Sensing and decision-making in natural ecosystems

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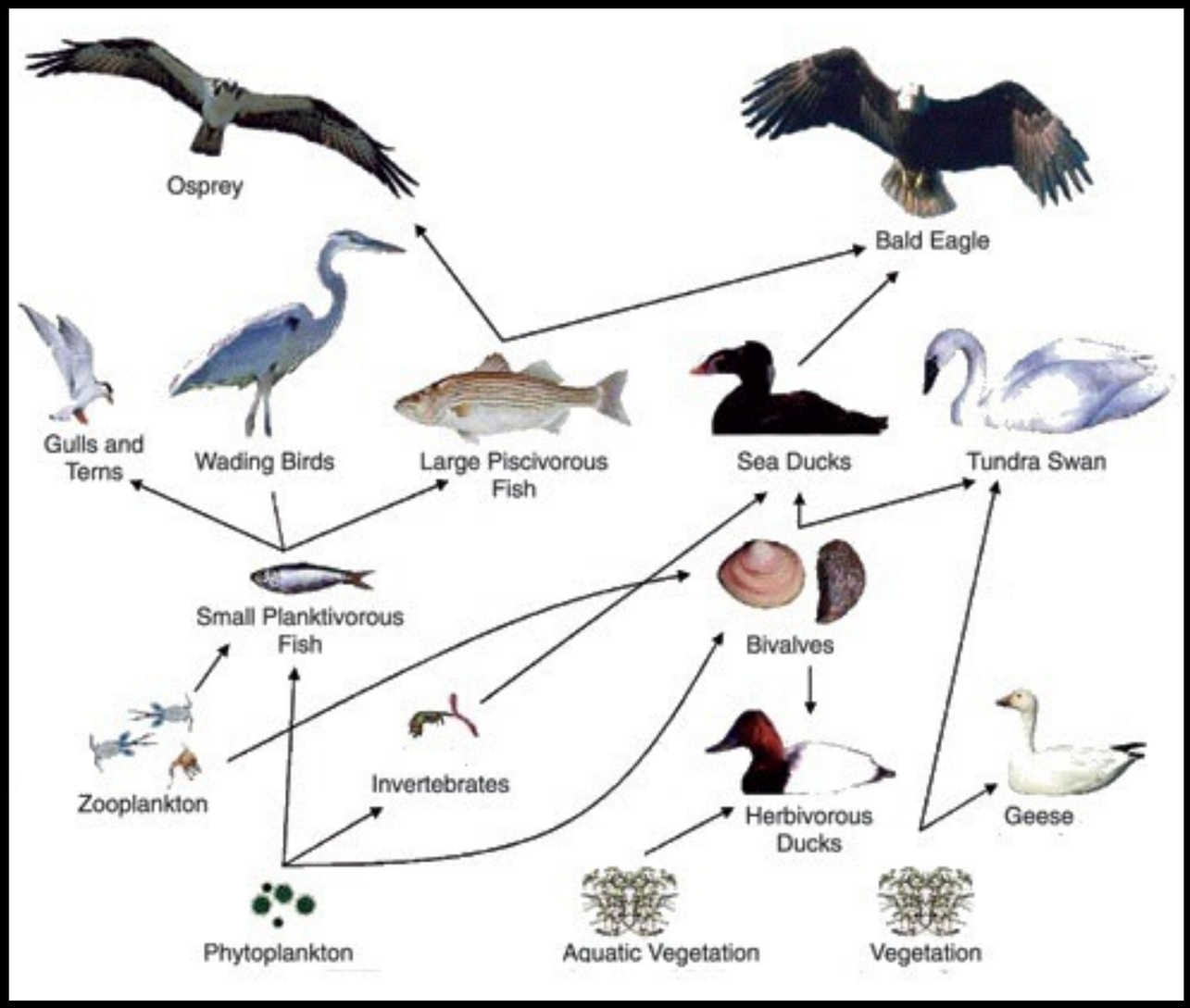
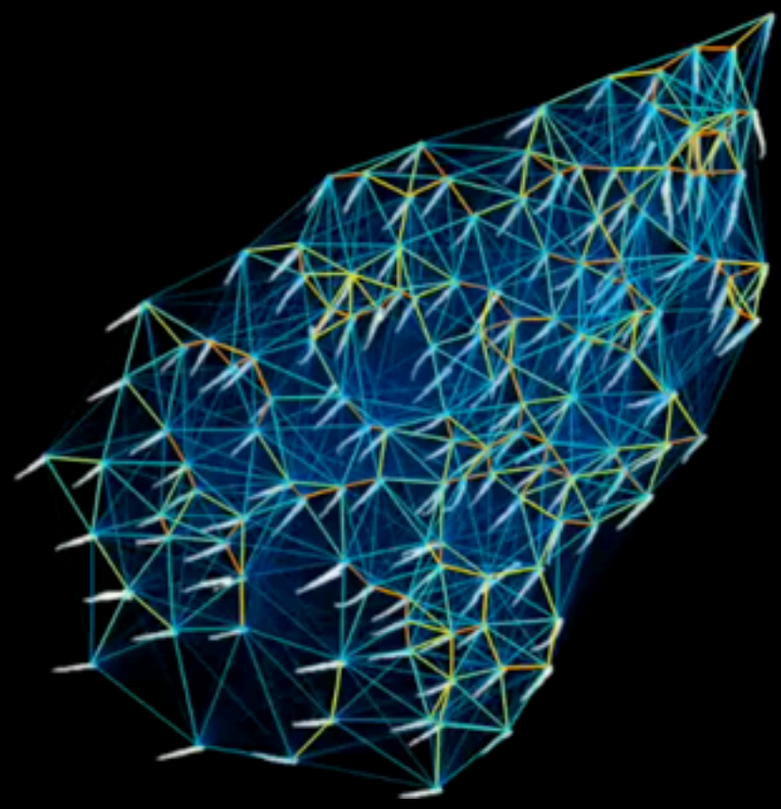
U.S. DEPARTMENT OF COMMERCE

Sensory systems evolved and operate in the context of ecosystems



Sensory feedbacks -> interactions with other individuals

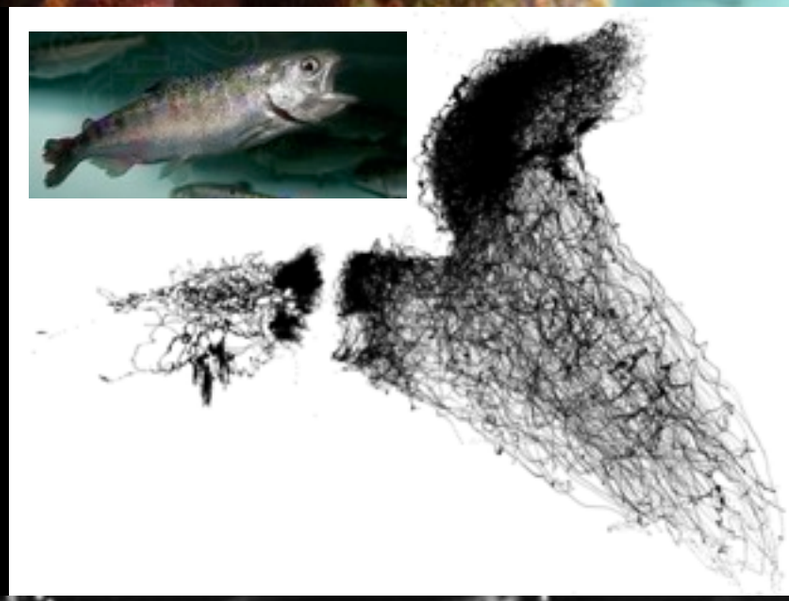
Individual and collective computation are simultaneous



