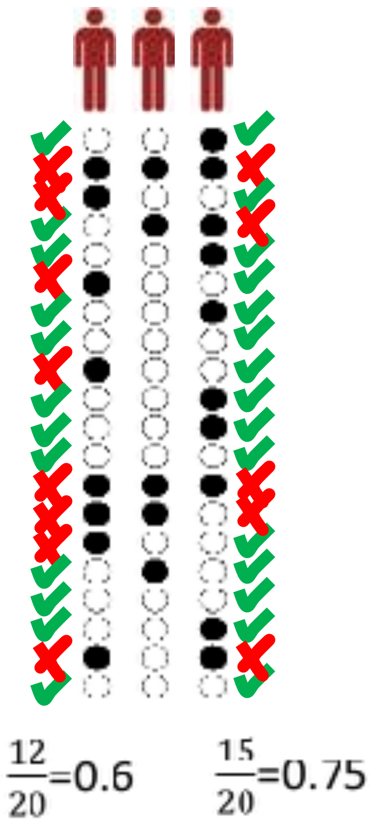


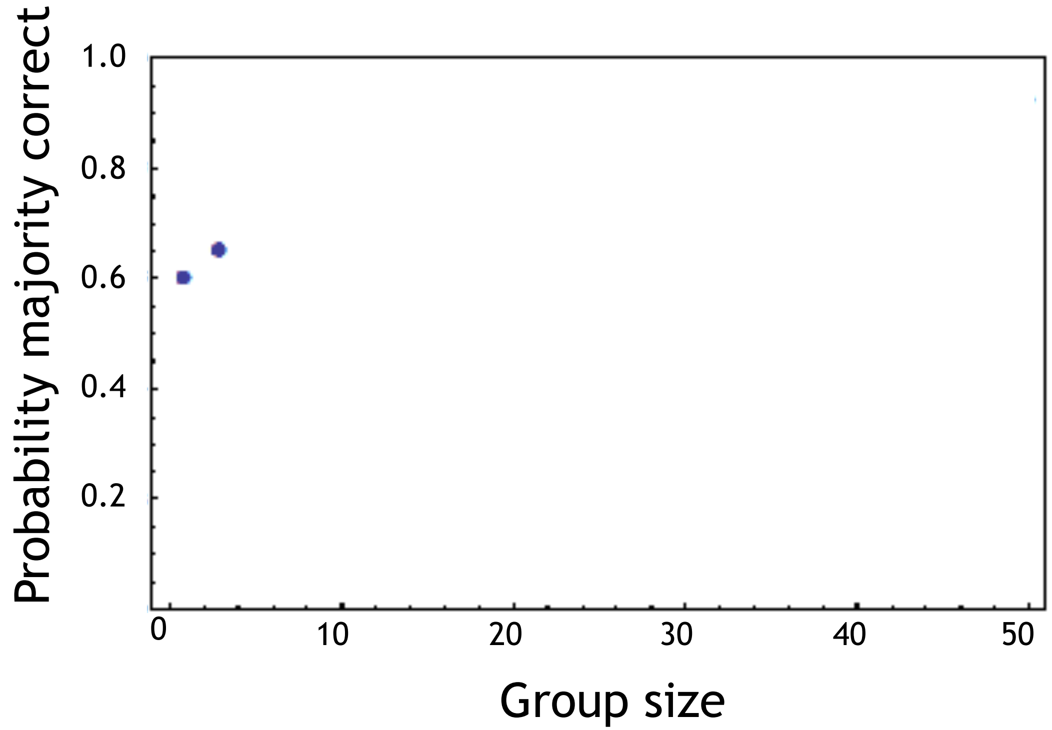
Condorcet (1785)



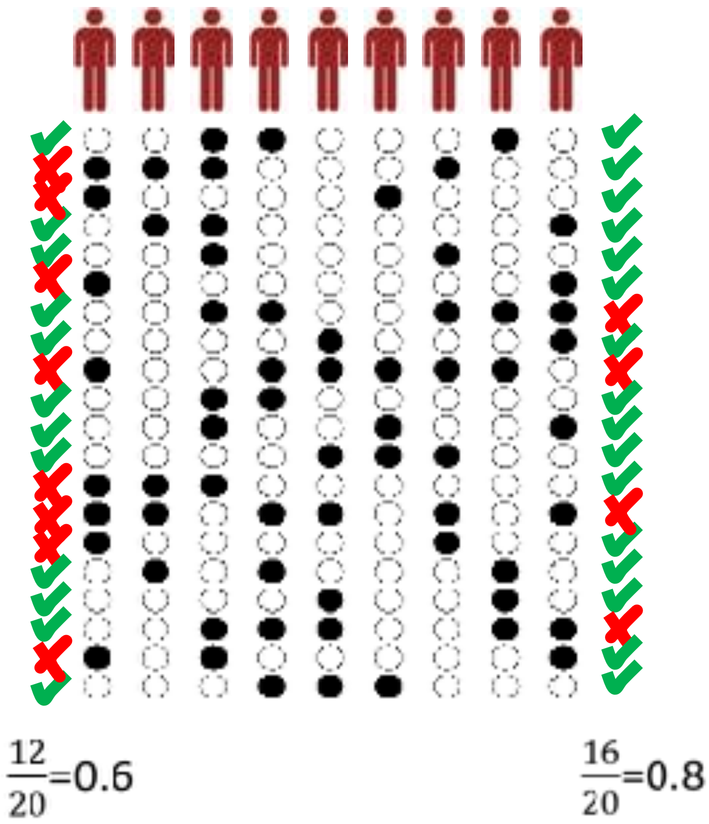


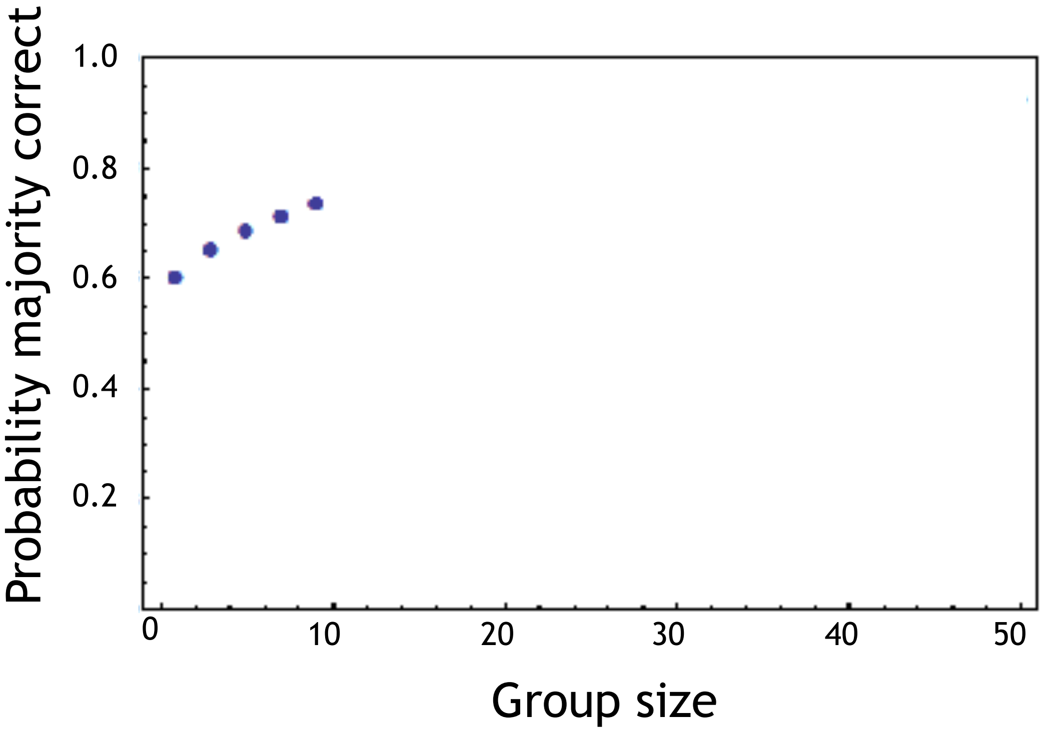
Condorcet (1785)



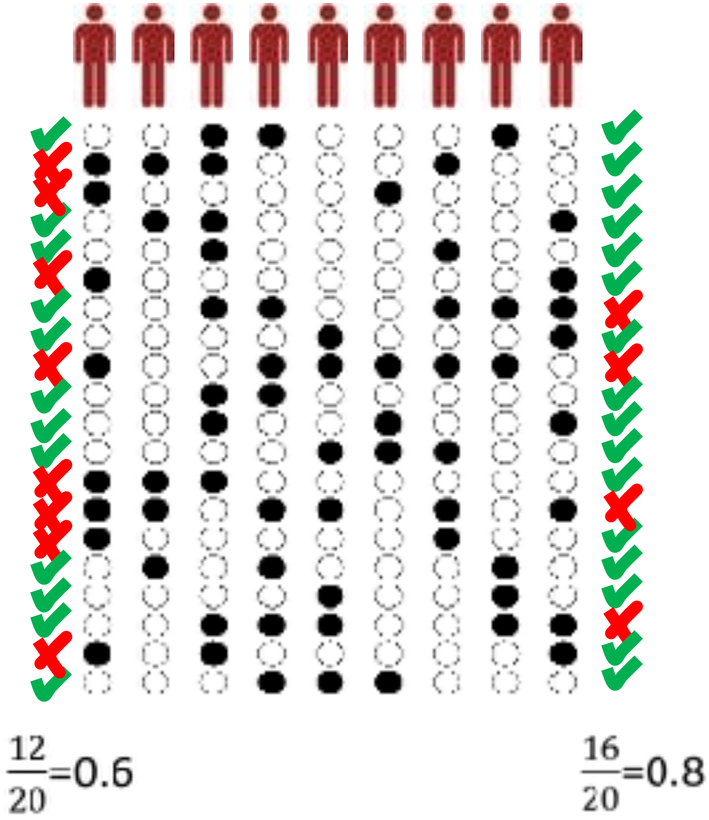


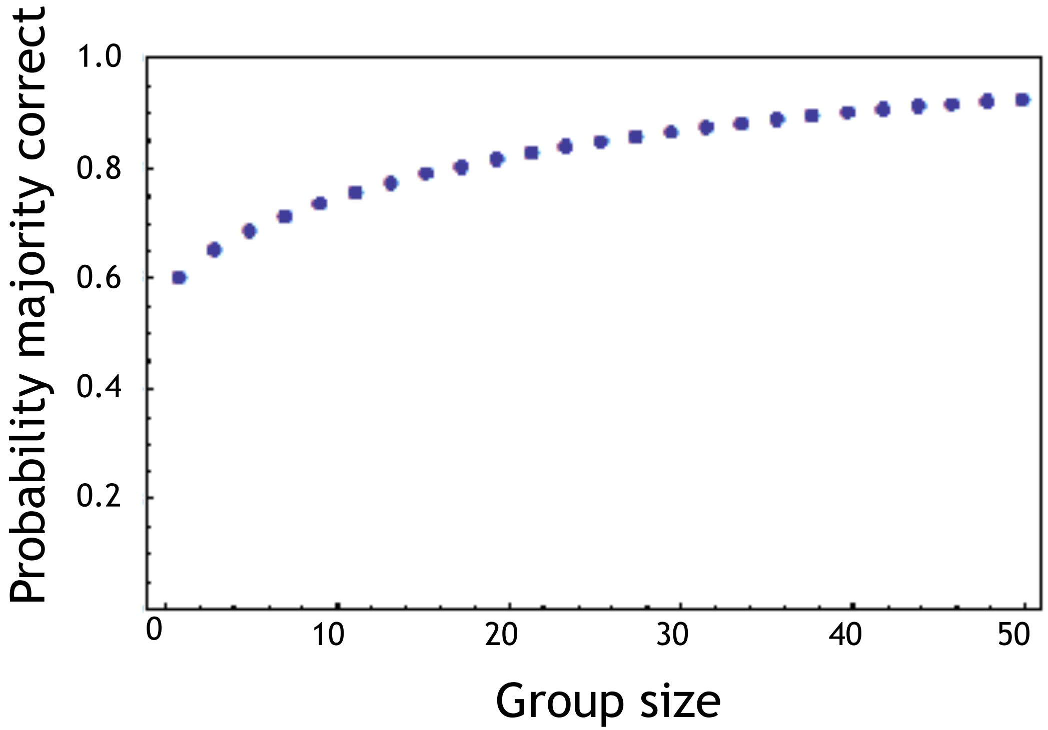
Condorcet (1785)



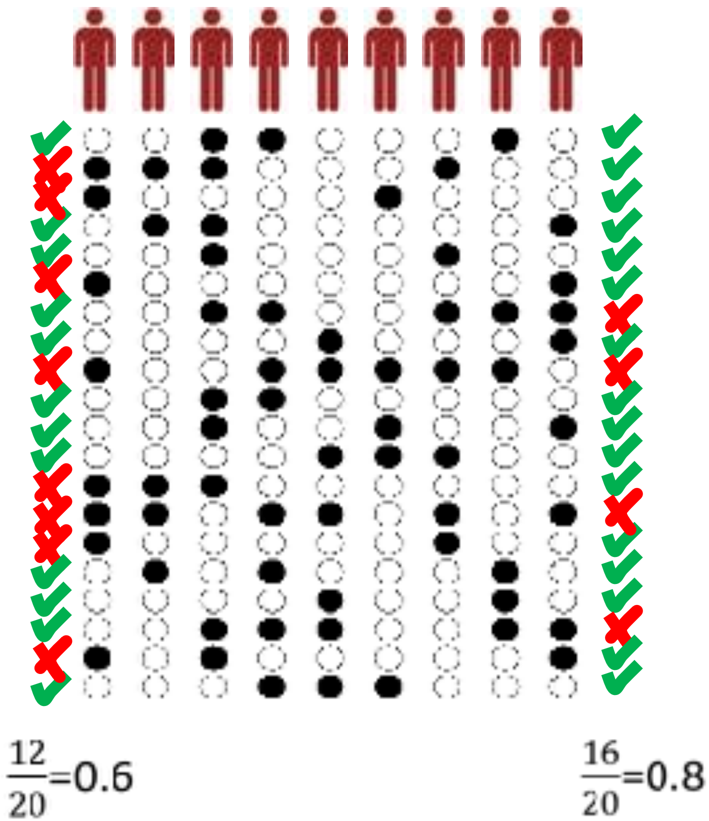


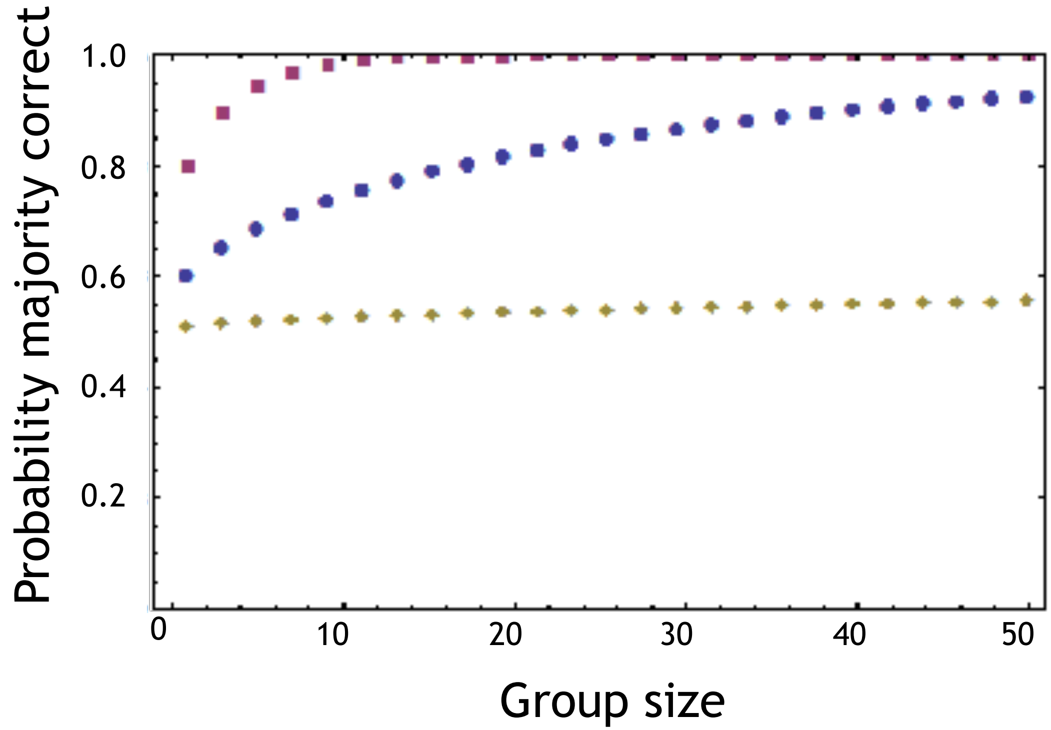
Condorcet (1785)



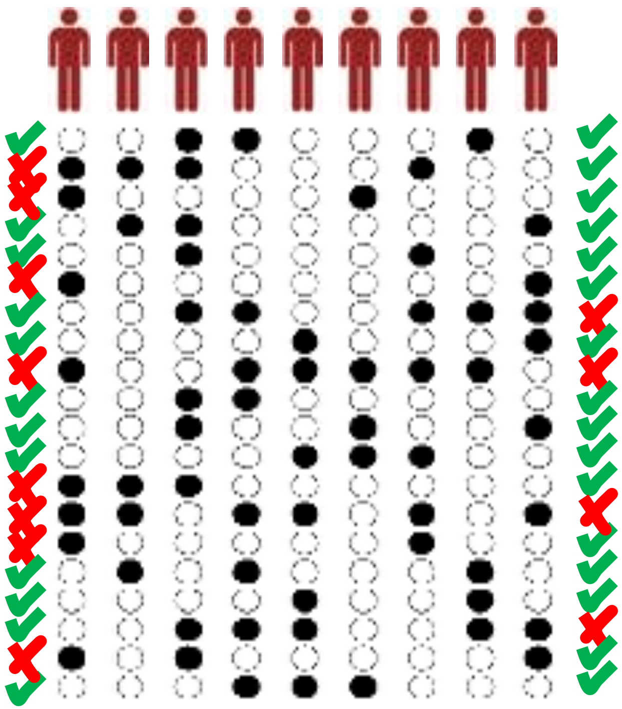


Condorcet (1785)



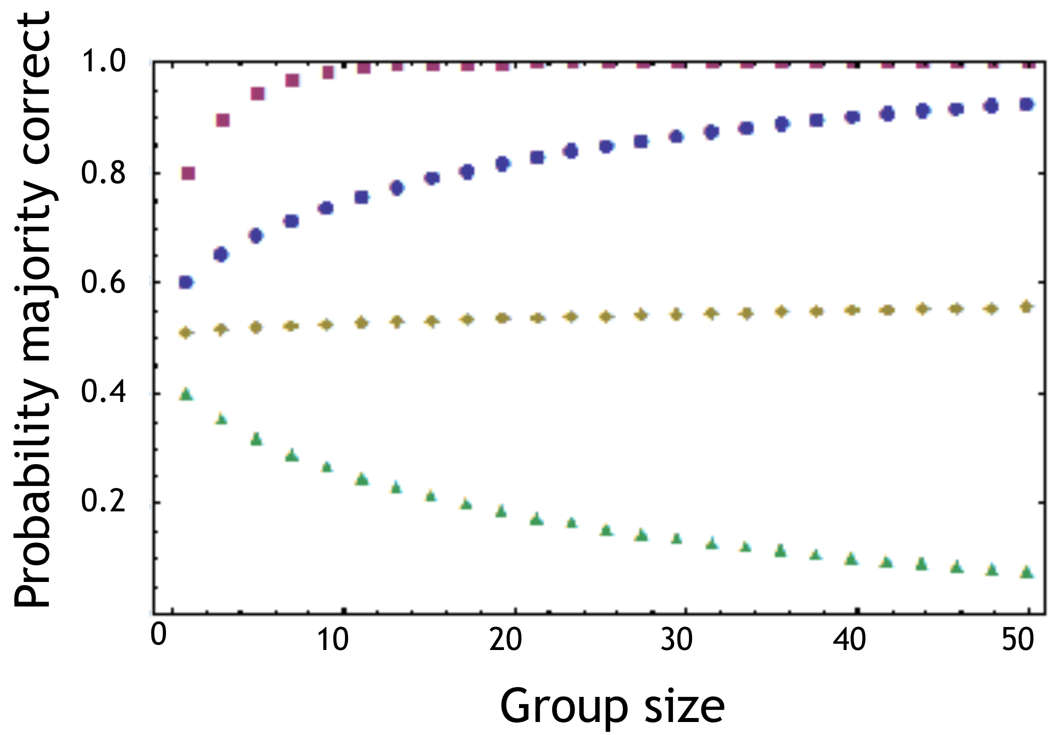


Condorcet (1785)



$\frac{12}{20}$=0.6

$\frac{16}{20}$=0.8



Condorcet (1785)

Is this a proof of Collective Intelligence?

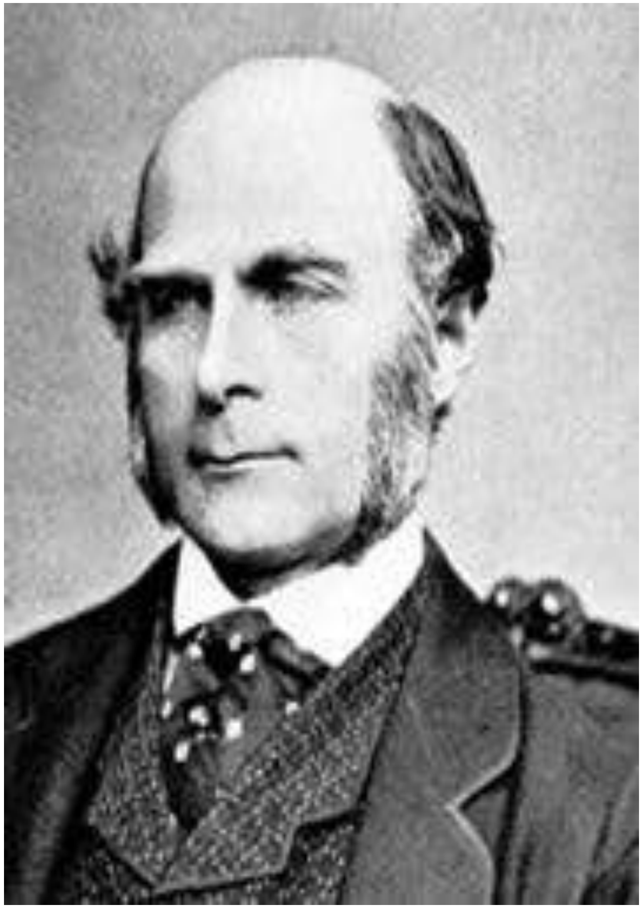
No, it assumes humans to be independent, and we are not because:

1. We receive similar information for many problems
2. We share a common historical/cultural background
3. We share a common cognitive architecture

LESSON 1:
with correlations among individuals, majority voting may NOT be collective intelligence

LESSON 2:
You also need individuals with **p>0.5**

Galton (1907)



Francis Galton

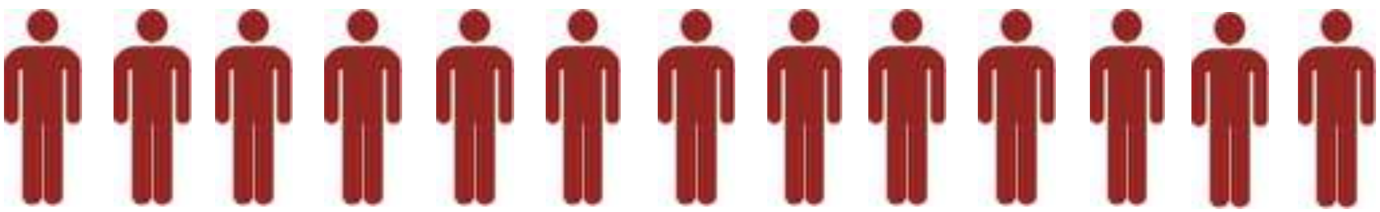
Vox Populi

IN these democratic days, any investigation into the trustworthiness and peculiarities of popular judgments is of interest. The material about to be discussed refers to a small matter, but is much to the point.

Galton (1907)

What is the weight of the ox?

Individuals (800) write down their answer independently of each other



Median value (middle observation of ordered list)= 1,198

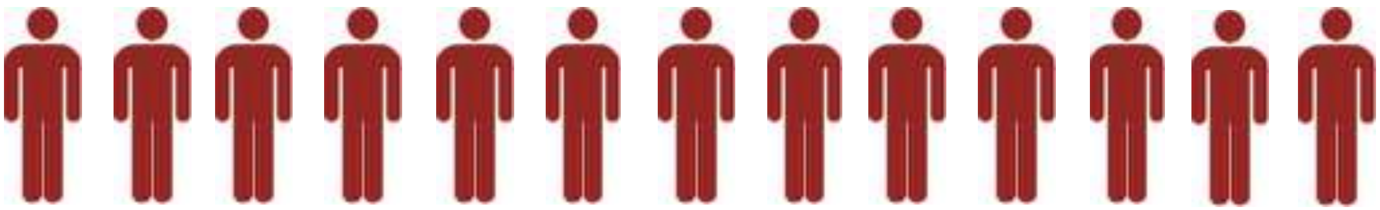
Real value = 1,207

} 1 % error

Galton (1907)

What is the weight of the ox?

Individuals (800) write down their answer independently of each other



400 645 650 700 840 990 1,198 2,050 2,100 2,140 2,320 2,520 3,100

Median value (middle observation of ordered list)= 1,198
Real value = 1,207
} 1 % error

What is the border length between Italy and Swizerland?

Median value = 302
Real value = 734
} 60 % error

Galton (1907)

LESSON 3:

In general, knowledge is not equally distributed in a collective,
so doing mean/median is NOT collective intelligence

‘Proofs’ that there is collective intelligence in general

Condorcet jury model
Galton experiment
Collective error is always smaller

I will show they are NOT proofs, but each will give us a lesson of what is needed for collective intelligence

How do animals do it? A couple of lessons from animals

Can we enhance it with AI?

A ‘proof’ of lower collective error

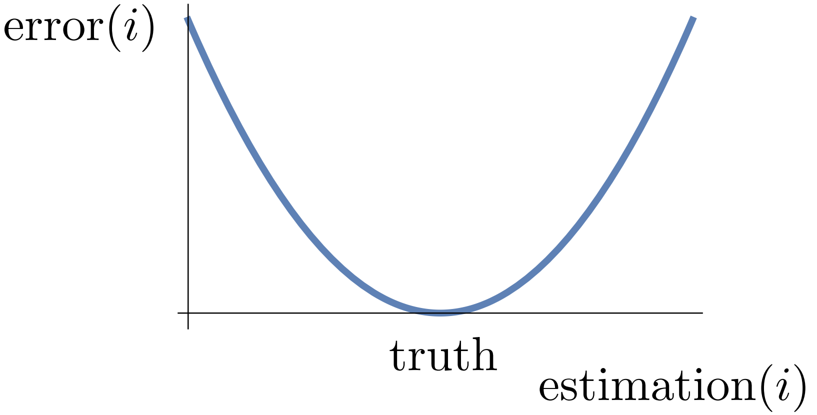
We have N individuals making estimations: $\text{estimation}(i) \quad \text{for} \quad i = 1, ..., N$

A 'proof' of lower collective error

We have N individuals making estimations: $\text{estimation}(i)$ for $i = 1, ..., N$

The error each individual makes is

$$\text{error}(i) = (\text{estimation}(i) - \text{truth})^2$$

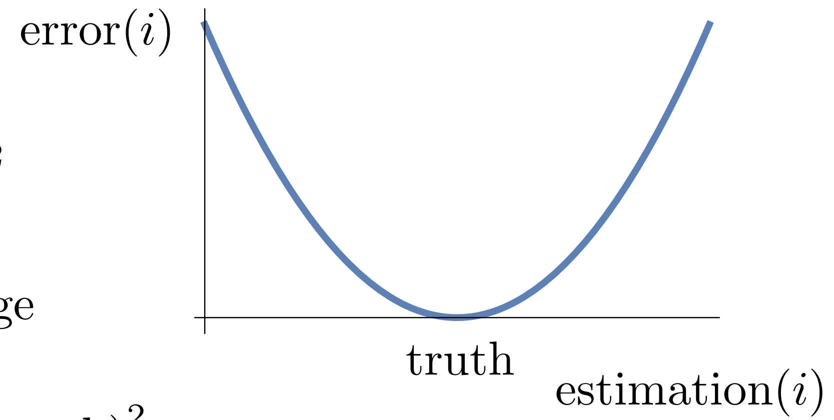


A ‘proof’ of lower collective error

We have N individuals making estimations: $\text{estimation}(i) \quad \text{for} \quad i = 1, ..., N$

The error each individual makes is

$$\text{error}(i) = (\text{estimation}(i) - \text{truth})^2$$



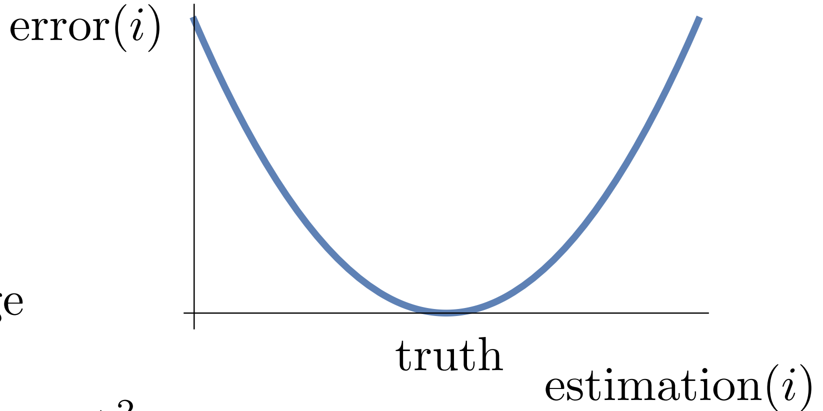
The error each an individual makes is on average

$$\overline{\text{error}(i)} = \frac{1}{N} \sum_{i=1}^{N} (\text{estimation}(i) - \text{truth})^2$$

A ‘proof’ of lower collective error

We have N individuals making estimations: $\text{estimation}(i) \quad \text{for} \quad i = 1, ..., N$

The error each individual makes is



$$\text{error}(i) = (\text{estimation}(i) - \text{truth})^2$$

The error each an individual makes is on average

$$\overline{\text{error}(i)} = \frac{1}{N}\sum_{i=1}^{N}(\text{estimation}(i) - \text{truth})^2$$

The collective estimation is simply the average estimation

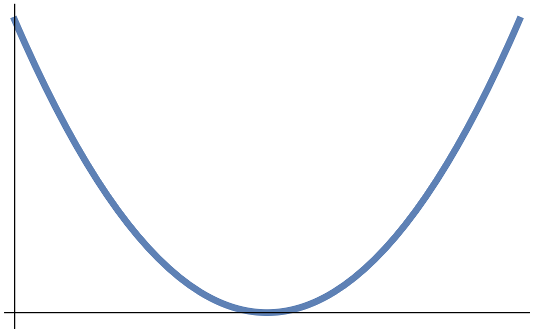
$$\text{collective estimation} = \frac{1}{N}\sum_{i=1}^{N}\text{estimation}(i)$$

$$\text{collective error} = (\text{collective estimation} - \text{truth})^2$$

A ‘proof’ of lower collective error

We have N individuals making estimations: $\text{estimation}(i)$ for $i = 1, ..., N$

The error each individual makes is



$$\text{error}(i) = (\text{estimation}(i) - \text{truth})^2$$

The error each an individual makes is on average

$$\overline{\text{error}(i)} = \frac{1}{N}\sum_{i=1}^{N}(\text{estimation}(i) - \text{truth})^2$$

The collective estimation is simply the average estimation

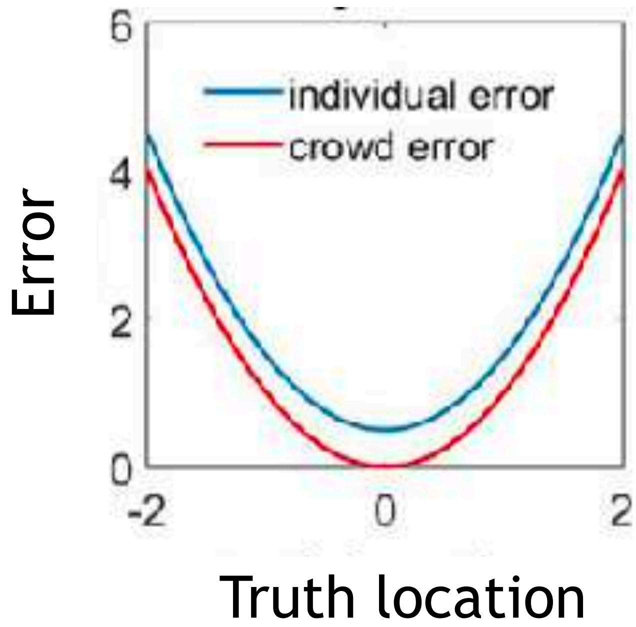
$$\text{collective estimation} = \frac{1}{N}\sum_{i=1}^{N}\text{estimation}(i)$$

$$\text{collective error} = (\text{collective estimation} - \text{truth})^2$$

Theorem: The collective estimation has on average less or the same error than a randomly picked individual

$$\text{collective error} \leq \overline{\text{error}(i)}$$

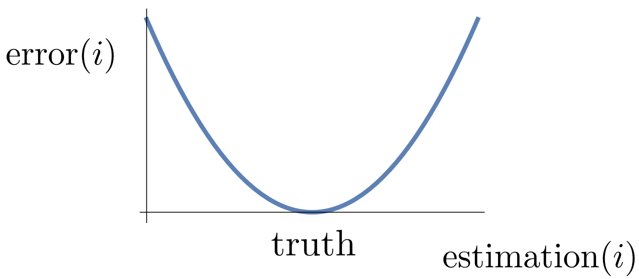
Example: 5 people estimate: -1,-0.5,0,0.5,1



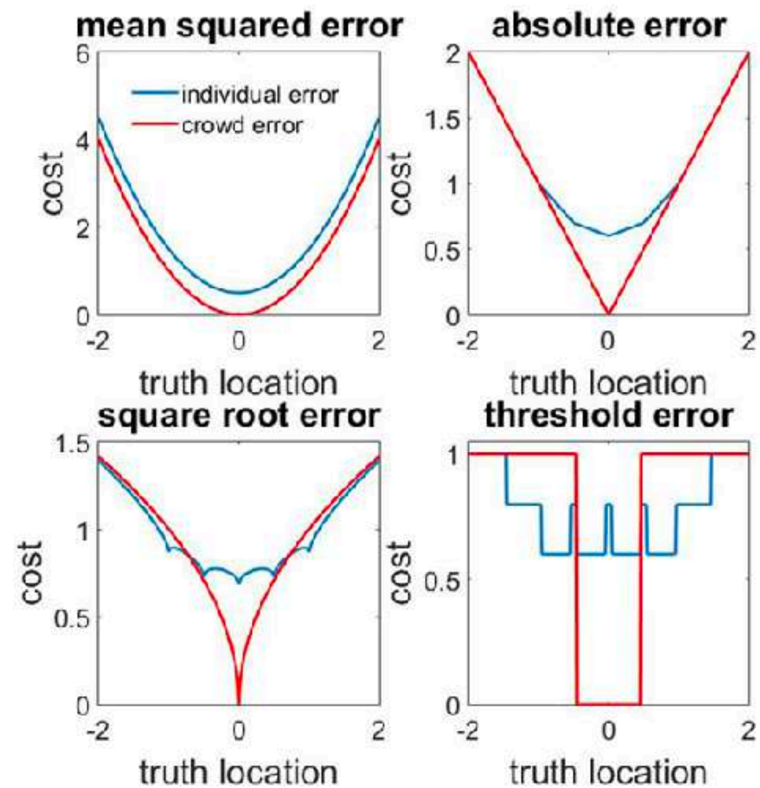
Crowd better on average
than an individual independently of truth

Example 2: Use the length of our noses to measure the height of Eiffel Tower.
Again, the crowd is better!

