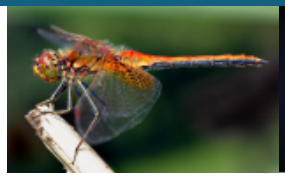
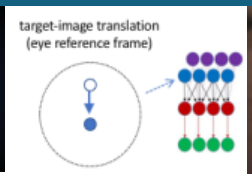
Sandia National Laboratories

SAND2021-5214PE

Not all computer bugs are bad: Looking to insects for neural-inspired computing





April 29, 2021

Frances S. Chance

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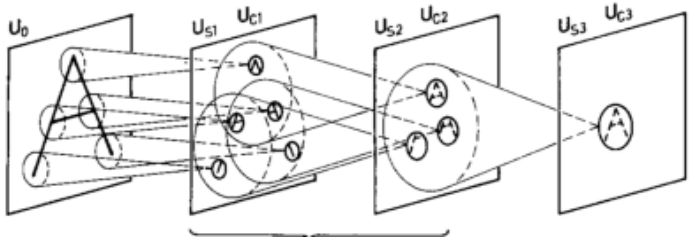
What do these animals have in common?

Neuroscience and computing



Fukushima, 1980

DeepMind

Neuroscience and computing

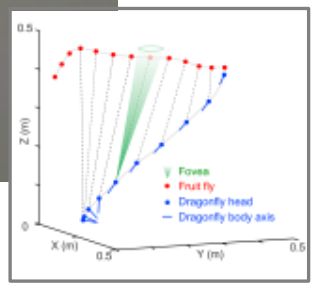
Interception

Common behavior in animals…

(Image: Wikipedia)


(Image: U. Oxford)


(Image: Westend61/Getty)



from Lin & Leonardo 2017

Why dragonflies?

Dragonflies are good at hunting (90-95% capture rate)

When hunting, dragonflies intercept their prey

Underlying neural circuitry is relatively simple

Dragonflies are fast

Why dragonflies?

Dragonflies are good at hunting (90-95% capture rate)

When hunting, dragonflies intercept their prey

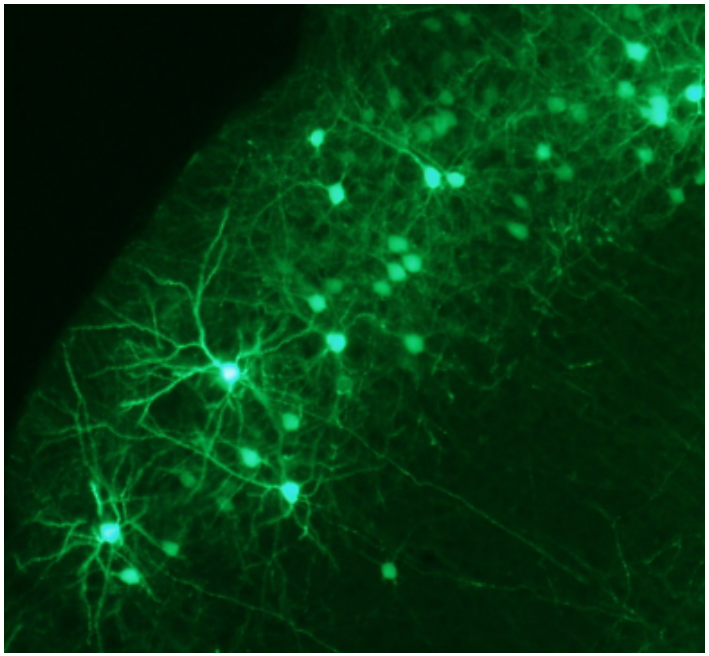
Underlying neural circuitry is relatively simple

Dragonflies fly fast (10-30 mph, fastest recorded was 60 mph)

Visual system is fast (equivalent to 200-300 fps) but poor spatial resolution (compared to humans)

The neural circuit computes interception fast

Why dragonflies?



Timescales of dragonfly interception computation

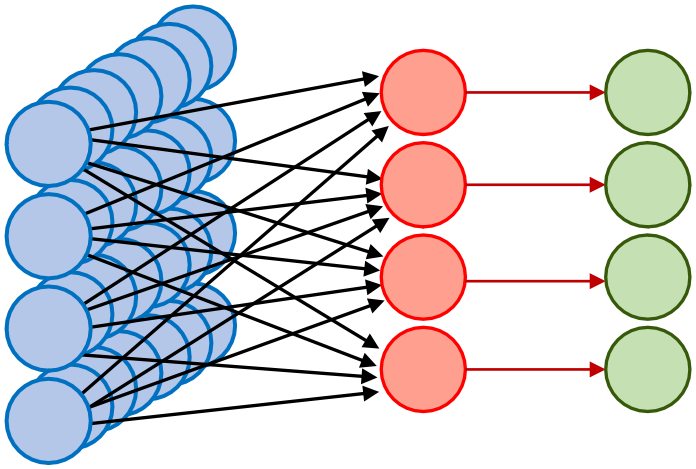
Latency to react to a prey maneuver: 50 ms

Time scales of a neurobiological system

Synaptic transmission: 1-5 ms

Neuronal integration: 10-50 ms

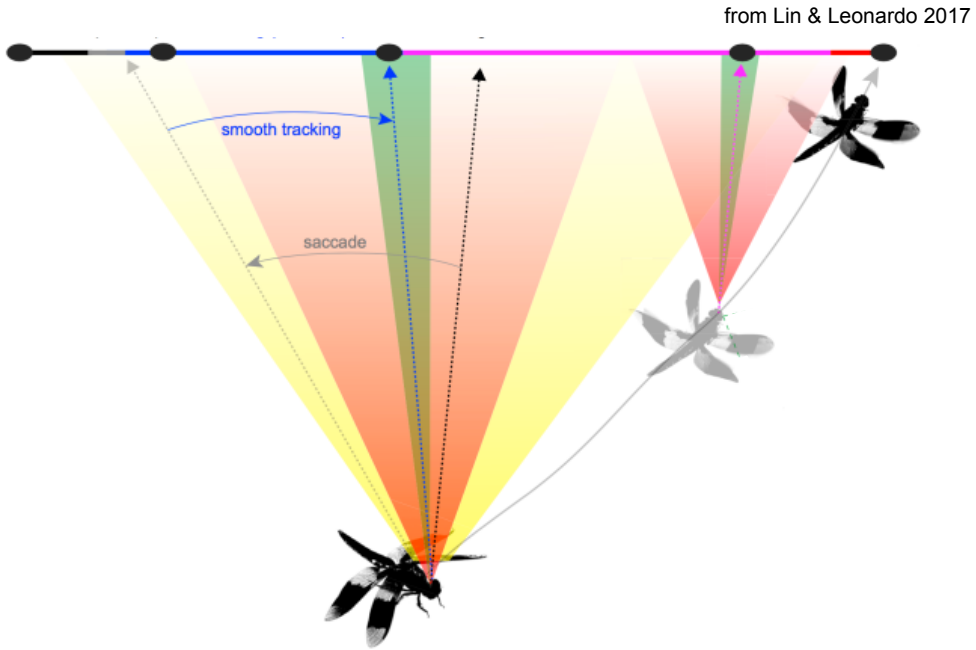
Muscle contraction: 5 ms to produce force



Underlying neural circuitry: 2-4 layer neural network?

