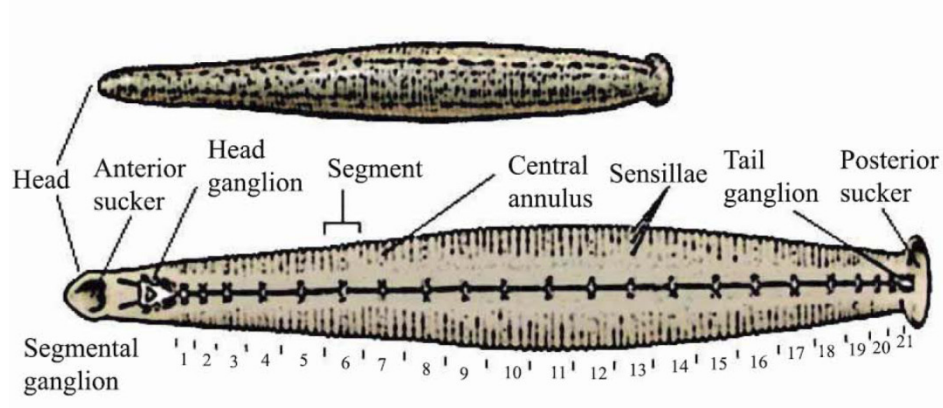
Data Analysis

Analysis of real neuronal data

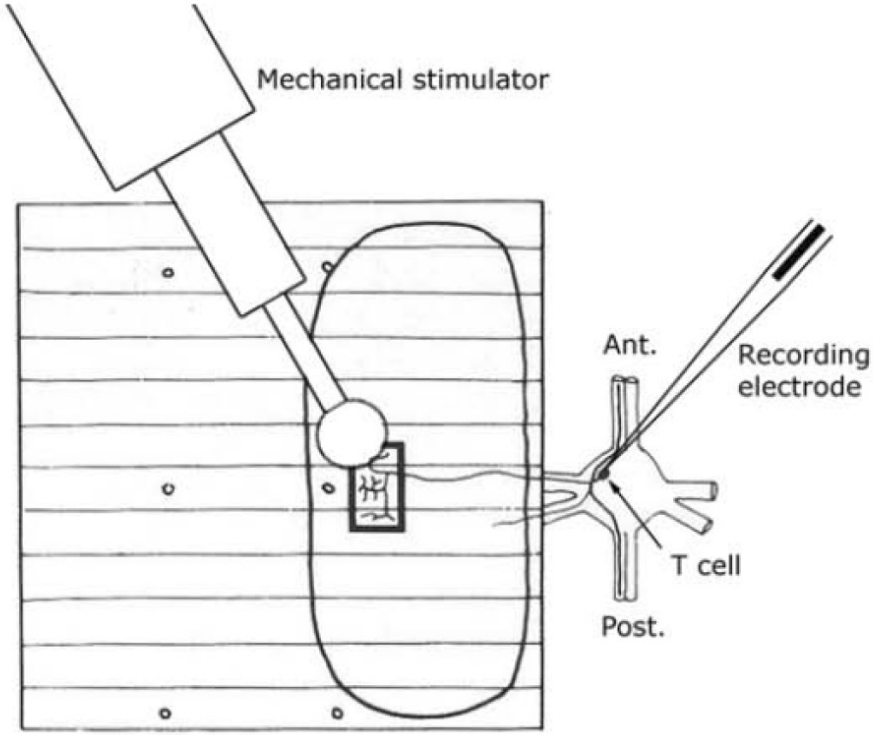
Finding spikes in a intracellular recording

Its nervous system:

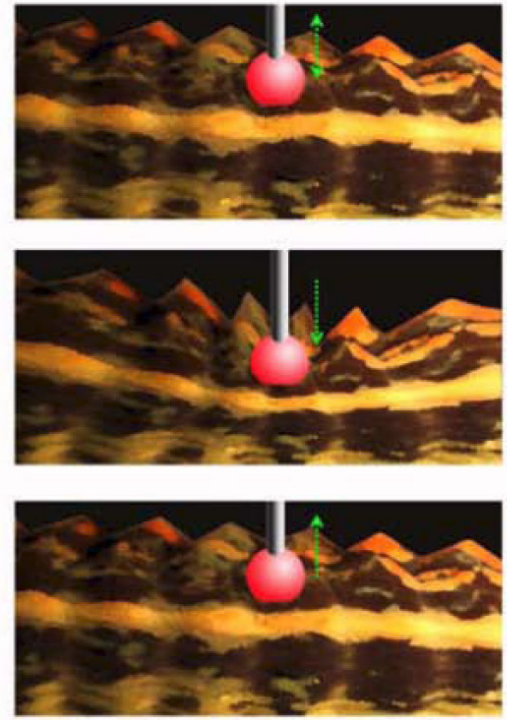


(a) Segmental body of the leech.

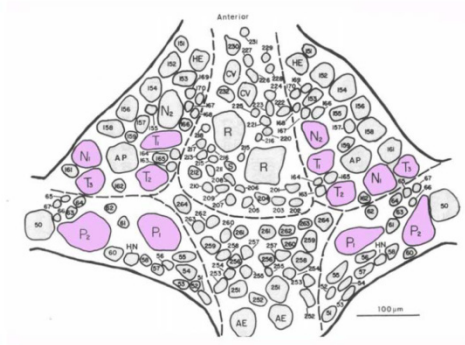
The experiment:



(a) Experimental scheme.



(b) Mechanical Stimulation.



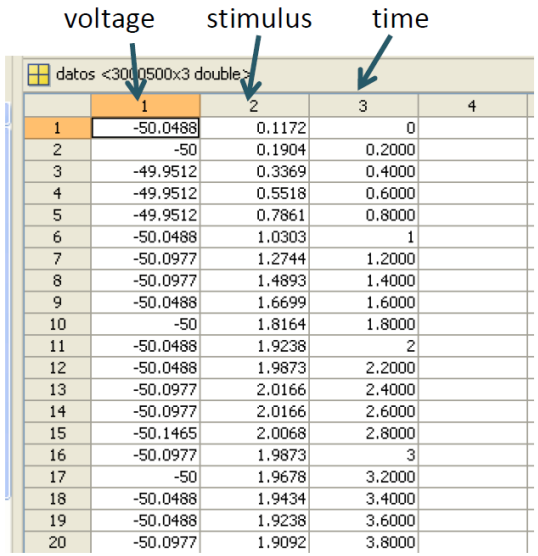
(a) Ventral side of leech ganglion.

Analysis

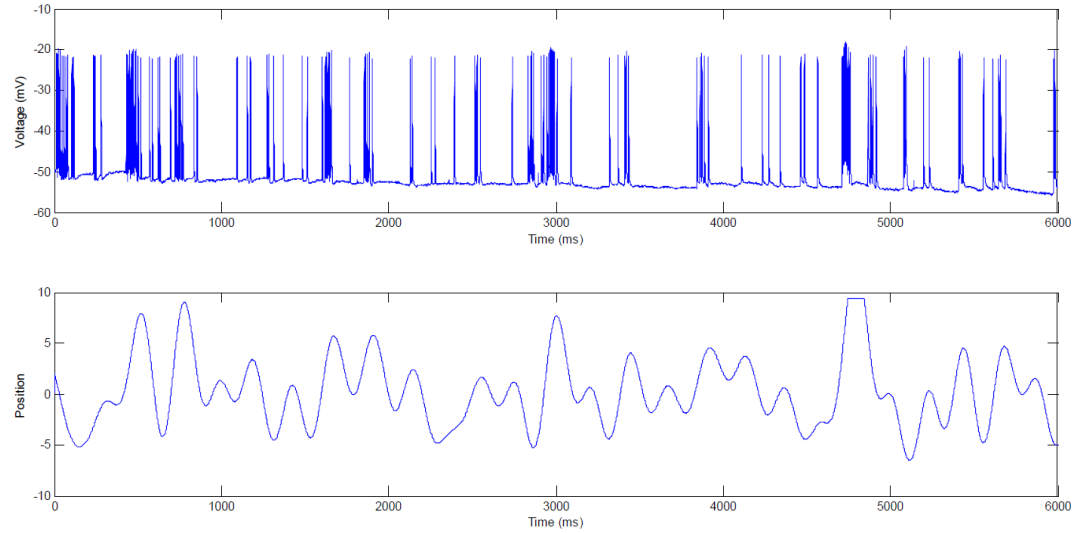
1) Load data:

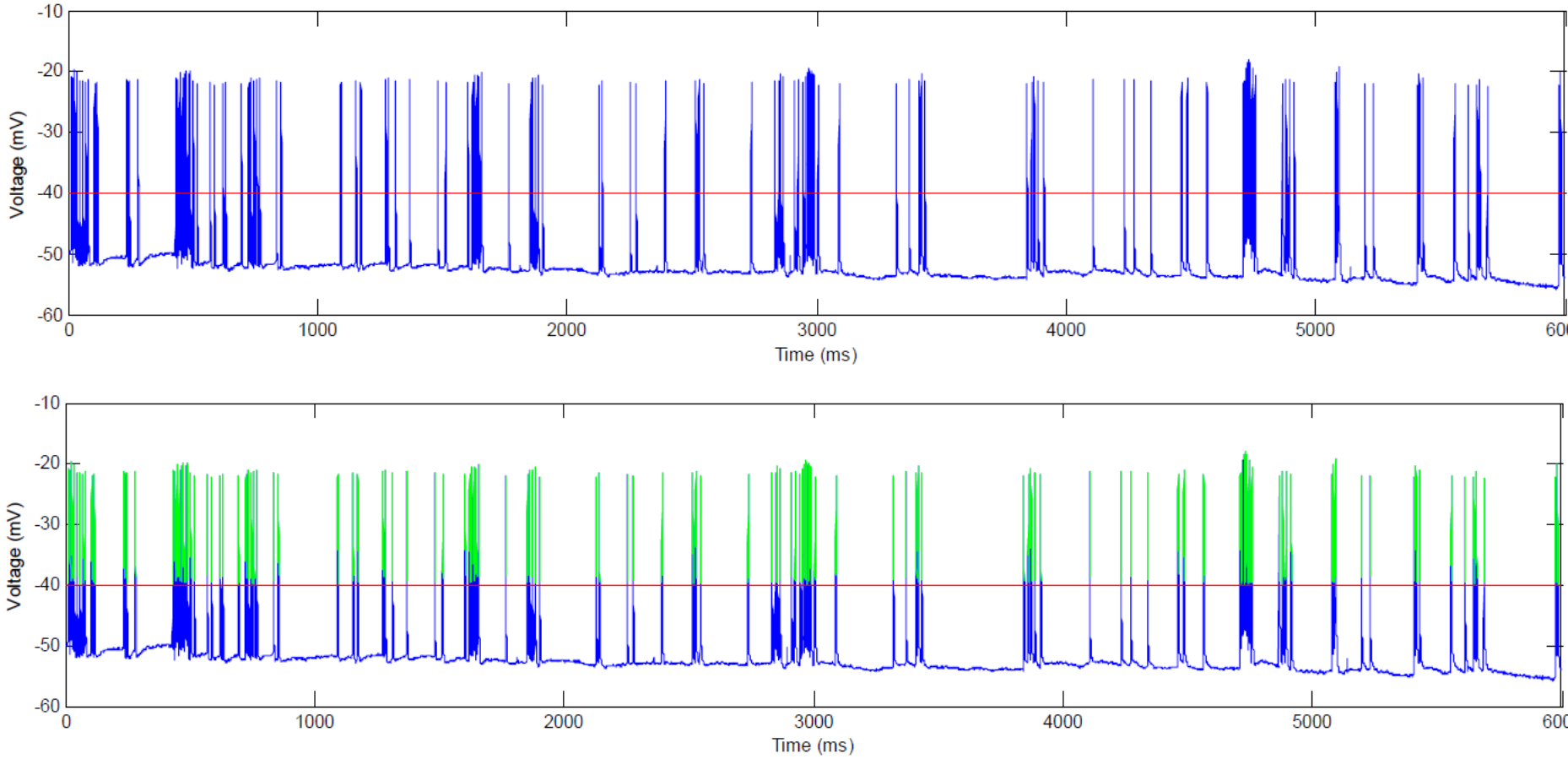
```
load('datos_MAAN.mat')
```

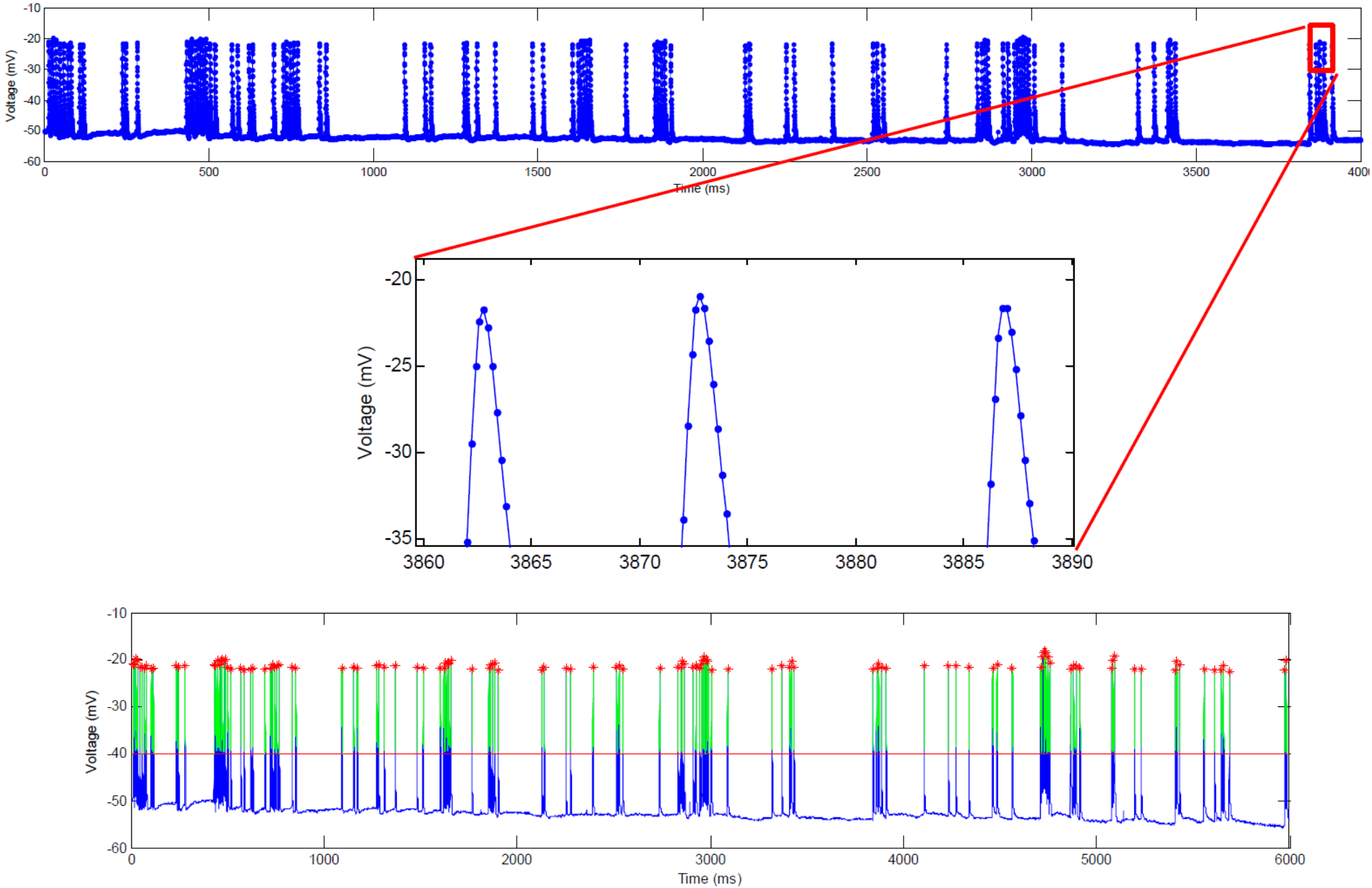
You will find 3 columns:



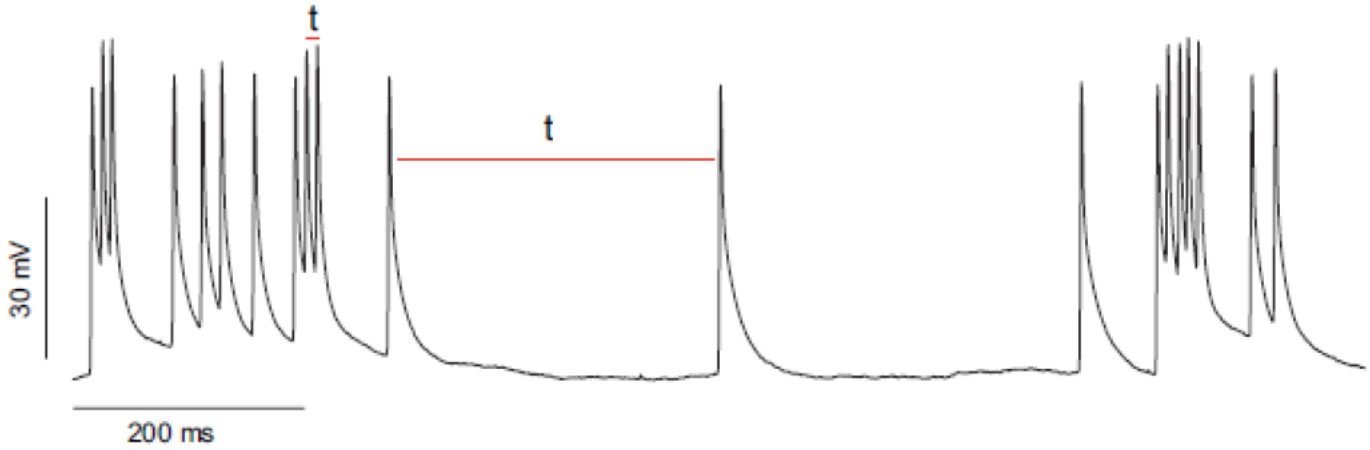
	1	2	3	4
1	-50.0488	0.1172	0	
2	-50	0.1904	0.2000	
3	-49.9512	0.3369	0.4000	
4	-49.9512	0.5518	0.6000	
5	-49.9512	0.7861	0.8000	
6	-50.0488	1.0303	1	
7	-50.0977	1.2744	1.2000	
8	-50.0977	1.4893	1.4000	
9	-50.0488	1.6699	1.6000	
10	-50	1.8164	1.8000	
11	-50.0488	1.9238	2	
12	-50.0488	1.9873	2.2000	
13	-50.0977	2.0166	2.4000	
14	-50.0977	2.0166	2.6000	
15	-50.1465	2.0068	2.8000	
16	-50.0977	1.9873	3	
17	-50	1.9678	3.2000	
18	-50.0488	1.9434	3.4000	
19	-50.0488	1.9238	3.6000	
20	-50.0977	1.9092	3.8000	

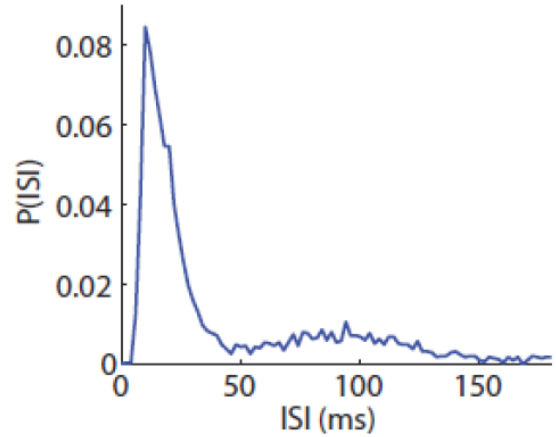


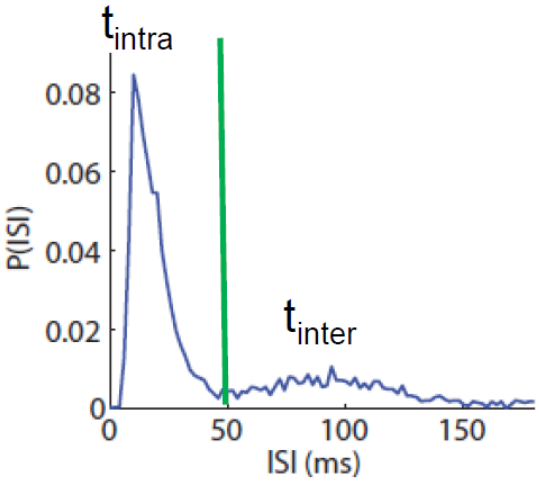

-10
-20
-30
-40
-50
-60
Voltage (mV)
0
1000
2000
3000
4000
5000
6000
Time (ms)
-10
-20
-30
-40
-50
-60
Voltage (mV)
0
1000
2000
3000
4000
5000
6000
Time (ms)

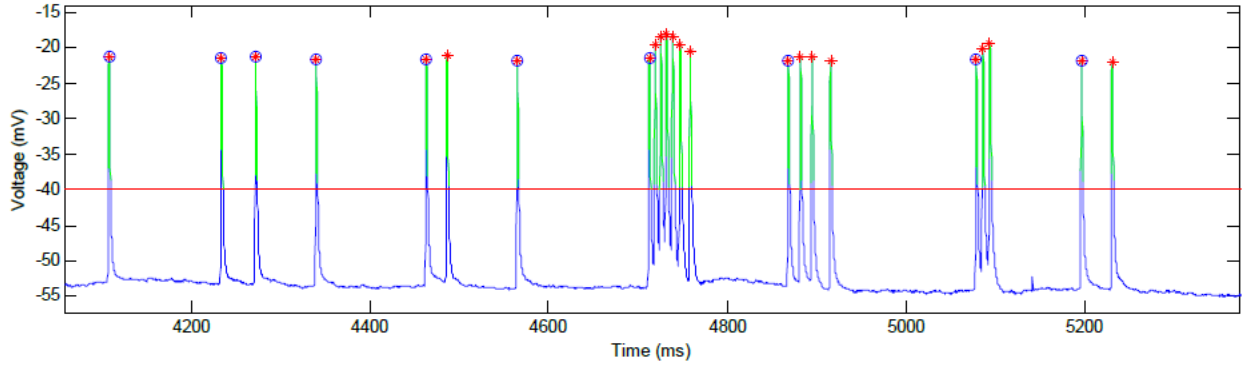

Voltage (mV)
-10
-20
-30
-40
-50
-60
0
500
1000
1500
2000
2500
3000
3500
4000
Time (ms)
Voltage (mV)
-20
-25
-30
-35
3860
3865
3870
3875
3880
3885
3890
Voltage (mV)
-10
-20
-30
-40
-50
-60
0
1000
2000
3000
4000
5000
6000
Time (ms)

Calculate ISI (Interspike intervals) and create a vector with their values (in ms).