What happens is that the error is assumed to be quadratic (because we are lazy intellectuals) but ***real*** errors need not be



For other errors the result is different



LESSON 4:

Errors in a collective can be smaller or higher than individual error depending on the error function

BIG LESSON:

There is no magic bullet for Collective Intelligence

Instead, it needs to be incentivised by methods that

Allow those with knowledge to have more weight (anti-Galton)

Correlations among individuals should be such the collective listens to those that at each point in time have the required knowledge to solve the task (anti-Condorcet)

Understand the cost incurred by mistakes (anti-Theorem)

Laan, Madirolas & de Polavieja, Frontiers in Robotics and AI (2017)

‘Proofs’ that there is collective intelligence

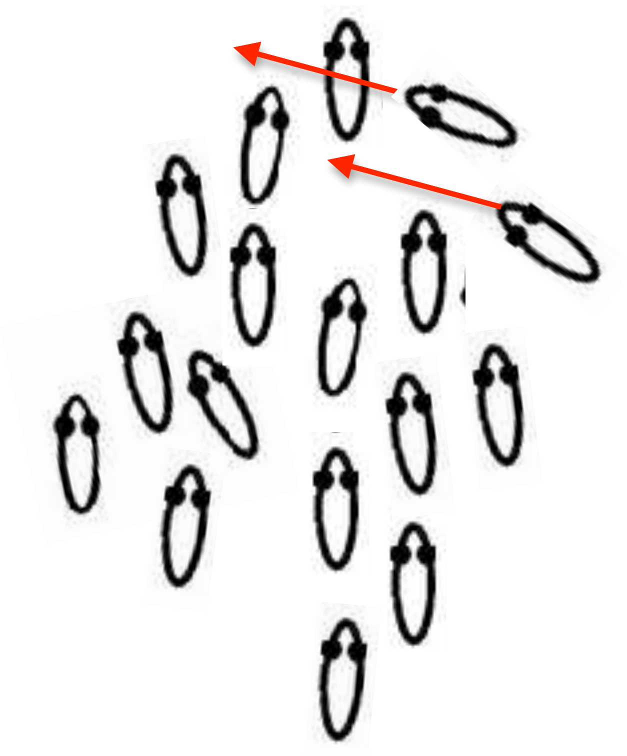
Condorcet jury model
Galton experiment
Collective error is always smaller

I will show they are NOT proofs, but each will give us a lesson of what is needed for collective intelligence

How do animals do it? A couple of lessons from animals

Can we enhance it with AI?

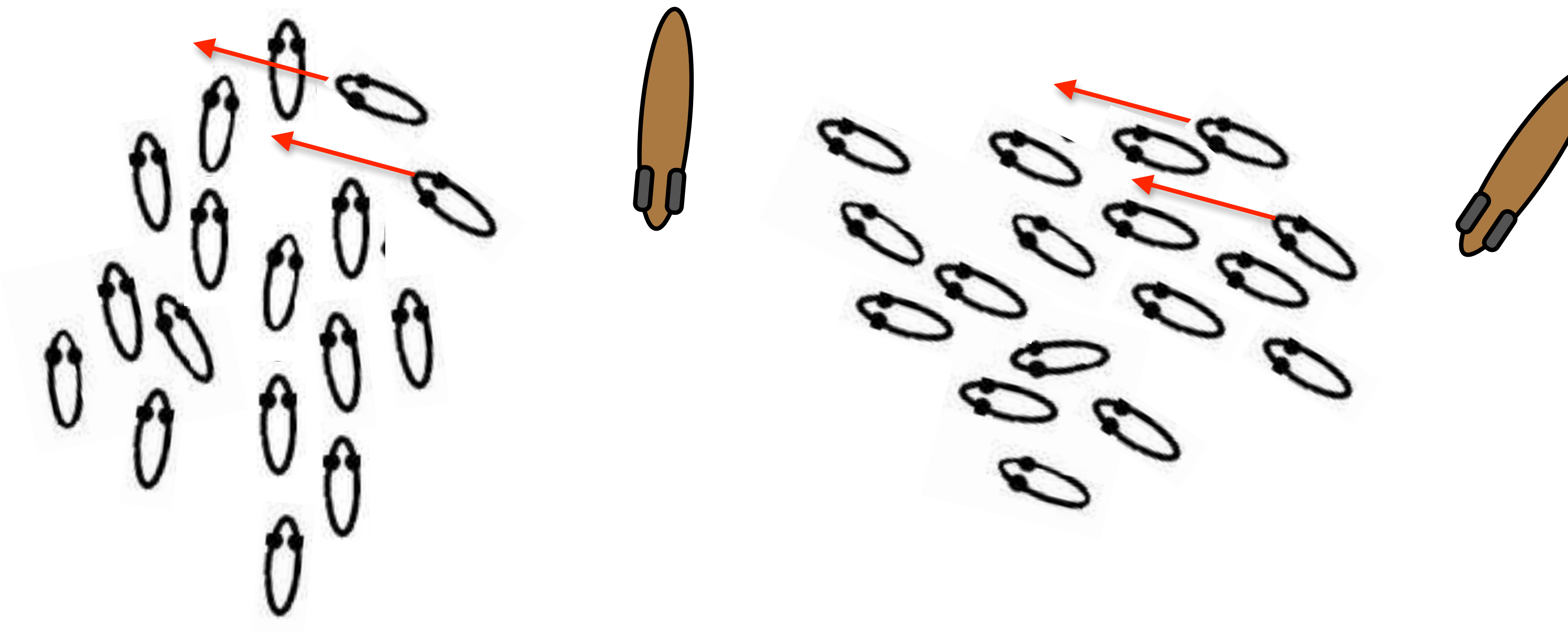
Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)
Perez-Escudero et al, Nat. Methods (2014)
Hinz & de Polavieja, *PNAS* (2017)
Perez-Escudero & de Polavieja, Interface (2017)
Laan, Gil de Sagredo & de Polavieja, Proc. Roy. Soc. (2017)
Vicente-Page, Perez-Escudero & de Polavieja, J. Theor. Ecology (2018)



Those with knowledge are copied by the rest (instead of using a majority vote)

Copy takes place more likely when those with knowledge **confidently** show it and those that do not have do not look as if they had it

(a) high velocity/acceleration changes & straight paths
(b) More so if >1 individual with properties in (a)



Those with knowledge are copied by the rest (instead of using a majority vote)

Copy takes place more likely when those with knowledge **confidently** show it and those that do not have do not act as if they had it

(a) high velocity/acceleration changes & straight paths
(b) More relevant if >1 individual with properties in (a)

Animal collectives are more intelligent when:

- Individuals with knowledge express it to the collective
- The others can recognise who has the knowledge and use it
- The diversity of knowledge to solve a task is present in the collective

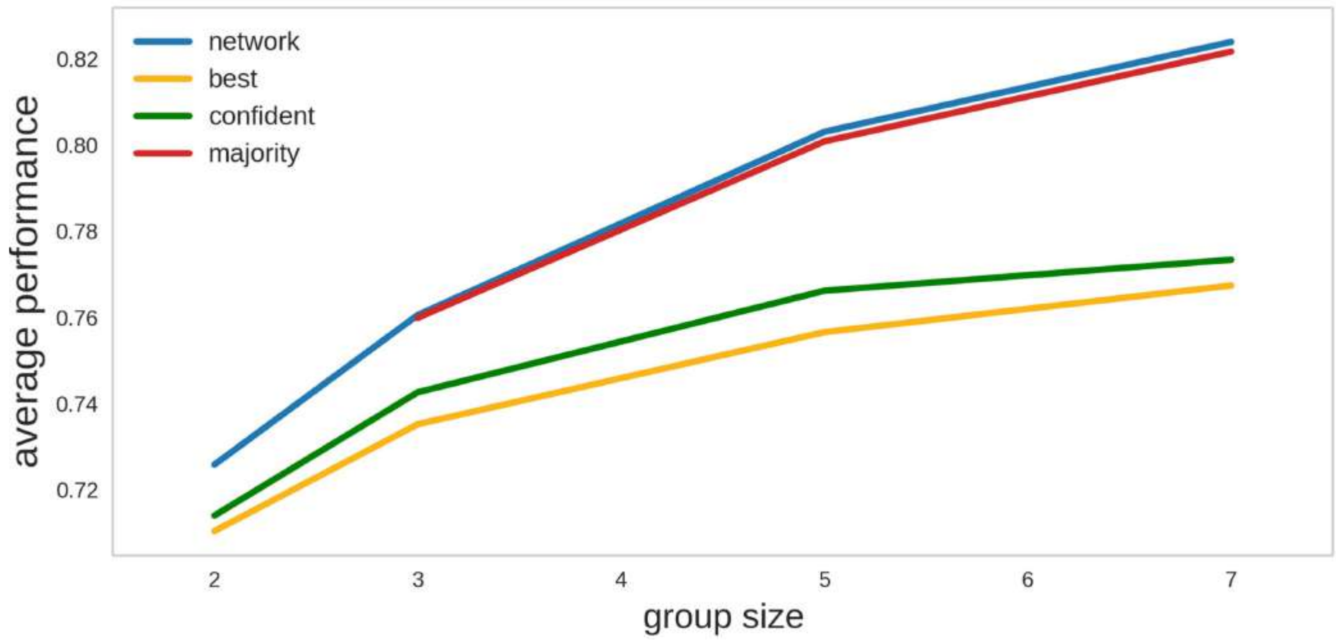
Does AI help?

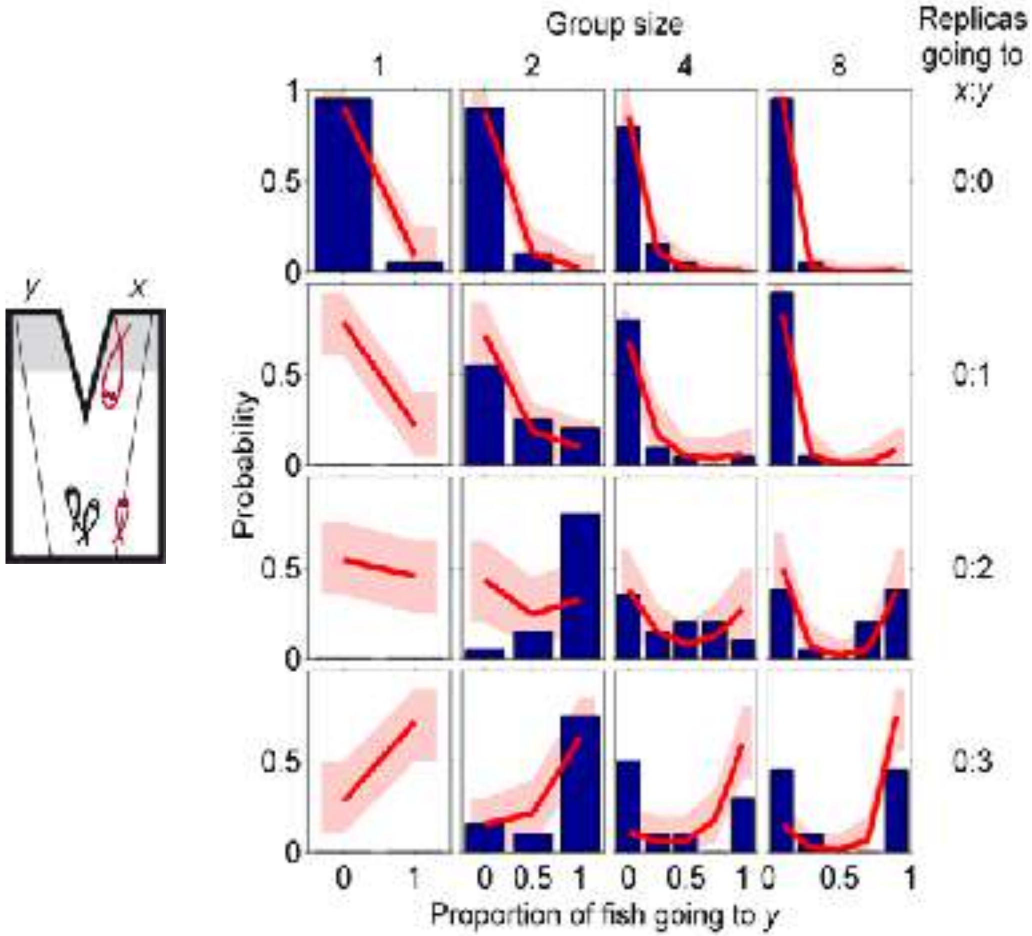
N doctors (*N*=2,3, 5 or 7) diagnose cancer/no cancer from image and also give confidence level and the % of successes until then

The strategy of choosing the best (higher % correct) or more confident is suboptimal. The majority opinion is quite good (because most doctors are reasonably good).

The network trained to combine doctors opinions, confidence levels and % correct is slightly better (significant for *N*=5 and *N*=7)

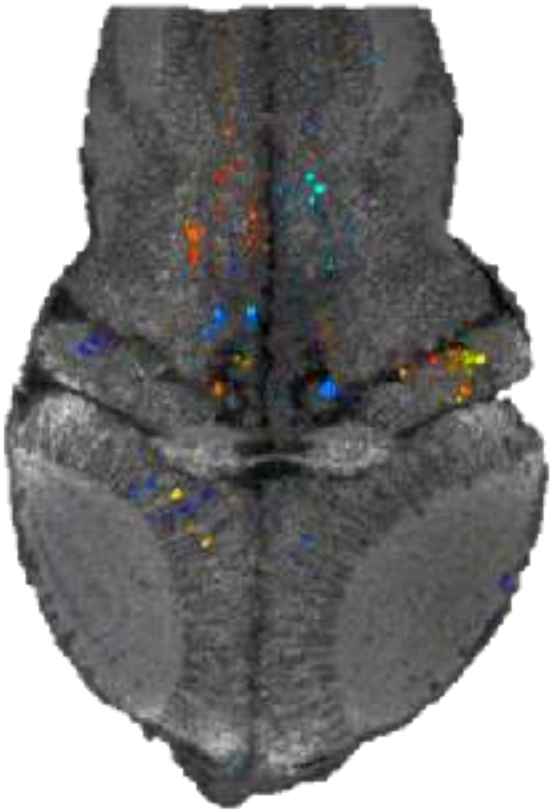
Collectives + AI might be a good method to extract collective intelligence, specially when knowledge is only in few individuals





Perez-Escudero & de Polavieja, Plos Comp. Biol. (2017)

What are our theories based upon?



Individuals use **inference**

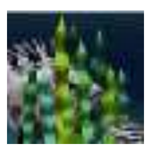
Individuals learn by **rewards**

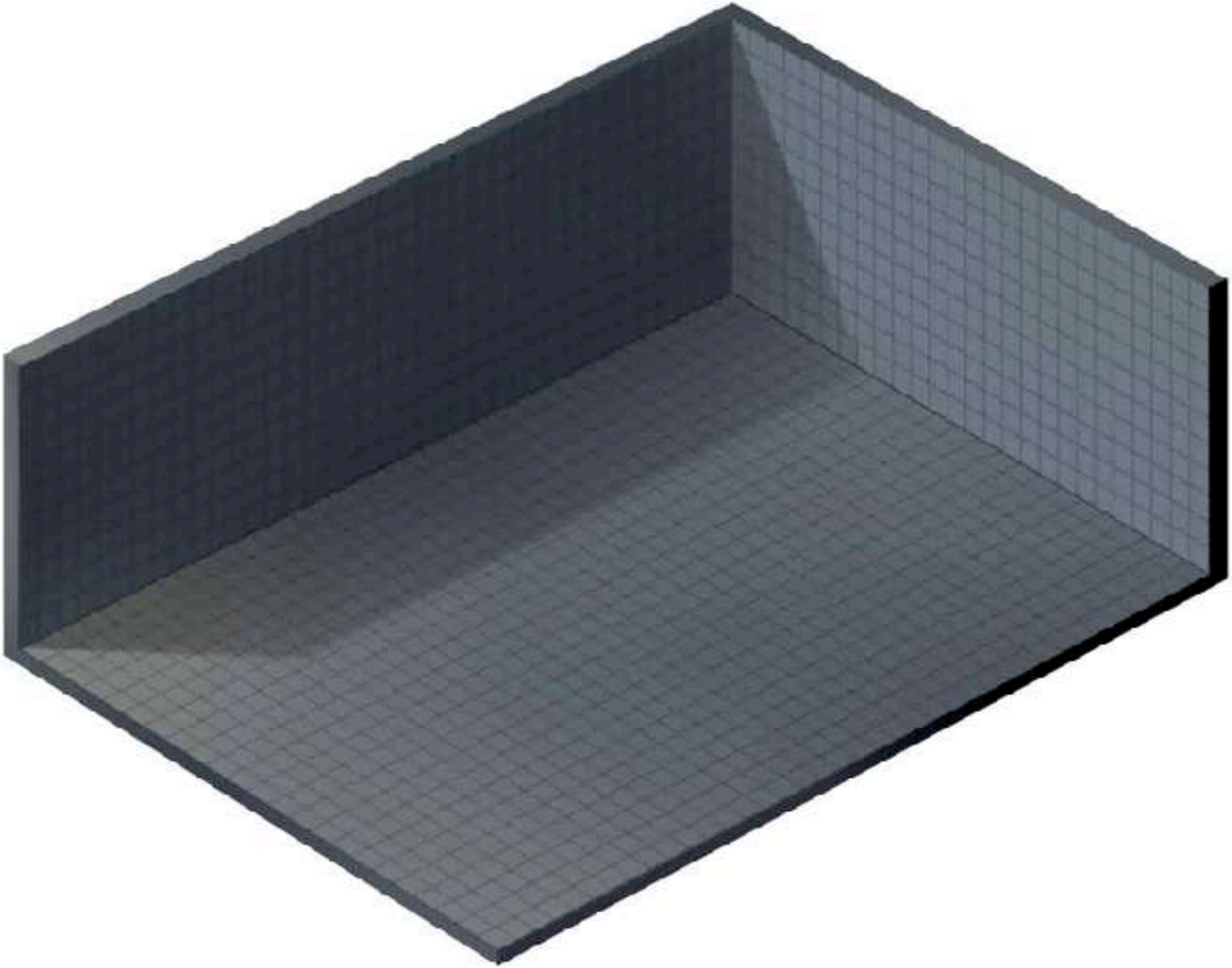
Individuals **control** their behavior according to some policies

Individuals use **heuristic** rules

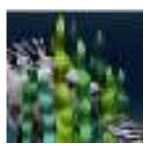
Individuals are a **neuronal network** coupled to a skeletal system

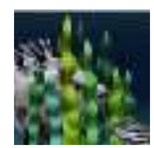
Brains generate decisions from ambiguous information

P( | )



Brains generate decisions from ambiguous information

P( | )

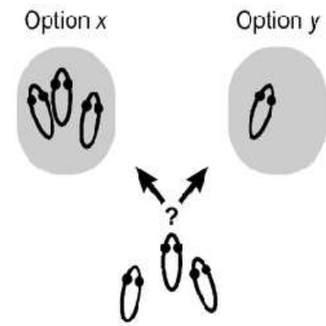
P( |  , )

$$P(Y|C,B)$$

Y 'y is the best option'

C 'private information'

B 'behaviors of others'



$$P(X|C,B) = 1 - P(Y|C,B)$$

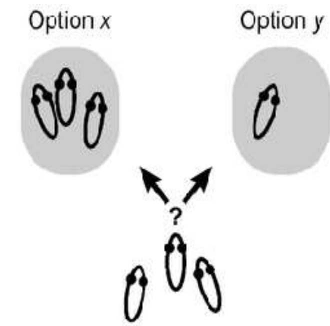
$$P(Y|C,B) = \frac{P(B|Y,C)P(Y|C)}{P(B|X,C)P(X|C) + P(B|Y,C)P(Y|C)}$$

$$P(Y|C,B) = \frac{1}{1+aS}$$

$$a = \frac{P(X|C)}{P(Y|C)}$$

$$S = \frac{P(B|X,C)}{P(B|Y,C)}$$

$$S = \frac{P(B|X,C)}{P(B|Y,C)}$$



$$B = \{b_i\}$$

Assuming focal agent does not use correlations among others
(see our PCB 2011 without this assumption)

$$P(B|Y,C) = Z \prod_{i=1}^{N} P(b_i|Y,C)$$

$$S = \prod_{i=1}^{N} \frac{P(b_i|X,C)}{P(b_i|Y,C)}$$

Instead of behaviours b_i consider β_x as ‘going to x’ and β_y ‘going to y’ with n_x animals going to x and n_y animals going to y

$$S = s_x^{n_x} s_y^{n_y}$$

$$s_x = \frac{P(\beta_x|X,C)}{P(\beta_x|Y,C)}$$

$$s_y = \frac{P(\beta_y|X,C)}{P(\beta_y|Y,C)}$$

$$S = s_x^{n_x} s_y^{n_y}$$

$$s_x = \frac{P(\beta_x|X,C)}{P(\beta_x|Y,C)} \quad s_y = \frac{P(\beta_y|X,C)}{P(\beta_y|Y,C)}$$

In the case of a symmetric set-up (both options identical)

$$s_x = \frac{1}{s_y} \equiv s$$

$$S = s_x^{n_x} s_y^{n_y} = s^{n_x} s^{-n_y} = s^{-(n_y - n_x)}$$

$$P(Y|C,B) = \frac{1}{1 + aS}$$

$$P(Y|C,B) = \frac{1}{1 + as^{-(n_y - n_x)}}$$

That is the estimation part of the derivation.

Now we need a decision-rule using this estimation.

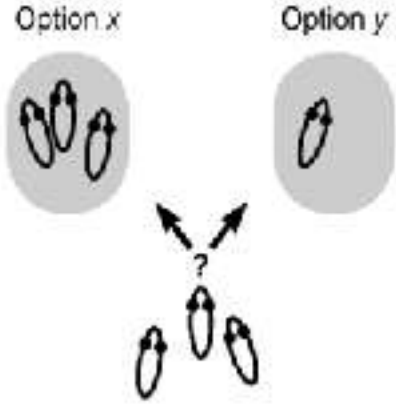
The pure one would be:

Choose y when $P(Y|C,B) > P(X|C,B)$. Otherwise, choose x

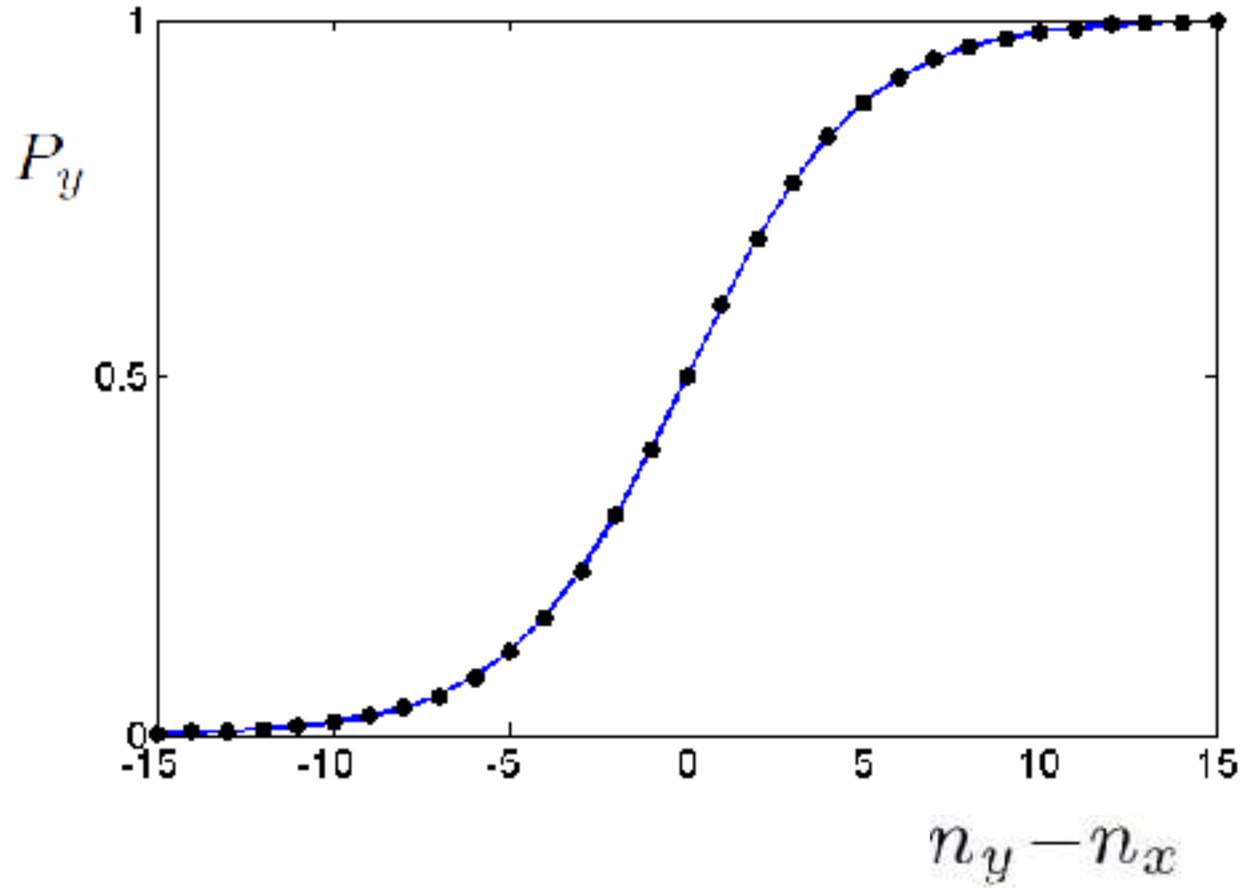
This pure rule does not correspond to data.

Instead we can add noise or use the softer parameter-free version (probability matching rule)

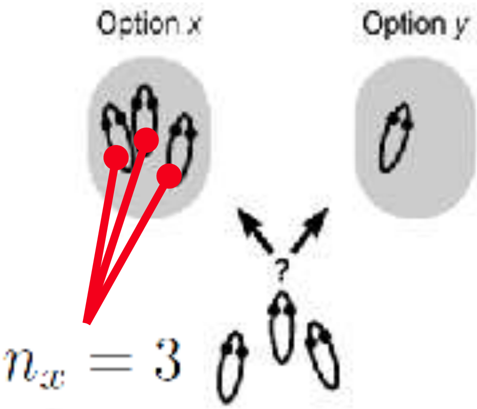
$$P_y = P(Y|C,B) = \frac{1}{1 + as^{-(n_y - n_x)}}$$



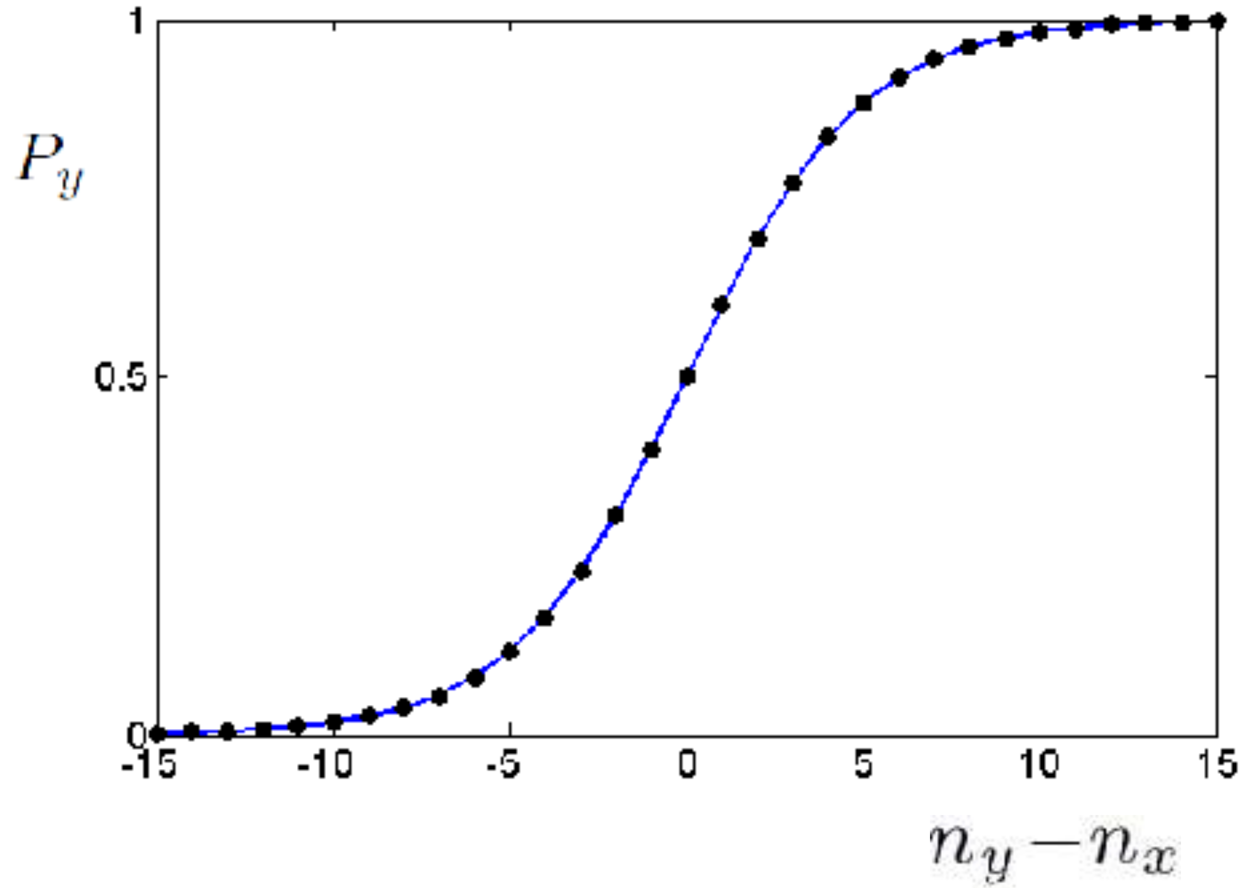
$$P_y = \frac{1}{1 + as^{-(n_y - n_x)}}$$



Perez-Escudero & de Polavieja, PLos Comp Biol (2011)

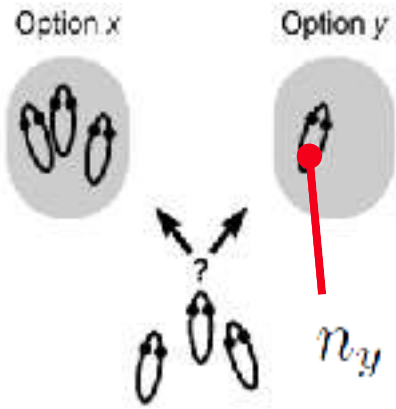


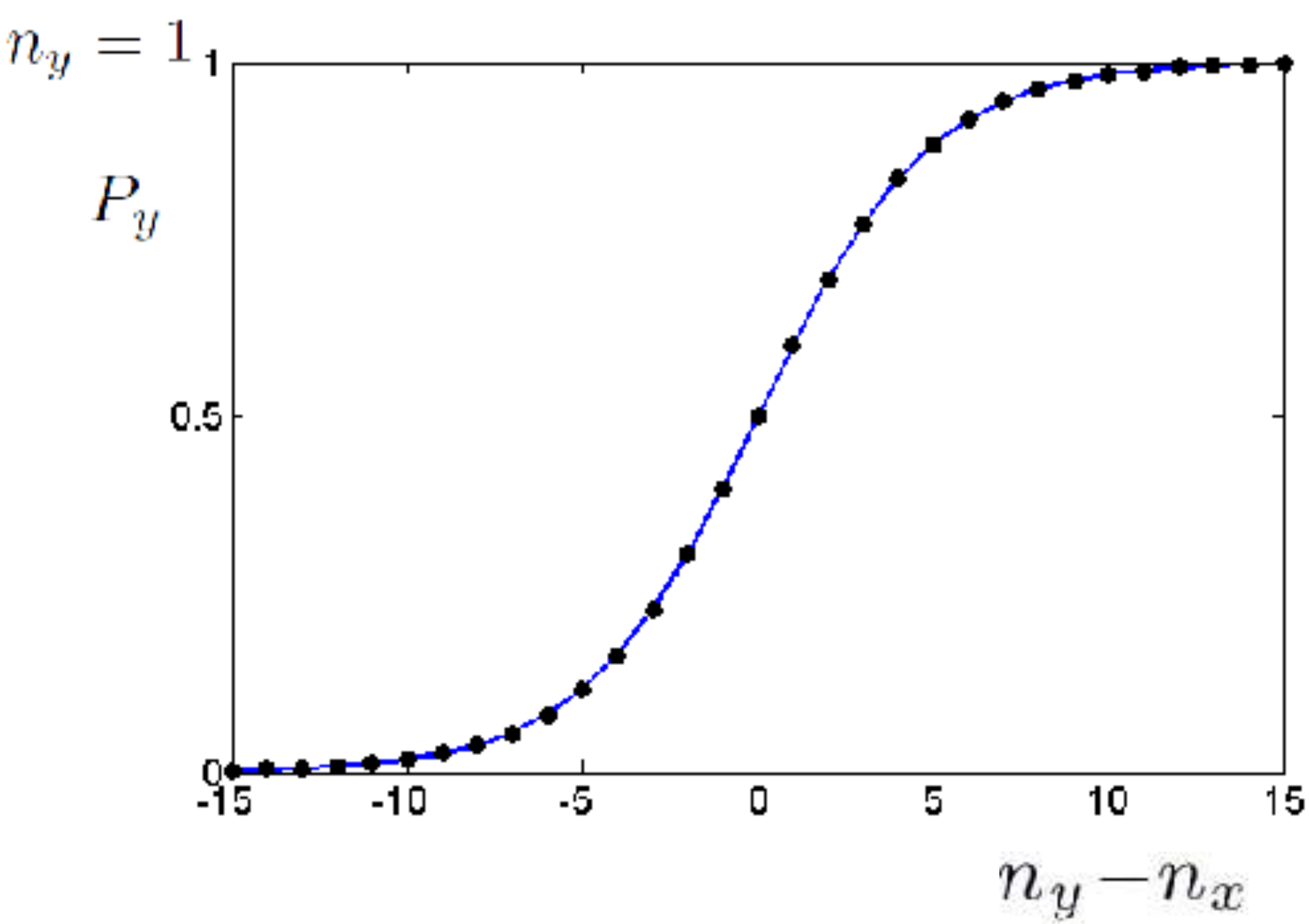
$$P_y = \frac{1}{1 + a s^{-(n_y - n_x)}}$$



