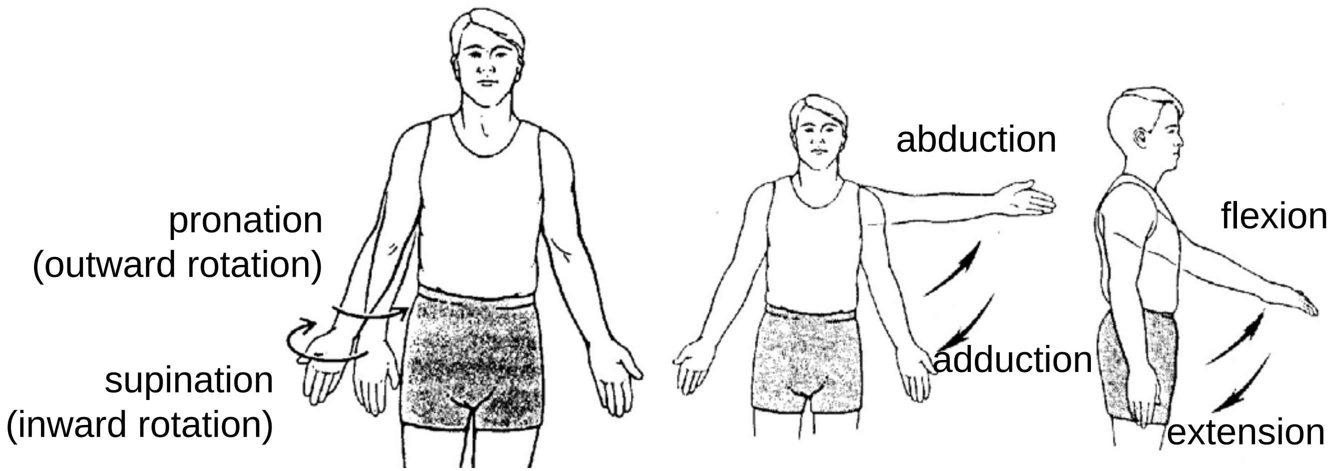
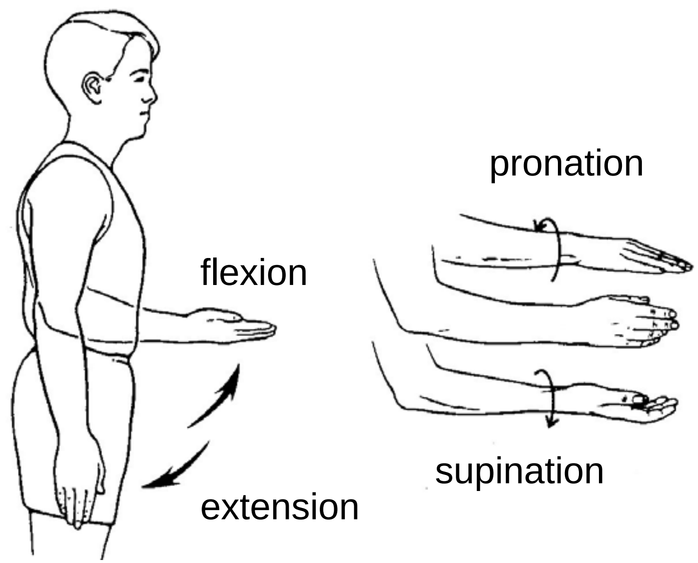
Reading: Chapters 9 (all) and 10.1