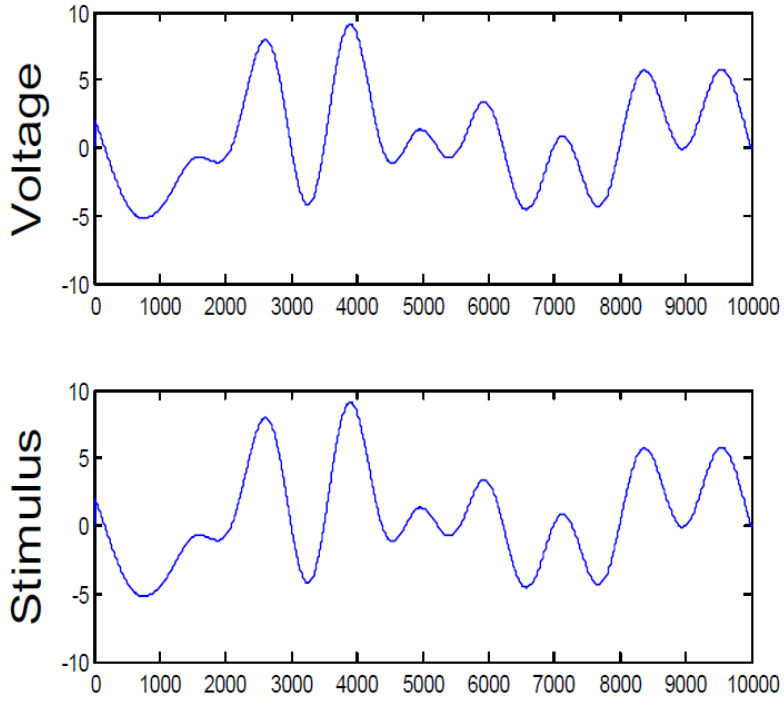




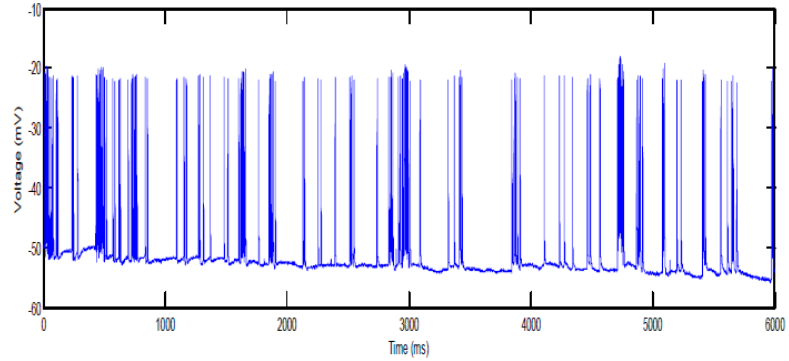
When time between a spike and the previous one is larger than the temporal threshold, we can identify this spike as the first of one burst.

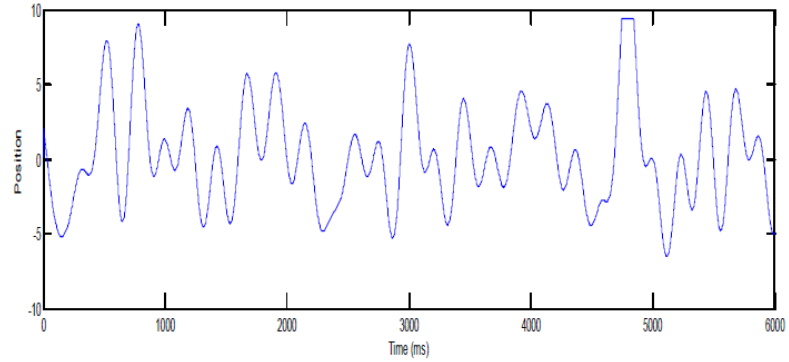
Finding the neuronal code

Simple code: Voltage proportional to stimulus



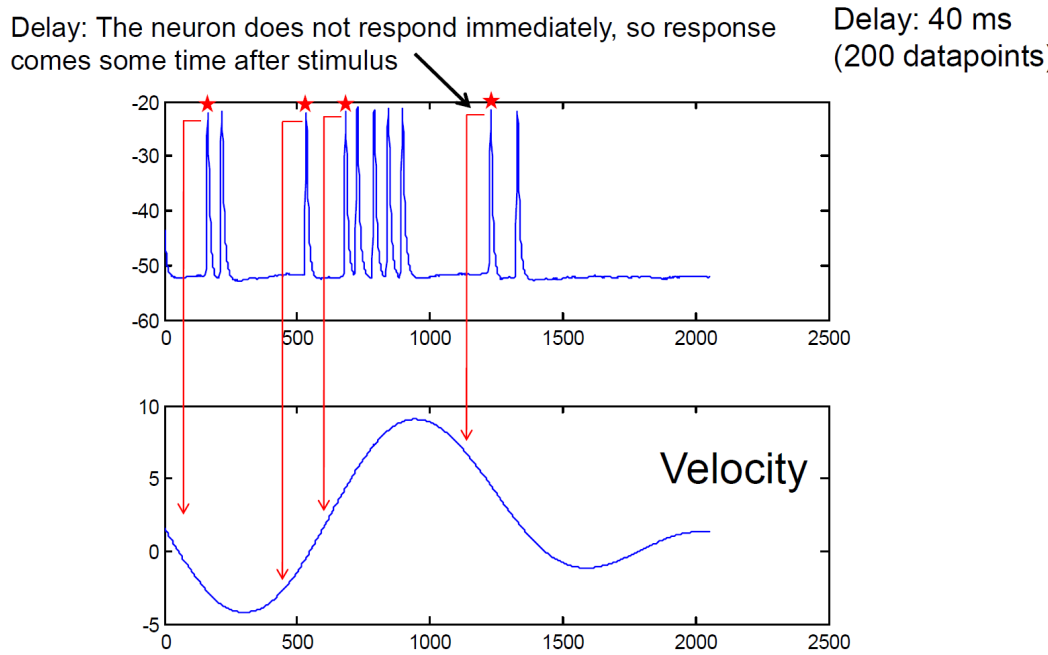
But we have spikes!

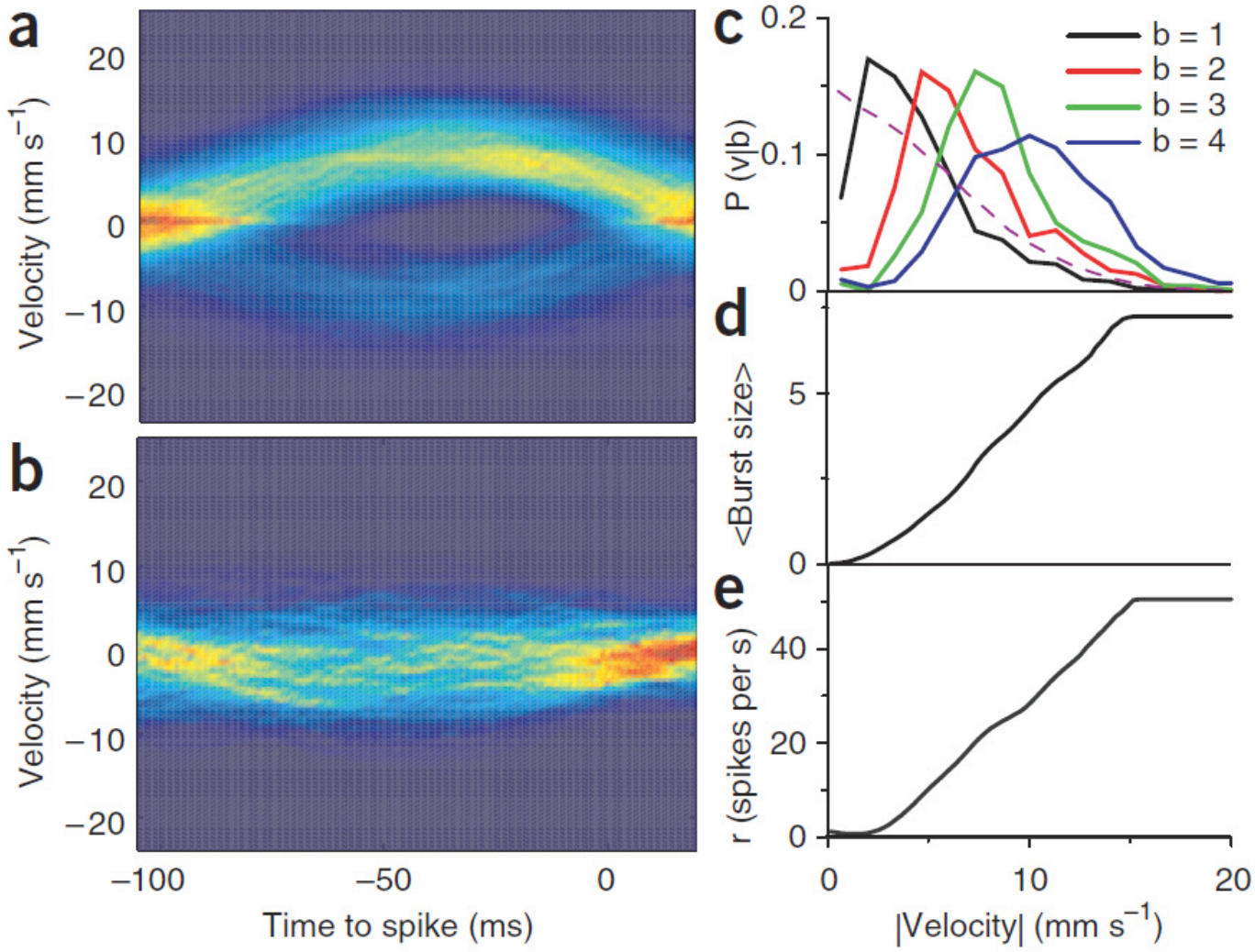


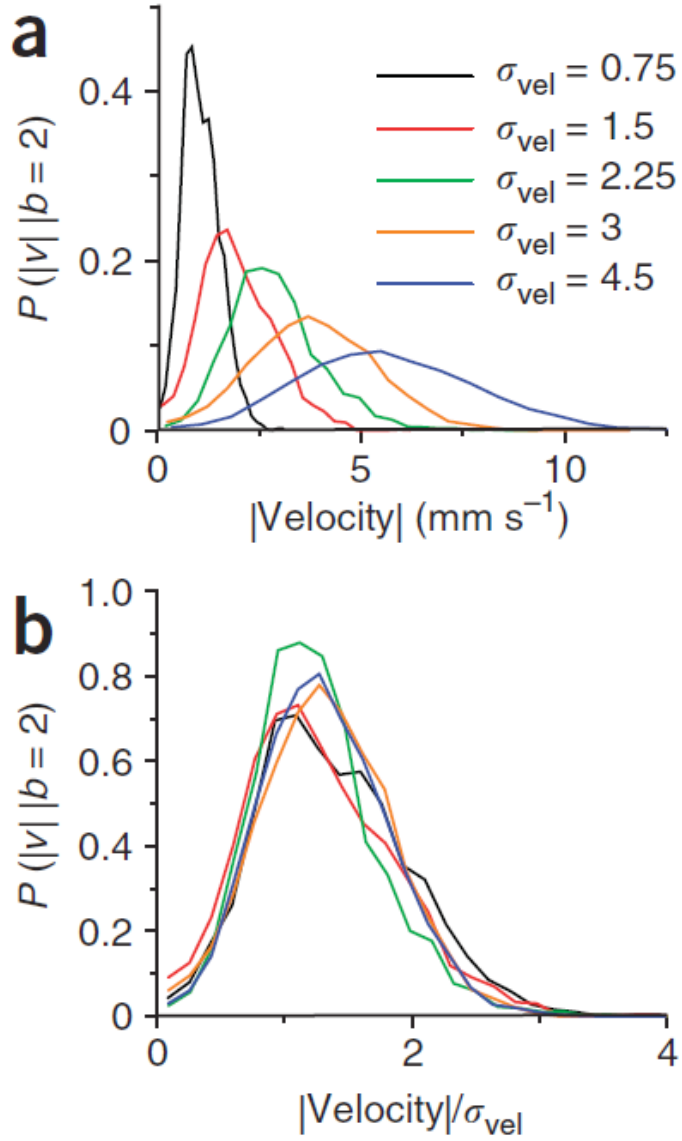


Possible codes with action potentials

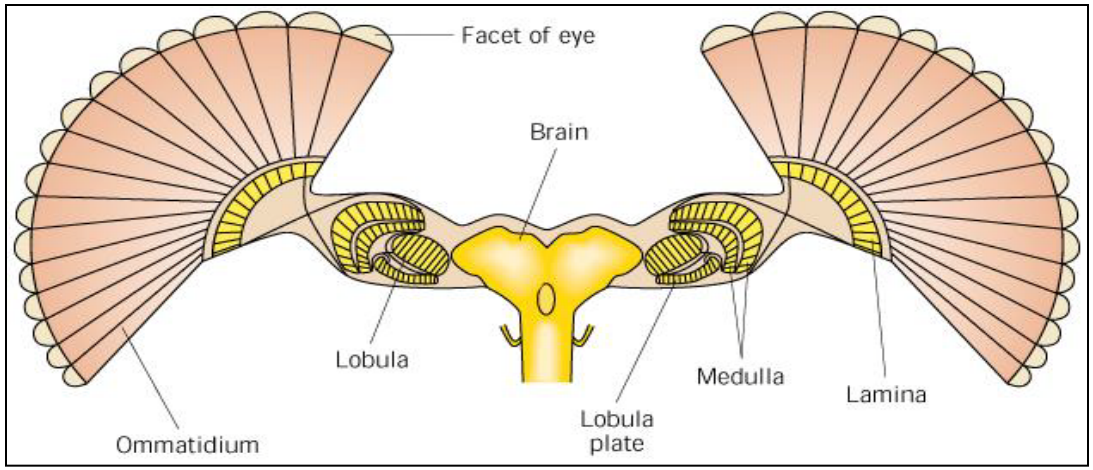
- Spike rate
- Temporal coding
- Burst size

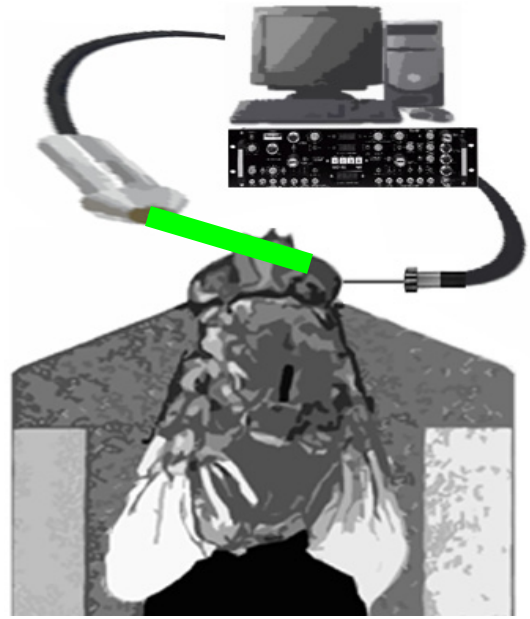


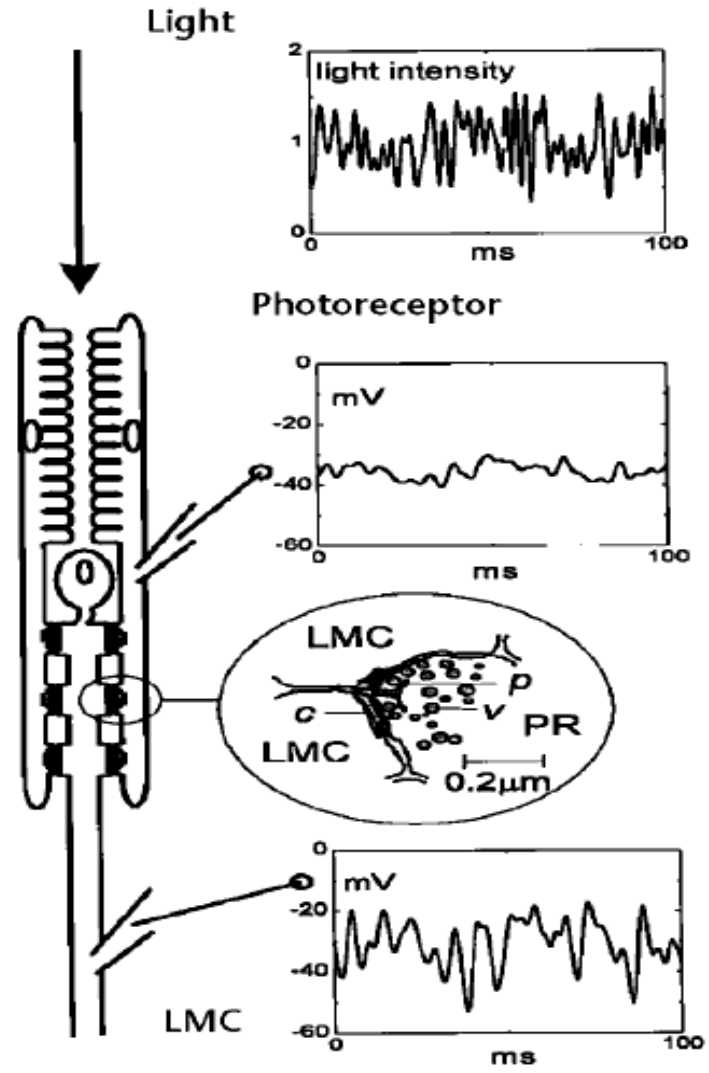

a
b
c
d
e
Velocity (mm s^{-1})
20
10
0
−10
−20
−100
−50
0
Time to spike (ms)
0.2
0.1
P (v|b)
b = 1
b = 2
b = 3
b = 4
<Burst size>
5
r (spikes per s)
40
20
10
|Velocity| (mm s^{-1})


a
0.4
0.2
0
P (|v| |b = 2)
σvel = 0.75
σvel = 1.5
σvel = 2.25
σvel = 3
σvel = 4.5
0
5
10
|Velocity| (mm s−1)
b
1.0
0.8
0.6
0.4
0.2
0
P (|v| |b = 2)
0
2
4
|Velocity|/σvel