Rosenthal et al. 2015 *PNAS*

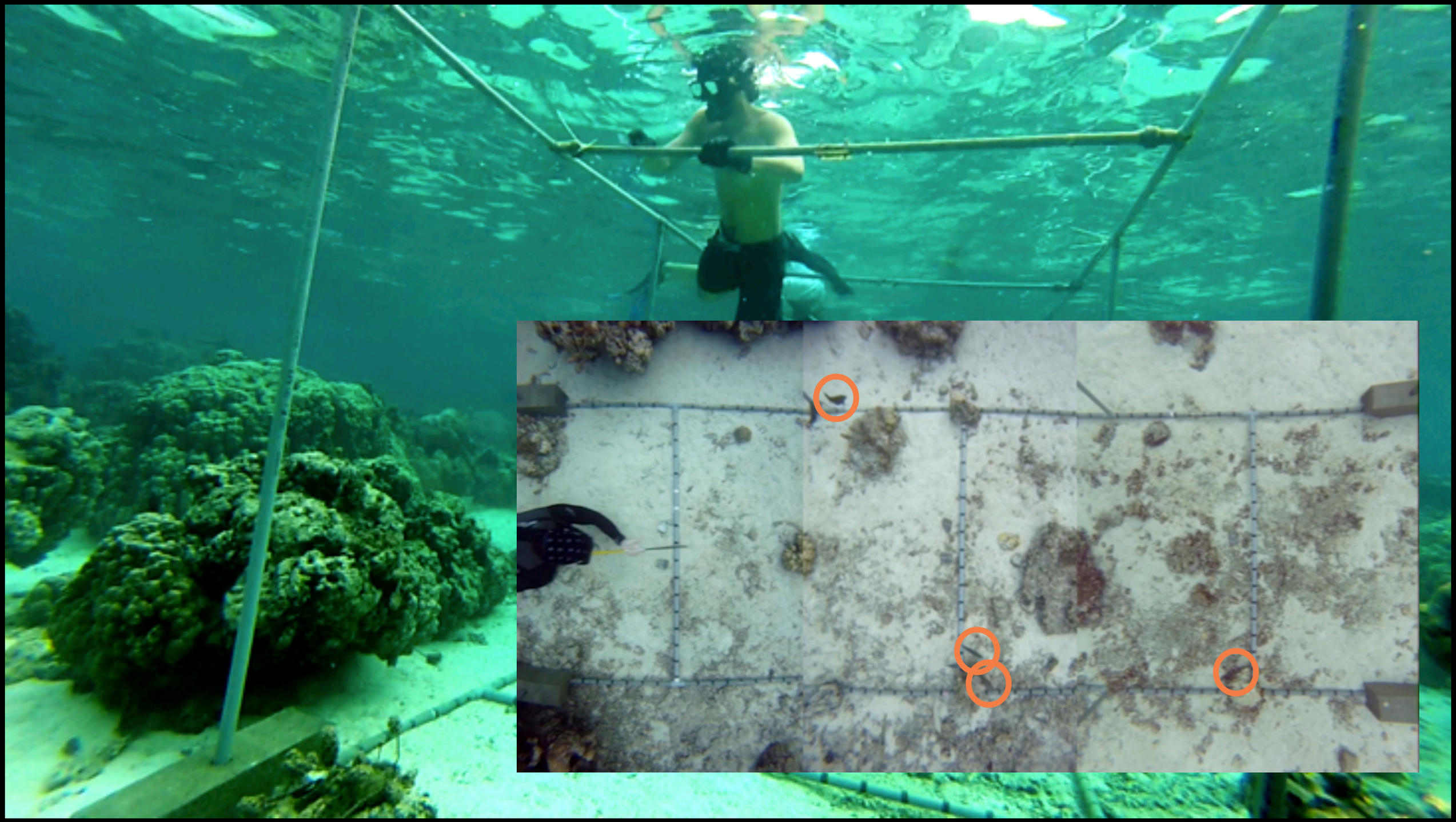
Decision-making in ecological systems

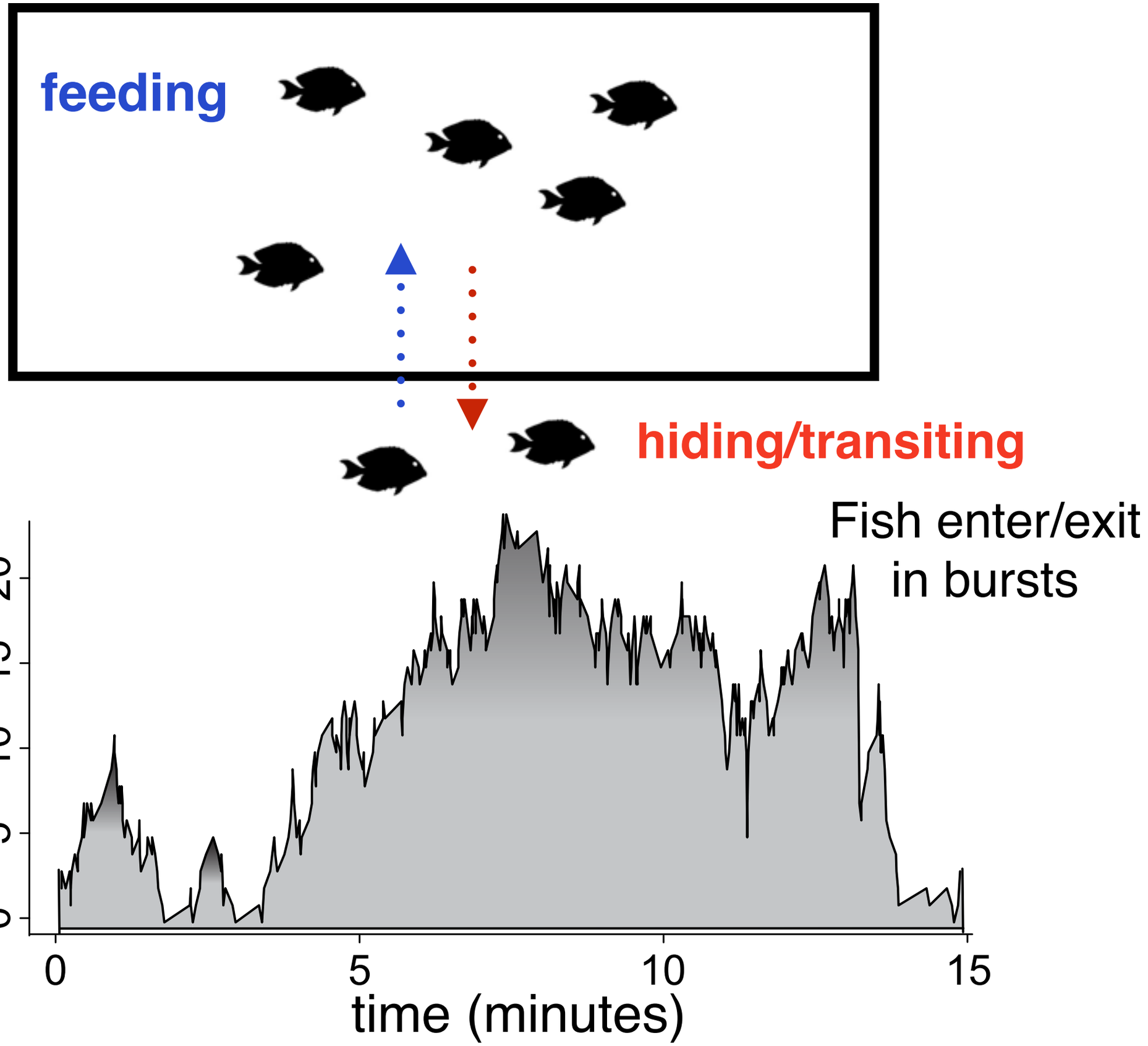
Navigation, attack, and evasion: robust behavioral control



Decision-making in the wild: taking the lab into the sea

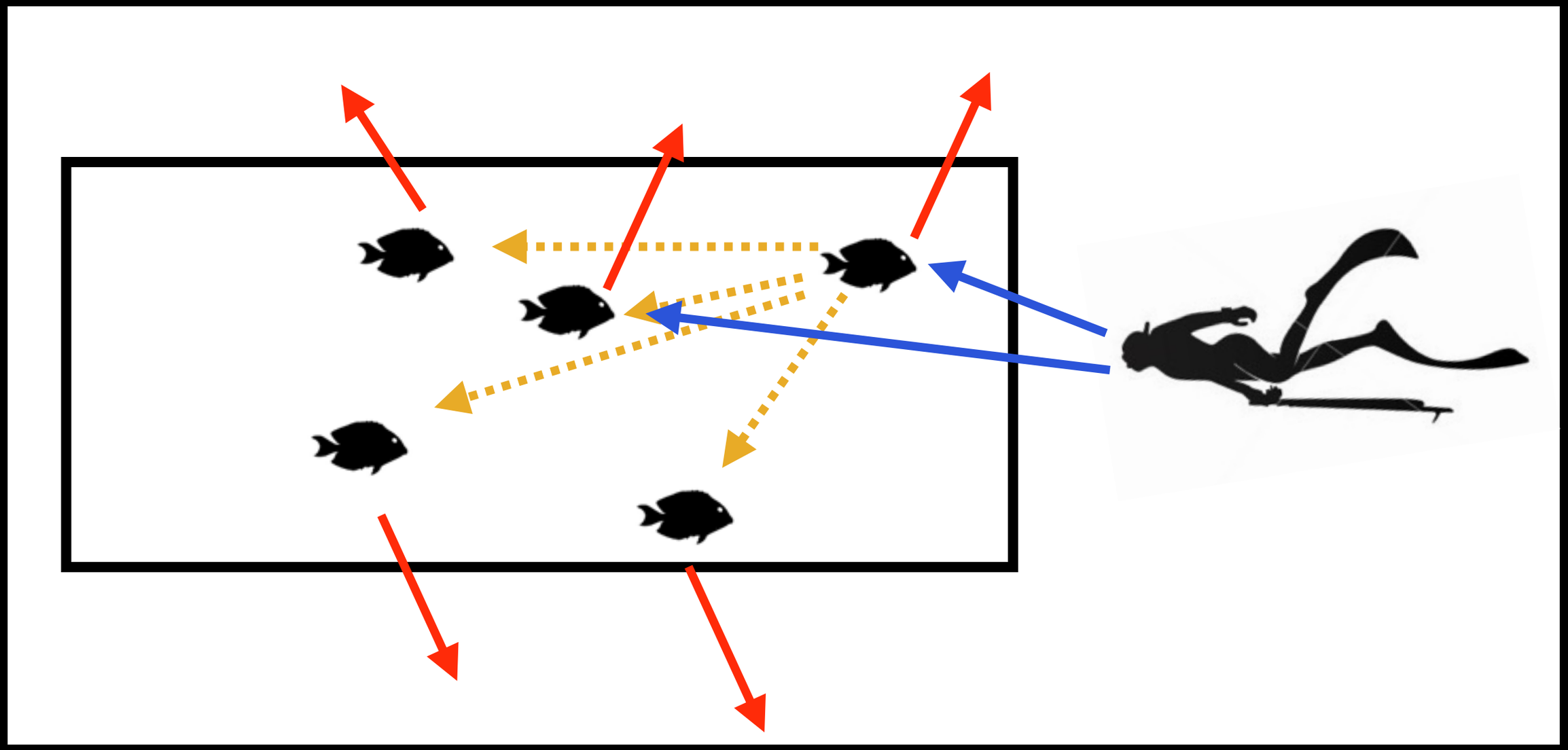
Mike Gil (Postdoc, UCSC)
Colin Twomey (U Penn)





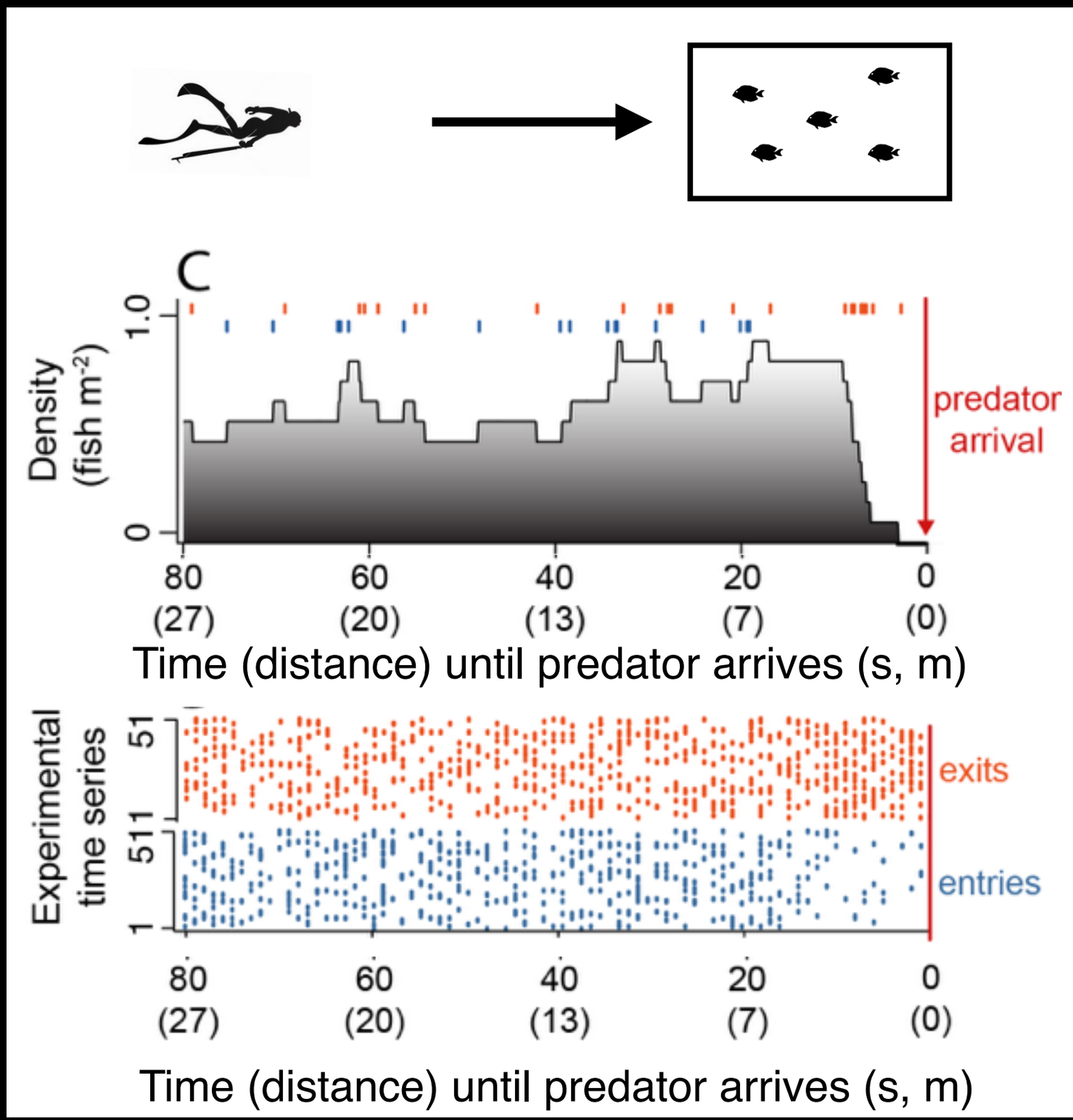
Gil and Hein *PNAS 2017*

Role of sensory information?