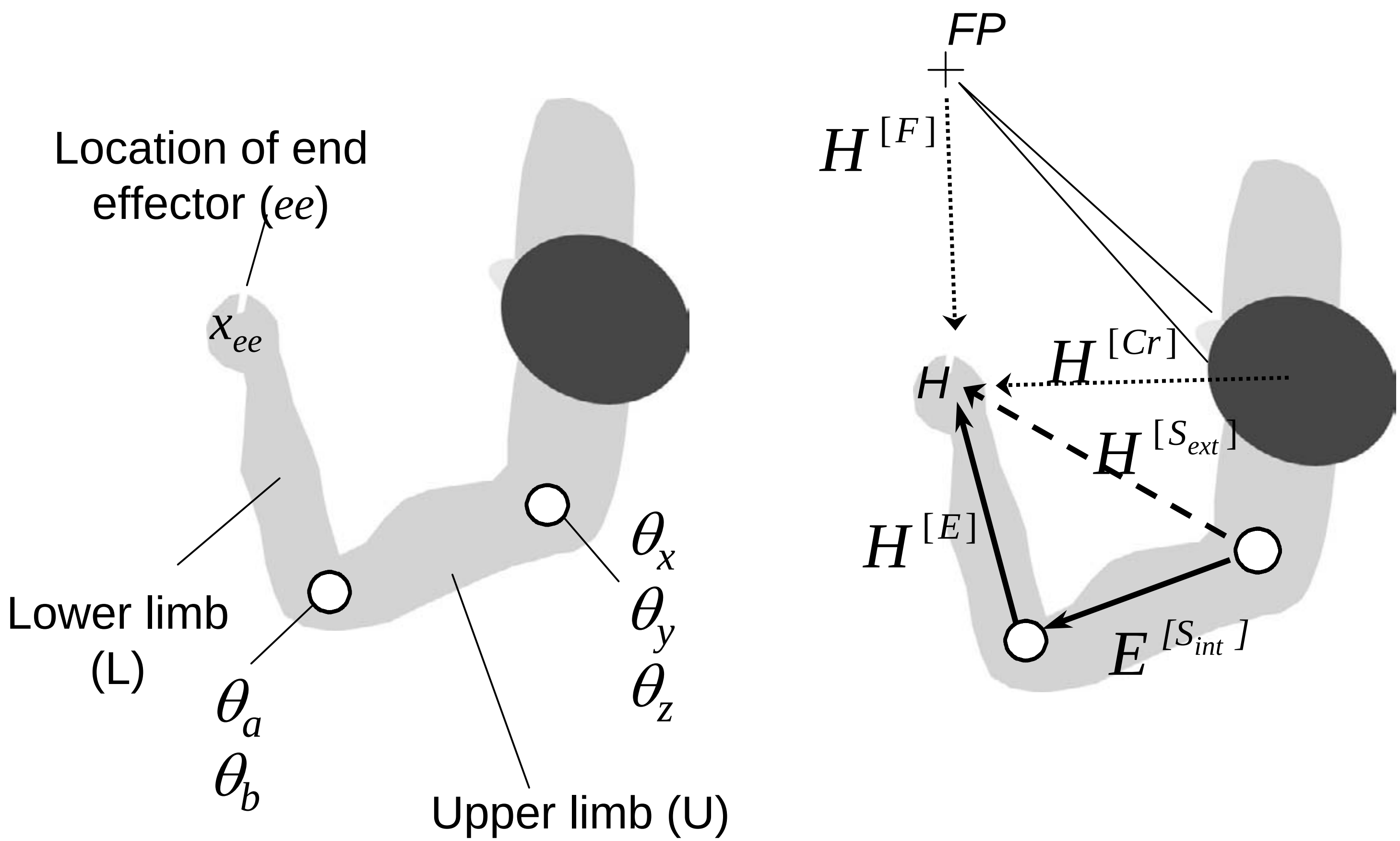
Kinematics vs. dynamics

Forward kinematics vs. inverse kinematics

End effectors and limb growth


pronation
(outward rotation)
supination
(inward rotation)
abduction
adduction
flexion
extension