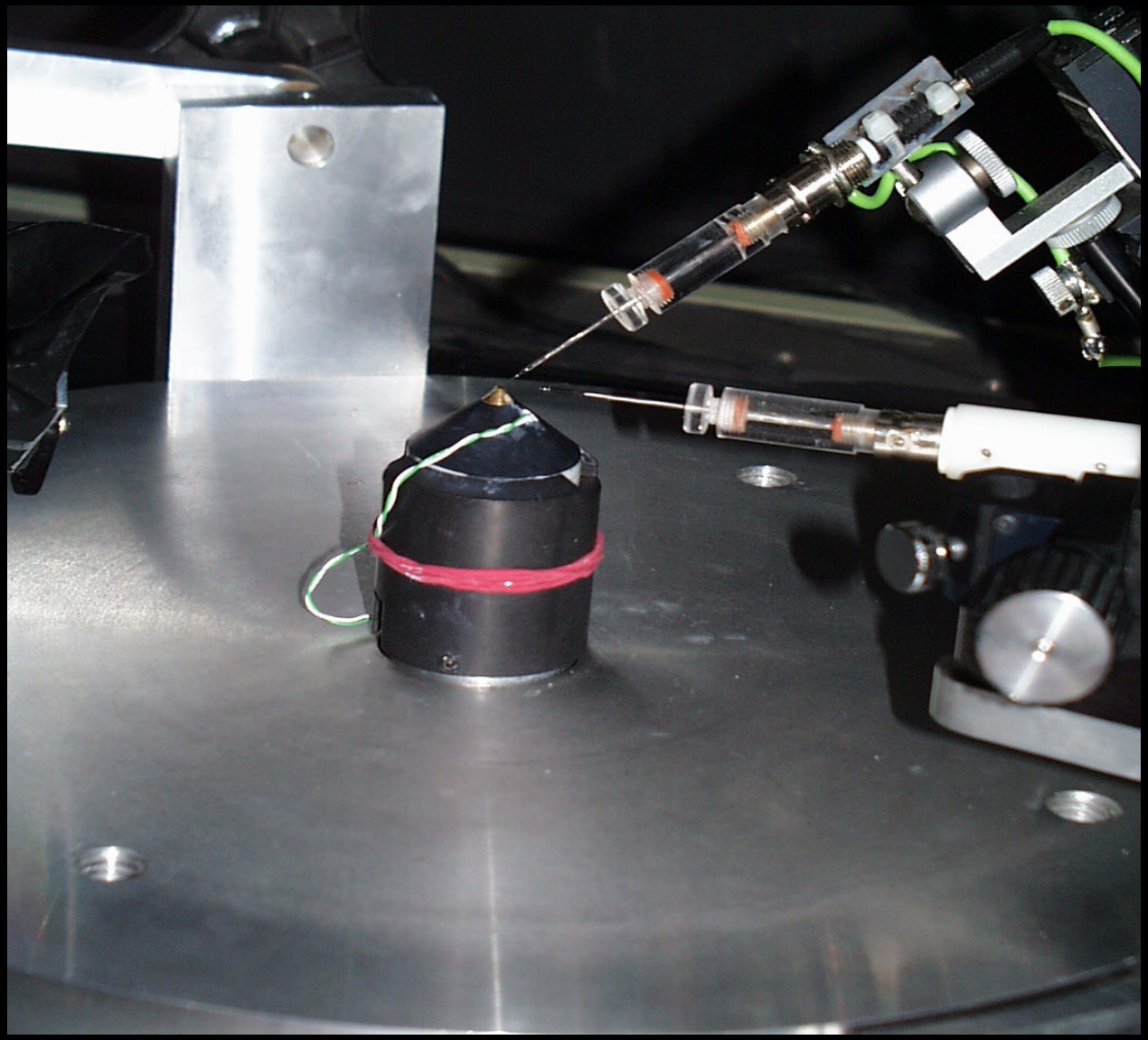
2. Recording from the visual system of a fly

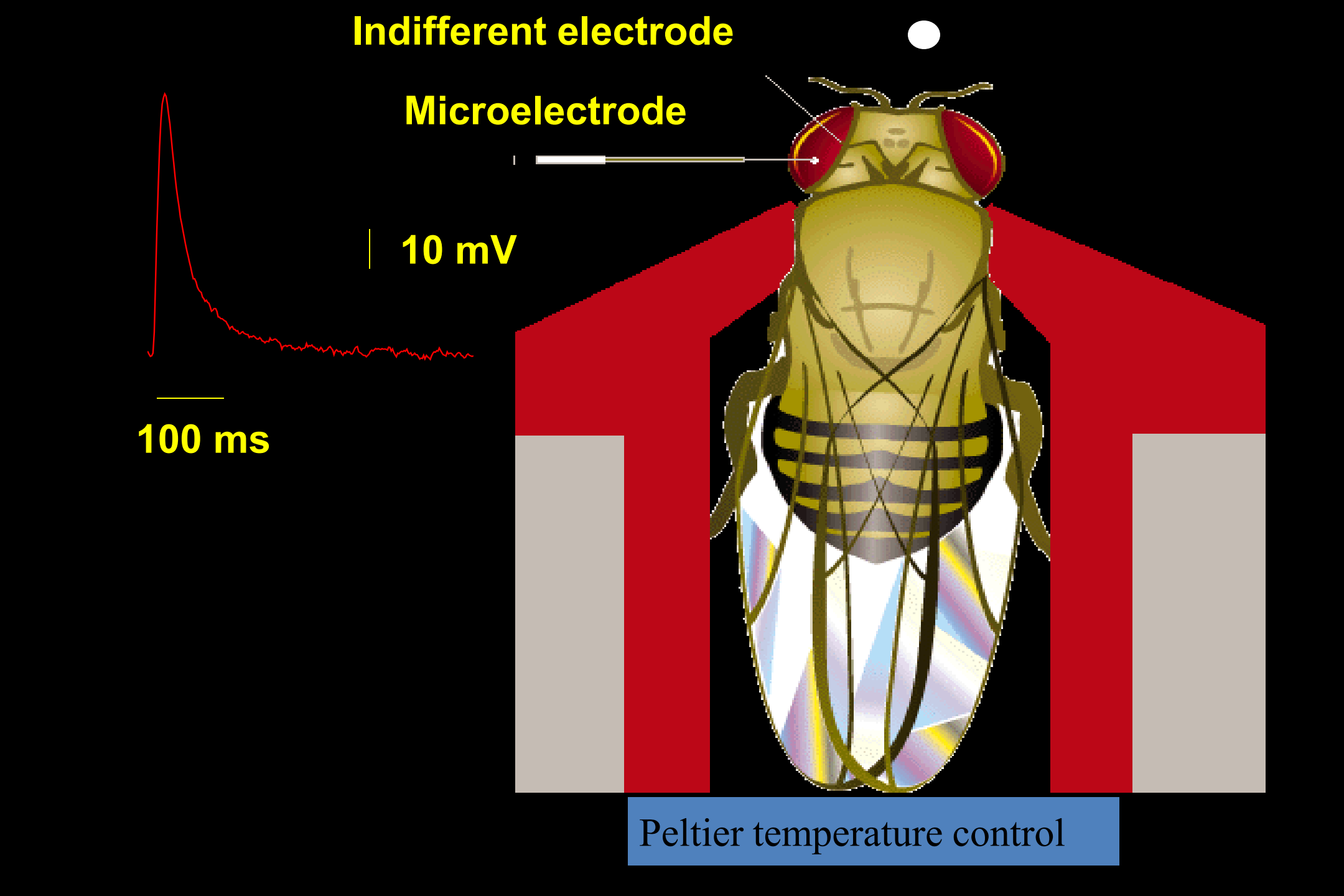






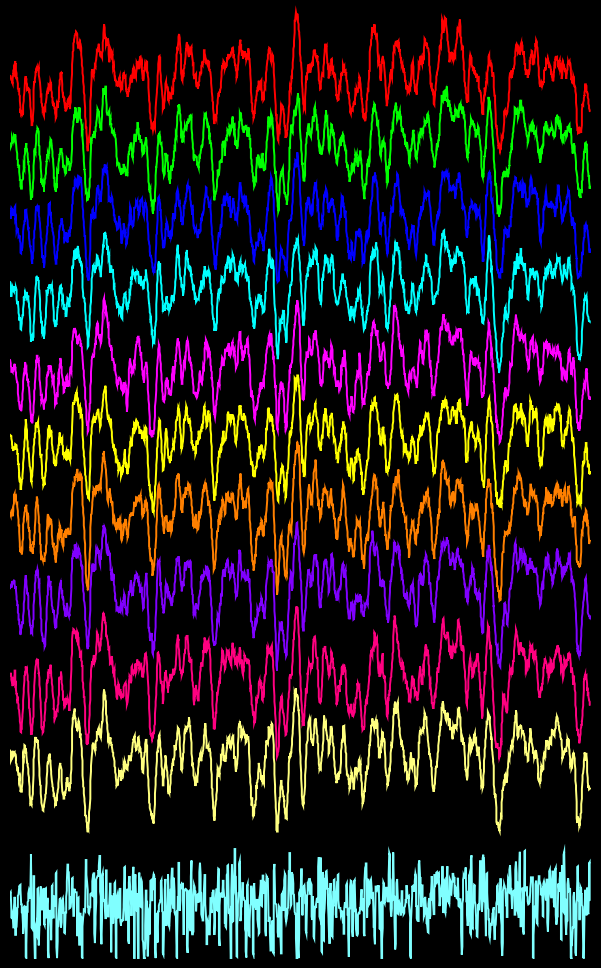
At the lab:




Indifferent electrode
Microelectrode
10 mV
100 ms
Peltier temperature control

Repeating WN stimulation

Voltage responses
Ri(t)

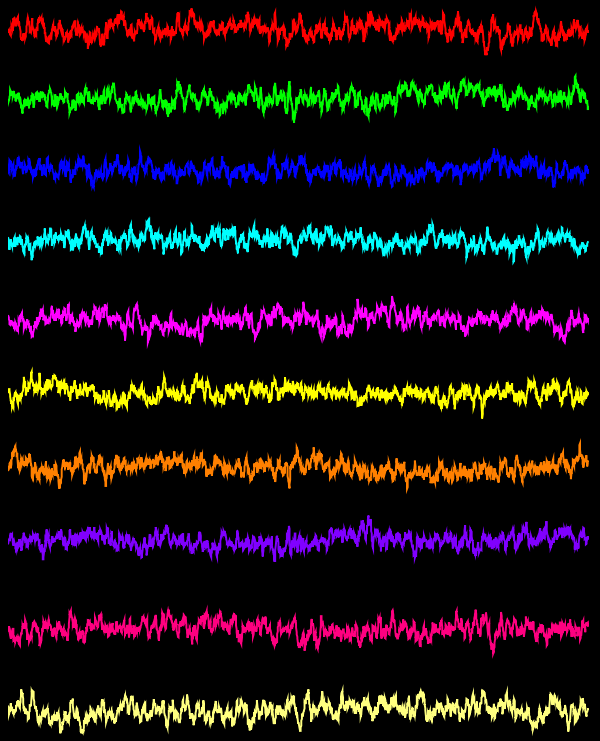


Stimulus

10 mV
1000 ms

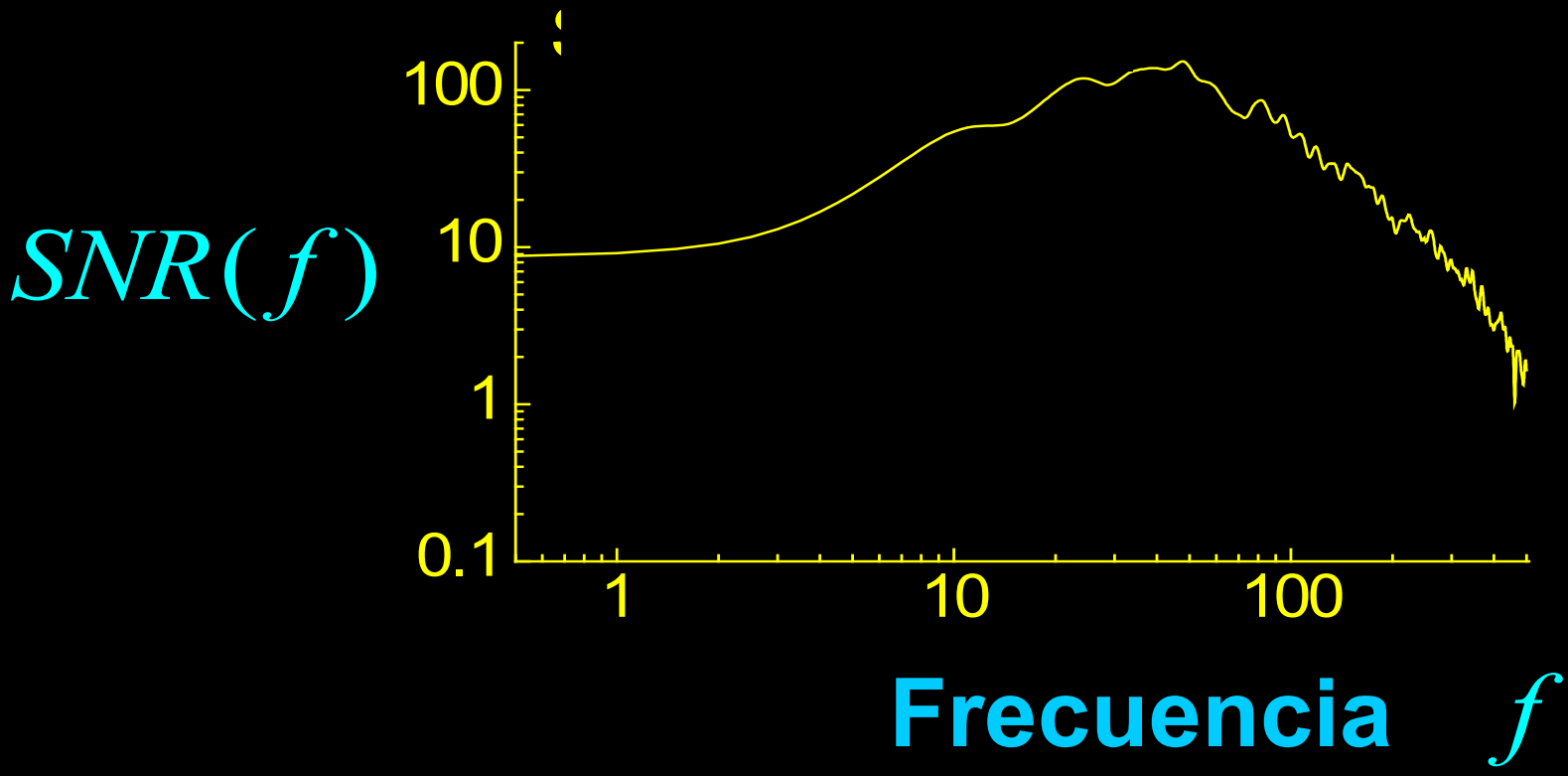
Average response
Signal, S(t)

Voltage Noise
Ni(t)=Ri(t)-S(t)

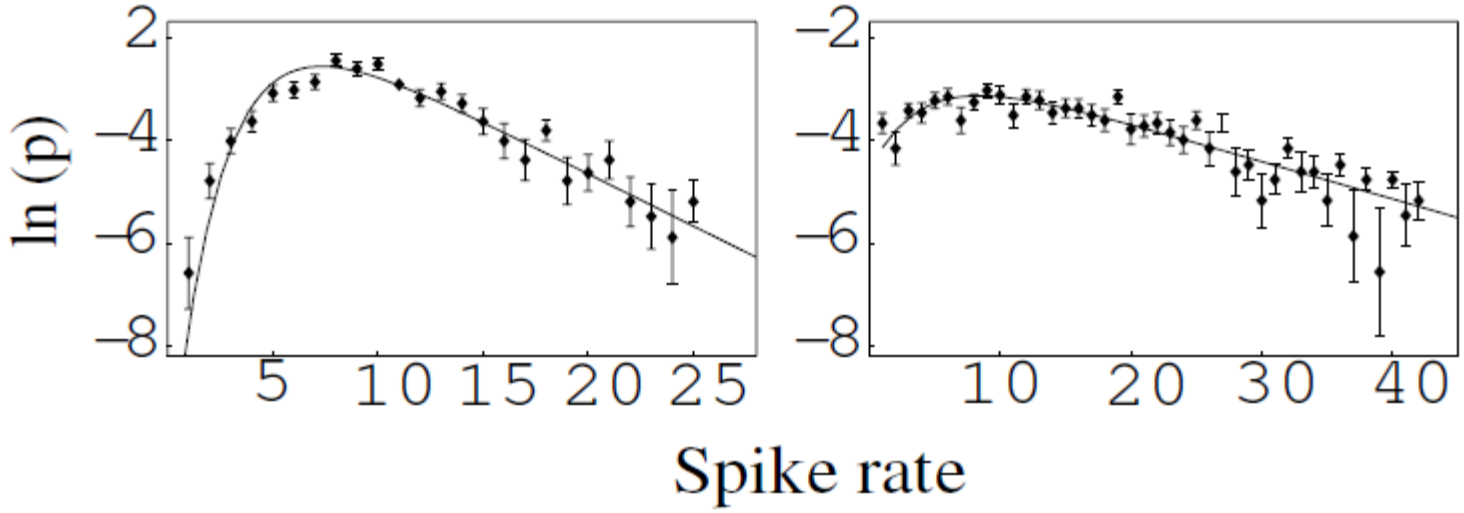


Juusola & de Polavieja (2003)

$$SNR(f) = \frac{S(f)}{N(f)} = \frac{FT[S(t)]}{FT[N(t)]}$$



3. Testing hypothesis about neuronal firing



HYPOTHESIS:
it is important for the nervous system to have high information rates at a low cost

$$\max_{p(s_i)} \left(I - \beta \left(\sum_j p(s_j)\,\varepsilon_j - E \right) - \lambda \left(\sum_j p(s_j) - 1 \right) \right)$$

$$I(C;S) = \sum_{i,i} p(c_i, s_j) \log \left(\frac{p(c_i, s_j)}{p(c_i) p(s_j)} \right)$$