Could generate observed “bursty” behavior

Gil *et al. TREE* 2018

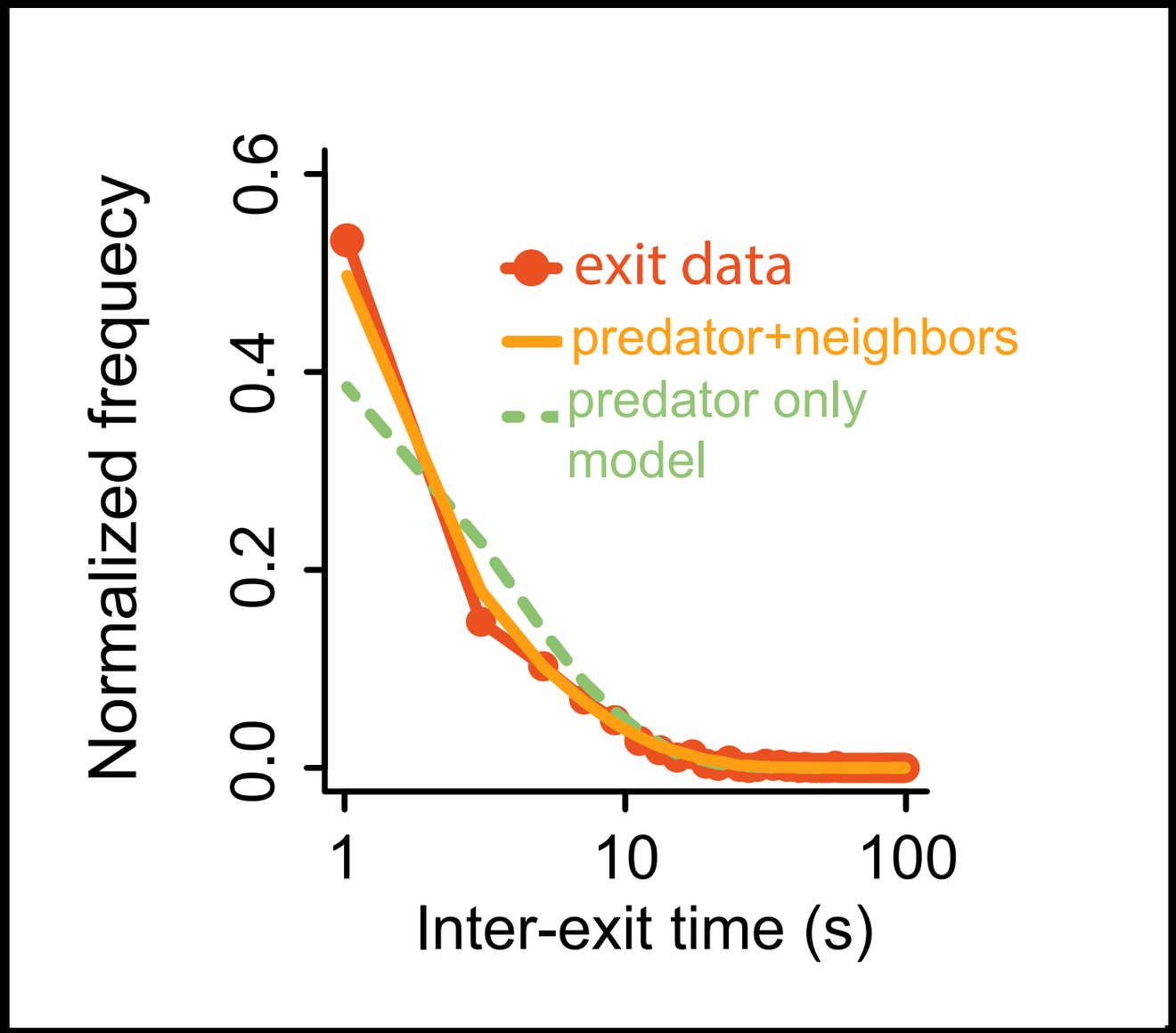


Formulate as self-exciting birth-death model

Likelihood-based method for comparing models

Gil and Hein *PNAS 2017*

Fish respond to both predators and other fish



Gil and Hein *PNAS 2017*

Two important effects of neighbor density:

social excitation

spontaneous

$$\text{rate} = \lambda(t) + \theta(t) + \psi(t)$$

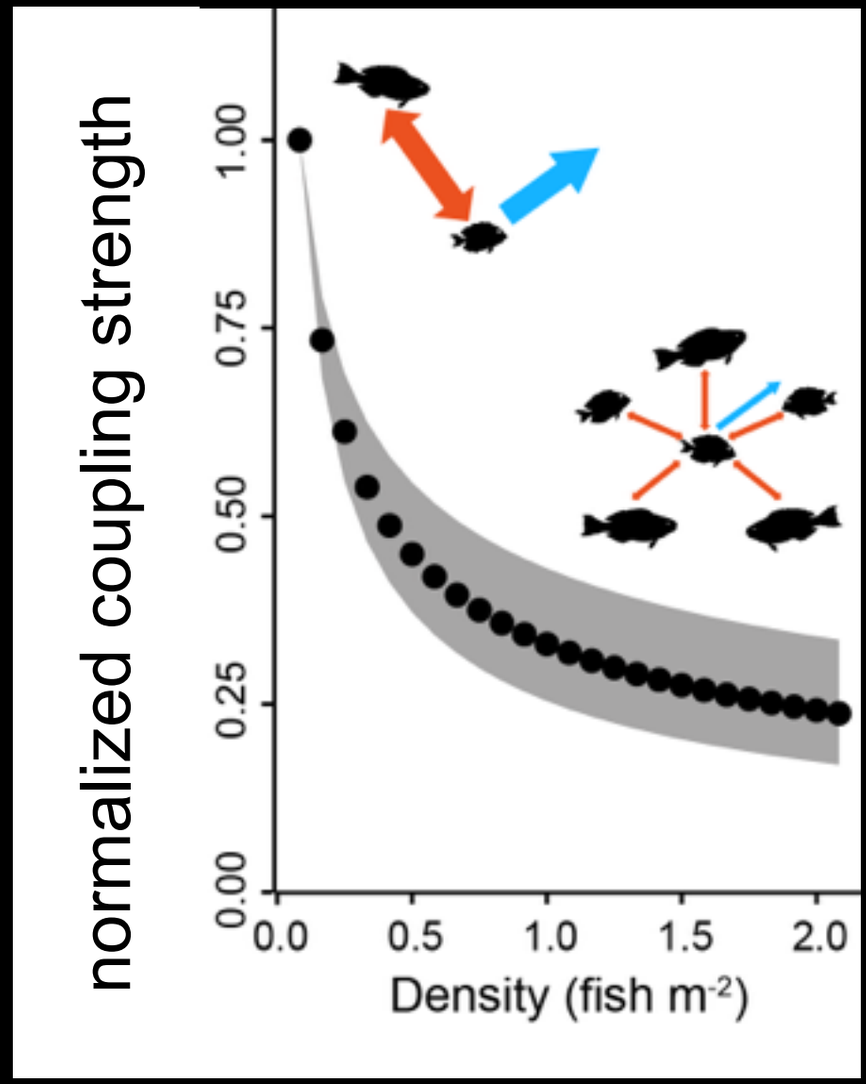
predator forcing

Lower spontaneous exit rate when more neighbors present

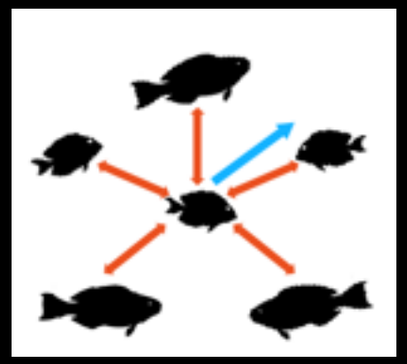
$$\lambda(t) = \lambda_0 N(t)^{-\eta}$$

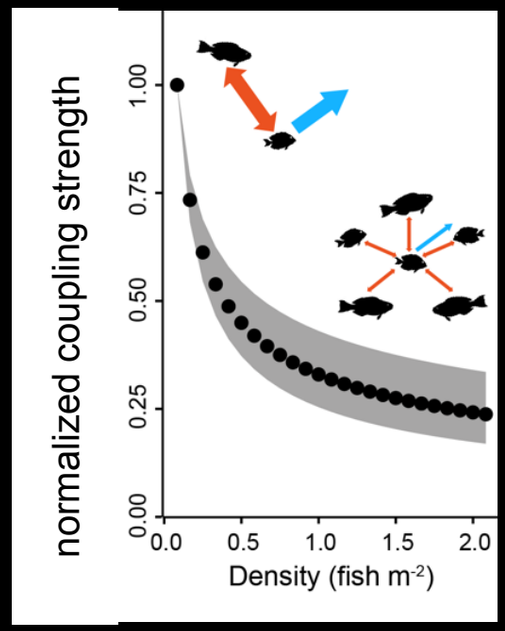
Less responsive to exits when more neighbors present

$$\psi(t) = \psi_0 N(t)^{-\gamma} \sum_{t_i < t} e^{-\alpha(t - t_i)}$$



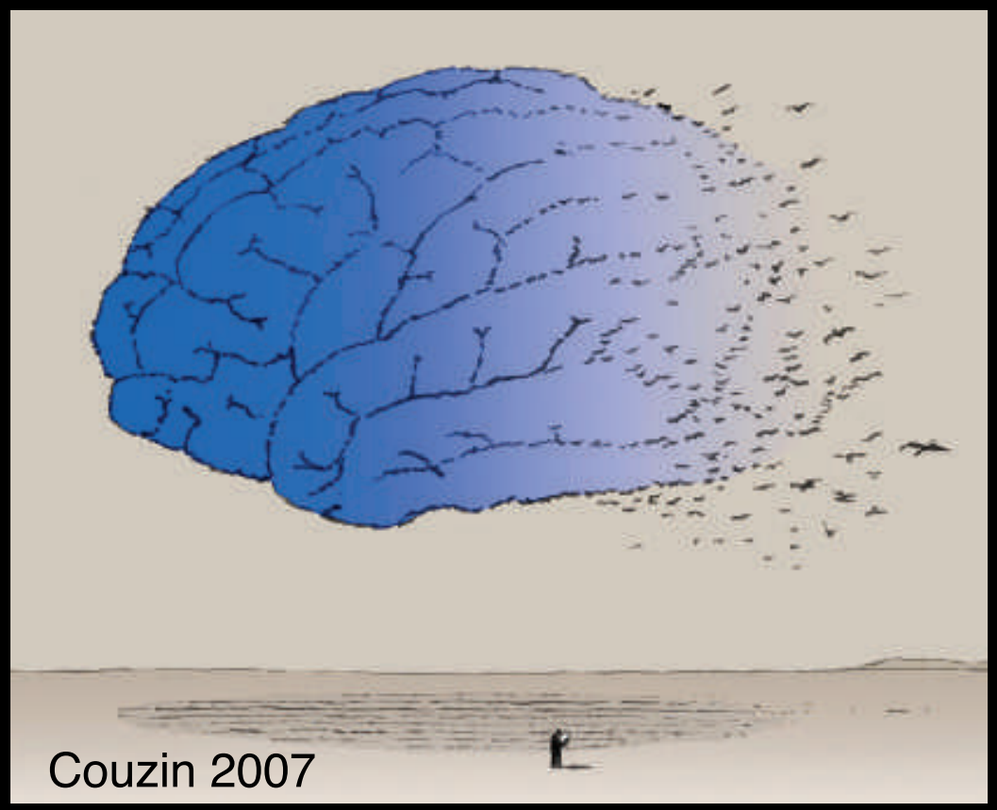
simulation experiment





Lowered responsiveness prevents hypersensitivity

Hypersensitivity/Hyposensitivity in collective systems



Couzin 2007

INTERFACE

rsif.royalsocietypublishing.org

Social information use and the evolution of unresponsiveness in collective systems

Anim. Behav., 1995, **50,** 1097–1108

Collective detection of predatory attack by social foragers: fraught with ambiguity?

Potential disadvantages of using socially acquired information

Luc-Alain Giraldeau[1*], Thomas J. Valone[2] and Jennifer J. Templeton[3]

eLIFE elifesciences.org

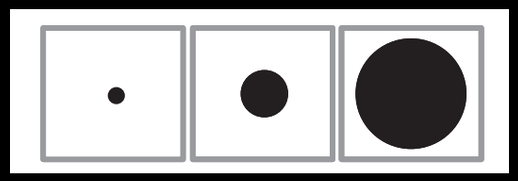
RESEARCH ARTICLE

The evolution of distributed sensing and collective computation in animal populations

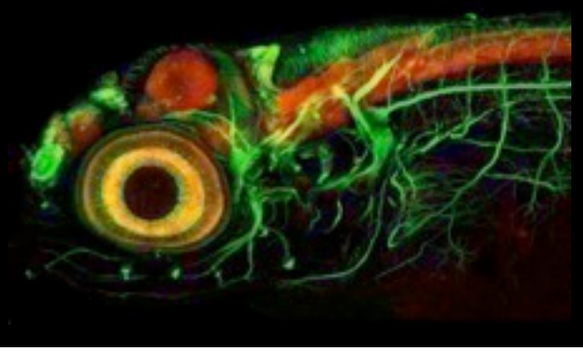
Andrew M Hein[1*†], Sara Brin Rosenthal[2,3†], George I Hagstrom[1†], Andrew Berdahl[4], Colin J Torney[5], Iain D Couzin[3,6*]

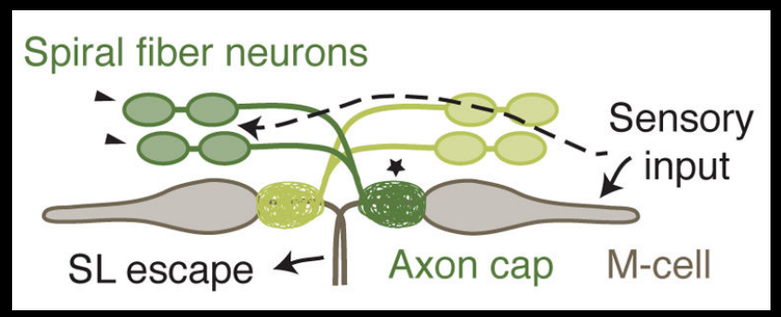
Hein et al. *eLife* 2015

What is the neural basis of these phenomena?