flexion
extension
pronation
supination

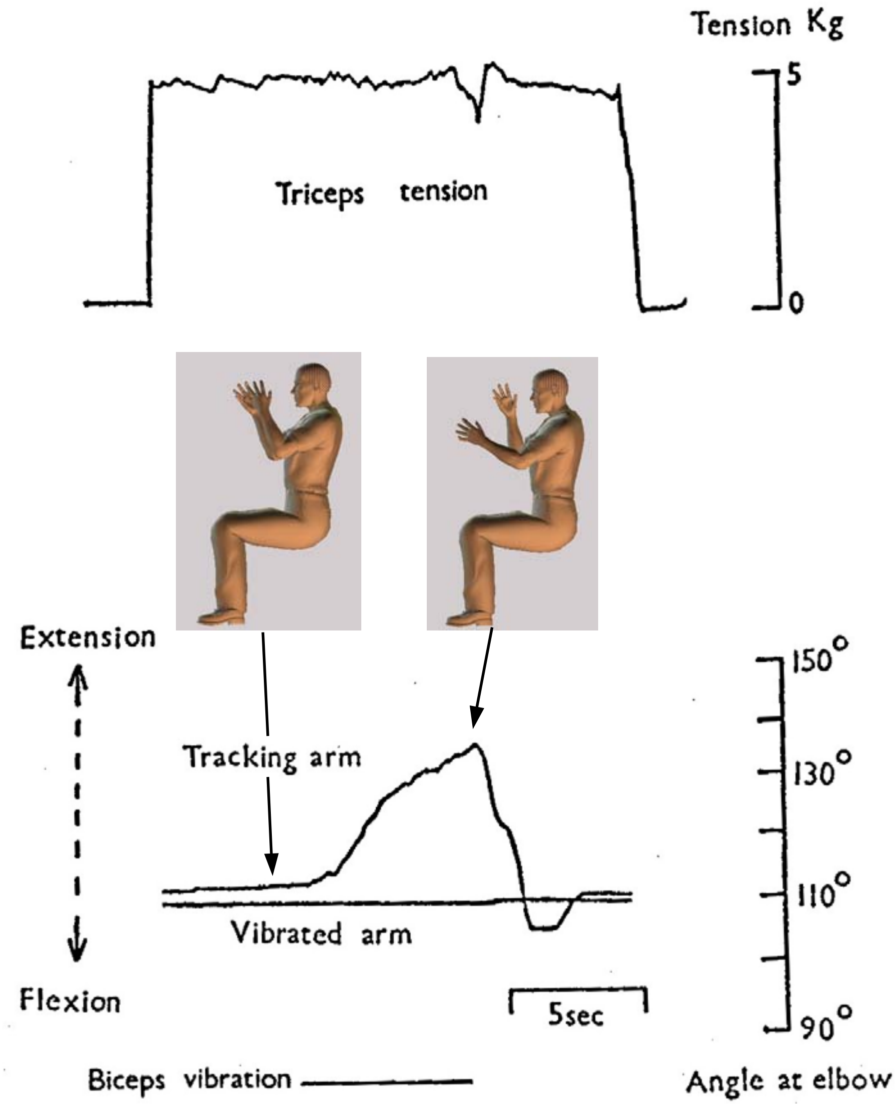


Location of end effector (*ee*)
x_{ee}
Lower limb (L)
θ_a
θ_b
Upper limb (U)
θ_x
θ_y
θ_z
FP
$H^{[F]}$
H
$H^{[Cr]}$
$H^{[S_{ext}]}$
$H^{[E]}$
$E^{[S_{int}]}$

Elbow on the table; forearm nearly vertical. Match the angle of the right arm by moving the left arm

Right arm (biceps) is vibrated while it is held steady (pulling down on a ceiling attached string).

Vibration strongly activates bicep spindles, giving an impression that the right elbow is extending.