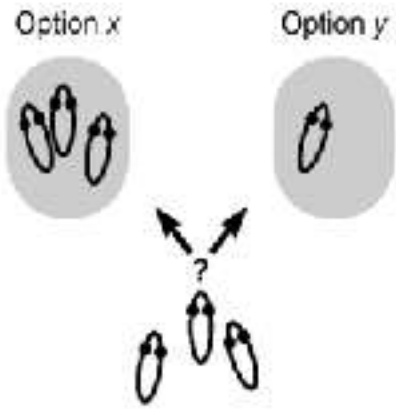
Perez-Escudero & de Polavieja, PLos Comp Biol (2011)

$$P_y = \frac{1}{1 + a s^{-(n_y - n_x)}}$$





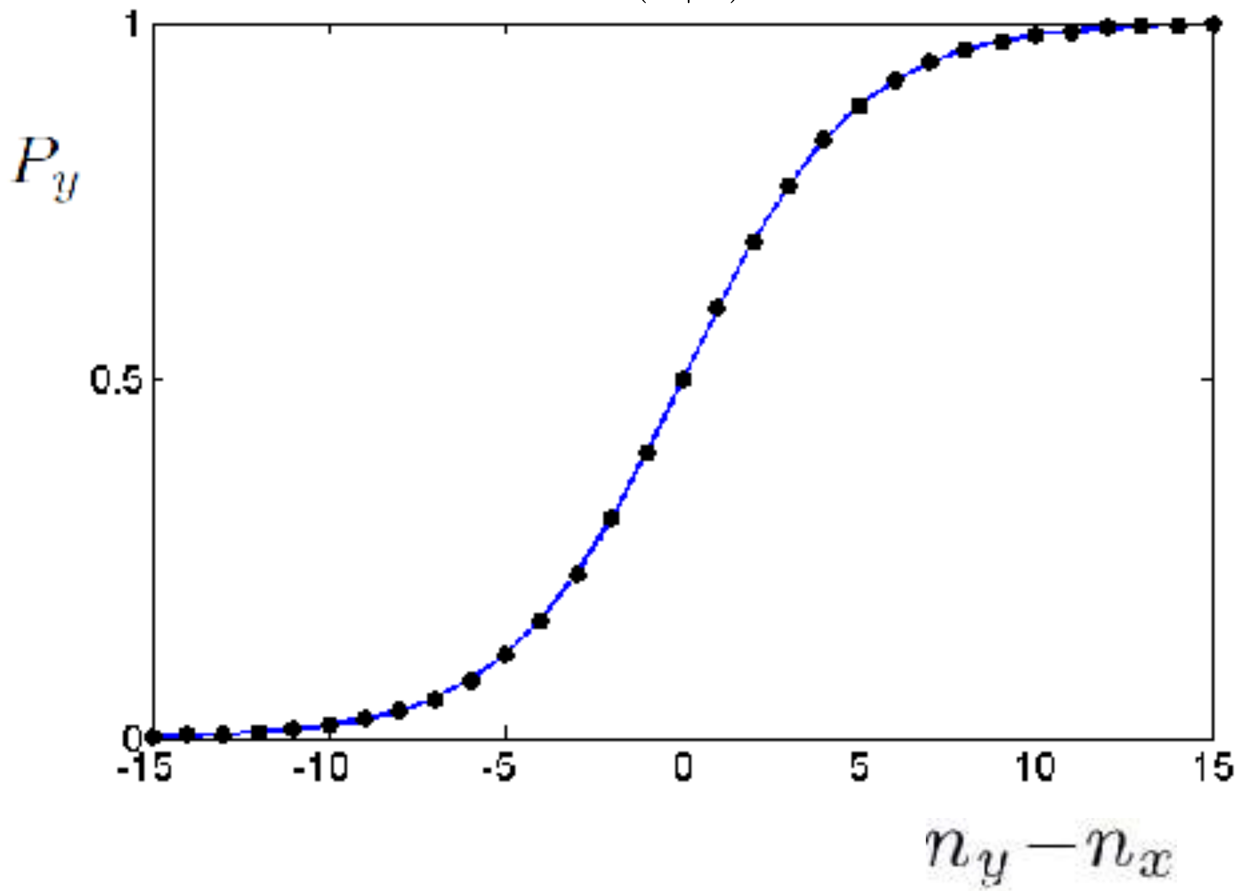
Perez-Escudero & de Polavieja, PLos Comp Biol (2011)



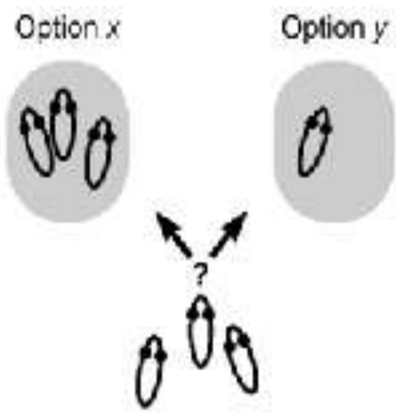
$$P_y = \frac{1}{1 + a s^{-(n_y - n_x)}}$$

$$a = \frac{P(X|C)}{P(Y|C)}$$

How private info alone tells George which option is best



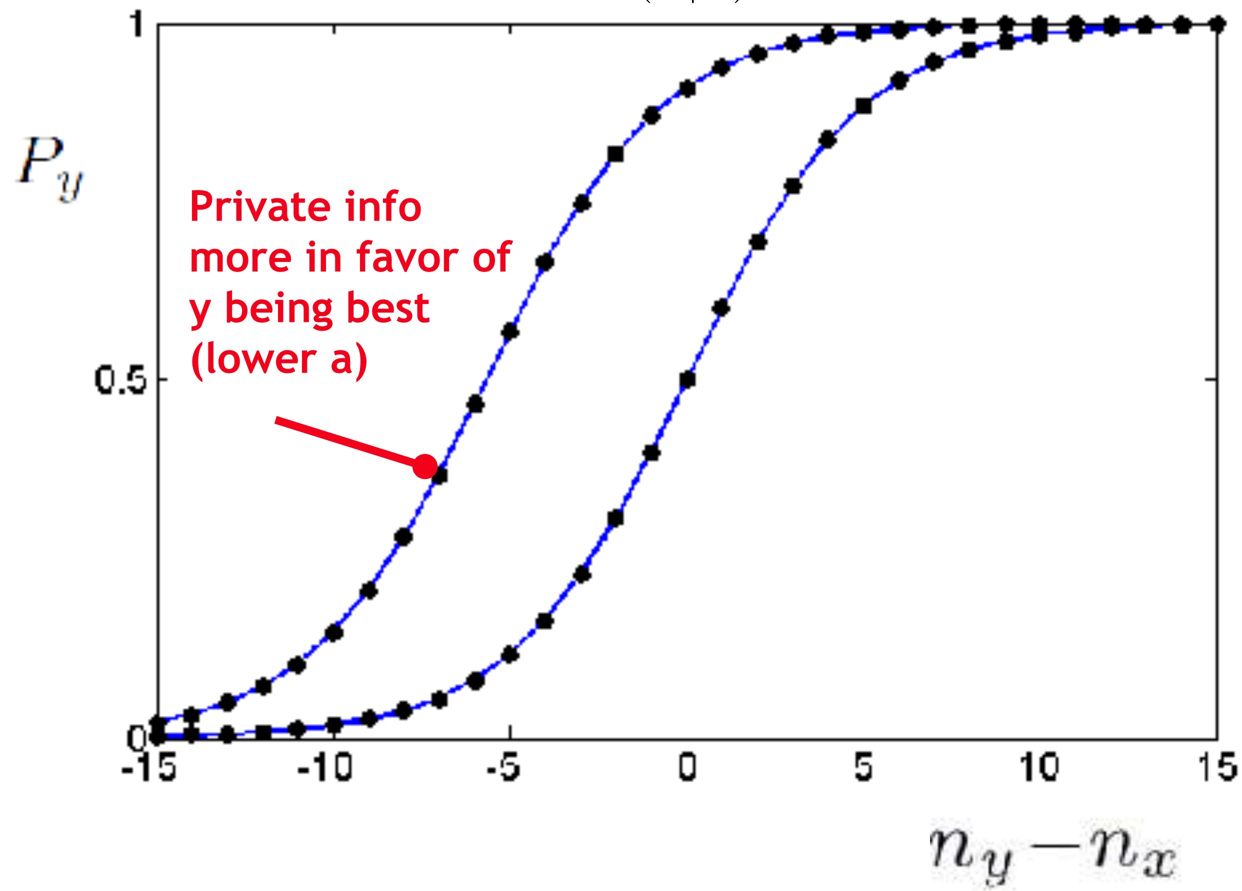
Perez-Escudero & de Polavieja, PLos Comp Biol (2011)



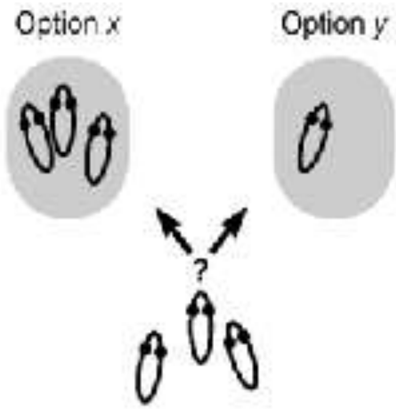
$$P_y = \frac{1}{1 + a s^{-(n_y - n_x)}}$$

$$a = \frac{P(X|C)}{P(Y|C)}$$

How private info alone tells George which option is best



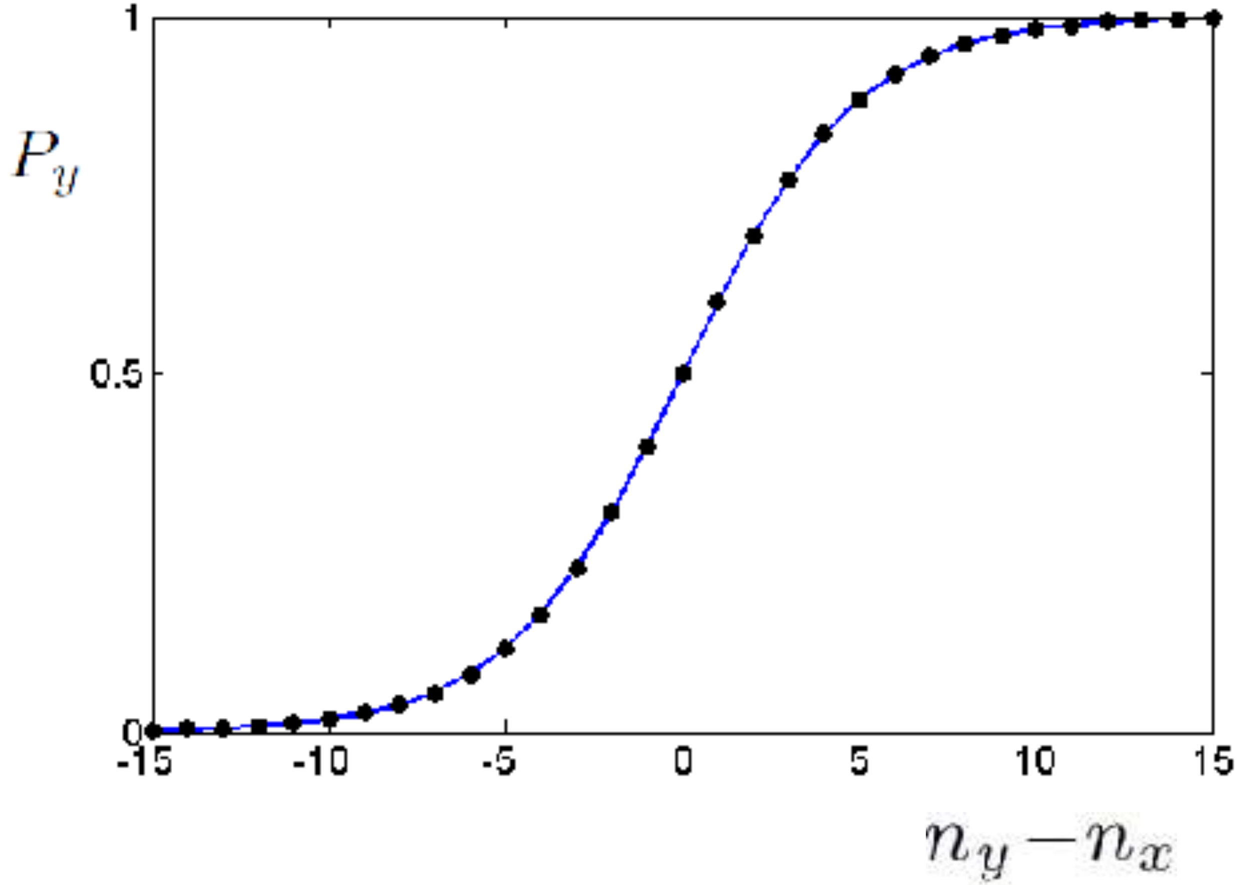
Perez-Escudero & de Polavieja, PLos Comp Biol (2011)



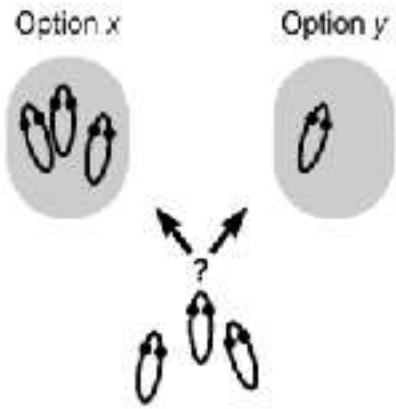
$$P_y = \frac{1}{1 + a s^{-(n_y - n_x)}}$$

$$s = \frac{P(\beta_y|Y,C)}{P(\beta_y|X,C)}$$

How reliably one of George's friends chooses one option when it is the best



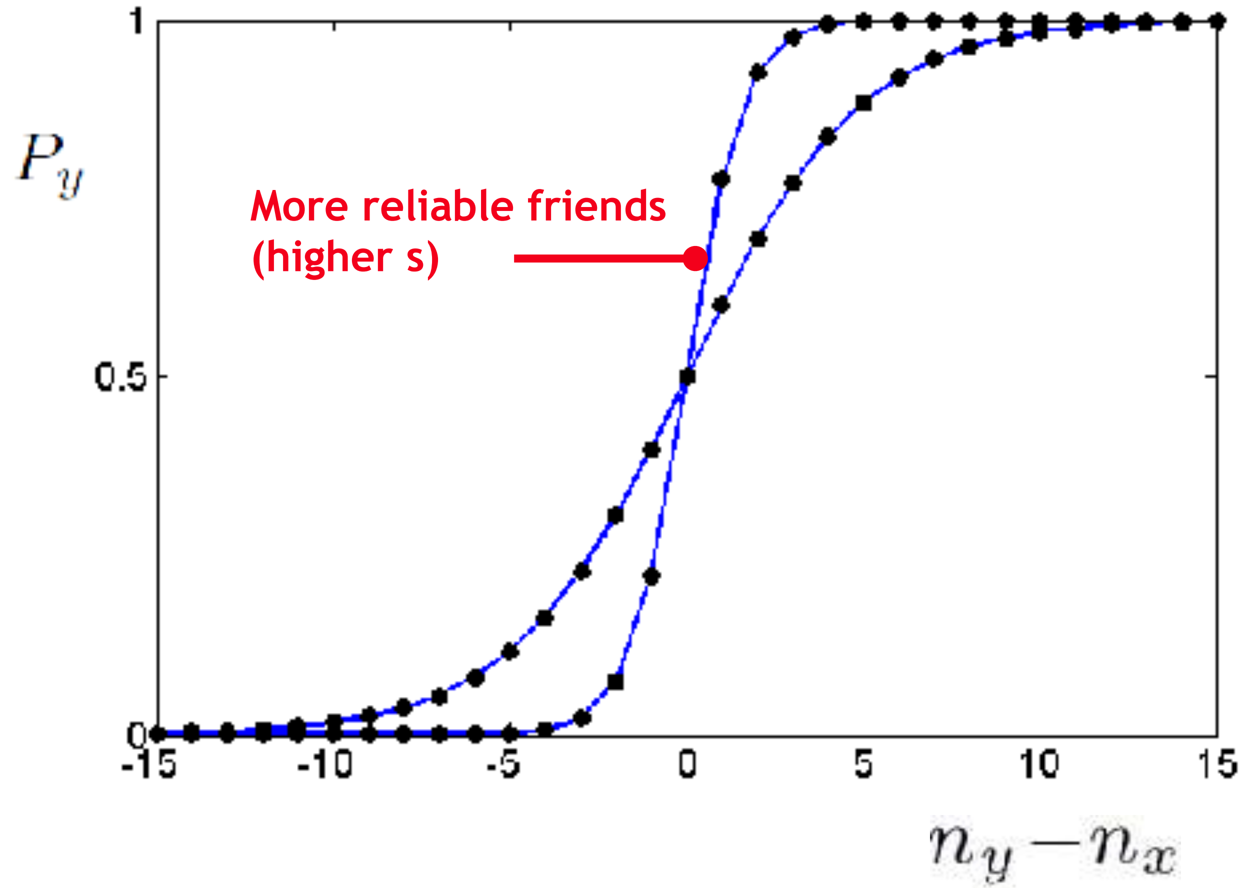
Perez-Escudero & de Polavieja, PLos Comp Biol (2011)



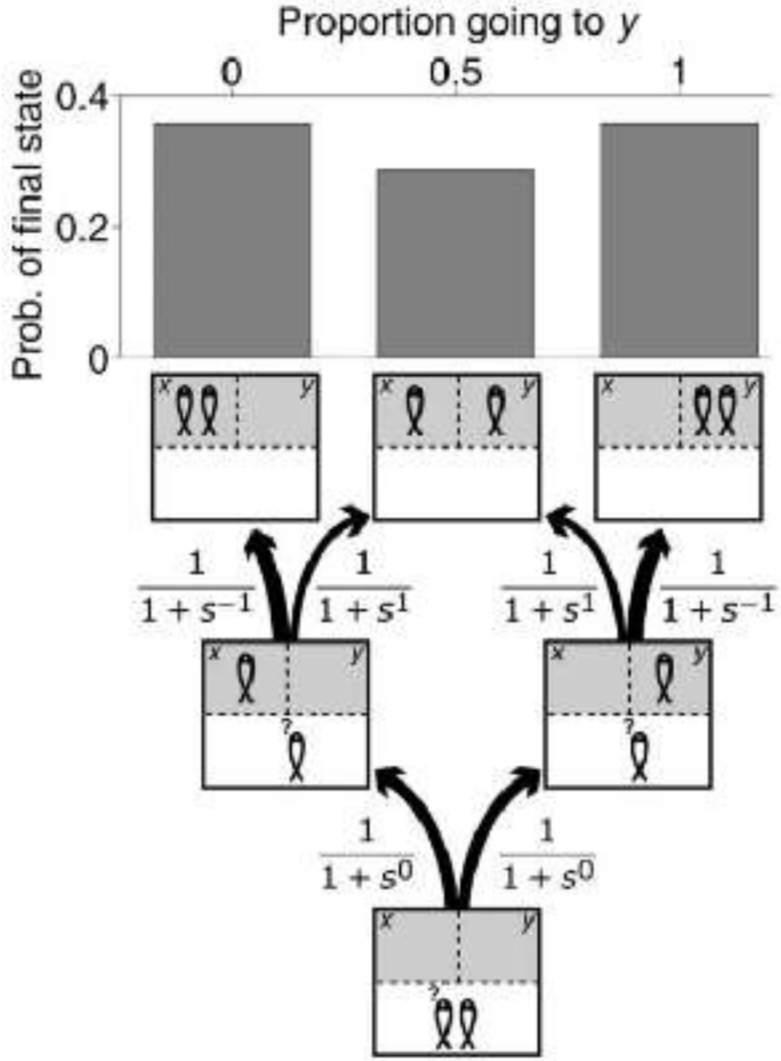
$$P_y = \frac{1}{1 + a s^{-(n_y - n_x)}}$$

$$s = \frac{P(\beta_y|Y,C)}{P(\beta_y|X,C)}$$

How reliably one of George's friends chooses one option when it is the best

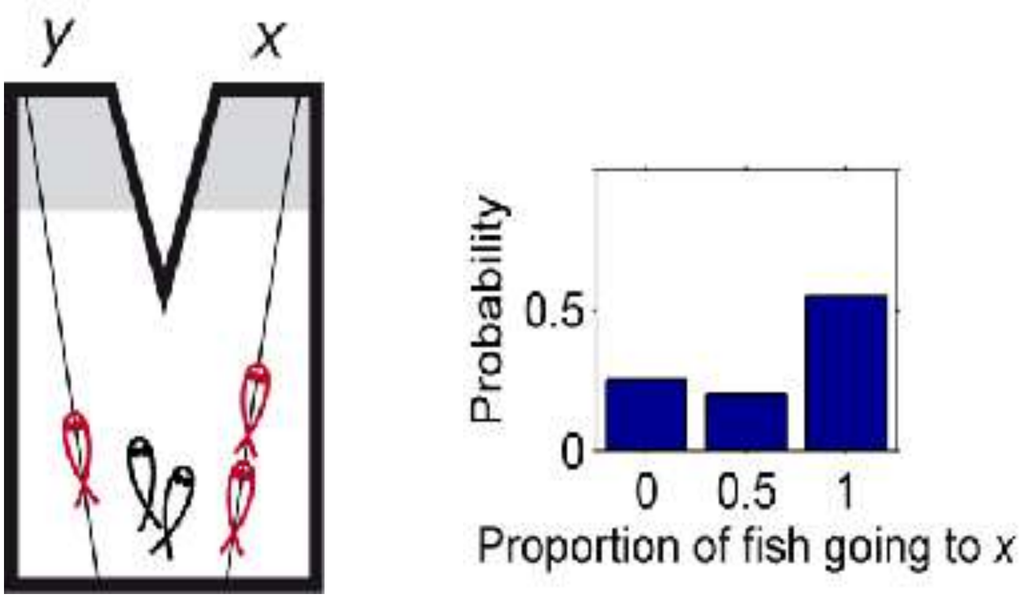


Perez-Escudero & de Polavieja, PLos Comp Biol (2011)



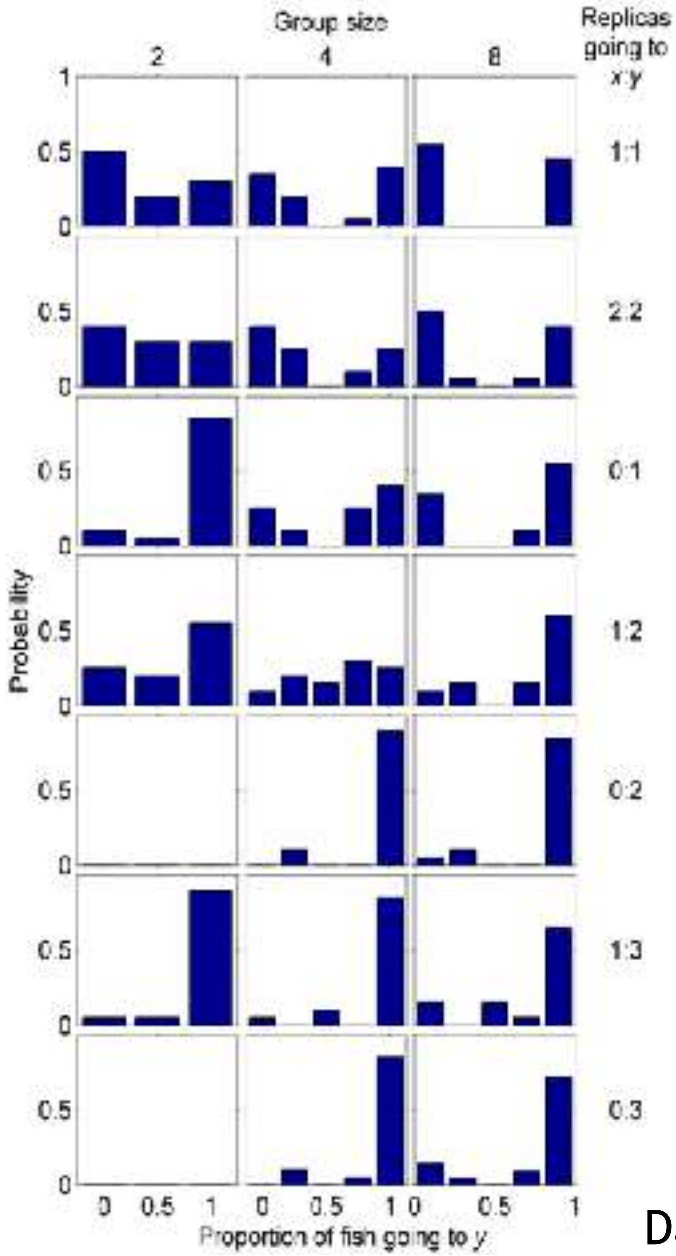
Perez-Escudero & de Polavieja, PLos Comp Biol (2011)

Test in sticklebaks



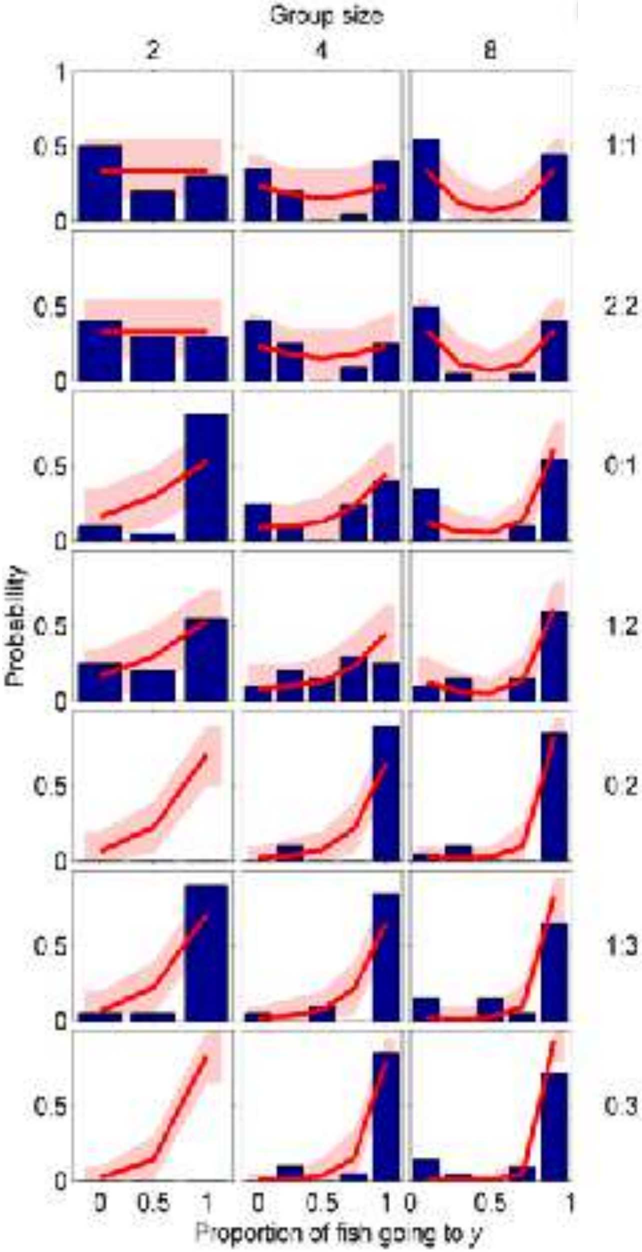
Data from Ward *et al*. (2005)

Test in sticklebaks



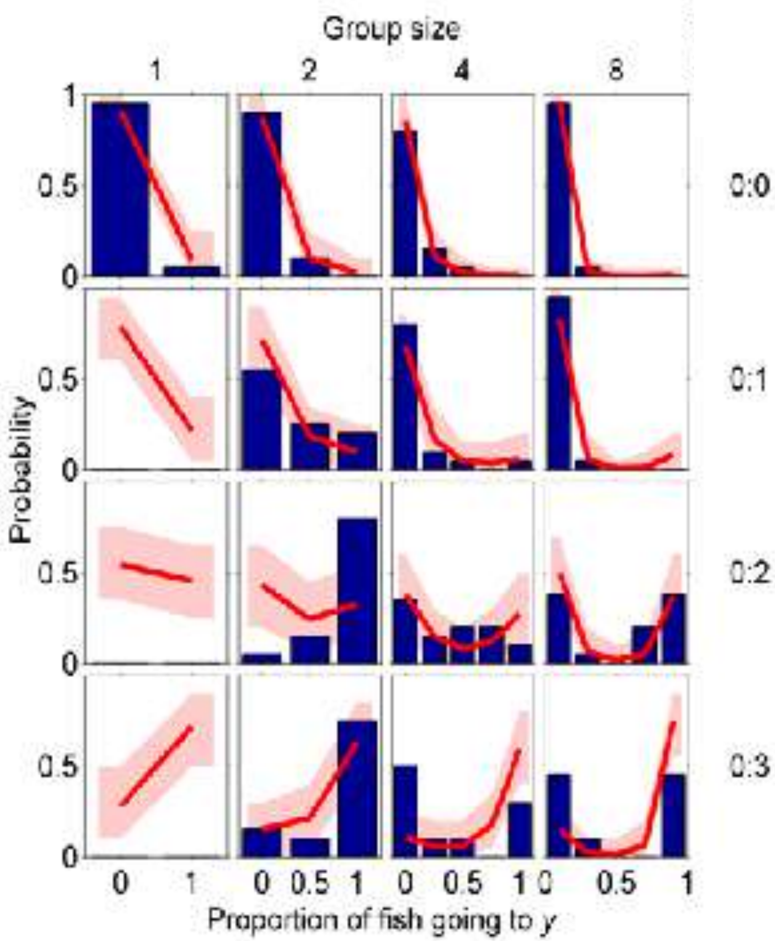
Data from Ward *et al*. (2005)

Test in sticklebaks



Data from Ward *et al*. (2005)

Test in sticklebaks

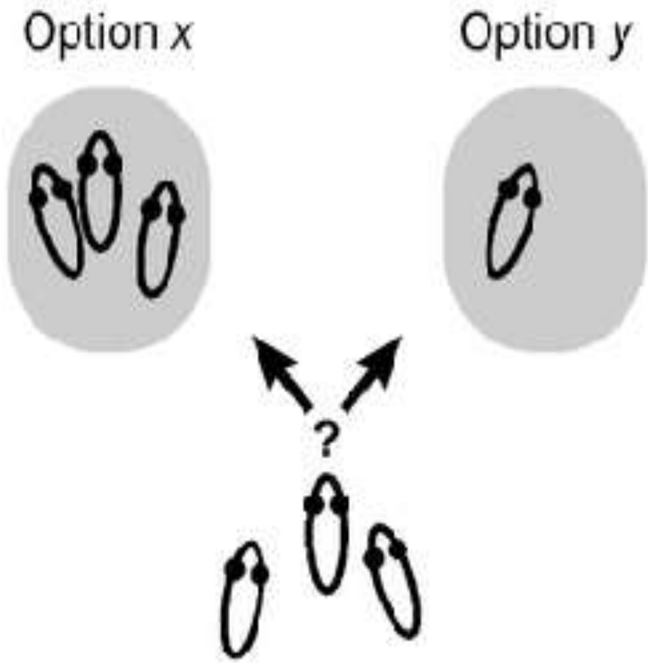


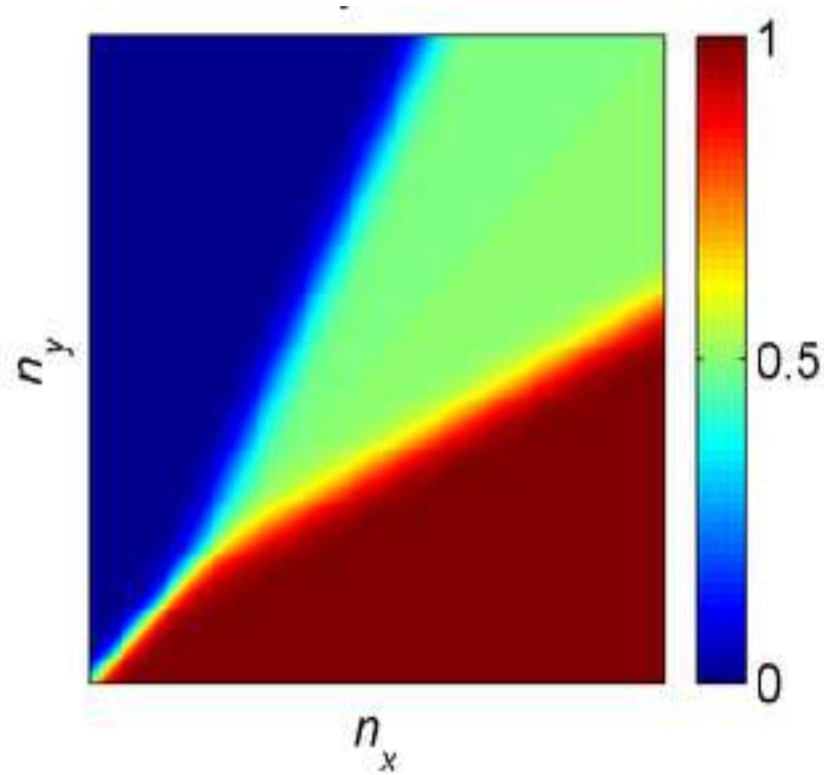
Data from Ward *et al*. (2005)

Before when one option is the best then other is the worst

Now the two options can in principle be good or bad

$$P_x = \left(1 + \frac{1 + a s^{-(n_x - k n_y)}}{1 + a s^{-(n_y - k n_x)}}\right)^{-1}$$