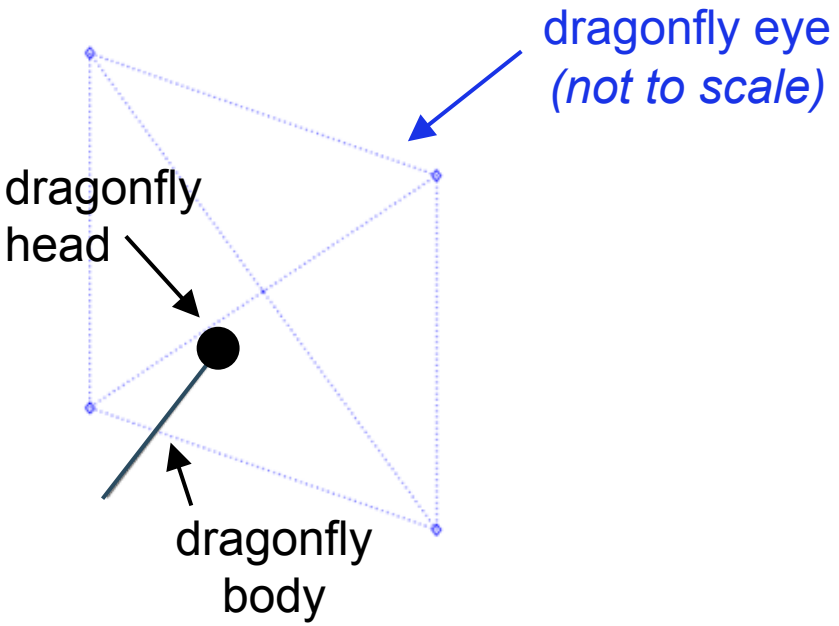
Building a dragonfly model

We know dragonflies keep the prey-image on a specific location on the eye…

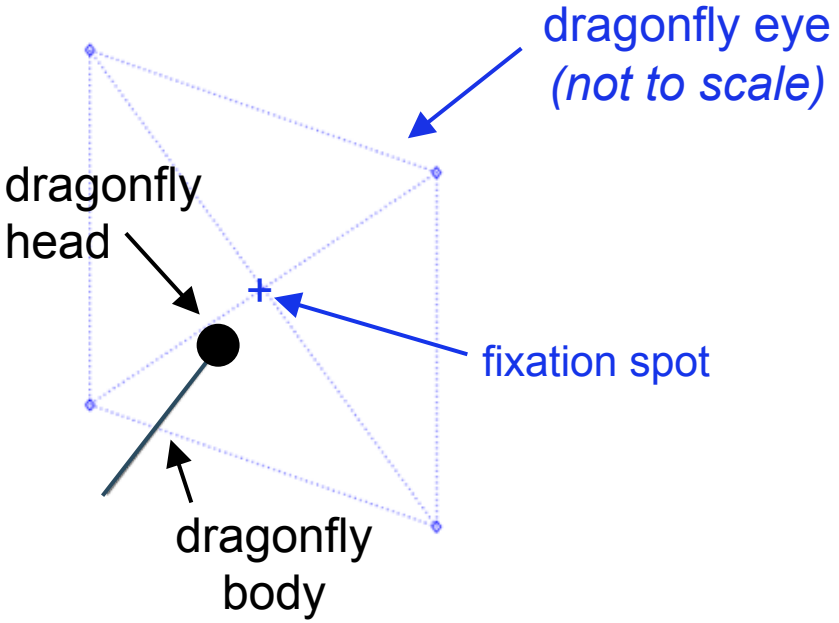


Does dragonfly interception equal holding prey-image at that location?

Building a dragonfly model

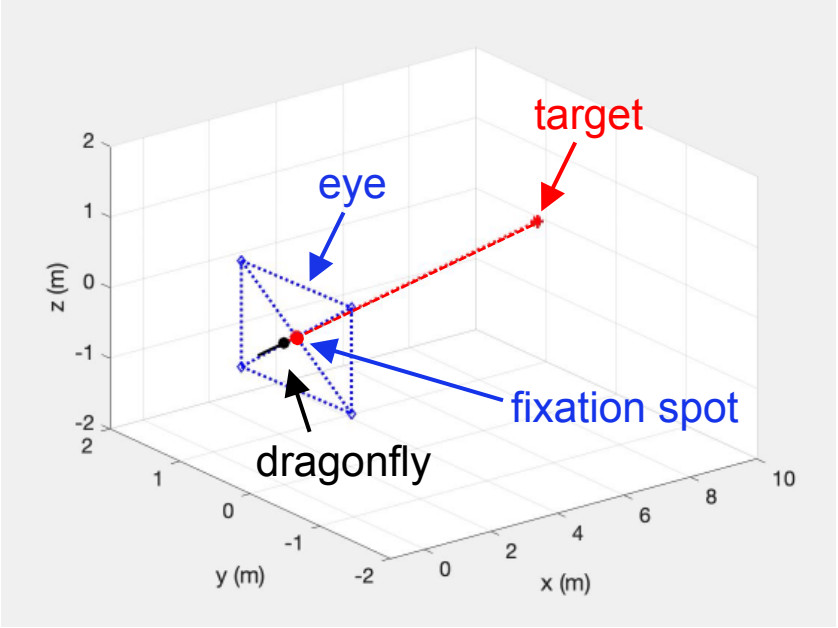


Building a dragonfly model



Model dragonfly turns to keep prey-image on a “fixation spot”

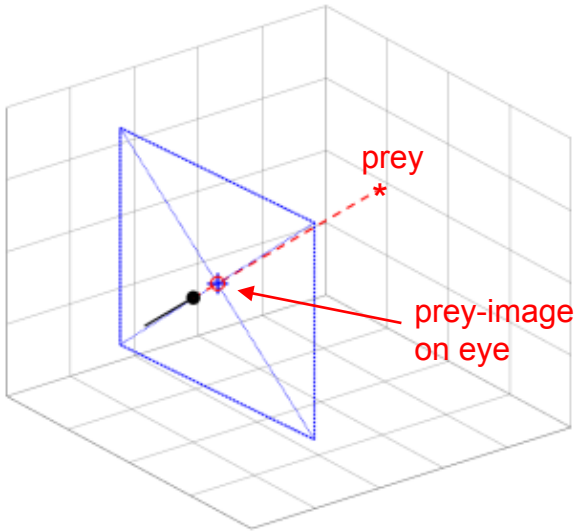
Building a dragonfly model

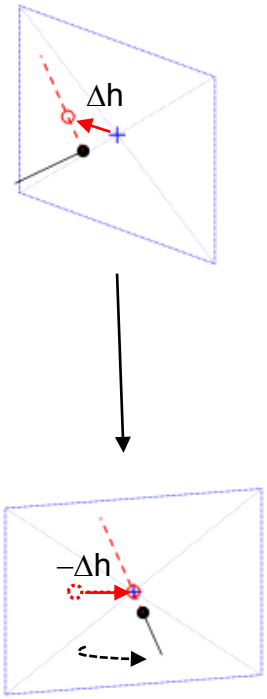


dragonfly-centered reference frame

Model dragonfly turns to keep prey-image on a “fixation spot”