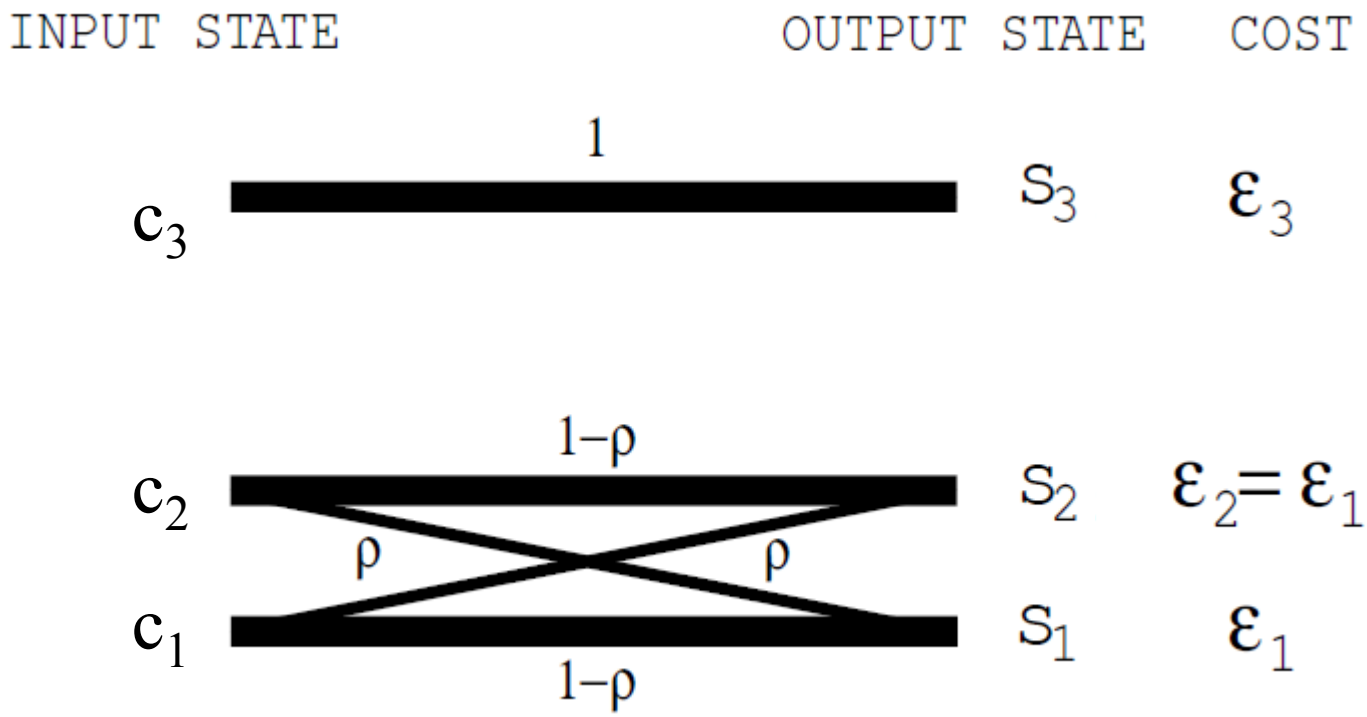
$$I = H(S) - H(S|C)$$

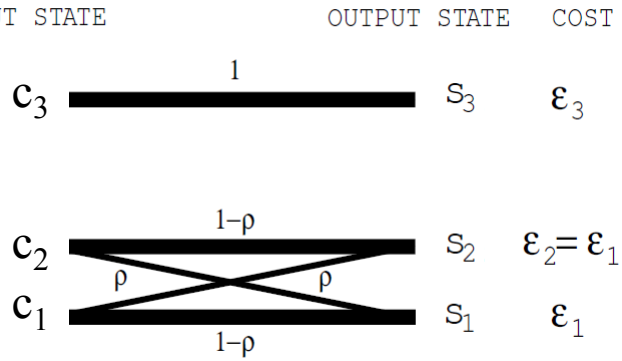
$$H(S) = -\sum_j p(s_j) \log p(s_j)$$

$$H(S|C) = -\sum_j p(s_j) \sum_k Q_{kj} \log P_{jk}$$

$$Q_{kj} = p(c_k|s_j)$$

$$P_{jk} = p(s_j|c_k) \qquad P_{jk} = (p(s_j) Q_{kj}) / (\textstyle\sum_i p(s_i)\, Q_{ki})$$


INPUT STATE
OUTPUT STATE
COST
1
c_3
s_3
ε_3
$1-\rho$
c_2
s_2
$\varepsilon_2 = \varepsilon_1$
ρ
ρ
c_1
s_1
ε_1
$1-\rho$



$$\epsilon_1 = \epsilon_2,\ \epsilon_3 > \epsilon_2$$

$$p(c_1|s_1) = p(c_2|s_2) = 1 - \rho$$

$$p(c_2|s_1) = p(c_1|s_2) = \rho \text{ and } p(c_3|s_3) = 1$$

$$H(S|C) = (p(s_1) + p(s_2))\,\xi \qquad \xi = -\rho \log \rho - (1-\rho)\log(1-\rho)$$

$$p(s_{1,2}) = p(m_{1,2}) = Z^{-1} \exp(-\beta\varepsilon_1 - \xi)$$

$$p(s_3) = p(m_3) = Z^{-1} \exp(-\beta\varepsilon_3)$$

Algorithm 1 Optimal signal usage with noise and cost constraints

Initialize the signal usage to a random vector $\mathbf{p}^1$.
for $t = 1,2,\ldots$ until convergence **do**

$$P^t_{jk} = \frac{p^t(s_j)\,Q_{kj}}{\sum_j p^t(s_j)\,Q_{kj}}, \tag{3}$$

$$p^{t+1}(s_j) = \frac{\exp -(\beta^t \varepsilon_j - \sum_k Q_{kj} \log P^t_{jk})}{\sum_i \exp -(\beta^t \varepsilon_i - \sum_k Q_{ki} \log P^t_{ik})}, \tag{4}$$

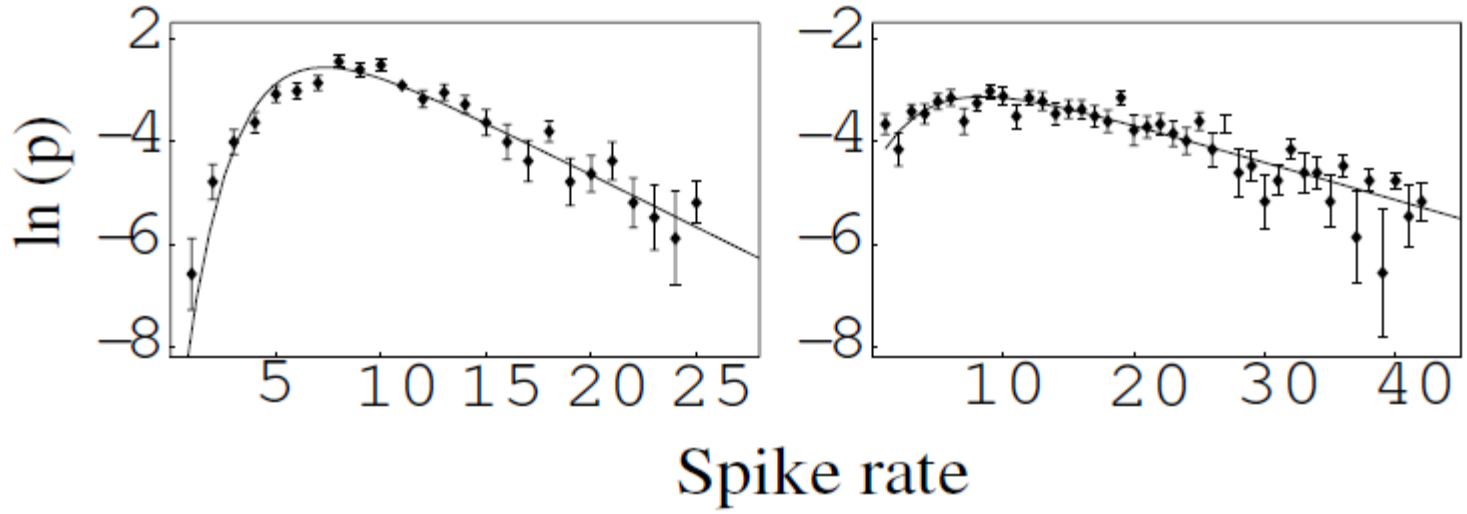
where β^t in eqn (4) has to be evaluated for each t from the cost constraint

$$\frac{\sum_j \varepsilon_j \exp -(\beta^t \varepsilon_j - \sum_k Q_{jk} \log P^t_{jk})}{\sum_j \exp -(\beta^t \varepsilon_j - \sum_k Q_{jk} \log P^t_{jk})} = E. \tag{5}$$

end for

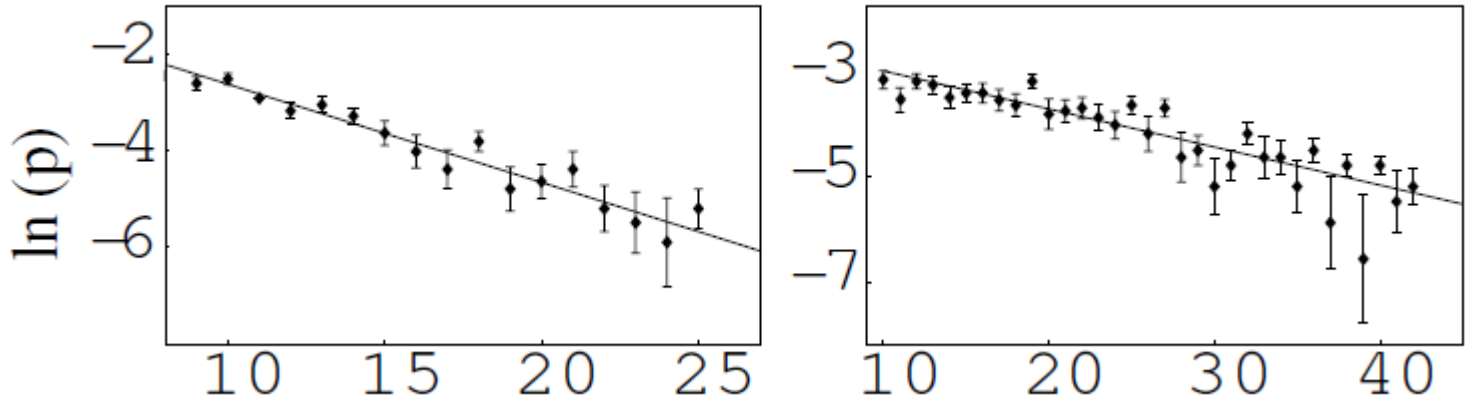
de Polavieja (2002)

Back to neurons

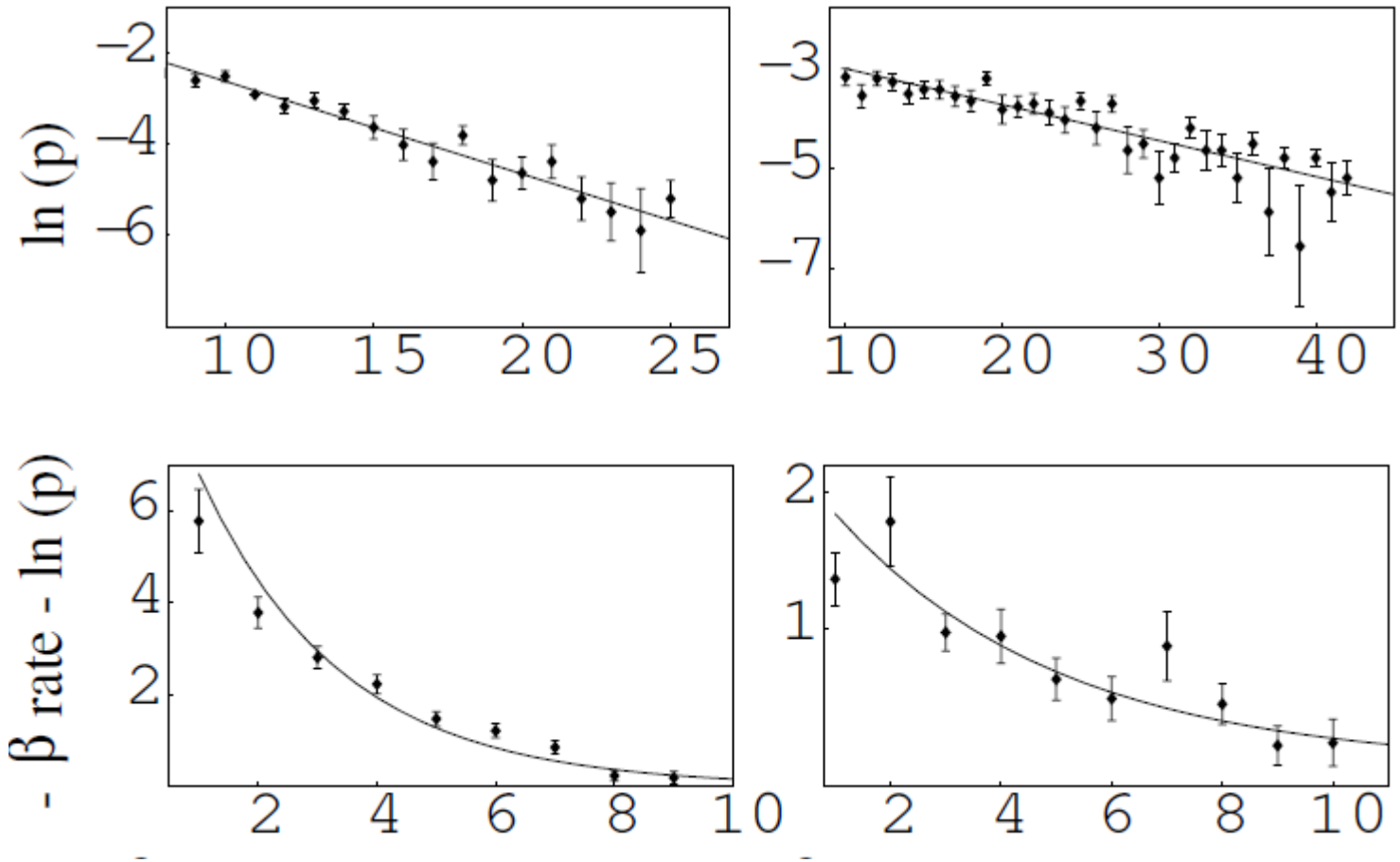


Assumptions

(1) Output states are firing rates
(2) The cost is linearly proportional to firing rate



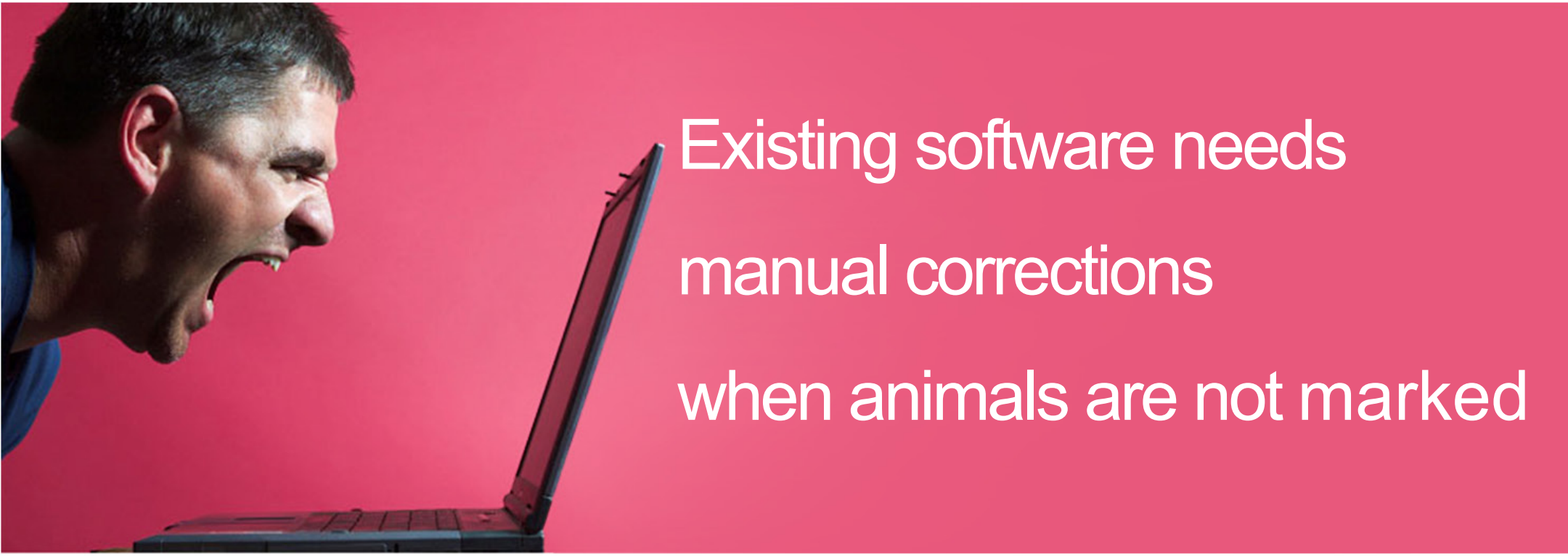
de Polavieja (2002)

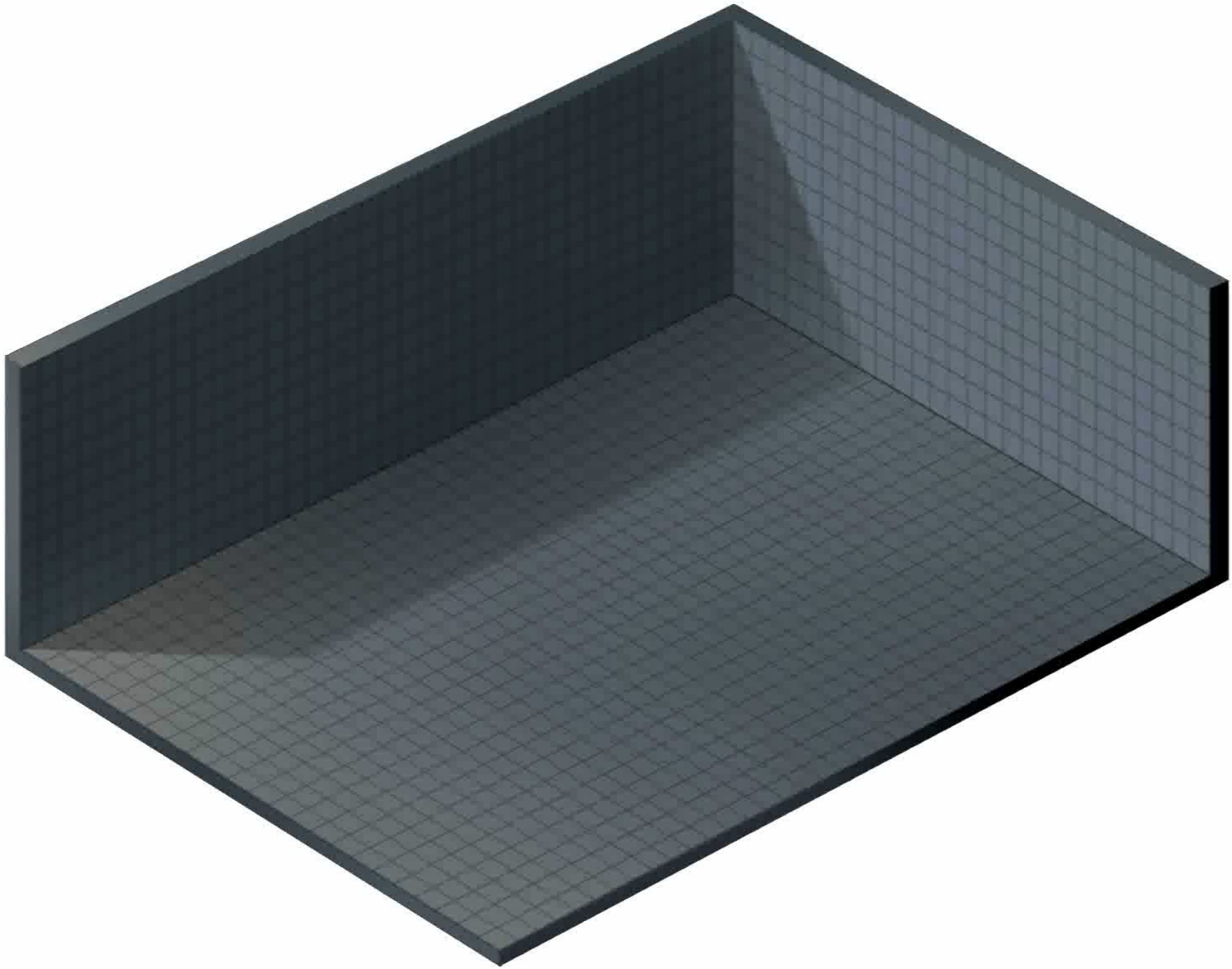


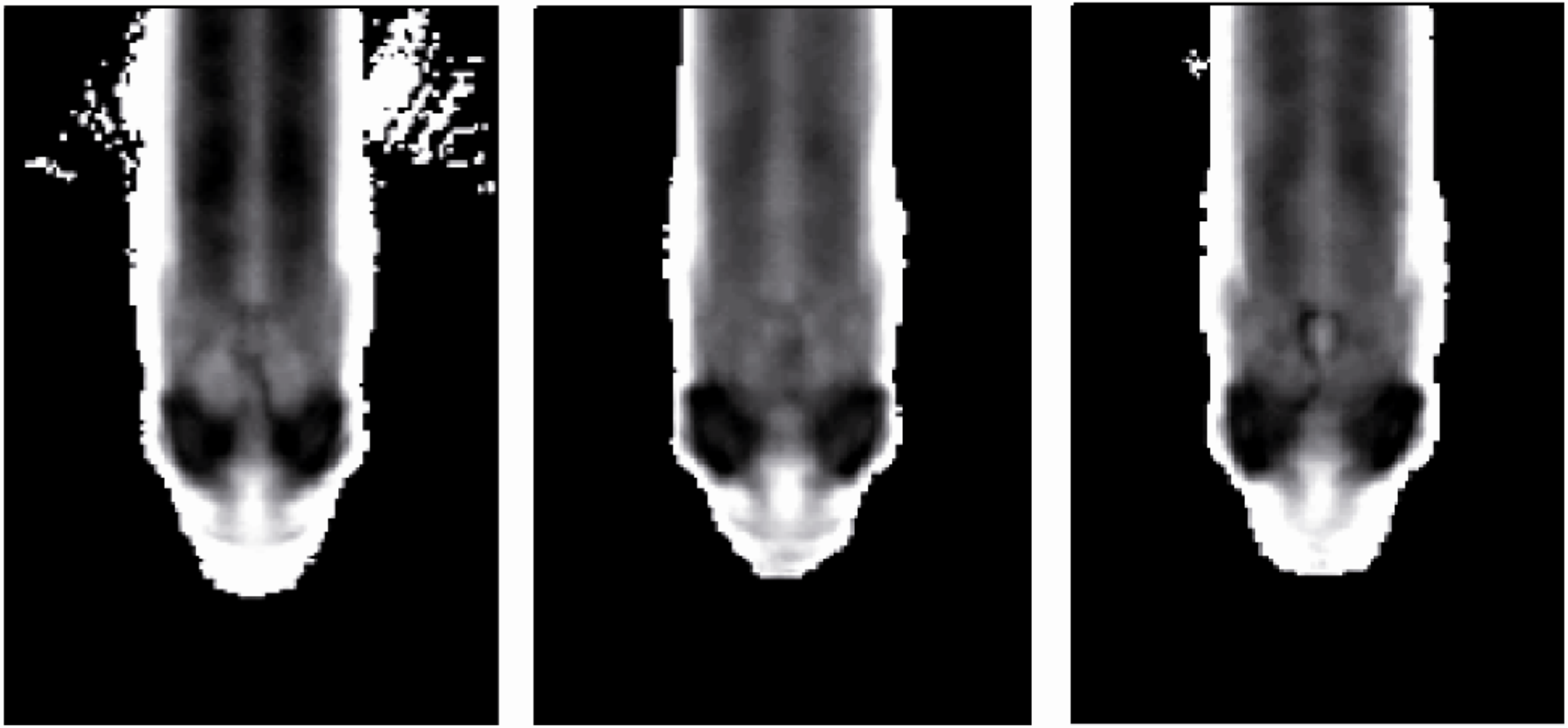
$$p(\text{rate}) \approx \text{Z}^{-1} \exp\left(-\beta \text{rate} - \exp\left(-\text{rate}/\alpha\right)\right)$$

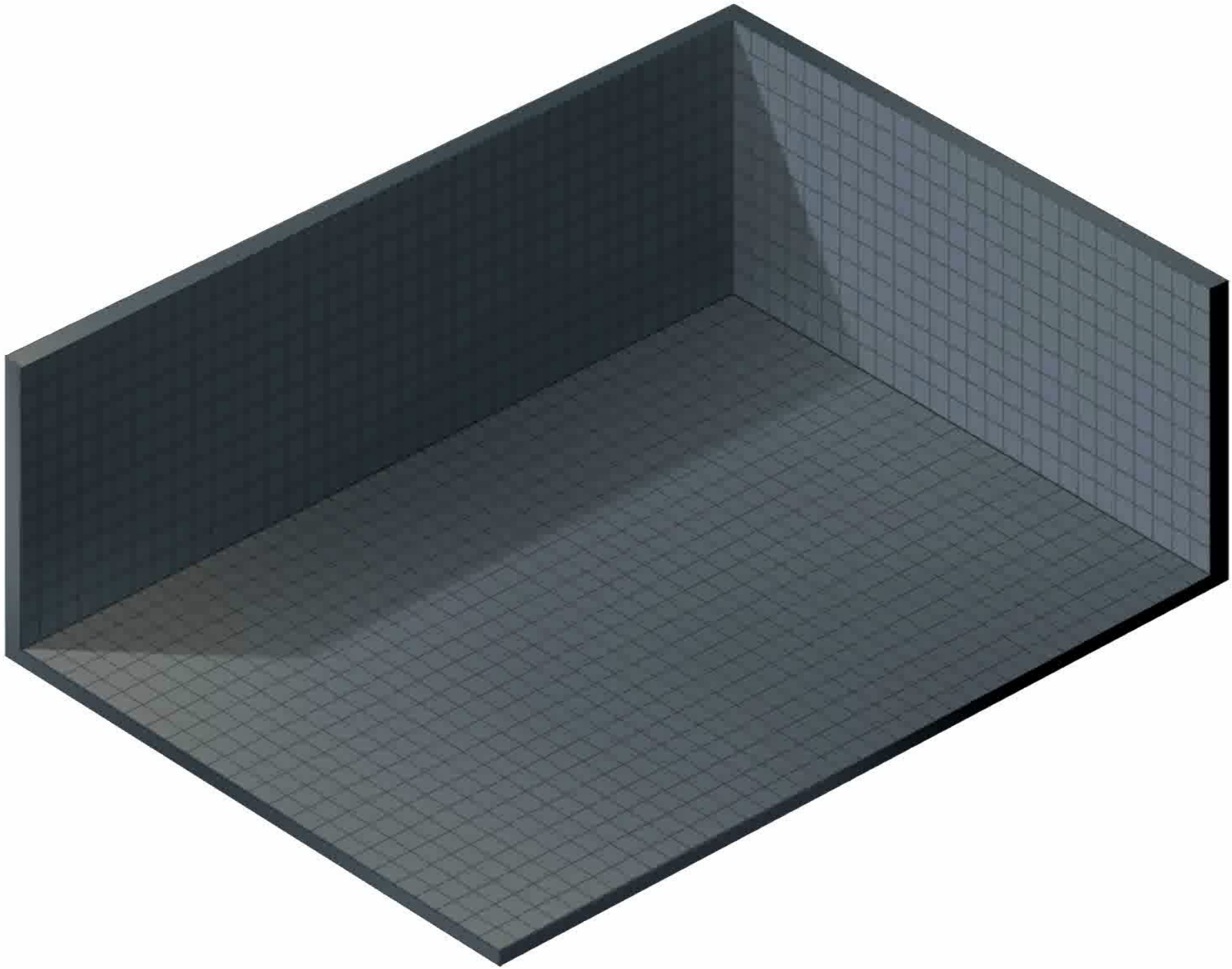
de Polavieja (2002)

3. Data adquisition in group behavior



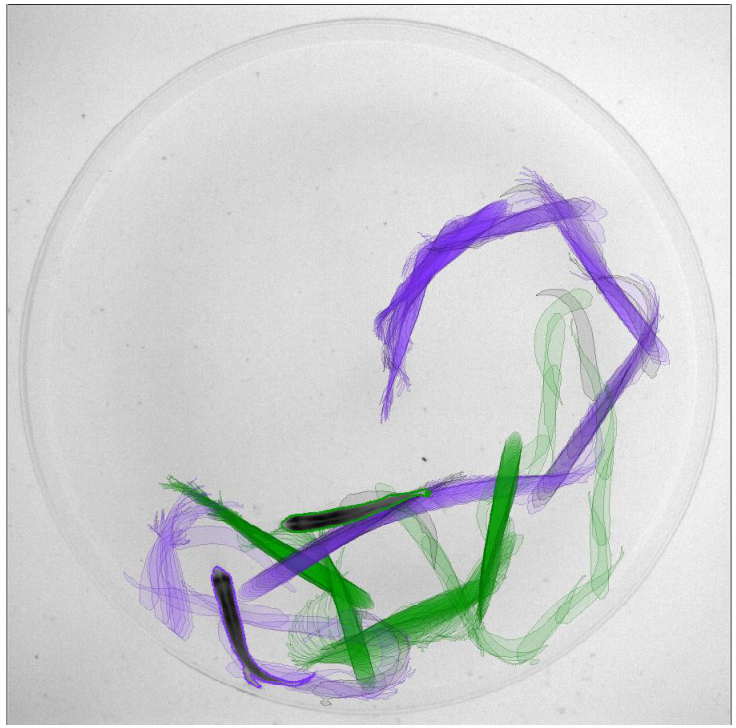




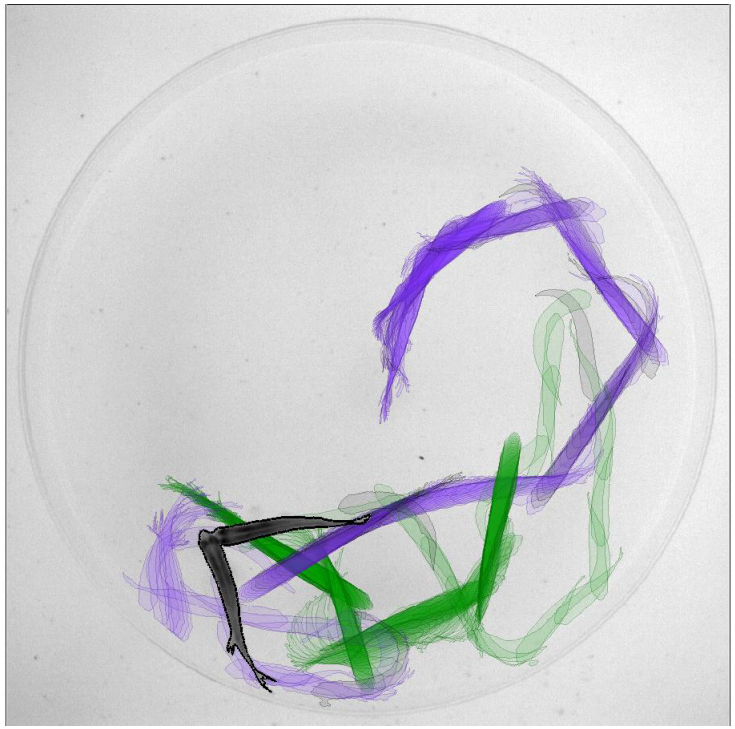


Tracking individuals in groups

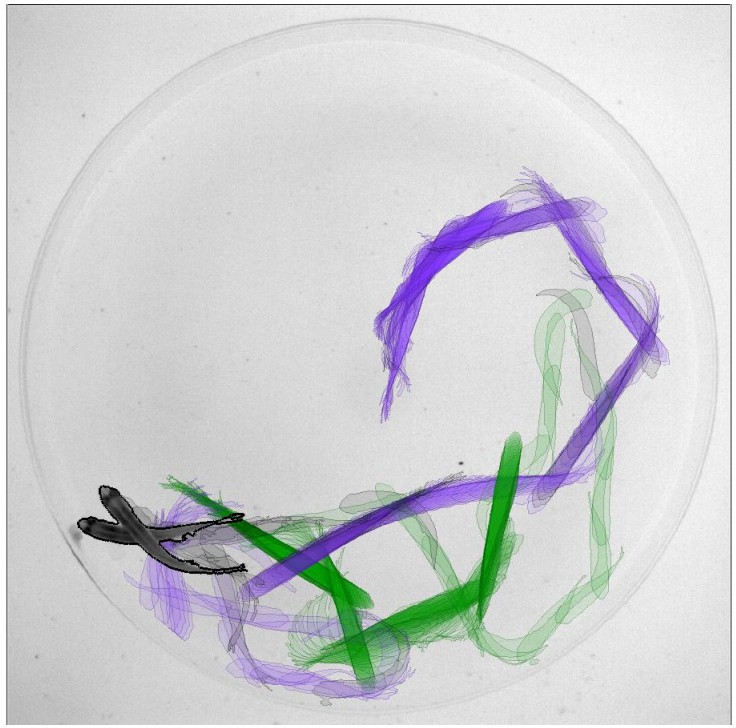
Tracking individuals in groups



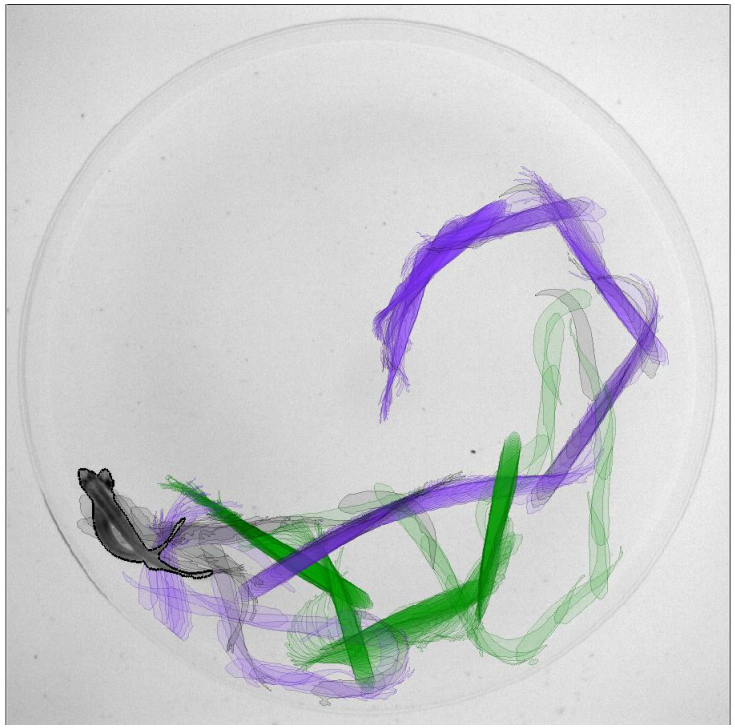
Tracking individuals in groups



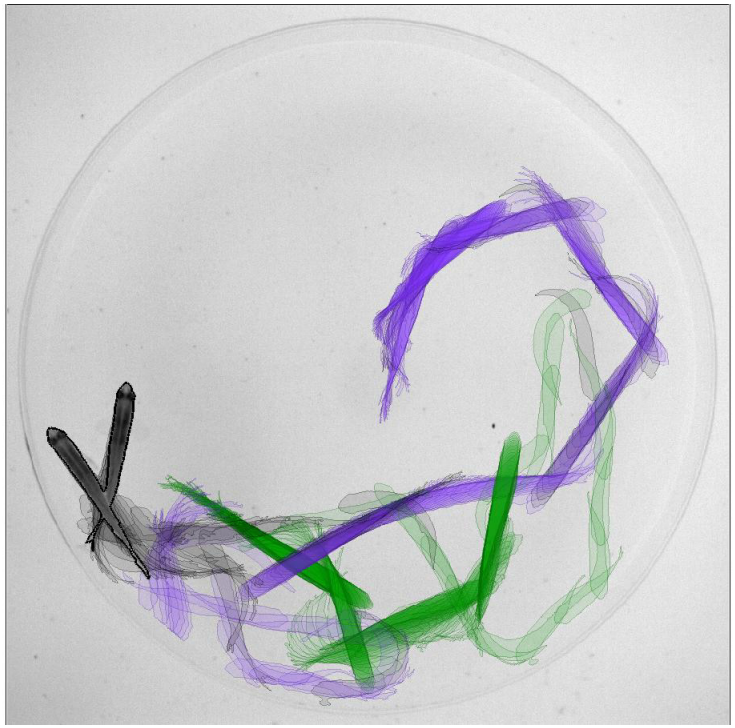
Tracking individuals in groups



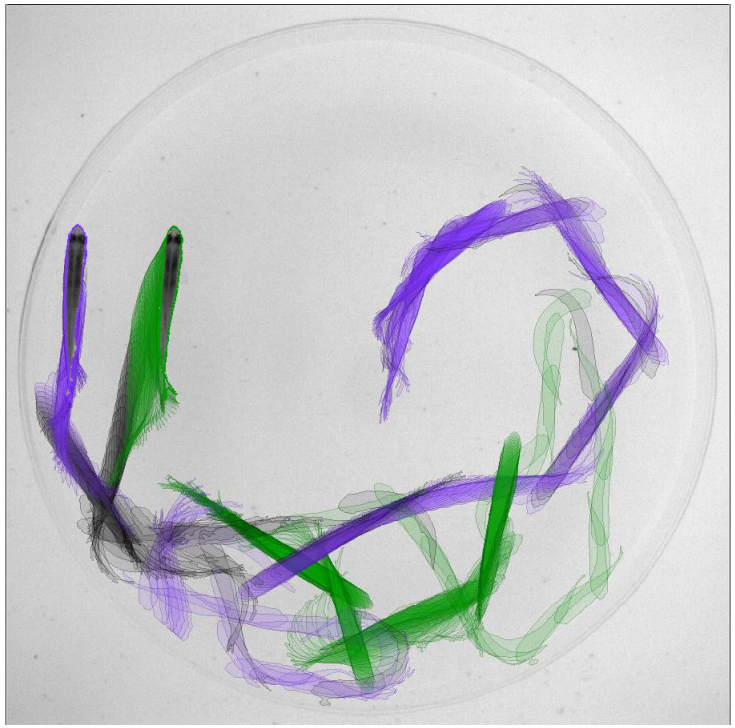
Tracking individuals in groups



Tracking individuals in groups



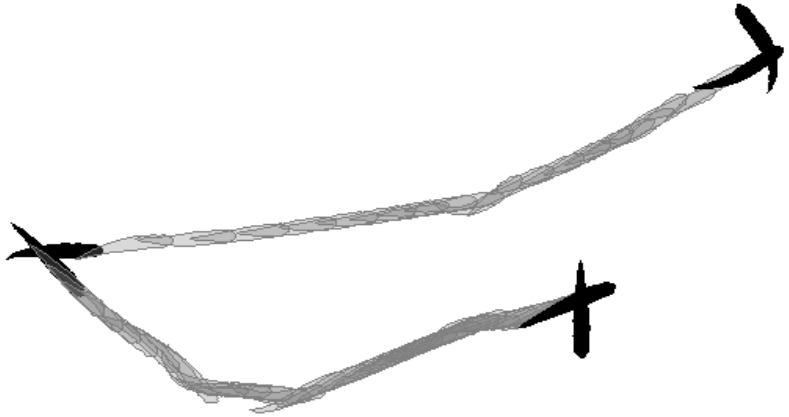
Tracking individuals in groups



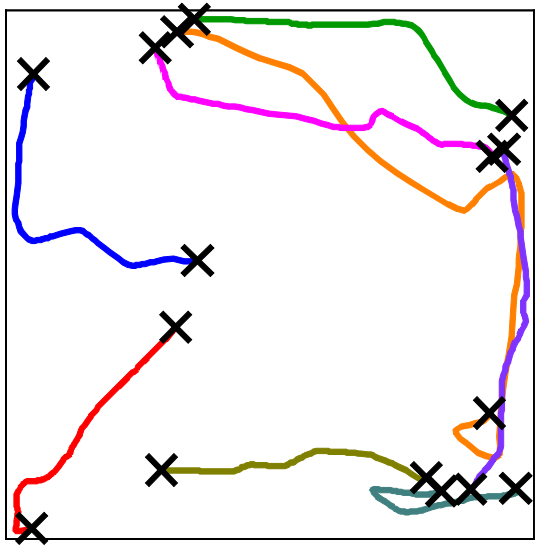

Raw video

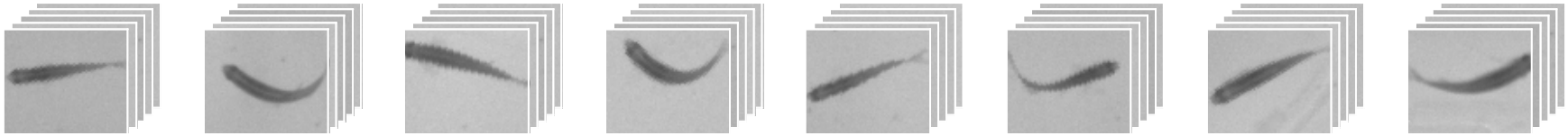
How does the automatic tracking work? Step 1: finding references

A. Find individual segments



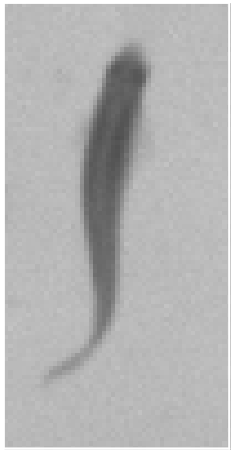
B. Find references (longest segments)

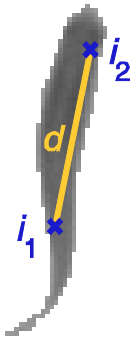


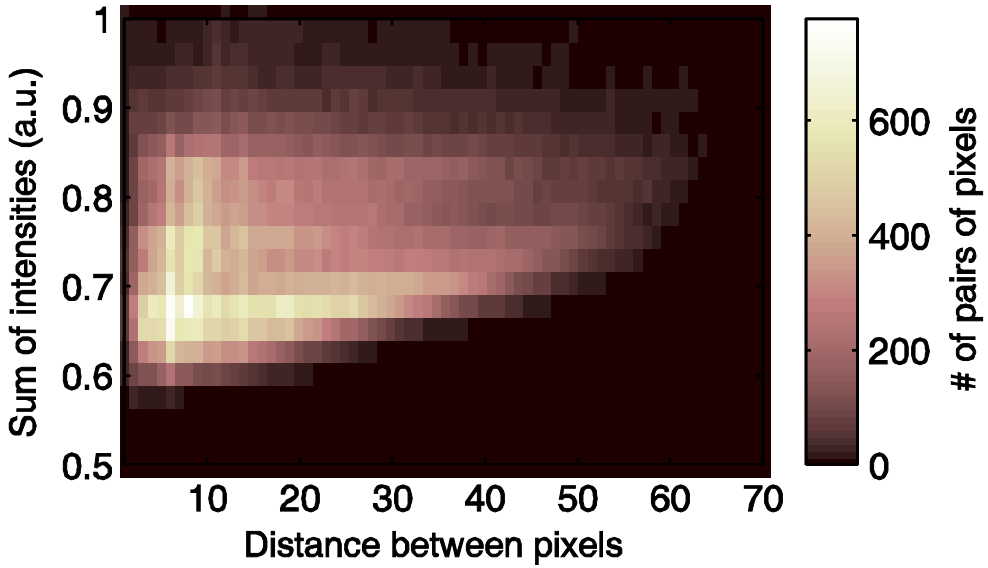


How does the automatic tracking work? Step 2: assigning frames

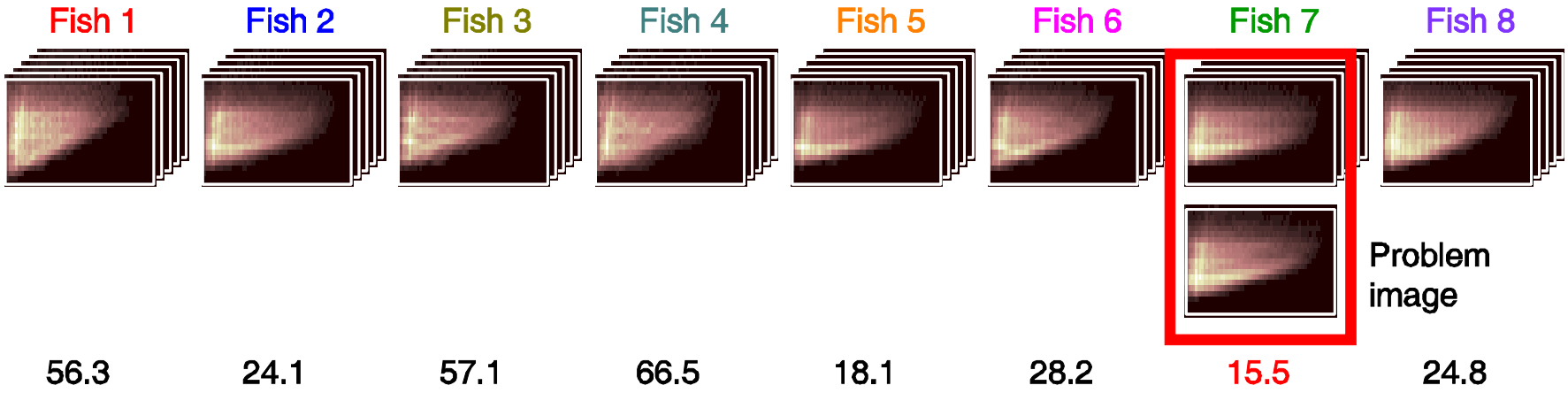
A. Transform each animal image (to have translational and rotational invariance)



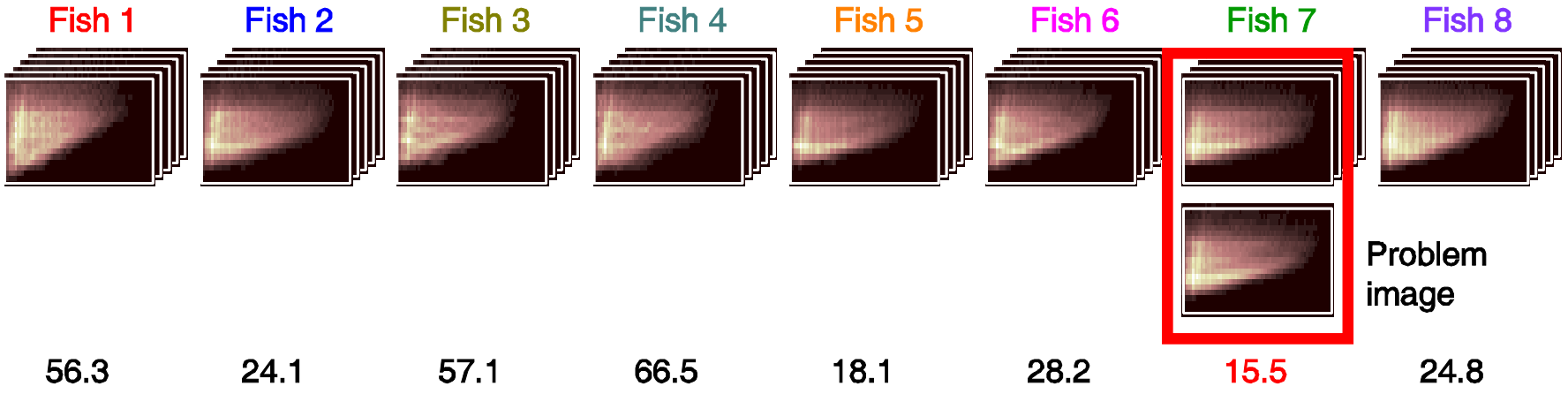




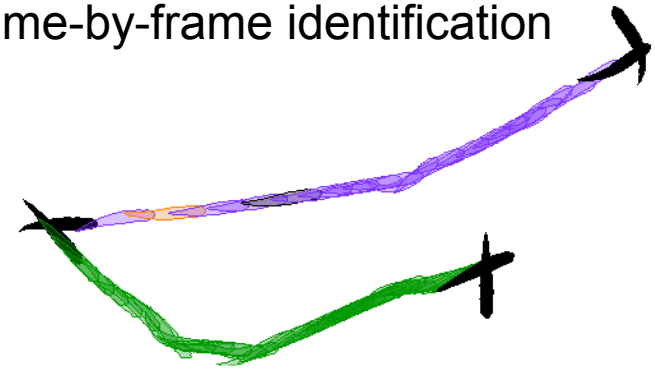
B. Assign each problem image to a reference animal



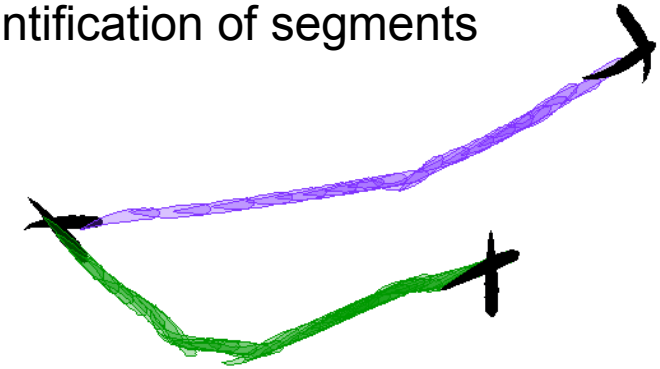
How does the automatic tracking work? Step 2: assigning frames



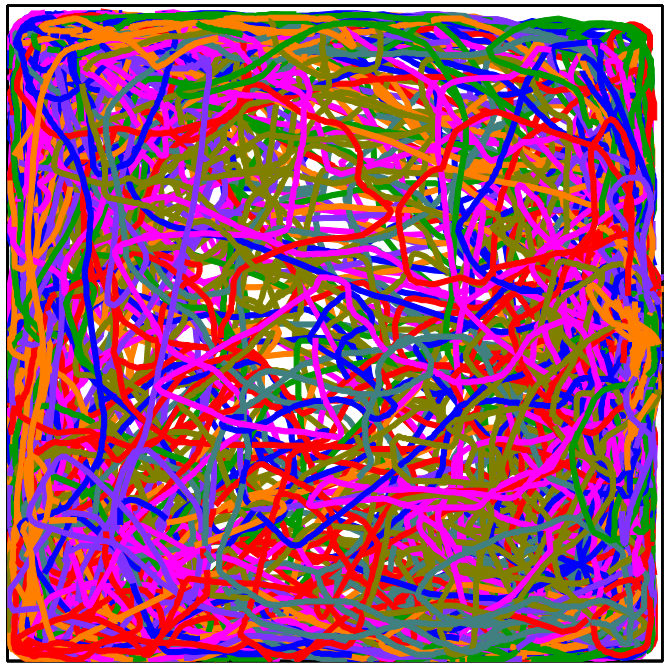
C. Frame-by-frame identification



D. Identification of segments

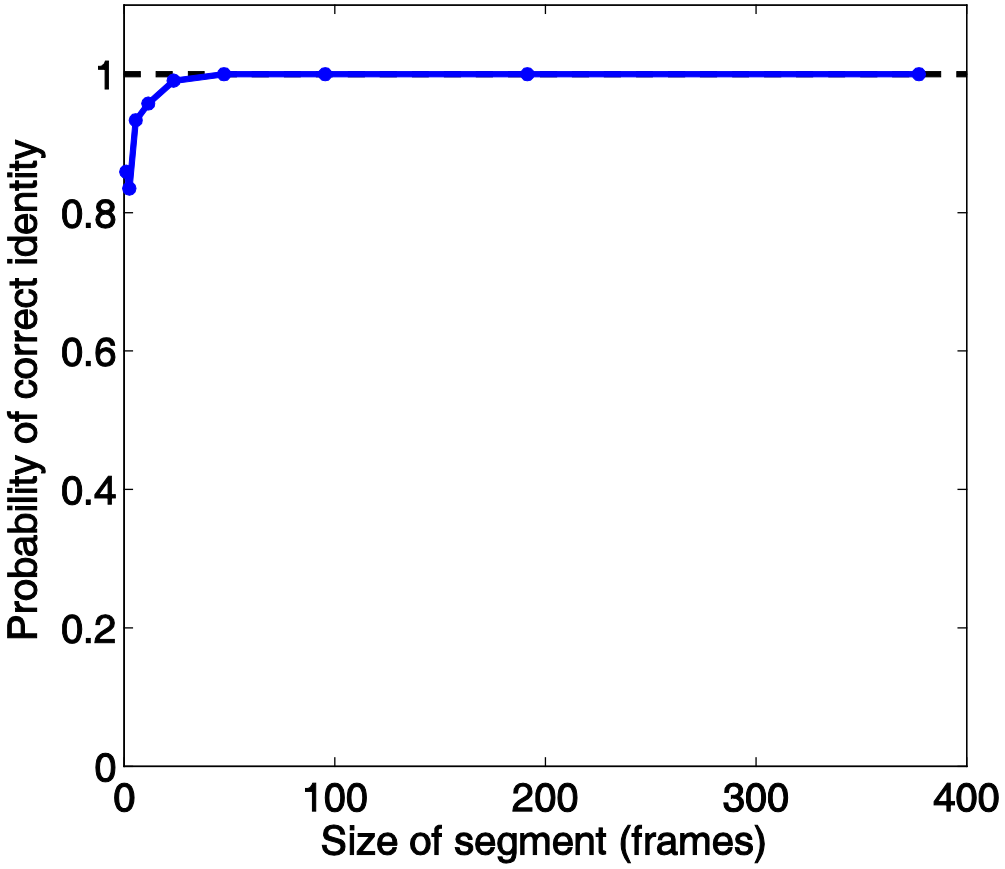


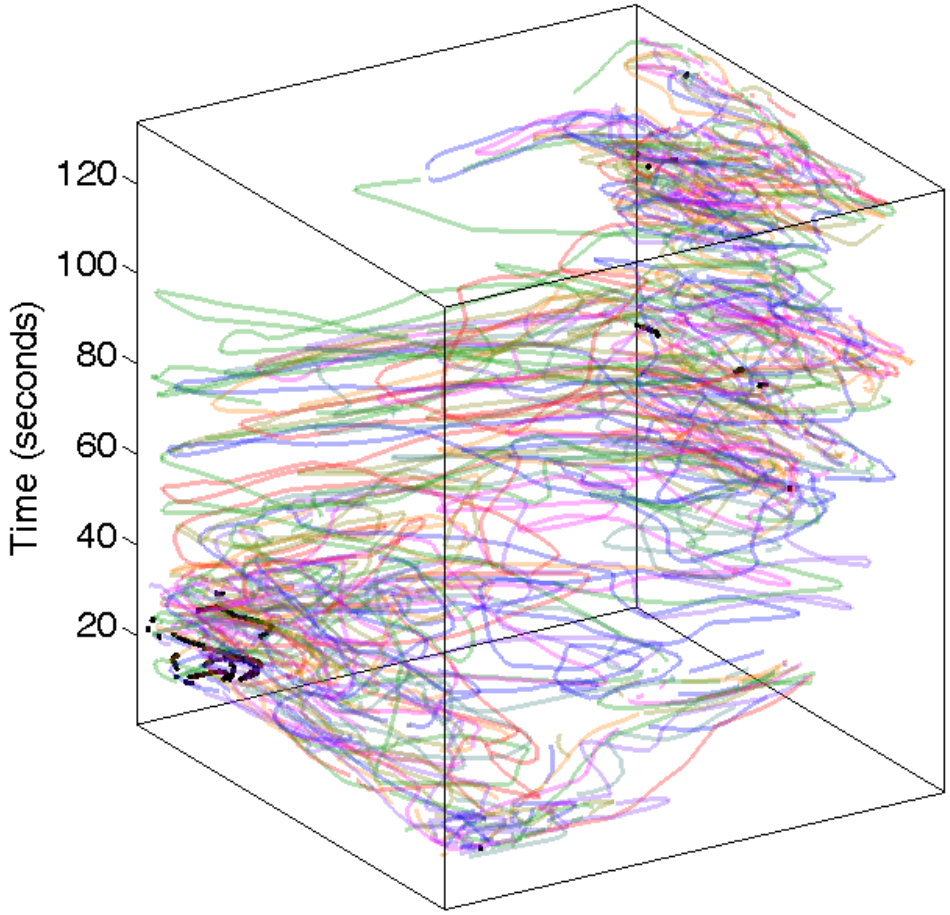
j Final trajectories



How does the automatic tracking work? Validation

Comparison with a human





0.5% incorrect frames
0.15% in ‘free motion’

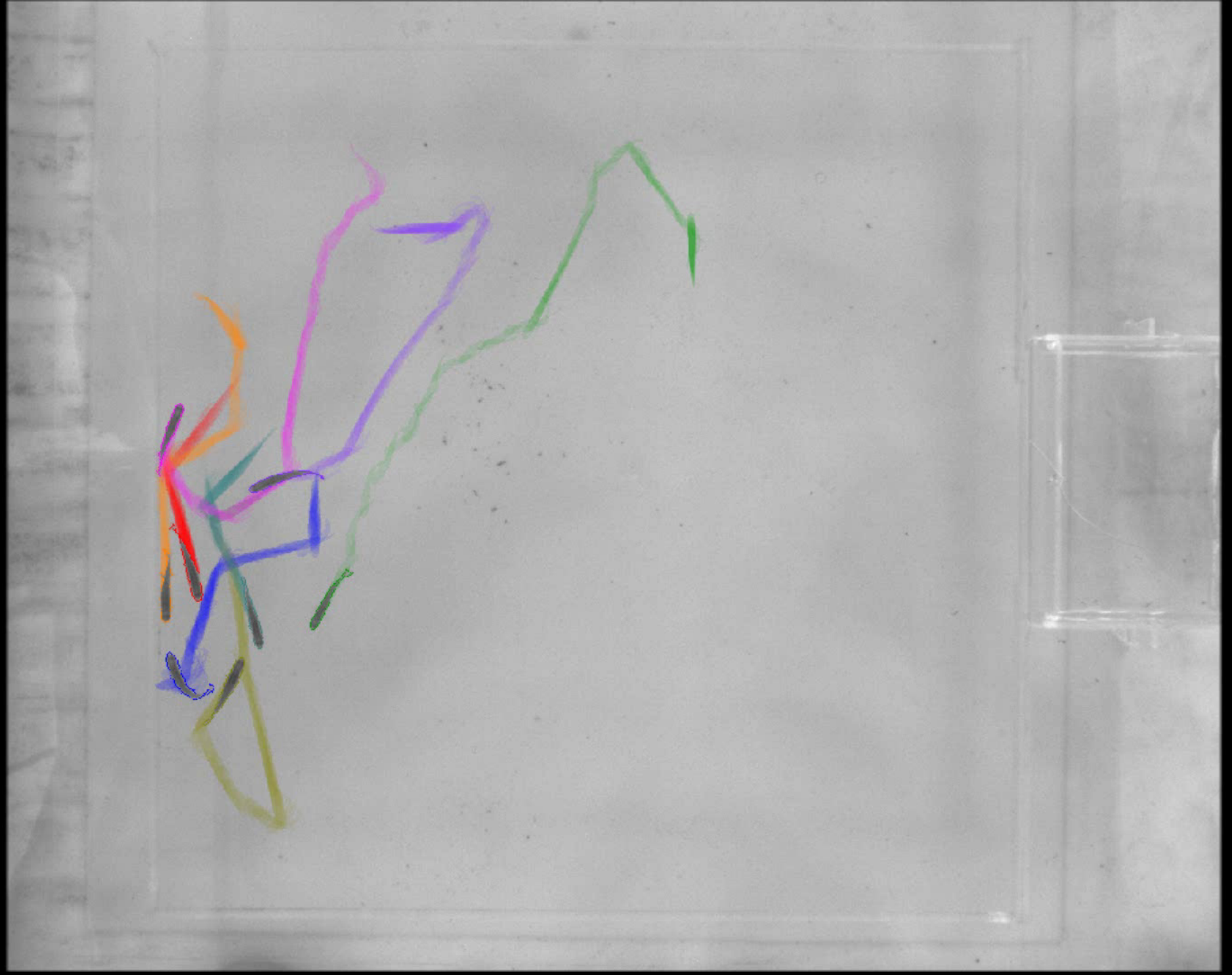
Other advantages (that makes it even better than a human)