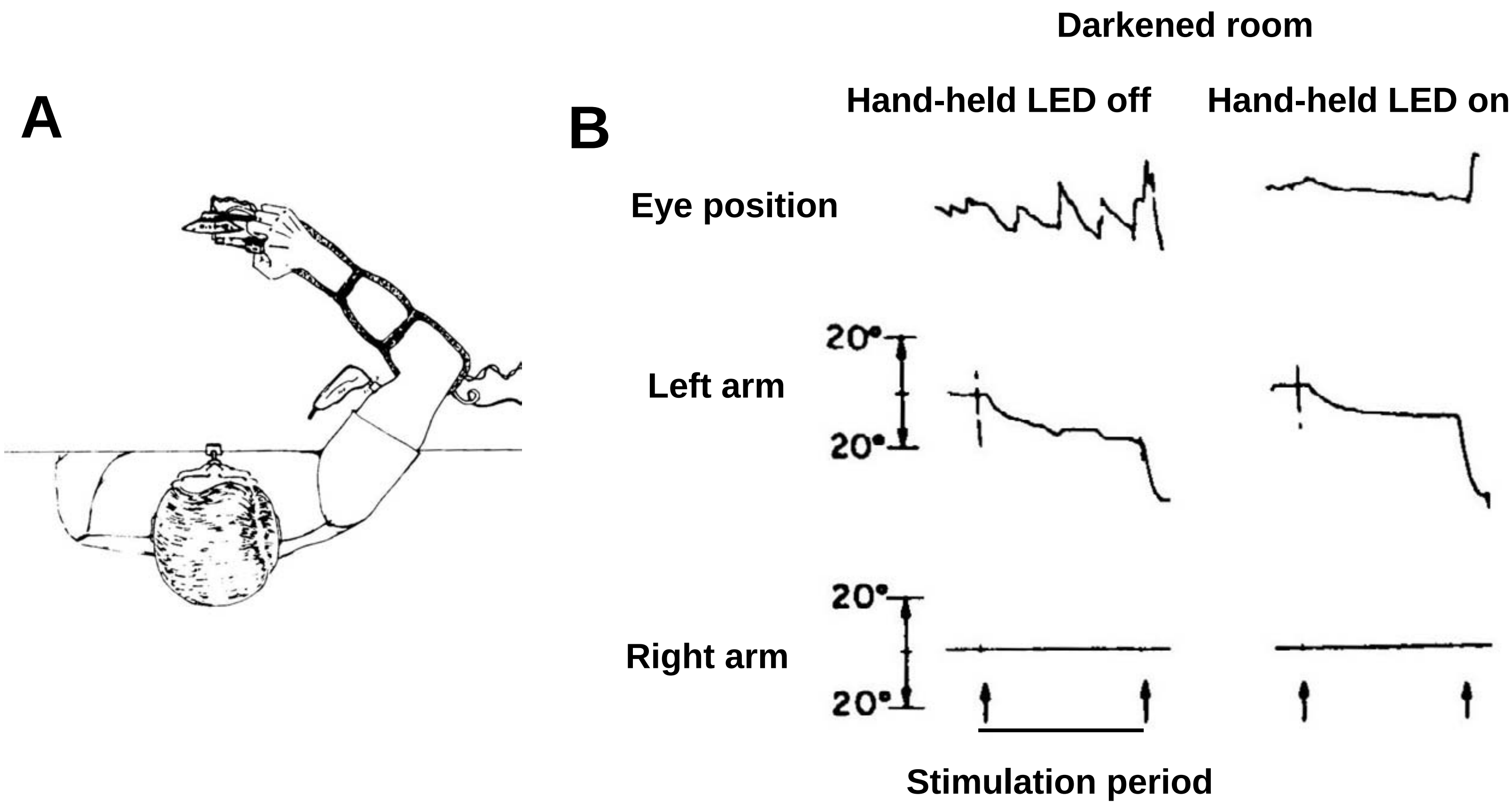
Stimulation of muscle-spindle afferents also affects the estimate of hand location.

Importantly, this estimate of hand location extends to the location of objects held in the hand, *i.e.*, to end effectors, generally.

For example, if you are holding a small light source or audio speaker in your hand, biceps vibration produces the illusion that the light or sound moves.

This percept occurs despite the fact that the visual system (in the case of light) or the auditory system (in case of the speaker) does not detect any motion of the object because, in fact, the object remains stationary

Task: In a darkened room, look at the estimated location of your right hand and point to it with your left hand (left hand underneath the table)



Task 2: Hold a small speaker in hand in darkened room.