Building a dragonfly model



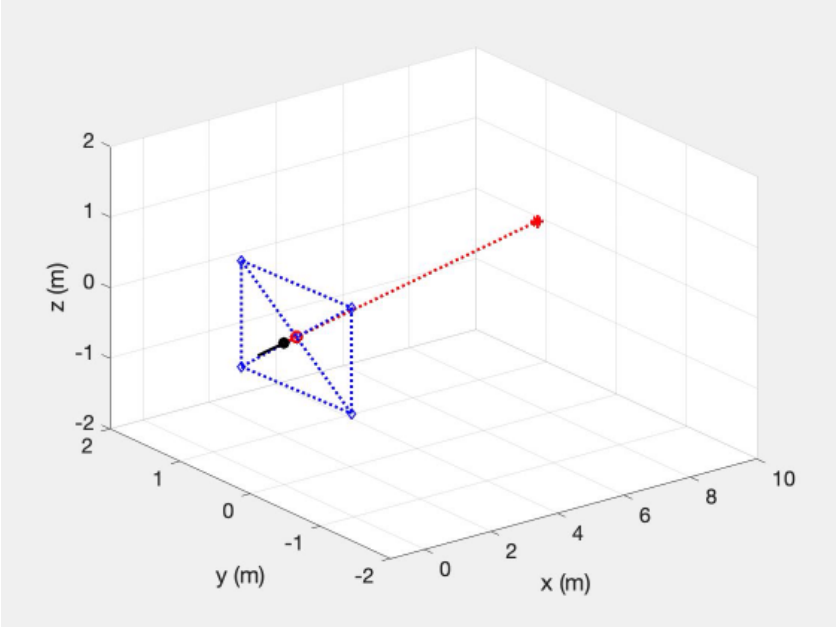


As the prey moves, prey image slips by Δh

Dragonfly turns to re-align prey image with fixation spot

Prey image translation = -Δh

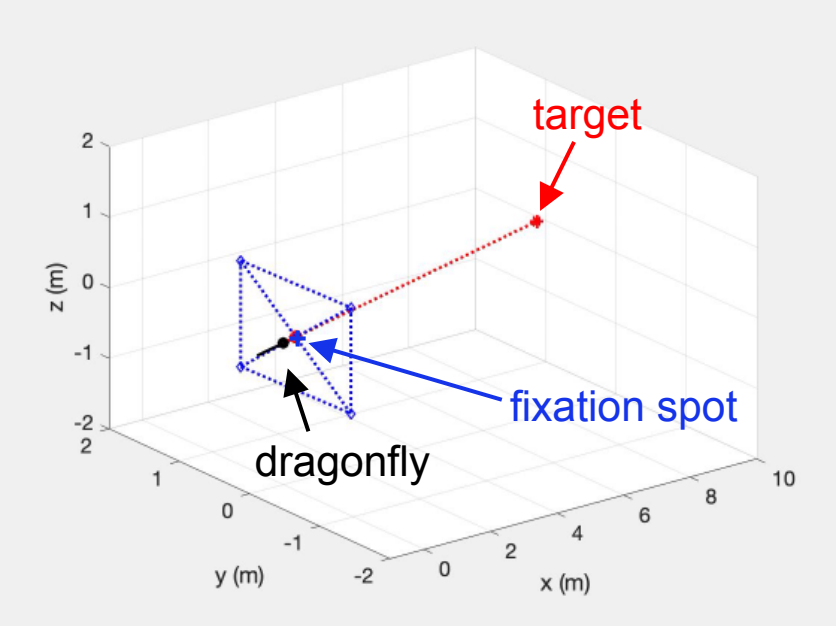
Building a dragonfly model



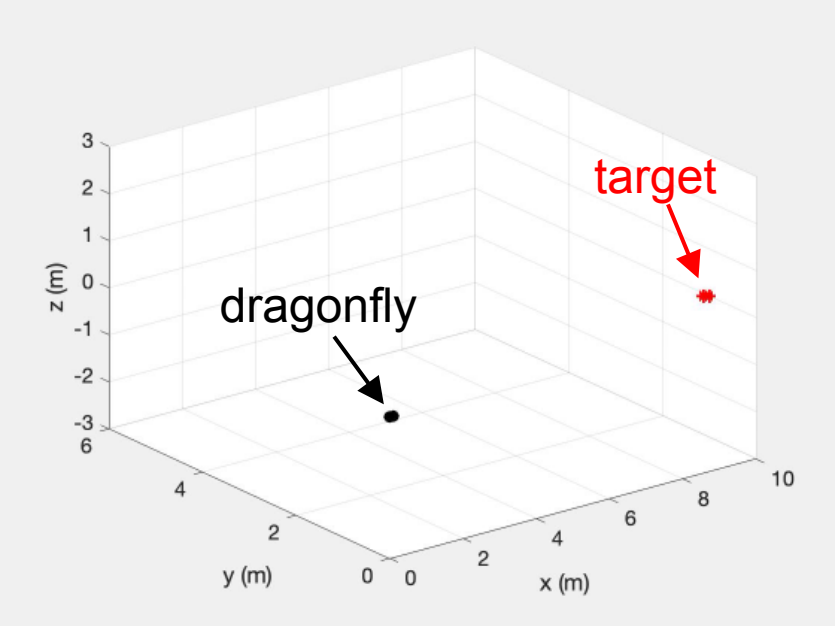
dragonfly-centered reference frame

dragonfly and prey move at the same speed, with the same maneuverability

Building a dragonfly model



dragonfly-centered reference frame



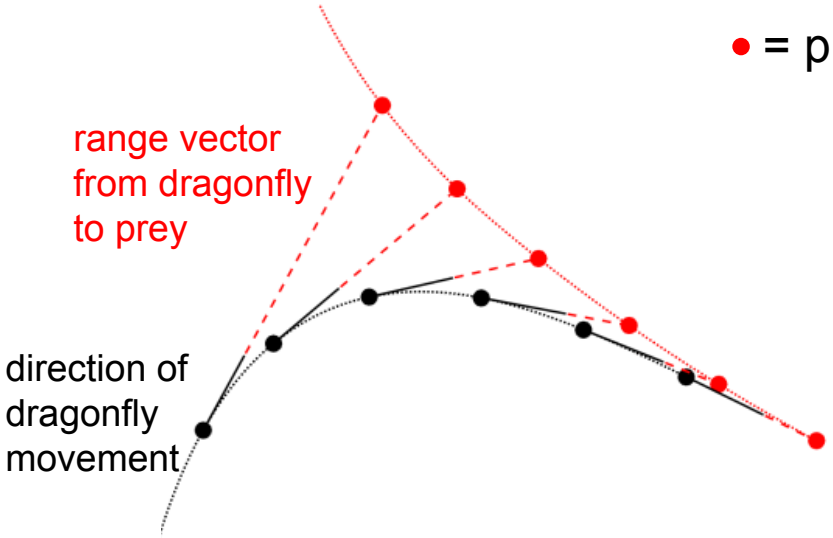
real-world reference frame

This behavior is known as “classical pursuit”

What is pursuit?

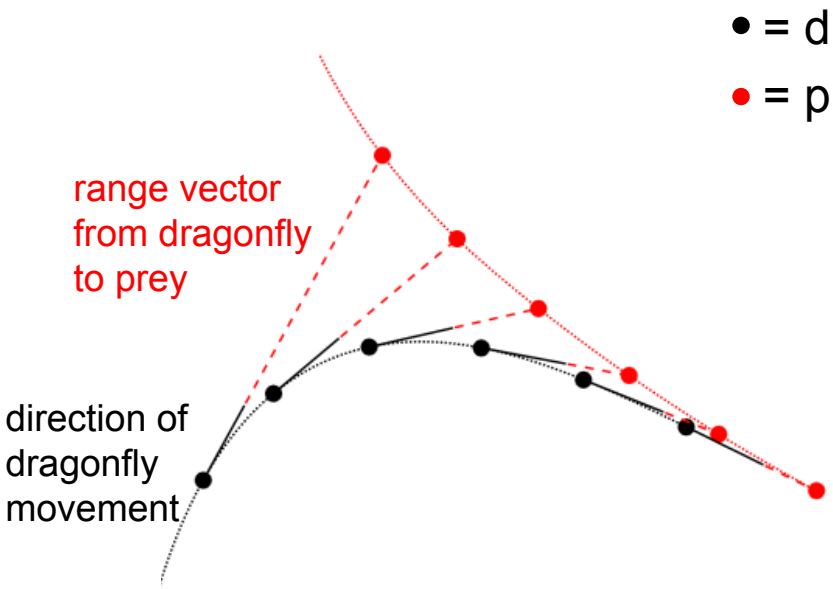
● = dragonfly

● = prey

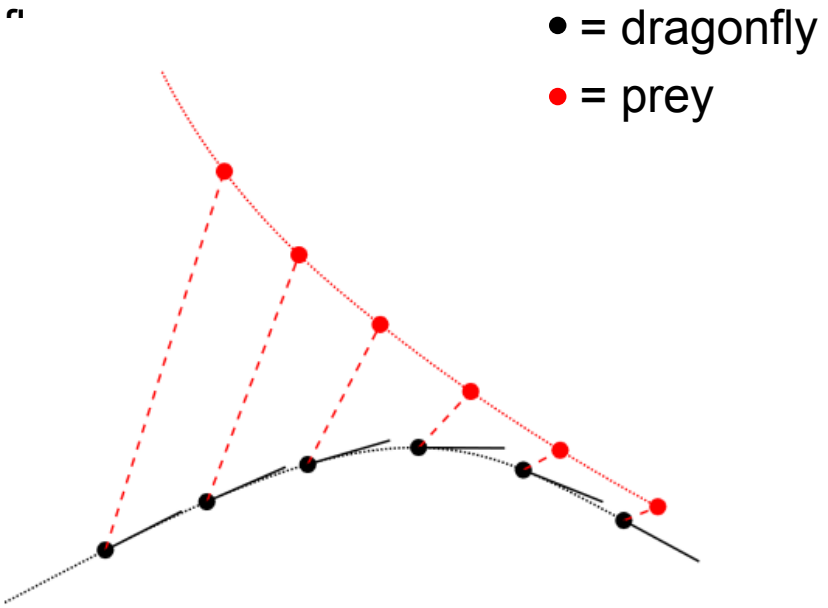


Classical pursuit
range vector = direction of movement

What is pursuit?

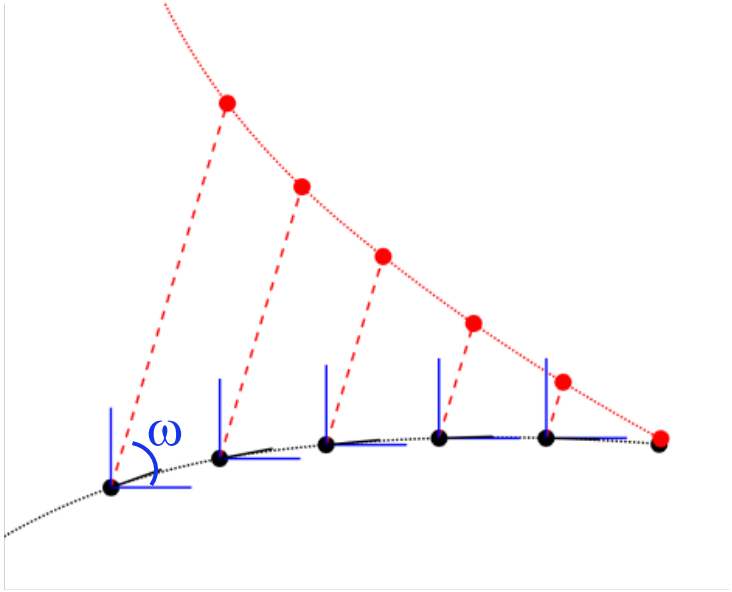


Classical pursuit
range vector = direction of movement



Deviated pursuit
constant angle between range vector and direction of movement

What is parallel navigation



Parallel navigation

aka constant-bearing decreasing-range
constant line-of-sight angle (relative to external reference frame)

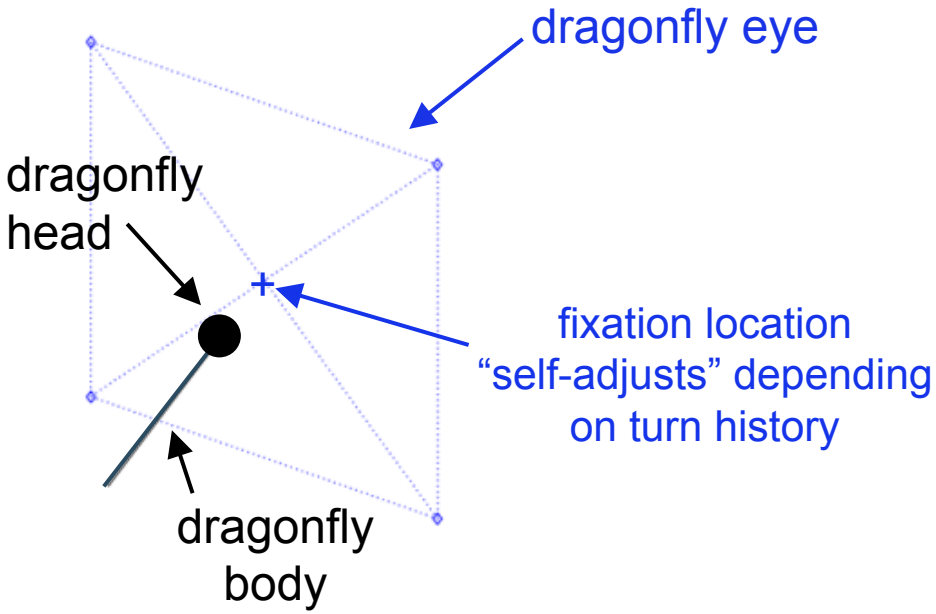
evidence that the dragonfly follows parallel navigation during final approach (Mischiati et al, 2015)

will produce the geometrically shortest path to interception if the prey is moving in a straight line