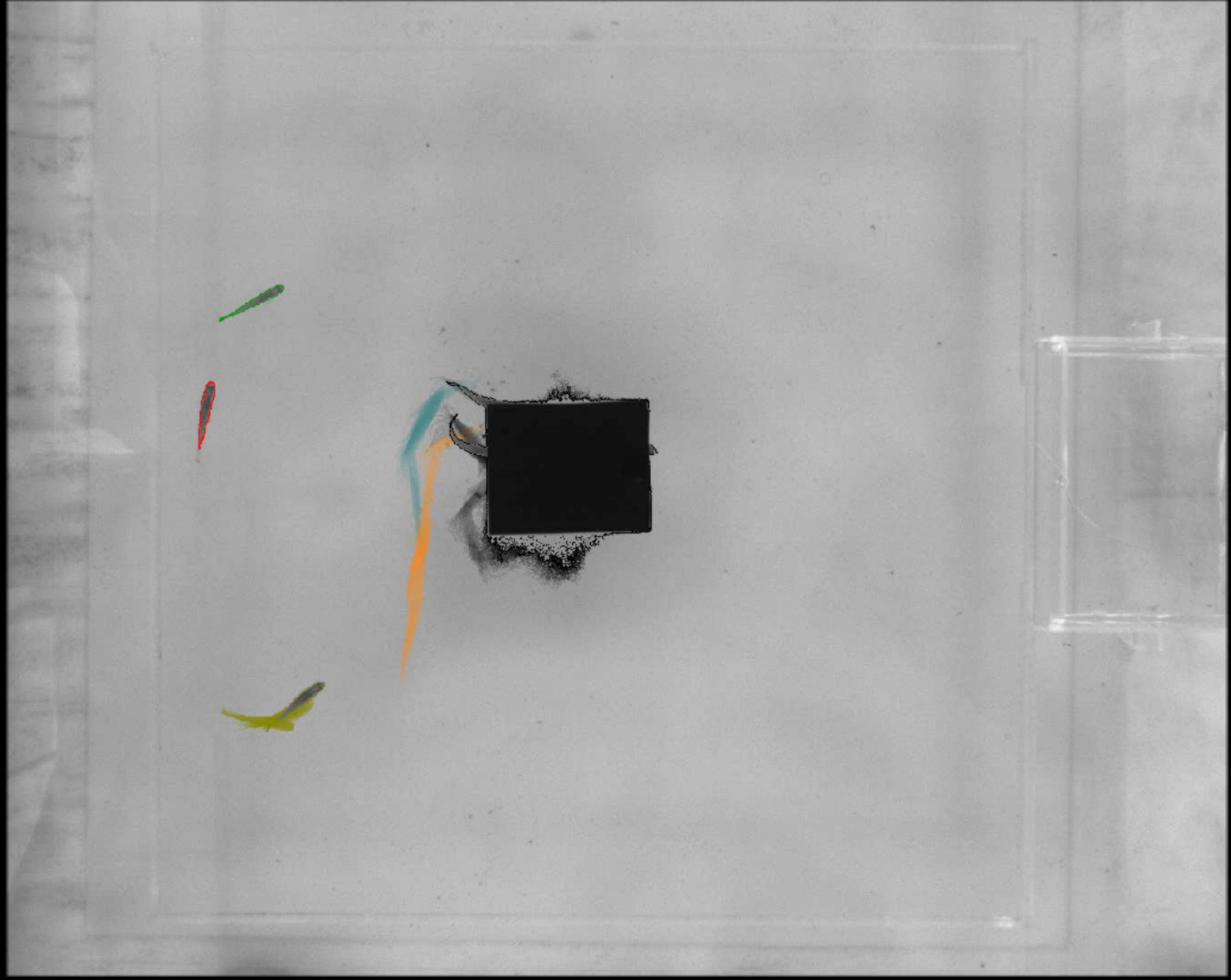
-Animals can dissapear from view

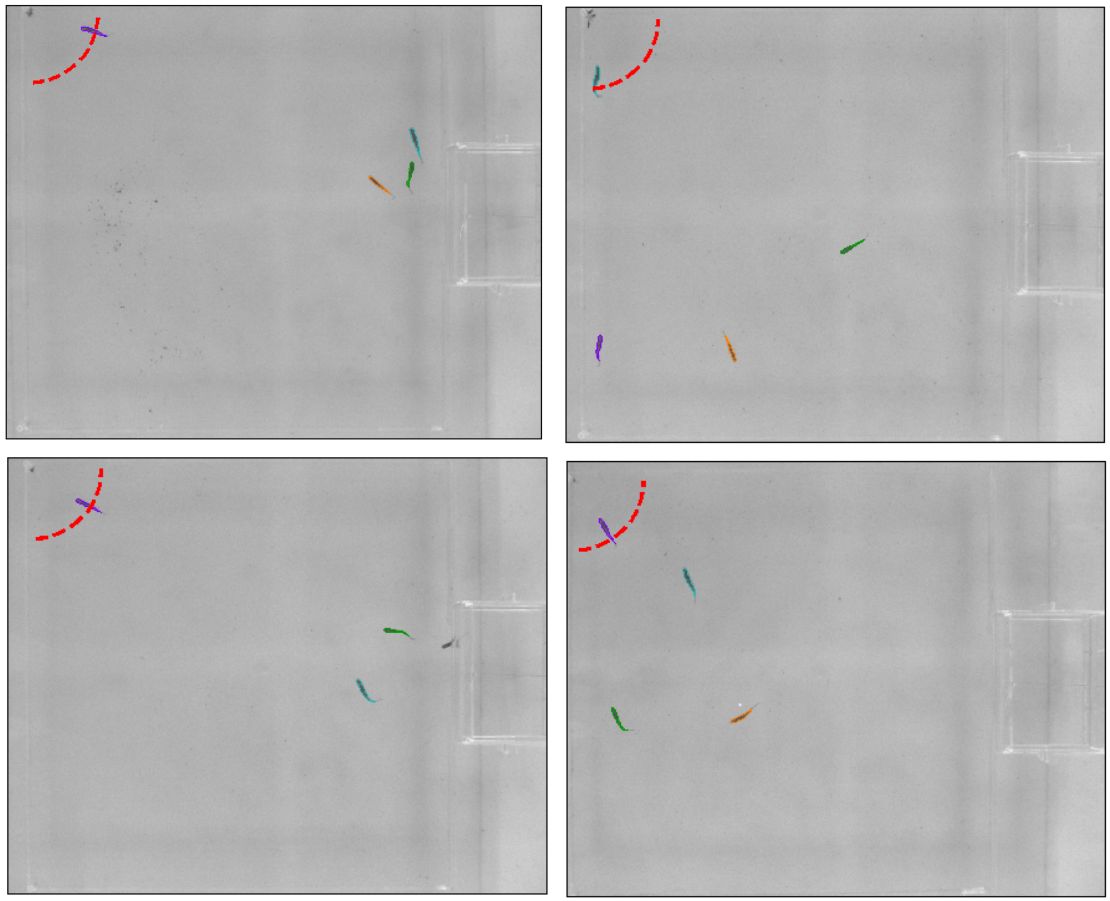
-Individuals can be followed through trials

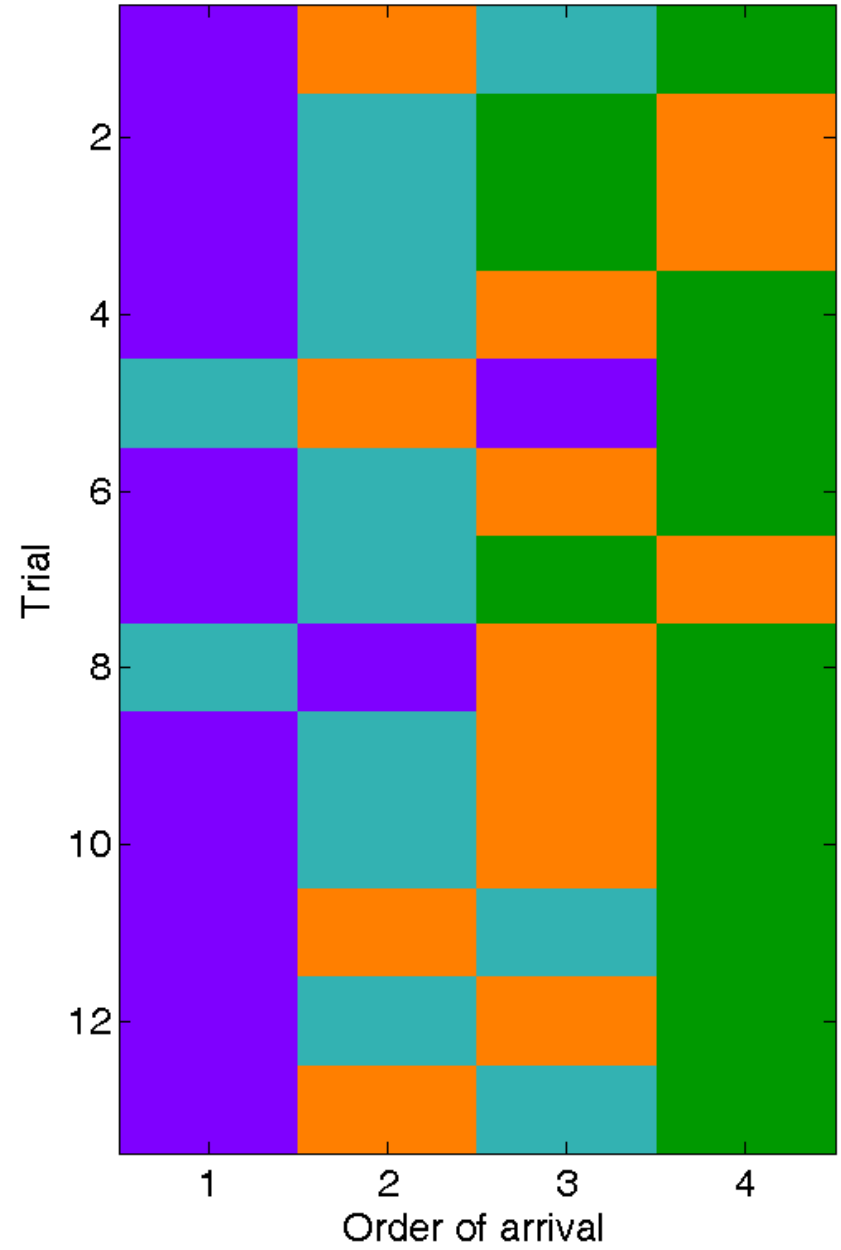
-Animals with different treatments can be followed in a group

