COMP 546

Lecture 10

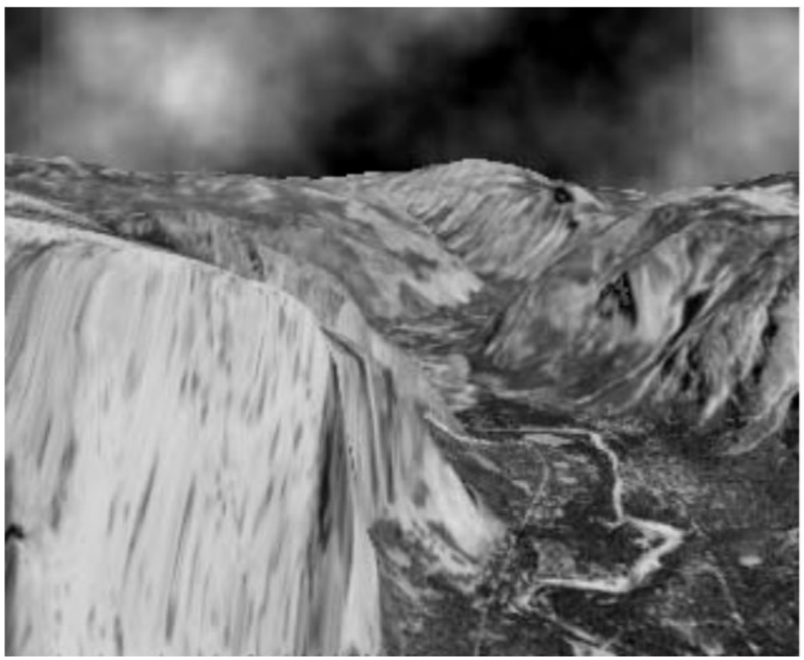
egomotion & eye movements

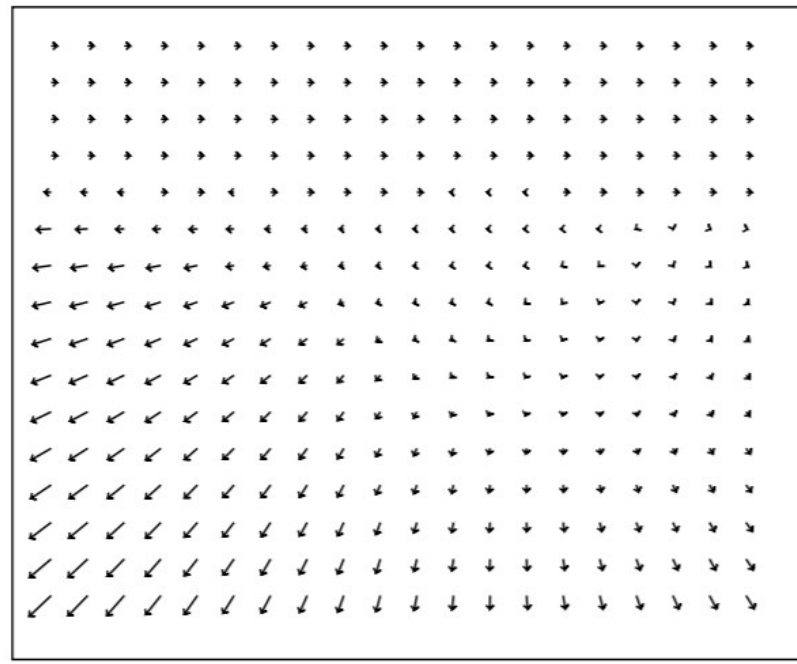
Tues. Feb. 12, 2018

What is the image motion seen by a moving observer? ("egomotion")

Motion field seen by moving observer

For each image location (x, y), there is a velocity (v_x, v_y).





The Yosemite sequence (flythrough for forward camera motion)

(Last lecture, I discussed how to estimate image velocities.)

What is the image motion seen by a moving observer?   ("egomotion")

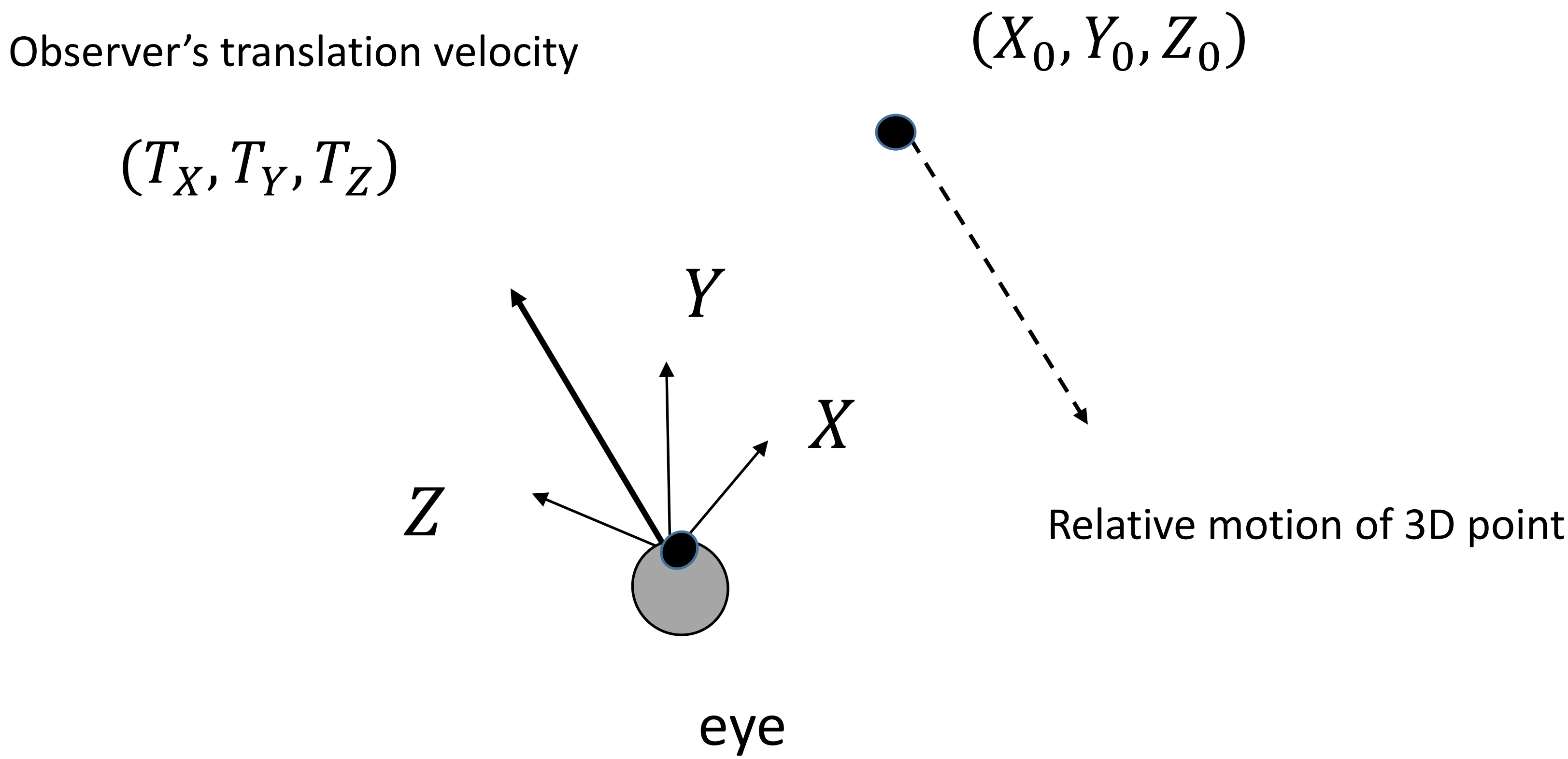
- Translation

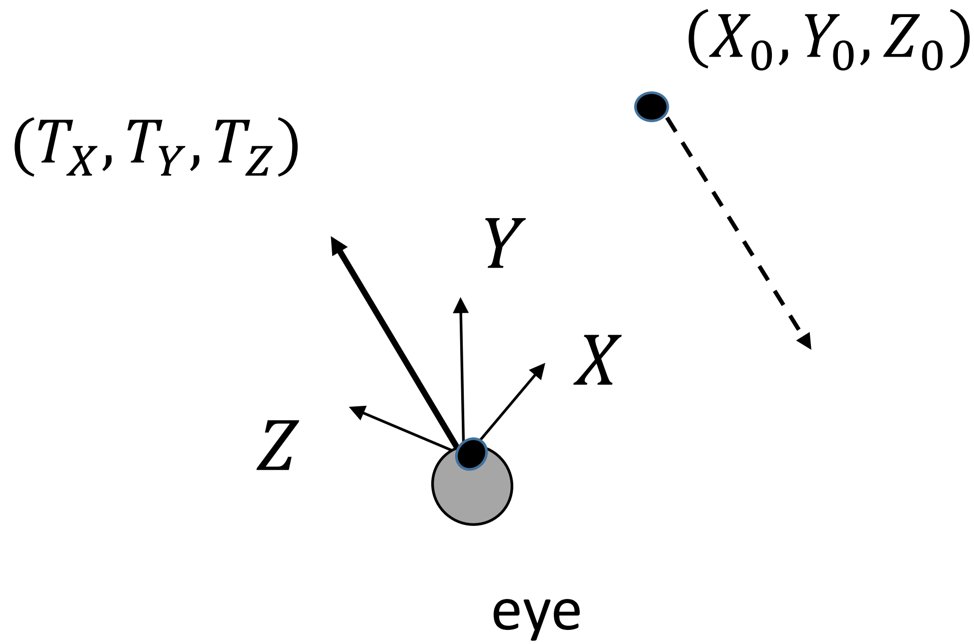
  (lateral,   forward)

- Rotation

  (pan, tilt, roll)

Motion field seen by a *translating* observer



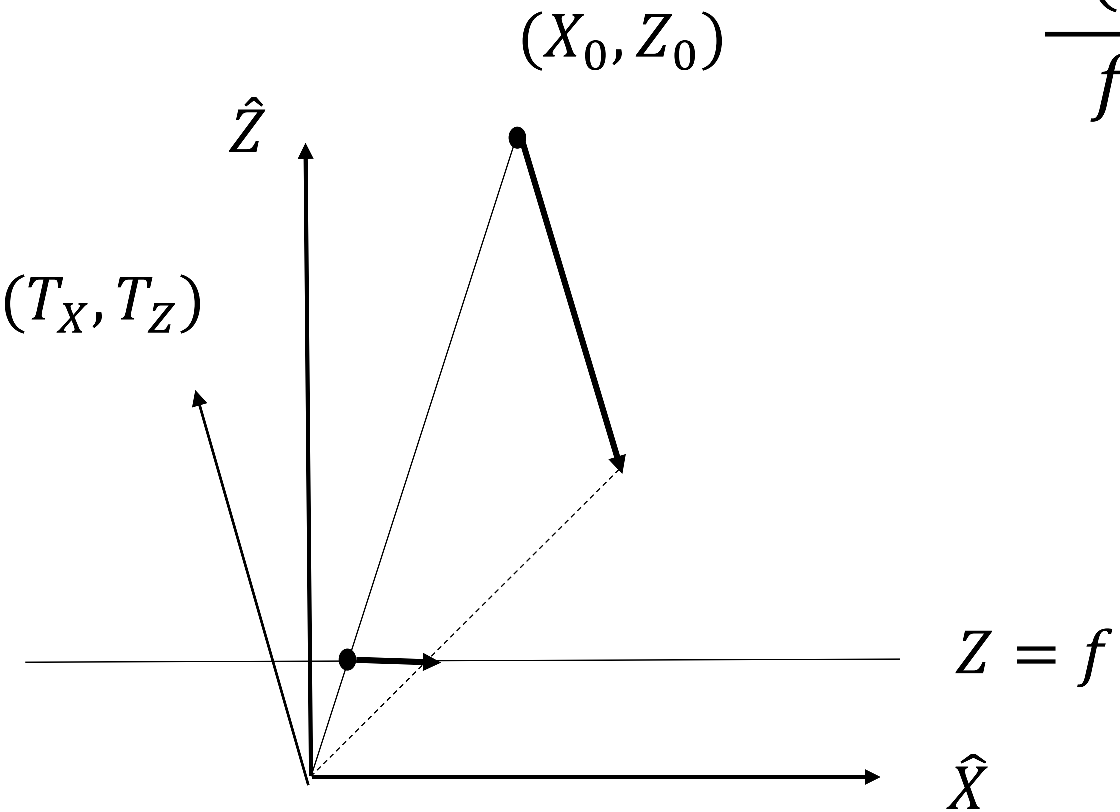


The path of the scene point in the eye's coordinate system is:

$$(X(t), Y(t), Z(t)) = \left(X_0 - T_x\, t, Y_0 - T_y\, t, Z_0 - T_z\, t\right)$$

The *relative* 3D velocity of the scene point $(-T_X, -T_Y, -T_Z)$

What is the **image path** of the scene point?