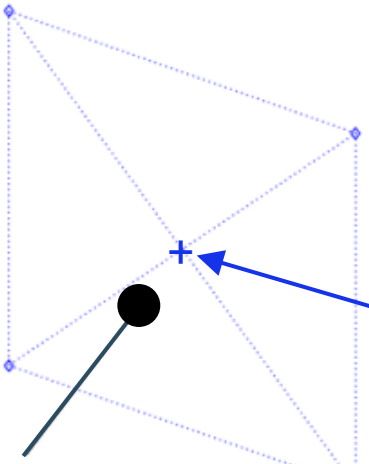
How does the dragonfly do parallel navigation

without an external reference?
- memory
- internal compass / IMU
- proprioception

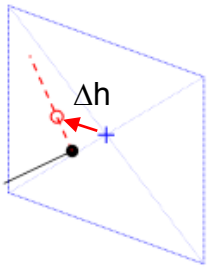
start with an abstracted model first



How does the dragonfly do parallel navigation

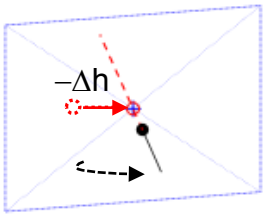


fixation spot location
"self-adjusts" depending
on turn history

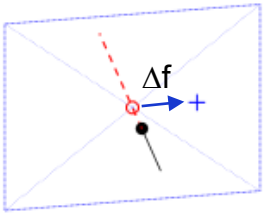


As the prey moves, prey image slips by Δh

Dragonfly turns to re-align prey image with fixation spot



Prey image translation = -Δh

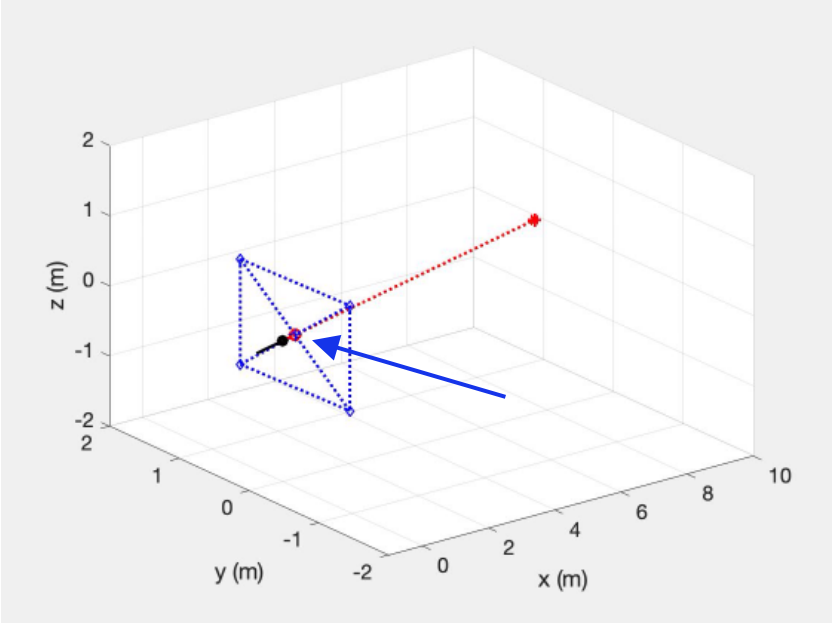


fixation spot is repositioned by $\Delta f = Q\Delta h$

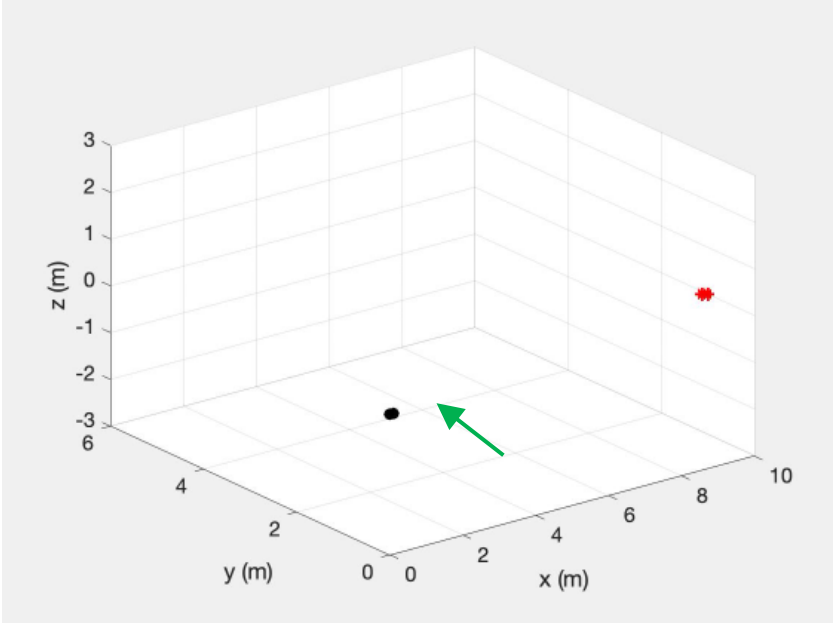
How does the dragonfly do parallel navigation

Fixation spot location “self-adjusts” depending on turn history

(initial condition: fixation spot at eye-center with dragonfly flying straight at target)



dragonfly-centered reference frame



real-world reference frame

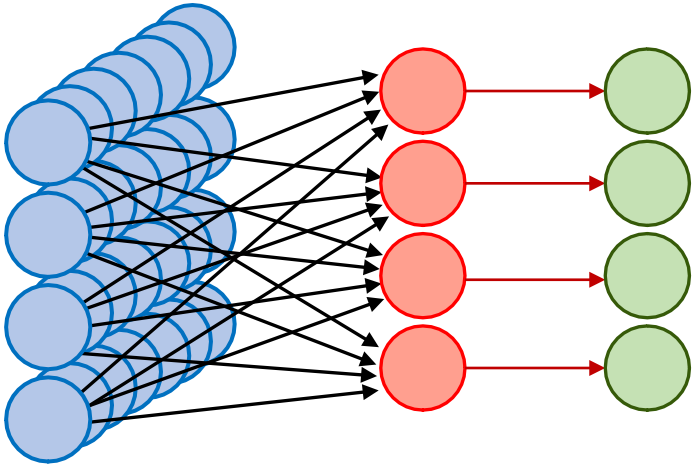
Does dragonfly interception equal holding prey-image at a specific location?

Yes (with location depending on self-knowledge of turns)

How does the dragonfly do parallel navigation

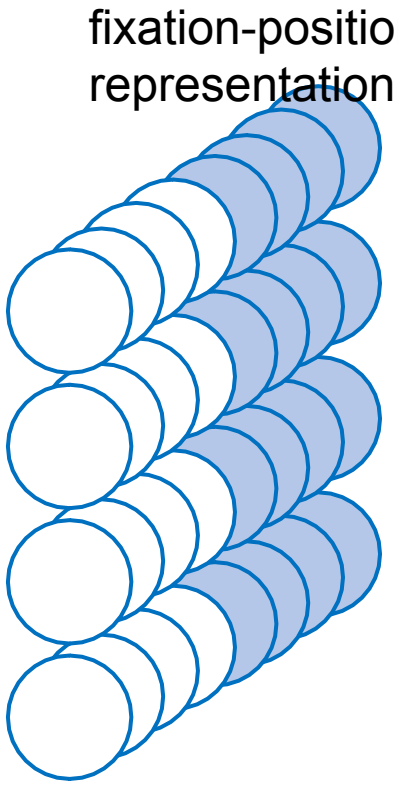
The model dragonfly can visual information without an external reference to implement parallel navigation

What does the underlying neural circuitry look like and how does it work?



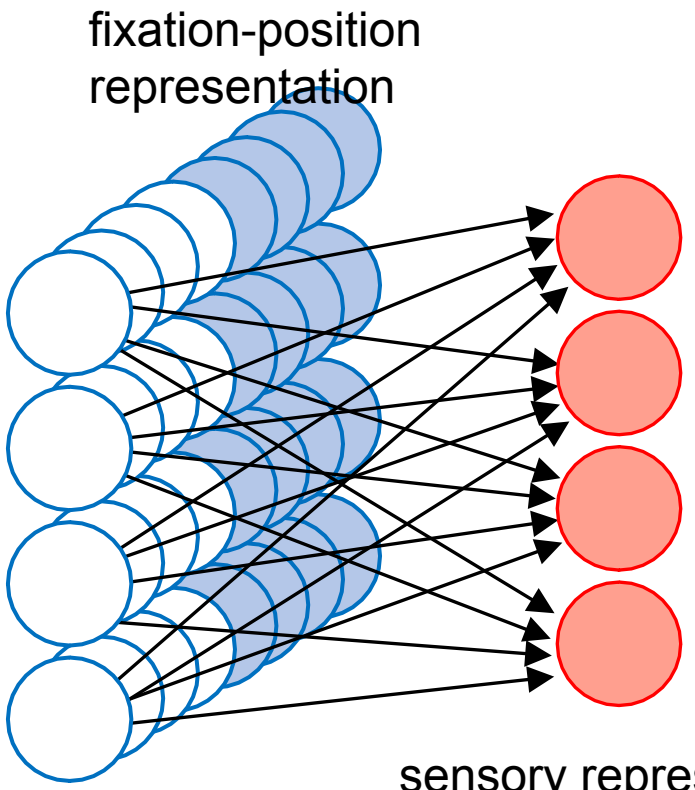
Underlying neural circuitry: 2-4 layer neural network?