-Works for all species tried so far

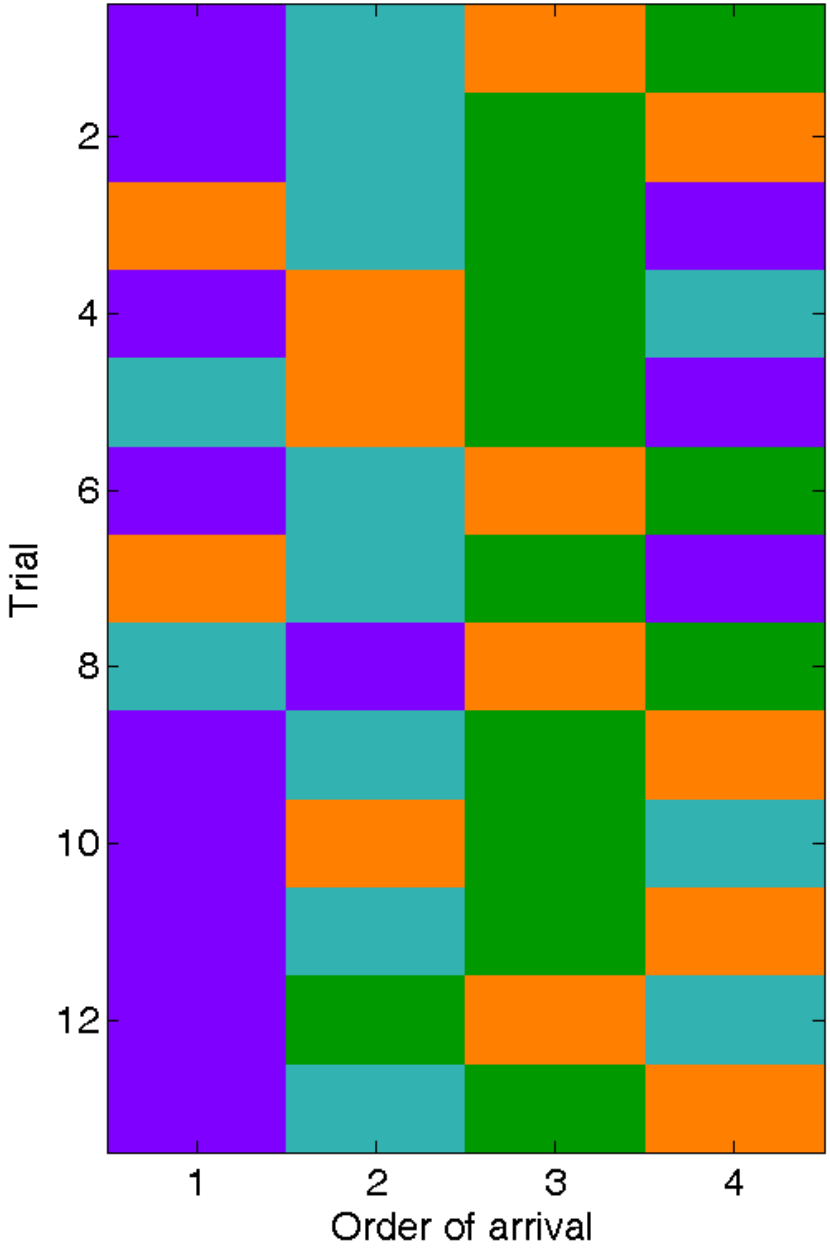




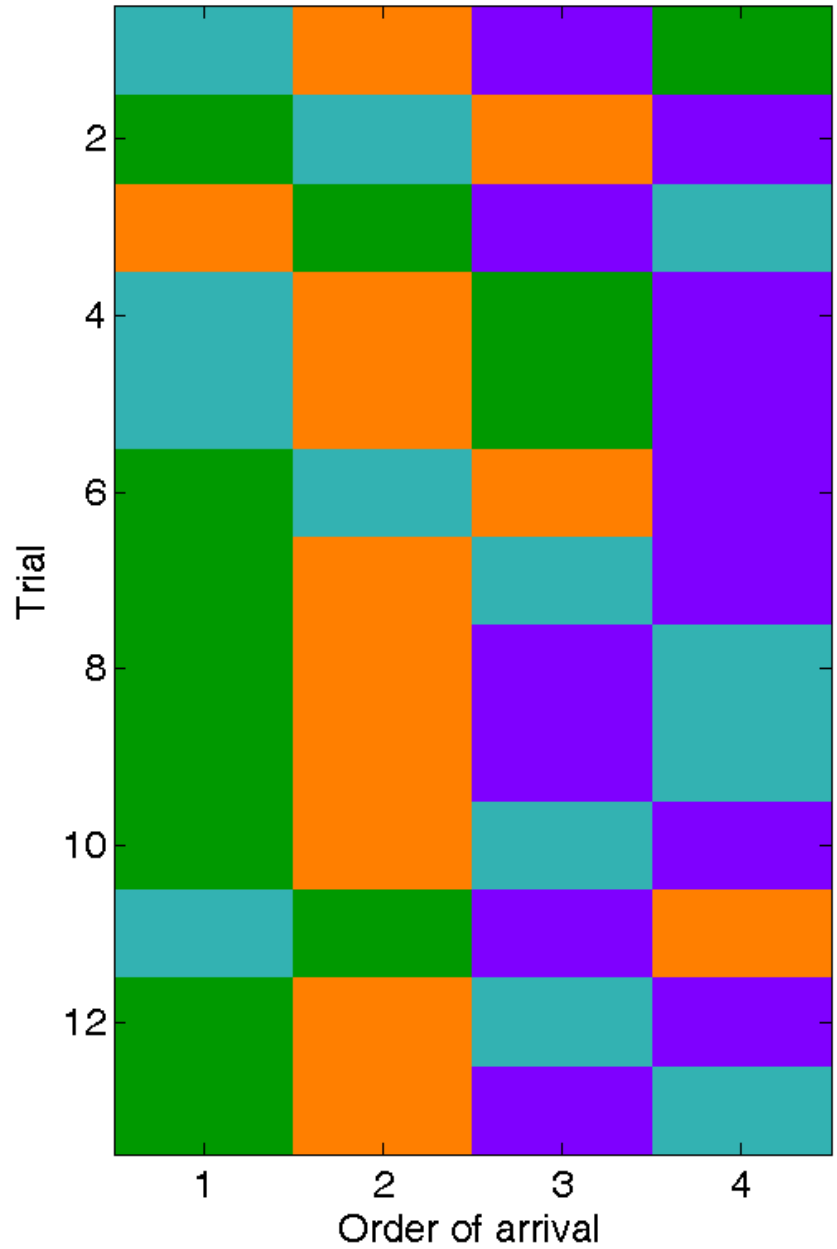


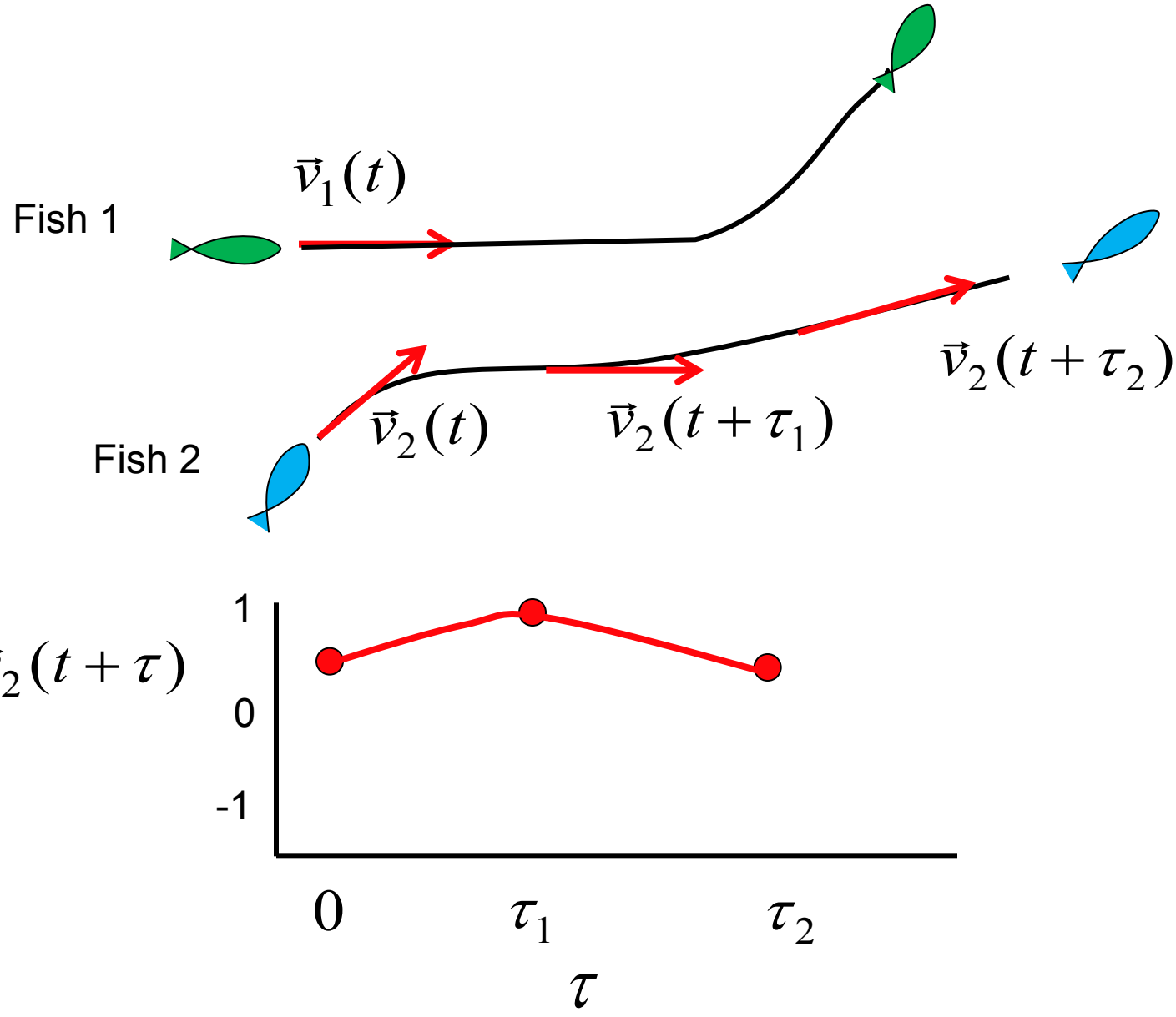

Trial
2
4
6
8
10
12
1
2
3
4
Order of arrival

Group 2

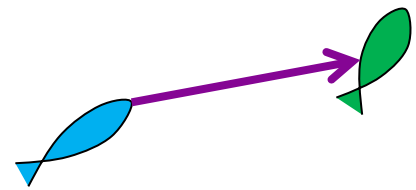


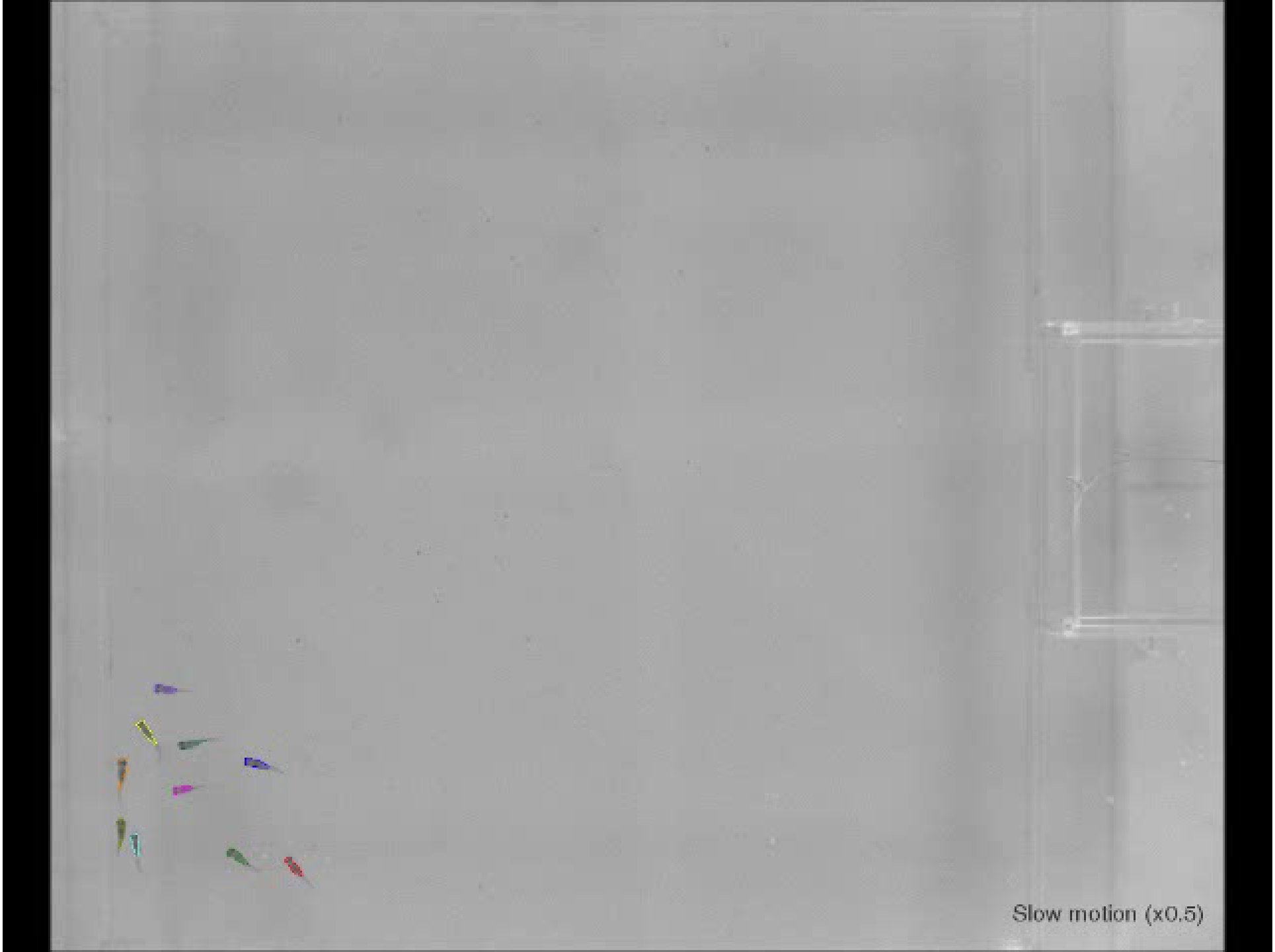
Group 3

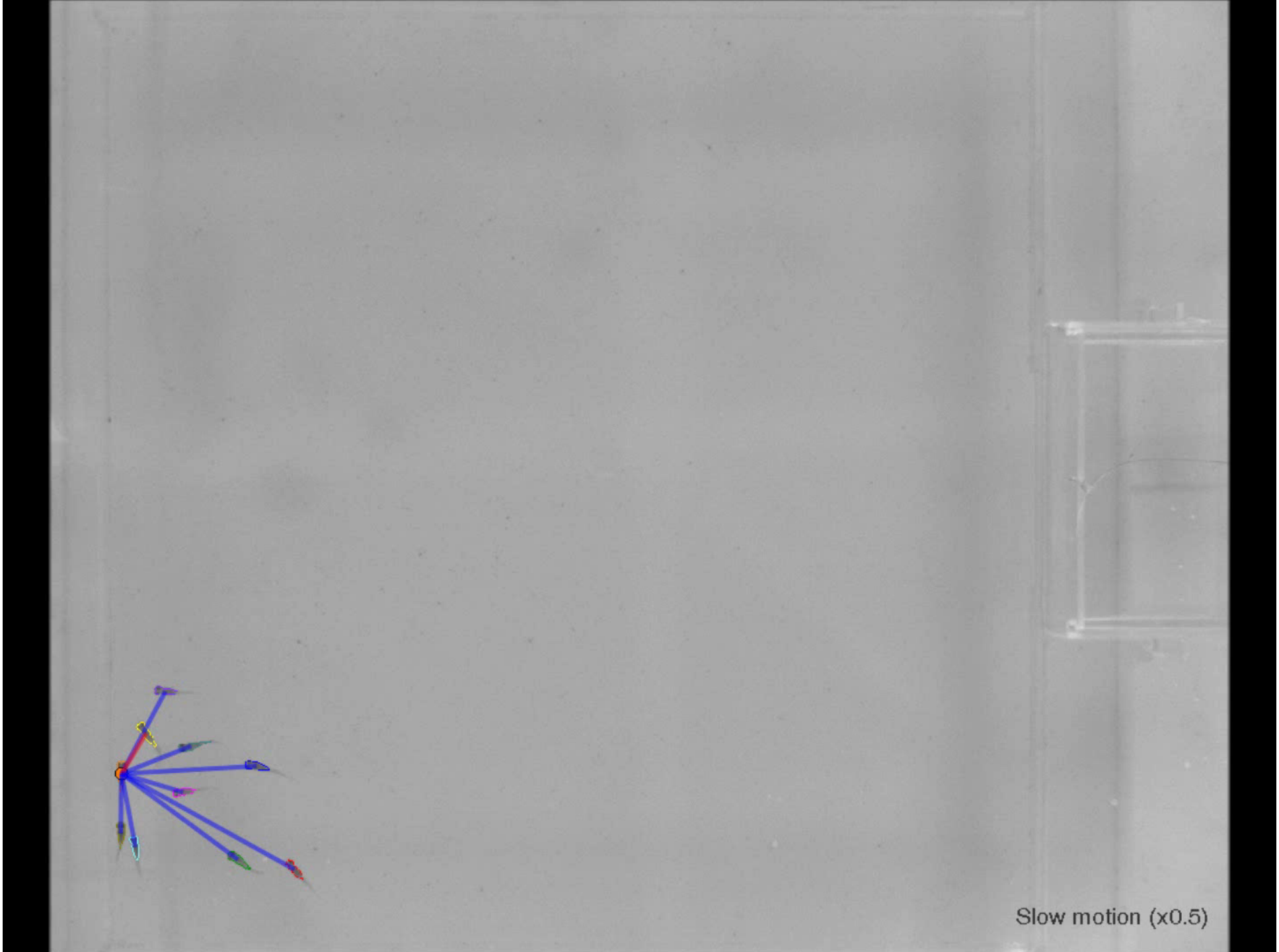


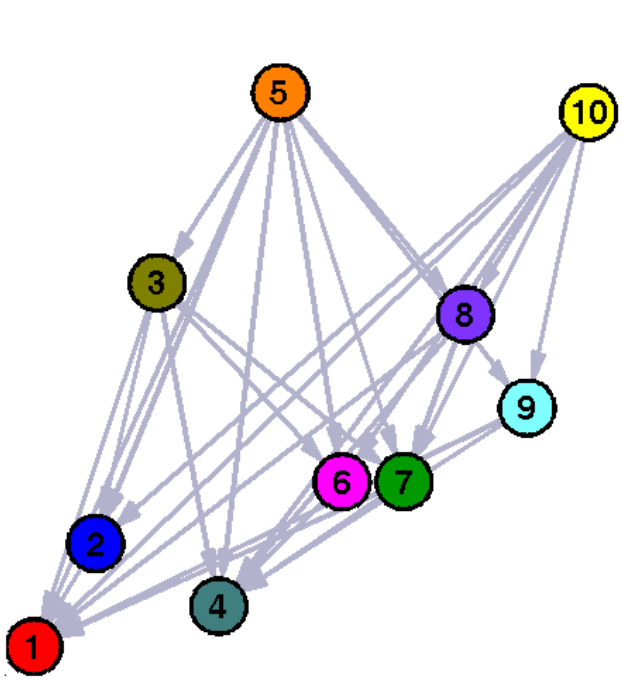


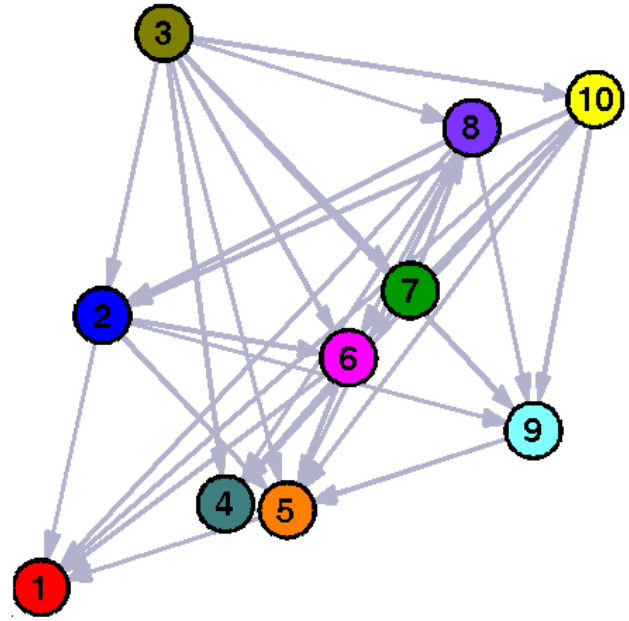
IF $\vec{v}_1(t) \bullet \vec{v}_2(t+\tau) > 0.7$ THEN

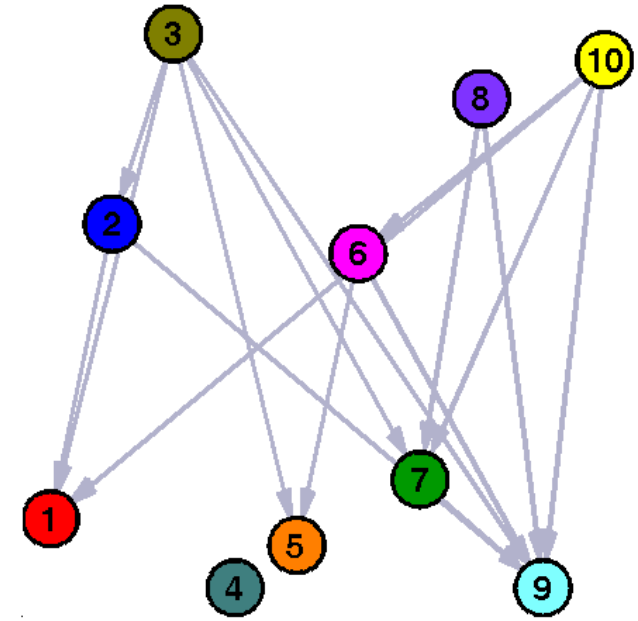



Slow motion (x0.5)


Slow motion (x0.5)

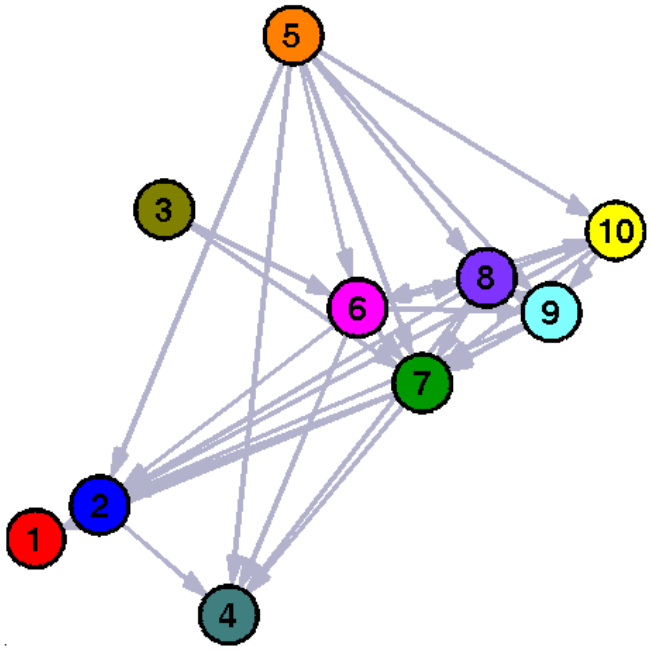


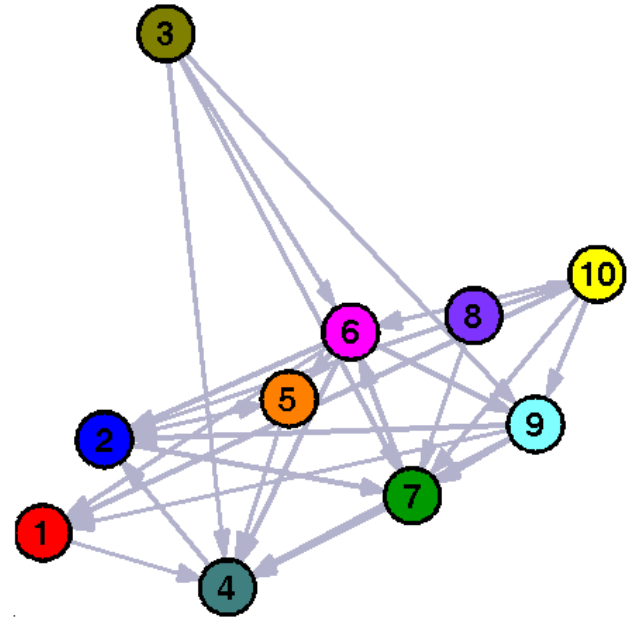


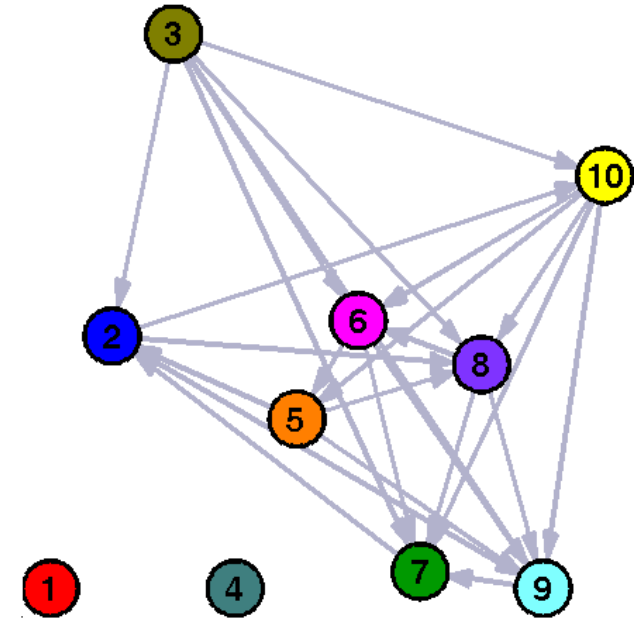


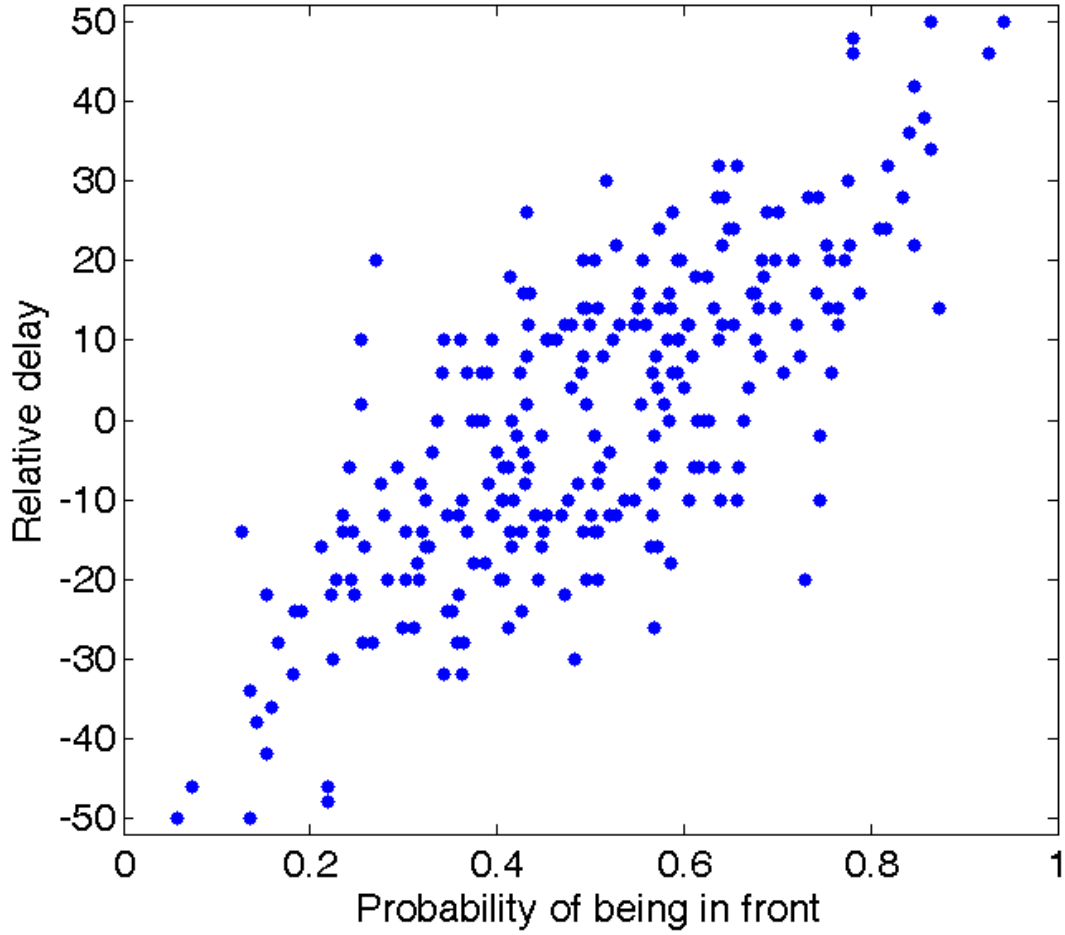
p =

0.0041


5
3
10
8
6
9
7
2
1
4


3
10
6
8
5
9
2
7
1
4


3
10
2
6
8
5
7
9
1
4


Relative delay
Probability of being in front
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
0.2
0.4
0.6
0.8
1

p =

2.8763e-047