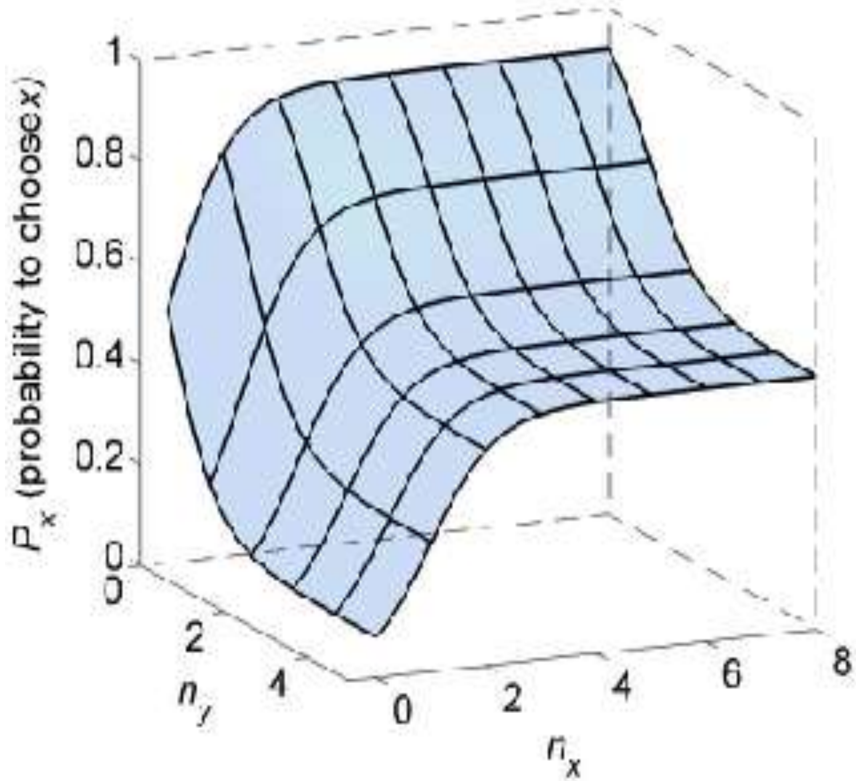




Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)

Decisions in zebrafish match the theory

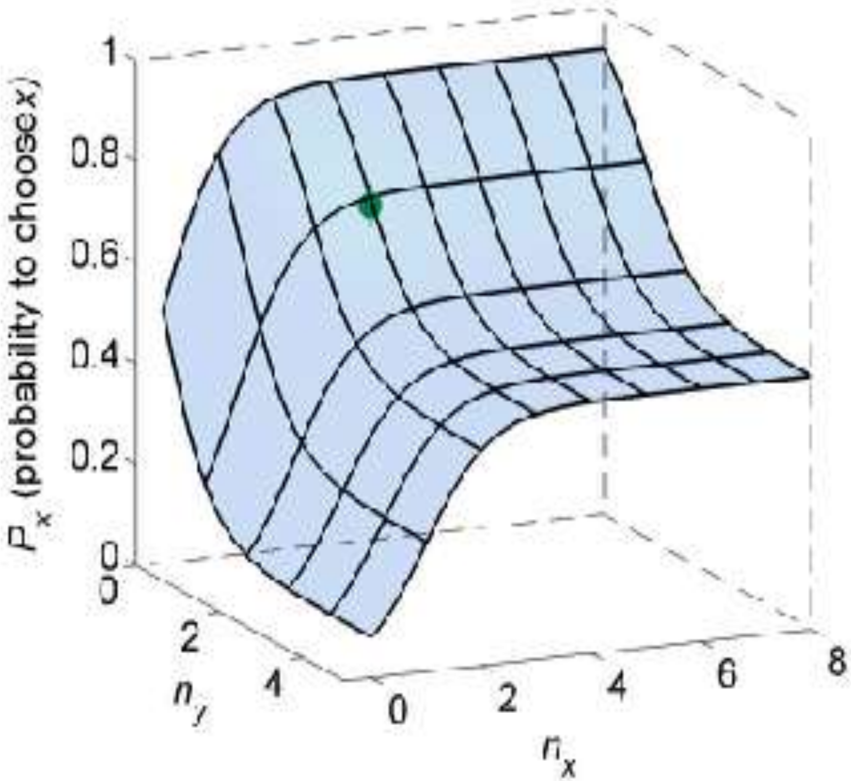
$$P_x = \left(1 + \frac{1 + as^{-(n_x - kn_y)}}{1 + as^{-(n_y - kn_x)}}\right)^{-1}$$



Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)

Decisions in zebrafish match the theory

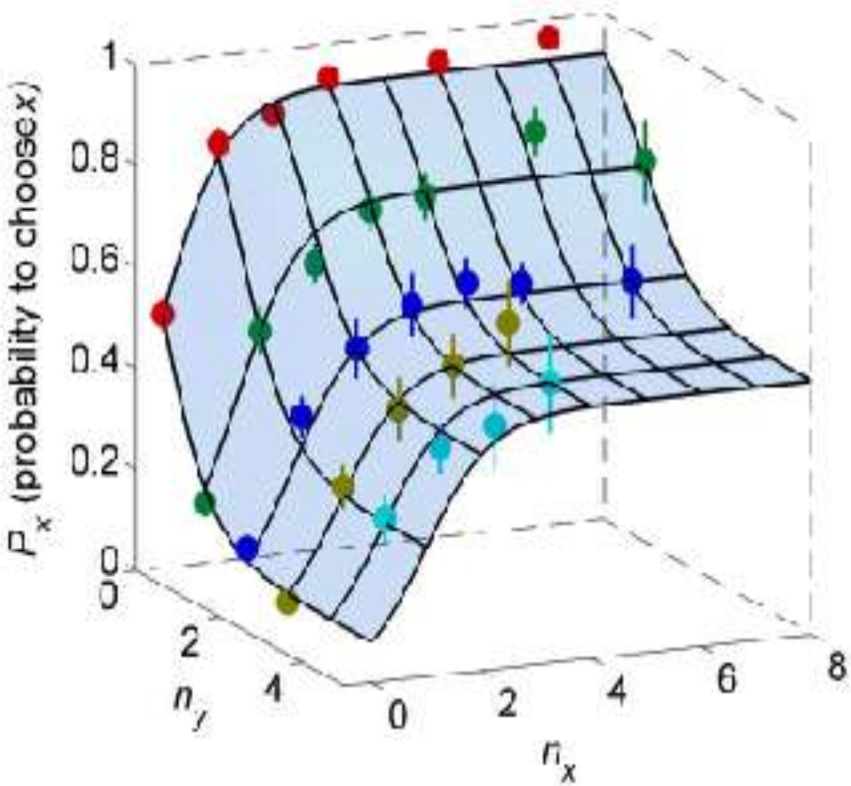
$$P_x = \left(1 + \frac{1 + a s^{-(n_x - k n_y)}}{1 + a s^{-(n_y - k n_x)}}\right)^{-1}$$



Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)

Decisions in zebrafish match the theory

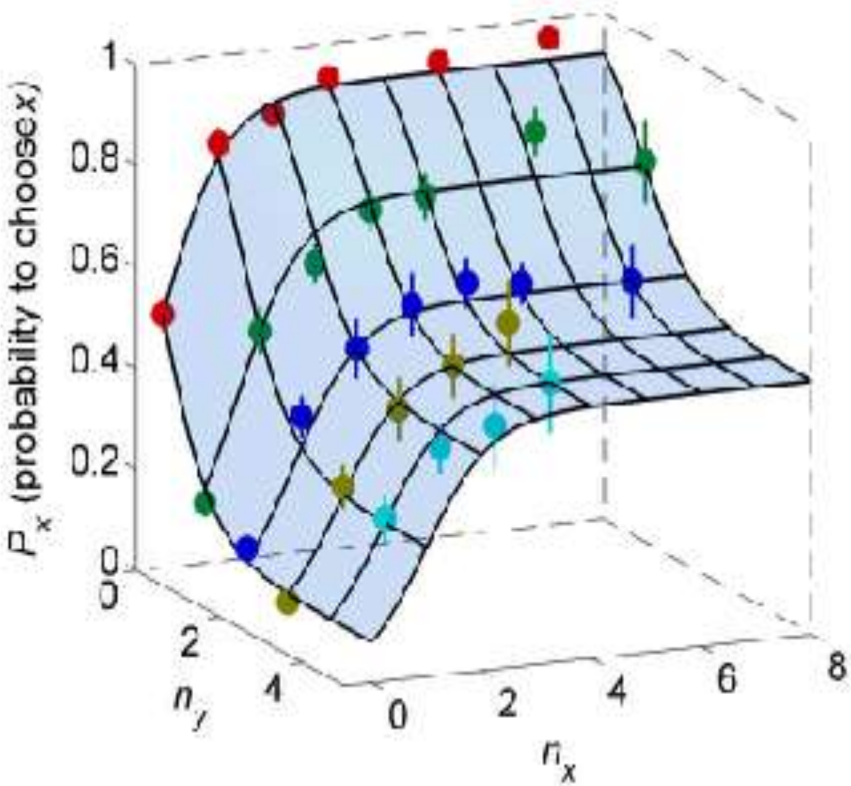
$$P_x = \left(1 + \frac{1 + a s^{-(n_x - k n_y)}}{1 + a s^{-(n_y - k n_x)}}\right)^{-1}$$



Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)

Decisions in zebrafish match the theory

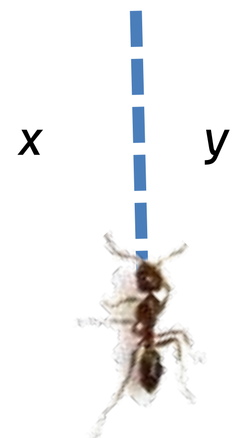
$$P_x = \left(1 + \frac{1 + as^{-(n_x - kn_y)}}{1 + as^{-(n_y - kn_x)}}\right)^{-1}$$



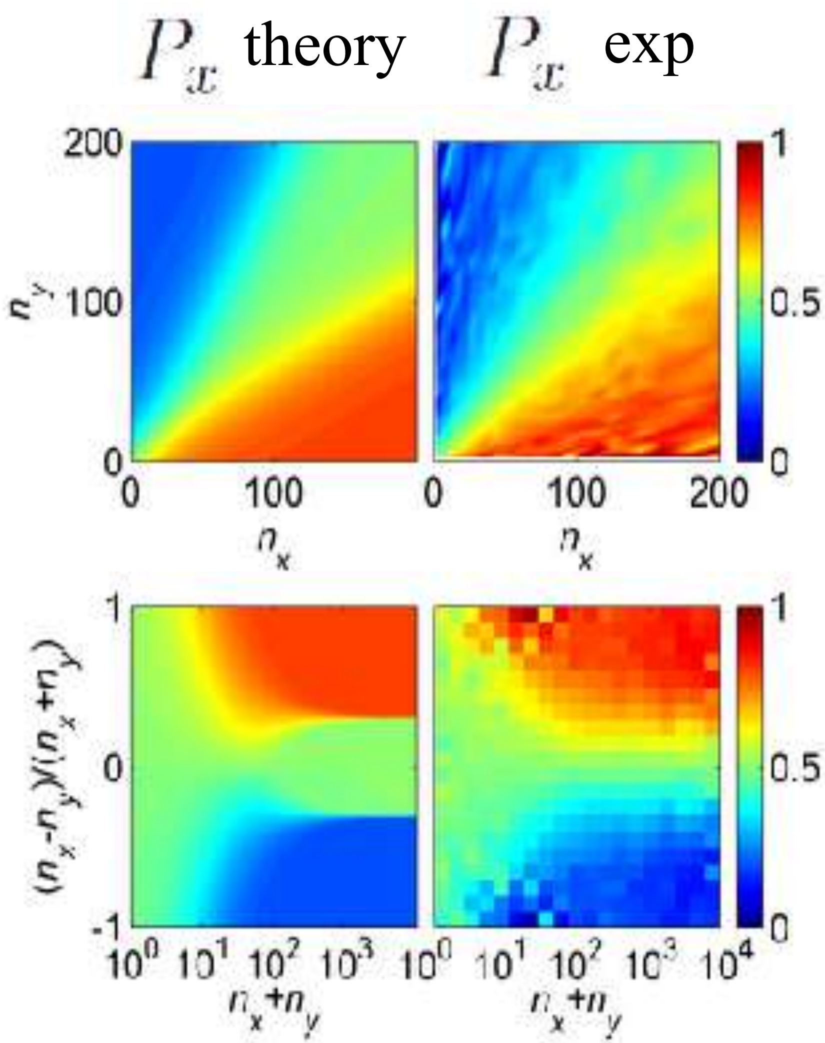
Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)

Also good match with ants

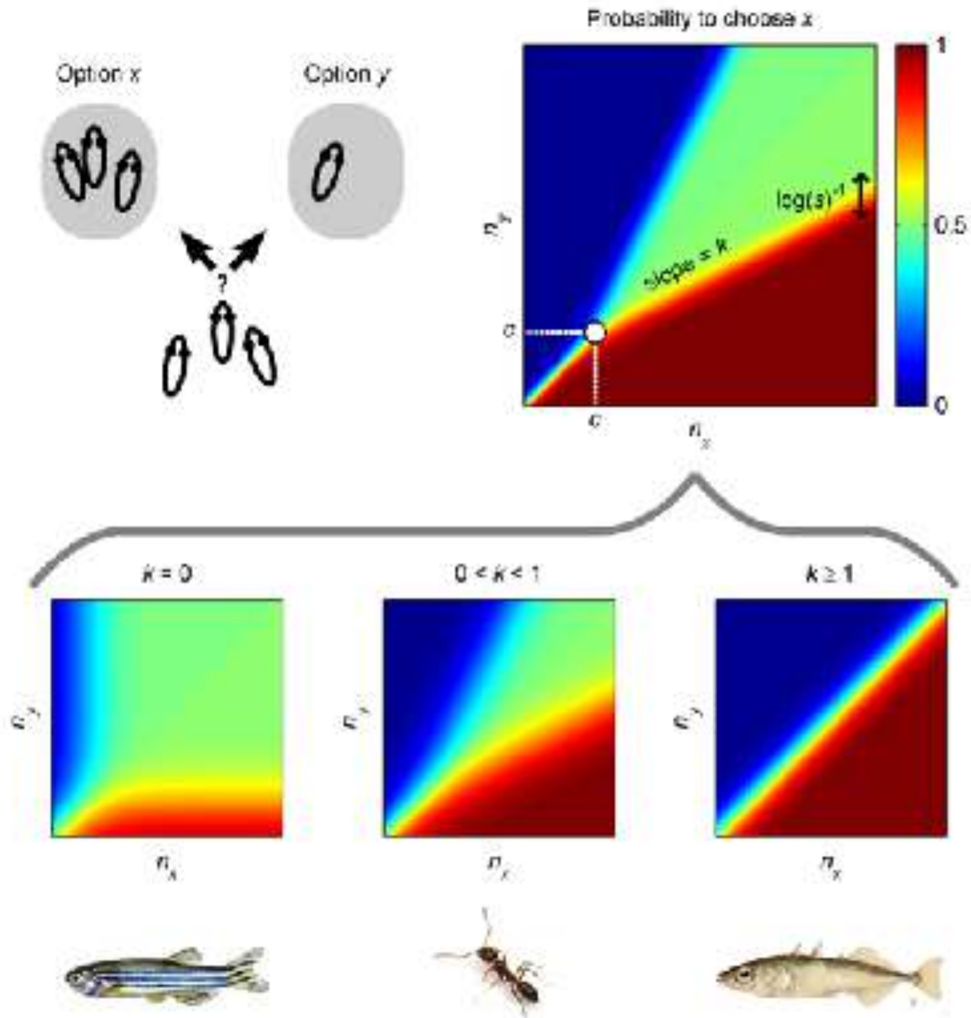
$$P_x = \left(1 + \frac{1 + as^{-(n_x - kn_y)}}{1 + as^{-(n_y - kn_x)}}\right)^{-1}$$



Data from Perna et al. (2012)

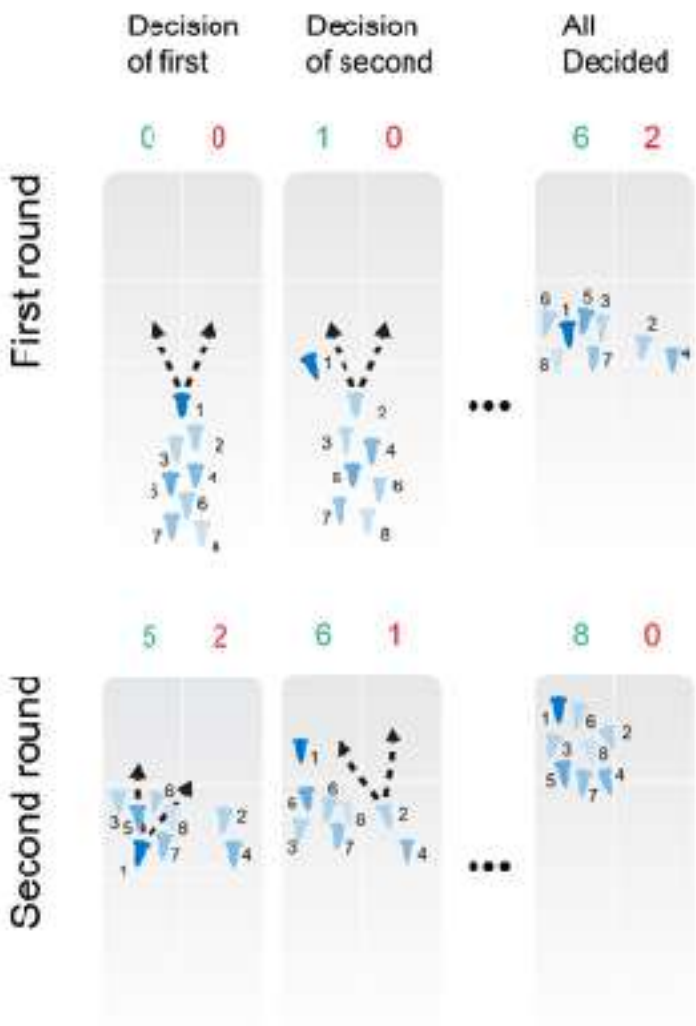


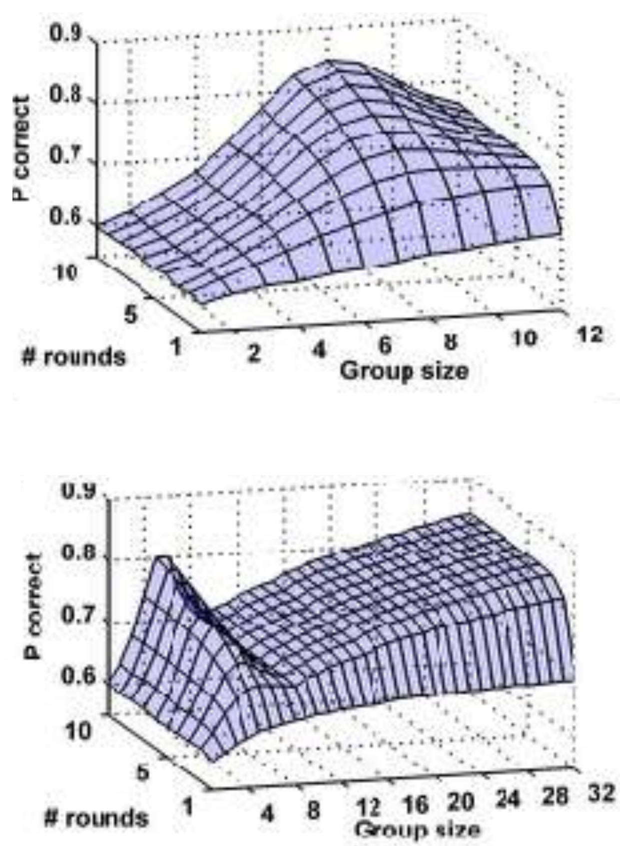
Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)



Arganda, Perez-Escudero & de Polavieja, *PNAS* (2012)

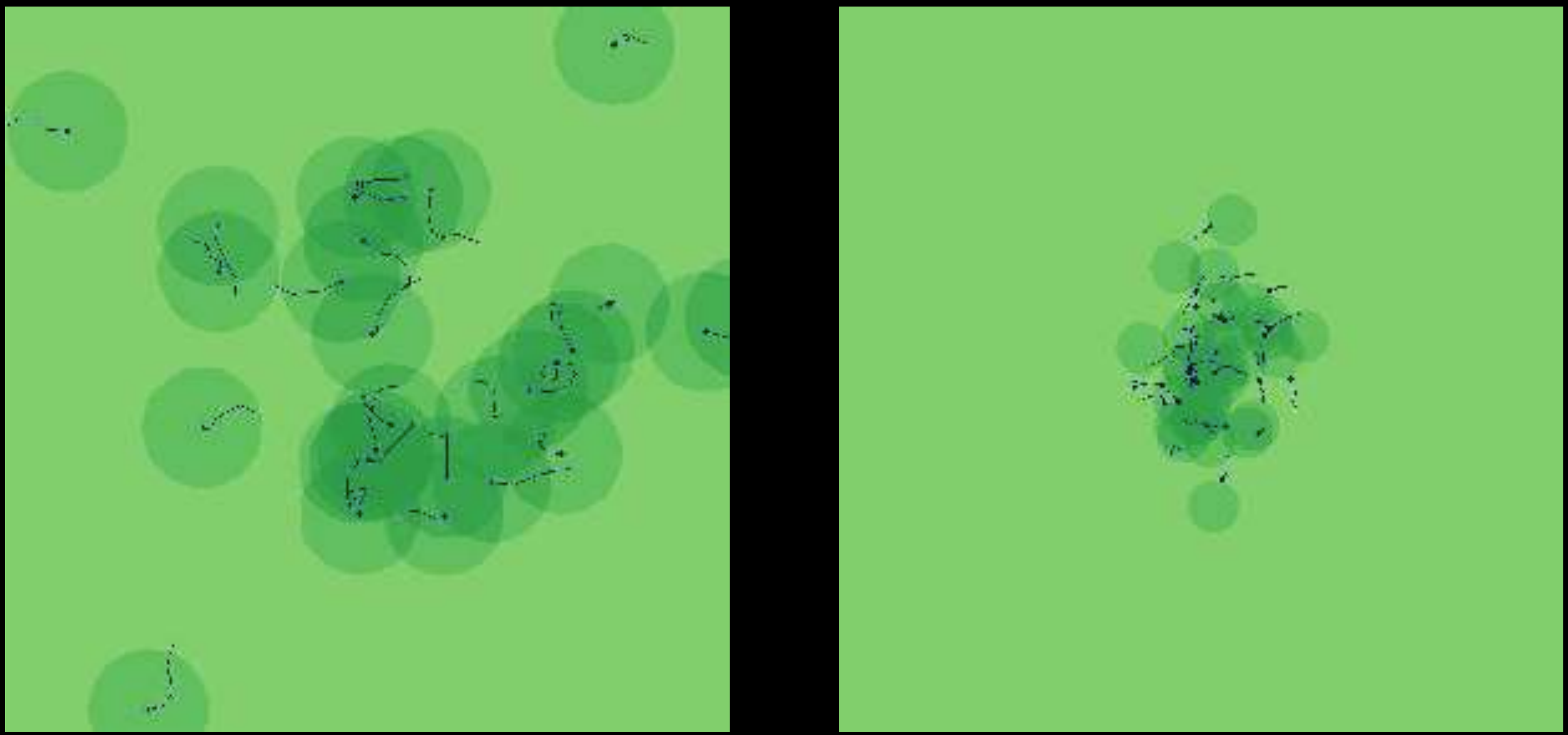
Models allow comparing the real system with virtual alternatives as reference





Vicente, Perez-Escudero & de Polavieja (2017)

Increased aggregation when all options are worse is for free: just changing a



Perez-Escudero & de Polavieja (2017)

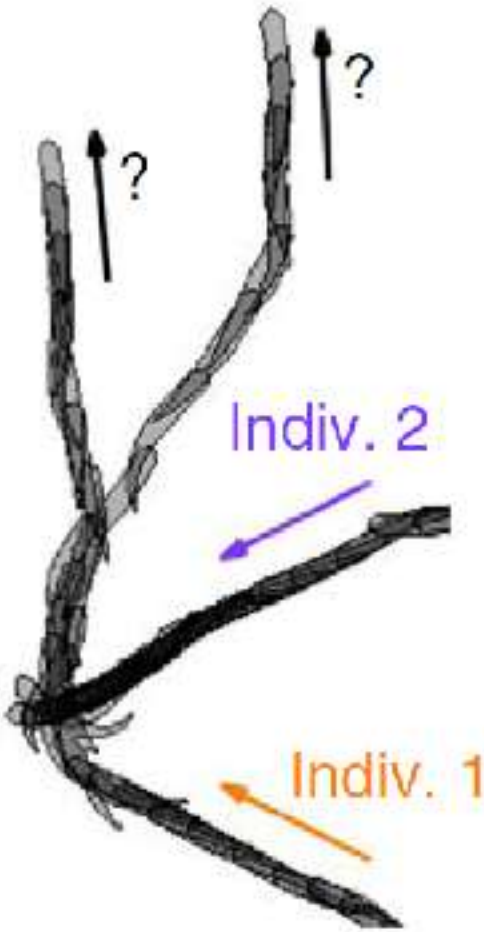
$$P_x = \left(1 + \frac{1 + as^{-(n_x - kn_y)}}{1 + as^{-(n_y - kn_x)}}\right)^{-1}$$

Theory of decision-making in groups

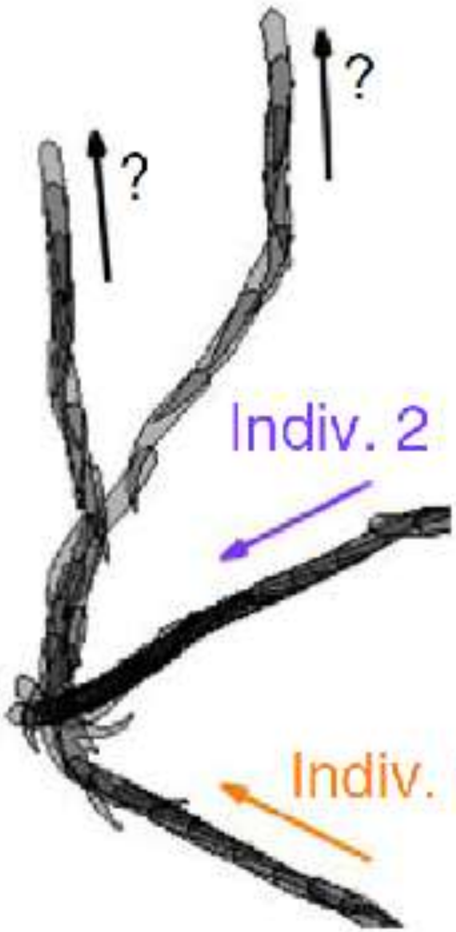
Data-driven study of collective behaviour