Neural network model of dragonfly interception



$$f(x_1, x_2) = \exp\left(-\frac{(\mathrm{a}_1 - \mathrm{x}_1)^2 + (\mathrm{a}_2 - \mathrm{x}_2)^2)}{2\sigma_{\mathrm{r}}^2}\right)$$

Neural network model of dragonfly interception

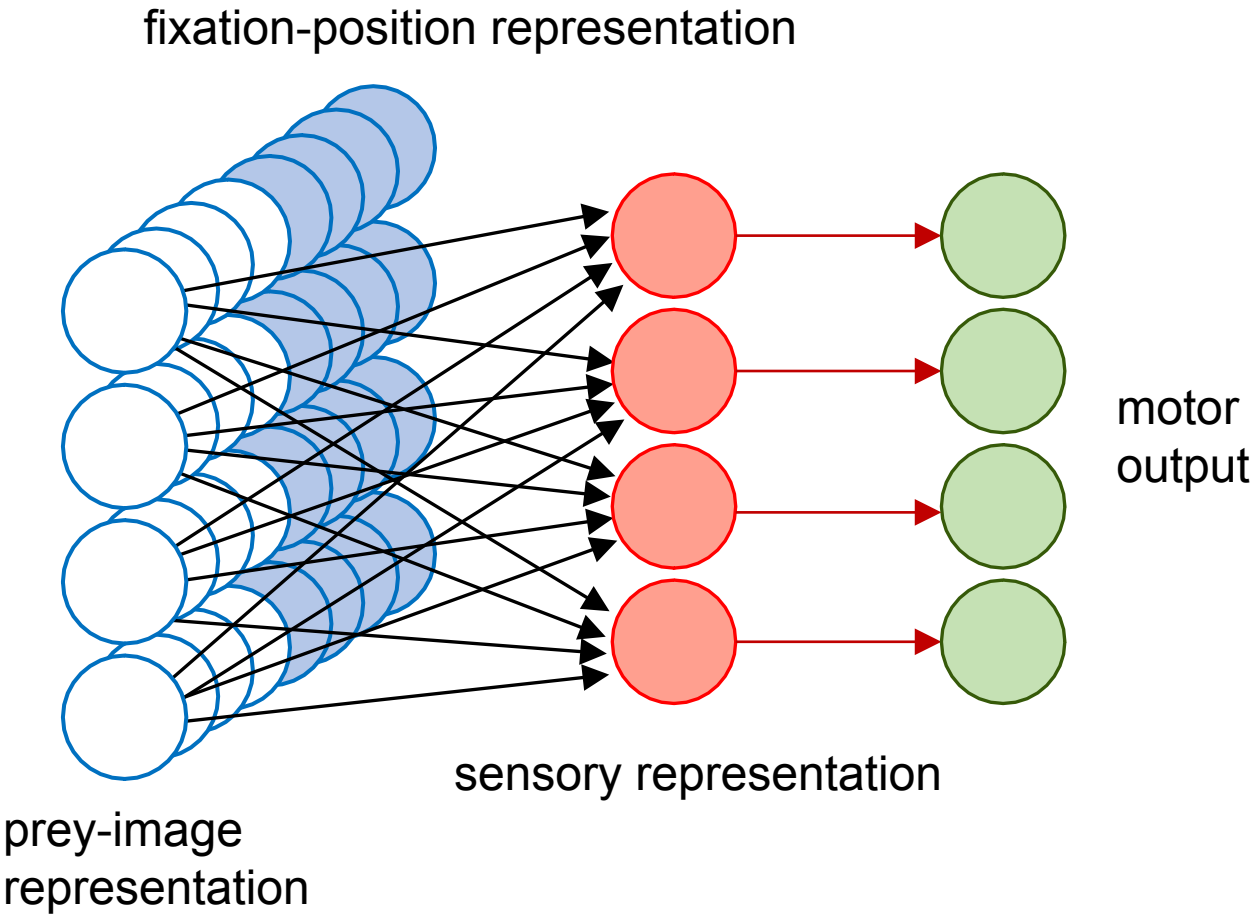


$$S_{ij} = f_i(x_1, x_2) g_j(y_1, y_2)$$

f = response of prey-image neuron

g = response of fixation-position neuron

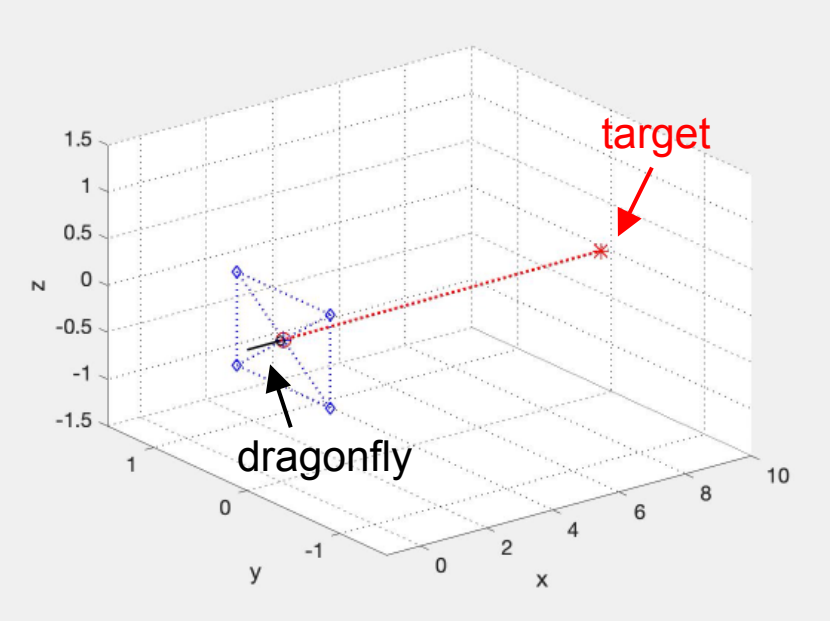
Neural network model of dragonfly interception



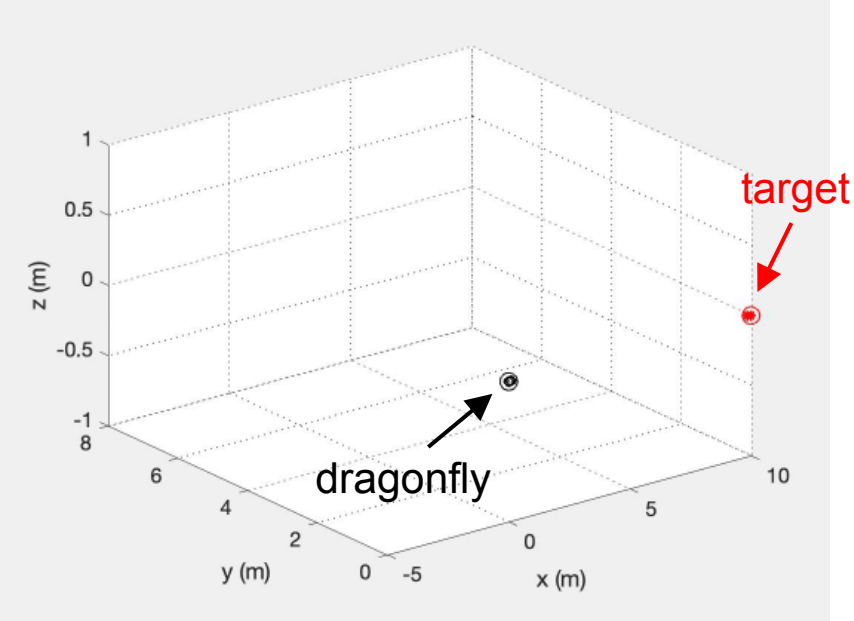
*neural network receives no training - weights are calculated
(see Zipser & Andersen, 1988; Salinas & Abbott, 1995)