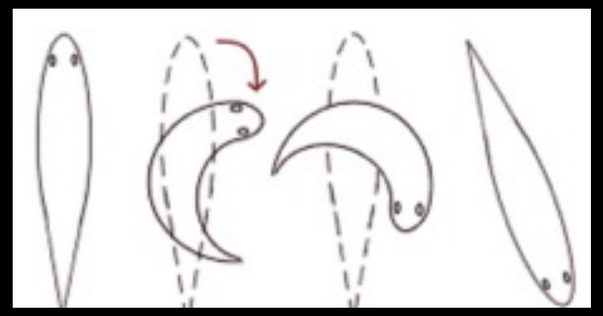


looming visual stimulus



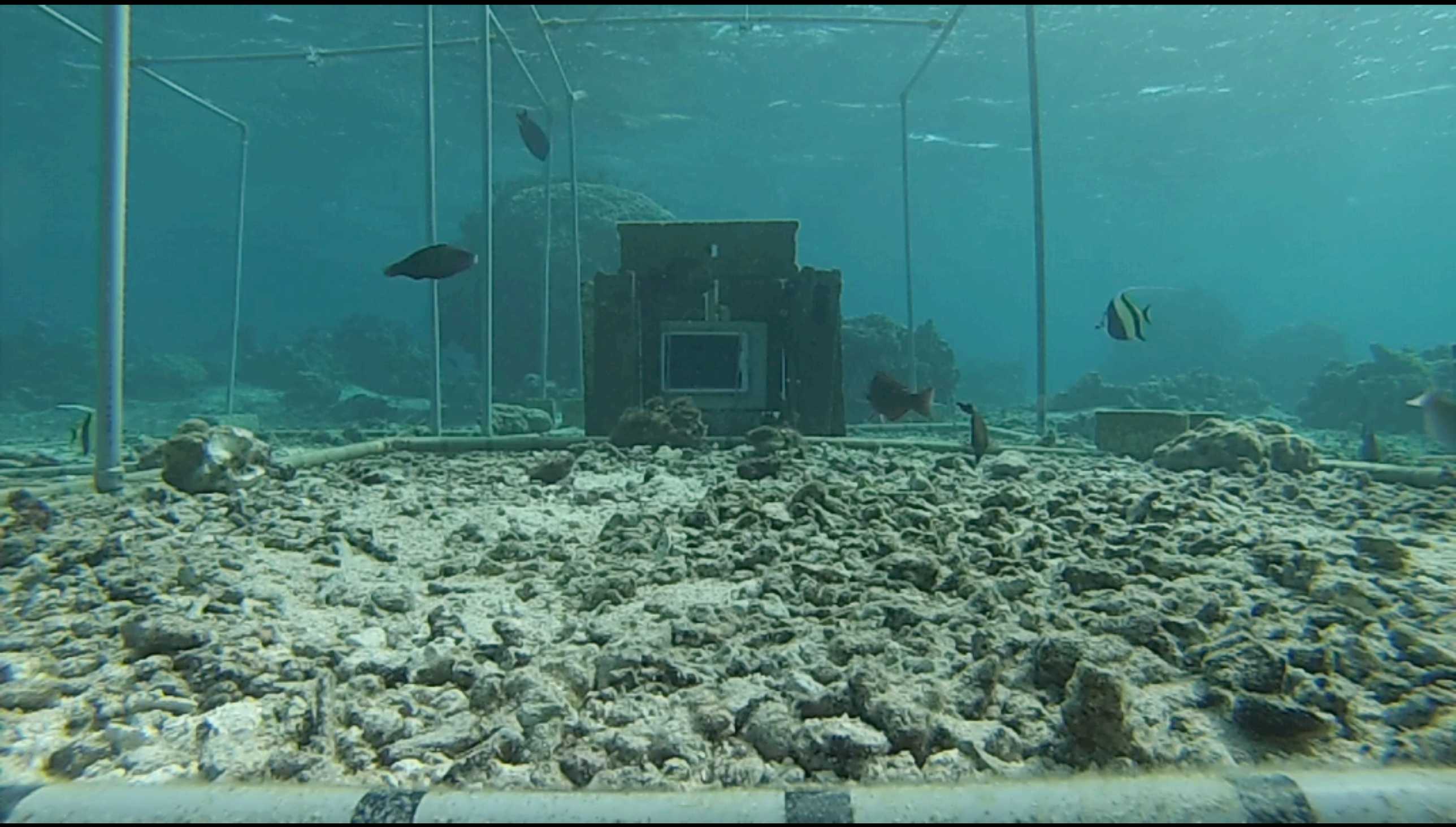


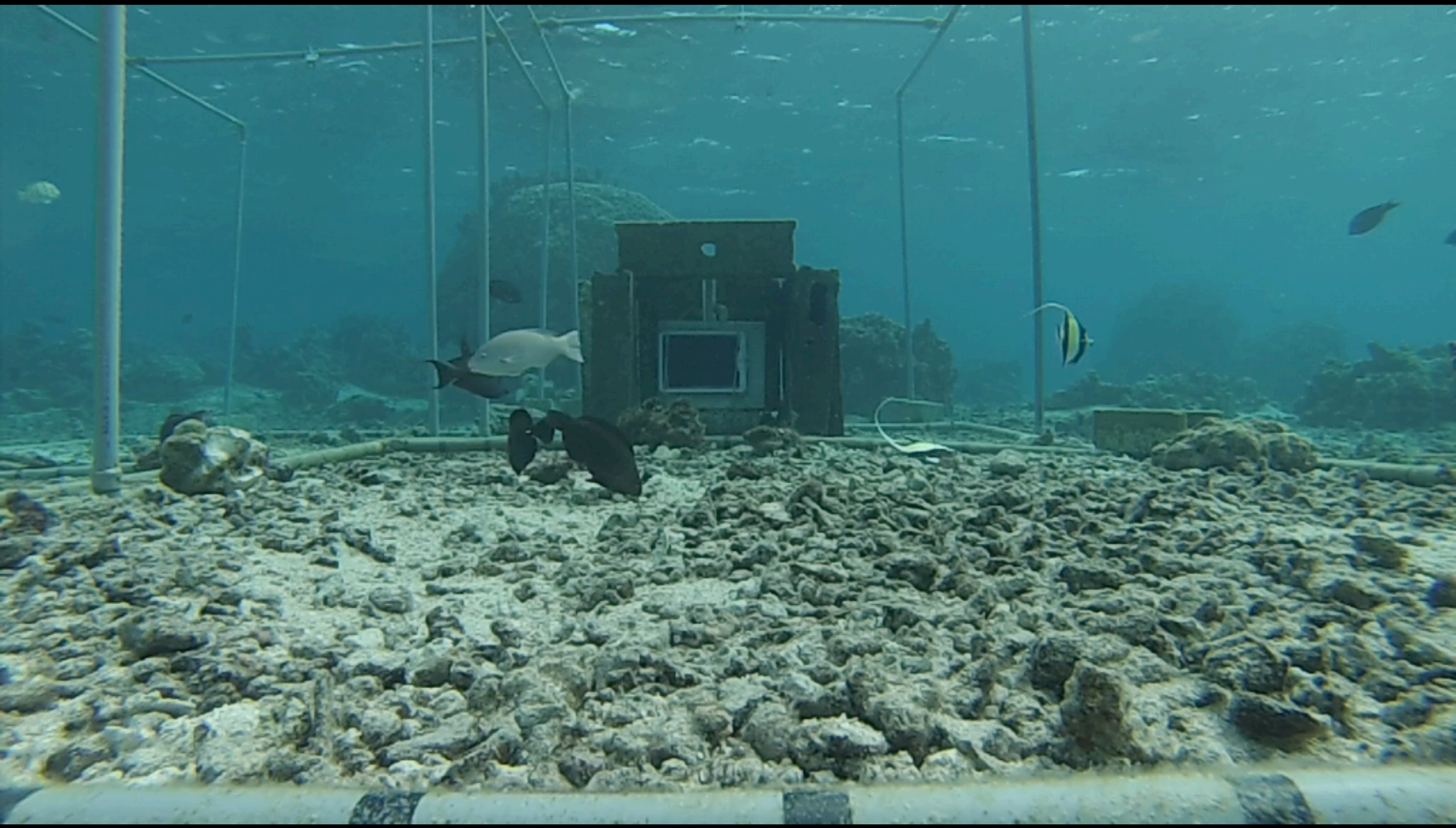
threat detection

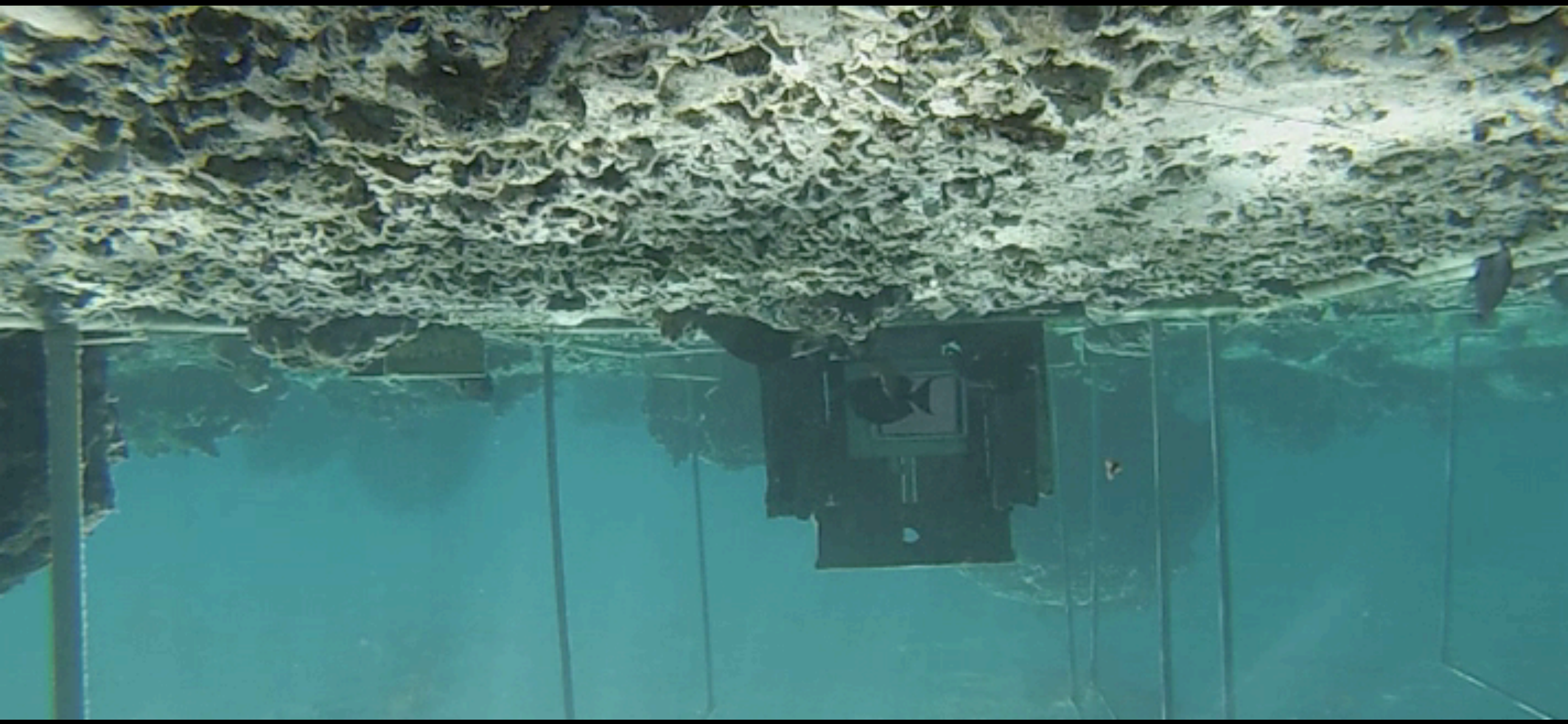


triggers escape response

Temizer et al. 2015 Curr. Biol., Dunn et al. 2016 Neuron





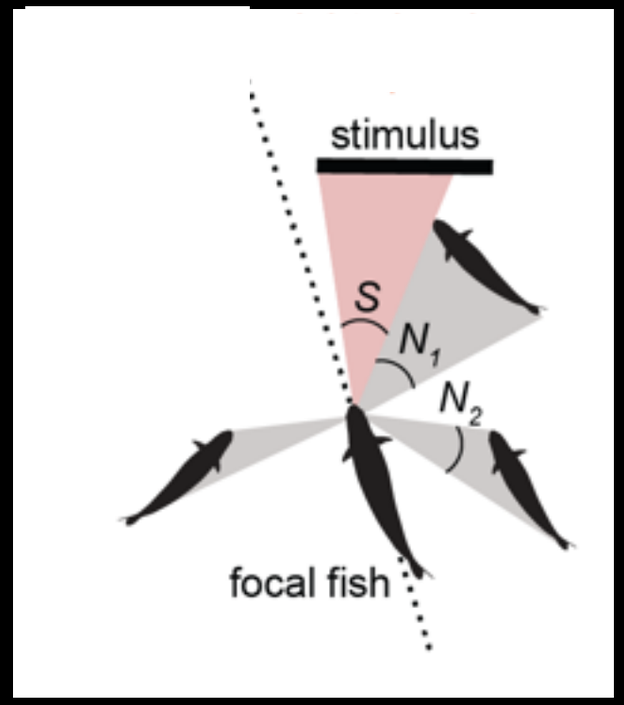


The nature of information flow

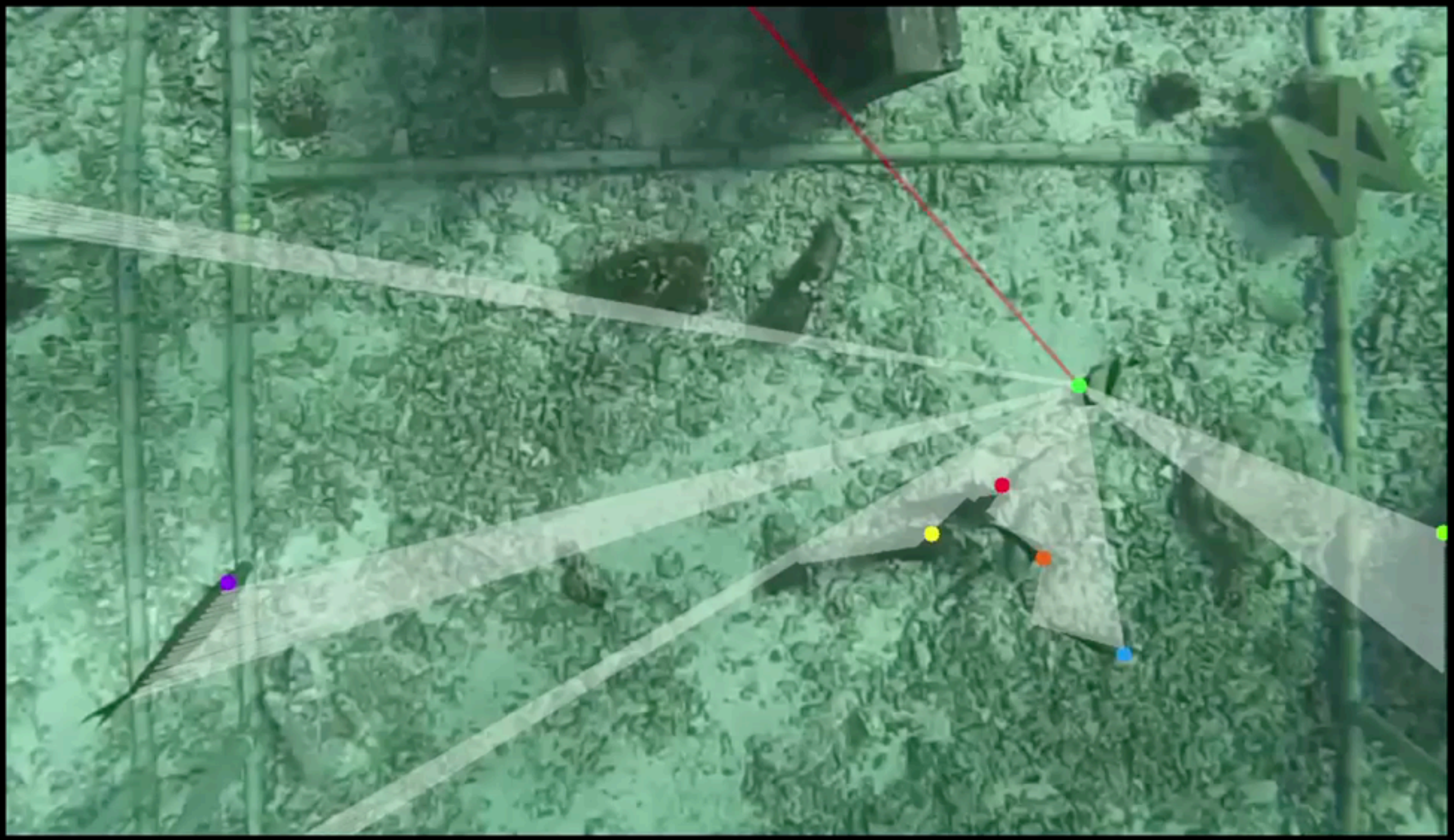
Data about threat transmitted through visual cues

What is the processing algorithm (decision rule) that transforms data into action?