Collective behavior in humans

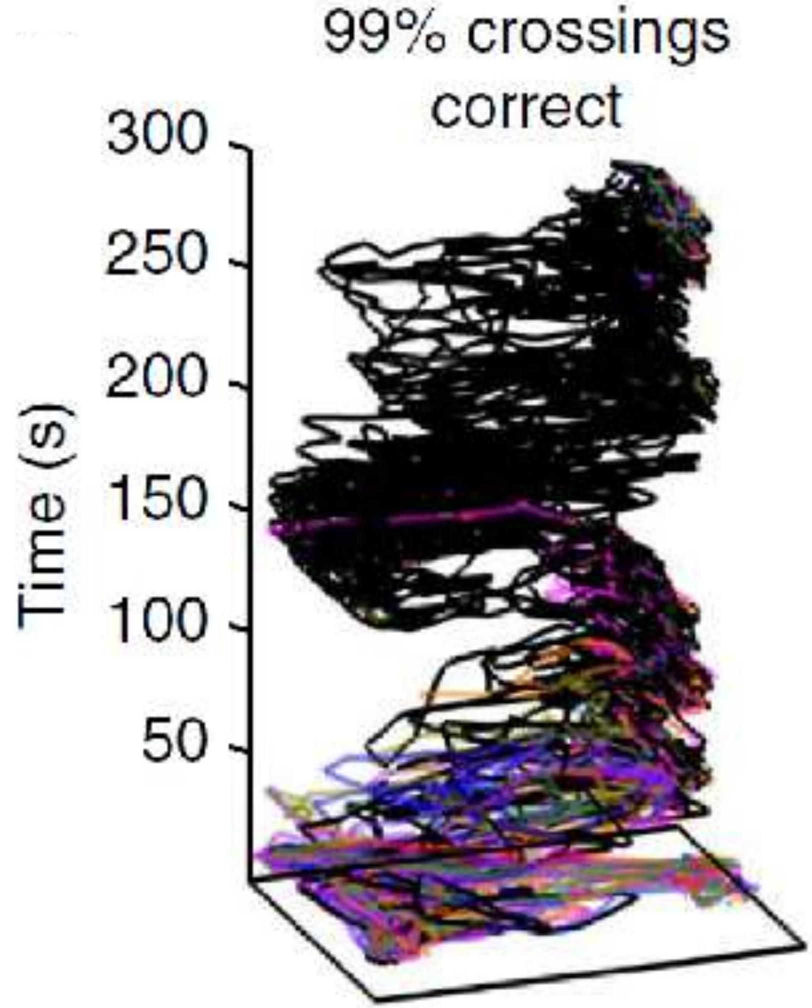
THE PROBLEM

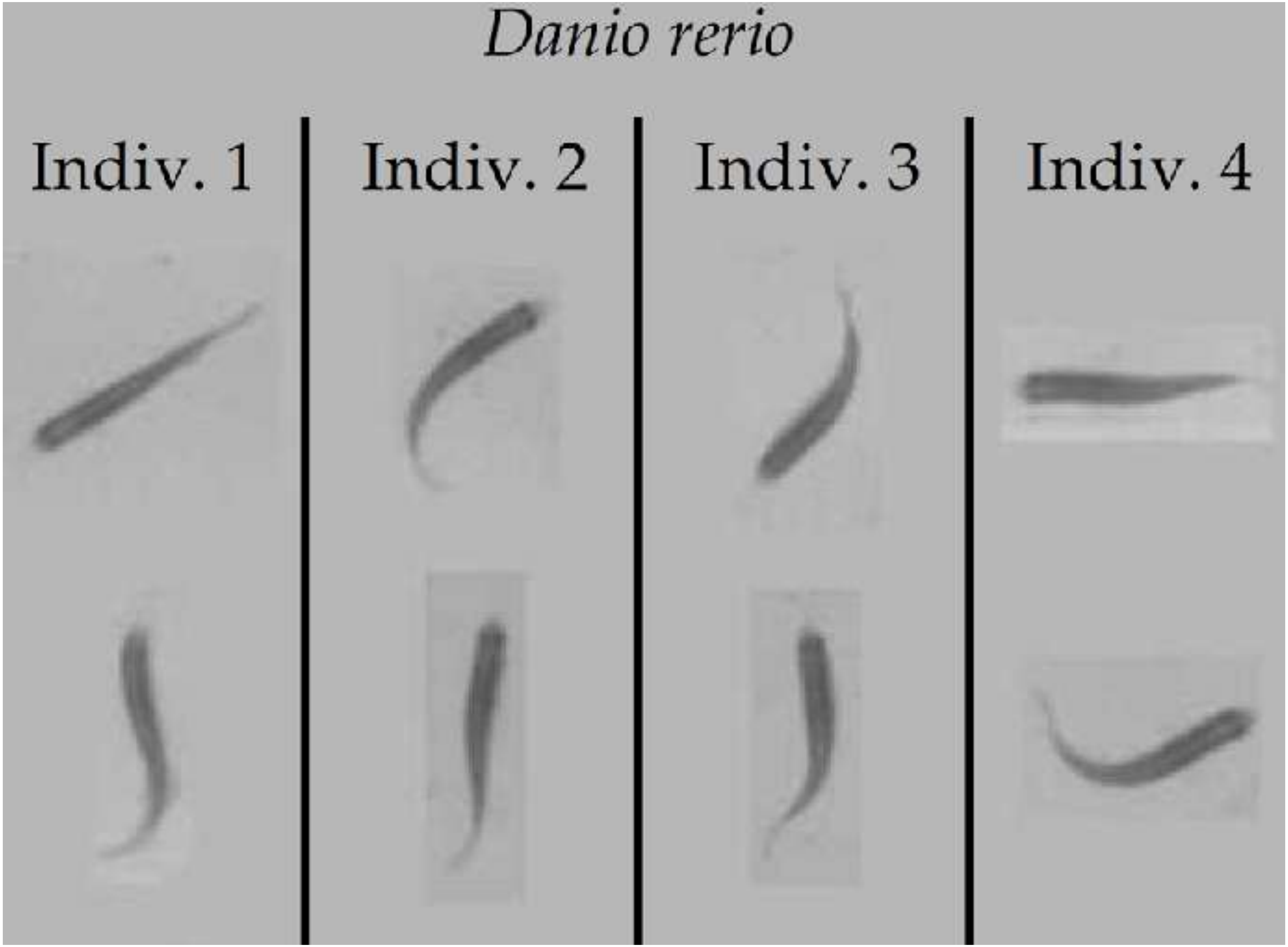


THE PROBLEM



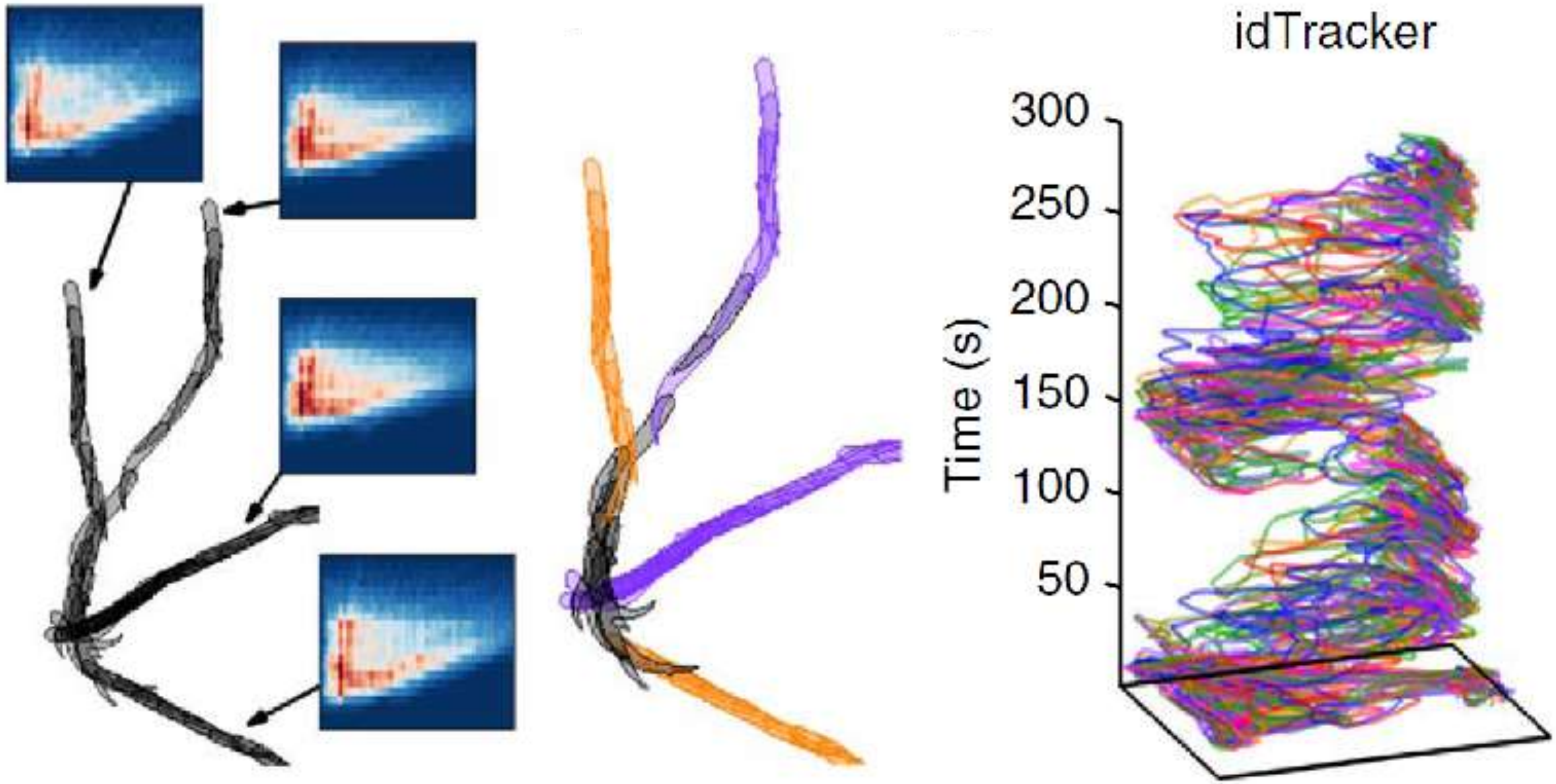
STANDARD SOLUTION



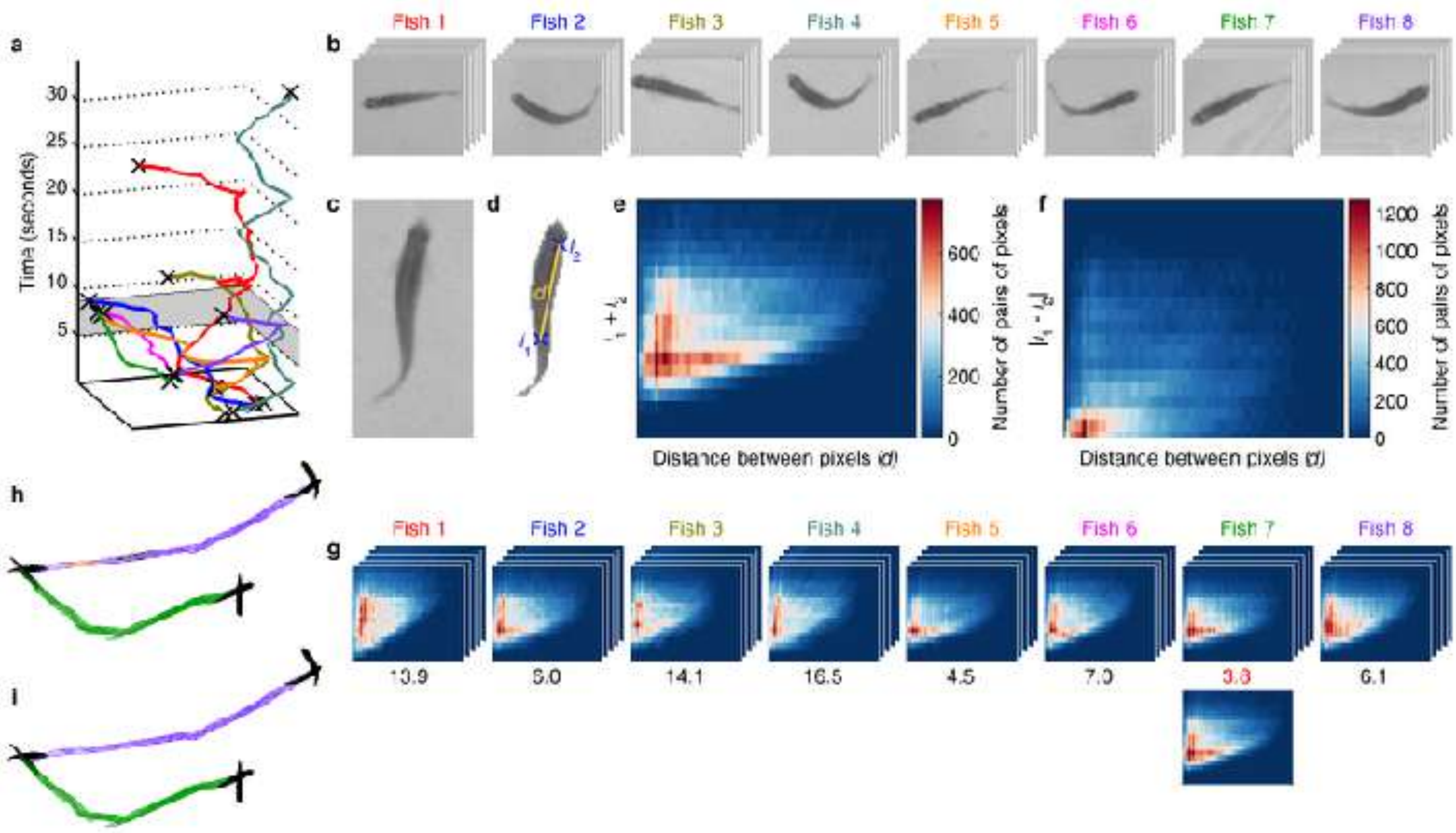


Danio rerio
Indiv. 1
Indiv. 2
Indiv. 3
Indiv. 4

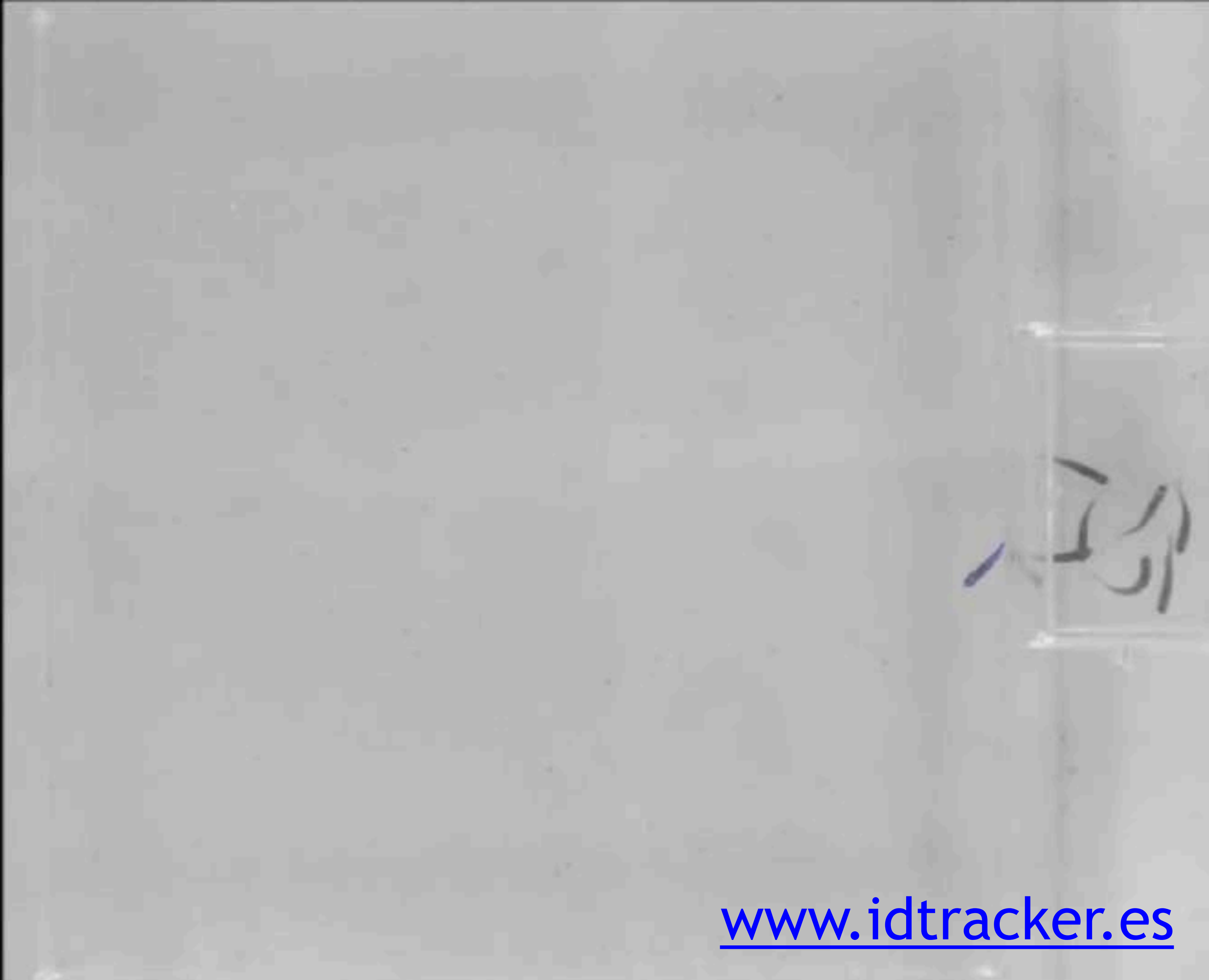
TRACKING BY FINGERPRINTING



Perez-Escudero et al., Nature Methods (2014)



Perez-Escudero et al., Nature Methods (2014)


www.idtracker.es

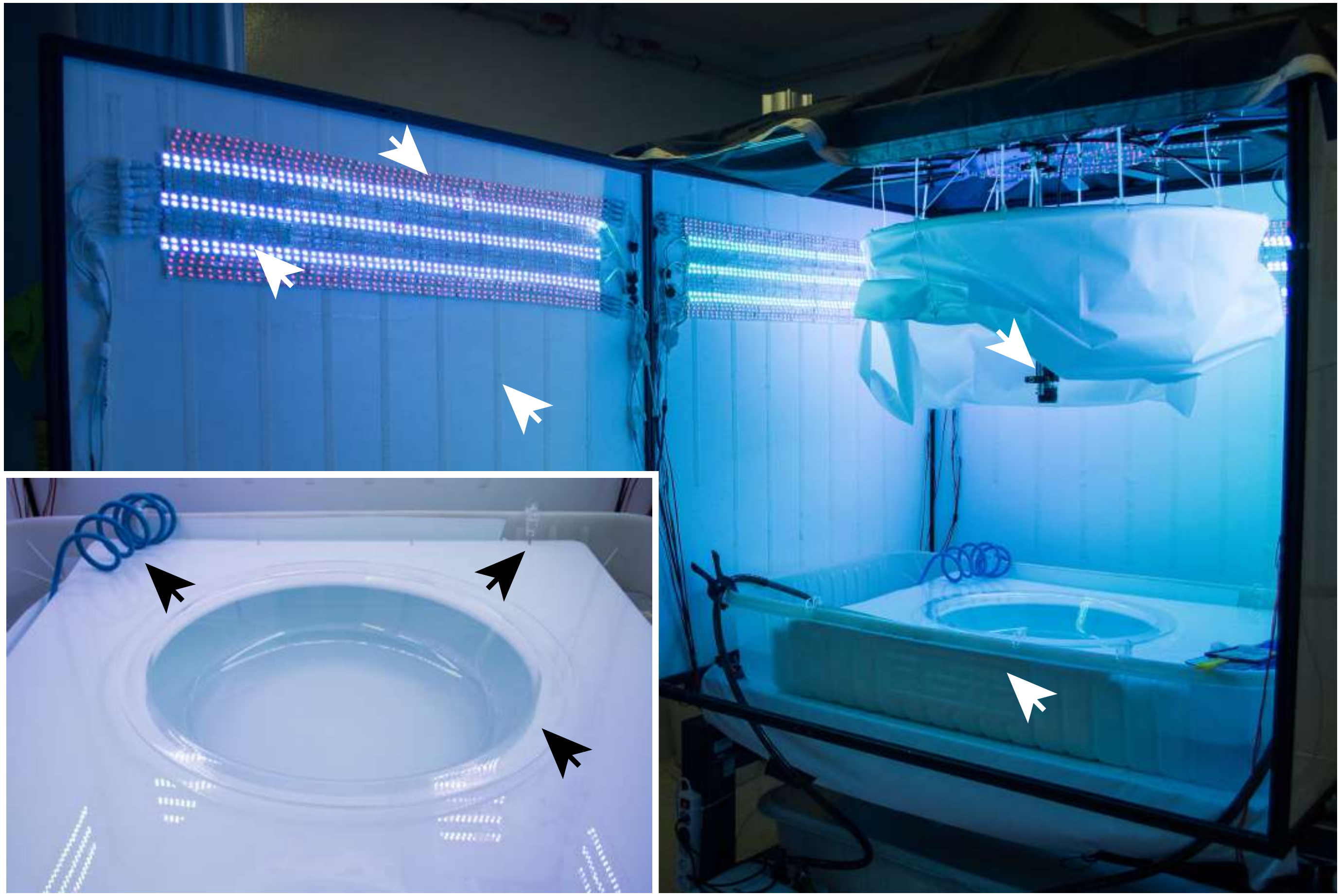
Romero-Ferrero, Bergomi et al. (in prep)

Accuracy in fish

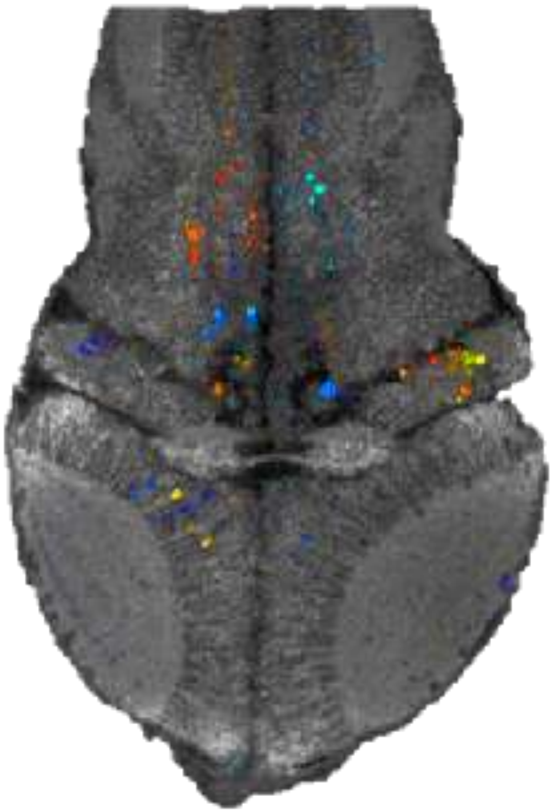
>99.99% accurate

groups of 60, 80 and 100

(still checking in flies)



What are our theories based upon?



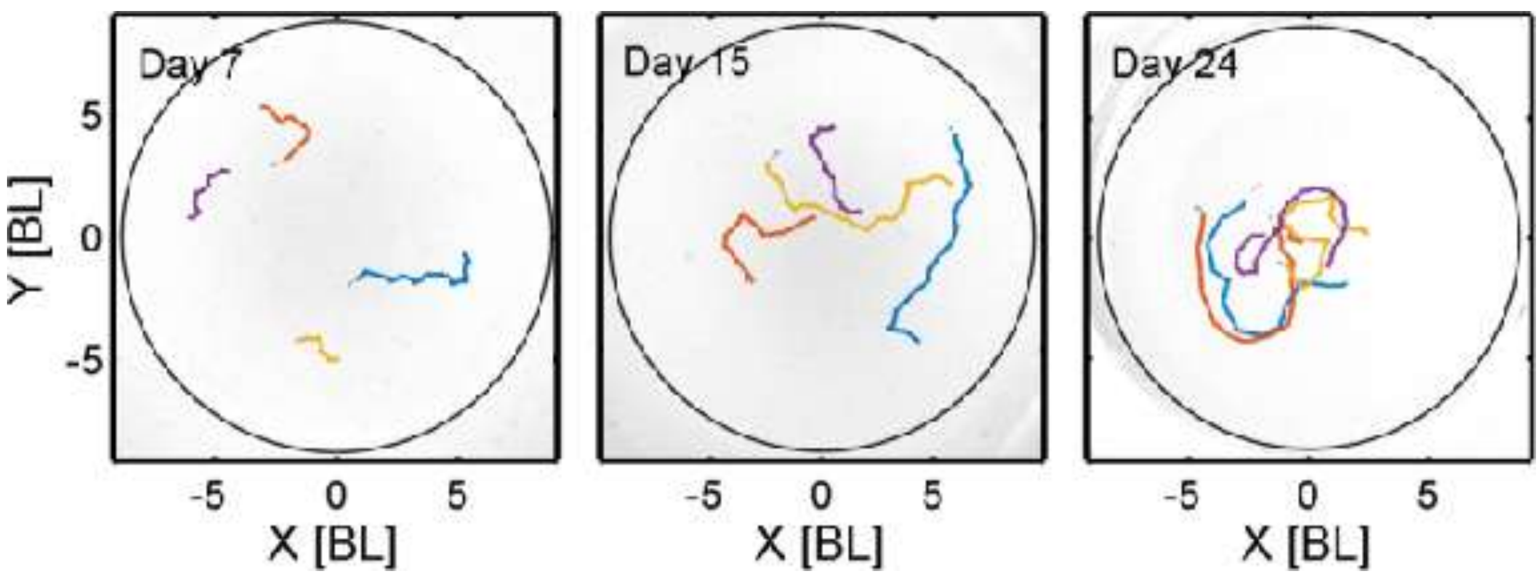
Individuals use **inference**

Individuals learn by **rewards**

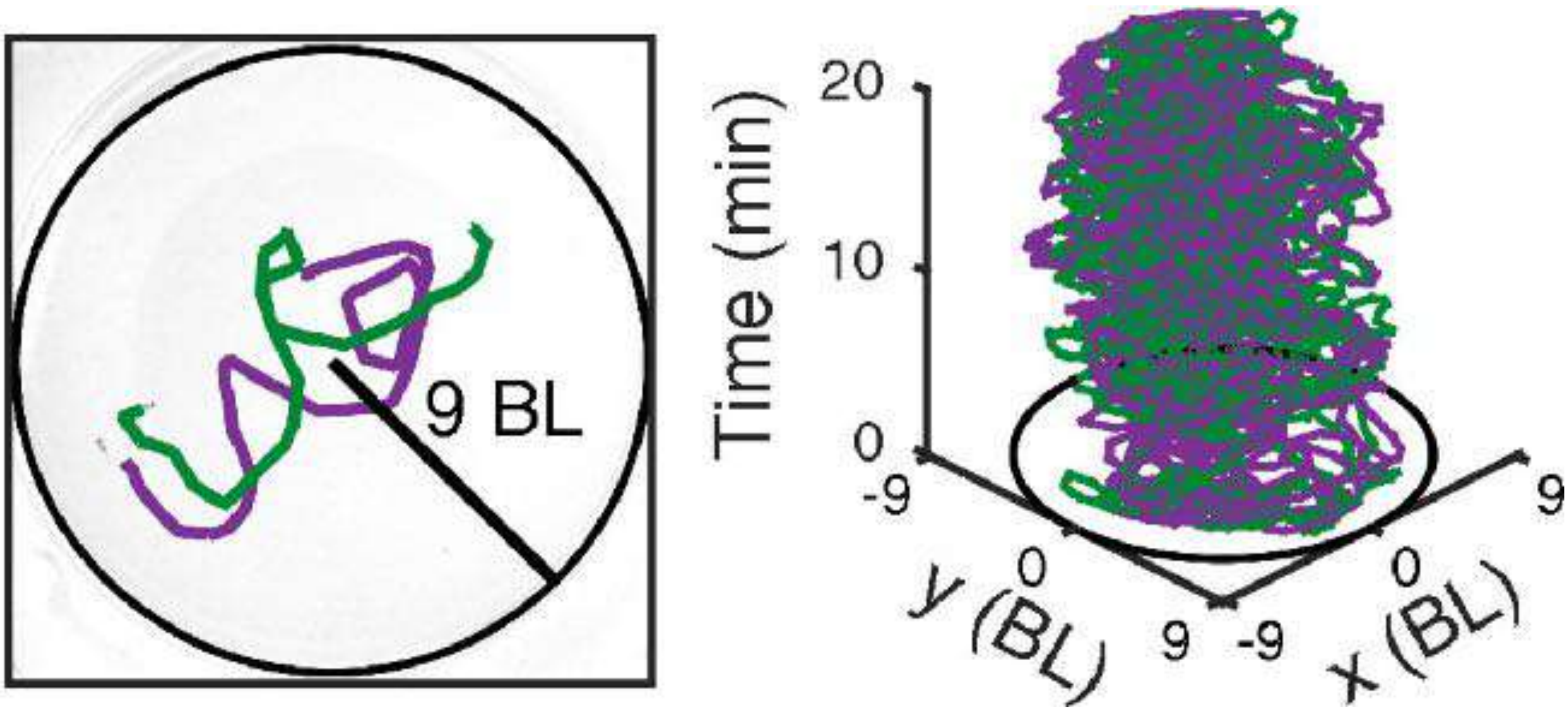
Individuals **control** their behavior according to some policies

Individuals use **heuristic** rules

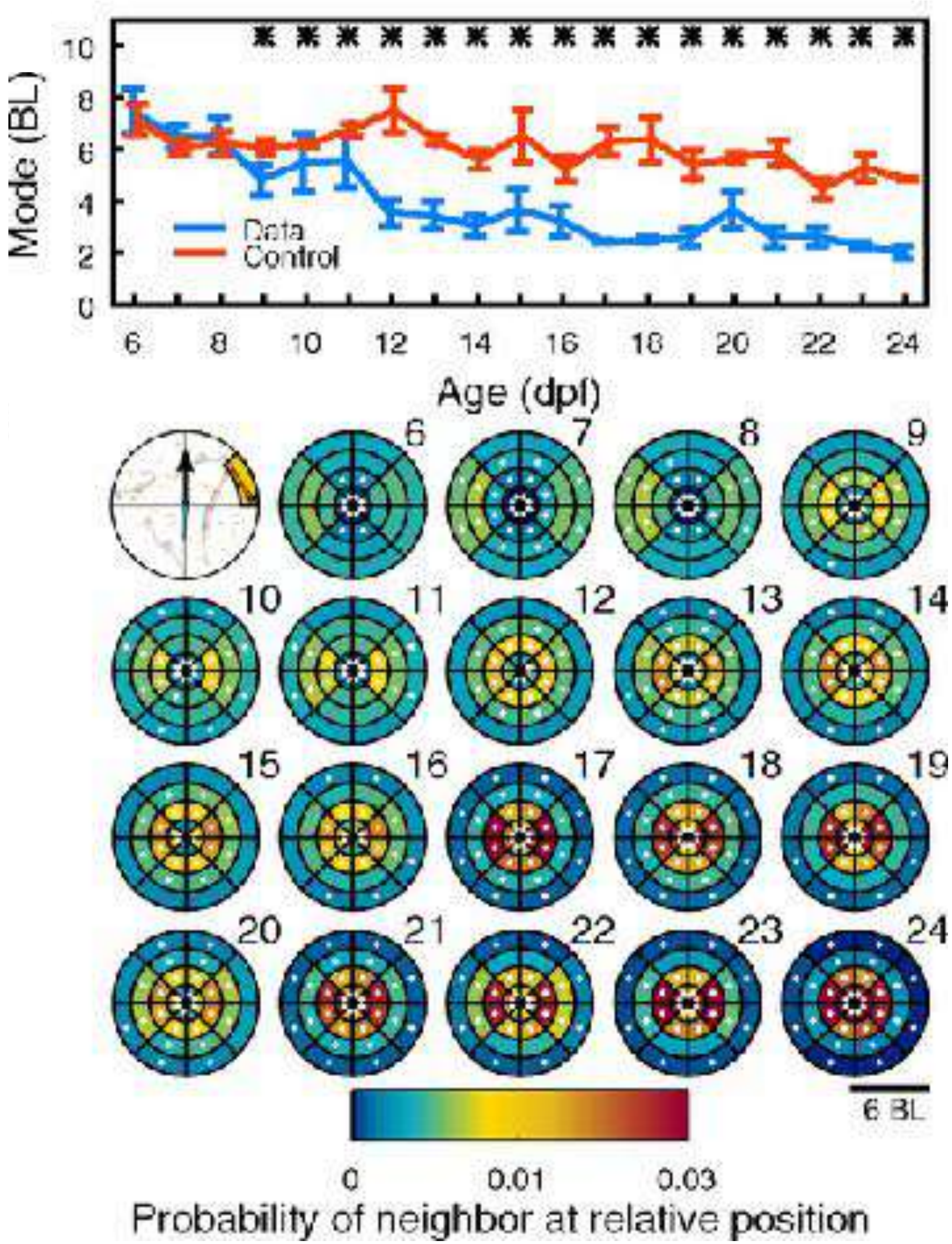
Individuals are a **neuronal network** coupled to a skeletal system



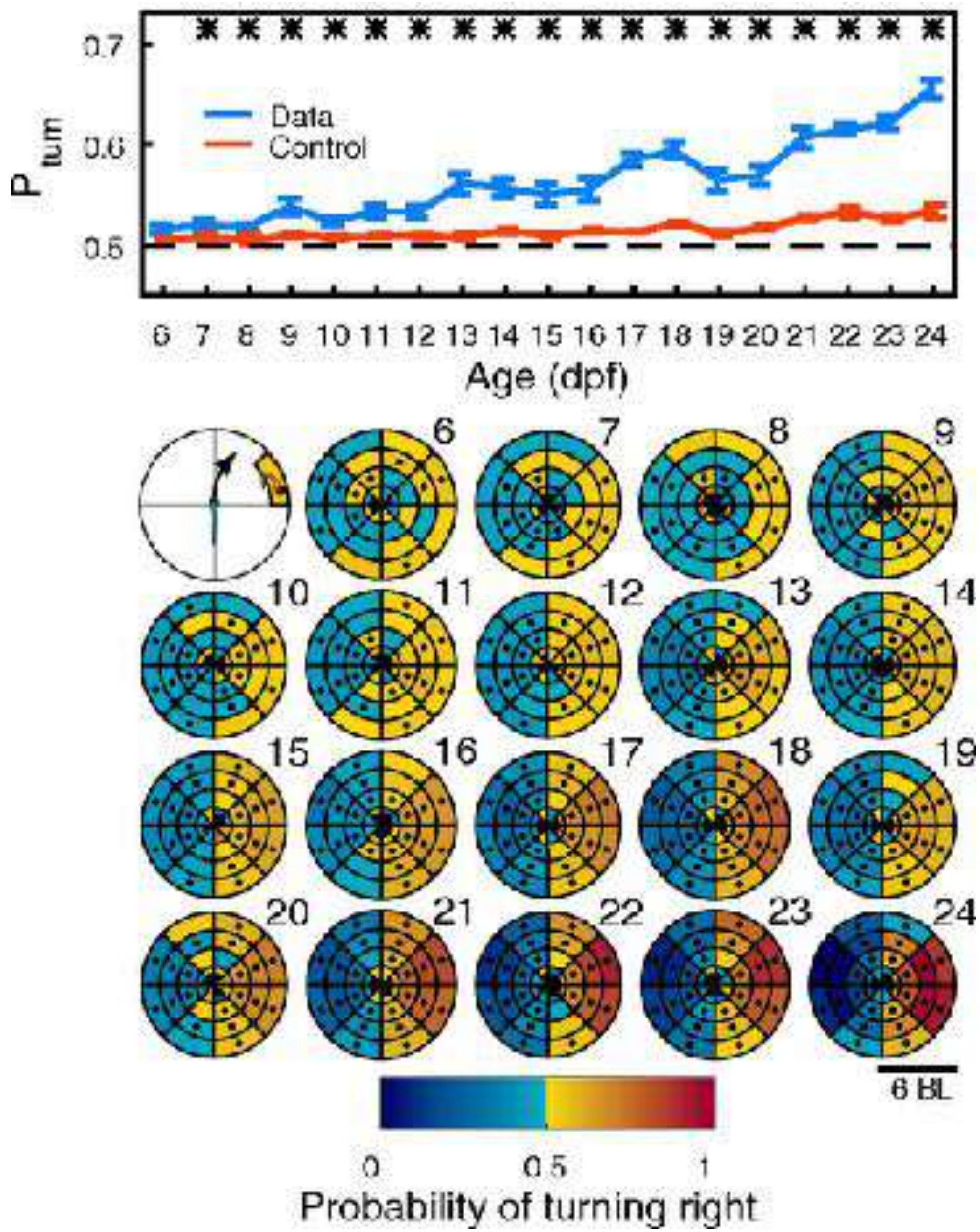
500 videos during 6-24 dpf



Hinz & de Polavieja *PNAS* (2017)

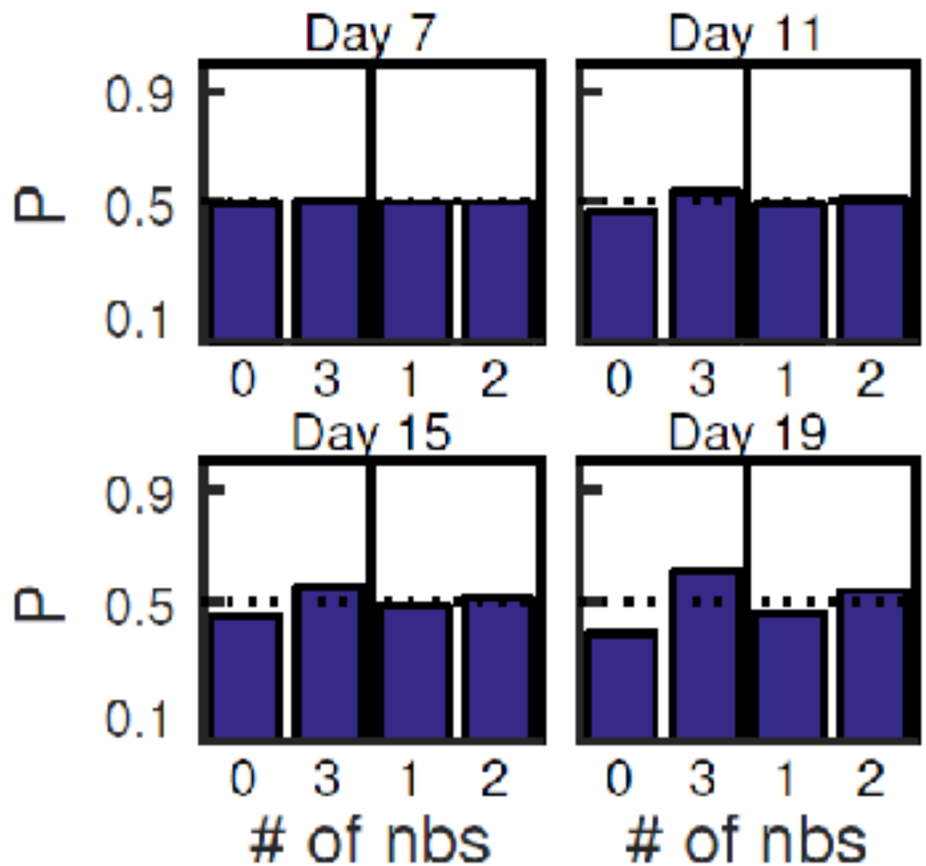


Hinz & de Polavieja *PNAS* (2017)



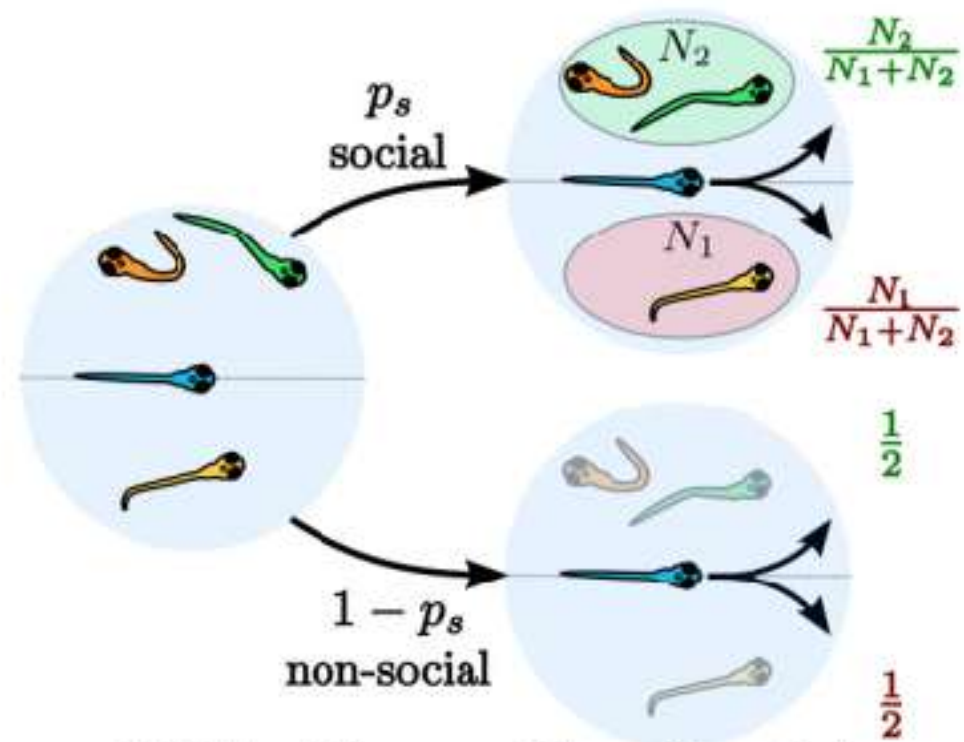
Hinz & de Polavieja *PNAS* (2017)

Experiments with 4 fish



Hinz & de Polavieja *PNAS* (2017)

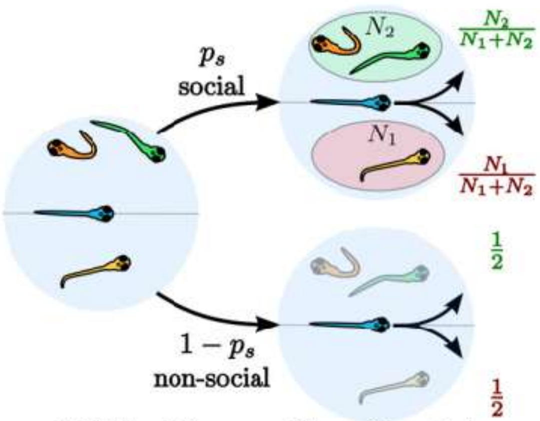
Moving towards an agent chosen at random



$$P(N_1|N_1:N_2) = p_s\,\frac{N_1}{N_1+N_2} + (1-p_s)\frac{1}{2}$$

Hinz & de Polavieja *PNAS* (2017)

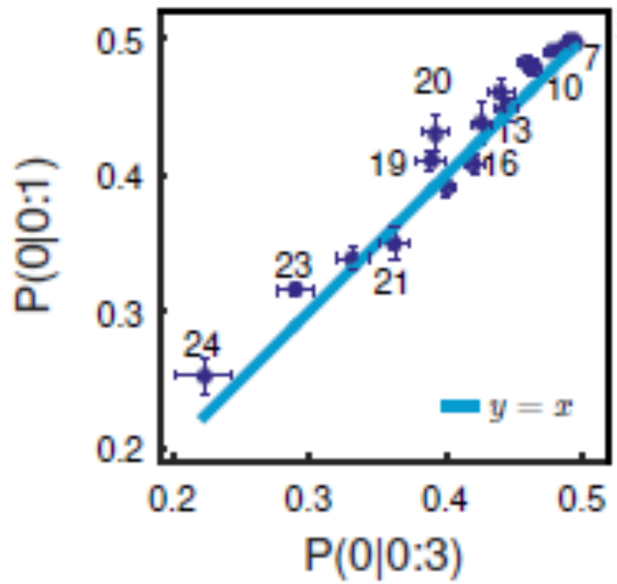
Parameter-free predictions of model

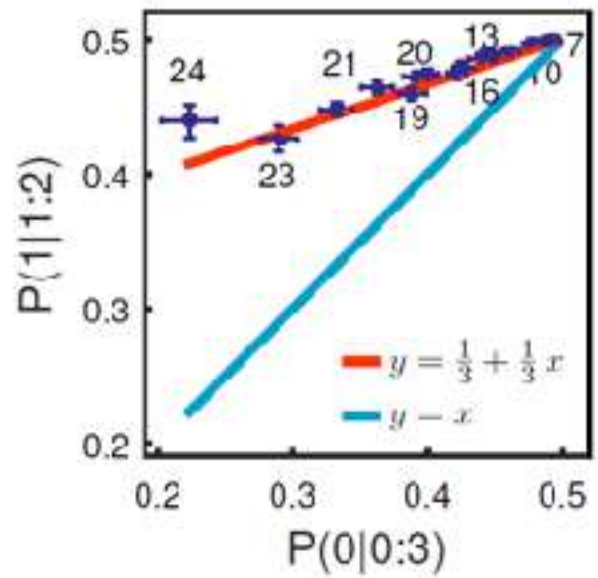


$$P(N_1|N_1:N_2) = \frac{1}{2} + \frac{(N_1-N_2)(\bar{N}_1+\bar{N}_2)}{(N_1+N_2)(\bar{N}_1-\bar{N}_2)}\left(P(\bar{N}_1|\bar{N}_1:\bar{N}_2)-\frac{1}{2}\right)$$

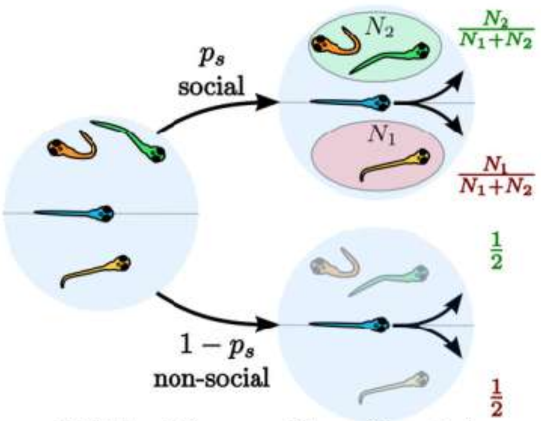
$$P(0|0:1) = P(0|0:3)$$

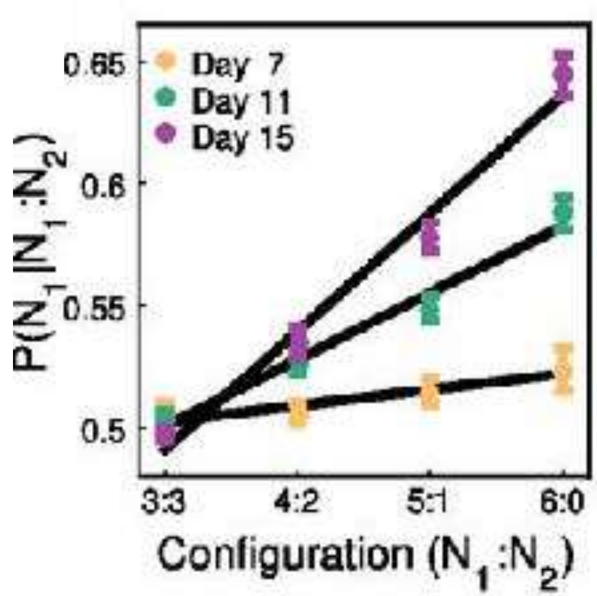
$$P(1|1:2) = \frac{1}{3} + \frac{1}{3}P(0|0:3)$$

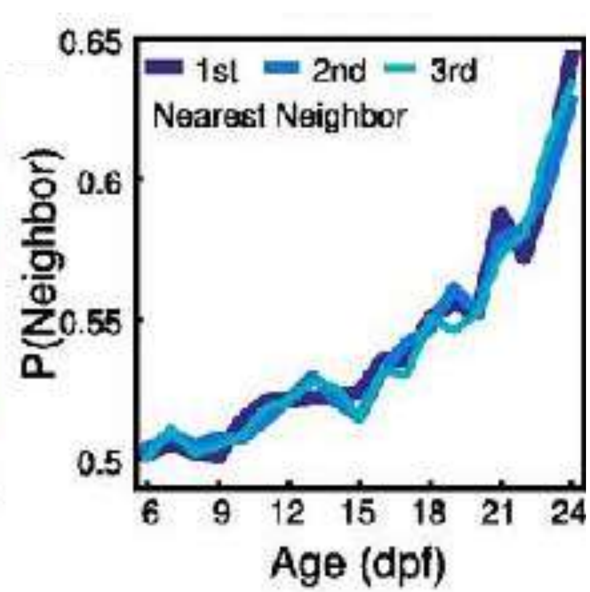


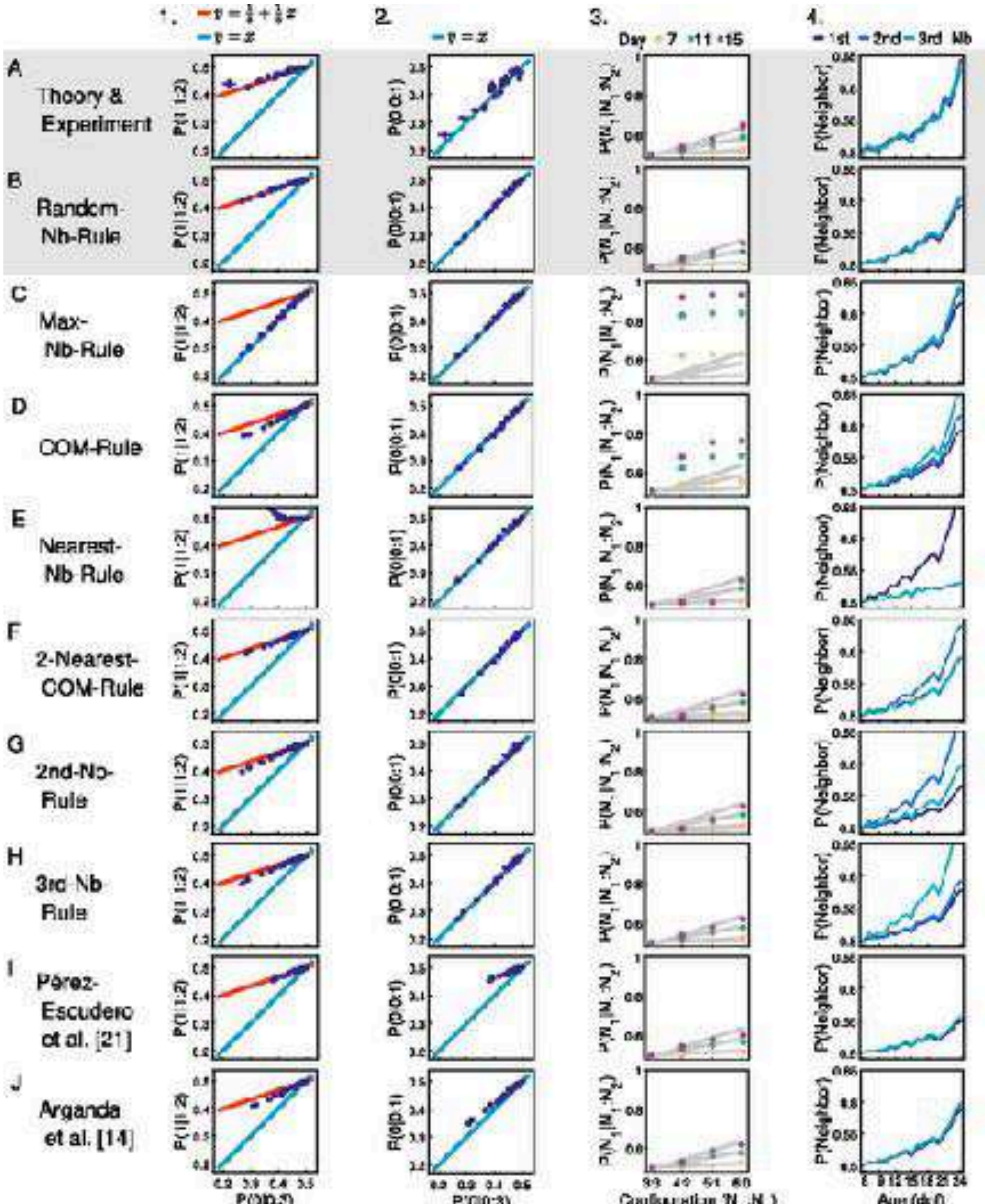


Other predictions



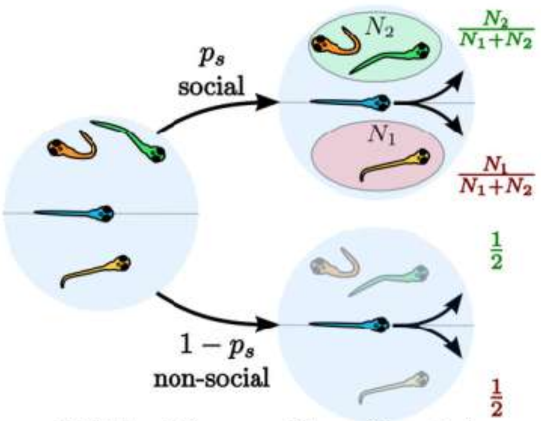




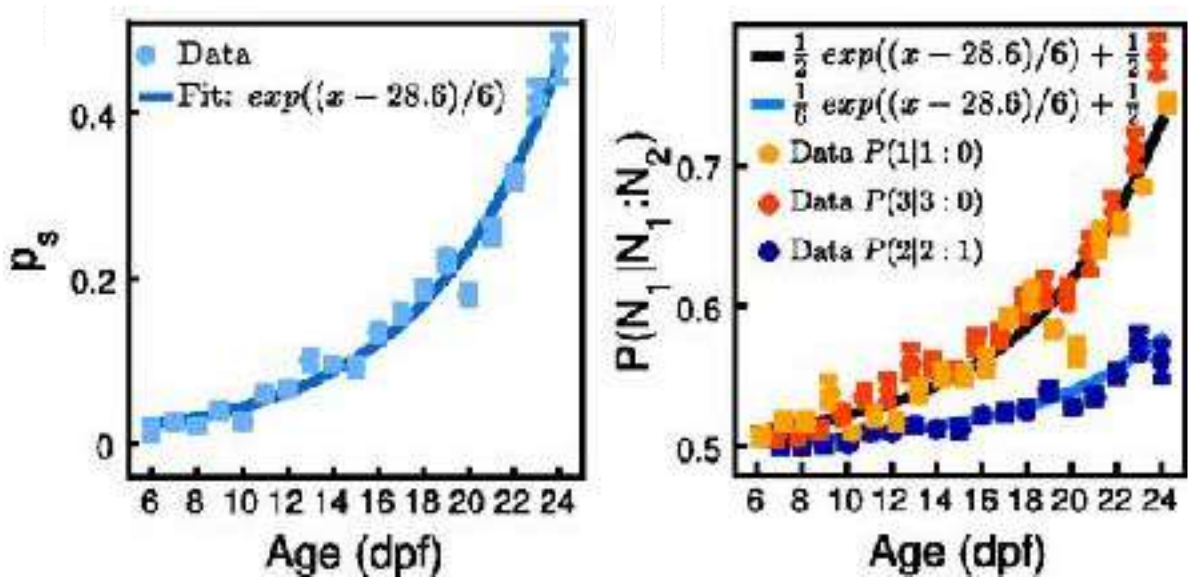


comparison with other models

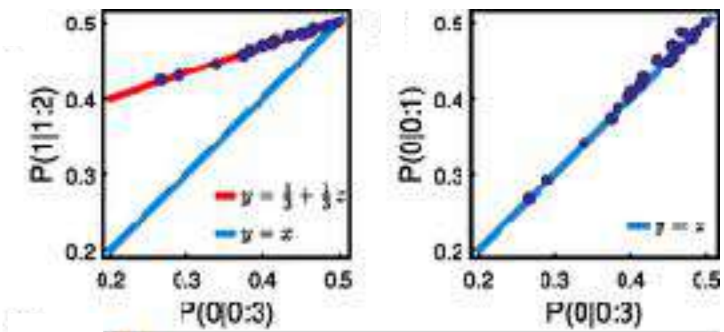
Changes during development

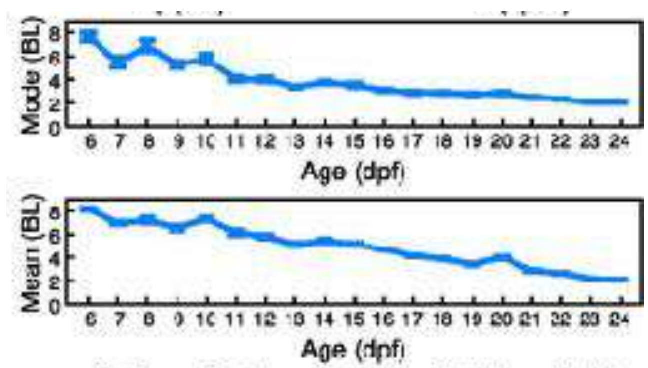


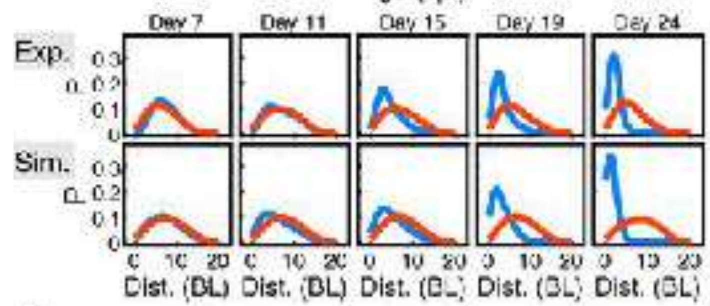
$$P(N_1|N_1:N_2) = p_s\,\frac{N_1}{N_1+N_2} + (1-p_s)\frac{1}{2}$$

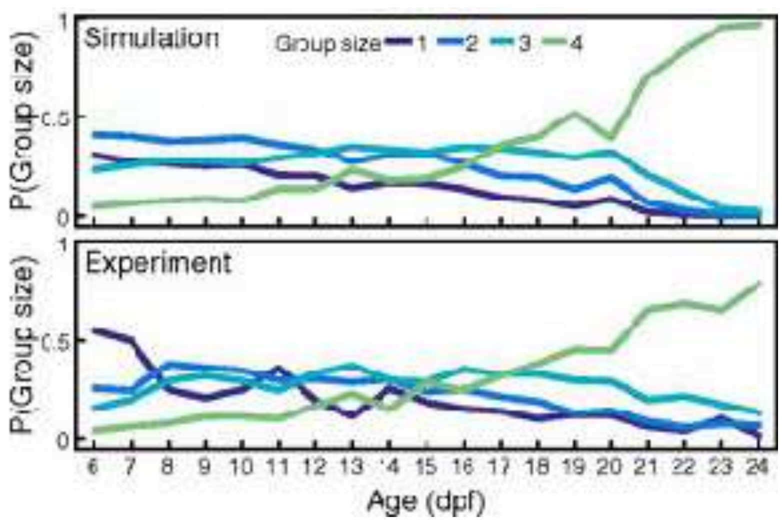


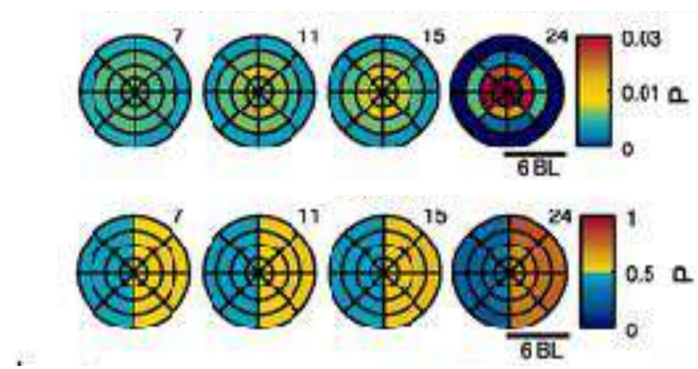
Running the model & analyse it as exp











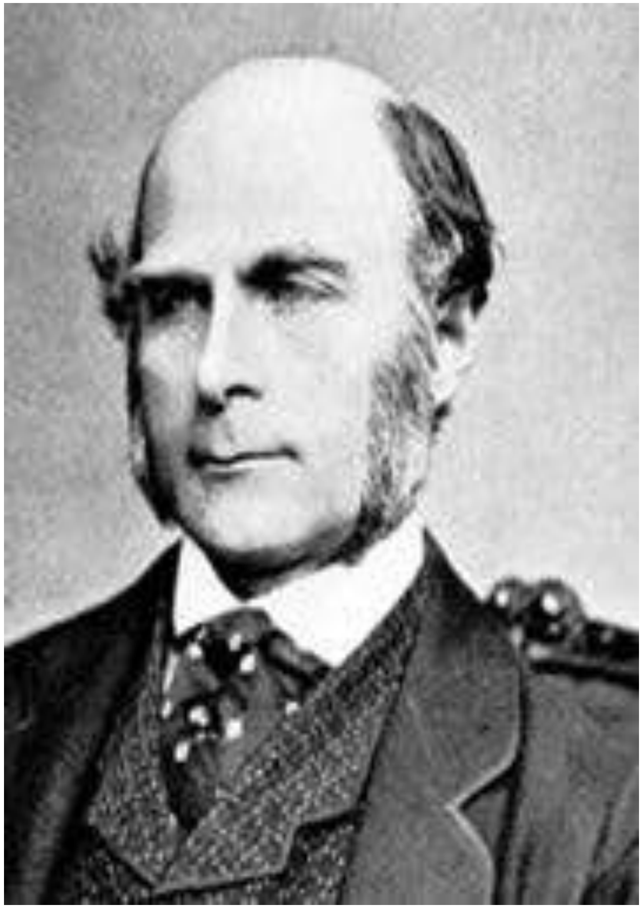
$$P_x = \left(1 + \frac{1 + as^{-(n_x - kn_y)}}{1 + as^{-(n_y - kn_x)}}\right)^{-1}$$

Theory of decision-making in groups

Data-driven study of collective behaviour

Collective behavior in humans

Galton (1907)



Francis Galton

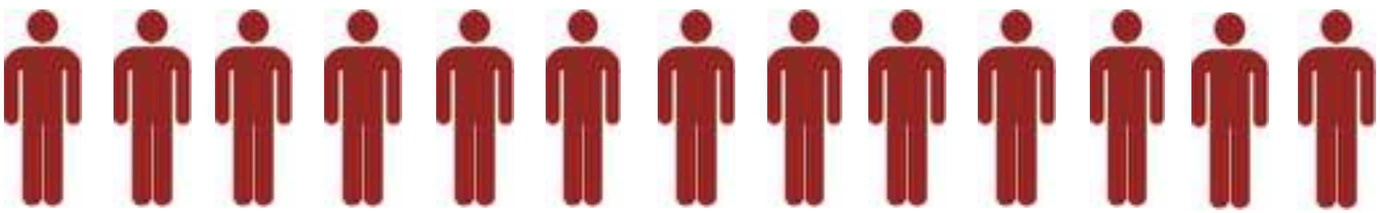
Vox Populi

IN these democratic days, any investigation into the trustworthiness and peculiarities of popular judgments is of interest. The material about to be discussed refers to a small matter, but is much to the point.

Galton (1907)

What is the weight of the ox?

Individuals (800) write down their answer independently of each other



400 645 650 700 840 990 1,198 2,050 2,100 2,140 2,320 2,520 3,100

Median value (middle observation of ordered list)= 1,198
Real value = 1,207

} 1 % error

What is the border length between Italy and Swizerland?

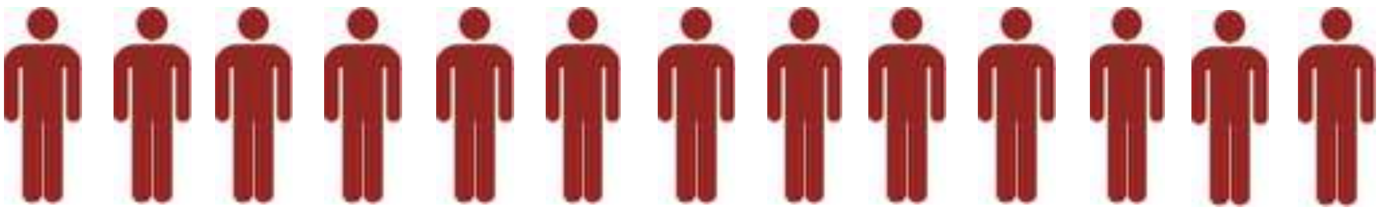
Median value = 302
Real value = 734

} 60 % error

Galton (1907)

What is the weight of the ox?

Individuals (800) write down their answer independently of each other



400 645 650 700 840 990 1,198 2,050 2,100 2,140 2,320 2,520 3,100

Median value (middle observation of ordered list)= 1,198

Real value = 1,207

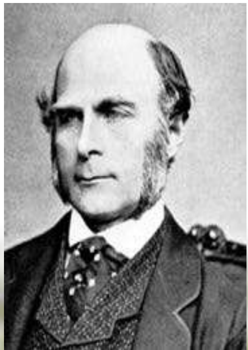
} 1 % error

What is the border length between Italy and Swizerland?

Median value = 302

Real value = 734

} 60 % error

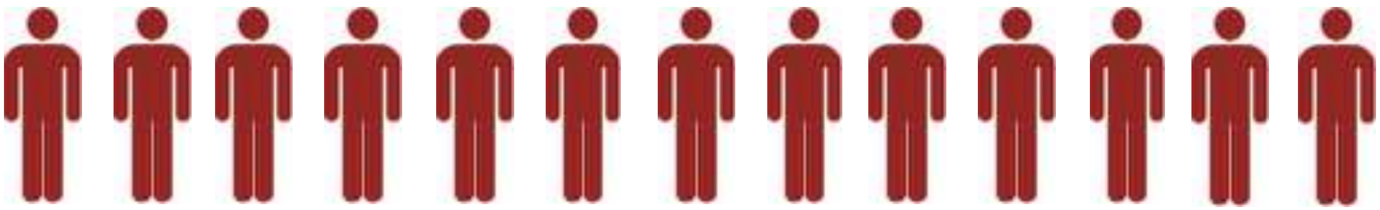


What is the weight of this ox?

Wisdom of the crowd

What is the weight of the ox?

Individuals (800) write down their answer independently of each other



400 645 650 700 840 990 1,198 2,050 2,100 2,140 2,320 2,520 3,100

Median value (middle observation of ordered list)= 1,198
Real value = 1,207
} 1 % error

What is the border length between Italy and Swizerland? From Lorenz et al (2011)

Median value = 302
Real value = 734
} 60 % error

Simple interactions make matters worse

What is the border length between Italy and Swizerland?

Median value 302 ± 495

Real value = 734

} 60 % error

Give all people the mean value, and ask again

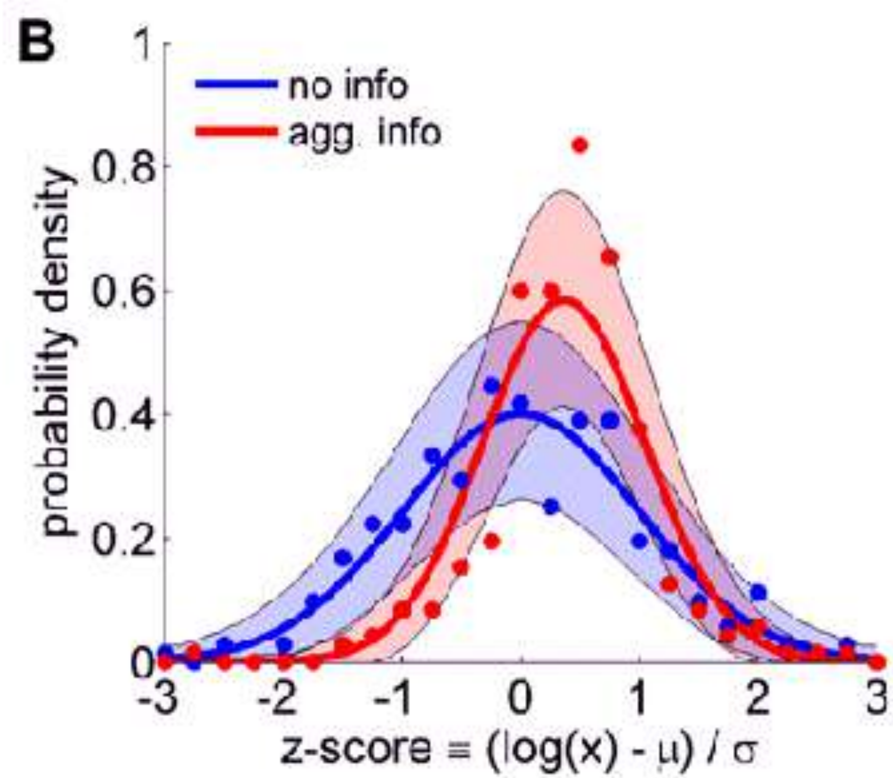
What is the border length between Italy and Swizerland?

Median value = 381 ± 279 They just copied

Using again Bayes Theorem and that counting distributions tend to be log-normal,

we obtain for $y = \log(x)$

$$P(y|p,s) \propto P(y|s)P(s|p,y) = \mathcal{N}(\mu_f, \sigma_f)$$



$$\mu_f = (1 - w_s)\mu_p + w_s\mu_s$$

$$\sigma_f = \sqrt{1 - w_s}\sigma_p$$

Madirolas & de Polavieja (2015)

A model for an individual compatible with the distributions is

$$x_2 = x_1^{1-w_s}\,\overline{x}_1^{\,w_s}$$

Social weight

Second estimation

First (private) estimation

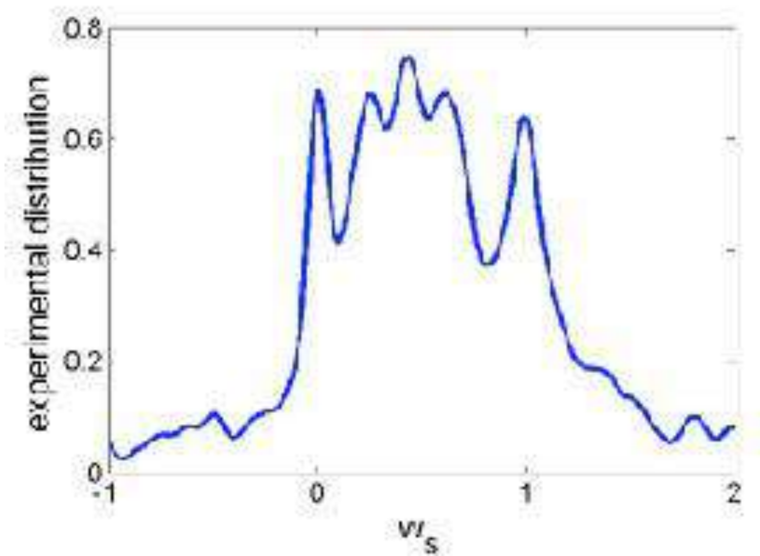
Social value

So from the two estimations, for each individual we can extract a social weight as

$$w_s = \frac{\log(x_2) - \log(x_1)}{\log(\overline{x}_1) - \log(x_1)}$$

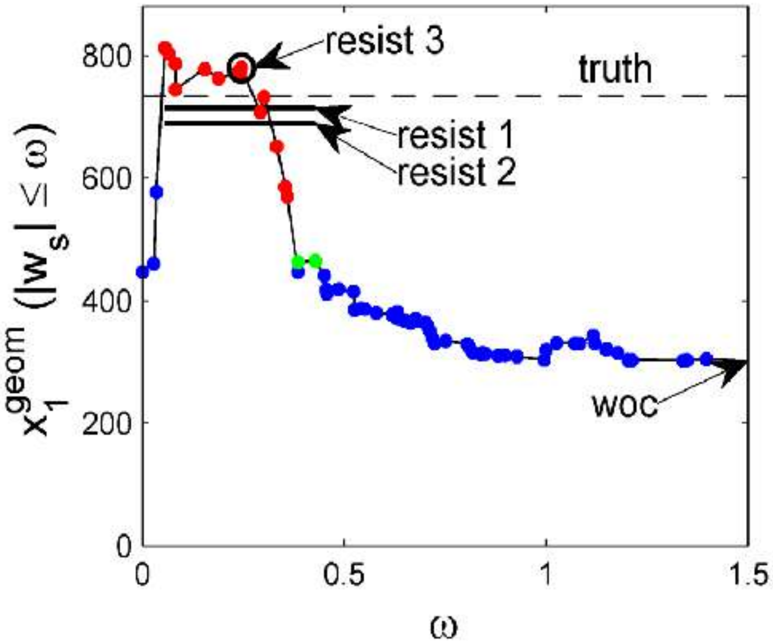
Change in opinion

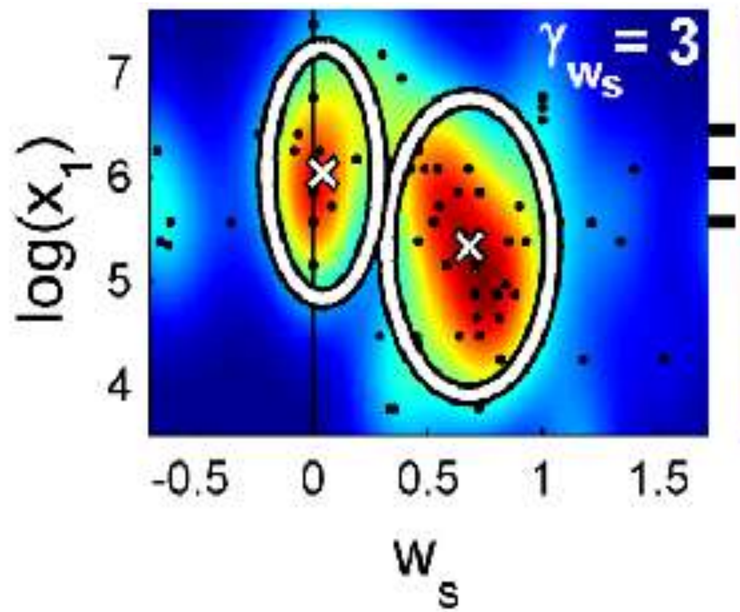
Distance from first estimation to social value



HYPOTHESIS:

Resistance to social influence statistically correlates with accuracy



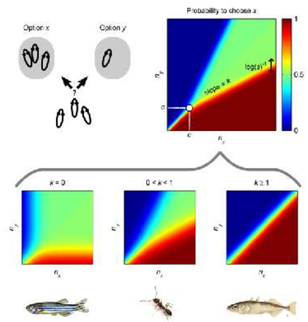


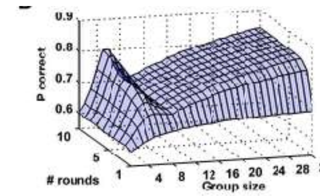
Madirolas & de Polavieja (2015)

Question	Truth	WOC	Resist
Border Length	734	302 (-59%)	715 (-2.6%)
Rapes	639	257 (-60%)	624 (-2.4%)
Assaults	9272	3685 (-60%)	7721 (-17%)
Population Density	184	115 (-38%)	168 (-8.9%)

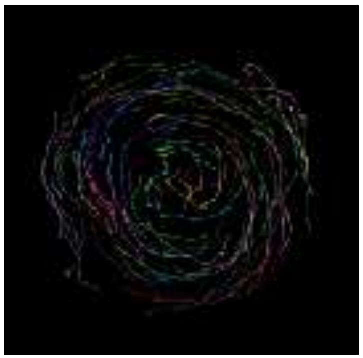
Theory of decision-making in groups

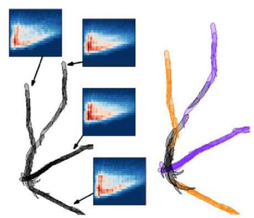
$$P_x = \left(1 + \frac{1+as^{-(n_x-kn_y)}}{1+as^{-(n_y-kn_x)}}\right)^{-1}$$

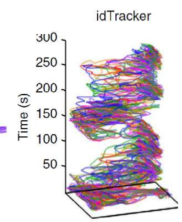


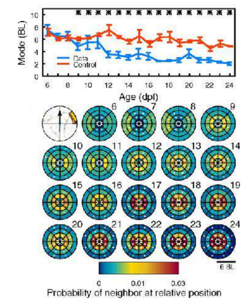


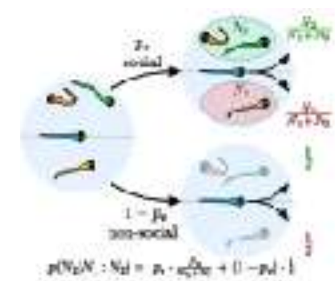
Data-driven study of collective behaviour



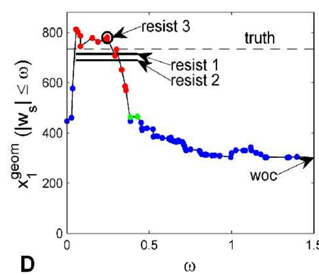


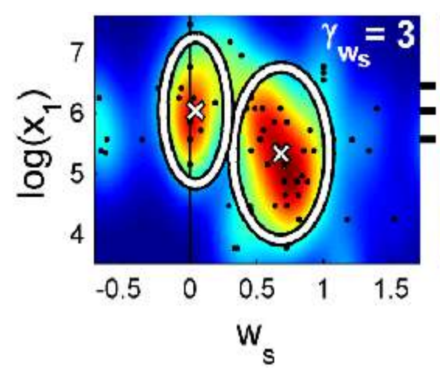






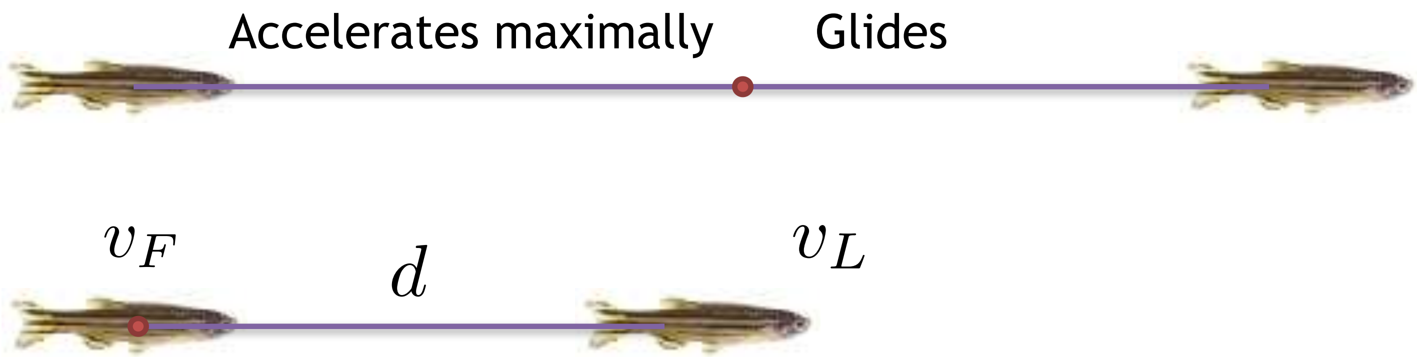
Collective behavior in humans



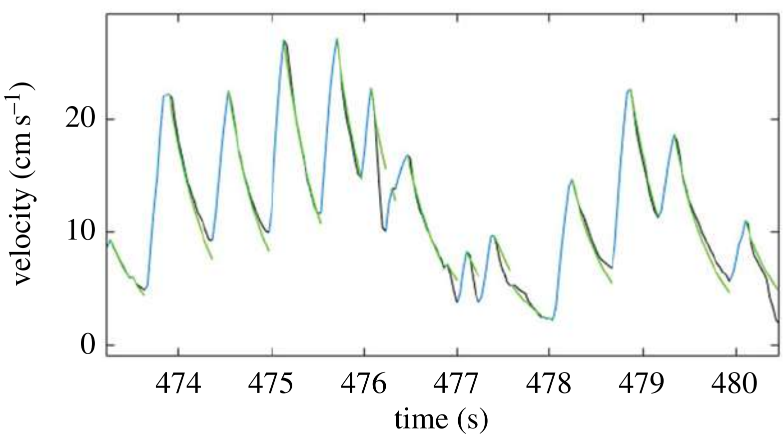


Champalimaud Foundation
FCT
Fundação para a Ciência e a Tecnologia
CSIC

How do two fish get close? The minimum time solution



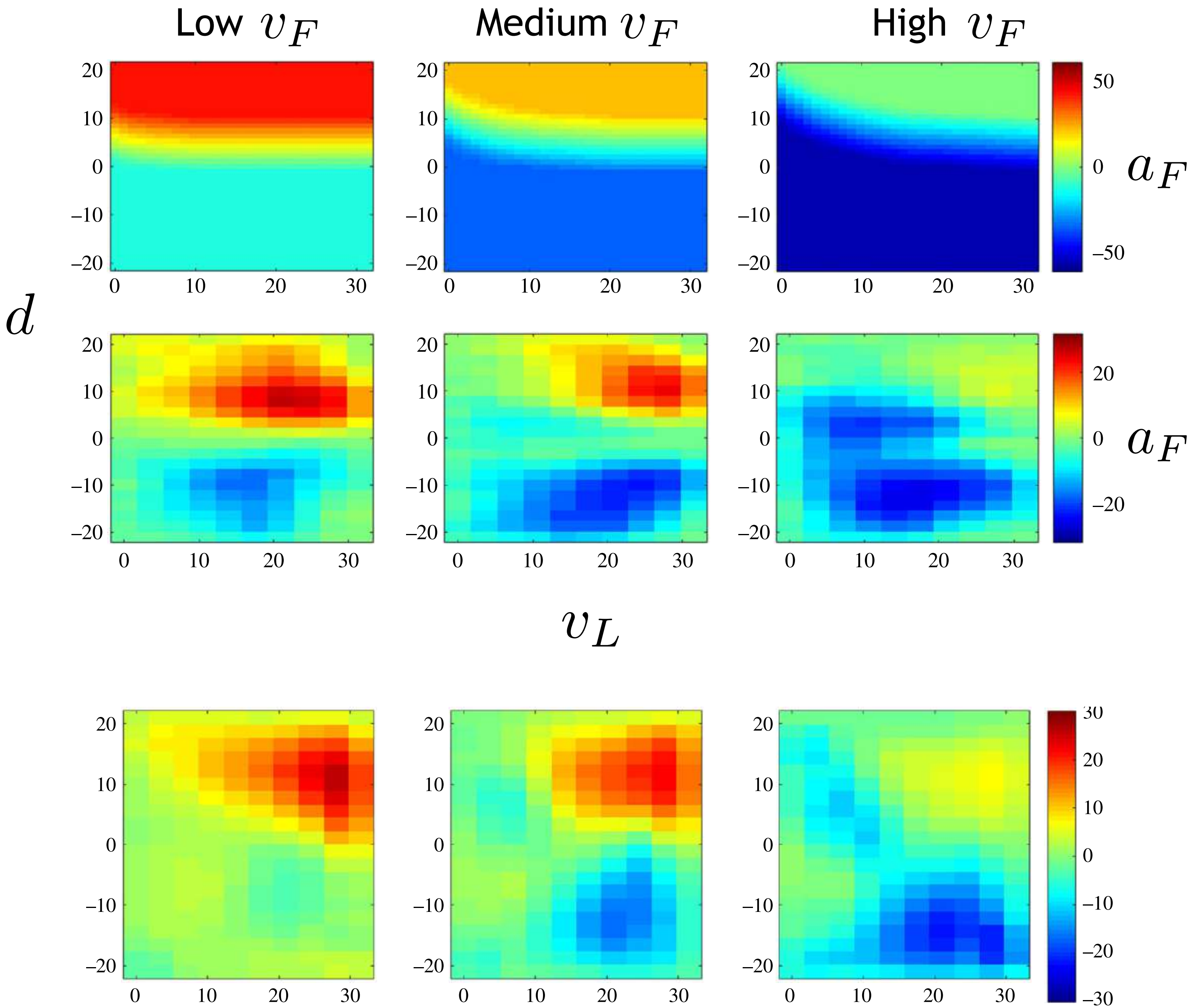
$$v_F(t_{eq}) = v_L$$



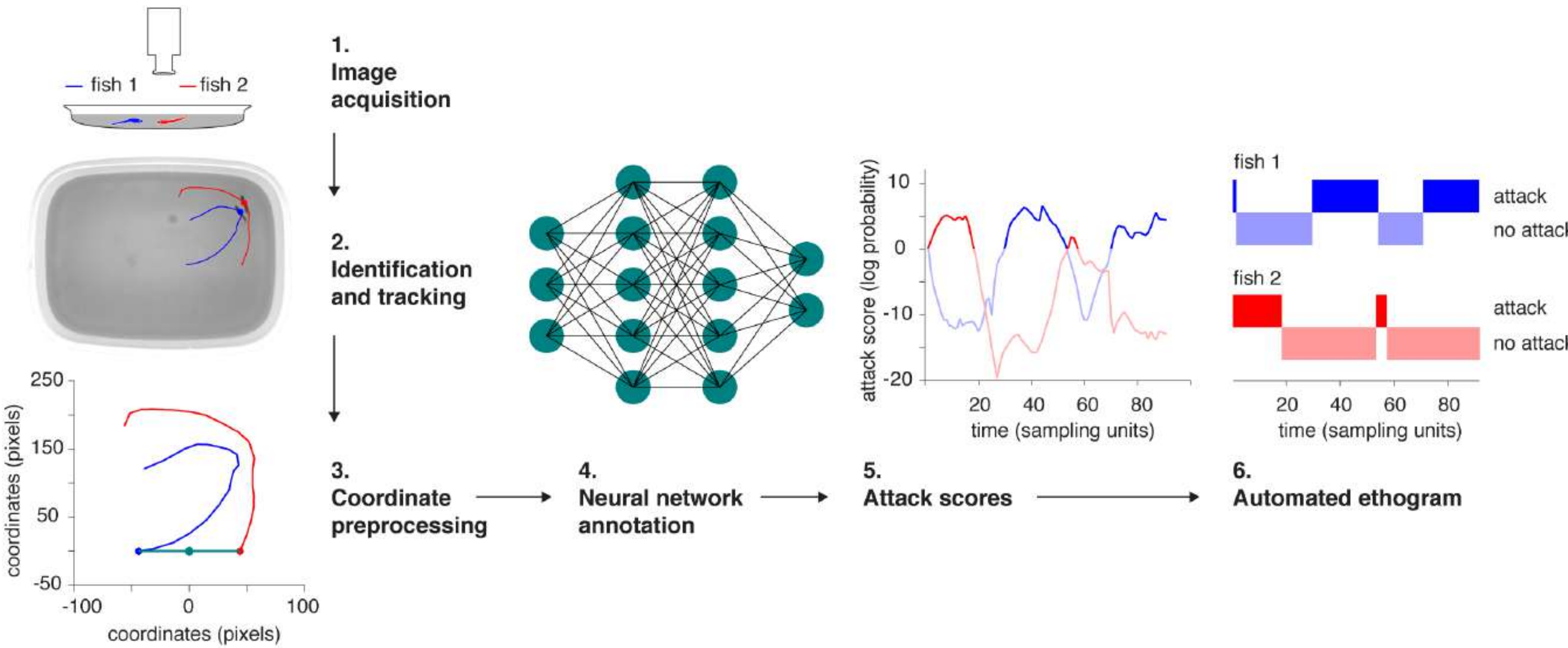
$$v_F(t) = v_F(0)\exp(-\alpha t)$$

$$\alpha = 2.7 s^{-1}$$

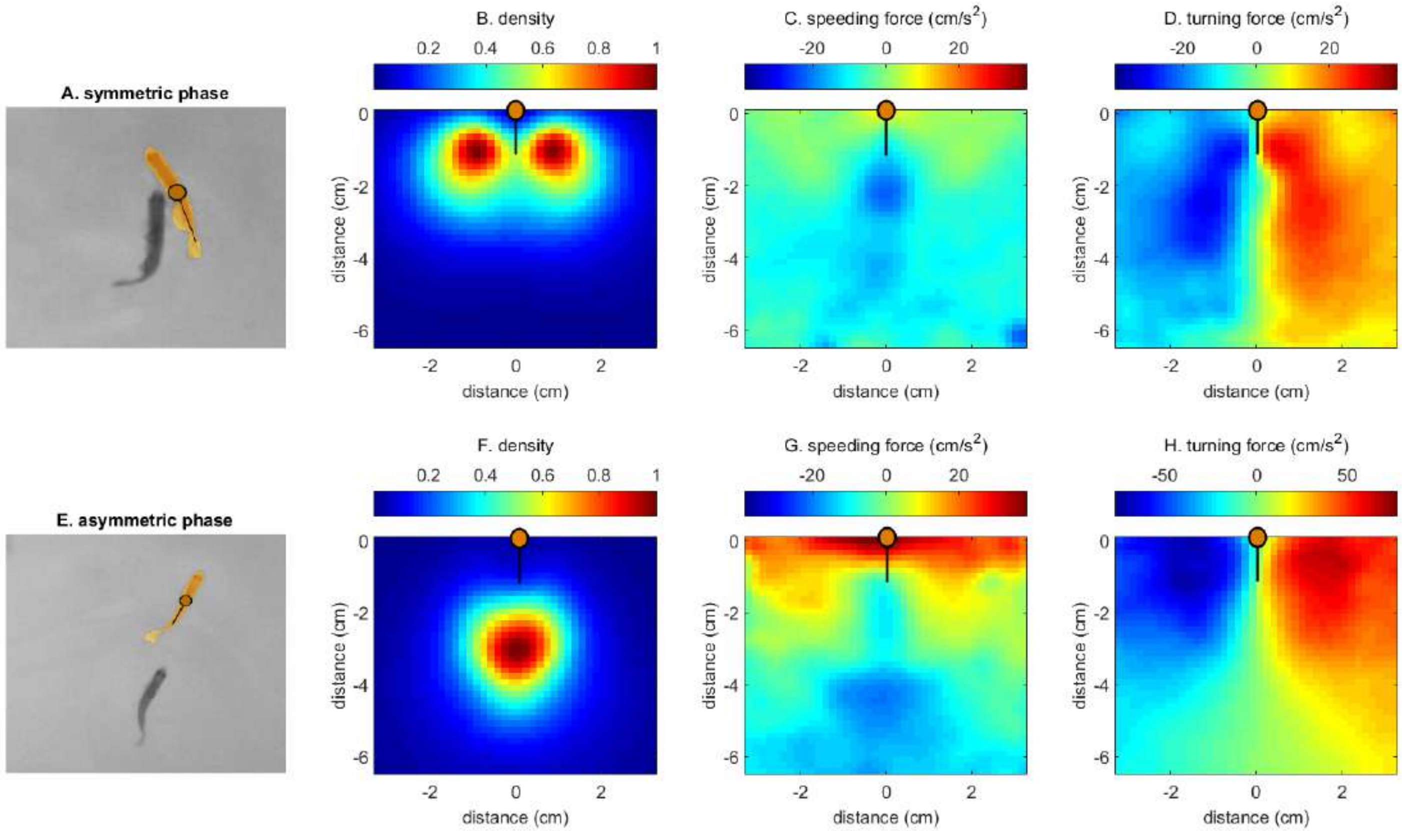
$$\frac{1}{2.7}(v_F - v_L) = d + \frac{v_L}{2.7}\log\frac{v_F}{v_L}$$



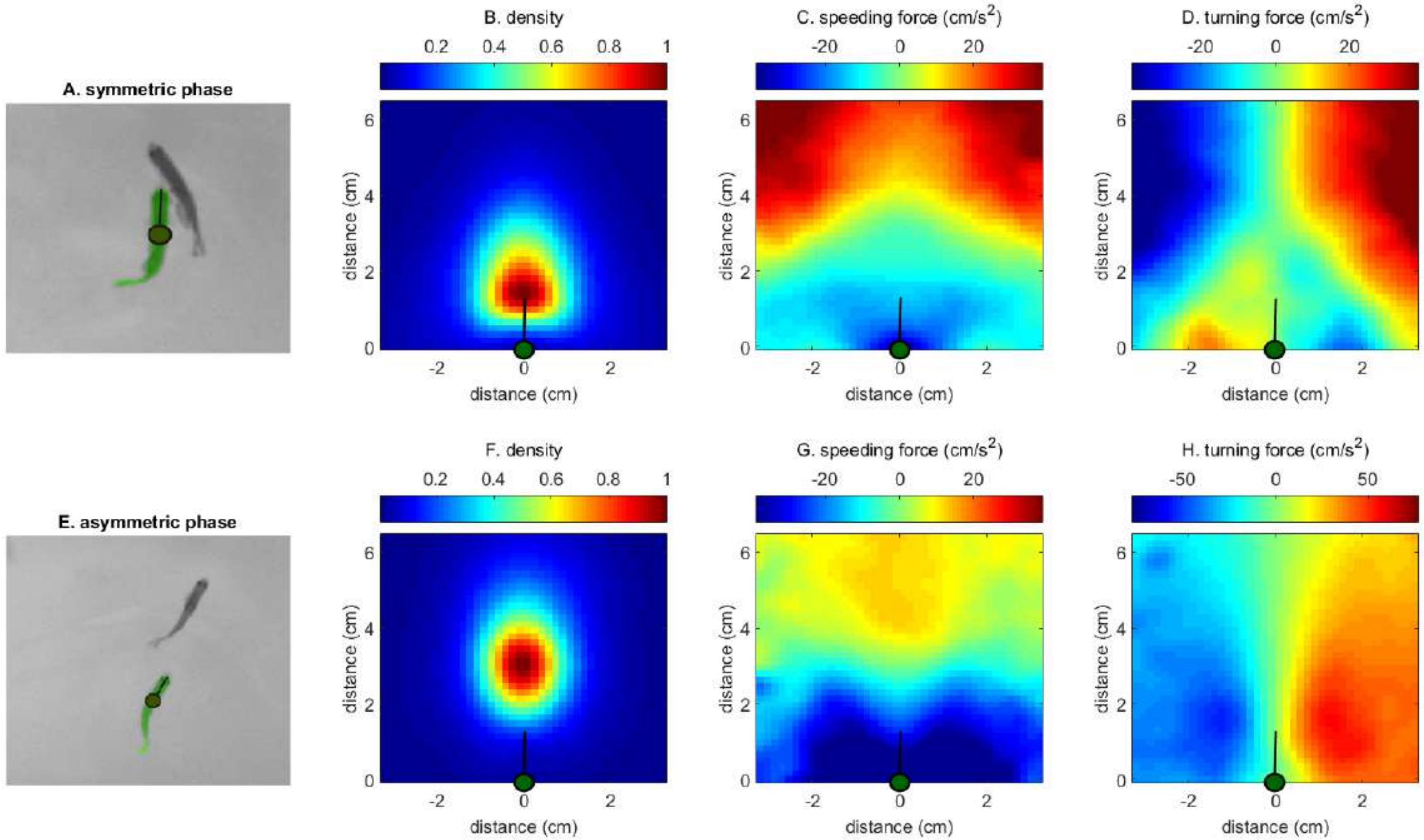
Low v_F
Medium v_F
High v_F
a_F
a_F
d
v_L

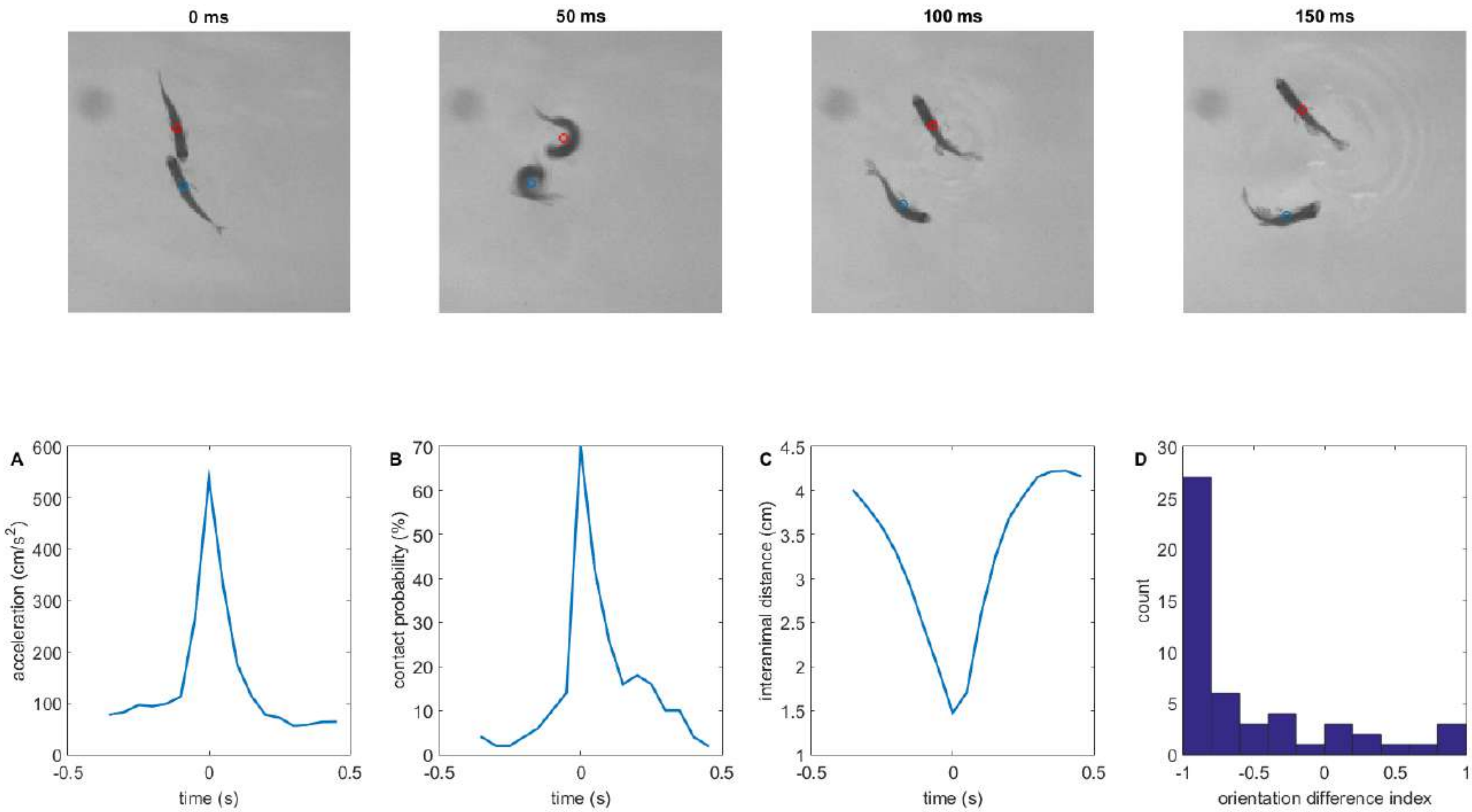


fish 1
fish 2
1. Image acquisition
2. Identification and tracking
3. Coordinate preprocessing
4. Neural network annotation
5. Attack scores
6. Automated ethogram
250
150
50
-50
-100
0
100
coordinates (pixels)
coordinates (pixels)
attack score (log probability)
10
0
-10
-20
20
40
60
80
time (sampling units)
fish 1
attack
no attack
fish 2
attack
no attack
20
40
60
80
time (sampling units)

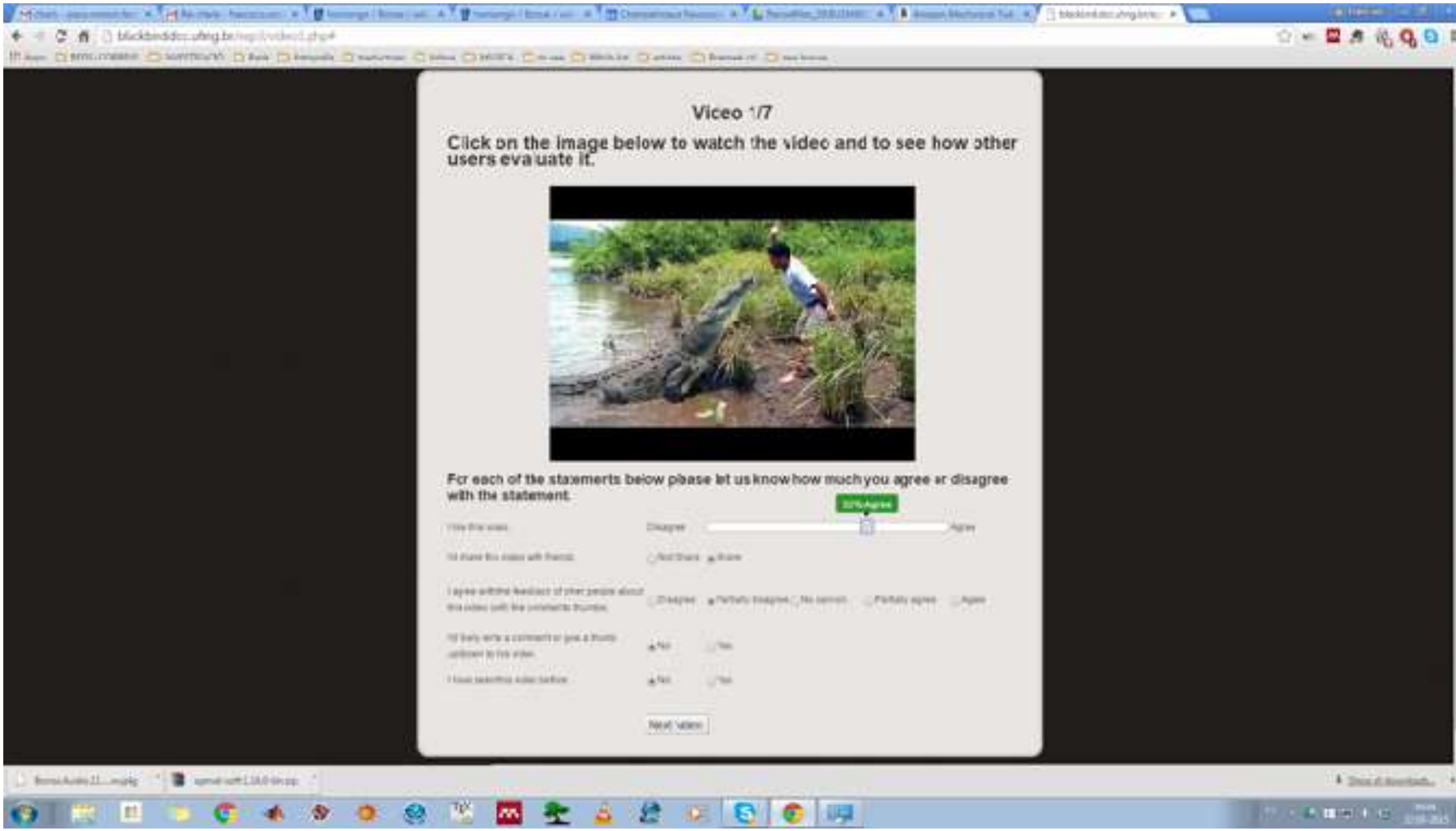


A. symmetric phase
B. density
0.2 0.4 0.6 0.8 1
C. speeding force (cm/s²)
-20 0 20
D. turning force (cm/s²)
-20 0 20
distance (cm)
0
-2
-4
-6
-2 0 2
distance (cm)
E. asymmetric phase
F. density
0.2 0.4 0.6 0.8 1
G. speeding force (cm/s²)
-20 0 20
H. turning force (cm/s²)
-50 0 50
distance (cm)
0
-2
-4
-6
-2 0 2
distance (cm)

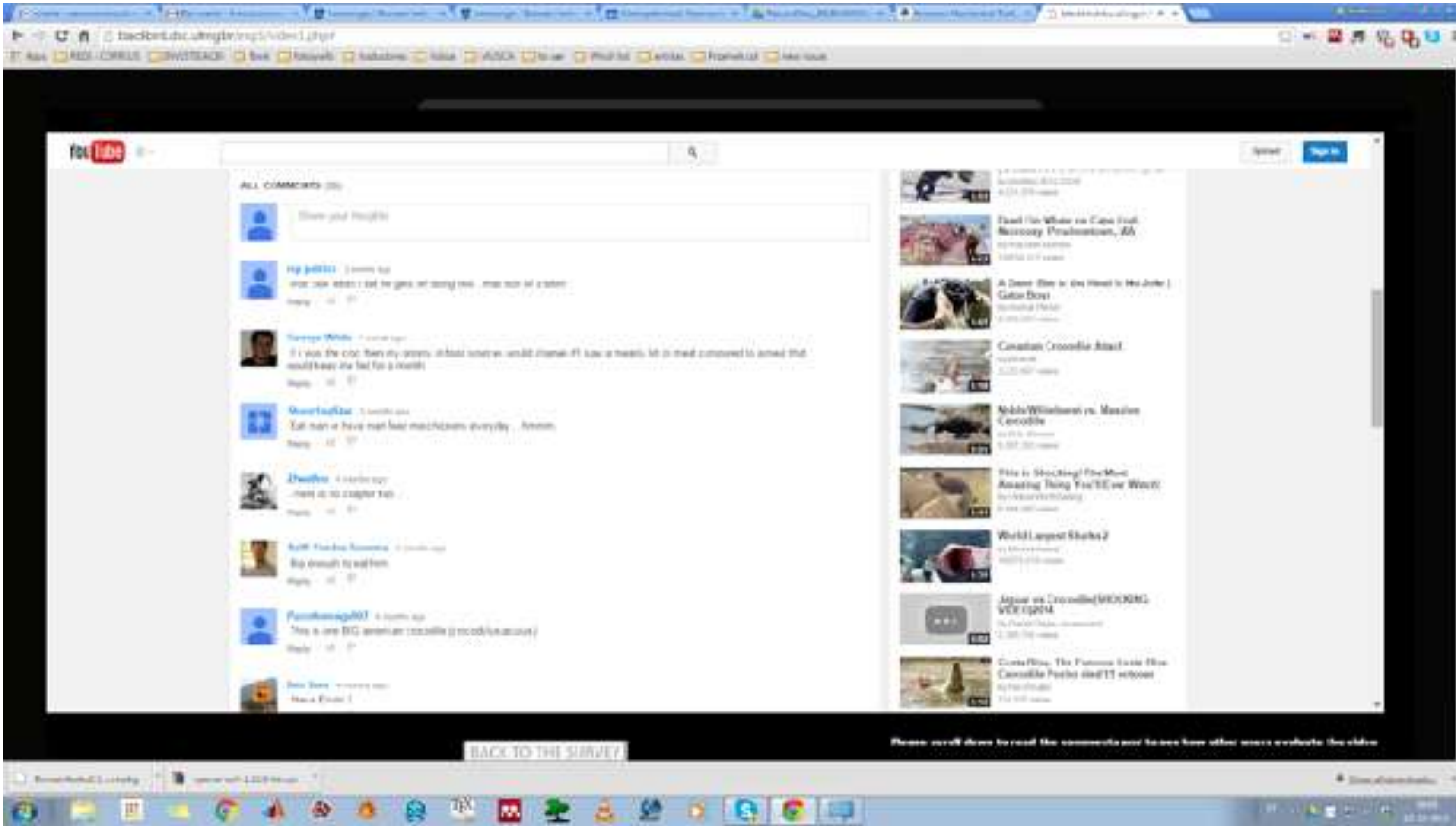

A. symmetric phase
B. density
0.2
0.4
0.6
0.8
1
C. speeding force (cm/s^2)
-20
0
20
D. turning force (cm/s^2)
-20
0
20
distance (cm)
0
2
4
6
-2
0
2
distance (cm)
E. asymmetric phase
F. density
0.2
0.4
0.6
0.8
1
G. speeding force (cm/s^2)
-20
0
20
H. turning force (cm/s^2)
-50
0
50
distance (cm)
distance (cm)


0 ms
50 ms
100 ms
150 ms
A
acceleration (cm/s^2)
time (s)
B
contact probability (%)
time (s)
C
interanimal distance (cm)
time (s)
D
count
orientation difference index

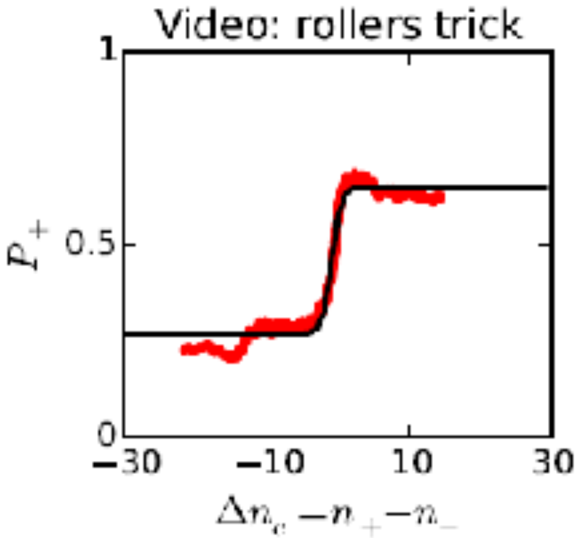
Do you like this video?



Prezsmylaw et al (in preparation)

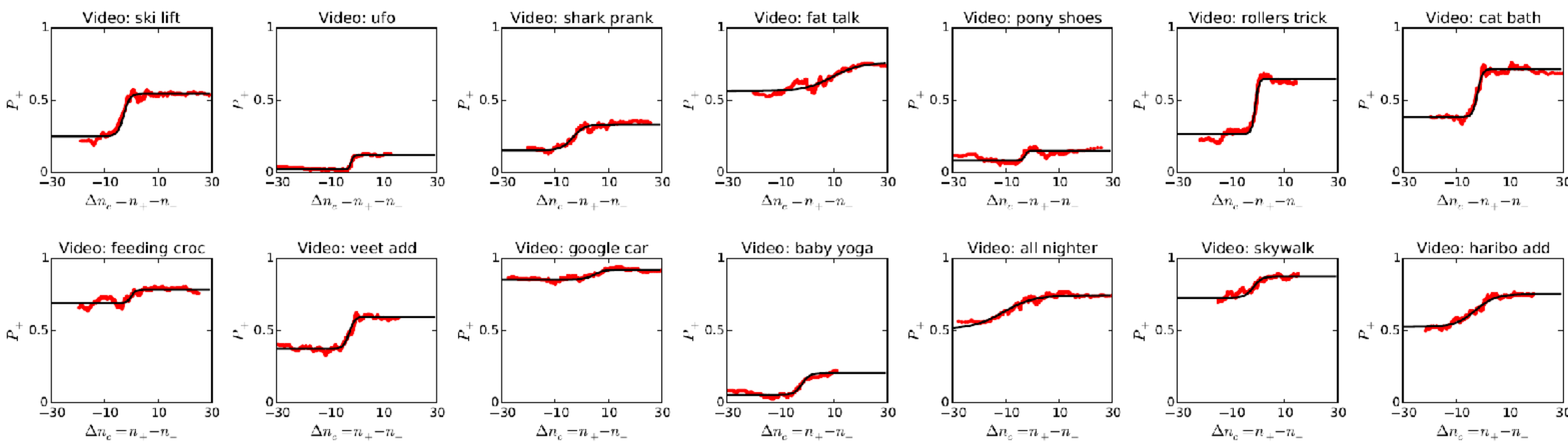


Prezsmylaw et al (in preparation)



You are more likely to like/disliked a video if people liked/disliked it in the comments

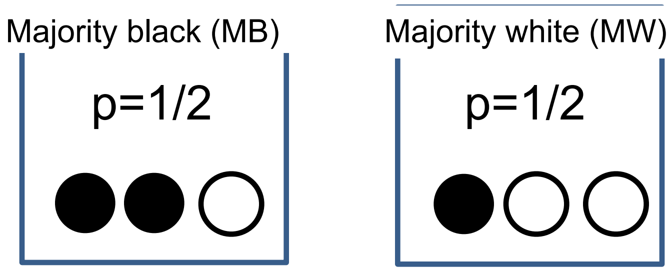
BUT some people are ‘immune’ to influence



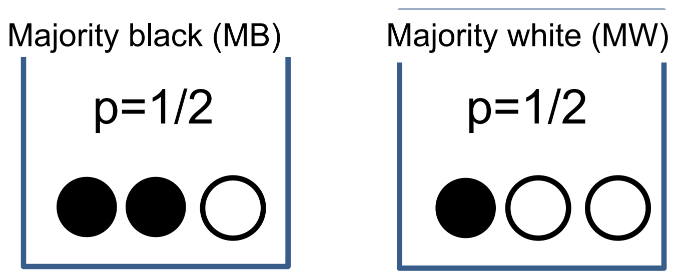
Prezsmylaw et al (in preparation)

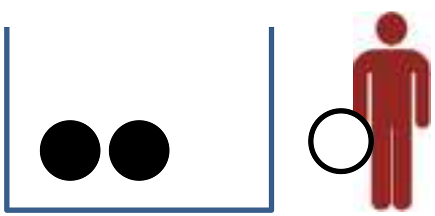
And social interactions?

Two types of boxes

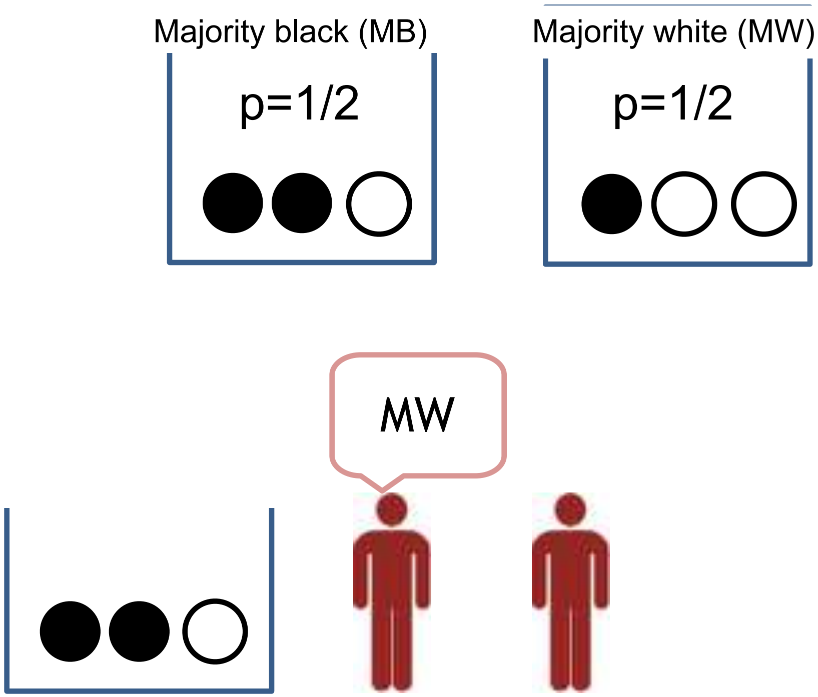


And social interactions?

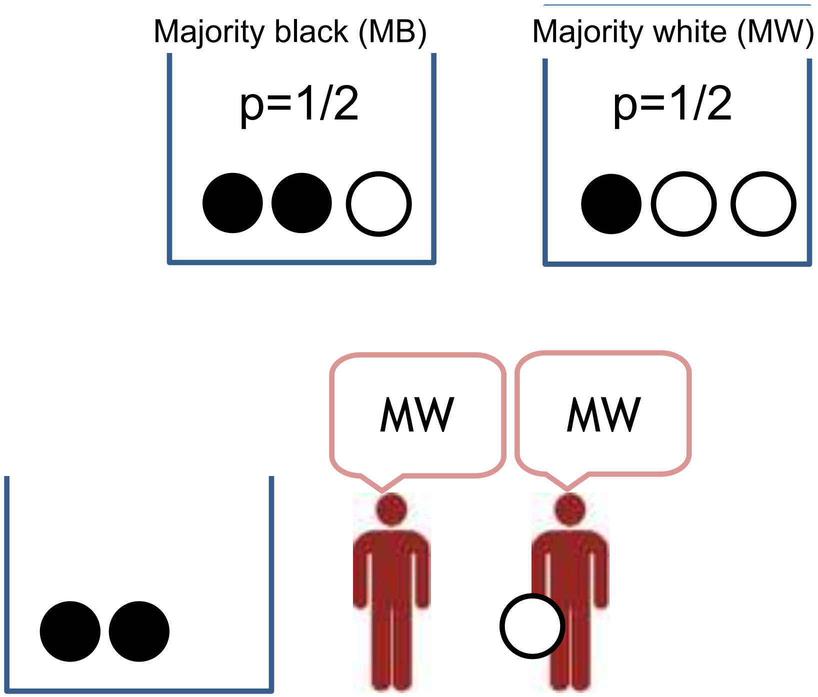




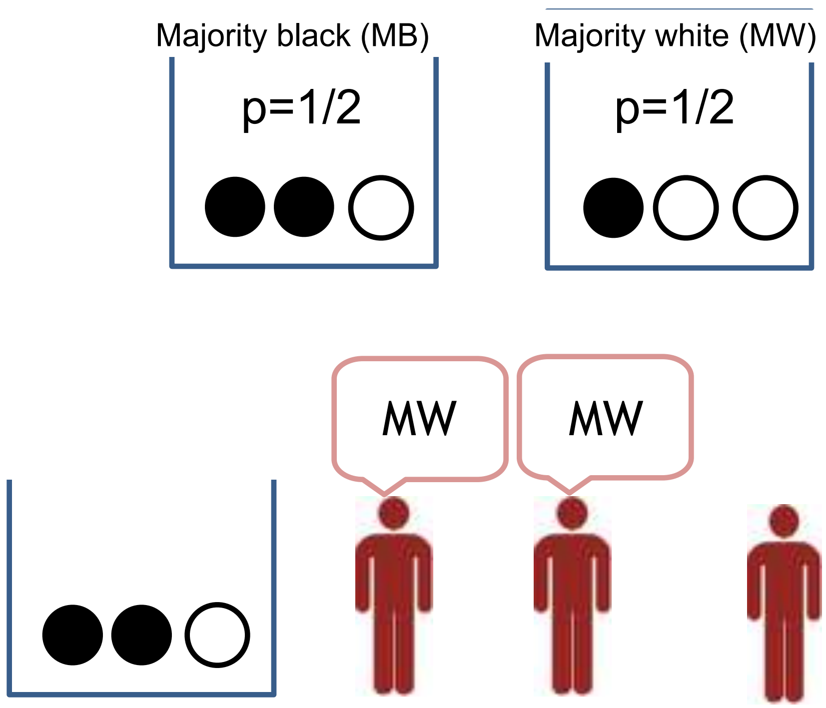
And social interactions?



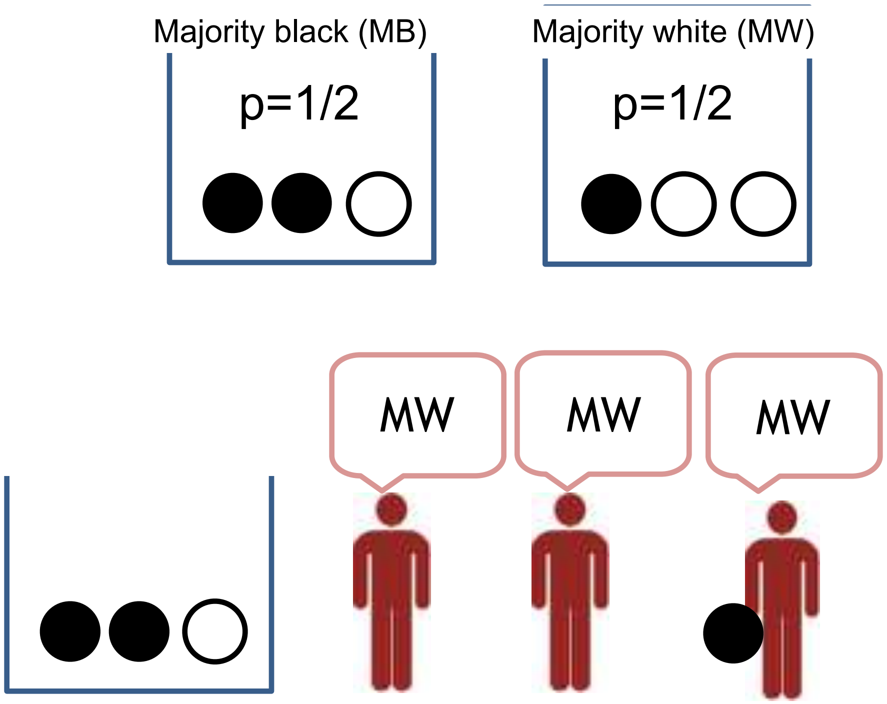
And social interactions?



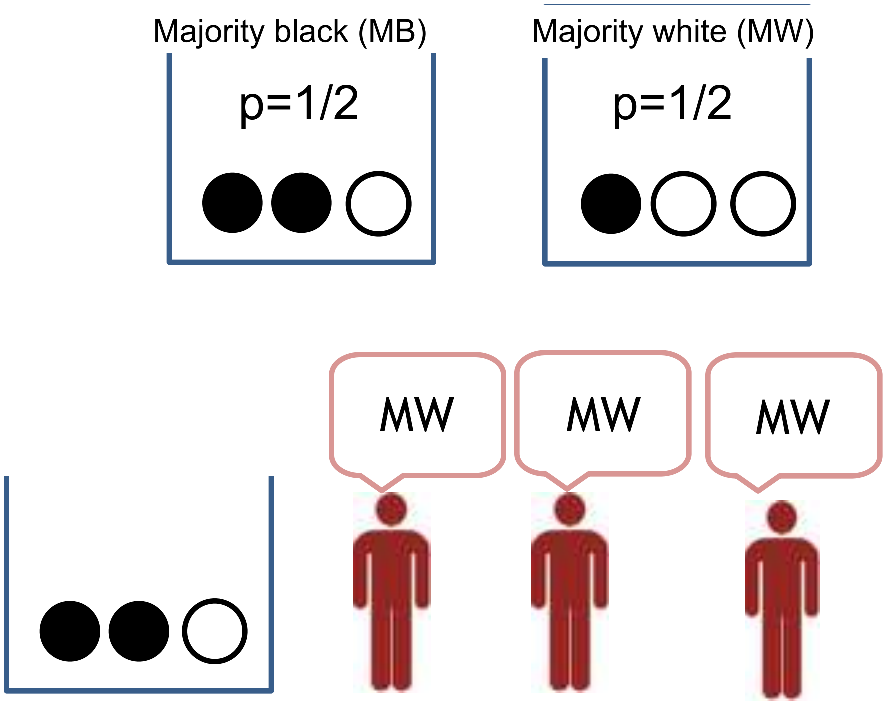
And social interactions?



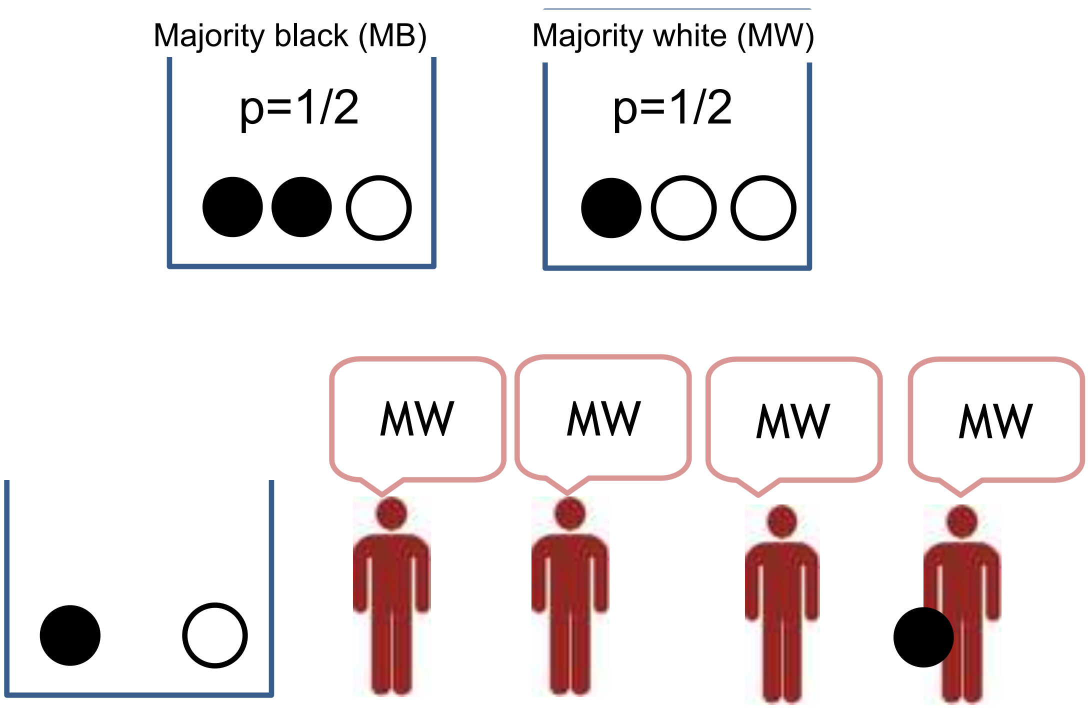
And social interactions?



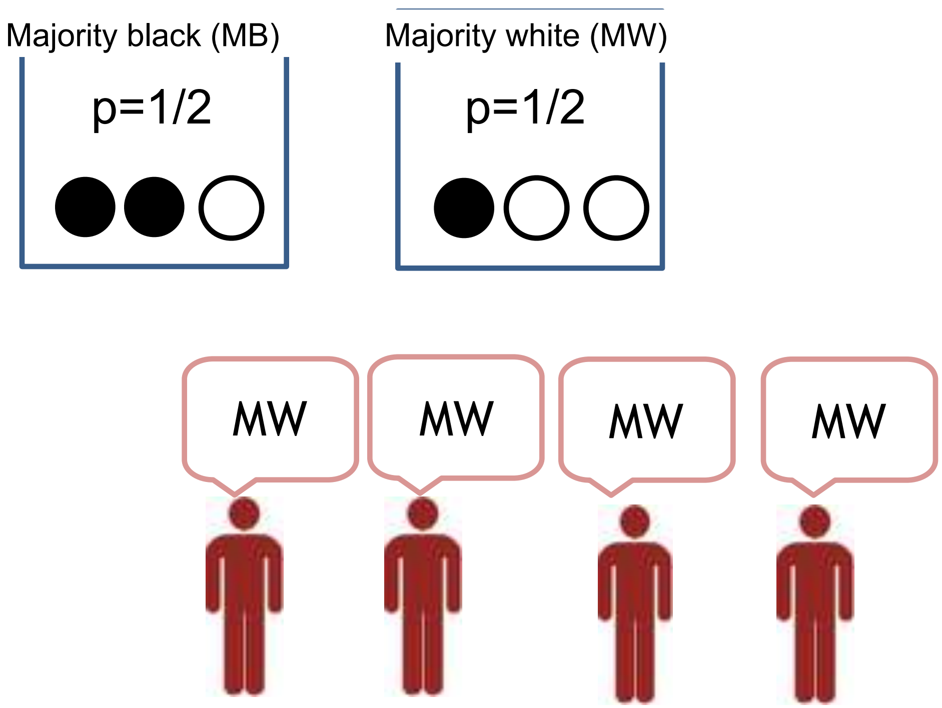
And social interactions?



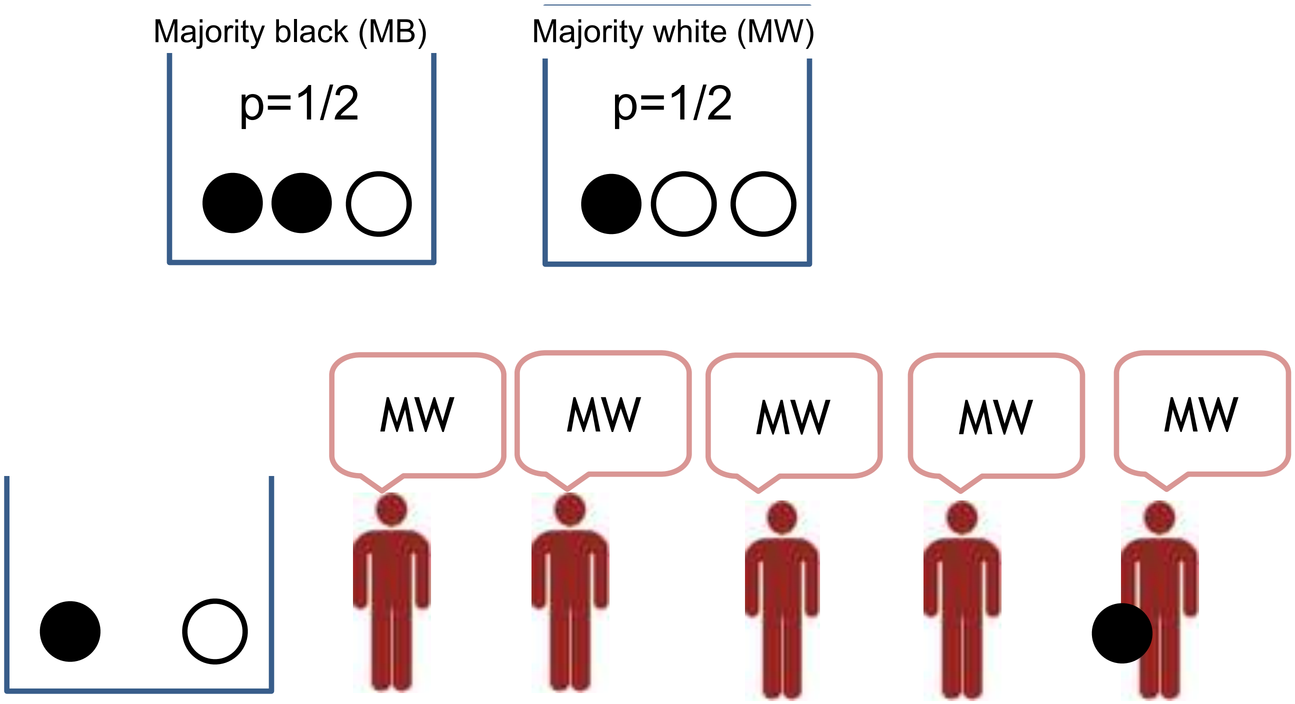
And social interactions?



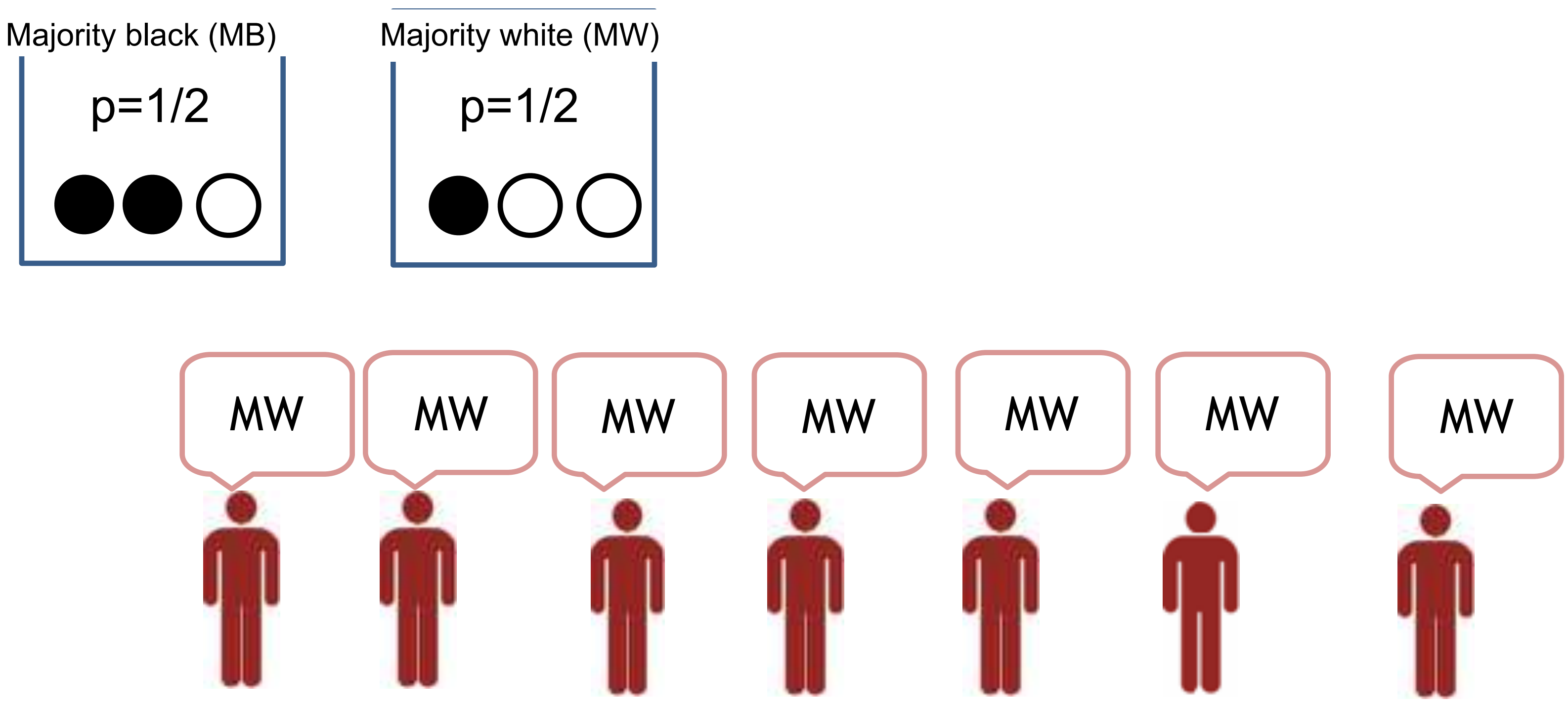
And social interactions?



And social interactions?



And social interactions?

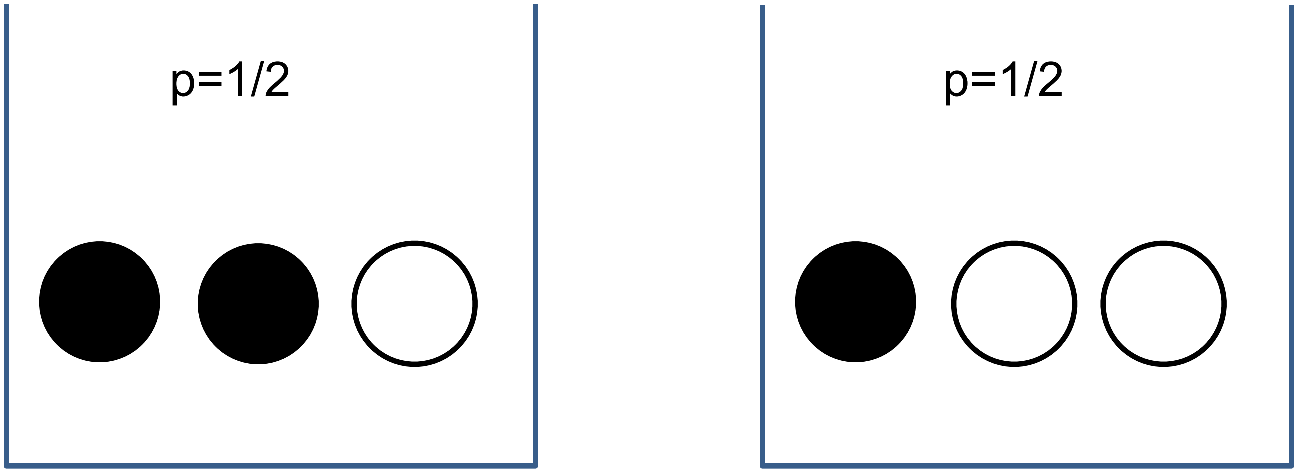


Social interactions can cascade an error EVEN if everyone is choosing the best they

Information cascades

Banerjee, Quart J Econ (1992)
Bikhchandani, Hirshleifer, Welch (1992) J Polit Econ

Assumes people are super-rational and decide in sequence



Majority black (MB) Majority white (MW)

You draw one ball and with that ball and what people have estimated before (MB or MW), you make an estimation (MB or MW)

Rational decision rule

Guess MW when P(MW| what you see and heard)>1/2
Else choose MB

From the setup we know

$P(MW)=P(MB)=1/2$
$P(w|MW)=p(b|MB)=2/3$

Decision by first person assumig she draw w

$P(MW|w)=P(w|MW)P(MW)/P(w)=2/3x1/2/1/2=2/3 > 1/2$ -> says MW

where
$P(w)=P(w|MW)P(MW)+P(w|MB)P(MB)=2/3 x1/2+1/3x1/2$

…

Third person

$P(MW|\ w\ w\ b)=P(w\ w\ b|MW)\ P(MW)\ /\ P(w\ w\ b)=4/27 \times 1/2\ /1/9=2/3 > 1/2$ -> says MW

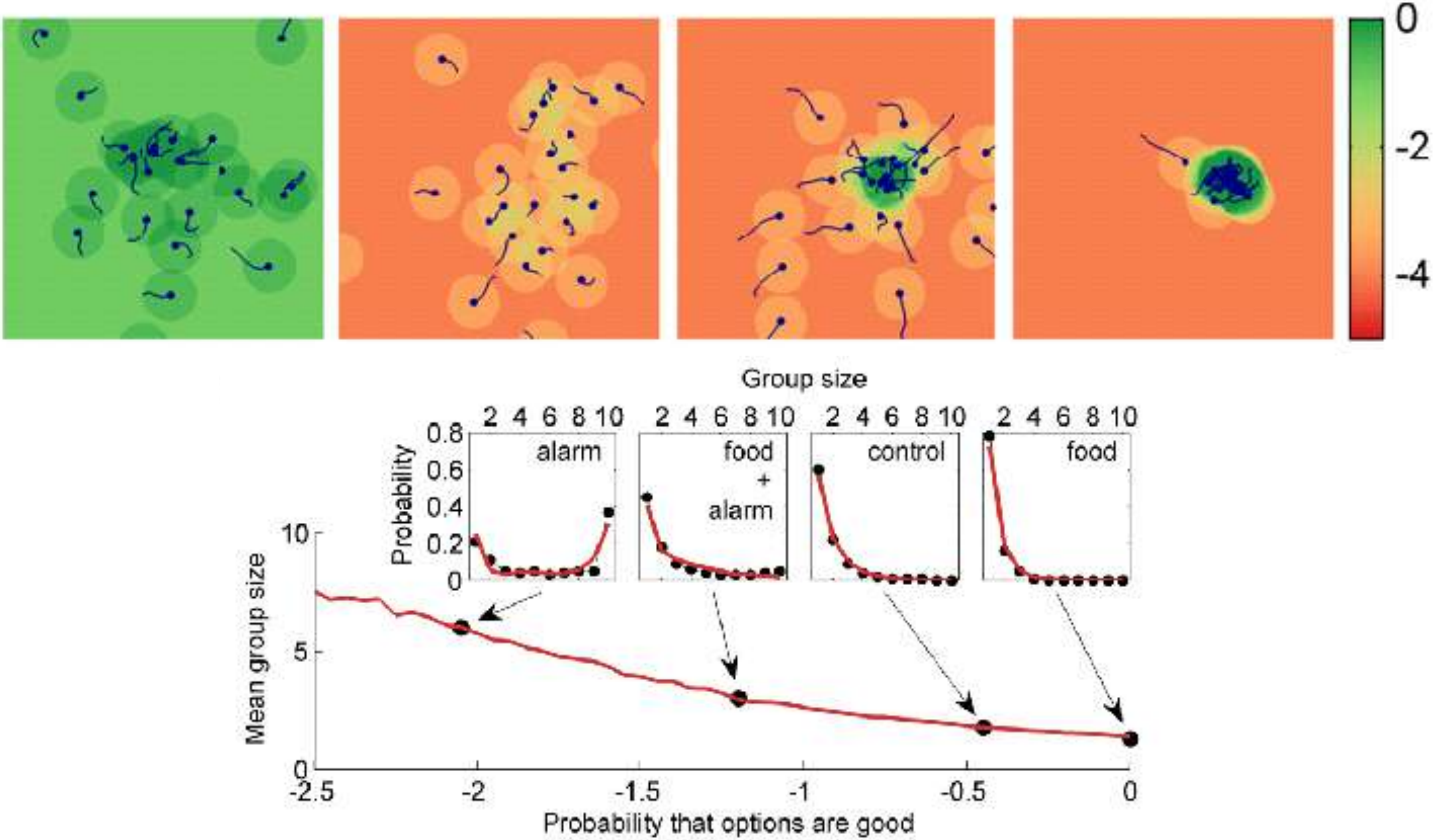
where

$P(w\ w\ b|MW)=P(w|MW)\ P(w|MW)\ P(b|MB)=2/2 \times 2/3 \times 1/3=4/27$
$P(MW)=1/2$
$P(w\ w\ b)=P(w\ w\ b|MW)\ P(MW) + P(w\ w\ b|MB)P(MB)=4/27x1/2+1/3x13x2/3x1/2=1/9$

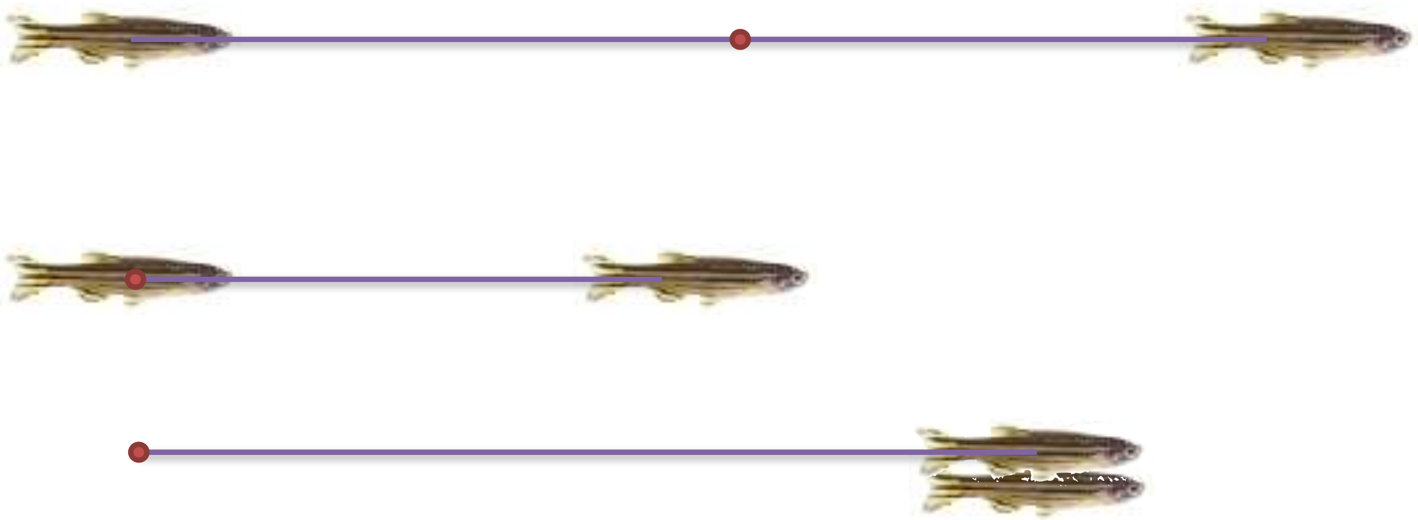
The thid person should choose w independently of what she sees
The same for the rest, so a cascade forms

It is rational to form a cascade in which people simply copy,
and they might get it wrong

Increased aggregation in adversity from decision-making



Perez-Escudero & de Polavieja (unpublished); data from Hoare et al (2004)



$v_F(0)$ v_L $v_F(0) > v_L$

d

$$v_F(t_{eq}) = v_L$$

$$d_F(t_{eq}) = d + d_L(t_{eq})$$

$$v_F(t_{eq}) = v_L$$

$$\frac{dv_F}{dt} = -\alpha v_F$$

$$v_F(t) = v_F(0)\exp(-\alpha t)$$

$$t = \frac{1}{\alpha}\ln\frac{v_F(0)}{v_F(t)}$$

$$t_{eq} = \frac{1}{\alpha}\ln\frac{v_F(0)}{v_L}$$

$$d_F(t_{eq}) = d + d_L(t_{eq})$$

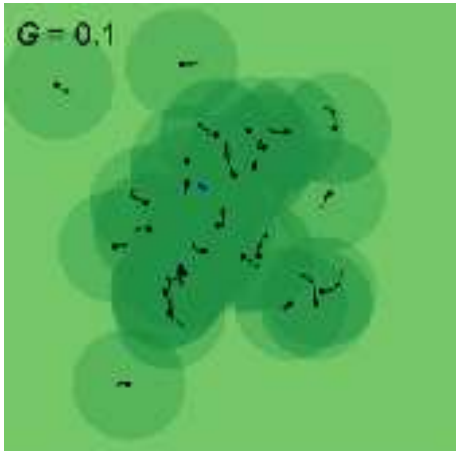
$$v_F(t) = v_F(0)\exp(-\alpha t)$$

$$d_F(t_{eq}) = \int_0^{t_{eq}} v_F(0)\exp(-\alpha t) = \frac{1}{\alpha}(v_F(0) - v_L)$$

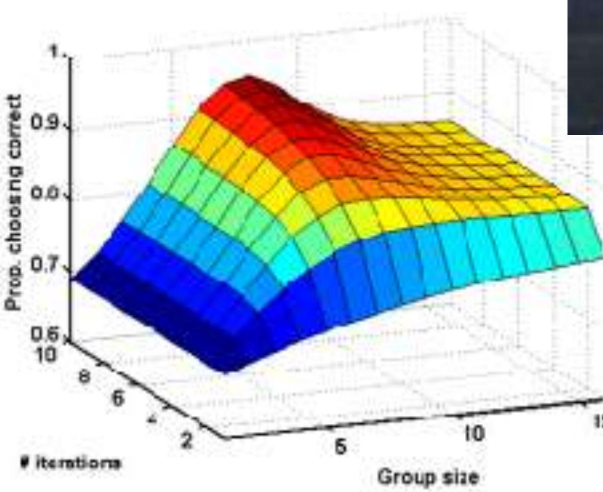
$$d_L(t_{eq}) = v_L t_{eq]} = \frac{v_l}{\alpha}\ln\frac{v_F(0)}{v_L}$$

$$\frac{1}{\alpha}(v_F(o) - v_L) = d + \frac{v_l}{\alpha}\ln\frac{v_F(0)}{v_L}$$

Other uses of modelling in collectives



Panic is decision-making
Perez-Escudero & de Polavieja (submitted)



Most accurate groups are small
Vicente-Page & de Polavieja (isubmitted)

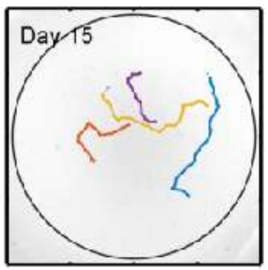
Approach as acceleration until gliding alone
takes a fish to another fish
Laan & de Polavieja (submitted)

Consensus in kids using a geometric mean
Ioannou, Madirolas & de Polavieja (in prep)

Subjetive opinion on videos obeys Bayesian rules

$$P_x = \left(1 + \frac{1 + as^{-(n_x - kn_y)}}{1 + as^{-(n_y - kn_x)}}\right)^{-1}$$

Theory of decision-making in groups



Collective behavior in zebrafish

Collective behavior in humans