Neural network model of dragonfly interception

dragonfly-centered reference frame



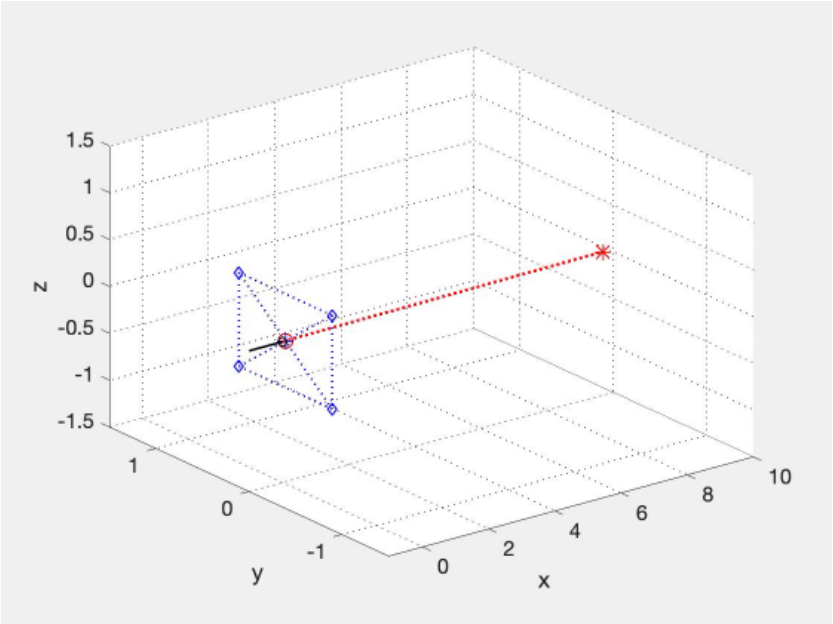
real-world reference frame



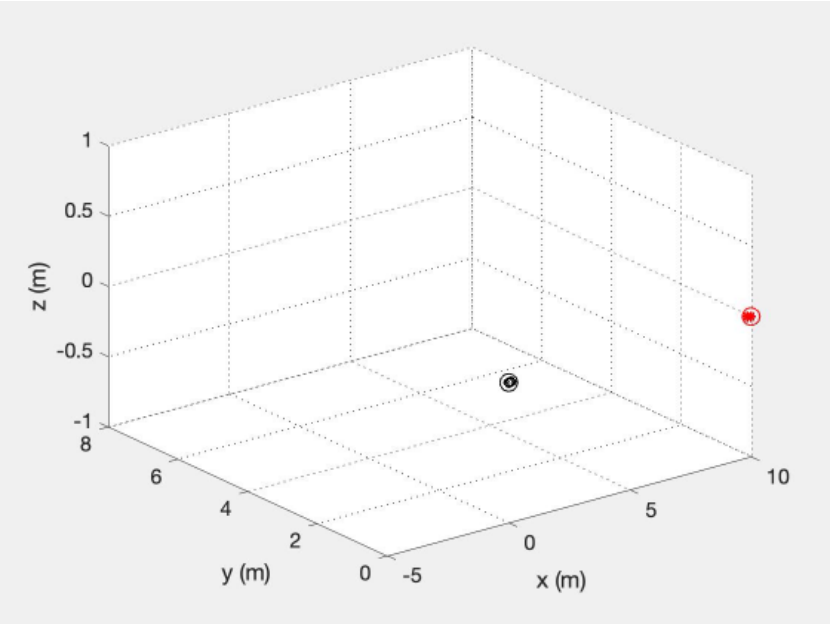
Fixation position in center of eye

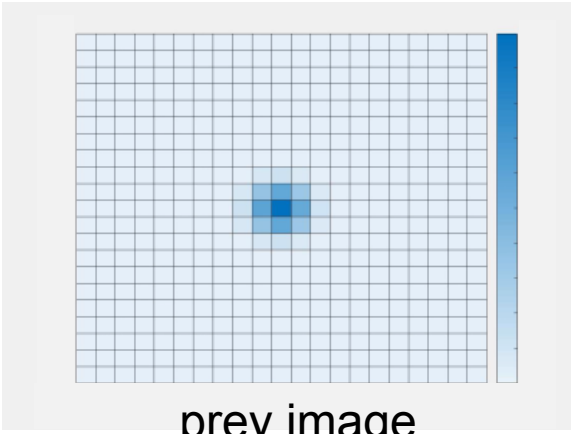
Neural network model of dragonfly interception

dragonfly-centered reference frame

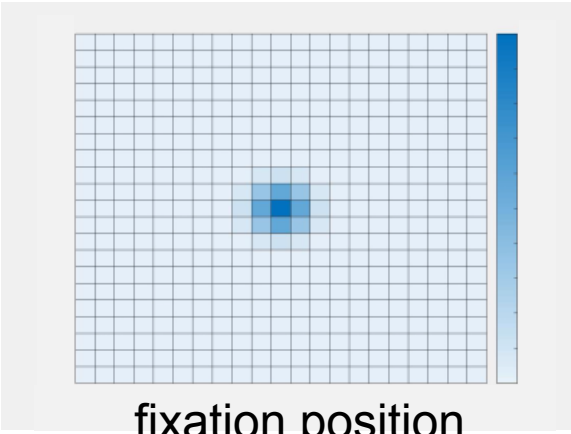


real-world reference frame

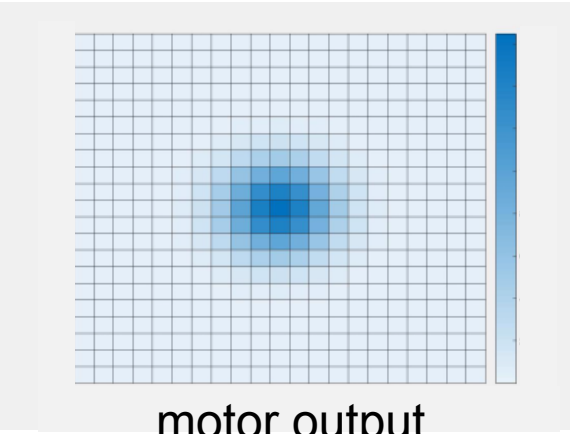




prey image

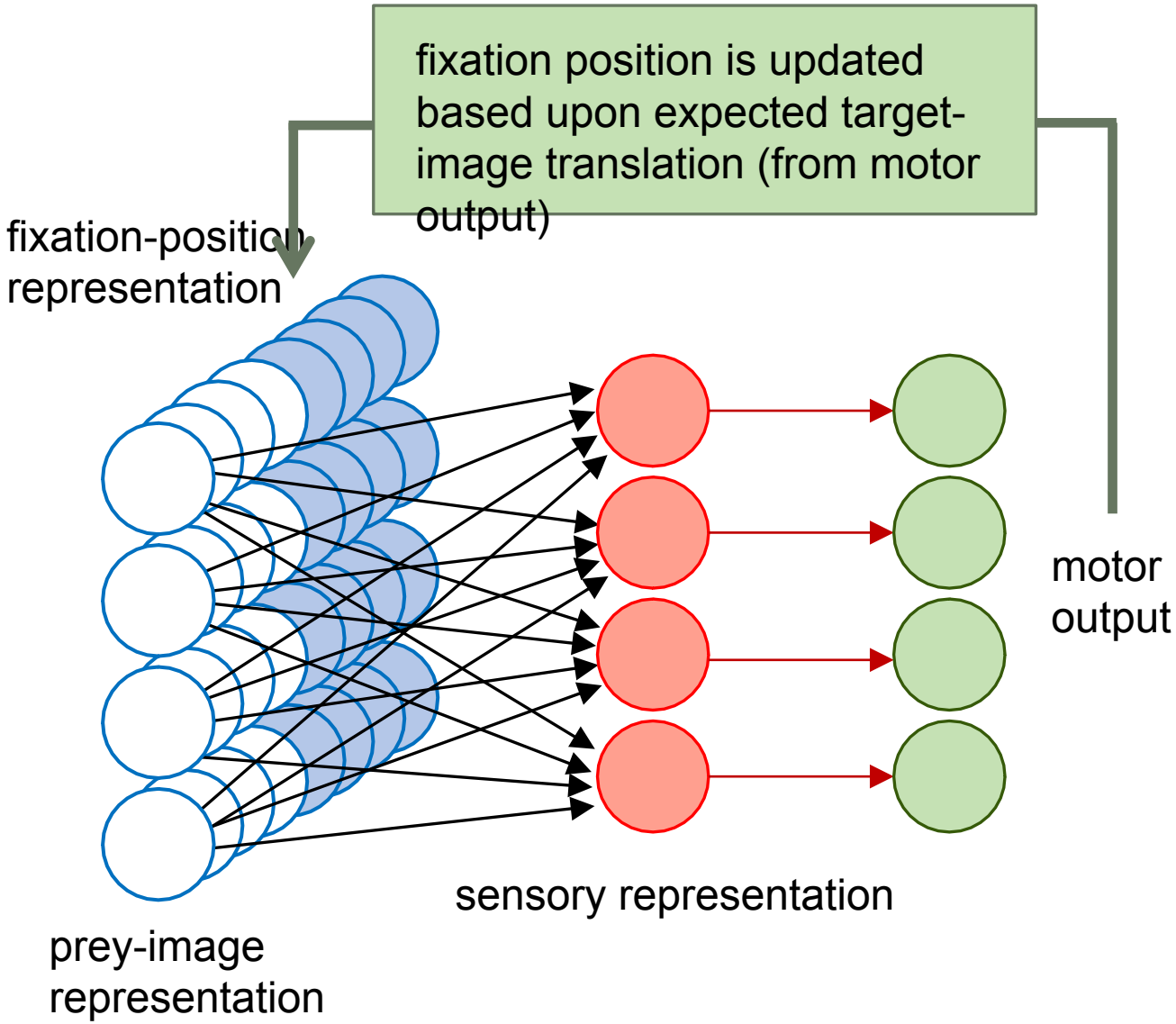


fixation position



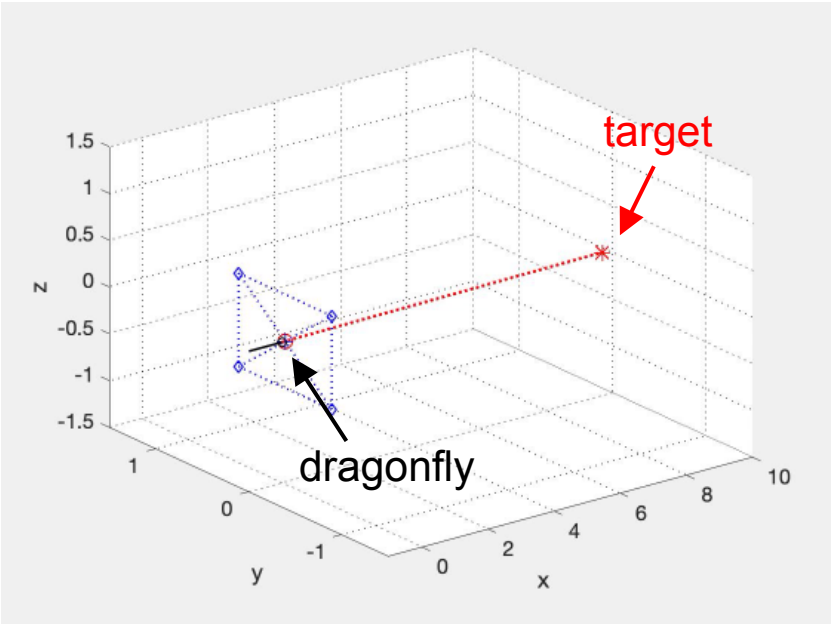
motor output

Neural network model of dragonfly interception

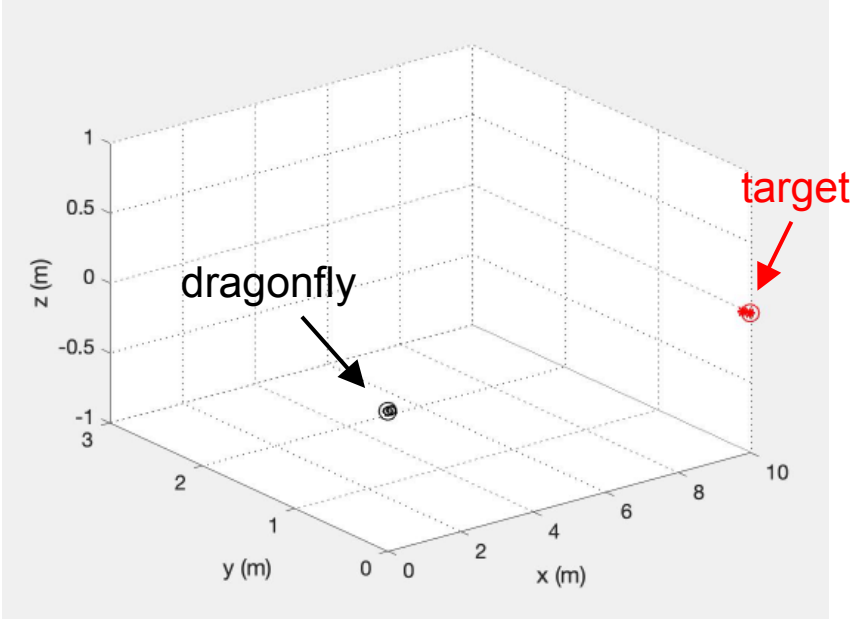


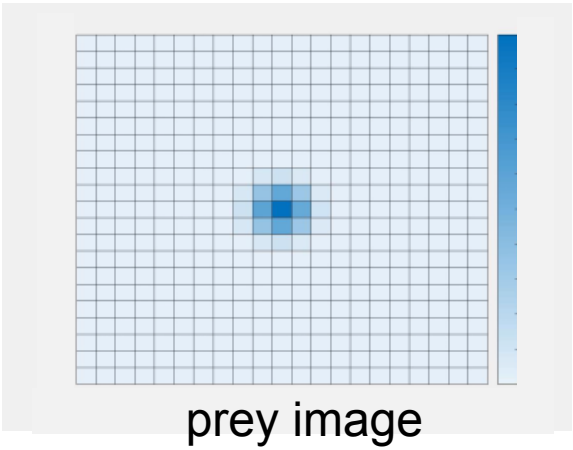
Neural network model of dragonfly interception

dragonfly-centered reference frame

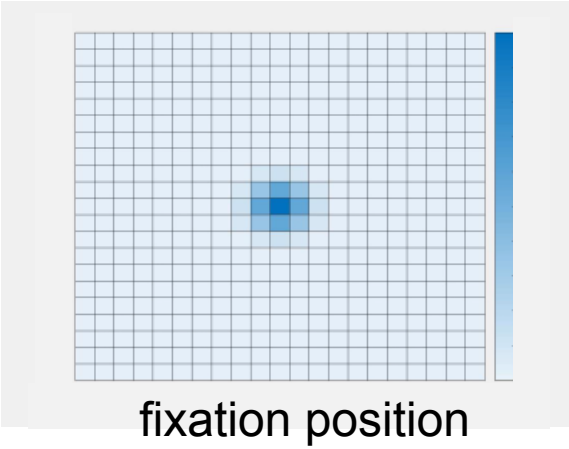


real-world reference frame

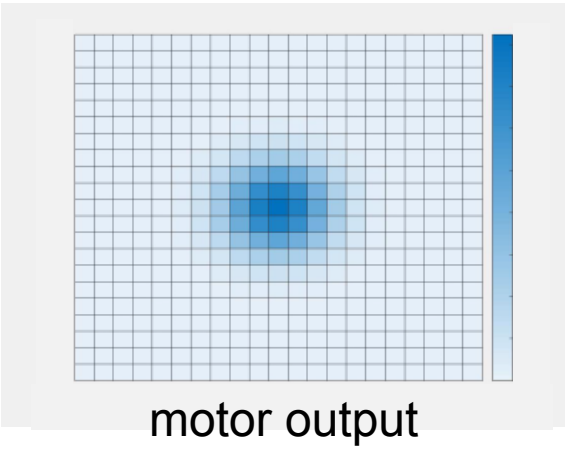




prey image



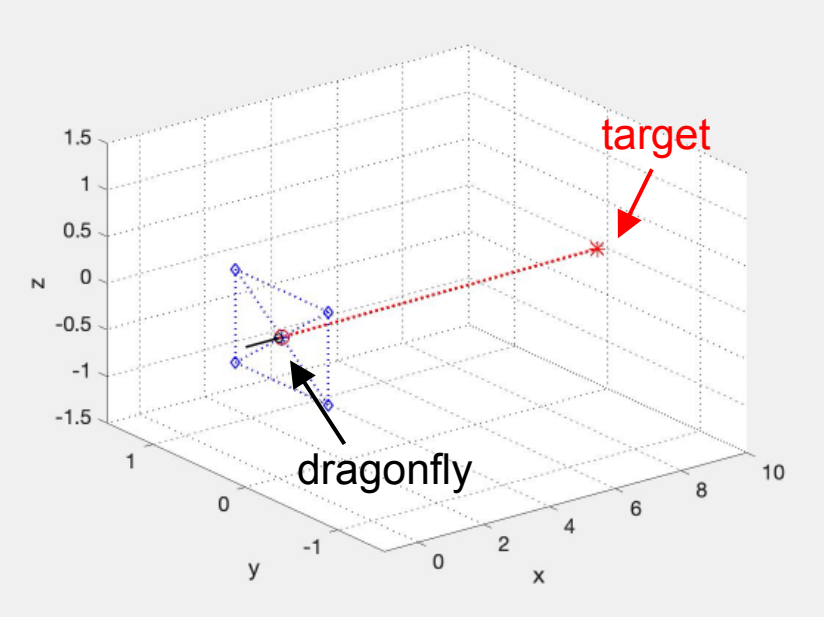
fixation position



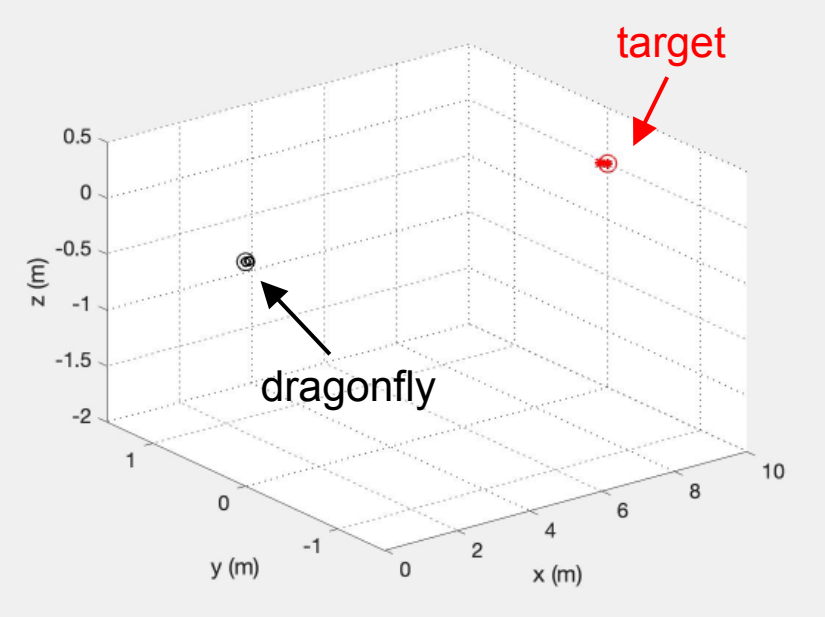
motor output

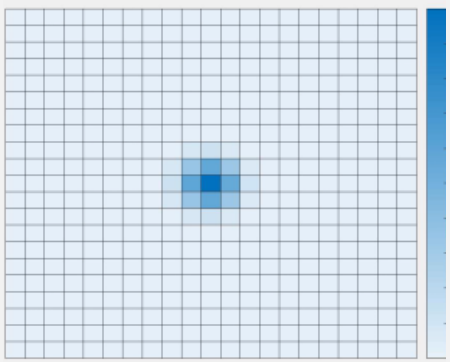
Neural network model of dragonfly interception

dragonfly-centered reference frame

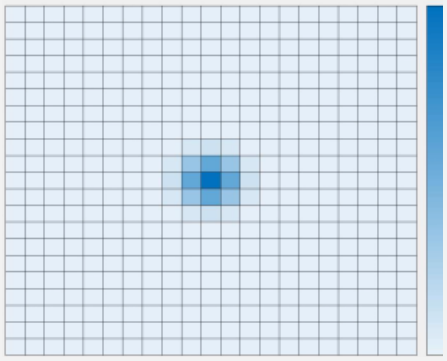


real-world reference frame

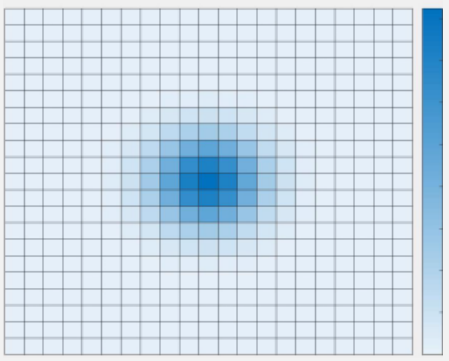




prey image

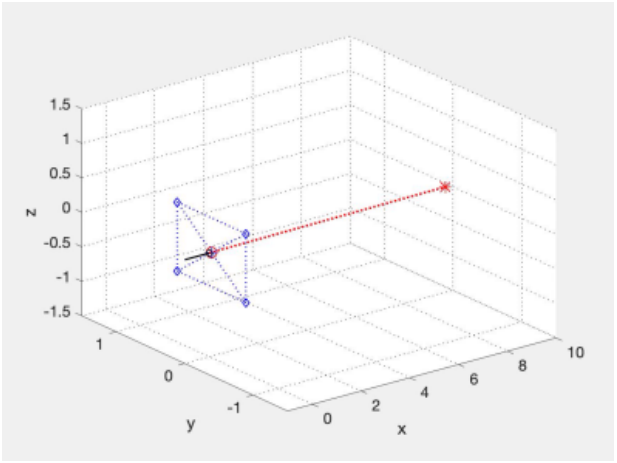


fixation position



motor output

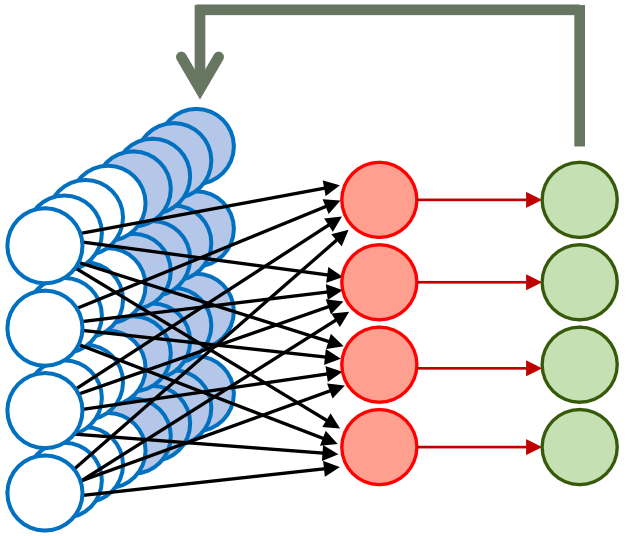
Neural network model - what is missing?



motion-sensitive neurons

a neck / gimbal

Neural network model - what is missing?



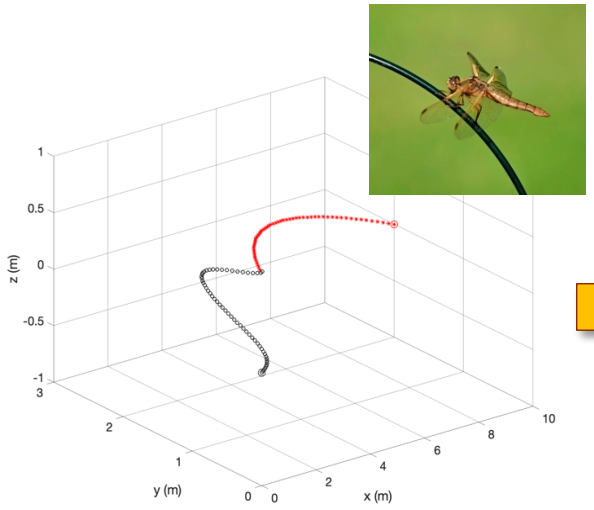
motion-sensitive neurons

a neck / gimbal

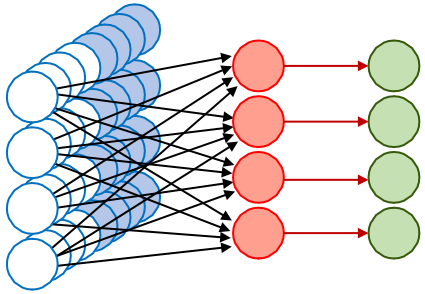
What is the fixation position signal?

What is the nature of the fixation-position update?

If we understood a dragonfly, what could come next?



Brain Algorithms



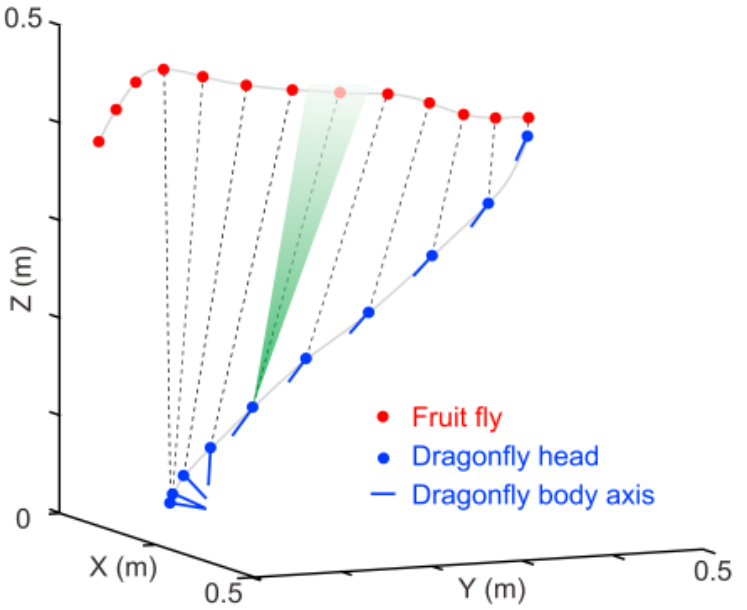
Neural Network Models

Models in Neuromorphic Hardware

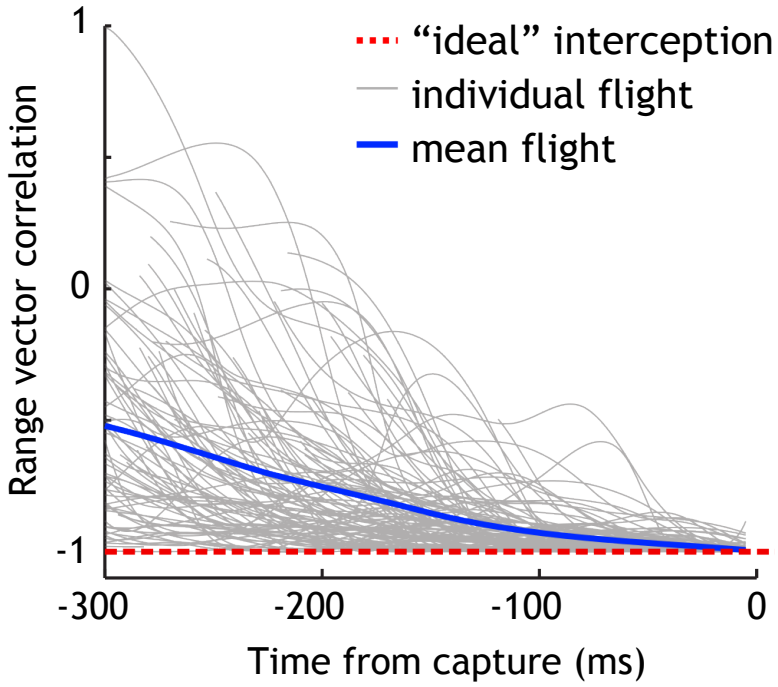
The End

Questions? Email fschanc@sandia.gov

Back to the dragonfly…



from Lin & Leonardo 2017



from Mischiati et al 2015

Data from Mischiati et al (2015) suggests dragonflies only reliably use proportional navigation close to capture …

Are dragonflies "searching" for the ideal approach?