Need to know exactly what fish saw



Sensory reconstruction



A decision-making circuit for threat response

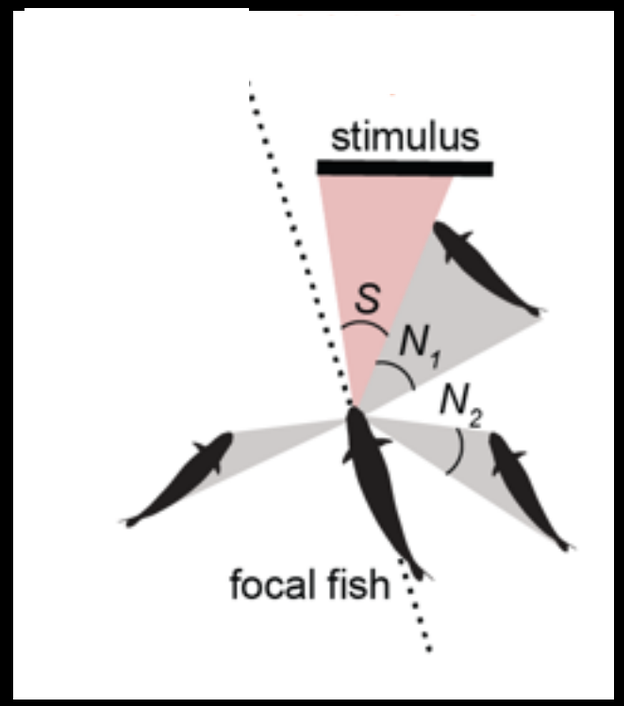
loom expansion rate

$$D(t) = \kappa_1 S' \exp(-\kappa_2 S - \kappa_3 N)$$

$k_i > 0$ are constants

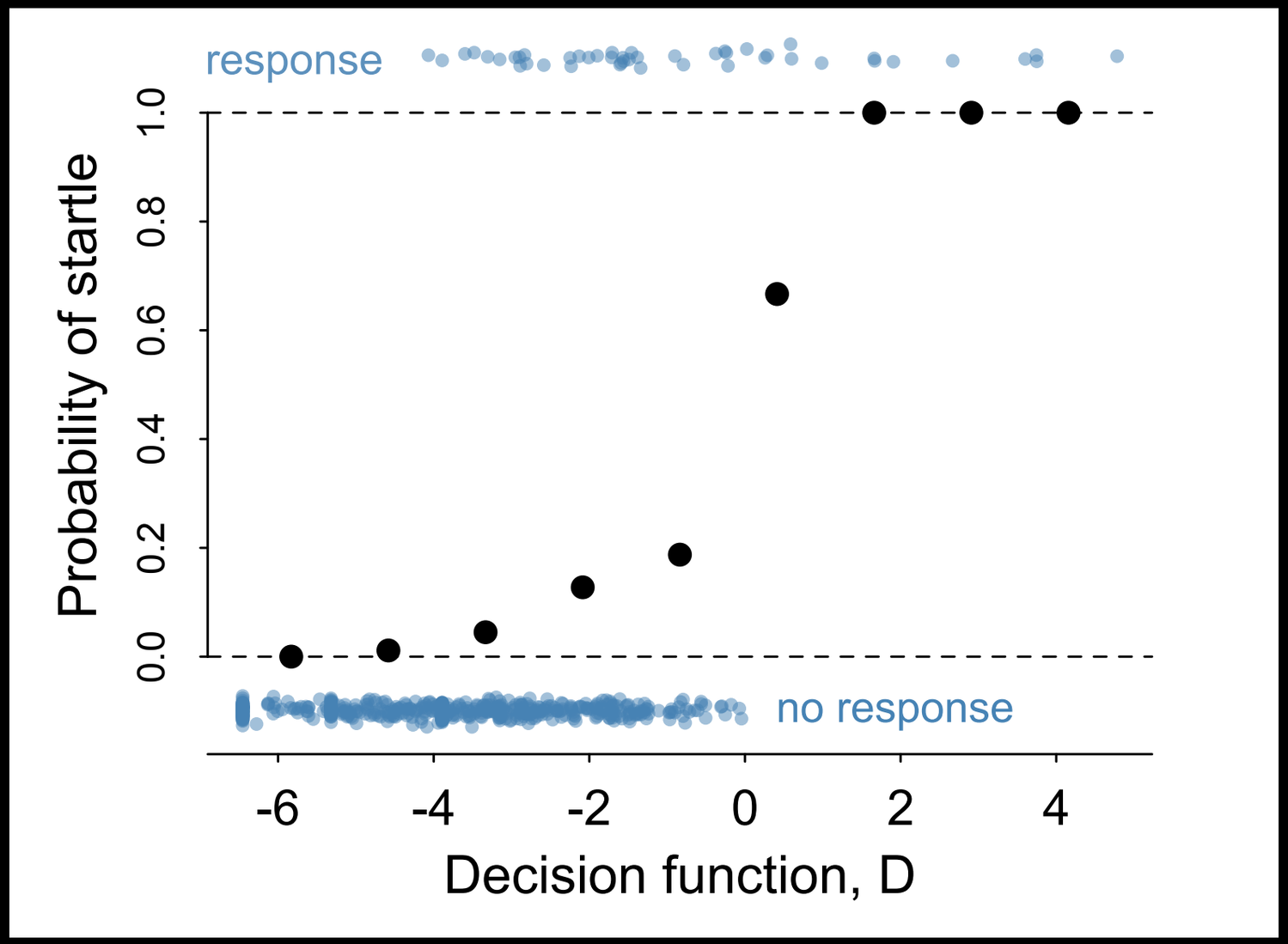
loom size

visual area occupied by neighboring fish



Mechanism for response rescaling from previous experiment

A decision-making circuit for threat detection



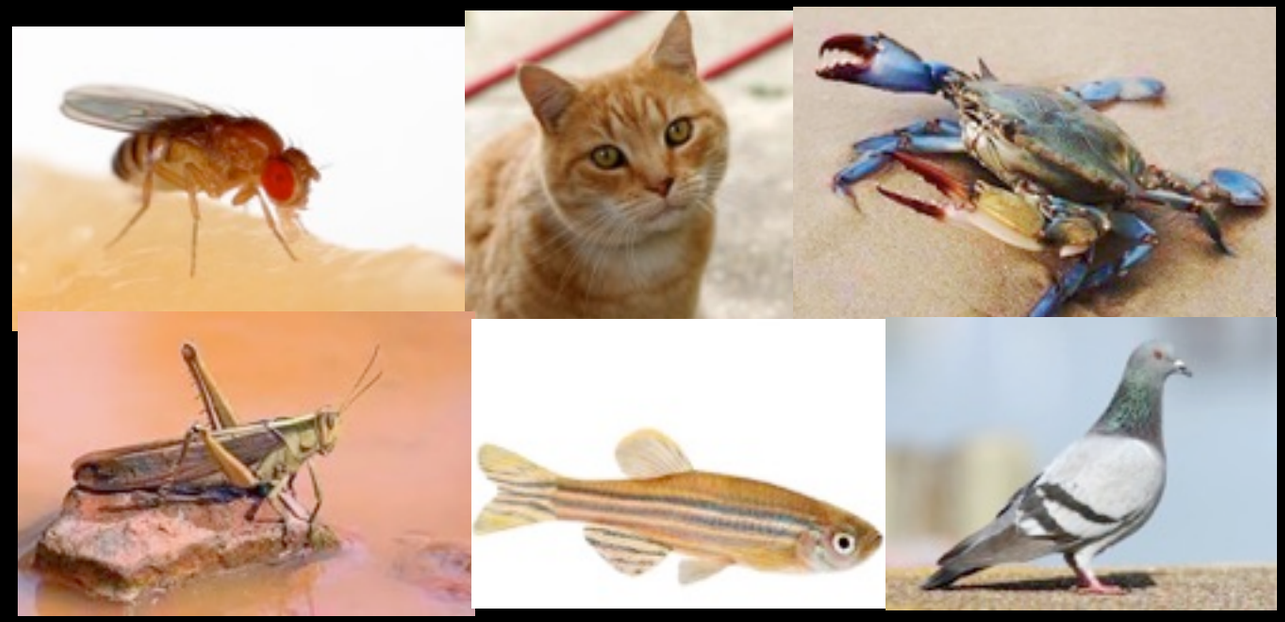
Correctly classifies
82-97% of responses
out of sample