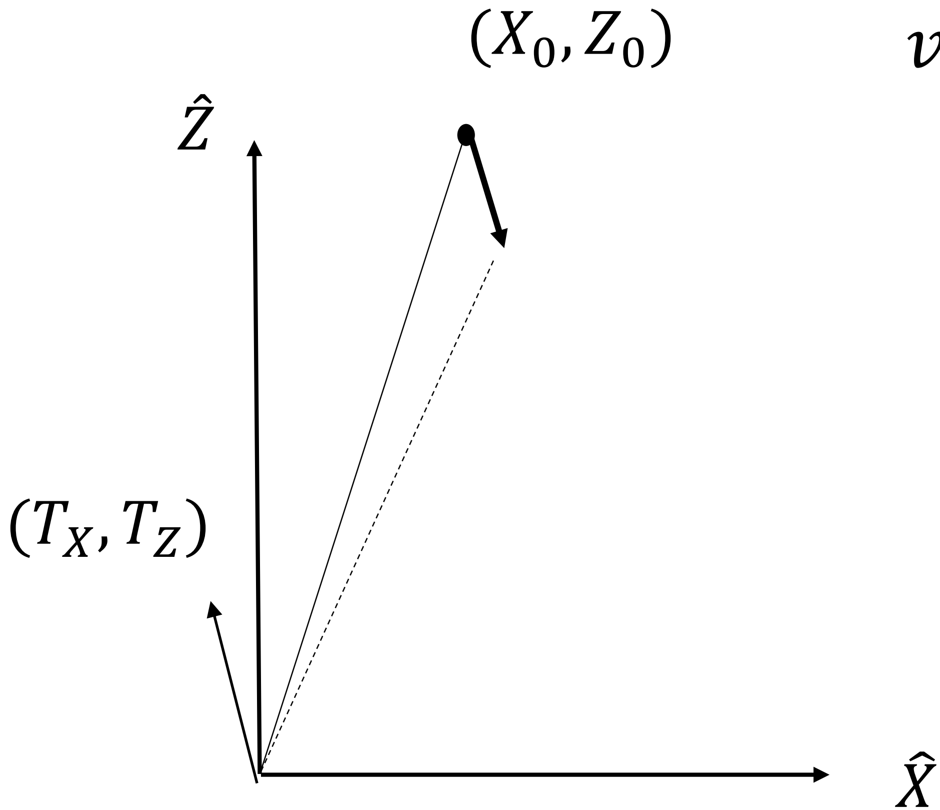


$$\frac{x(t)}{f} = \frac{X(t)}{Z(t)}$$

$$= \frac{X_o - T_X\, t}{Z_o - T_Z\, t}$$

Notation: here $x(t)$ is a position in the plane $Z = f$.

What is the **image** (angular) **velocity** of the scene point?



$$v_x = \frac{d}{dt}\left(\frac{x(t)}{f}\right) \Big|_{t=0}$$

$$= \frac{-\,T_X\,Z_0 + T_Z\,X_0}{{Z_o}^2}$$

Notation: here $v_x(t)$ is an angular velocity (radians/sec, assuming small angle approximation) rather than a velocity in the plane $Z = f$.

$$(v_x, v_y) = \left(\frac{-T_X Z_0 + T_Z X_0}{{Z_o}^2}, \frac{-T_Y Z_0 + T_Z Y_0}{{Z_o}^2} \right)$$

Previous slide

Same derivation for Y.

$$(v_x, v_y) = \left(\frac{-T_X Z_0 + T_Z X_0}{{Z_o}^2}, \frac{-T_Y Z_0 + T_Z Y_0}{{Z_o}^2} \right)$$

$$= \frac{1}{Z_o} (-T_X, -T_Y) \quad + \quad \frac{T_Z}{Z_o} \underbrace{\left(\frac{X_o}{Z_o}, \frac{Y_0}{Z_o} \right)}_{\left(\frac{x}{f}, \frac{y}{f} \right)}$$

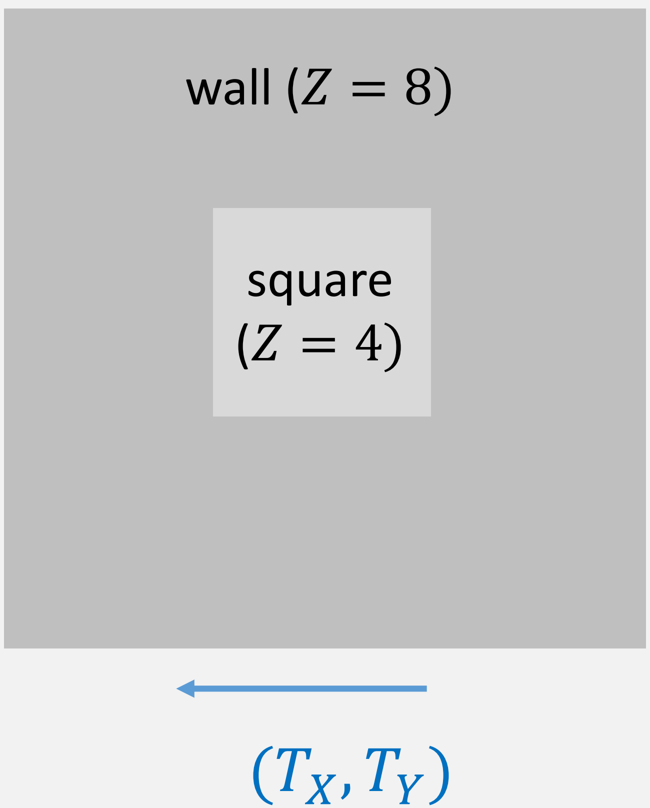
Lateral translation component

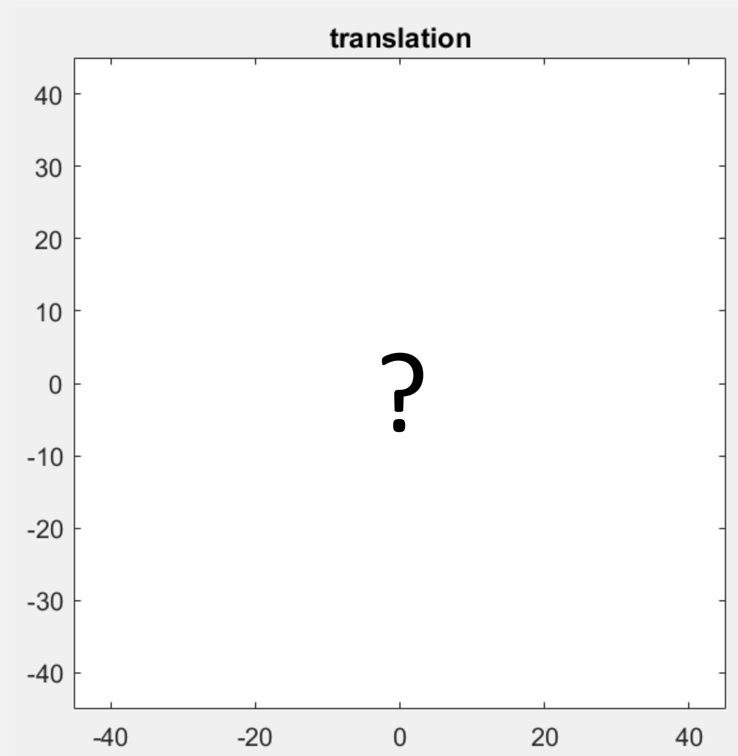
Forward translation component

Lateral translation $(T_Z = 0)$

$$\left(v_x, v_y\right) = \frac{1}{Z_o}\left(-T_X, -T_Y\right)$$

Example:



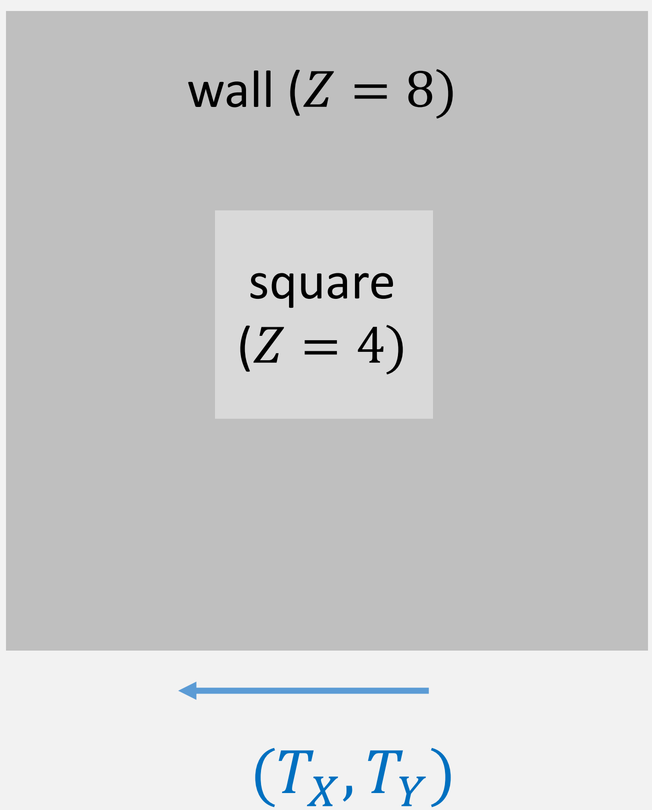


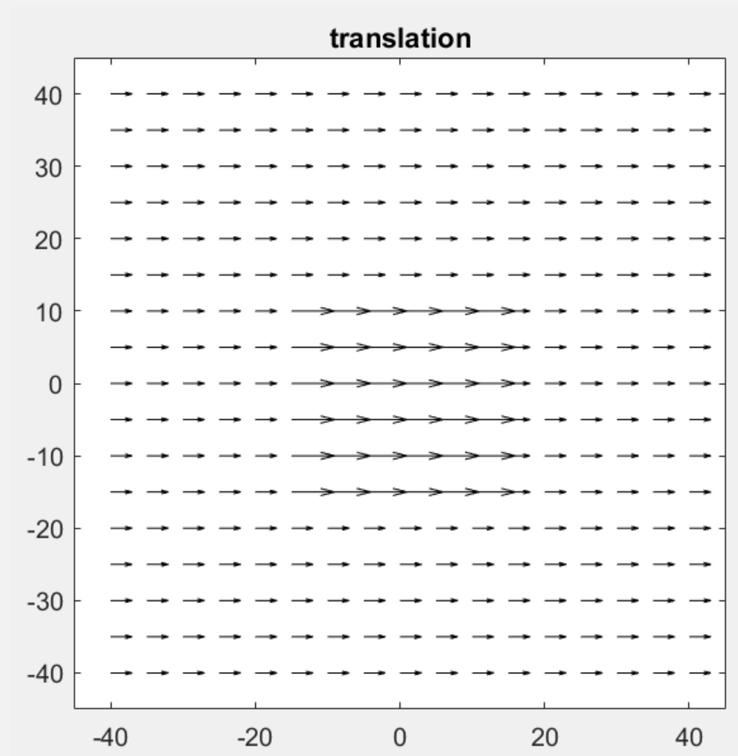
eccentricity (deg.)

Lateral translation ($T_Z = 0$)

$$\left(v_x, v_y\right) = \frac{1}{Z_o}\left(-T_X, -T_Y\right)$$

Example:



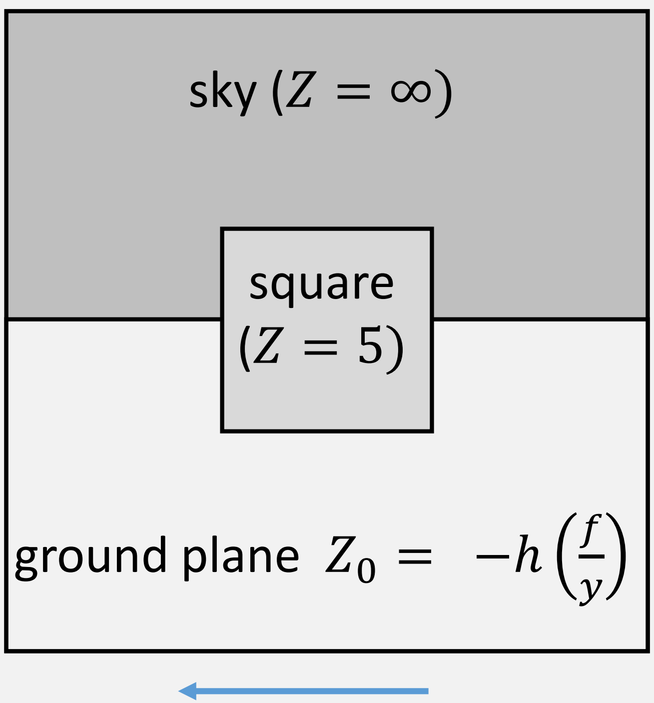


eccentricity (deg.)

