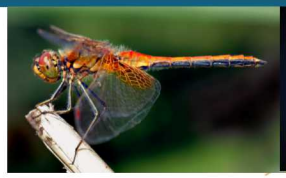
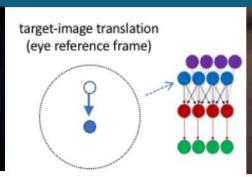
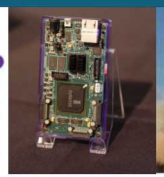
SAND2019-10769PE

Dragonfly-Inspired Intercept Approaches







Missile Defense Agency Workshop, September 5 2019

Frances S. Chance

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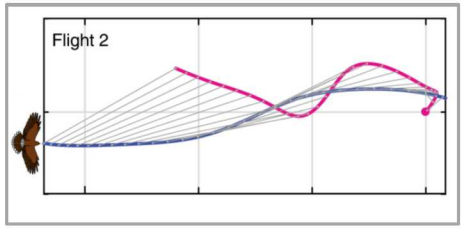
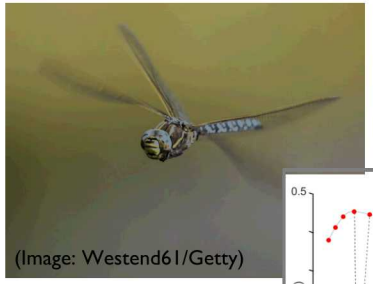
Interception

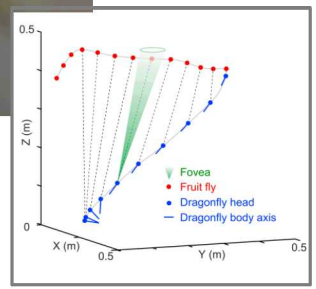
Common behavior in animals…

(Image: Wikipedia)



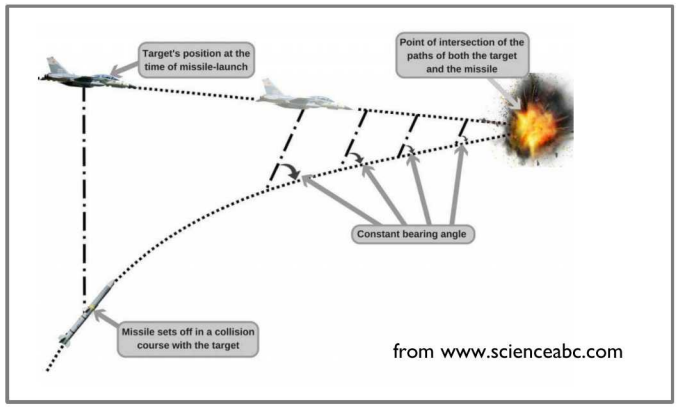

(Image: U. Oxford)


(Image: Westend61/Getty)



from Lin & Leonardo 2017

Still need solutions for man-made platforms…

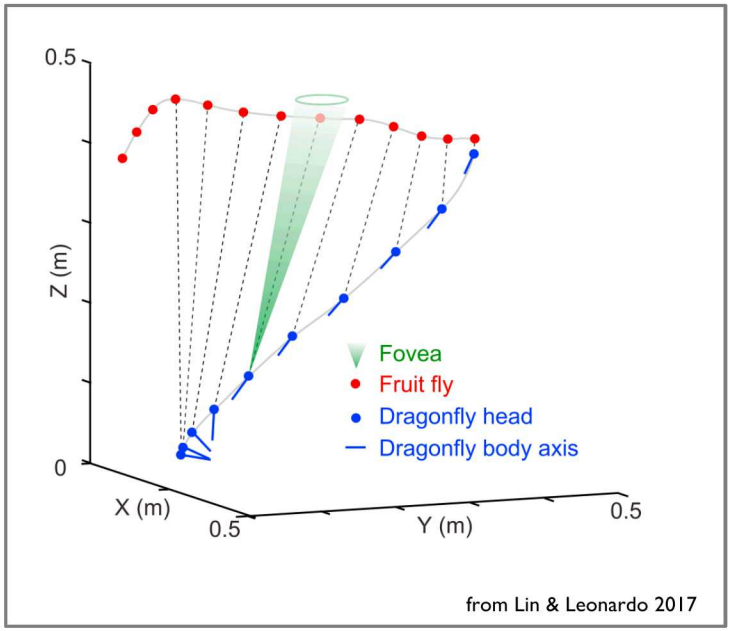


Dragonflies as inspiration for an interception algorithm

- Dragonflies intercept prey when hunting
- Good at it (90-95% capture rate)

- 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)

- Known to use a strategy that is "proportional-navigation-like"



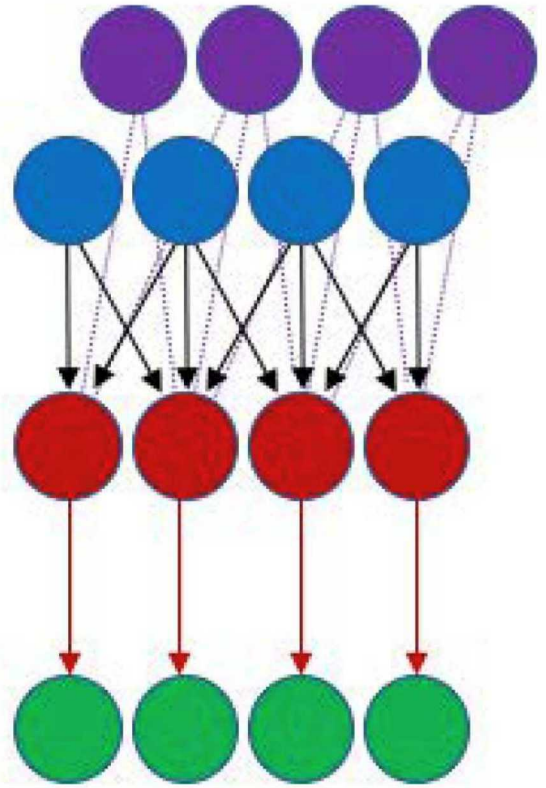
Dragonflies as inspiration for an interception algorithm

Time scales of dragonfly interception computation

- Latency to react to prey maneuver: 50 ms

Time scales of a neurobiological system

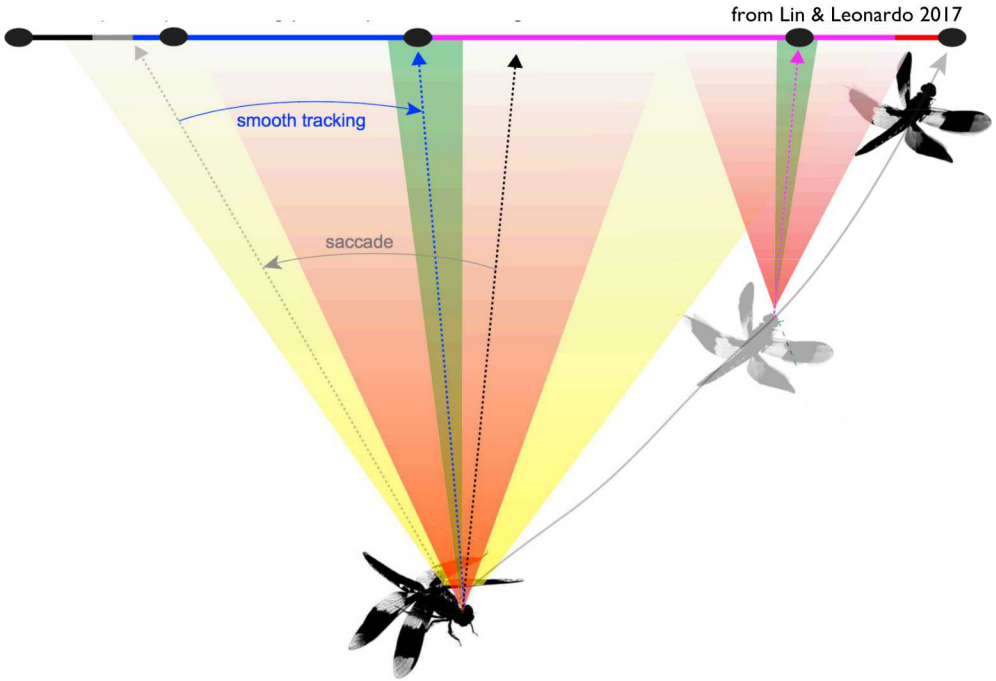
- Synaptic transmission: 1-5 ms
- Neuronal integration: 10-50 ms
- Muscle contraction: 5 ms to produce force



- Time scale of computation suggests not more than 2-4 layers
- Multiple modalities of inputs on the first layer (proprioception, visual input)

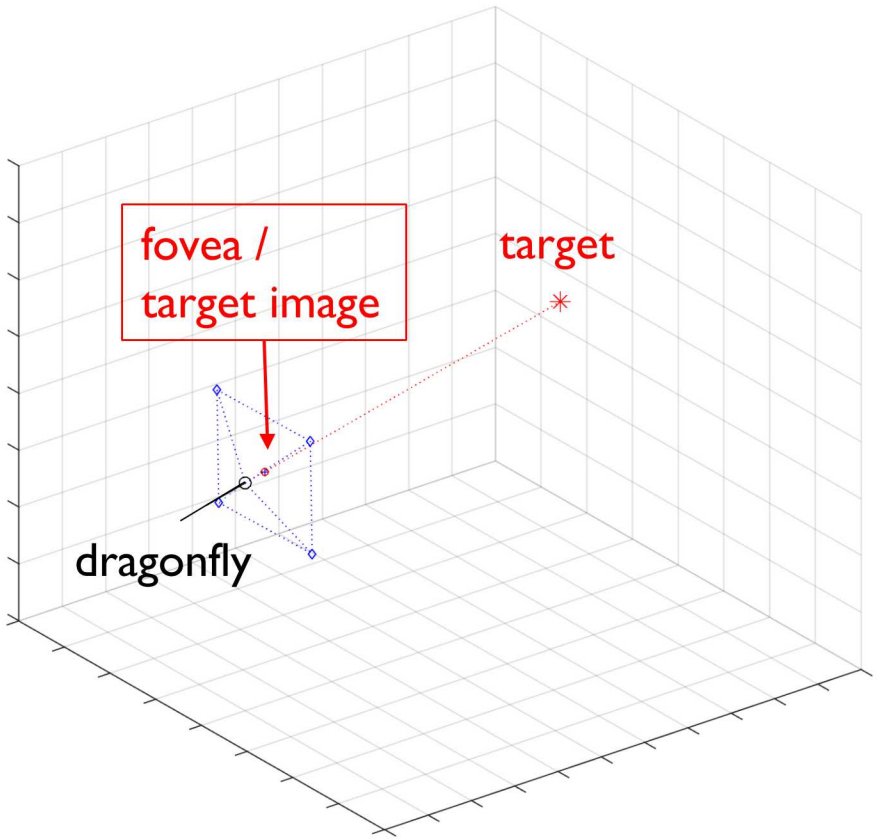
Dragonflies as inspiration for an interception algorithm

Dragonflies maintain prey at a particular eye-position (foveation) during approach



Is target-image slippage on eye enough information for a robust interception algorithm?

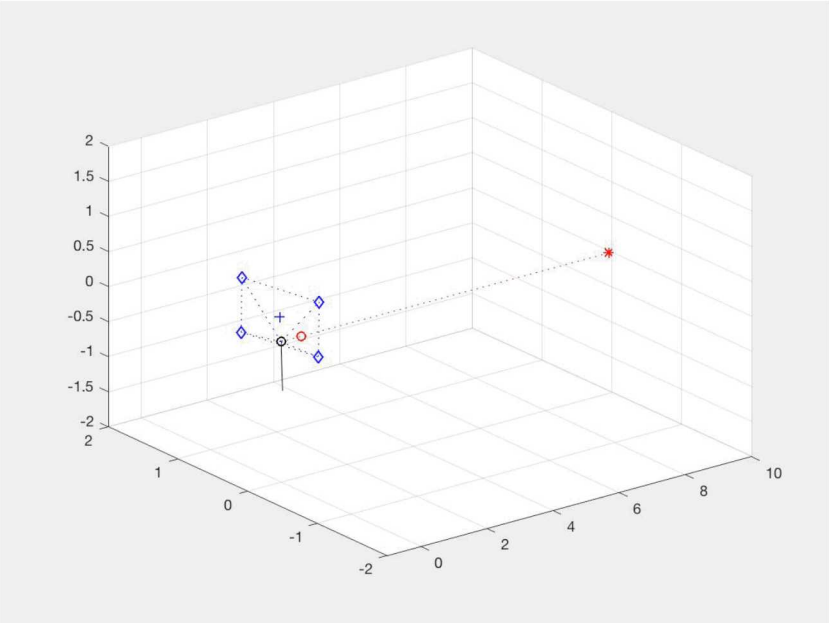
Simulating a dragonfly



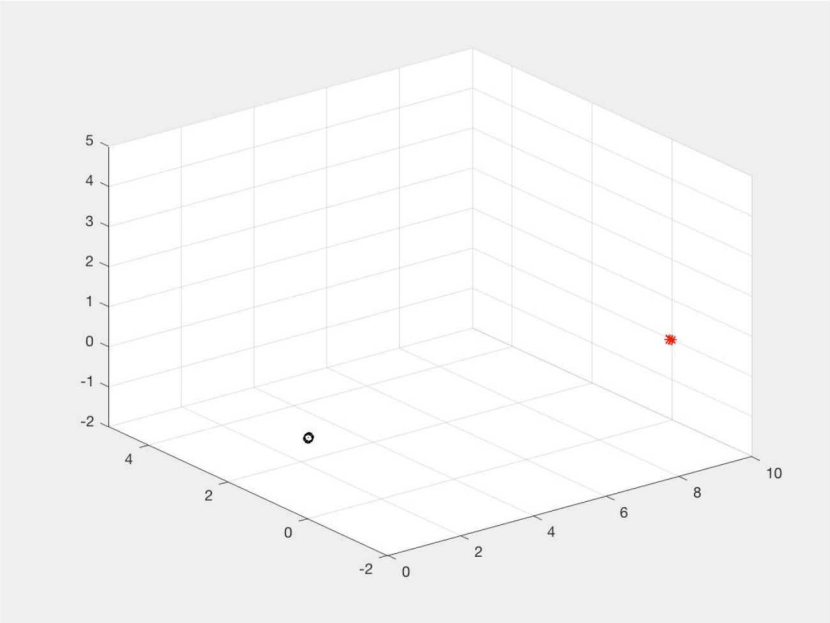
- dragonfly eye simulated as a 2D screen
- fovea at the center of the eye/screen
- dragonfly maneuvers to keep prey-image on fovea (changes in pitch and yaw are calculated based upon target-image slippage)
- dragonfly and prey move at same maximum speed (unrealistic but more challenging)

Simulating a dragonfly – target held at eye center

Dragonfly maneuvers to keep prey-image at eye-center (fovea)



dragonfly-centered reference frame

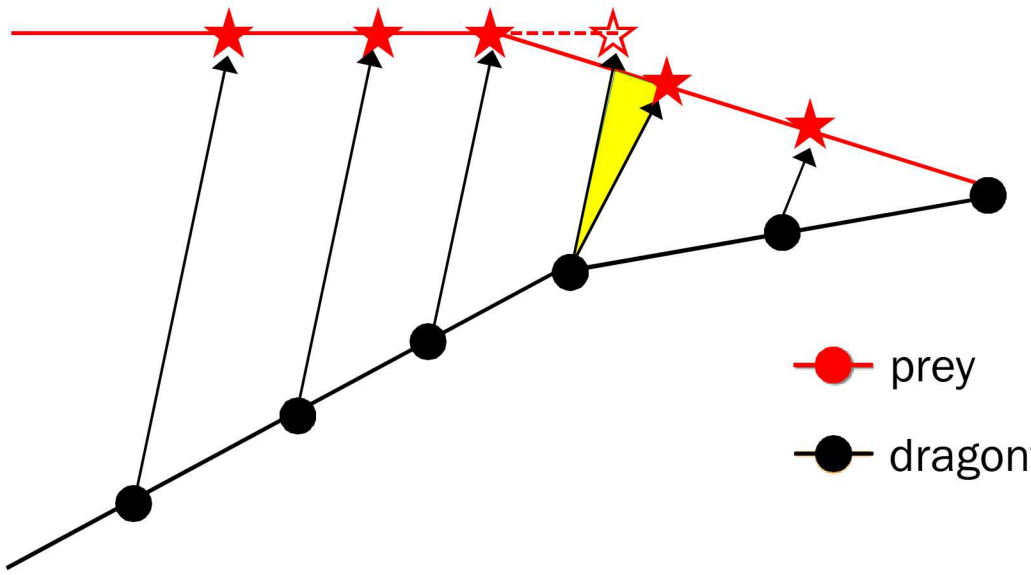


physical-space reference frame

- Classic pursuit behavior (dragonfly heads straight towards prey)
- Viable interception strategy except vulnerable to ”endless pursuit”
- Not what the dragonfly does (but some successful biological systems do)

Proportional navigation (what the dragonfly does)

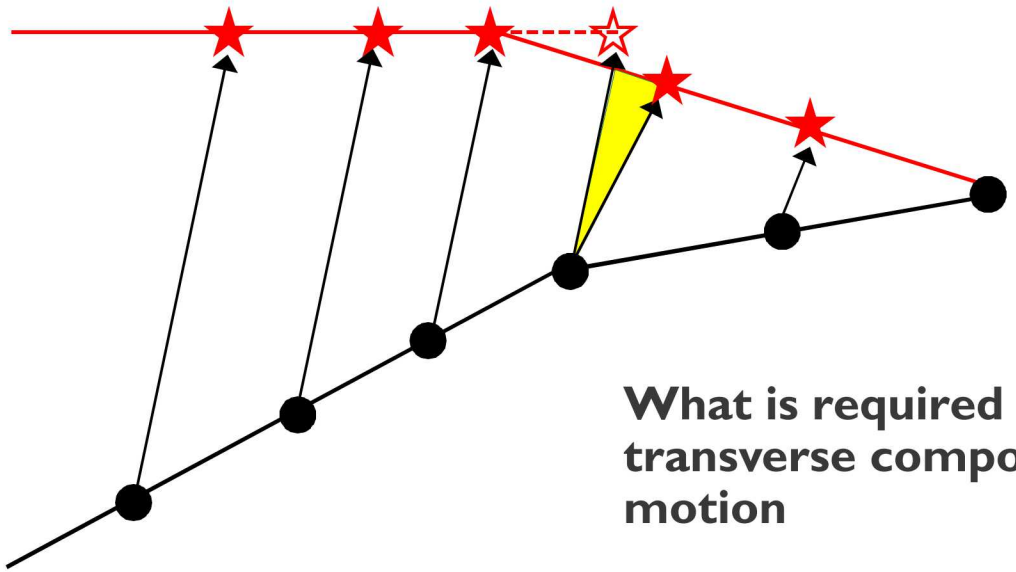
aka CBDR (constant-bearing decreasing-range) or parallel navigation



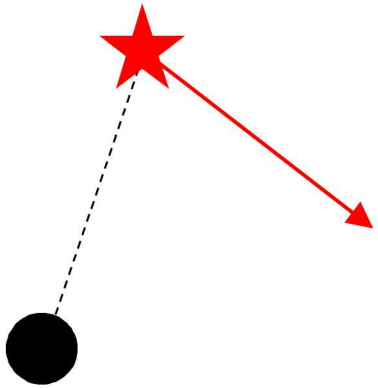
Generates the geometrically shortest interception trajectory

Proportional navigation (what the dragonfly does)

aka CBDR (constant-bearing decreasing-range) or parallel navigation



What is required is matching the transverse component of target motion



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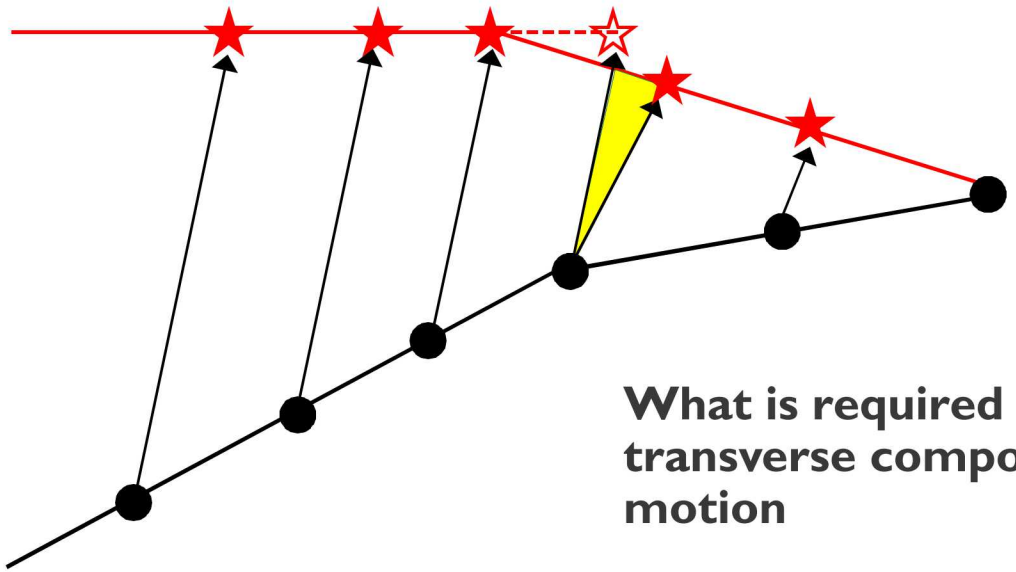

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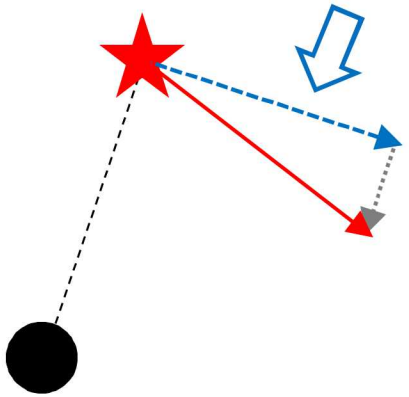

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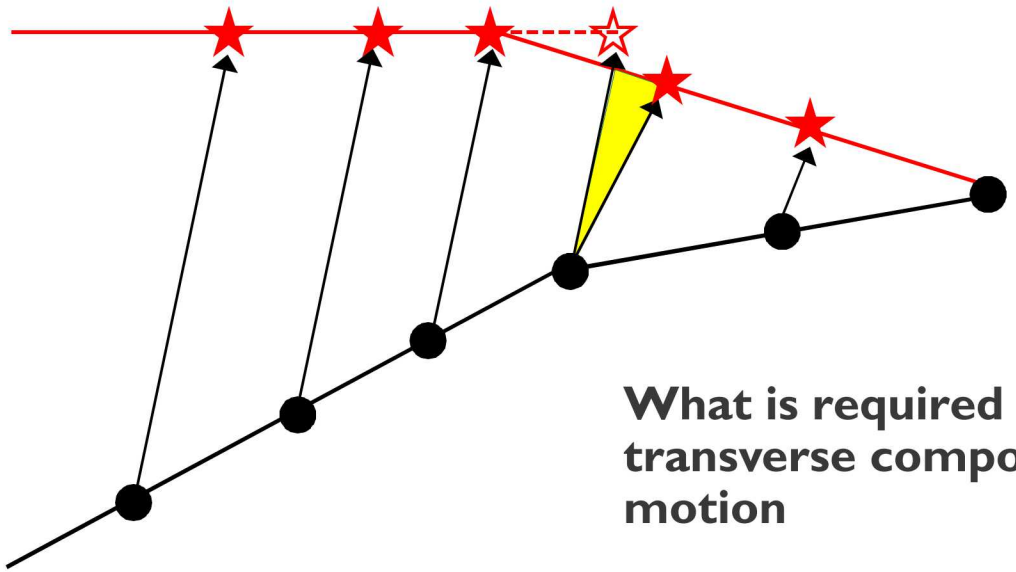

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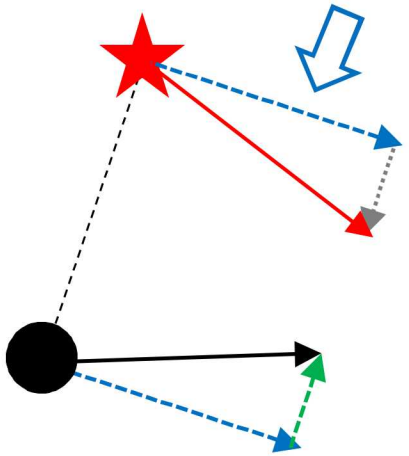
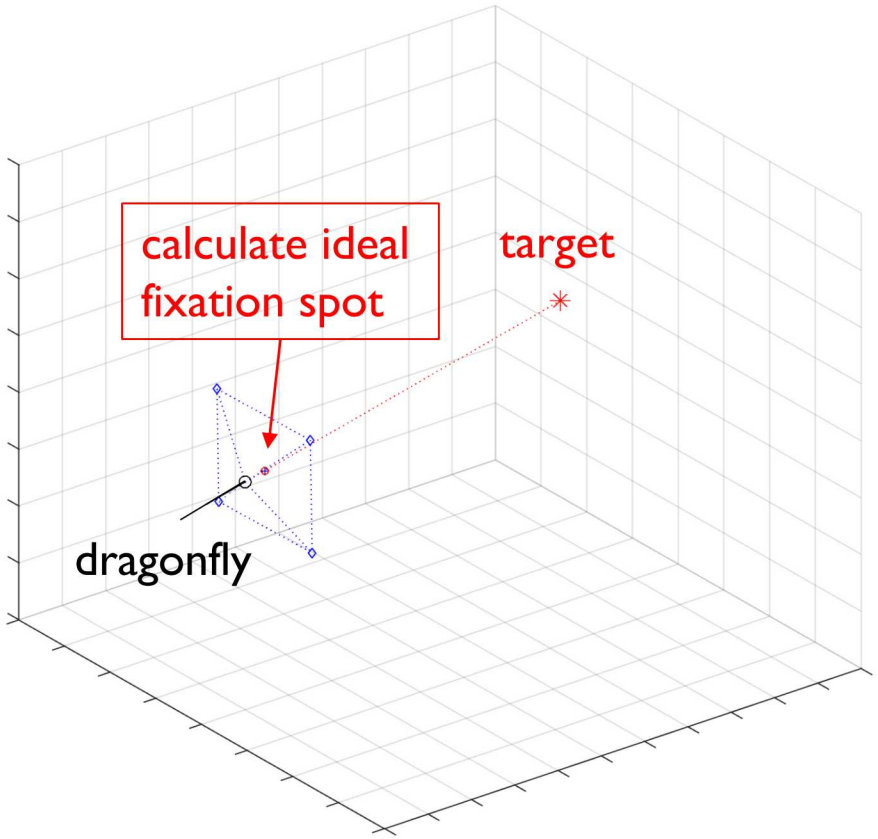


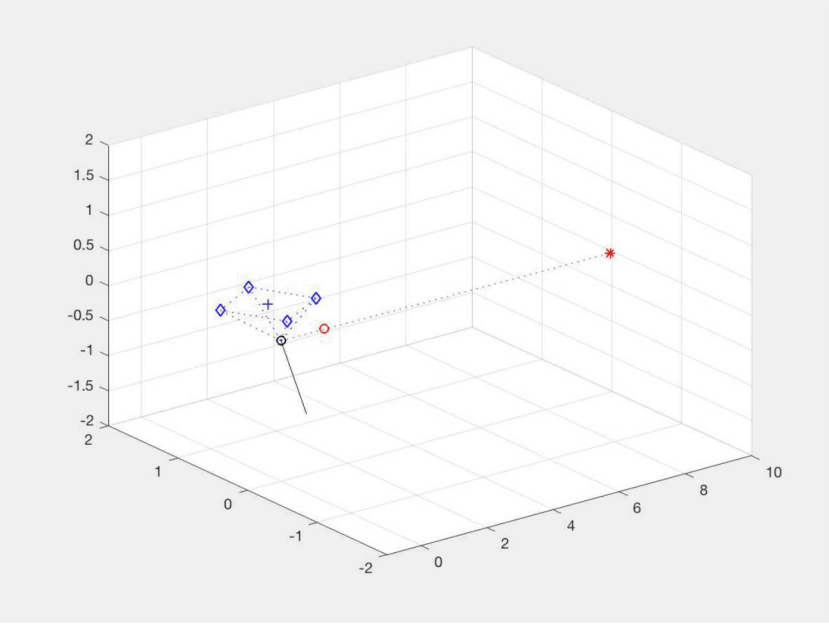
Can proportional navigation be implemented using prey-image slippage on the eye?



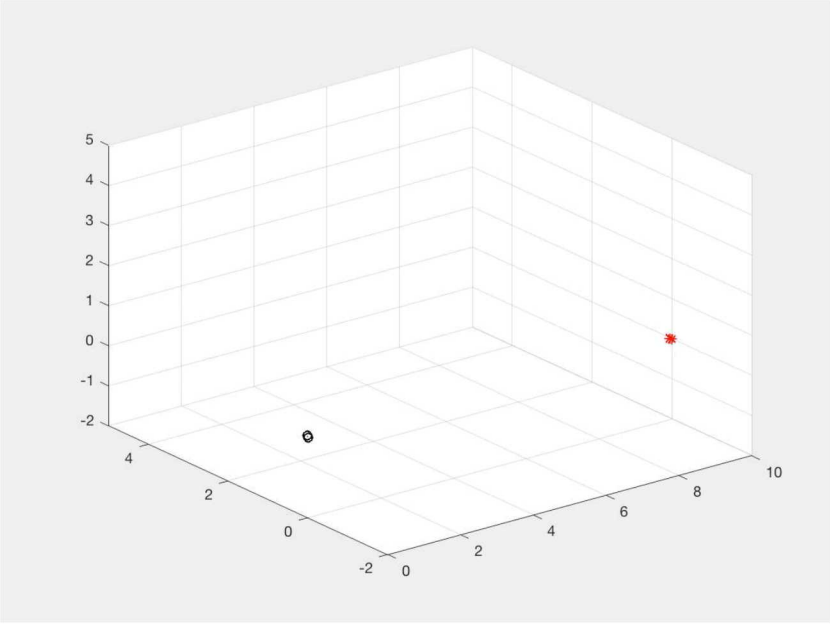
- initially correct "fixation spot" is calculated based on the trajectory of the prey (relative to dragonfly trajectory)
- dragonfly maneuvers to keep prey-image on fixation spot (changes in pitch and yaw are calculated based upon target-image slippage from fixation spot)
- dragonfly and prey move at same maximum speed

Can proportional navigation be implemented using prey-image slippage on the eye?

Dragonfly maneuvers to keep prey-image at fixation spot (calculated)



dragonfly-centered reference frame

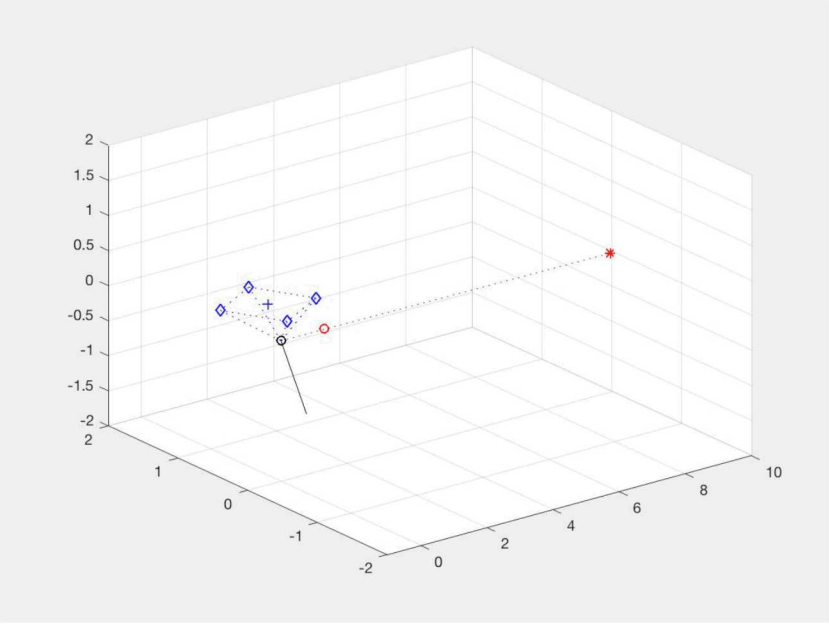


physical-space reference frame

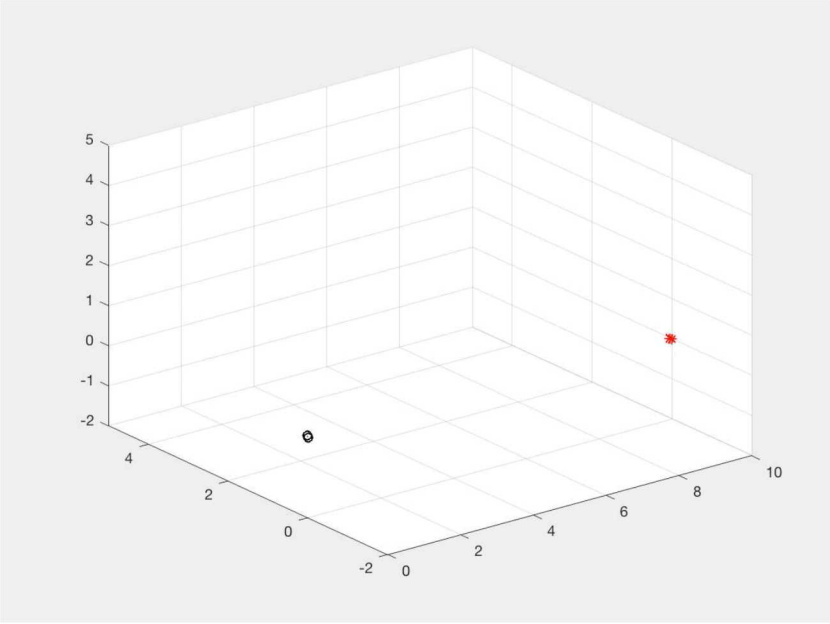
If knowledge of prey-trajectory is known (if fixation spot is "correct"), can achieve proportional navigation

Can proportional navigation be implemented using prey-image slippage on the eye?

Dragonfly maneuvers to keep prey-image at fixation spot (calculated)



dragonfly-centered reference frame



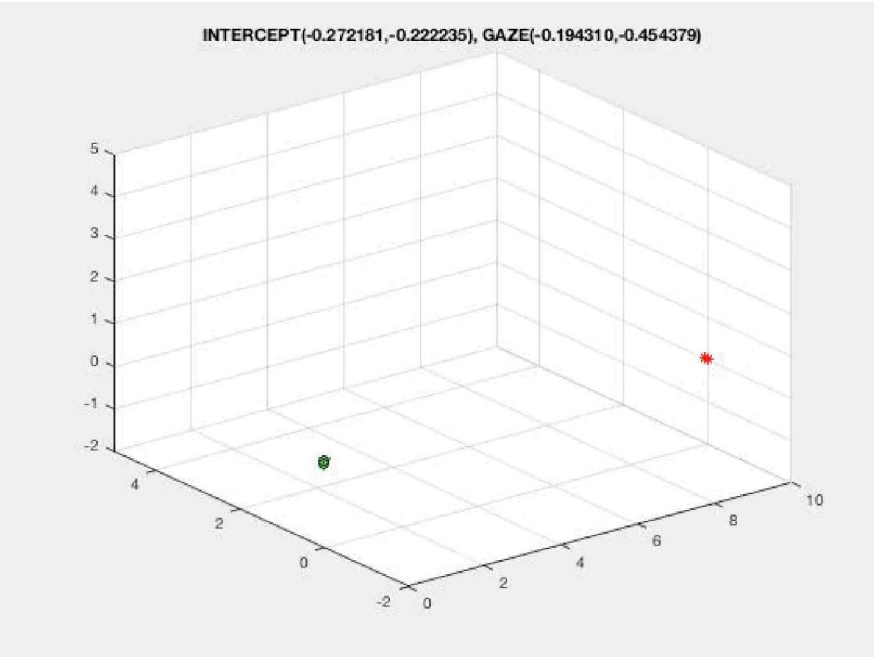
physical-space reference frame

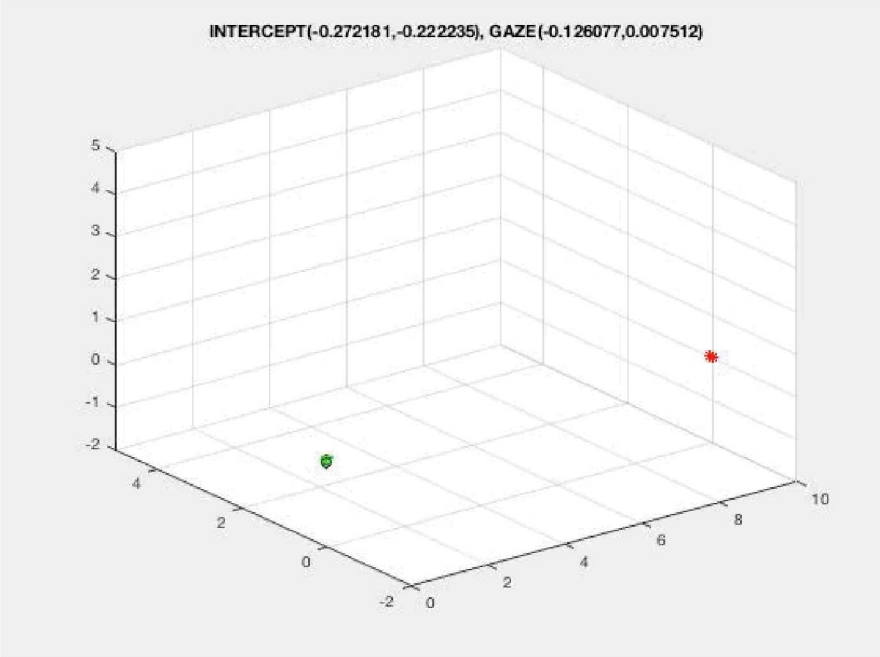
Potentially more robust strategy if prey has similar speed capabilities

However, vulnerable to rapid evasive prey maneuvering

What if the fixation spot is off?

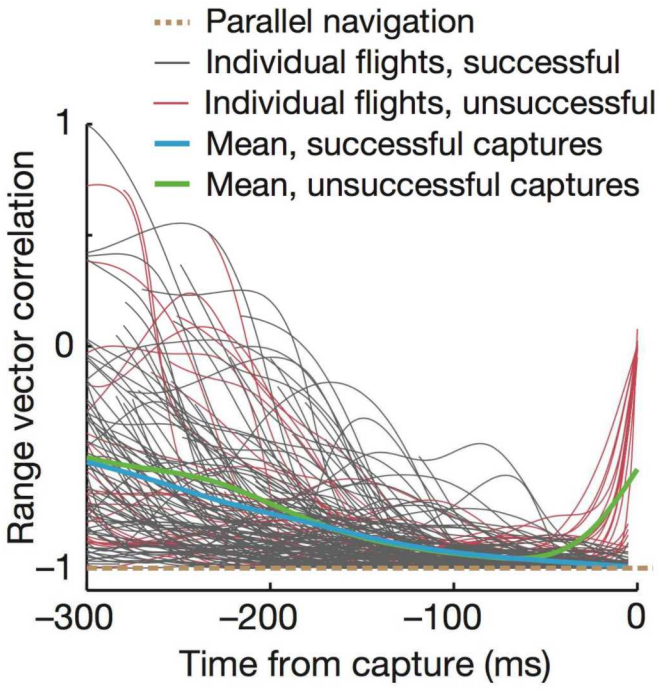
Dragonfly maneuvers to keep prey-image at fixation spot (with noise added)

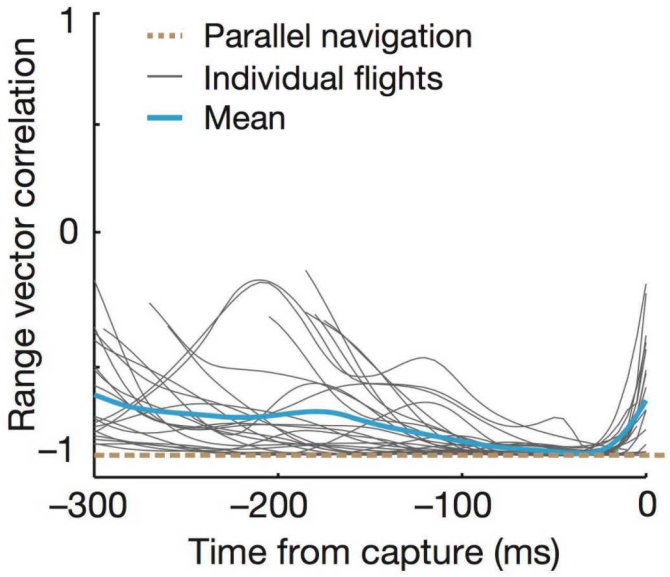




Dragonfly is "aware" that something is off based upon target-image slipping behavior – is it possible to compensate in real-time?

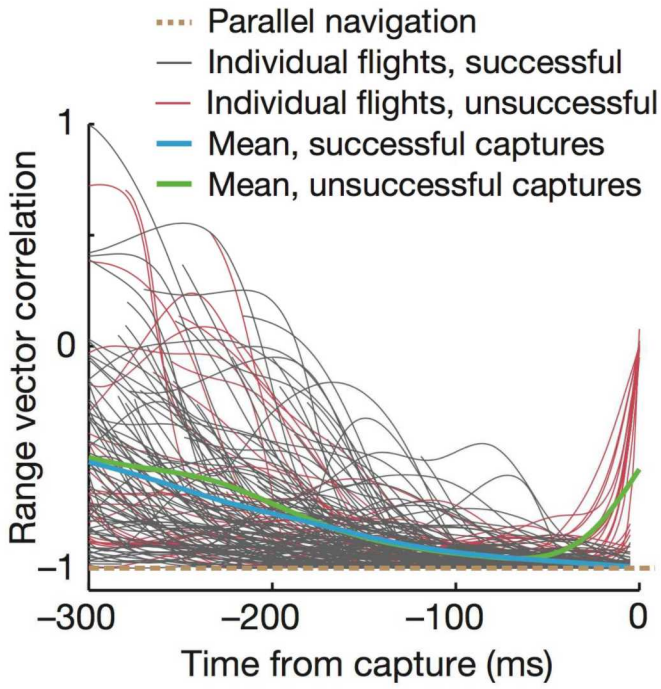
Back to the dragonfly…

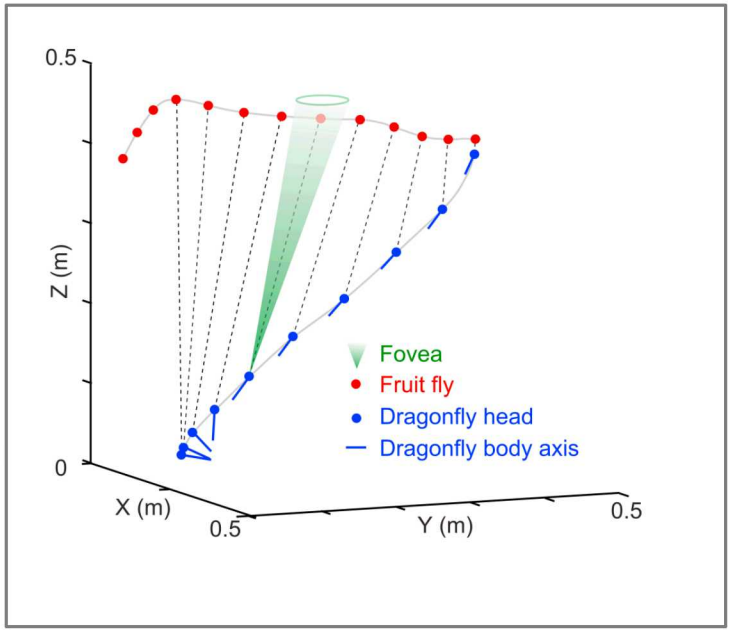




data from Mischiati et al (2015) suggests dragonflies only reliably use proportional navigation close to capture

Back to the dragonfly…



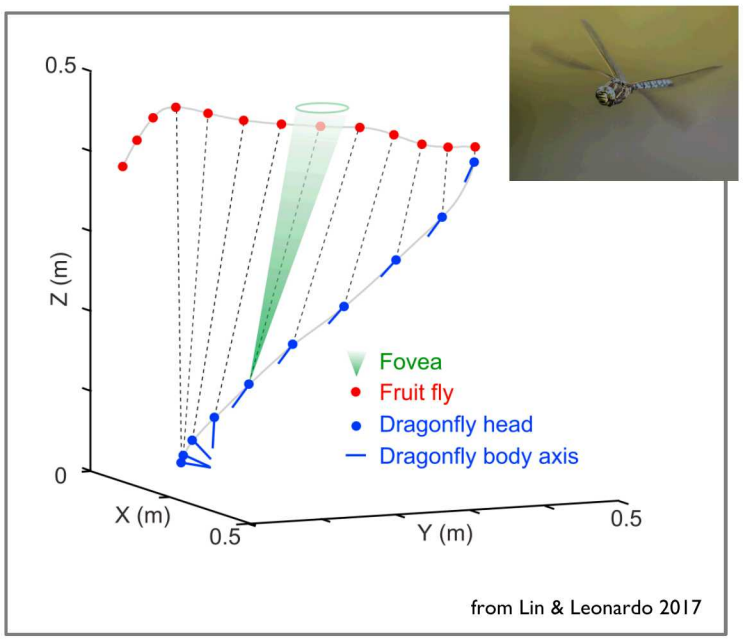


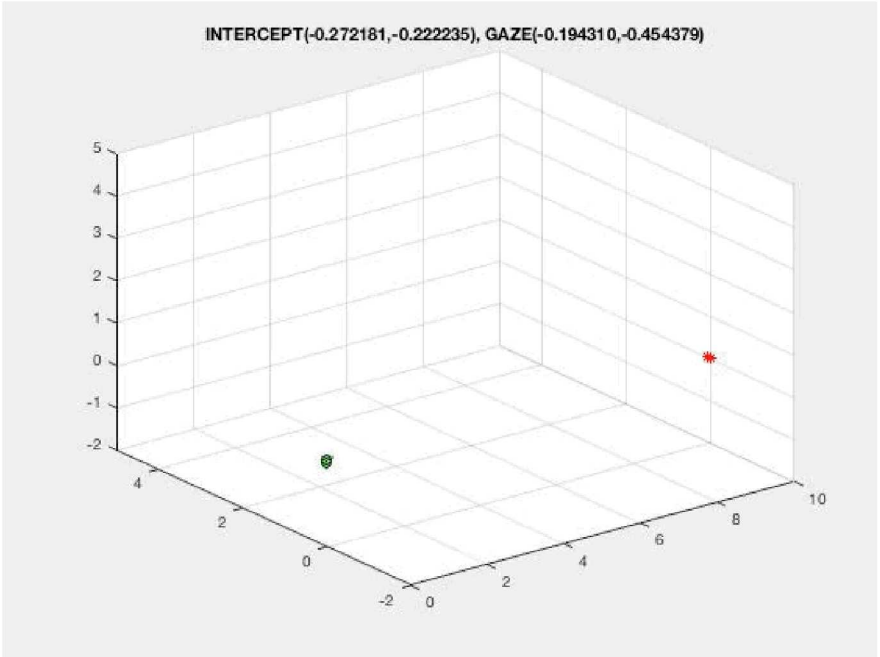
data from Mischiati et al (2015) suggests dragonflies only reliably use proportional navigation close to capture

Our assertion is that dragonflies are converging to proportional navigation (because they can not adjust their fovea)

Dragonfly-inspired error correction

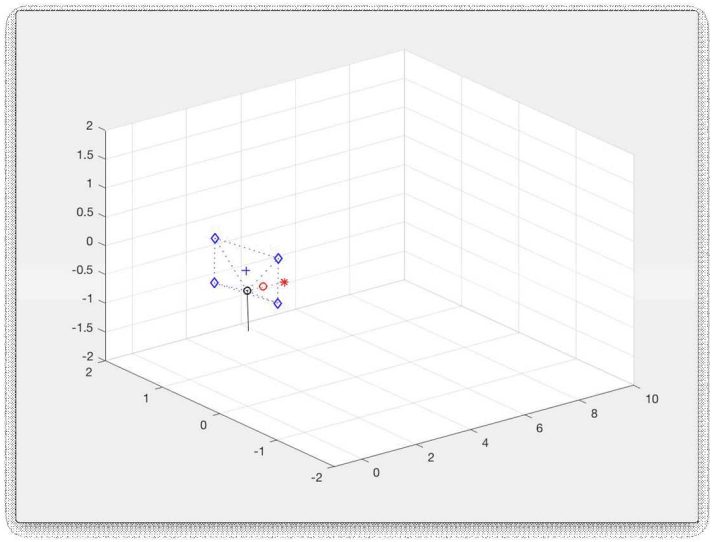
If the dragonfly not only maneuvers to keep prey-image on fovea, but also uses prey image to converge to proportional-navigation trajectory…

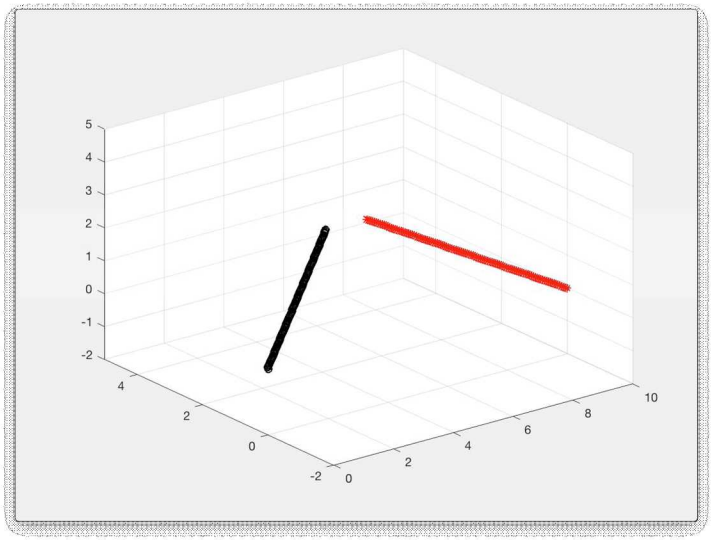




Can target-image slippage be used for online correction or adaptation of fixation spot? Currently working on a model for this - will be applicable for incomplete sensor information, evasive prey, error corrections.

Next steps





1) Demonstrate that target-image translation on eye is sufficient for interception (including proportional navigation)

2) Demonstrate that target-image translation on eye is sufficient for correcting interception "errors": Can online adaptation of fixation spot be used to correct trajectory?

3) What types of errors can adaptation of fixation spot be used for? (sensing noise, target evasion, etc)

What will the dragonfly model look like?

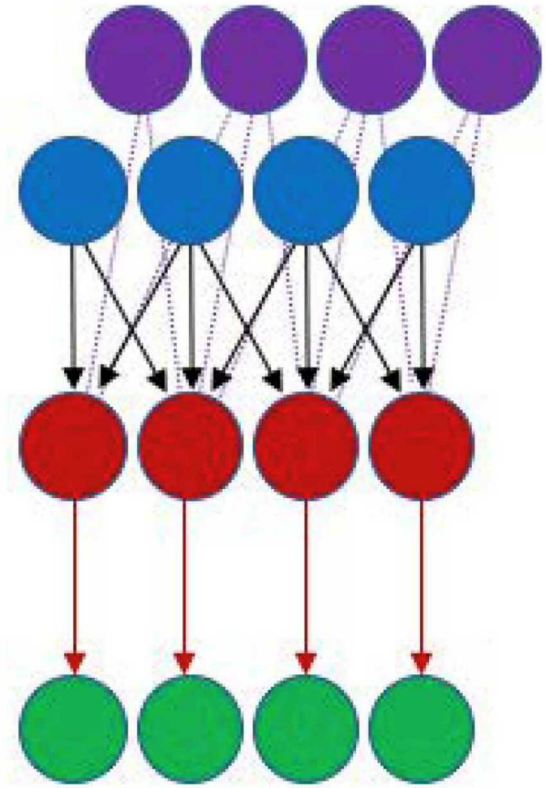
Dragonfly neural network (hypothetical)

proprioception

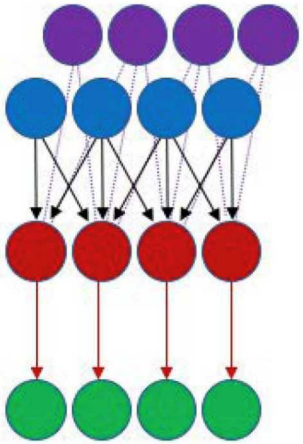
motion-detection (speed and direction in eye-centered coordinates)

TSDNs: respond to target motion in body-centered coordinates

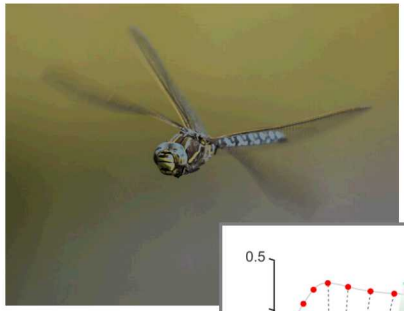
motor commands

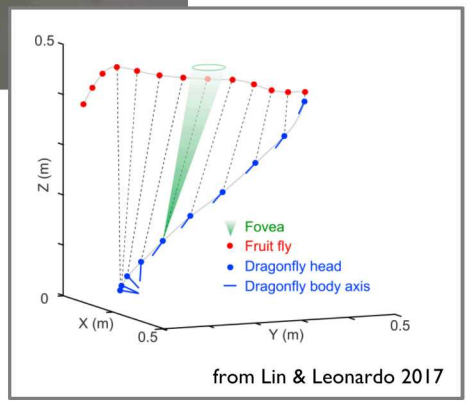


Summary



- Buliding a model of dragonfly-prey interception
- Focus on how dragonflies use visual input to calculate interception trajectories
- Dragonfly maneuvers to maintain prey-image on a particular fixation spot
  - Pursuit behavior if fixation spot is in center of eye
  - Proportional navigation if fixation spot is calculated based upon prey trajectory
- Ideal strategy may be some hybrid between pursuit and proportional navigation
- With online adjustment of fixation spot (and thus trajectory) depending on observed target-image slippage





The End

Questions? Email fschanc@sandia.gov