$$D(t) = \kappa_1 S' \exp(-\kappa_2 S - \kappa_3 N)$$

Same rule applies to 12 species in 9 families

We weren't the first to find this decision rule

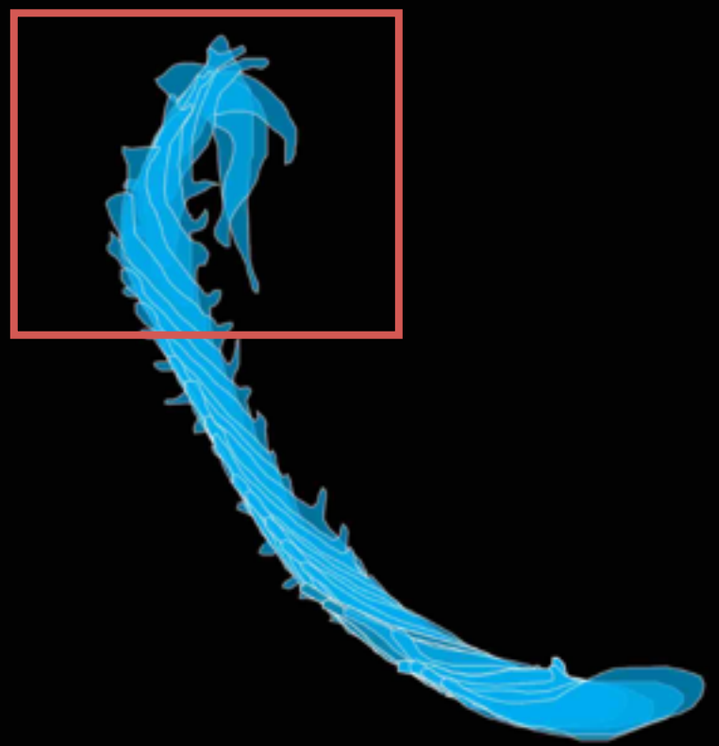
$$D(t) = k_1 S' \exp(-k_2 S)$$

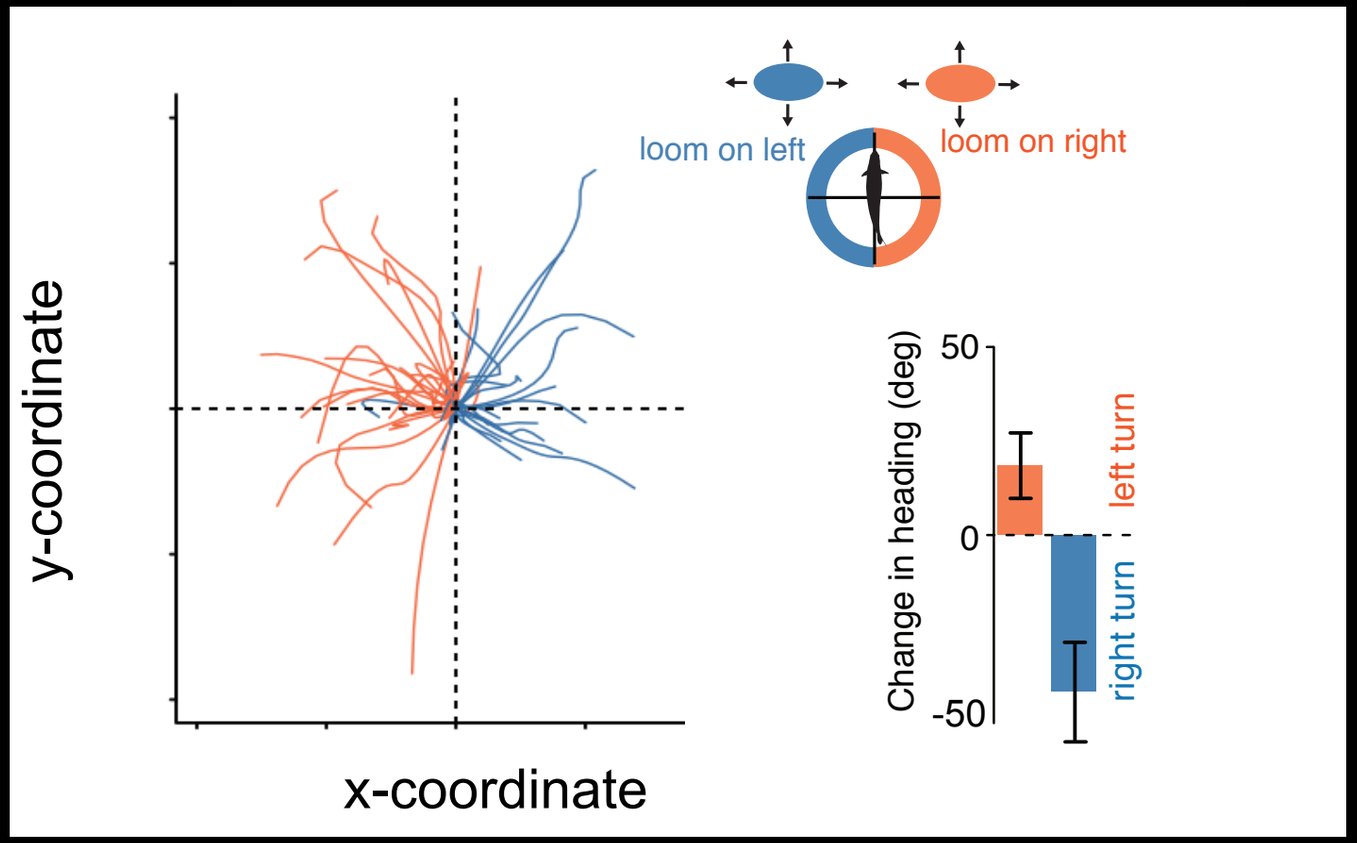


Conserved algorithm translates data into escape responses

Hatsopolous et al. 1995, Fotowat & Gabbiani 2011, Peek & Card 2016

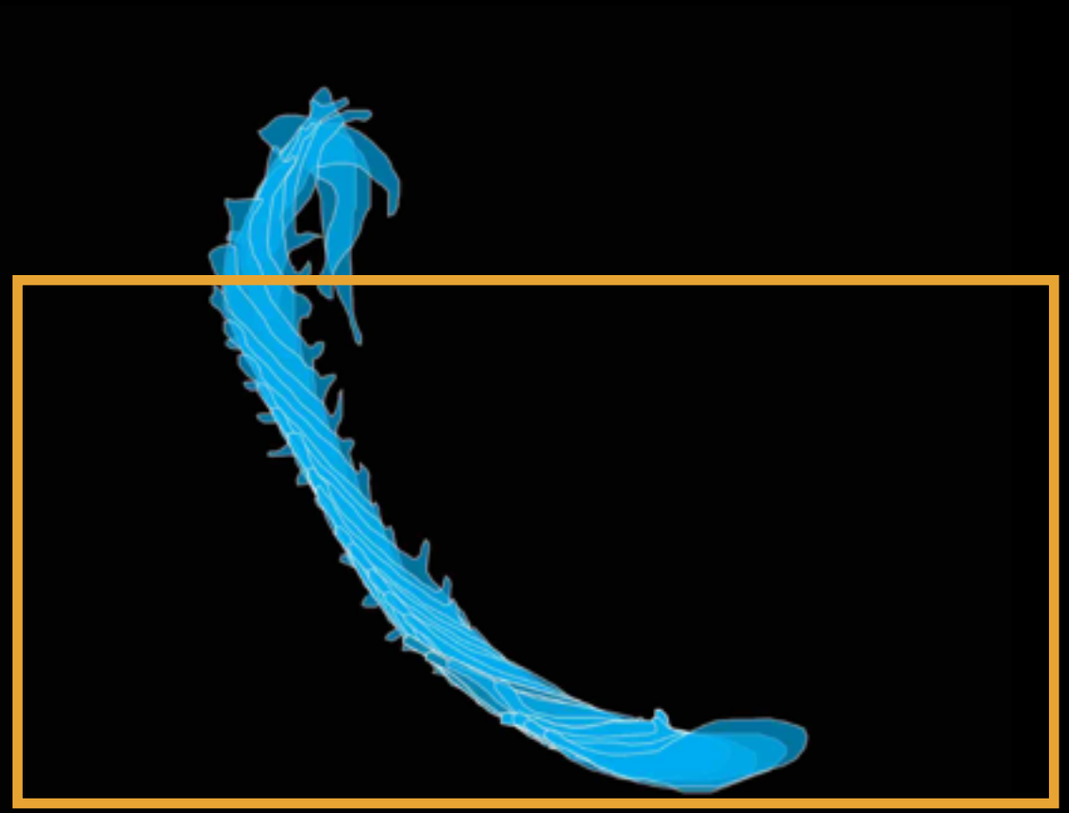
A nod to Navigation

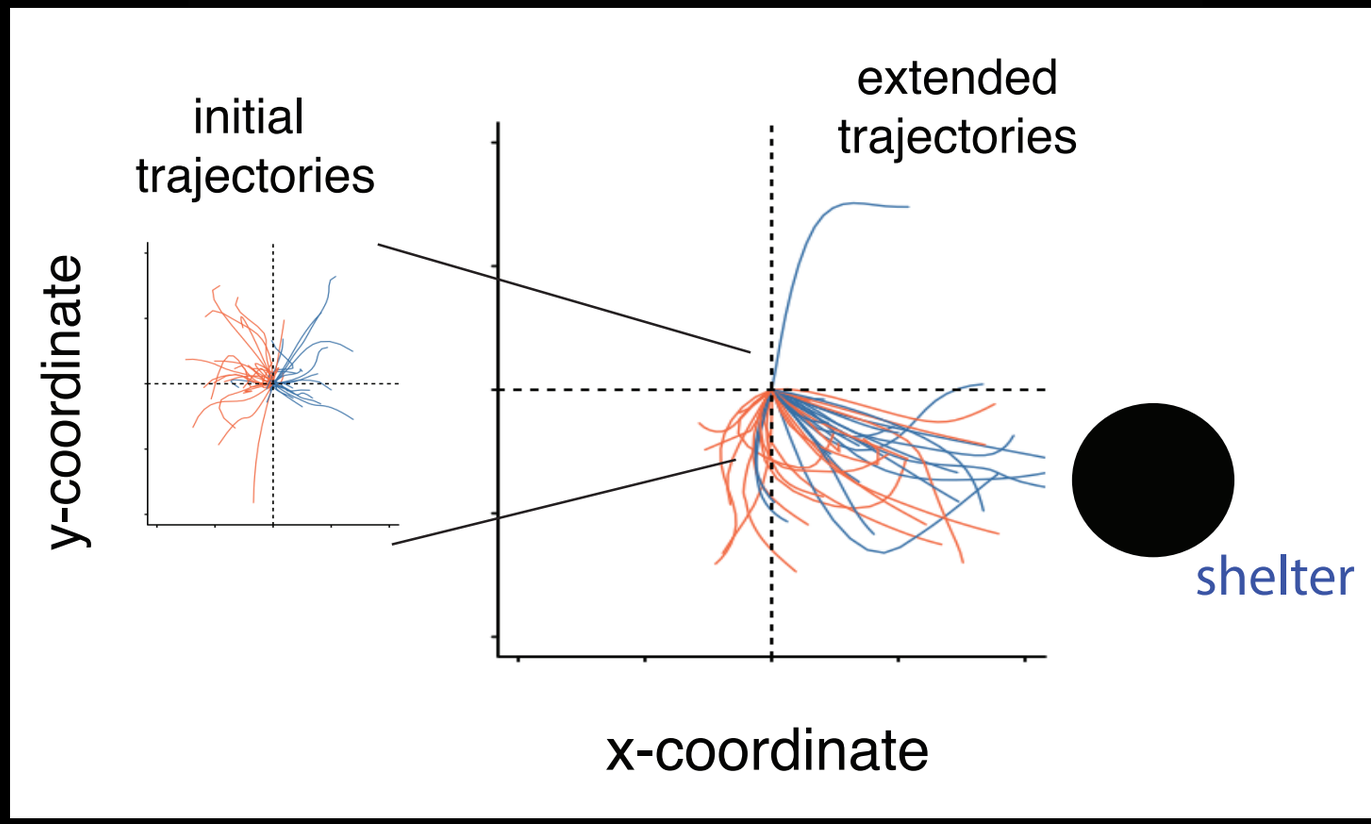