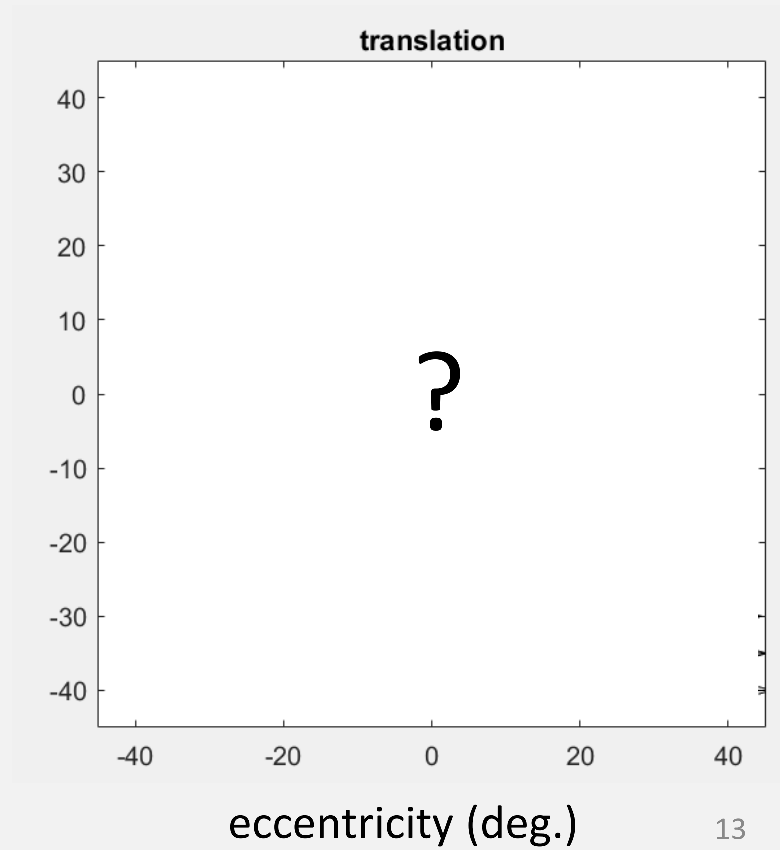
Lateral translation $(T_Z = 0)$

$$\left(v_x, v_y\right) = \frac{1}{Z_o}\left(-T_X, -T_Y\right)$$

Example:



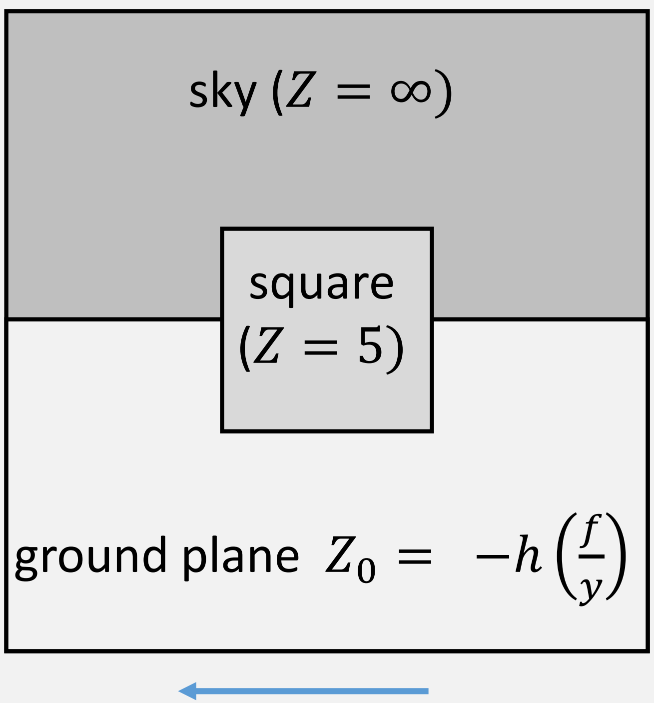
(T_X, T_Y)



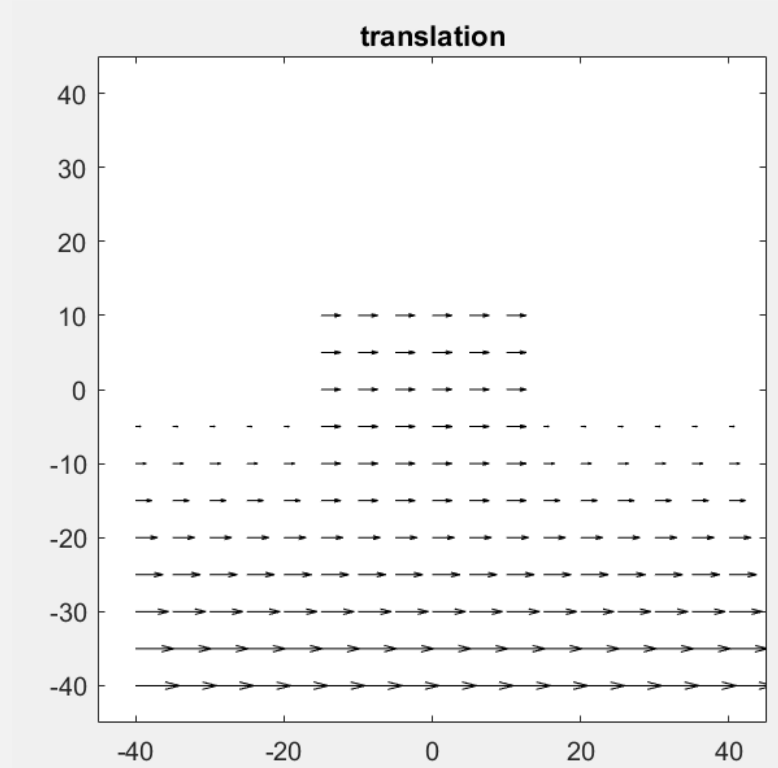
Lateral translation $(T_Z = 0)$

$$\left(v_x, v_y\right) = \frac{1}{Z_o}\left(-T_X, -T_Y\right)$$

Example:



(T_X, T_Y)

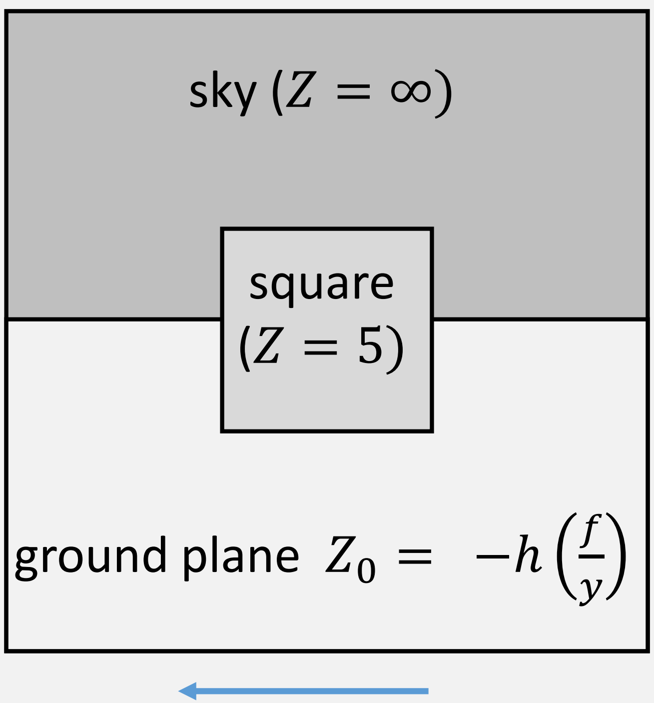


eccentricity (deg.)

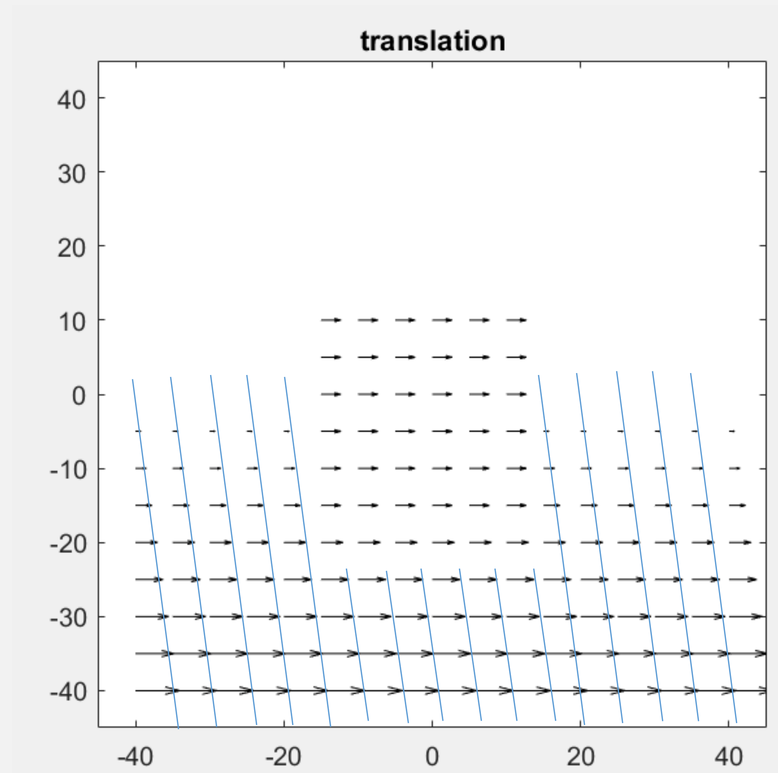
Lateral translation ($T_Z = 0$)

$$(v_x, v_y) = \frac{1}{Z_o}(-T_X, -T_Y)$$

Example:



(T_X, T_Y)

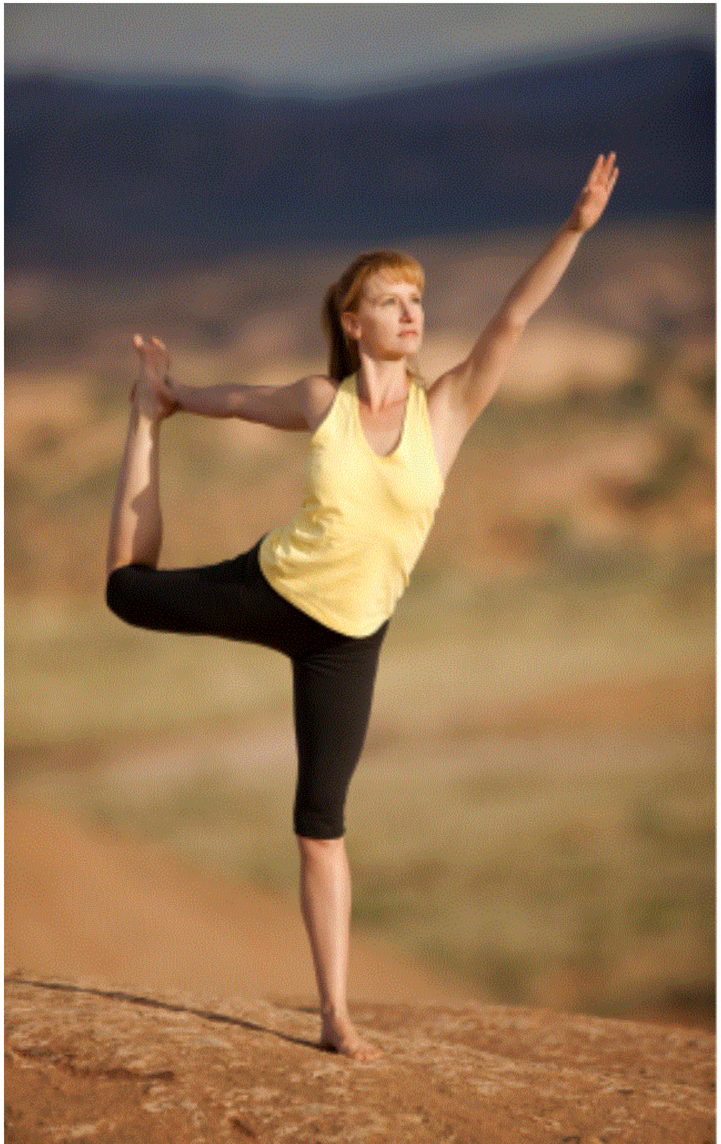


eccentricity (deg.)

Dizziness (‘height vertigo’)

Not to be confused with a more general ‘acrophobia’ (fear of heights)

Lateral Motion and Balance



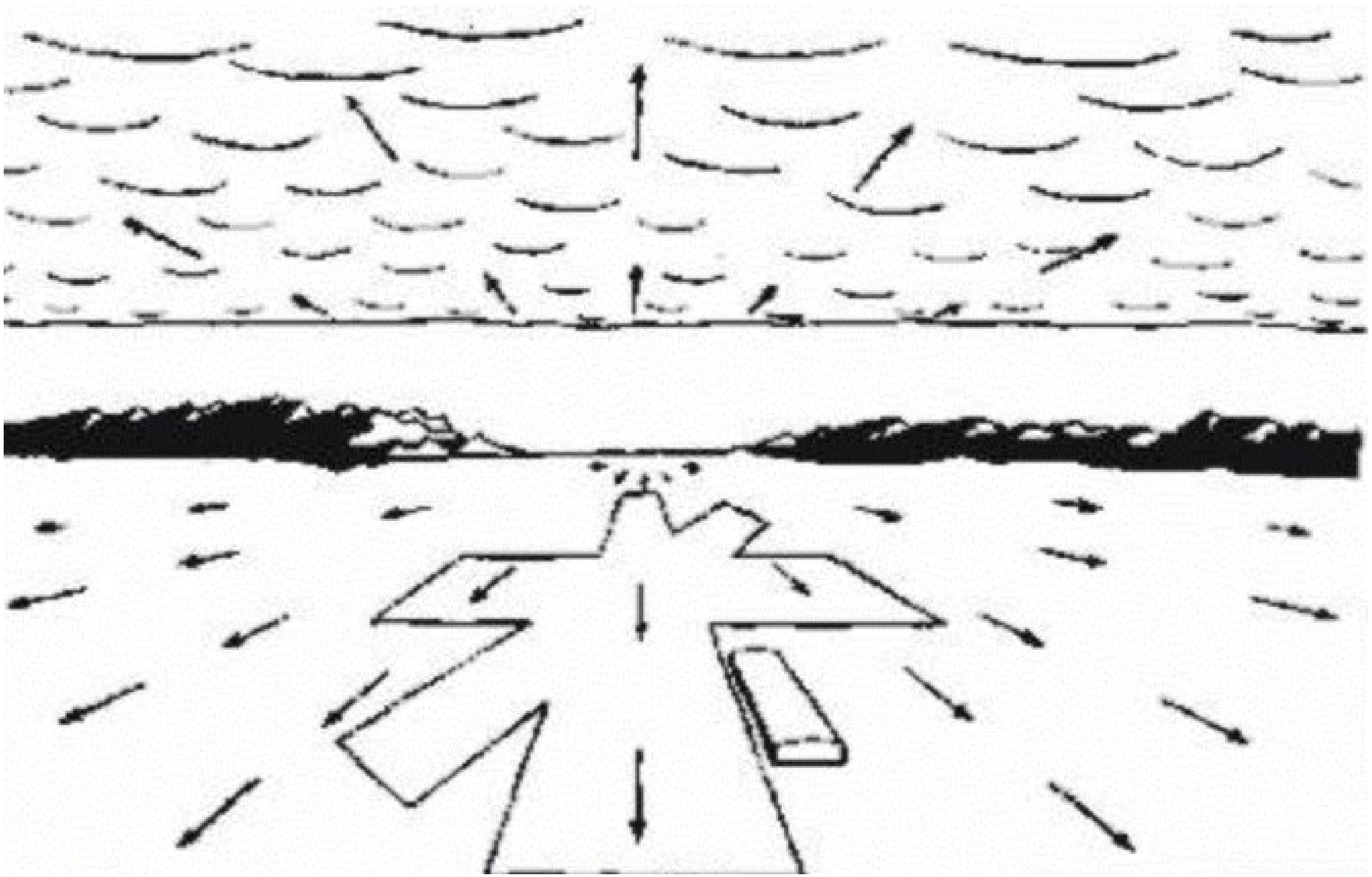
Holding this pose is more difficult when looking up than when looking down.

Why?

Forward Component $(T_X = T_Y = 0)$

$$(v_x, v_y) = \frac{T_Z}{Z_o}(x, y)$$

Let $f = 1$, so units of position are radians i.e. visual angle.

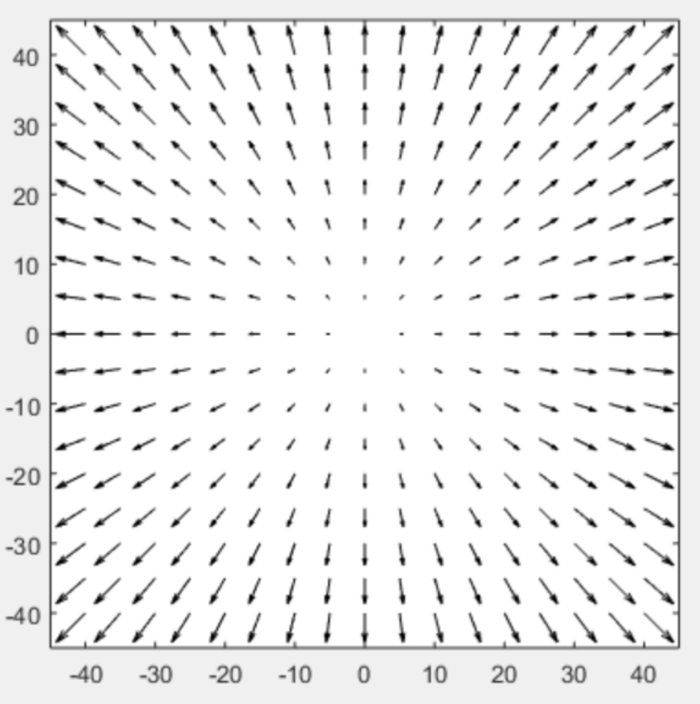


What does a pilot see when approaching the runway?

(from JJ Gibson 1950)

Forward Component $(T_X = T_Y = 0)$

$$(v_x, v_y) = \frac{T_Z}{Z_o}(x, y)$$

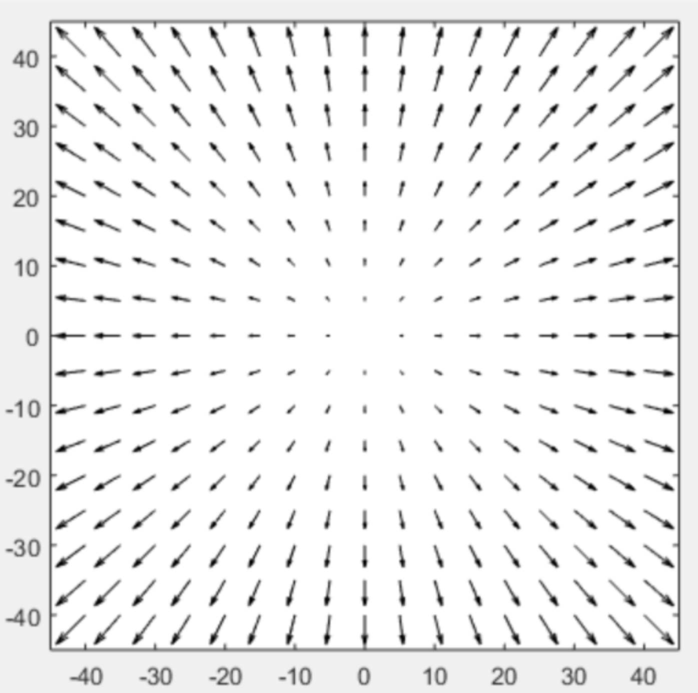


wall

Z_o = constant.

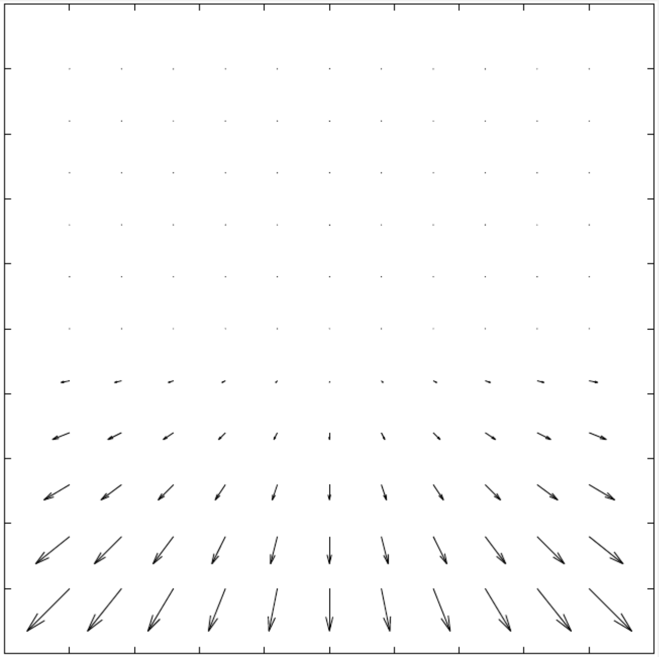
Forward Component $(T_X = T_Y = 0)$

$$(v_x, v_y) = \frac{T_Z}{Z_o}(x, y)$$



wall

Z_o = constant



ground plane

(see Exercises)

What is the image motion seen by a moving observer? ("egomotion")

- Translation

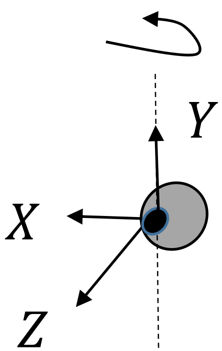
  (lateral, forward)

- Rotation

  (pan, tilt, roll)

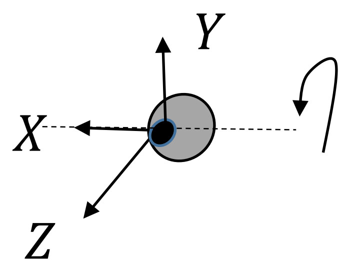
Motion field seen by a rotating observer ?

Ω_Y



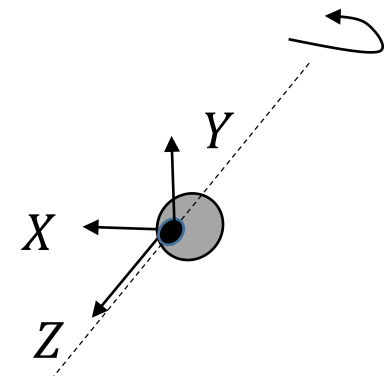
pan

Ω_X



tilt

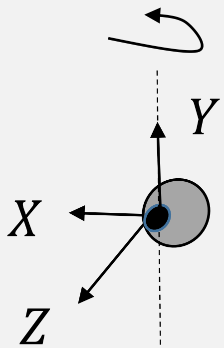
Ω_Z



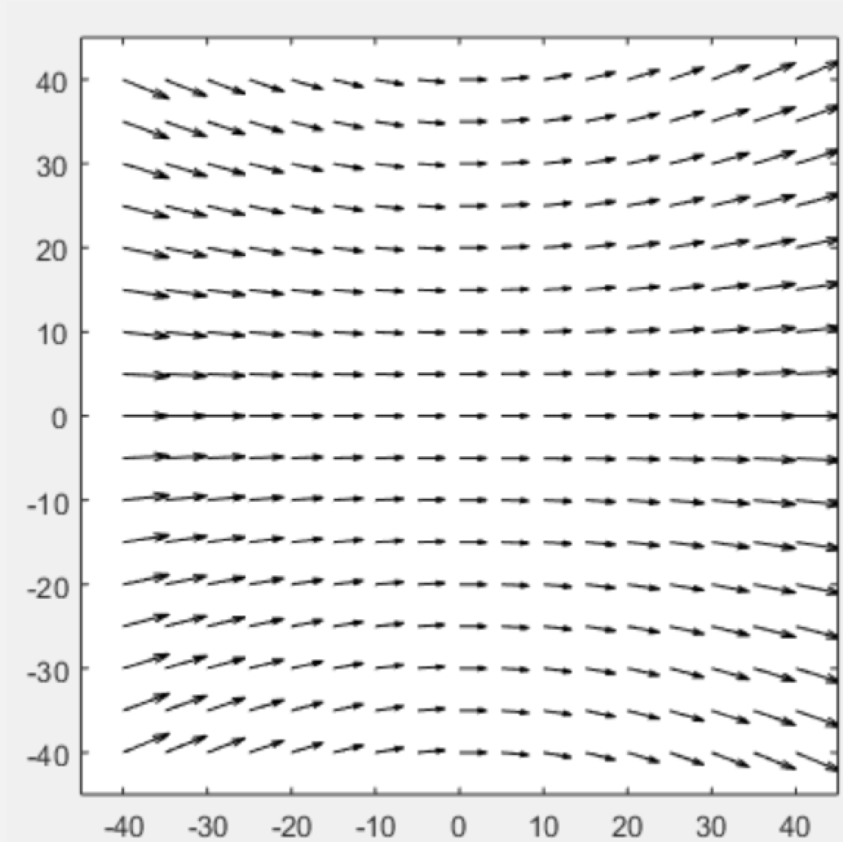
roll

We can rotate the eye and the head (and often both).

Ω_Y

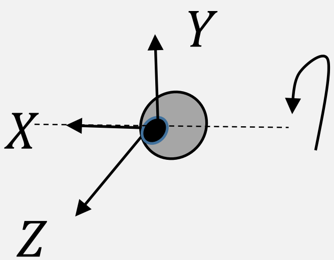


pan

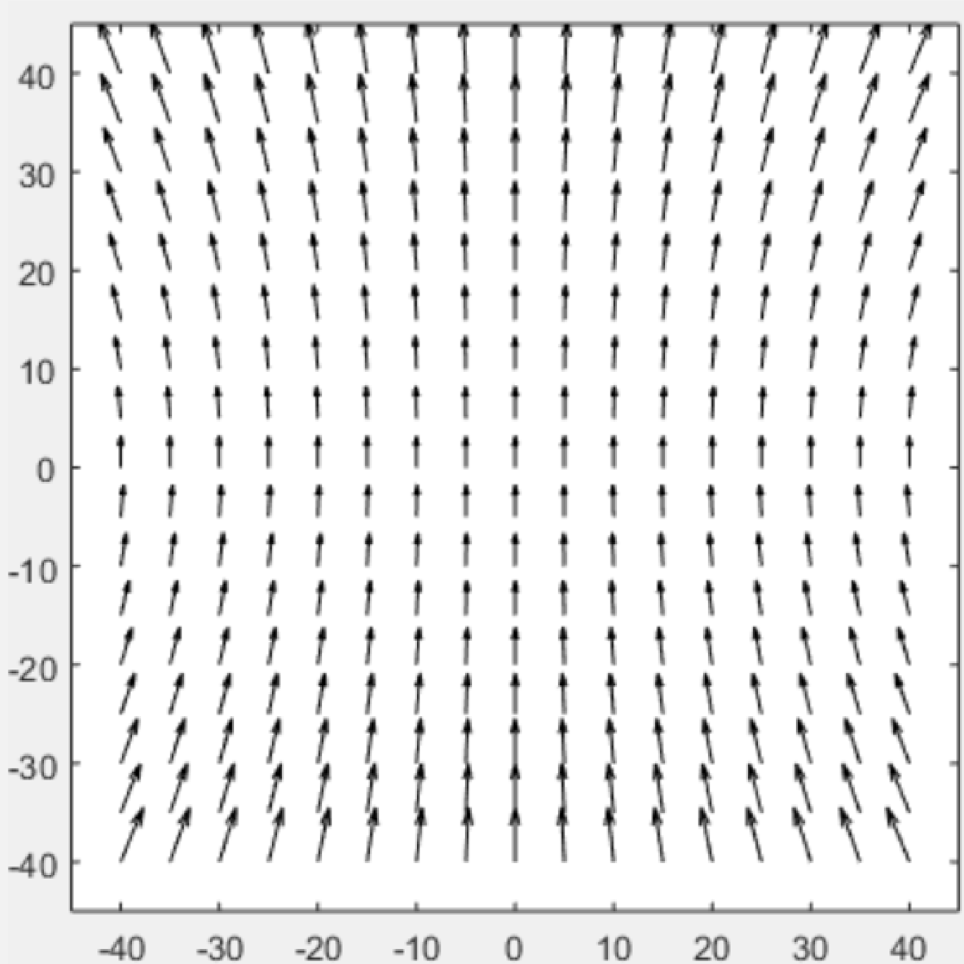


The non-linearities in the motion field at large eccentricities are due to projection onto a rotating sensor *plane*. (Details not relevant for human vision, since sensor is not a plane.)

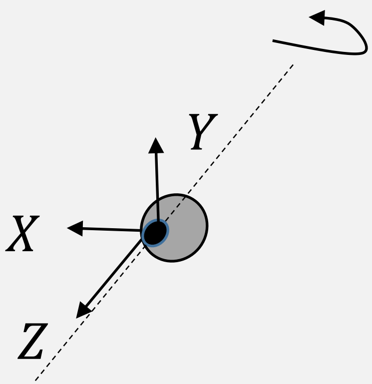
Ω_X



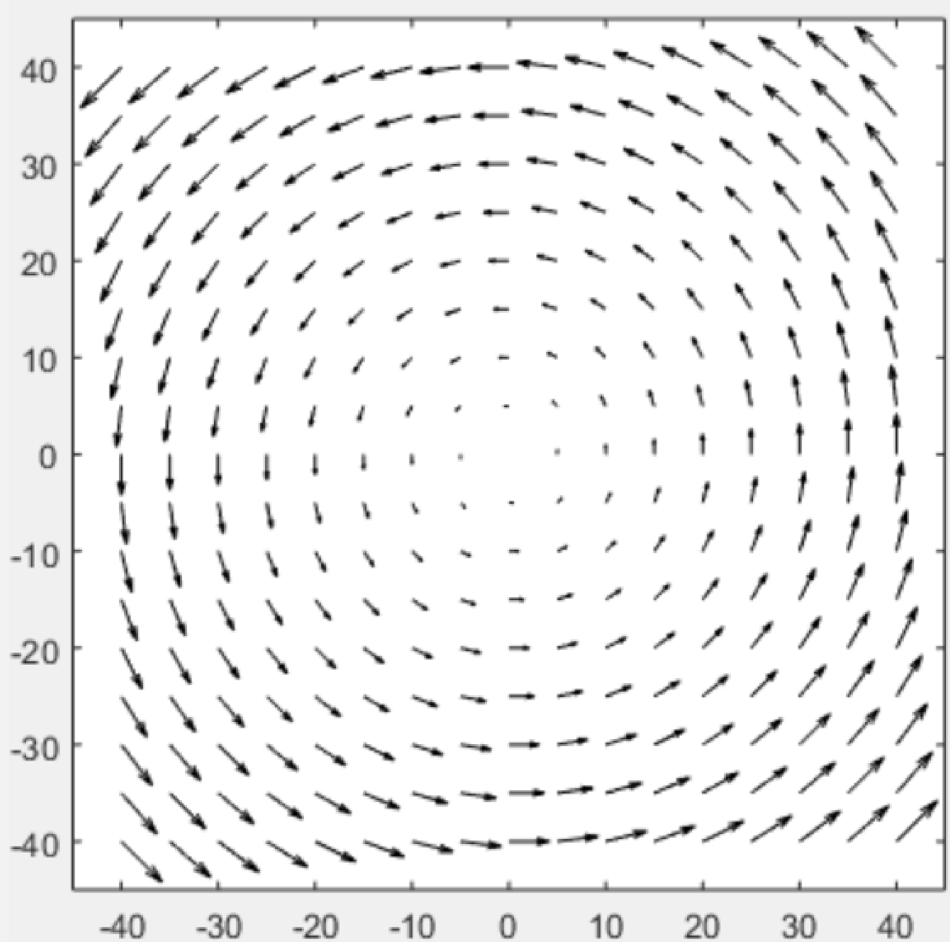
tilt



Ω_Z

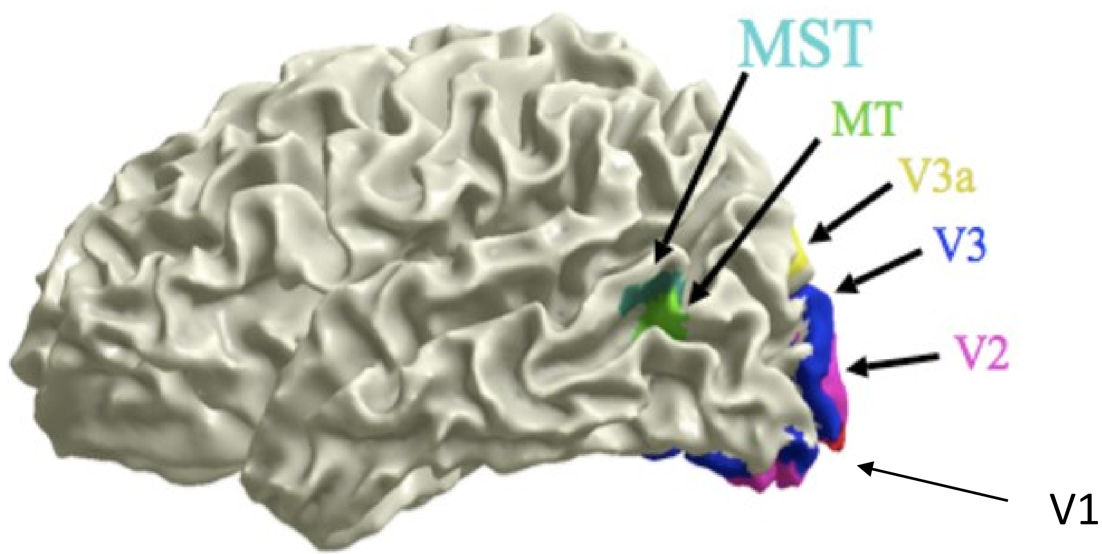


roll



ASIDE: Visual motion processing in the brain

- estimate normal velocities V1
- estimate velocities (v_x, v_y) MT (middle temporal lobe)
- **estimate global motion field** MST (medial superior temporal lobe)

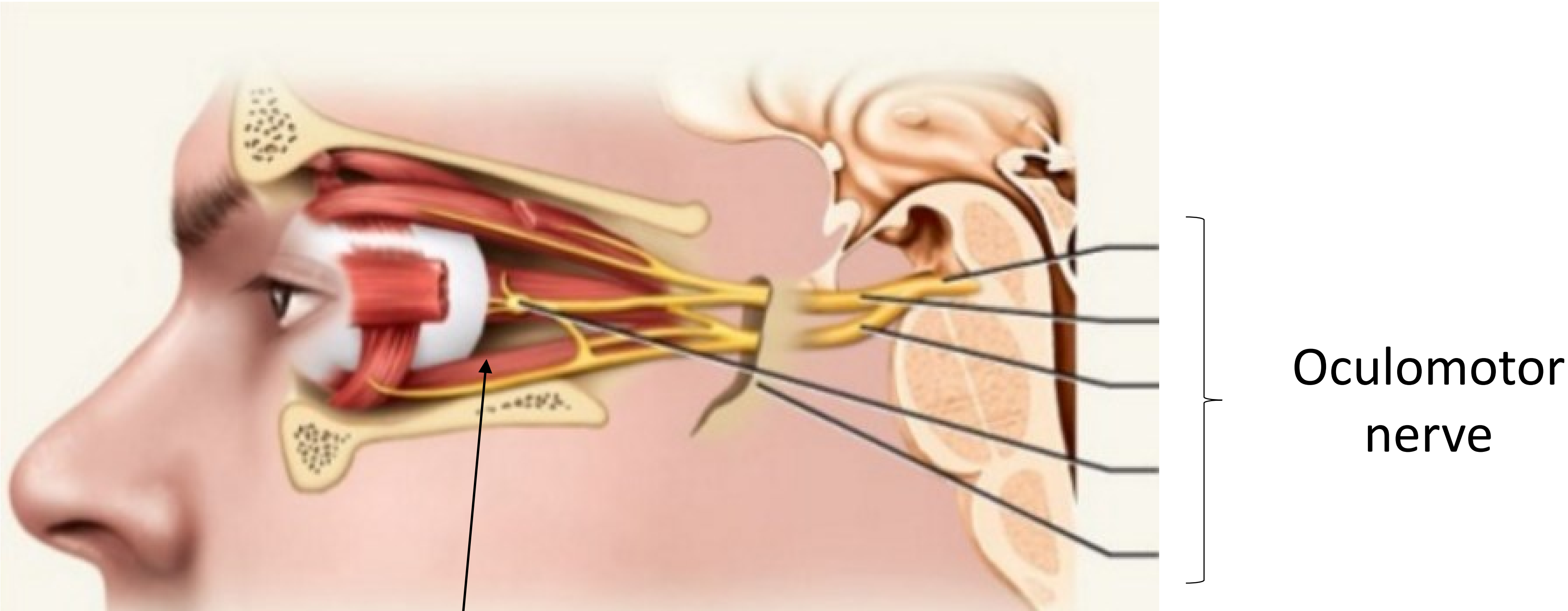


COMP 546

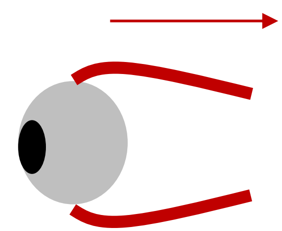
Lecture 10

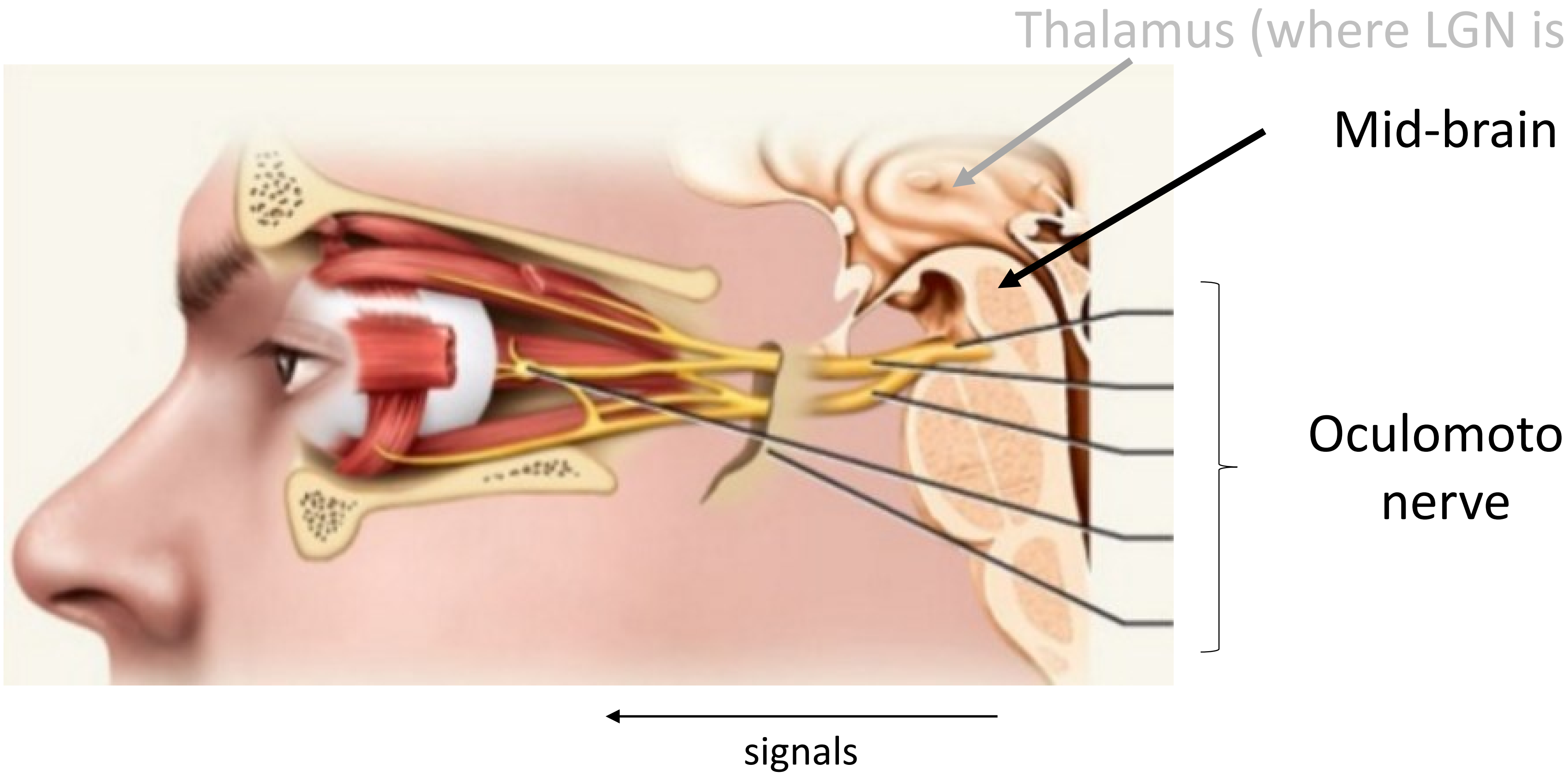
egomotion & eye movements

Tues. Feb. 12, 2018



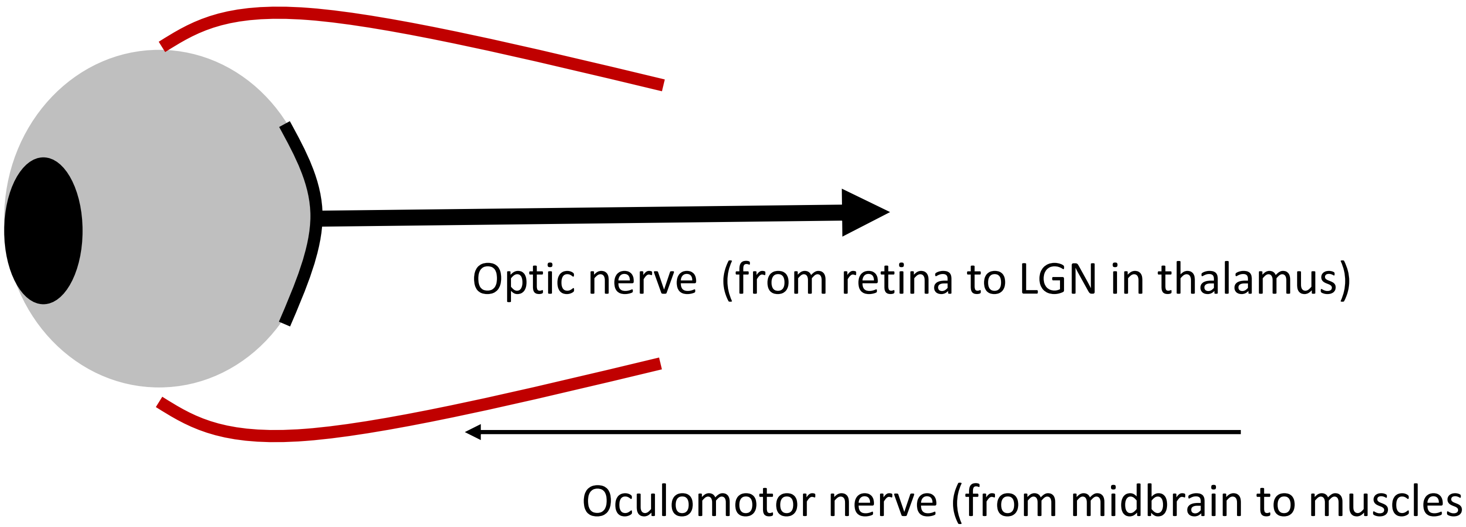
Muscles control eye position using a pulley system.
Motor signals sent to the muscles of the eye.
They can roll, pan, and tilt the eye.





All eye movement *motor* (output) signals come from mid-brain via the various branches of the oculomotor nerve(s).

These nerves also control accommodation, blinks, pupil contraction.


Optic nerve (from retina to LGN in thalamus)
Oculomotor nerve (from midbrain to muscles)

Types of eye movements

- smooth pursuit
- vestibulo-ocular reflex (VOR)
- saccades
- OKN (optokinetic nystagmus) OMIT

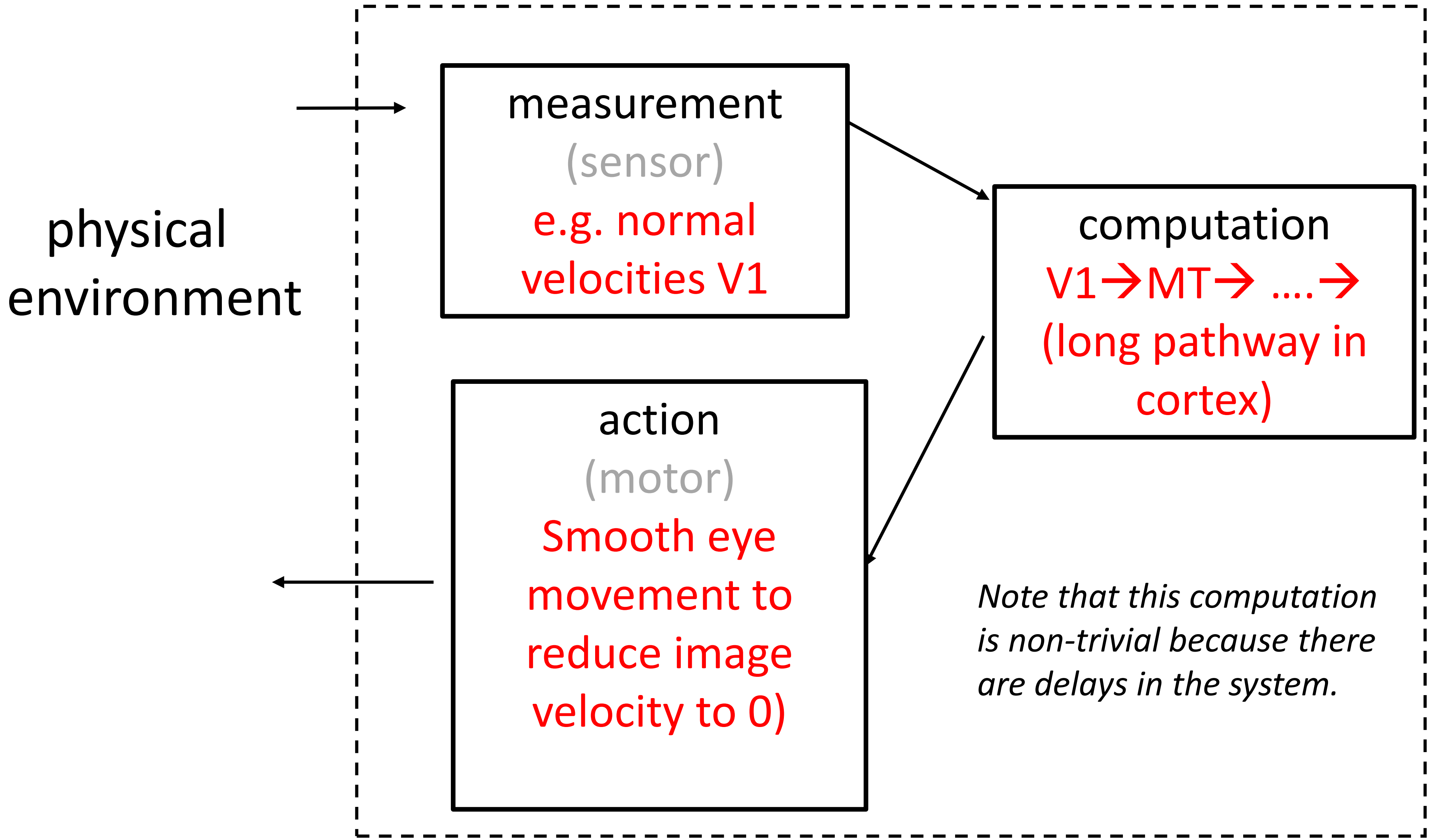
Smooth Pursuit Eye Movements

- tracking a moving object

- tracking a static object as the observer moves

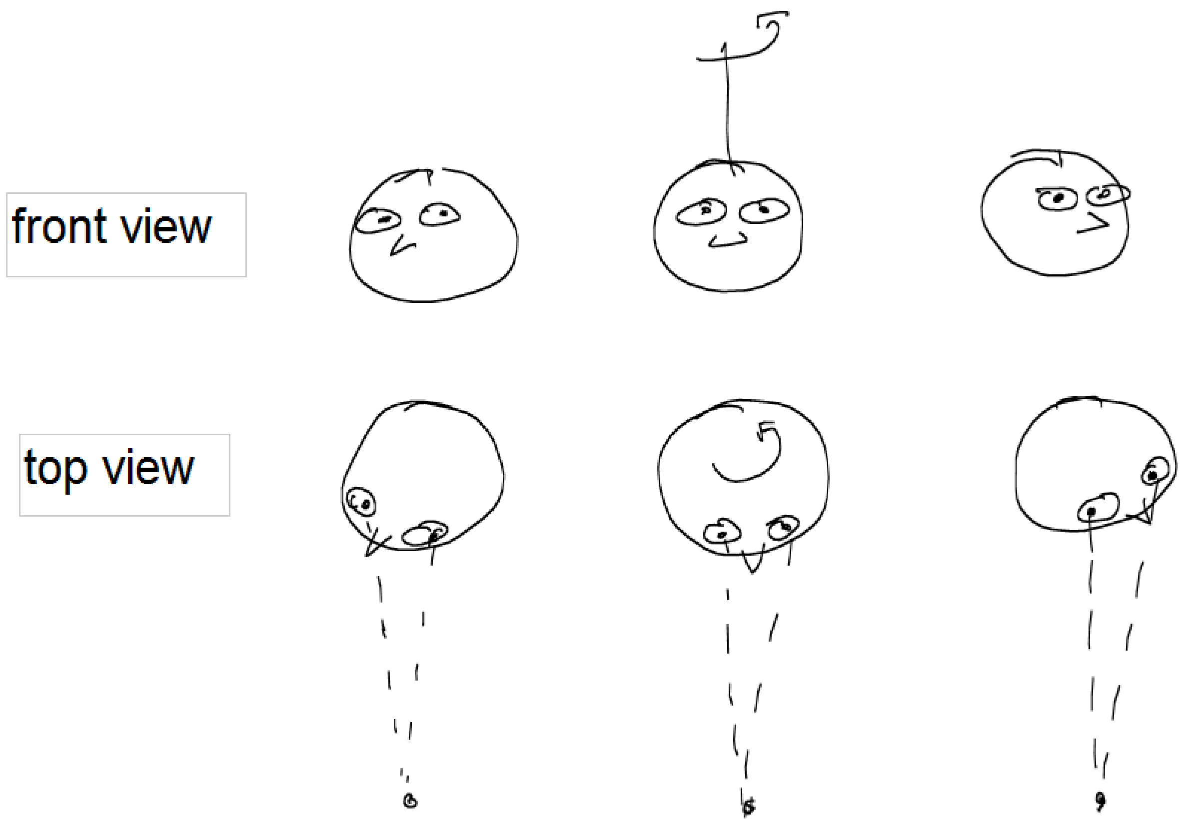
In both cases, it reduces retinal motion of the object to 0.

Smooth Pursuit

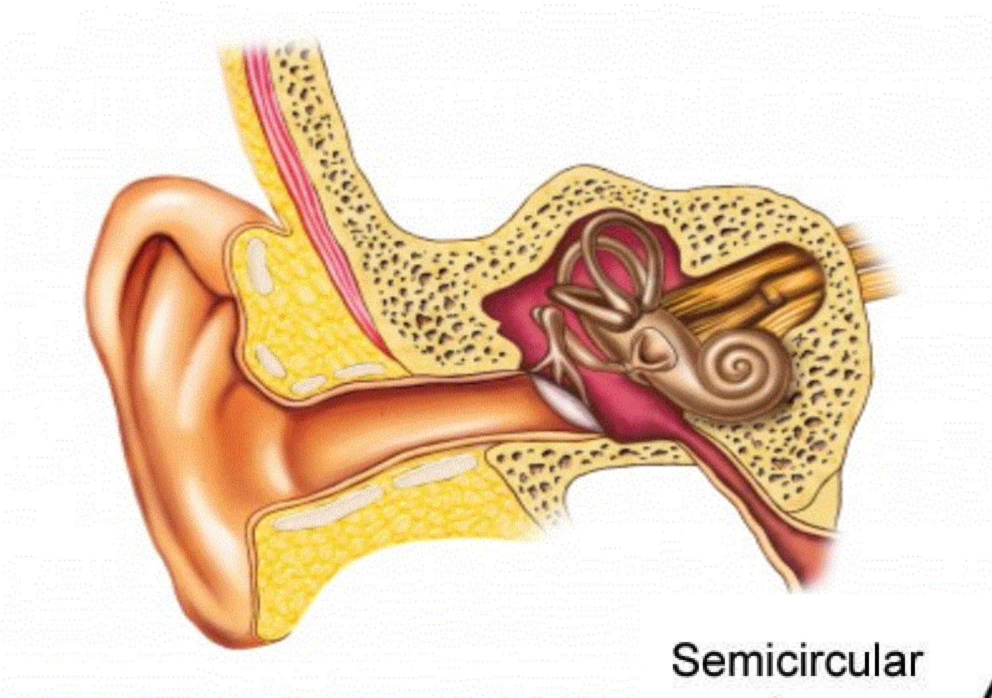


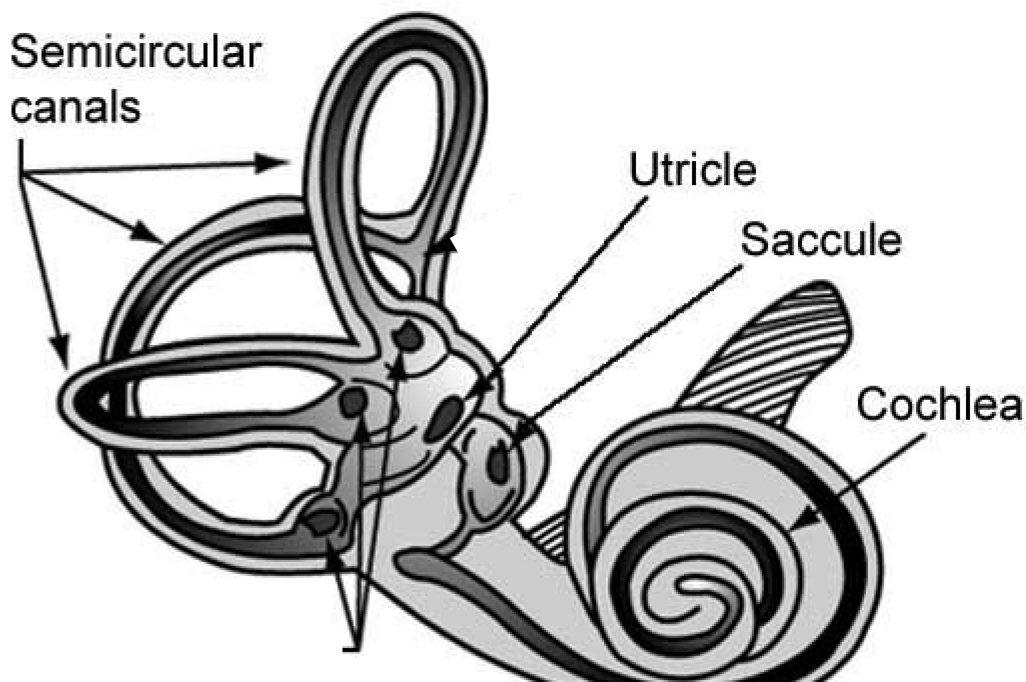
Vestibulo-Ocular Reflex (VOR)

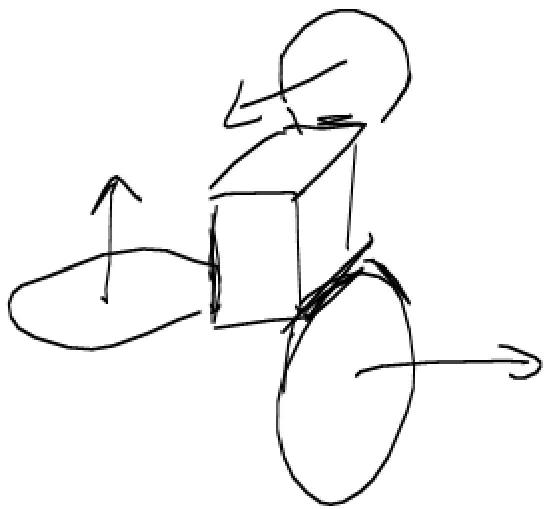
(eye rotations *due to* head movement)



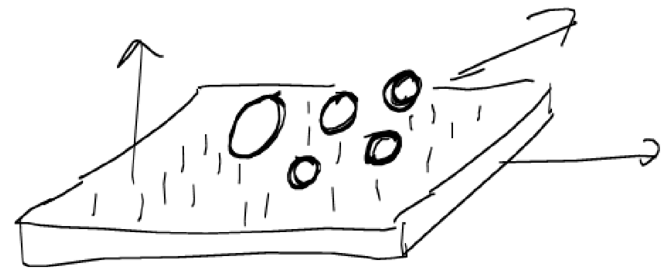
Vestibular System
(in the inner ear)







otoliths



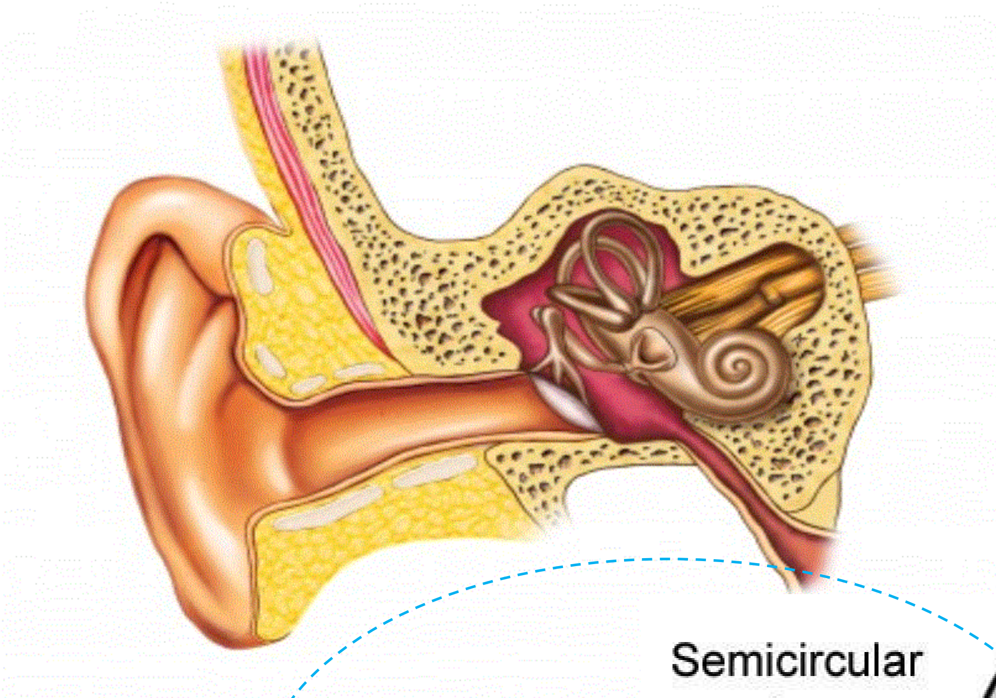
Rotation
(angular acceleration)

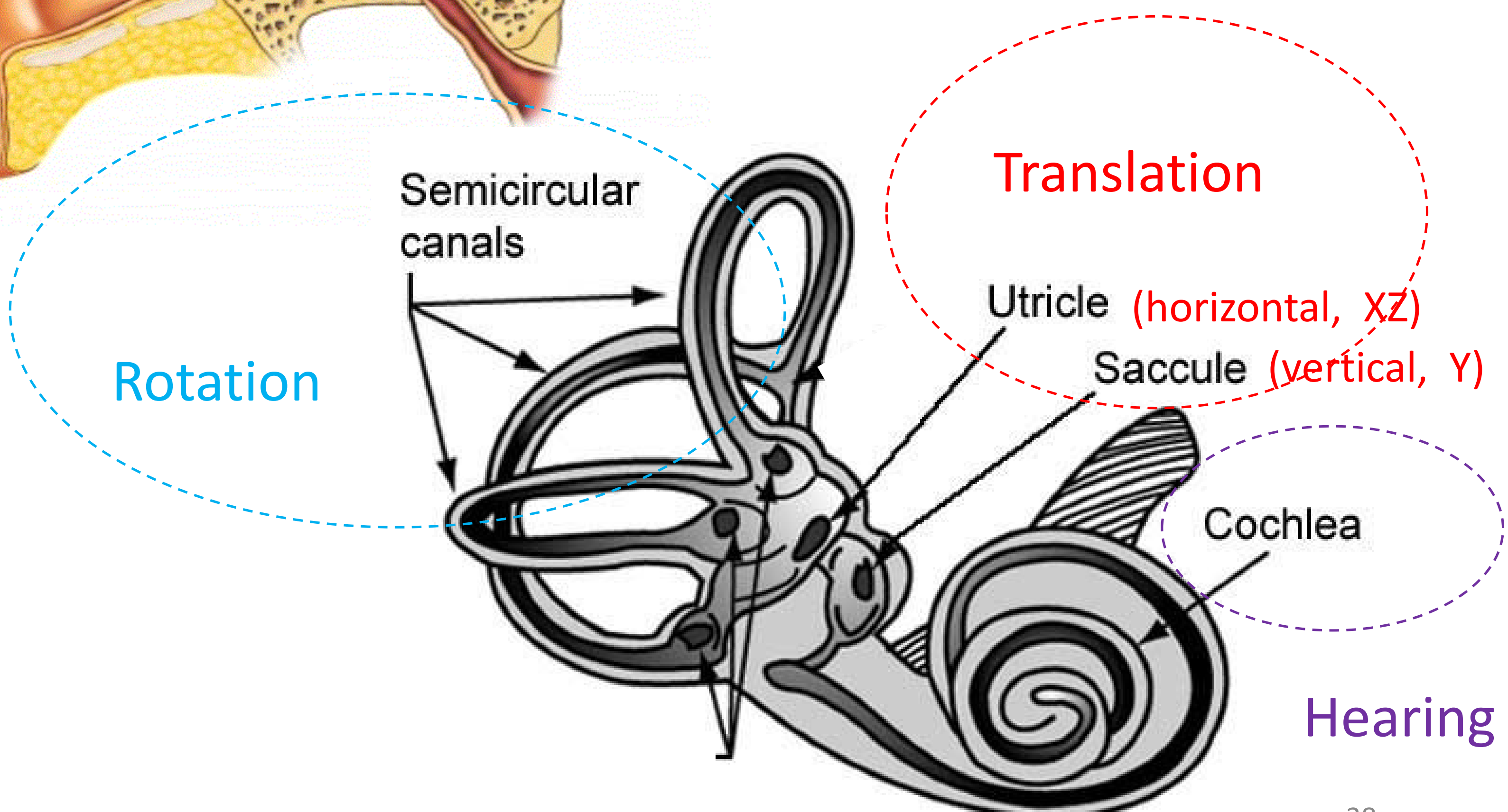
Translation
(linear acceleration)

$$\frac{d}{dt}(\Omega_X , \Omega_Y , \Omega_Z)$$

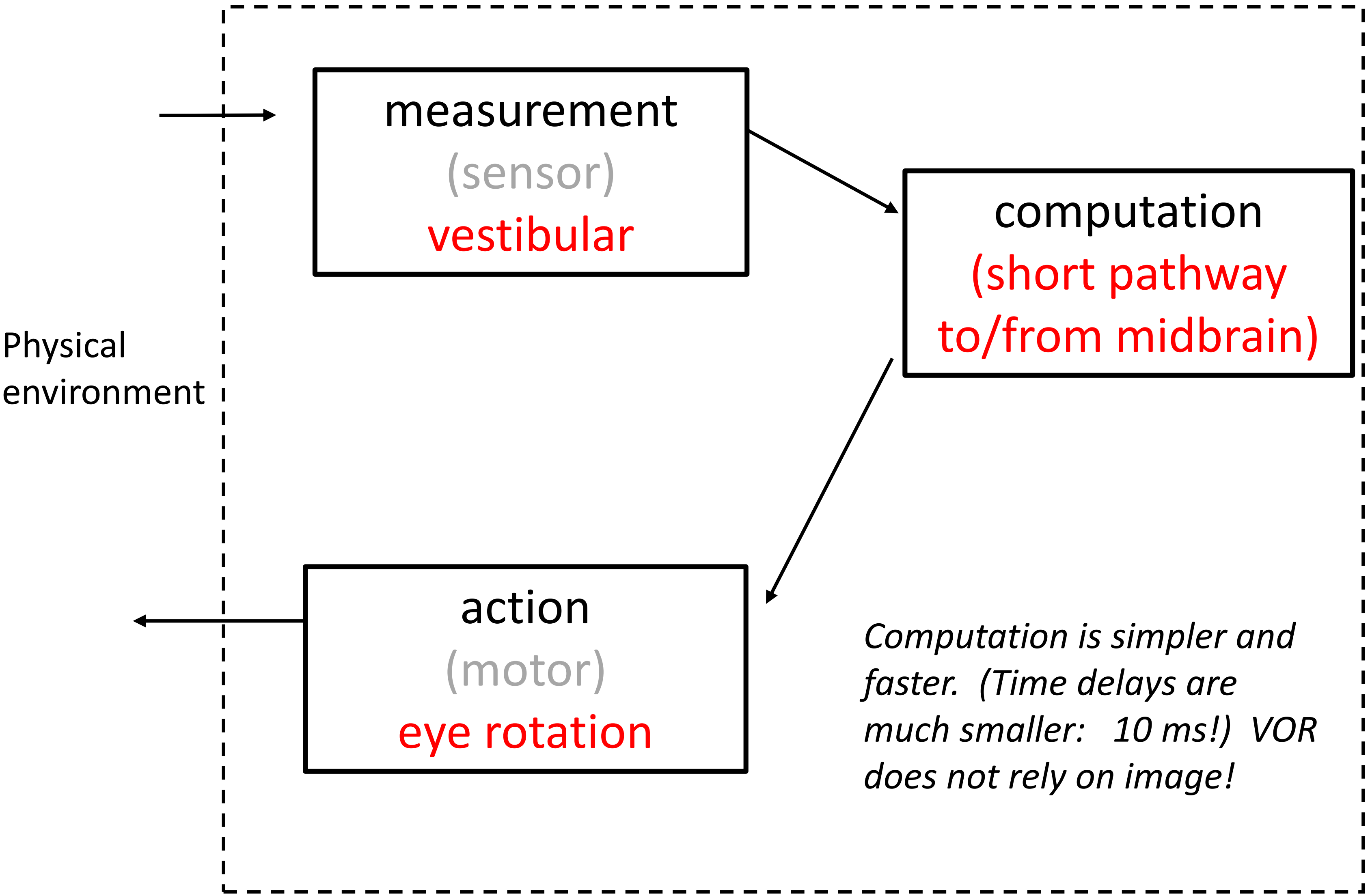
$$\frac{d}{dt} \quad (T_X, T_Y, T_z)$$

Vestibular System
(in the inner ear)

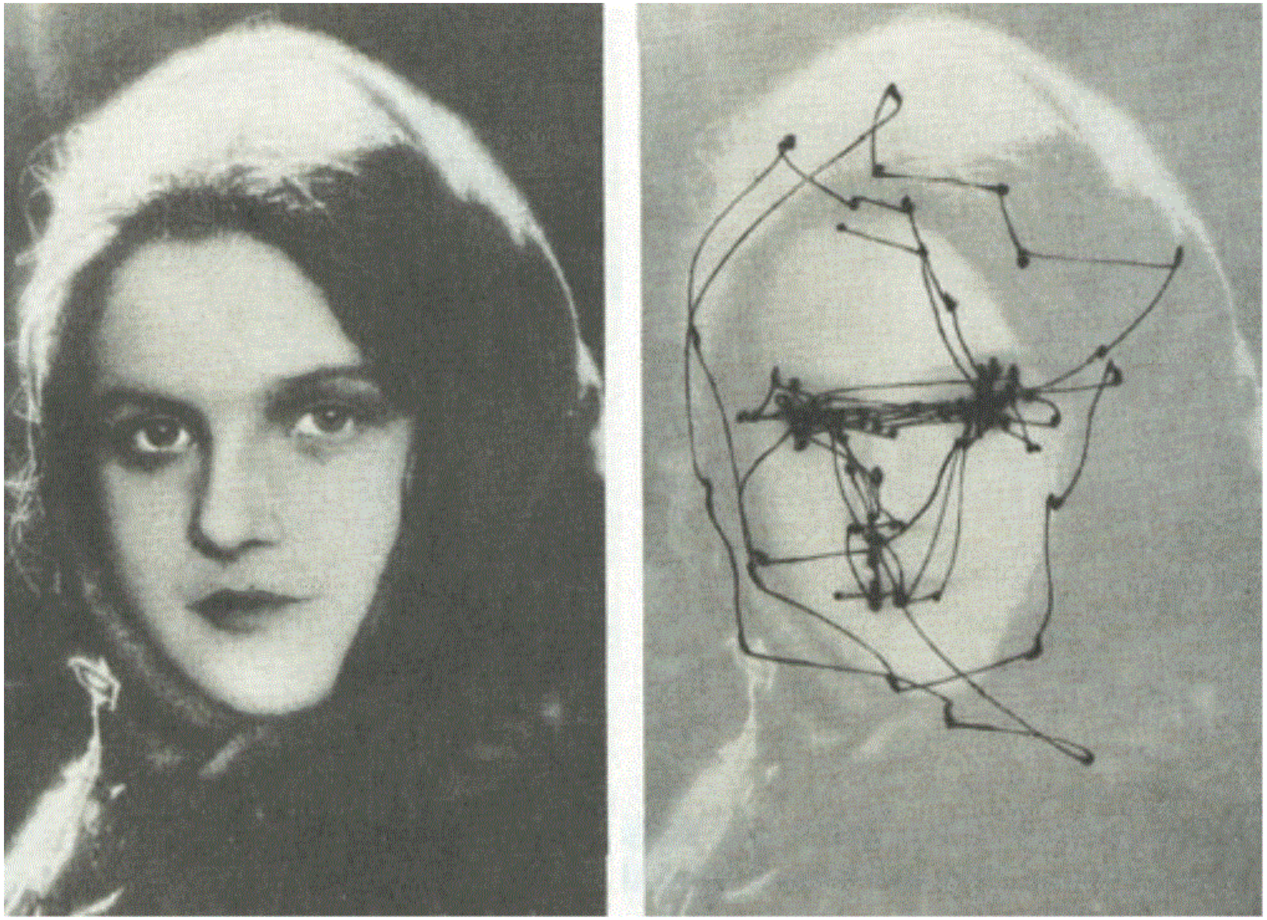




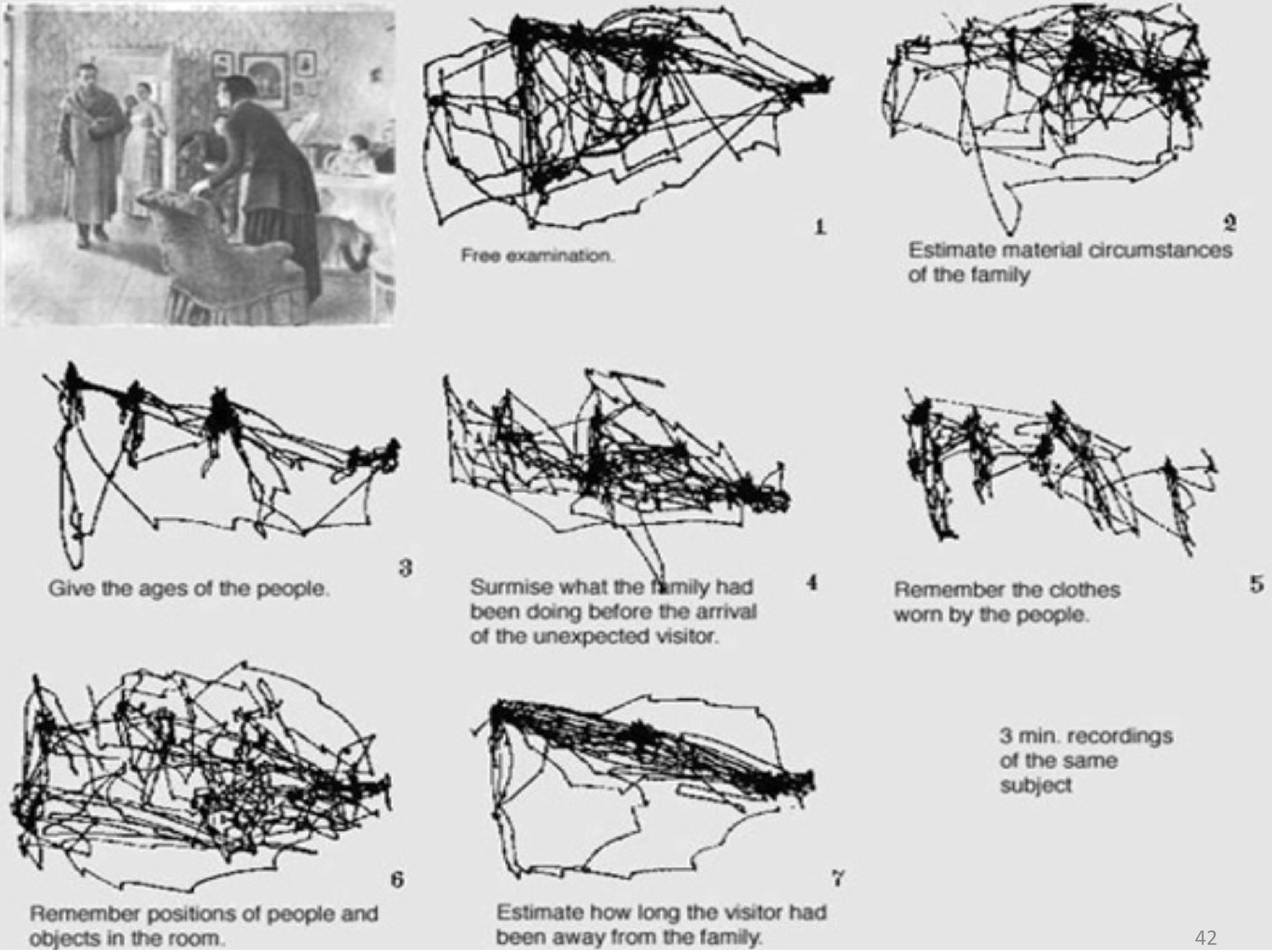
Vestibulo-ocular Reflex (VOR)



Saccades



"The Unexpected Visitor"
classic experiment by Yarbus 1960s

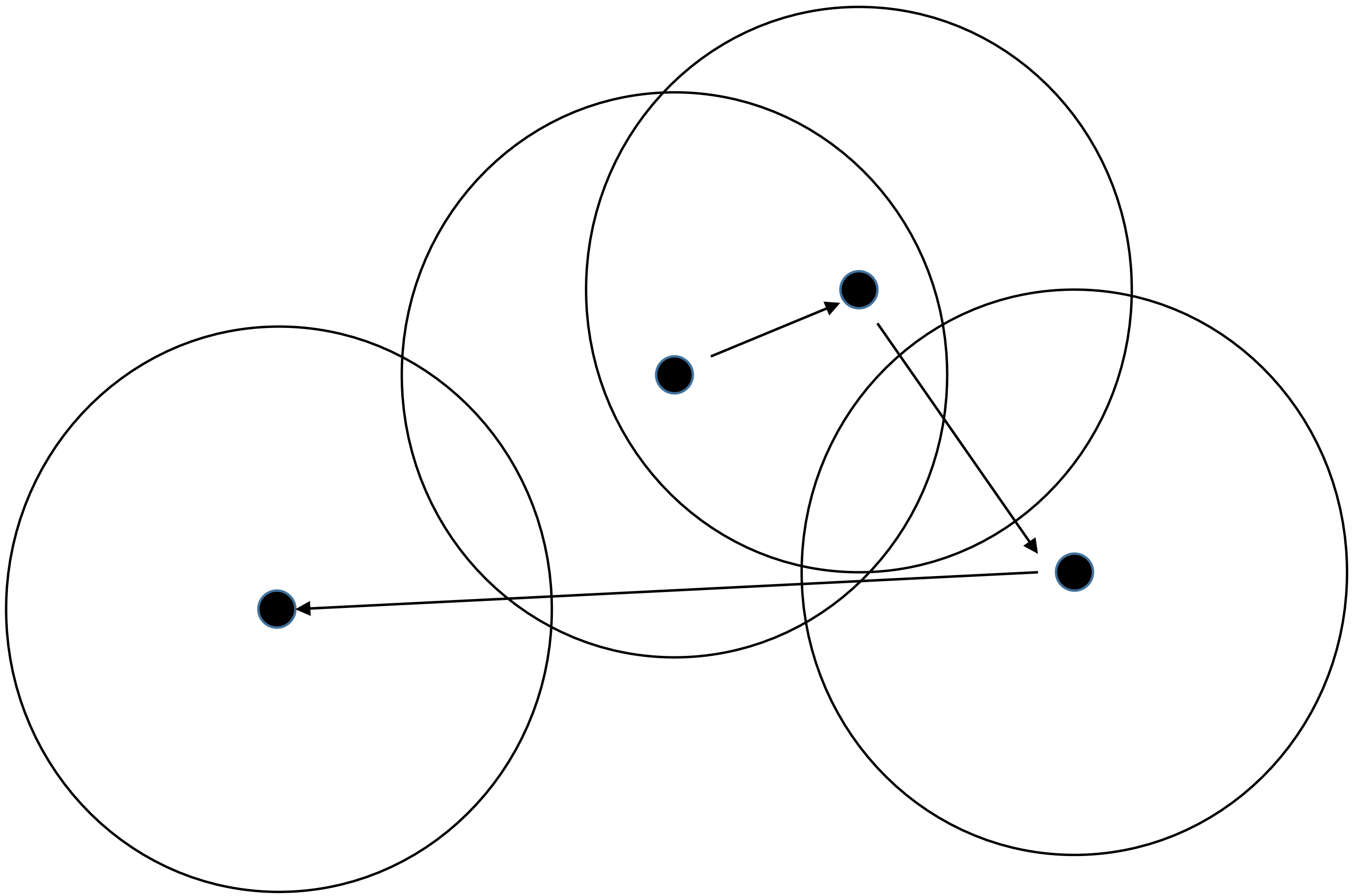

Free examination.
1
Estimate material circumstances of the family
2
Give the ages of the people.
3
Surmise what the family had been doing before the arrival of the unexpected visitor.
4
Remember the clothes worn by the people.
5
Remember positions of people and objects in the room.
6
Estimate how long the visitor had been away from the family.
7
3 min. recordings of the same subject

Eye Tracking

Making a cup of tea

Driving a car

How to integrate the images?



What computational vision problems are they solving?