Levine & Lackner, Exp Brain Res 1979

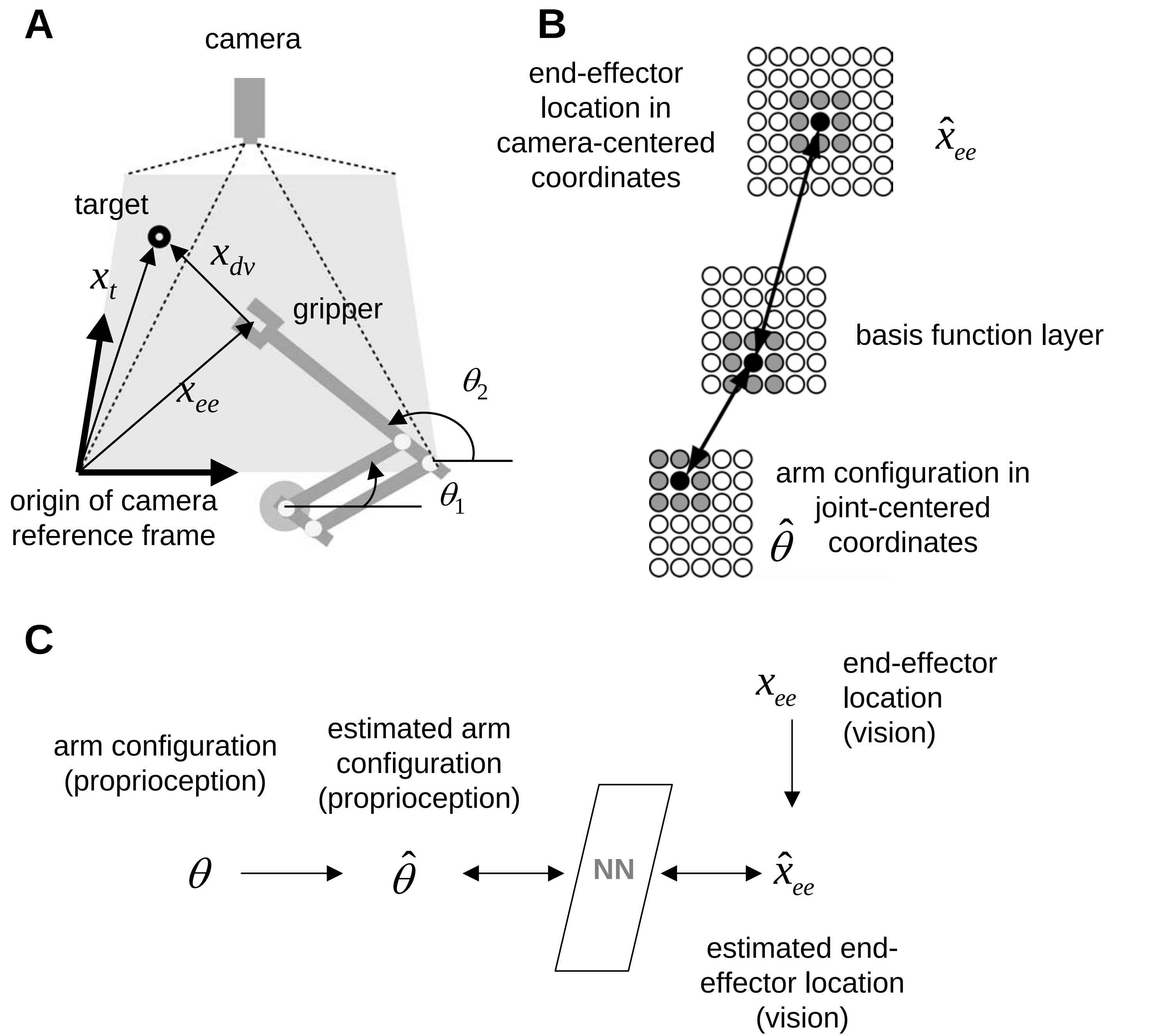
Results:

Muscle stimulation produces visual illusion.
Your sense of where the light is located changes because the source of the light is in your hand.

Muscle stimulation produces auditory illusion.
Your sense of where the sound is coming from changes because the source of the sound is in your hand.

Inference:

You do not have 3 independent measures of hand location: one based on vision, one based on audition, and one based on proprioception. You have one estimate that is an alignment between the three sources of information.



A
camera
target
x_t
x_{dv}
gripper
x_{ee}
θ_2
θ_1
origin of camera reference frame
B
end-effector location in camera-centered coordinates
$\hat{x}_{ee}$
basis function layer
arm configuration in joint-centered coordinates
$\hat{\theta}$
C
arm configuration (proprioception)
estimated arm configuration (proprioception)
x_{ee}
end-effector location (vision)
θ
$\hat{\theta}$
NN
$\hat{x}_{ee}$
estimated end-effector location (vision)

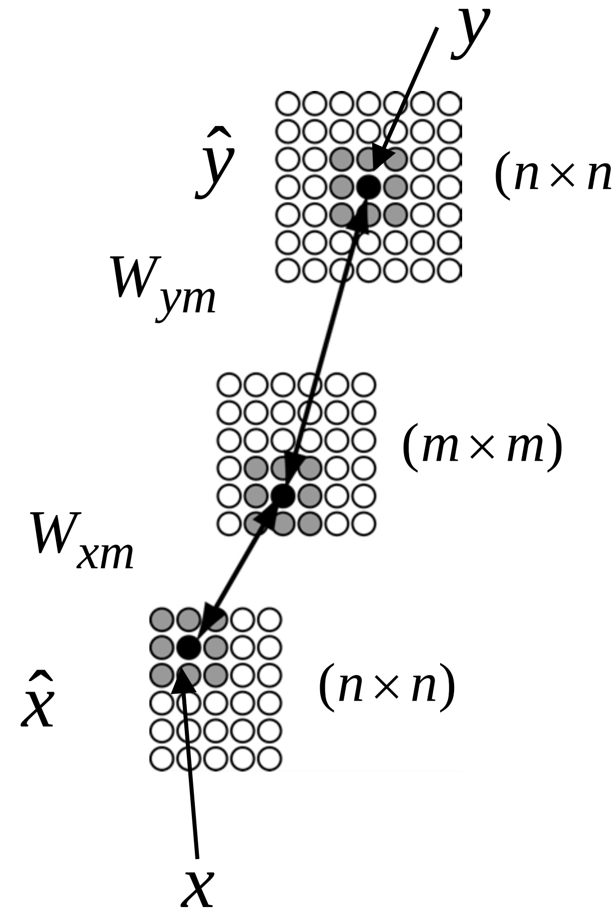
Aligning *x* and *y* using a recurrent network

1. Initial conditions in the network

$$\hat{y}_{i,j}(0) = a(1+\varepsilon)\exp\left(\frac{-\left|y(0)-(i,j)\right|^2}{2\sigma^2}\right)$$

$$\hat{x}_{i,j}(0) = a(1+\varepsilon)\exp\left(\frac{-\left|x(0)-(i,j)\right|^2}{2\sigma^2}\right)$$

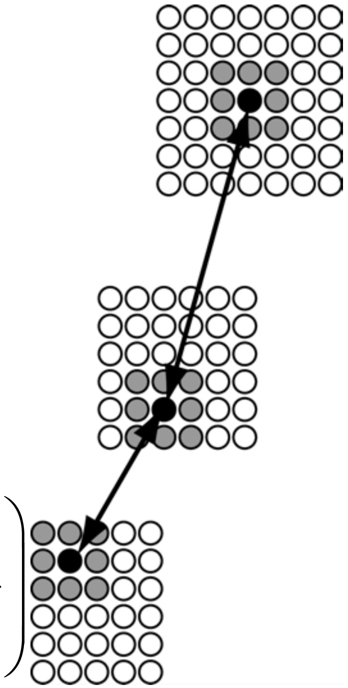
$$m_{i,j}(0) = 0$$



2. Weights in the network

$$W_{xm}[i,j,m_1,m_2] = \exp\left(\frac{-\left|(i,j)-(\frac{1}{2}+\frac{n}{2m}+\frac{nm_1-n}{m},\frac{1}{2}+\frac{n}{2m}+\frac{nm_2-n}{m})\right|^2}{2\sigma^2}\right)$$

3. Propagation of activations



$$\tilde{m}_{m1,m2}(t) = \sum_{i,j} W_{xm}[i,j,m_1,m_2]\hat{x}_{i,j}(t) + \sum_{i,j} W_{ym}[i,j,m_1,m_2]\hat{y}_{i,j}(t)$$

$$m_{m1,m2}(t+1) = \frac{\tilde{m}_{m1,m2}(t)^2}{s + \mu \sum_{p,q} \tilde{m}_{p,q}(t)^2}$$

$$\tilde{x}_{i,j}(t) = \sum_{m1,m2} W_{xm}[i,j,m_1,m_2] m_{m1,m2}(t) + a(1+\varepsilon)\exp\left(\frac{-\left|x(t)-(i,j)\right|^2}{2\sigma^2}\right)$$

$$\hat{x}_{i,j}(t+1) = \frac{\tilde{x}_{i,j}(t)^2}{s + \mu \sum_{p,q} \tilde{x}_{p,q}(t)^2}$$

$$\tilde{y}_{i,j}(t) = \sum_{m1,m2} W_{ym}[i,j,m_1,m_2] m_{m1,m2}(t) + a(1+\varepsilon)\exp\left(\frac{-\left|y(t)-(i,j)\right|^2}{2\sigma^2}\right)$$

$$\hat{y}_{i,j}(t+1) = \frac{\tilde{y}_{i,j}(t)^2}{s + \mu \sum_{p,q} \tilde{y}_{p,q}(t)^2}$$