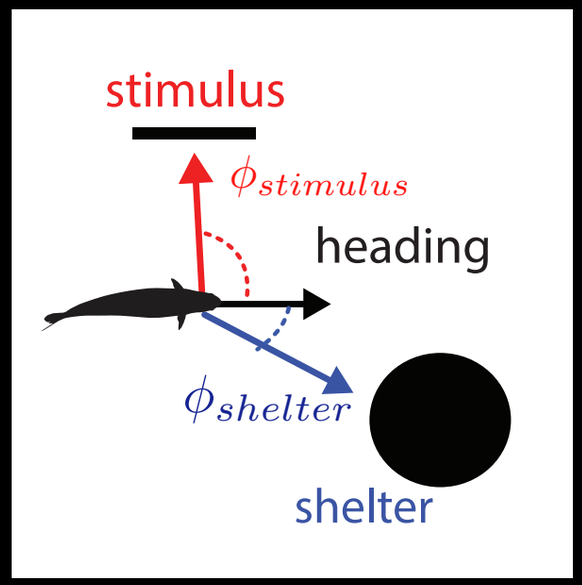
Dunn et al. 2016
Neuron

Transition in trajectory control

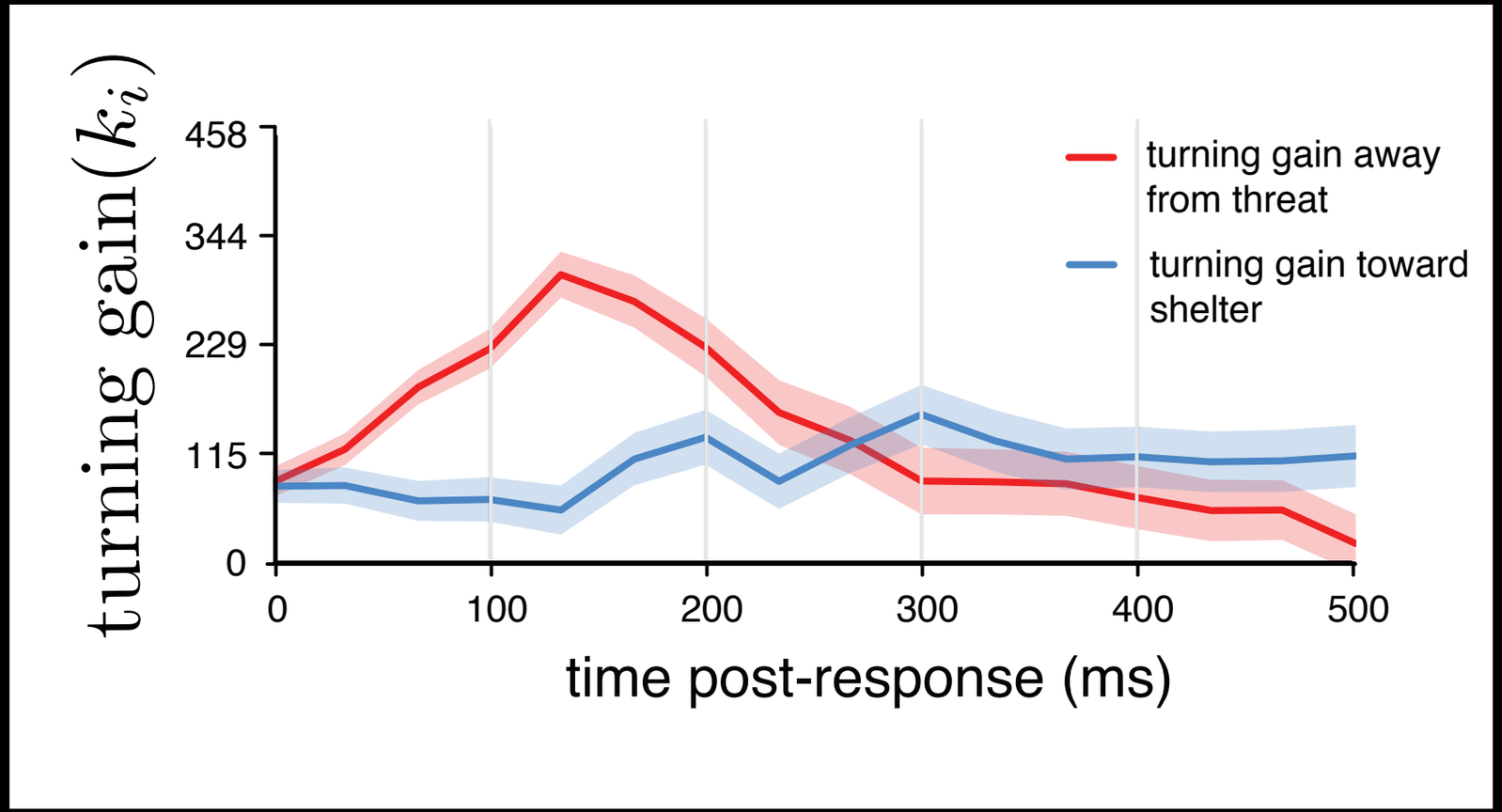




Dynamic gain control



$$\frac{d\theta}{dt} = k_0(t)\phi_{shelt}(t) - k_1(t)\phi_{stim}(t)$$



Decision-making in an ecological system

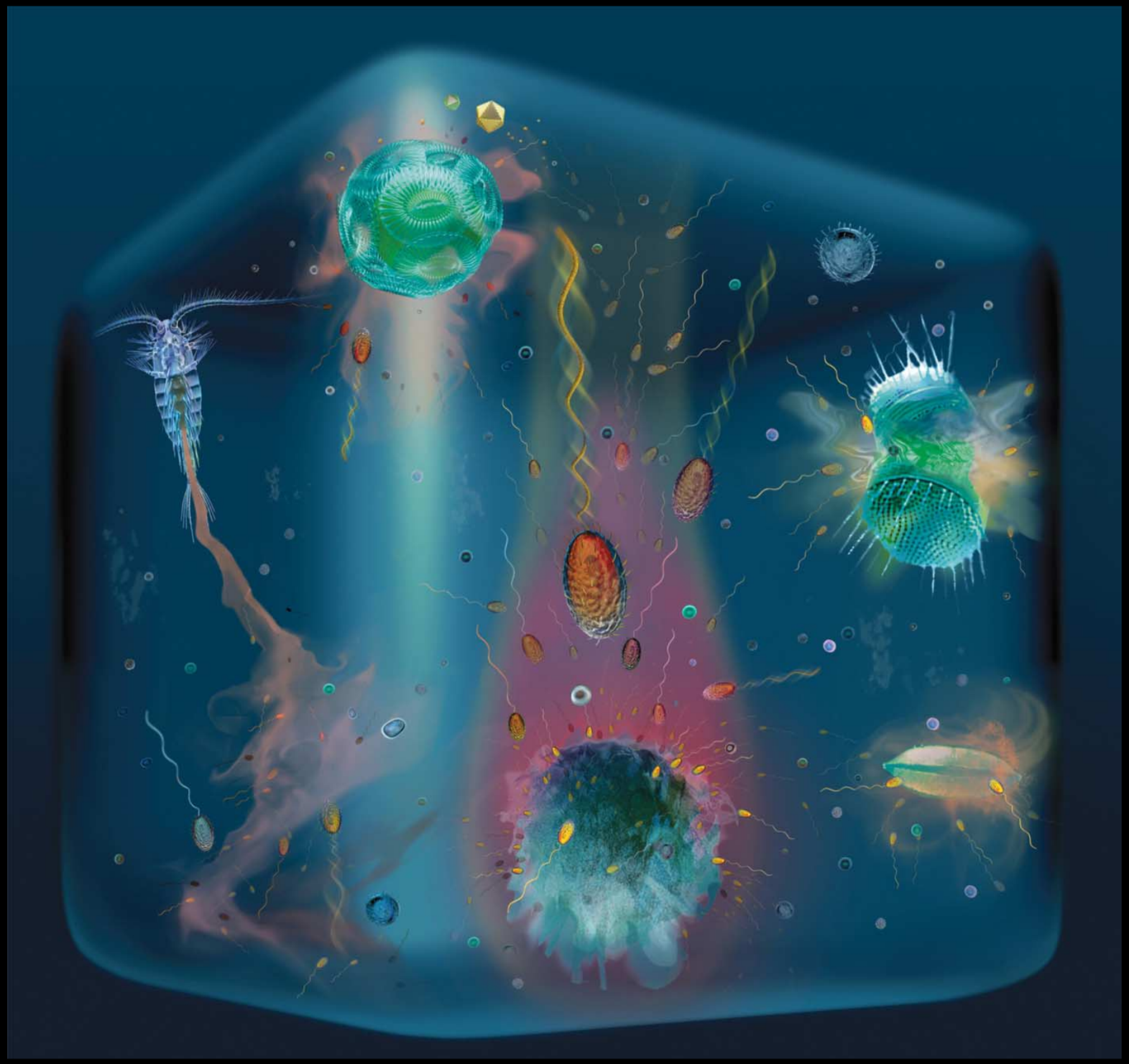
- Individual and collective computations simultaneous

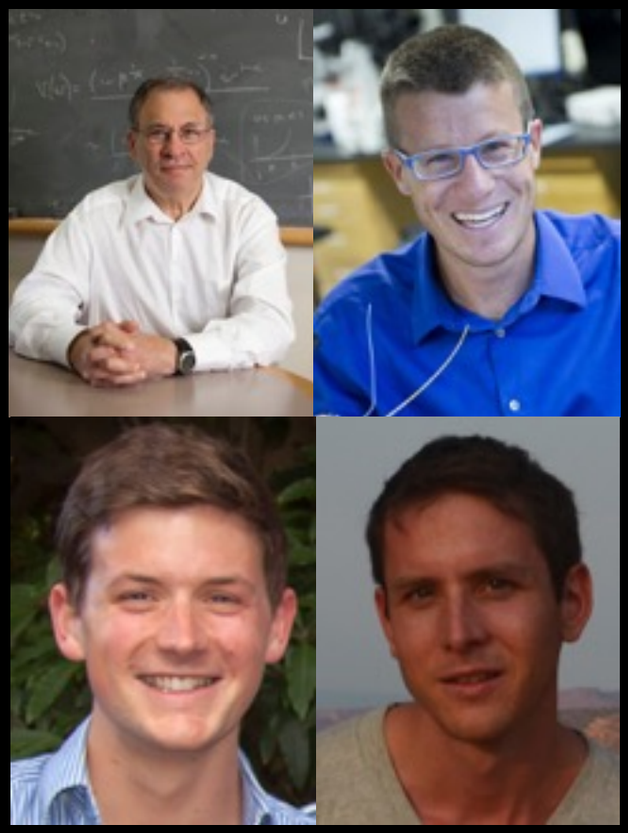
- Multi-objective navigation

- Response rescaling, gain control

- Specific neural circuits implicated (M-cell)

Bacterial navigation in dynamic seascapes

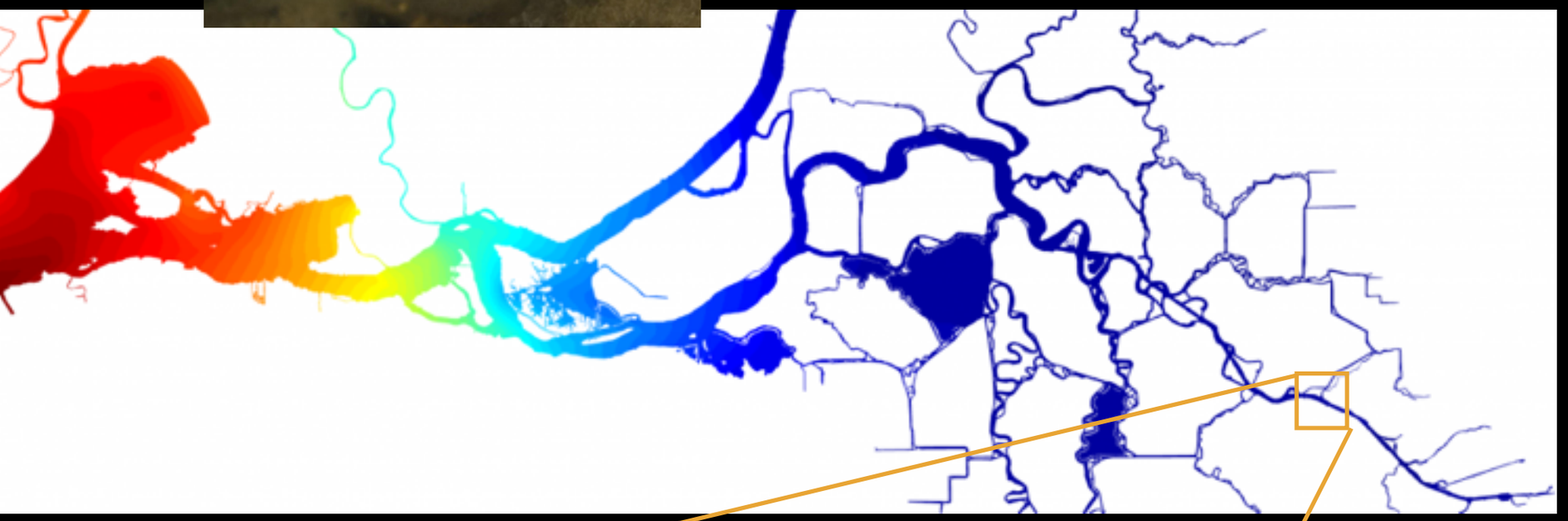




Simon Levin
Roman Stocker
Francesco Carrara
Doug Brumley

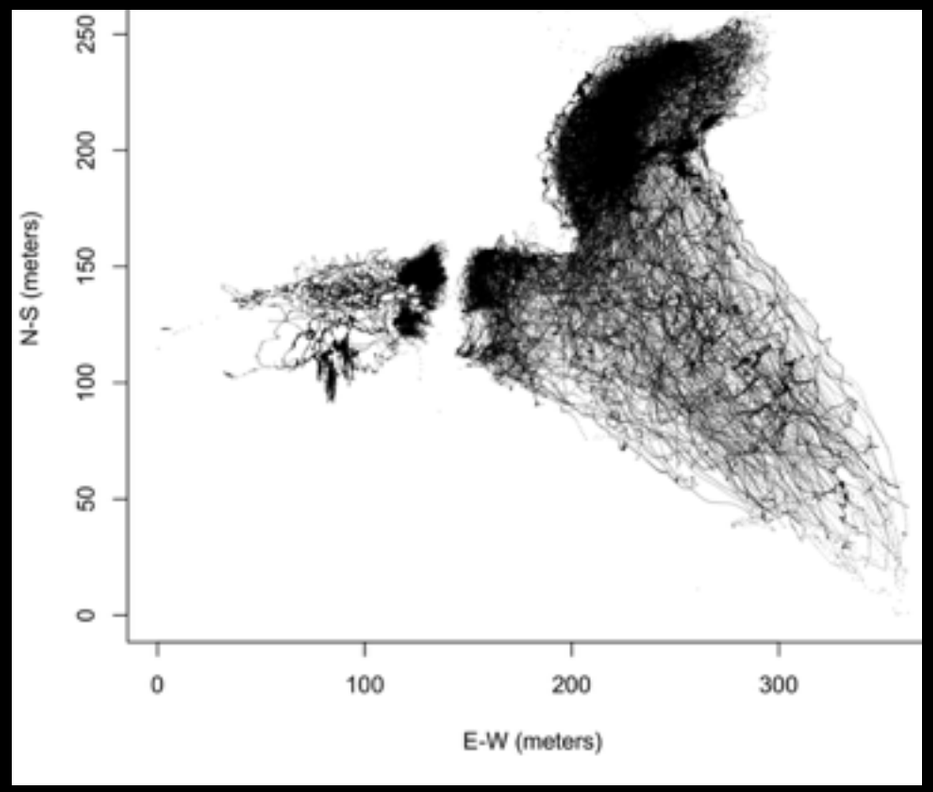
Brumley et al. *in prep,* Hein et al. 2016 *JRS Interface*, Hein et al. 2016 *PNAS*

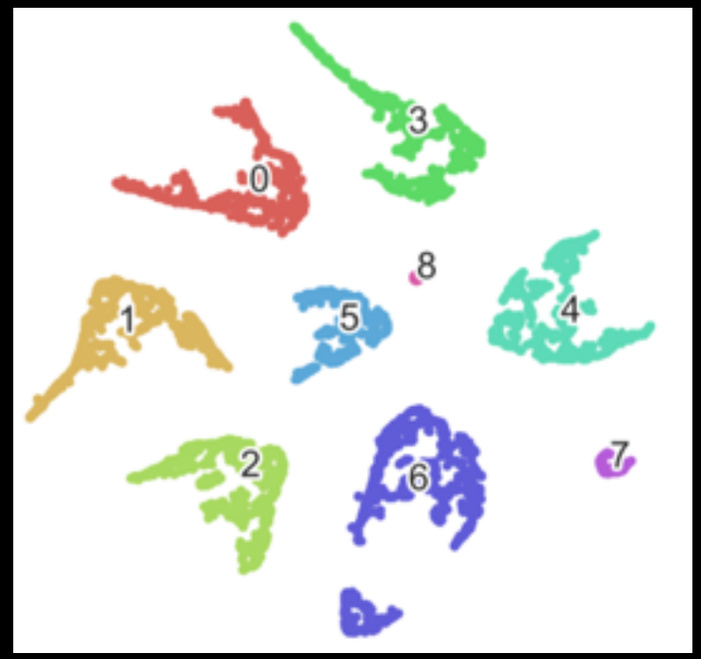
Fish navigation through rivers and estuaries



Natnael Hamda
Vamsi Sridharan

Fish navigation through rivers and estuaries: behavioral repertoire mapping



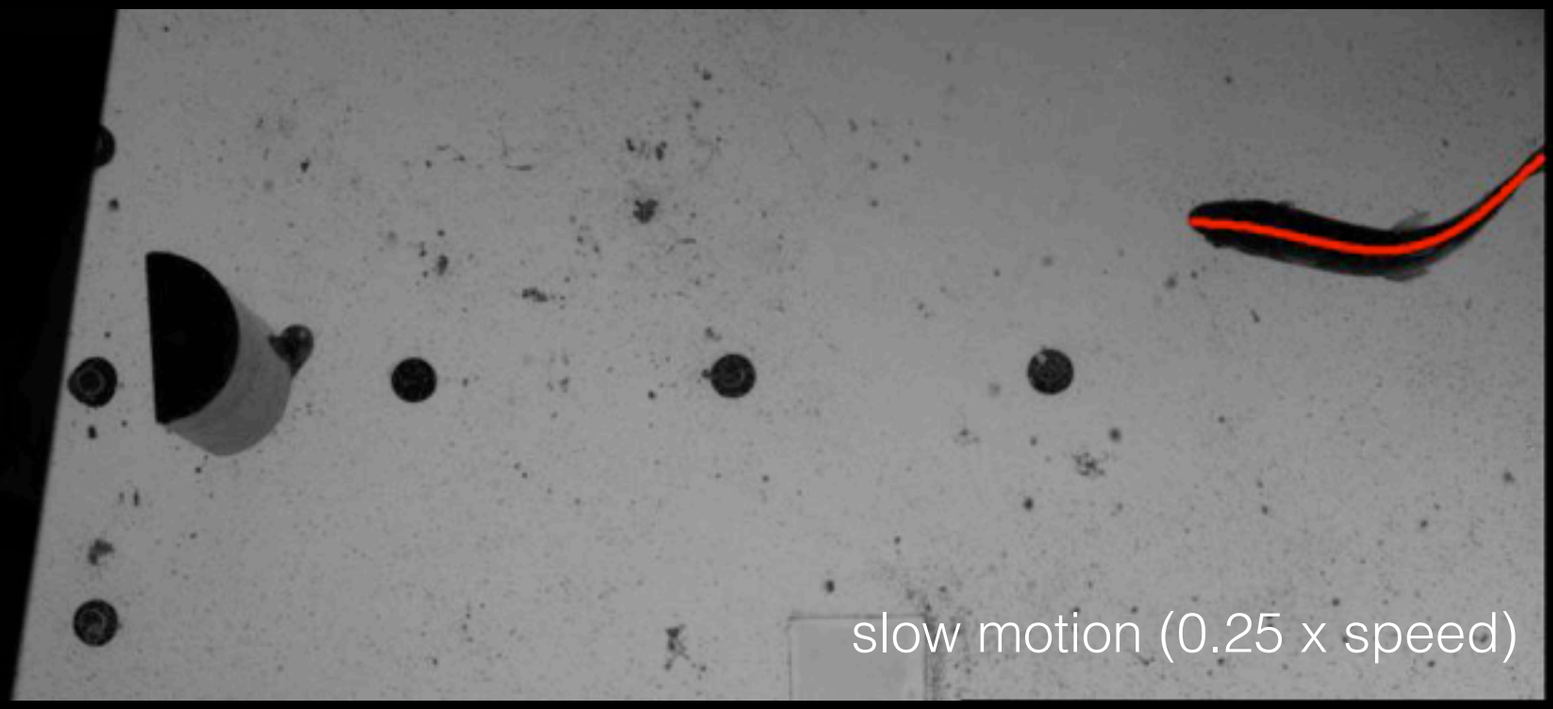


Natnael Hamda
Vamsi Sridharan

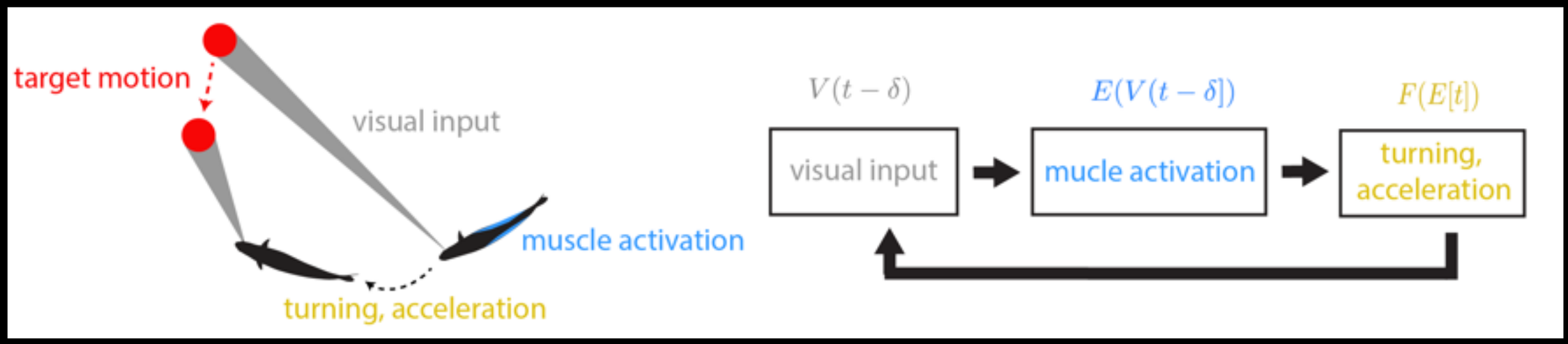
Berman et al.
2014, 2016

DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA

Behavioral control during attack and evasion in turbulence



Jimmy Liao
Ben Martin
Steve Munch



Untangling the bank

behavior, decision-making, information processing

Algorithms

image credit: kearley.co.uk, MBaquarium.org, getty.com, falconphotos.com

Collaborators

Mike Gil (UC Davis)
Colin Twomey (U Penn)
Brin Rosenthal (UCSD)
Iain Couzin (Max Planck)
Ben Martin (UCSC NOAA)
Simon Levin (Princeton, EEB)
Roman Stocker (ETH Zurich, Engineering)
Francesco Carrara (ETH Zurich)
Doug Brumley (U Melbourne)
Steve Munch (UCSC NOAA)
Jimmy Liao (UF)

James S. McDonnell Foundation

NSF

SIMONS FOUNDATION

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE