GDC | March 21-25, 2022
San Francisco, CA

Technical Artist Summit 2022

#GDC22 #TechArtSummit2022

GDC
March 21-25, 2022
San Francisco, CA

Human Perception of Motion of Animation

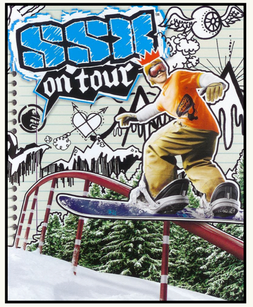
Sergei Savchenko

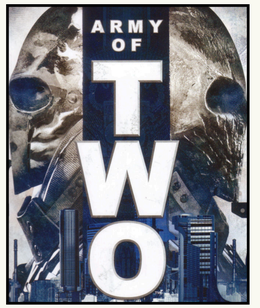
Technical Lead
Bethesda Game Studios

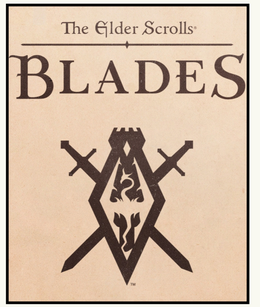
#GDC22

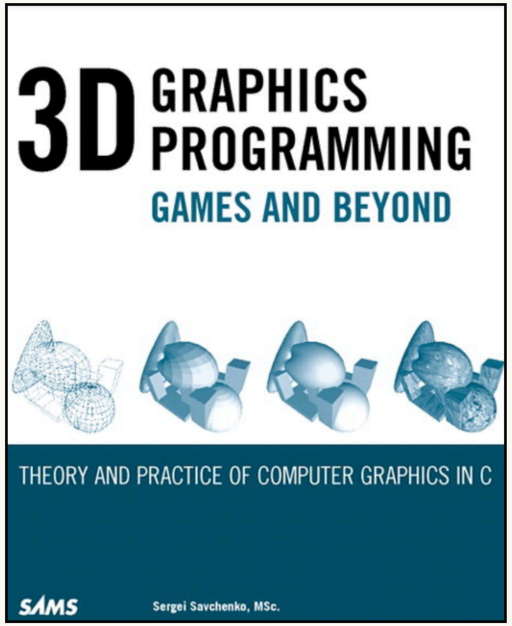
Sergei Savchenko

- Technical Lead at Bethesda Game Studios
- Also worked at 3DO, EA and Warner Bros.
- Consoles, Handhelds and Mobiles
- Wrote a book on computer graphics years back









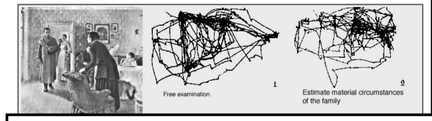
Better Computer Graphics Through Understanding of Human Visual System

Sergei Savchenko

Technical Lead
Bethesda Game Studios

Fixations

- Eye movement patterns are task specific
- Faces are almost always salient (even in peripheral vision!)
- Feet position may also be salient
- Shape interiors are rarely fixated on…



Cone Receptors

- Rod receptors (night or scotopic vision)
- Cone receptors (day or photopic vision)
- Long, Medium, Short wavelength cone receptors rather than Red, Green and Blue
- Chromatic aberration issues: S vs L and M

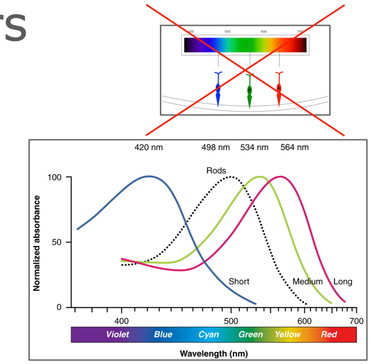
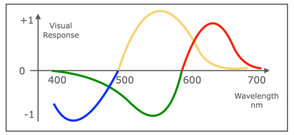
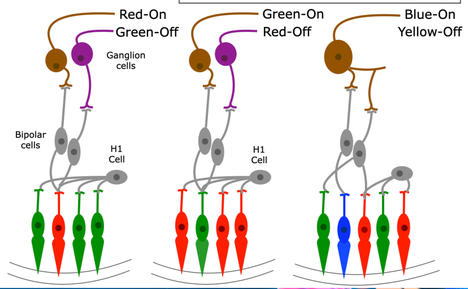


Image by OpenStax College, CC BY 3.0

Hue Perception

- There is an ongoing debate about specifics of the mechanism…
- Many textbooks will outline parvocellulare mechanism:
  - R-G = L-M
  - B-Y = S-(M+L)
- though this is most probably wrong…





Central and Peripheral Vision

- Foveal vision <5°
- At 2°, acuity is down to ~50%
- At 4°, it is down to ~30%
- Color perception strong at 20° but declining at 40° (not equally for all hues though)

LGN and Striate Cortex

- Midget and Parasol cells project to different layers of Lateral Geniculate Nucleus (LGN)
- LGN projects into Striate cortex (V1 area)
- Left and Right visual fields are localized in opposite hemispheres
- Beyond Striate there is evidence for several visual pathways: ventral or "what" and dorsal or "where"

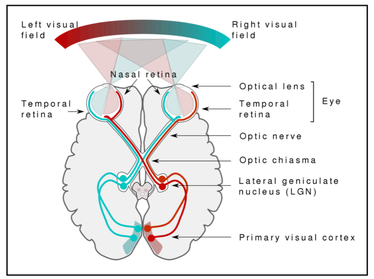


Image by Miguel Perello Nieto, CC BY-SA 4.0

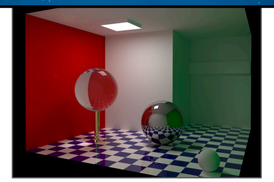
Image by Vanessa Ezekowitz BY-SA 3.0. Image by Zyxwv99 CC BY-SA 4.0

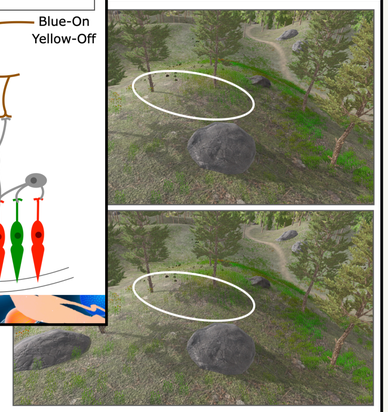
Perception of G… Illumination

Scenes are likely segm… into areas where illumi… mostly the same

There is evidence that people mostly perceive influence from one or two light directions per object

Diffuse to diffuse interactions (e.g. small color bleeding) may be less perceptually salient





Images by Barahag, CC BY-SA 4.0

What’s strange about human visual perception?

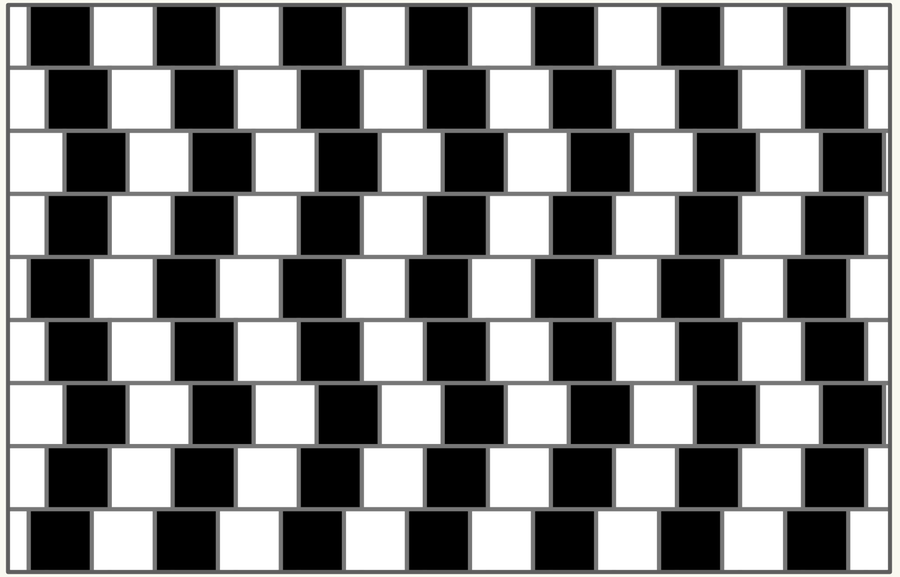


Image by Fibonacci, CC BY-CA 3.0

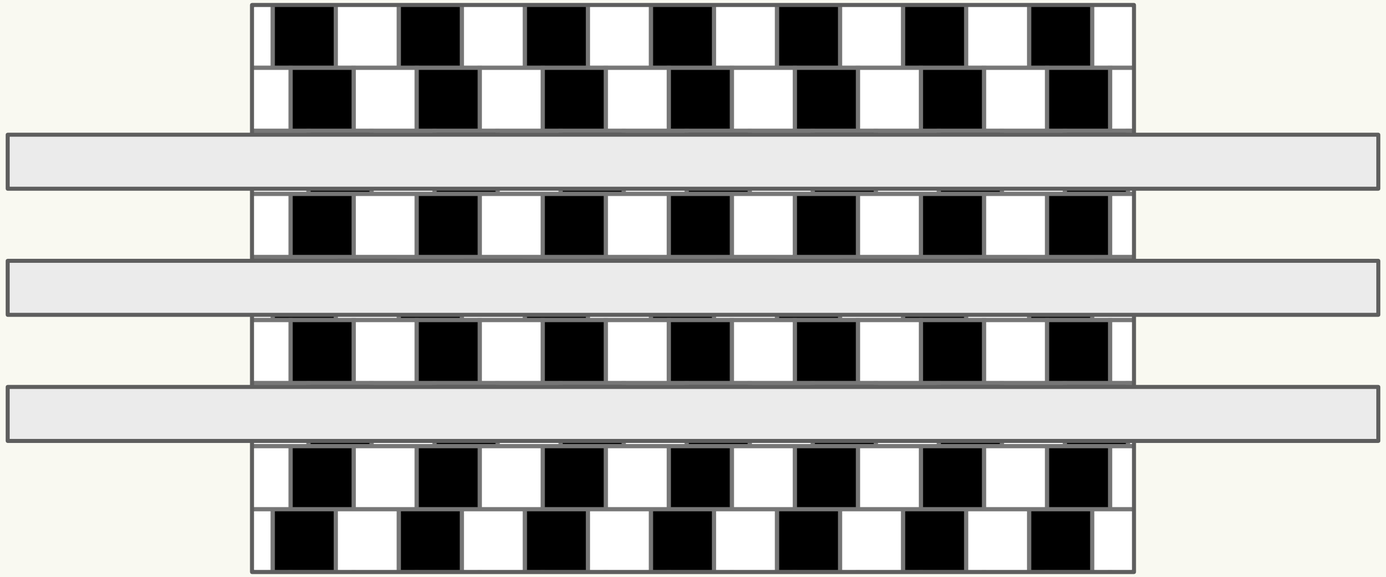
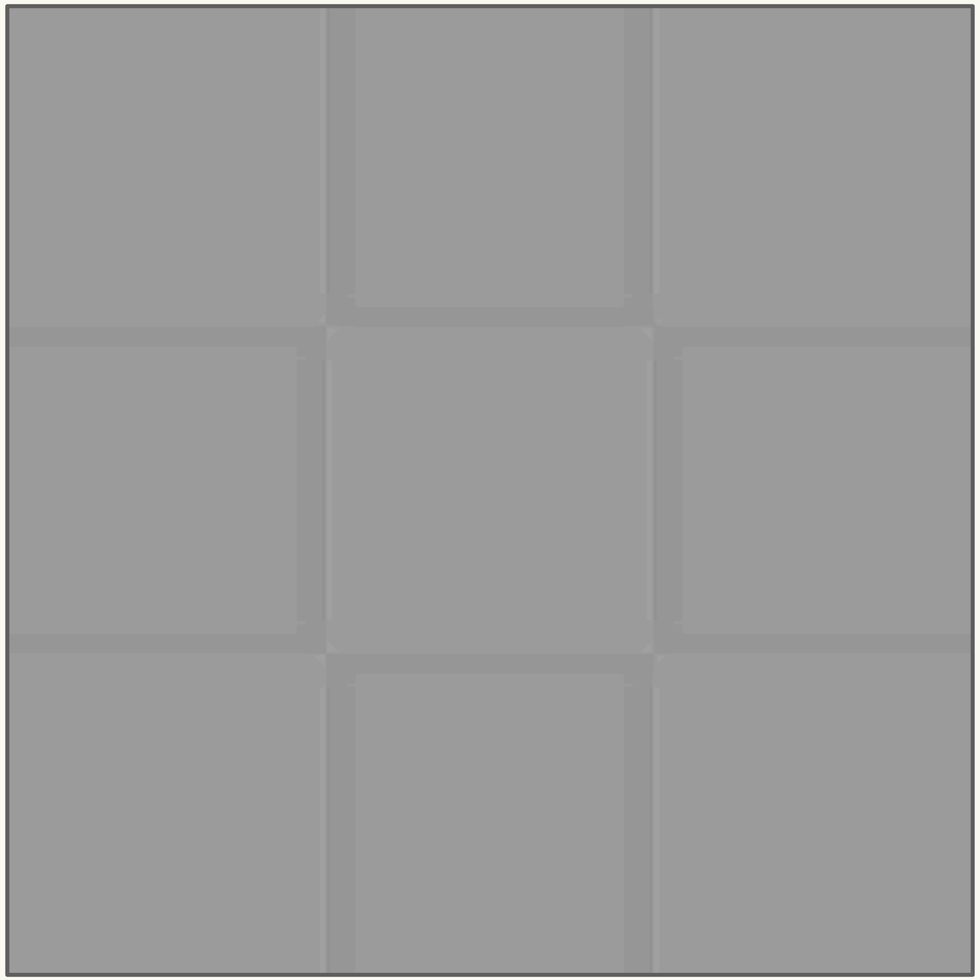
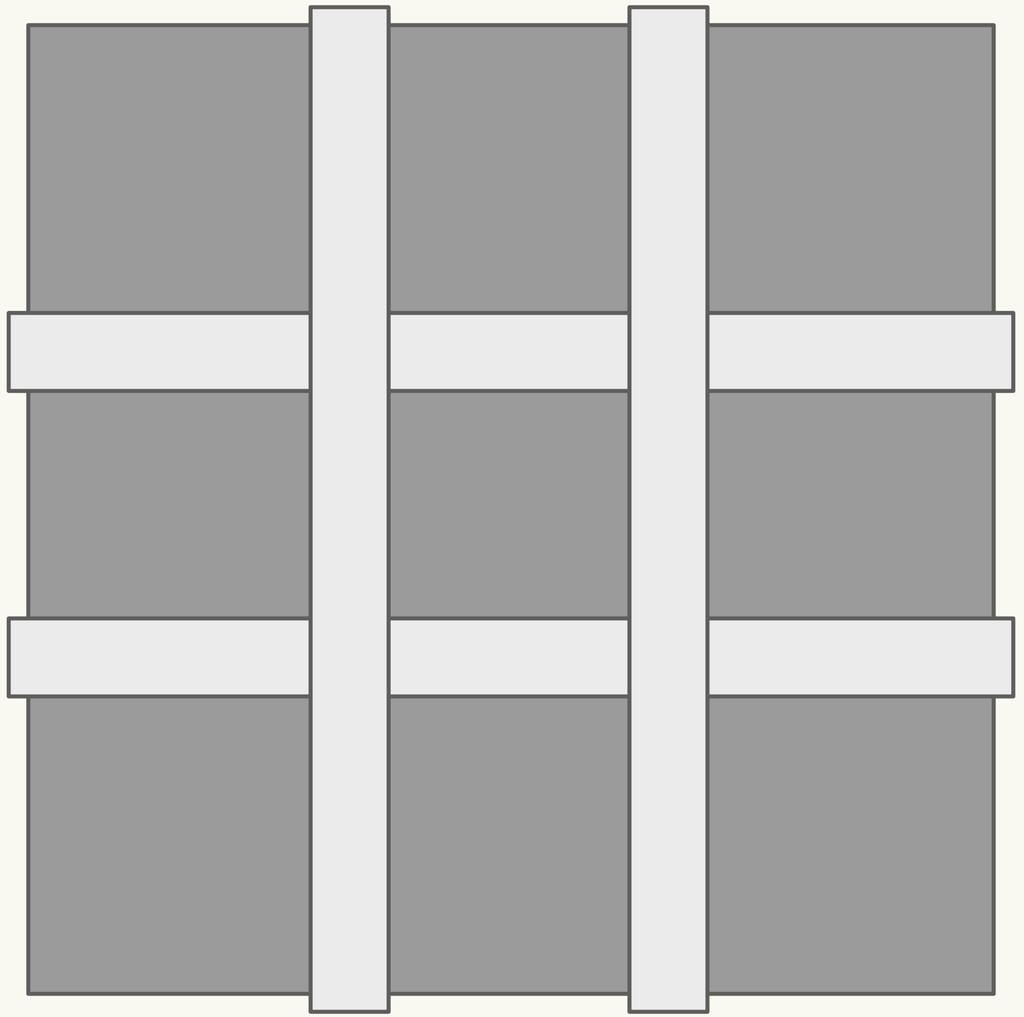


Image by Fibonacci, CC BY-CA 3.0





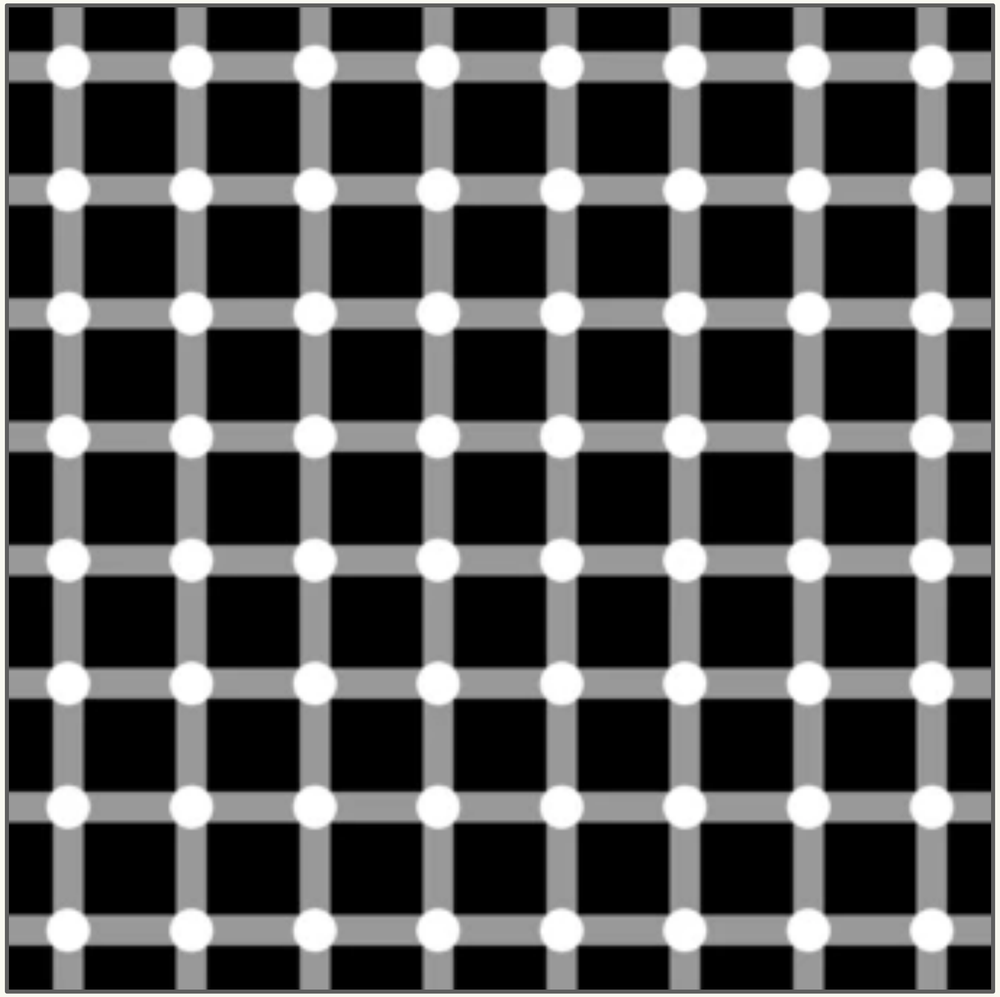


Image by António Miguel de Campos, Public Domain

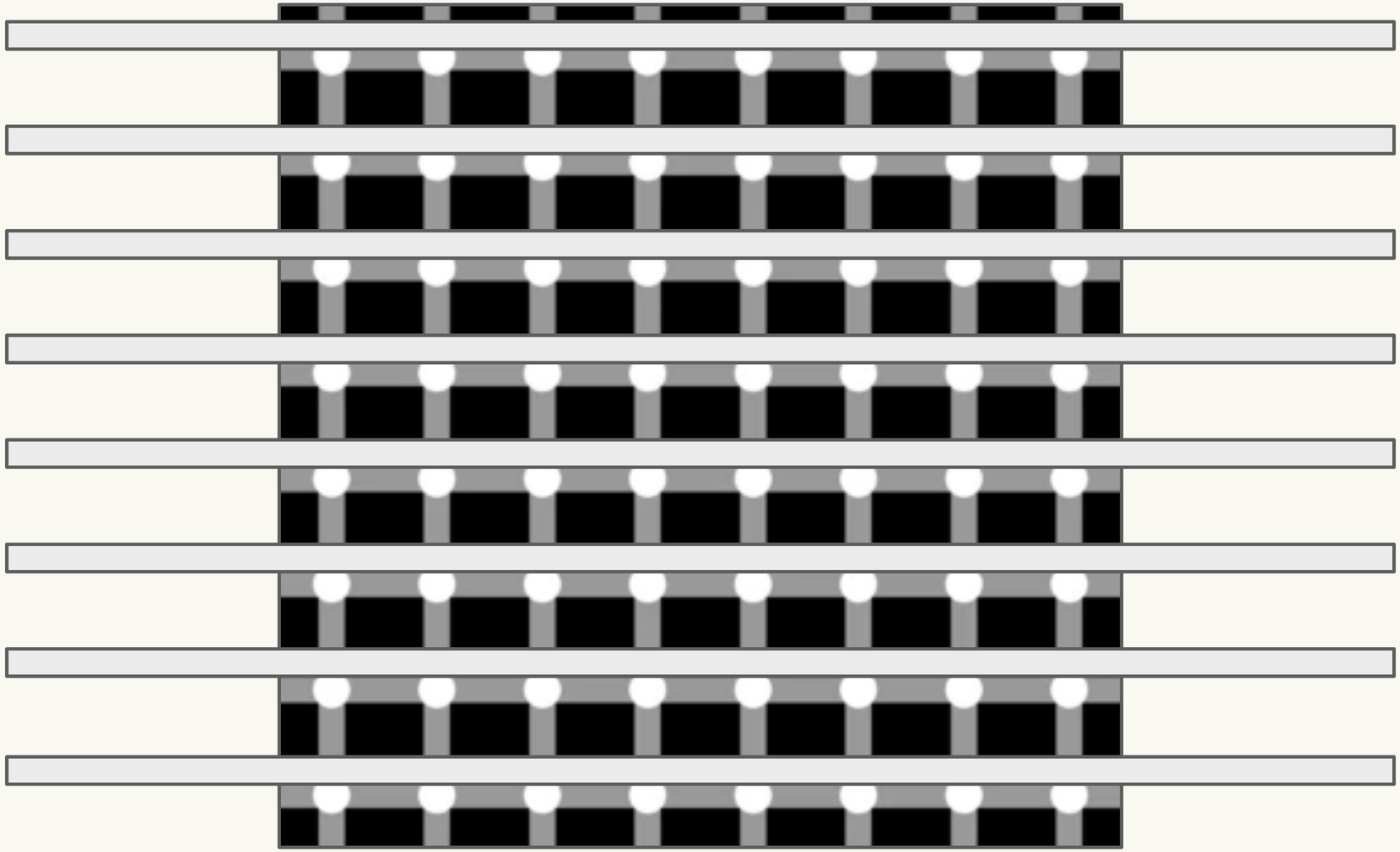


Image by António Miguel de Campos, Public Domain

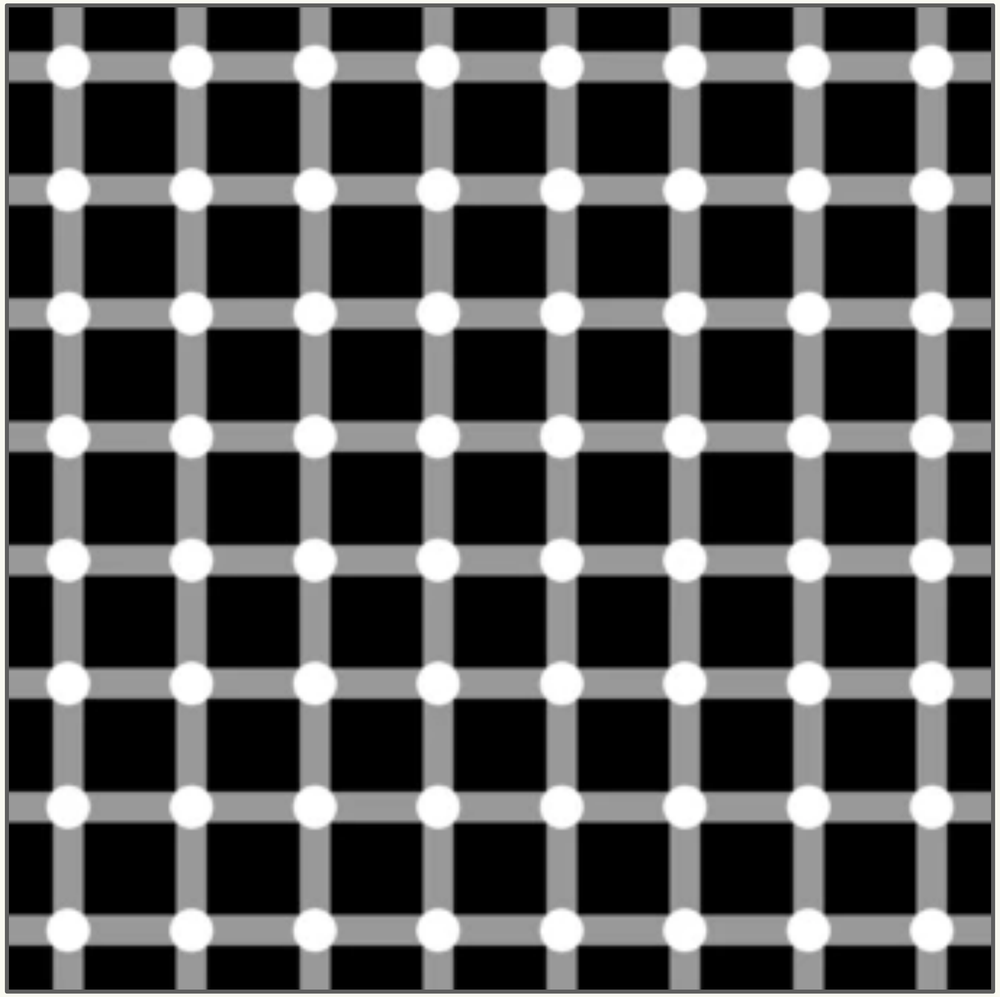


Image by António Miguel de Campos, Public Domain

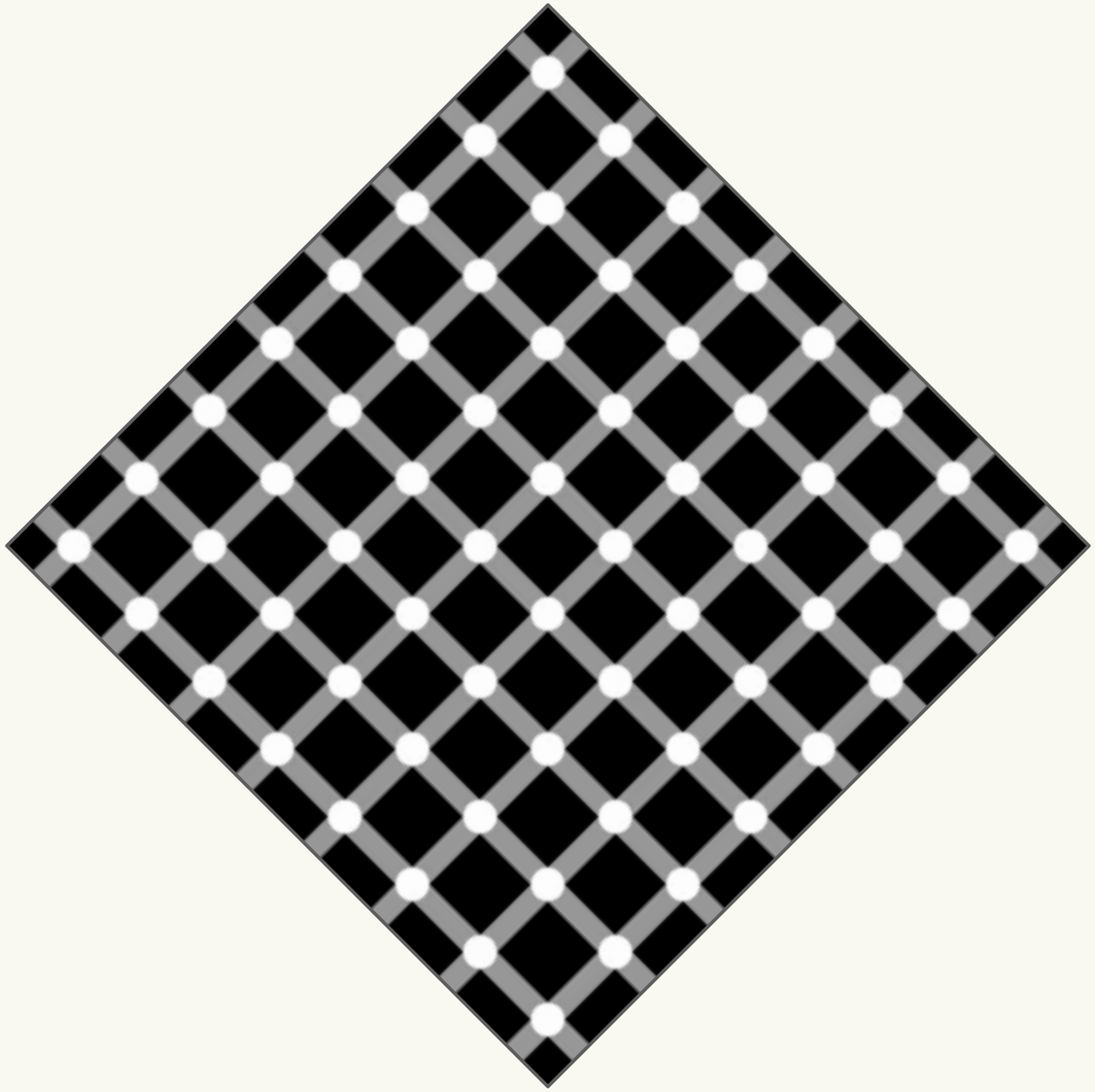


Image by António Miguel de Campos, Public Domain

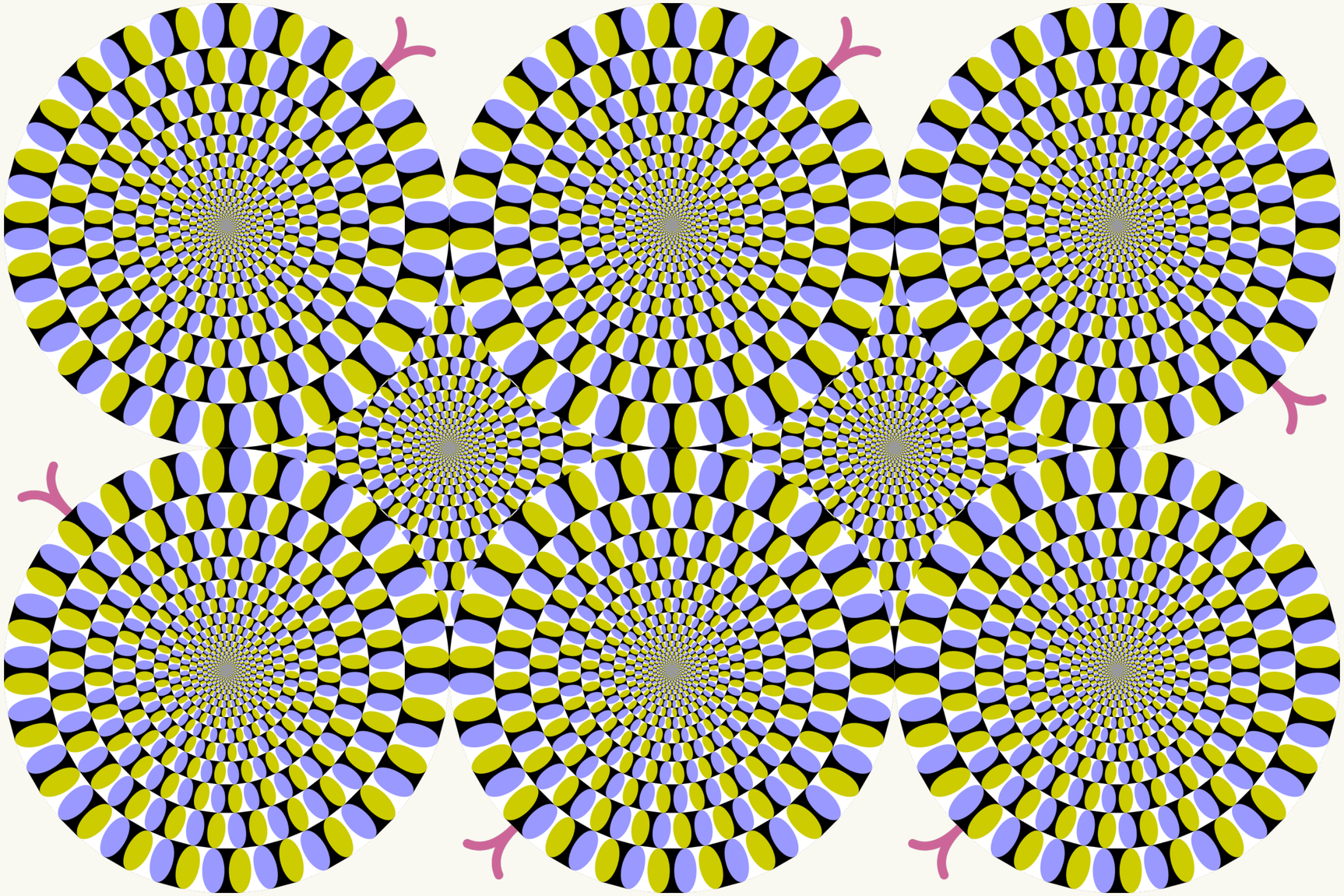
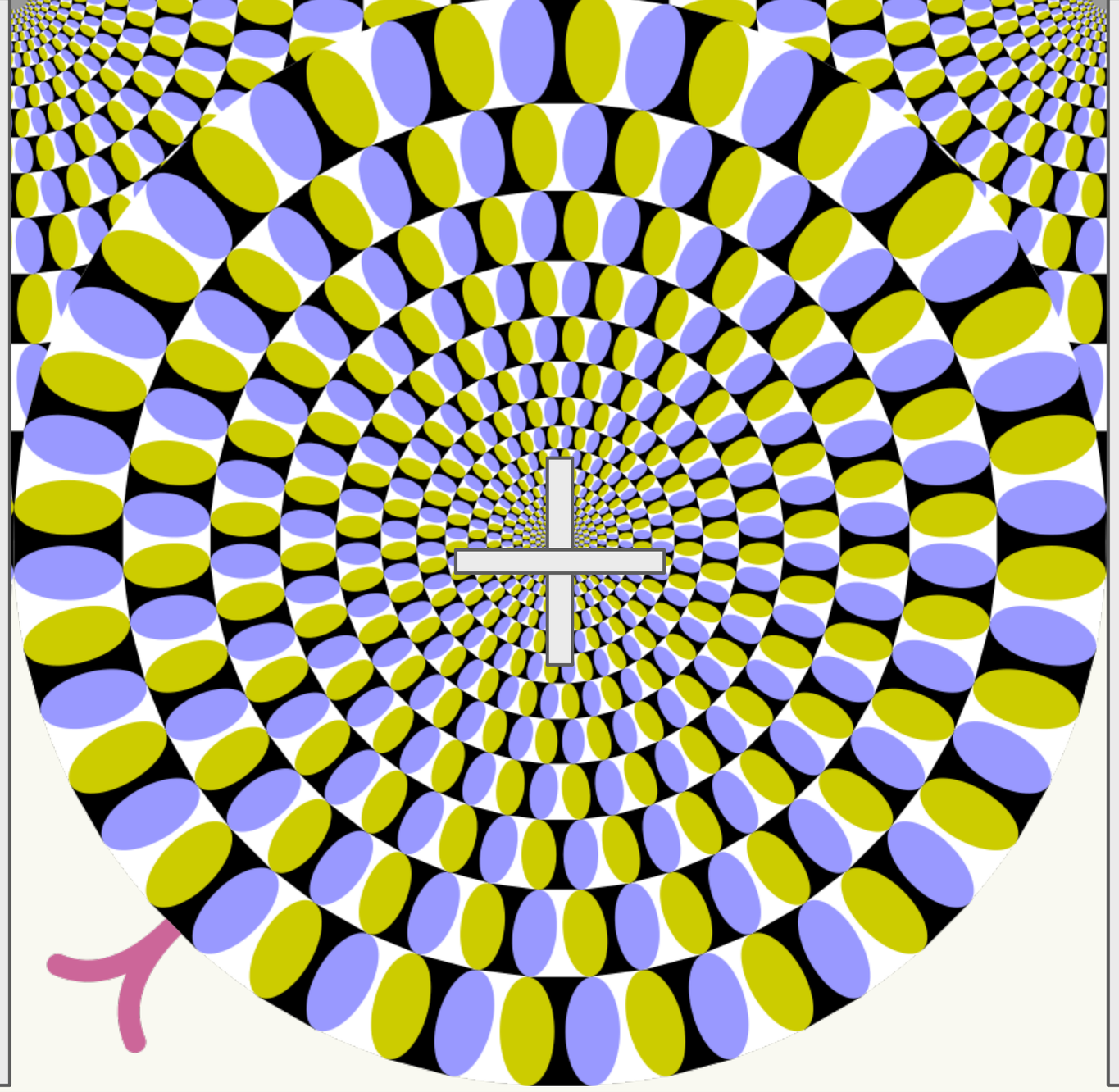


Image by Cmglee based on work by Kitaoka Akiyoshi, CC BY-SA 3.0



Why does it matter?

- Human vision, including detection of motion, while effective, is technically not accurate…
- A finer physics based simulation of reality has significant perceptual limits…

Human Vision

Vision Fidelity

- Detail vision is very narrow, central and slow
- Peripheral vision is not sensitive to detail but quite sensitive to motion and change be it at course resolution

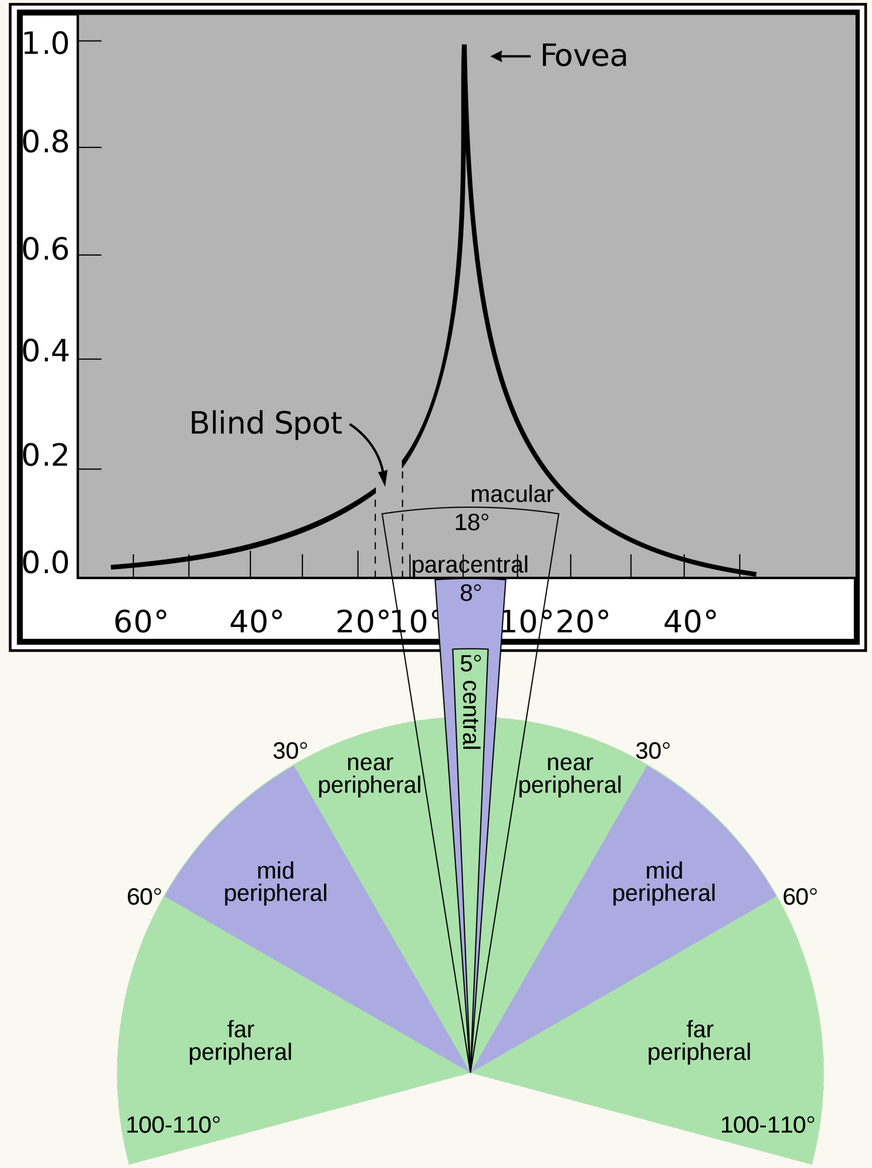
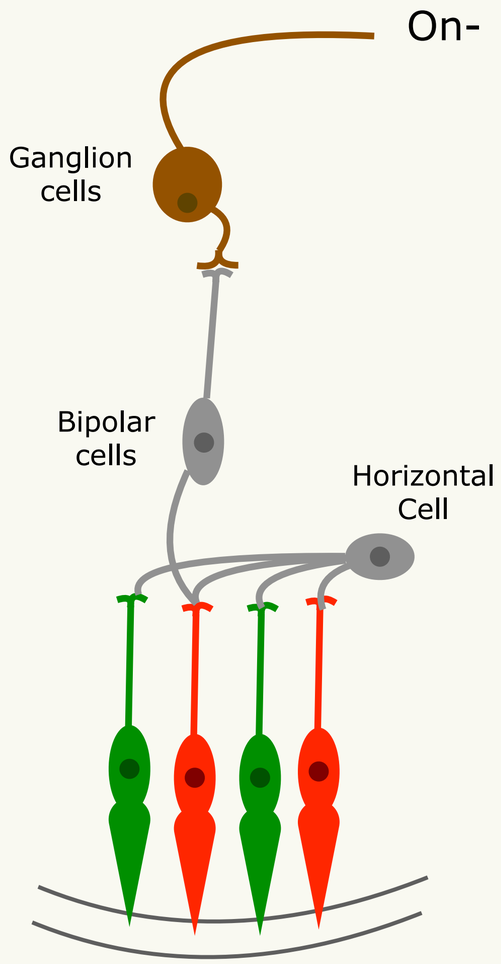
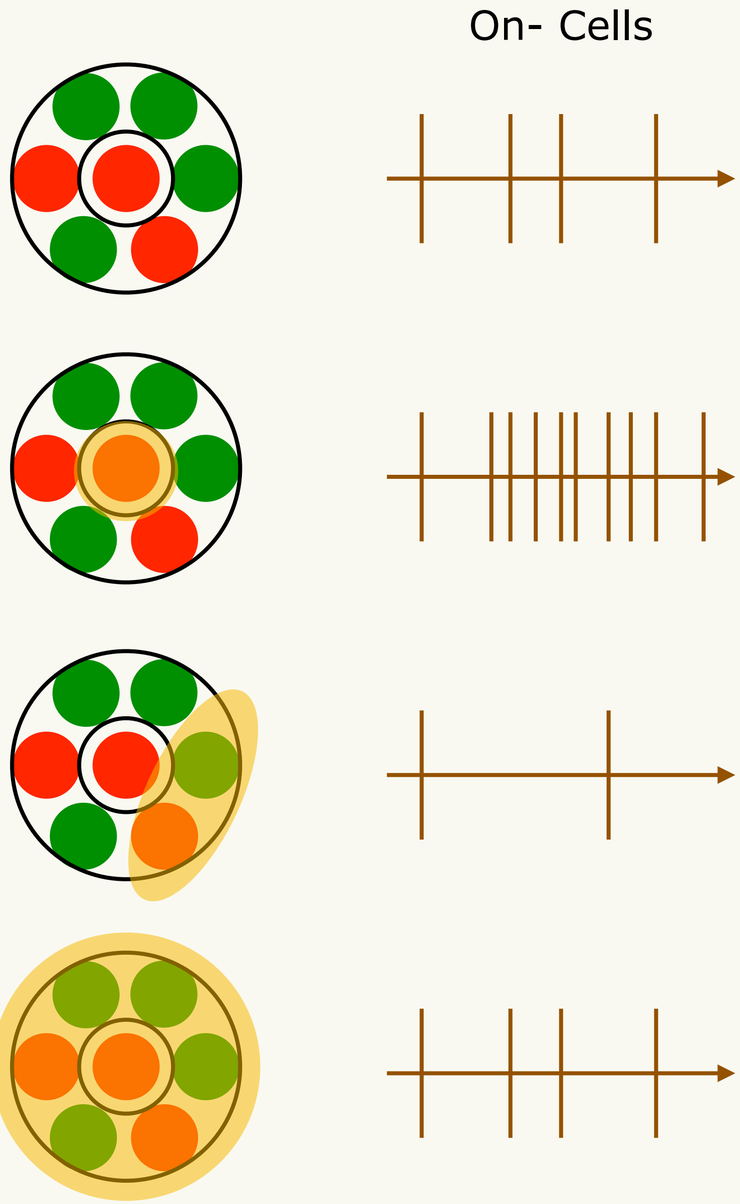


Image by Vanessa Ezekowitz BY-SA 3.0. Image by Zyxwv99 CC BY-SA 4.0

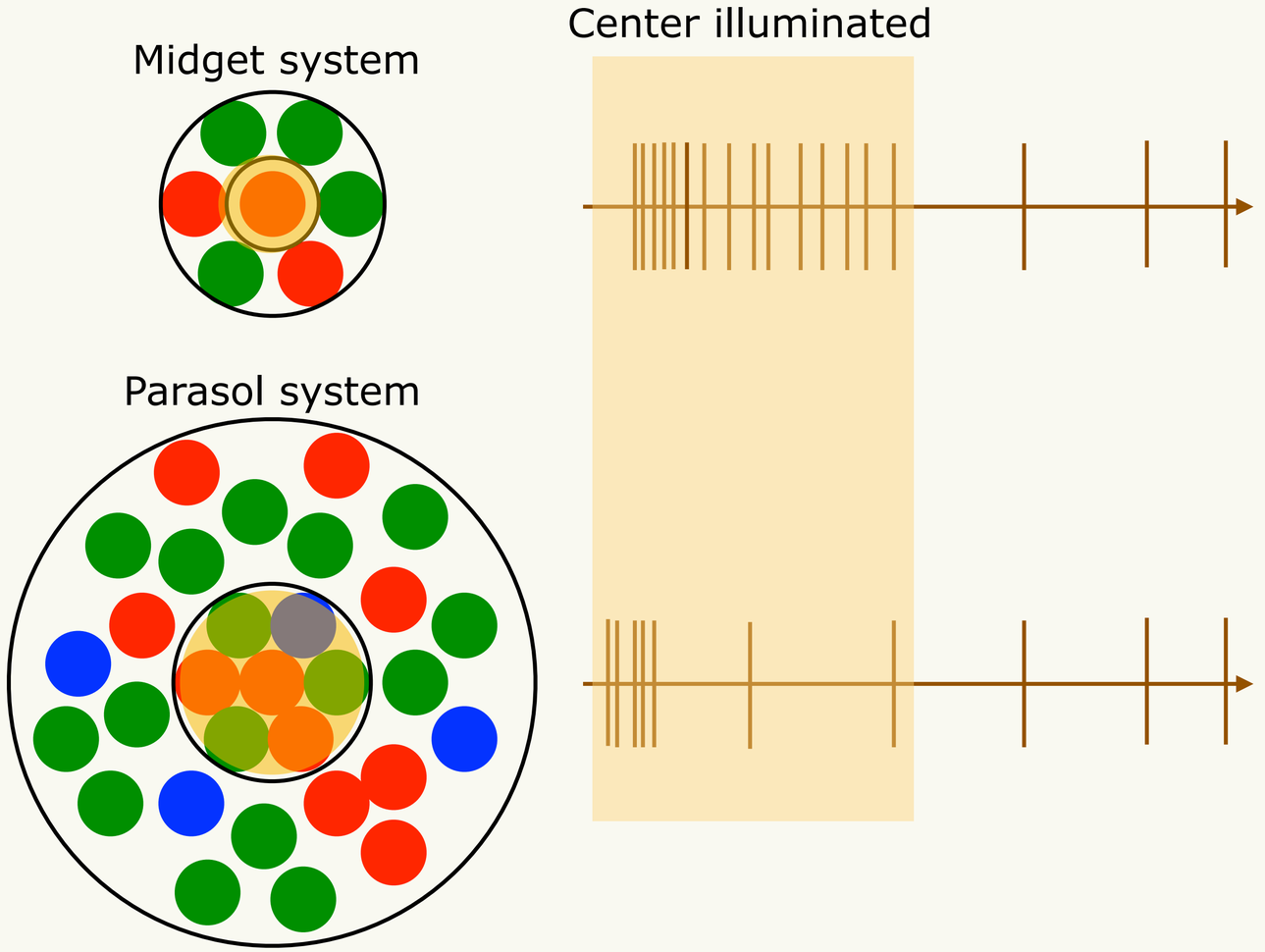
Cell Signals





Receptive Fields

- Midget/parvocellulare pathways (~90% of all RGCs)
  - Achromatic and chromatic vision
  - Slow temporal response
- Parasol/magnocellulare pathways (~5% of all RGCs)
  - Motion, change
  - Fast temporal response



Oriented Edges

- Simple and complex cells are wired to multiple retinal receptive fields and respond to oriented stimuli
- May respond to moving oriented stimuli
- There may be more cells responding to vertical and horizontal stimuli!

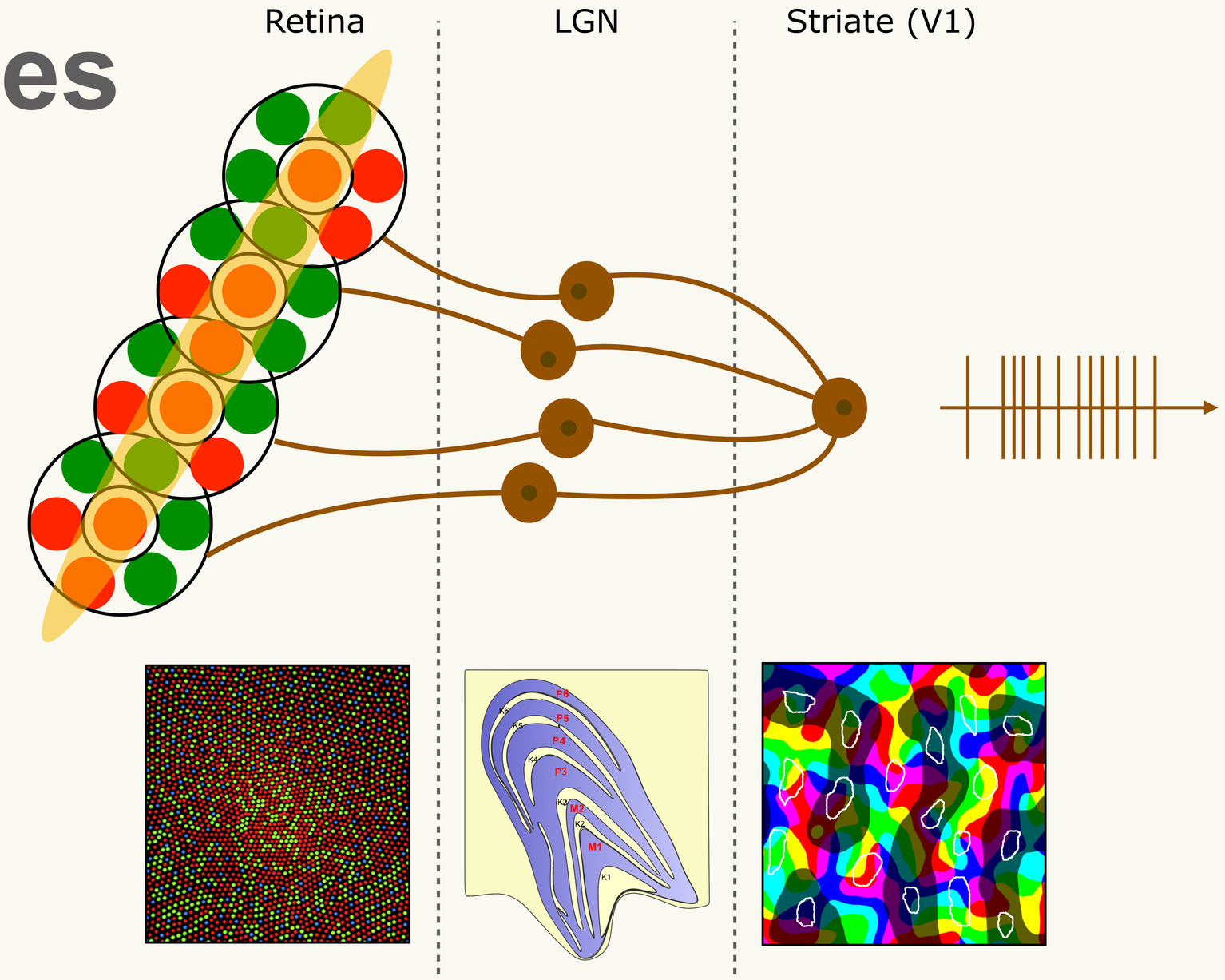
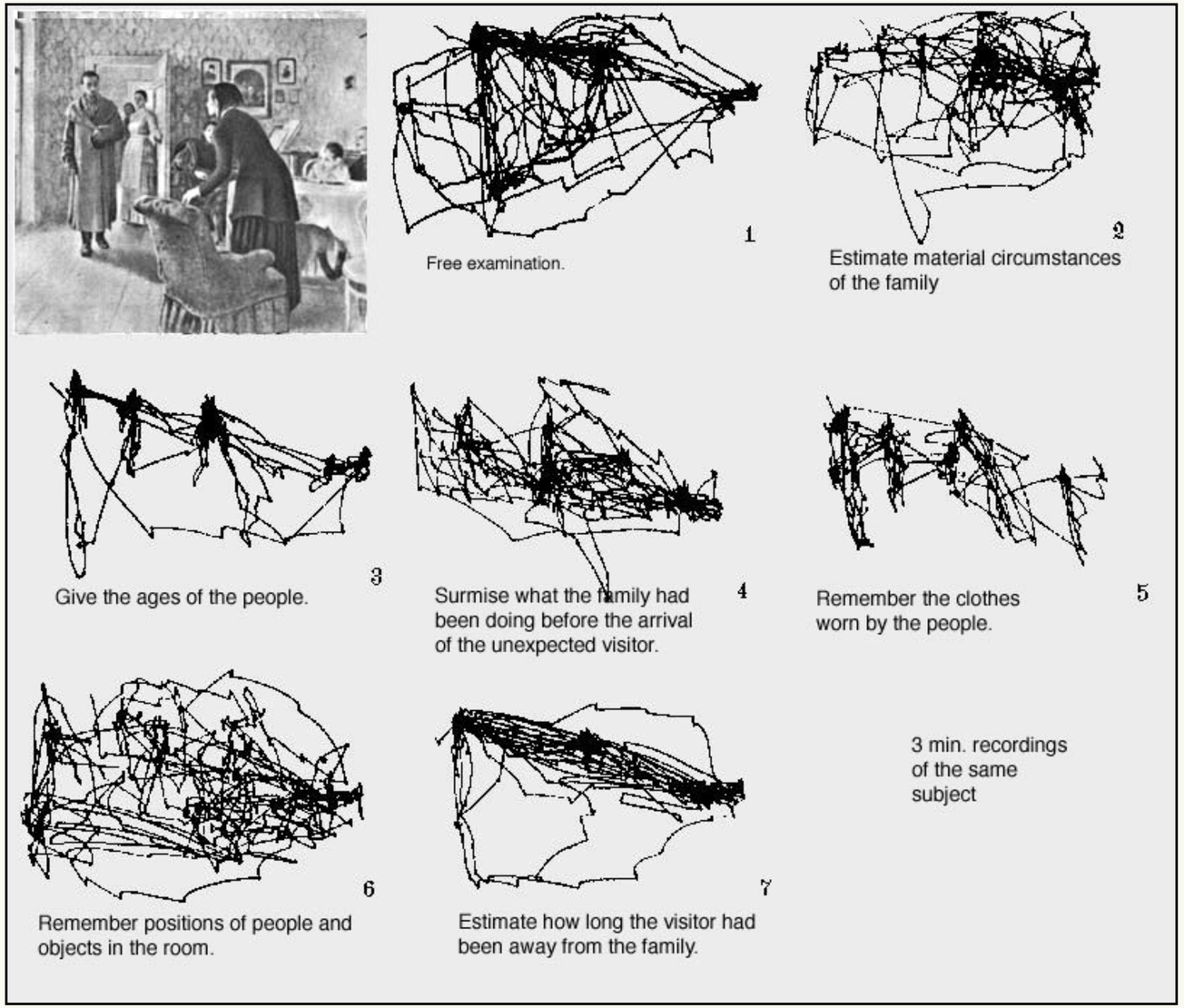


Image by Mark Fairchild, CC BY-SA 3.0, Image by Pancrat, CC BY-SA 3.0, Image by Paul C. Foster, CC BY-SA 3.0

Eye Movement

- We fixate on very few elements of the visual scene
- We are blind during saccadic eye movements and have limited memory of the visual scene before and after saccades and eye blinks
- Smooth pursuit eye movement follows moving objects



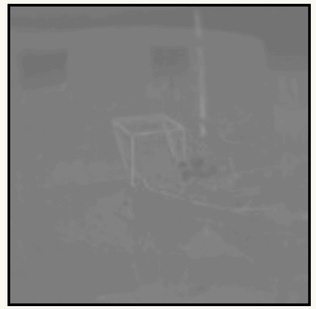
From Alfred Yarbus Eye Movement and Vision, 1967. Image by Lucs-Kho, Public Domain

Color Vision

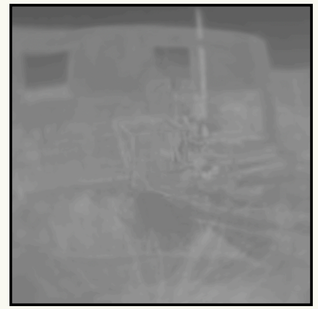
- We cannot see greenish reds or yellowish blues
- Changes in greenish intensities are easier to recognize
- Red and Blue may not be the best for small foreground elements
- Colors are likely perceived by much lower resolution compared to edges

Edges

Red/Green

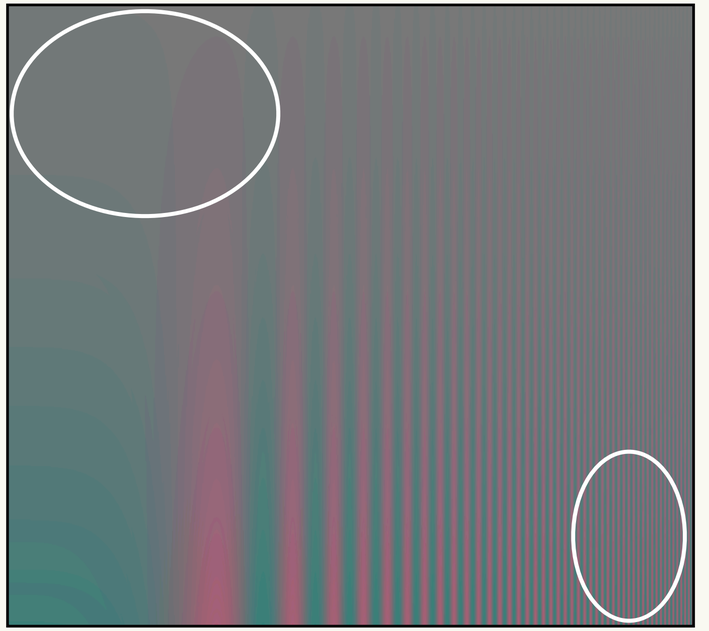


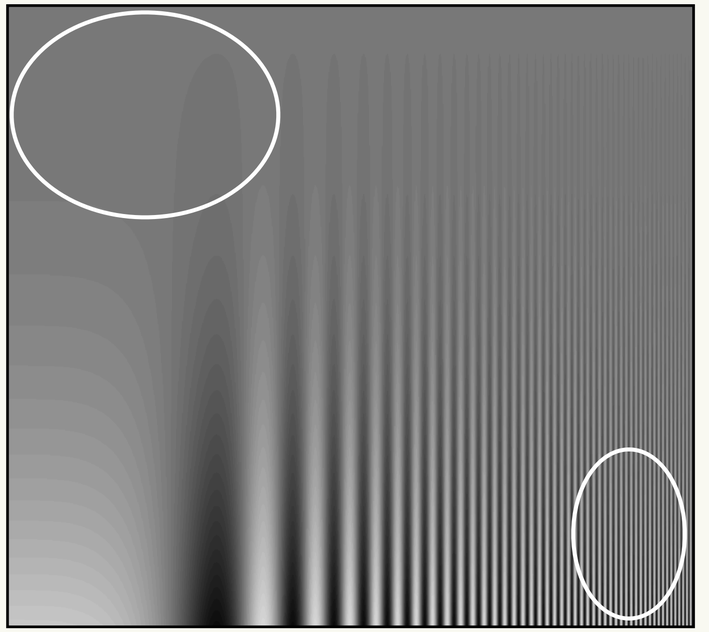
Blue/Yellow



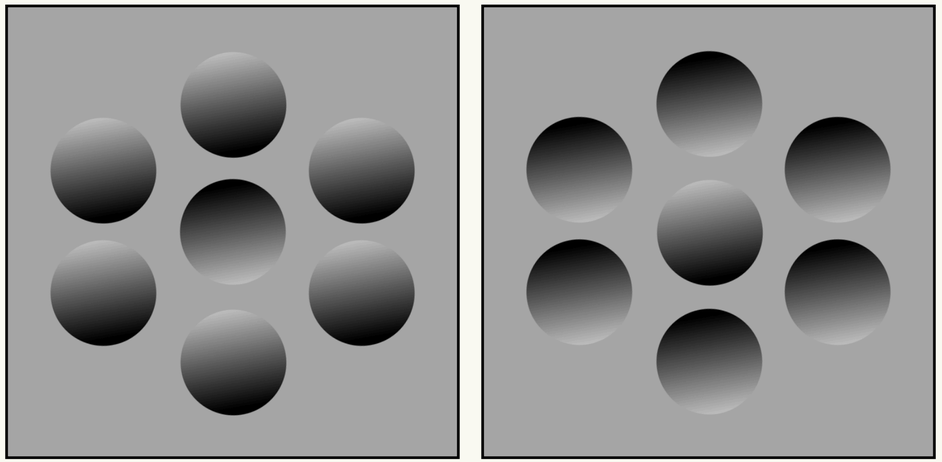
Shape Perception

- Humans have different limits to chromatic and achromatic details at different frequencies
- We are hyper acute to visual discontinuities (e.g.: breaks in straight lines)
- There is a specialized brain area responsible for face recognition

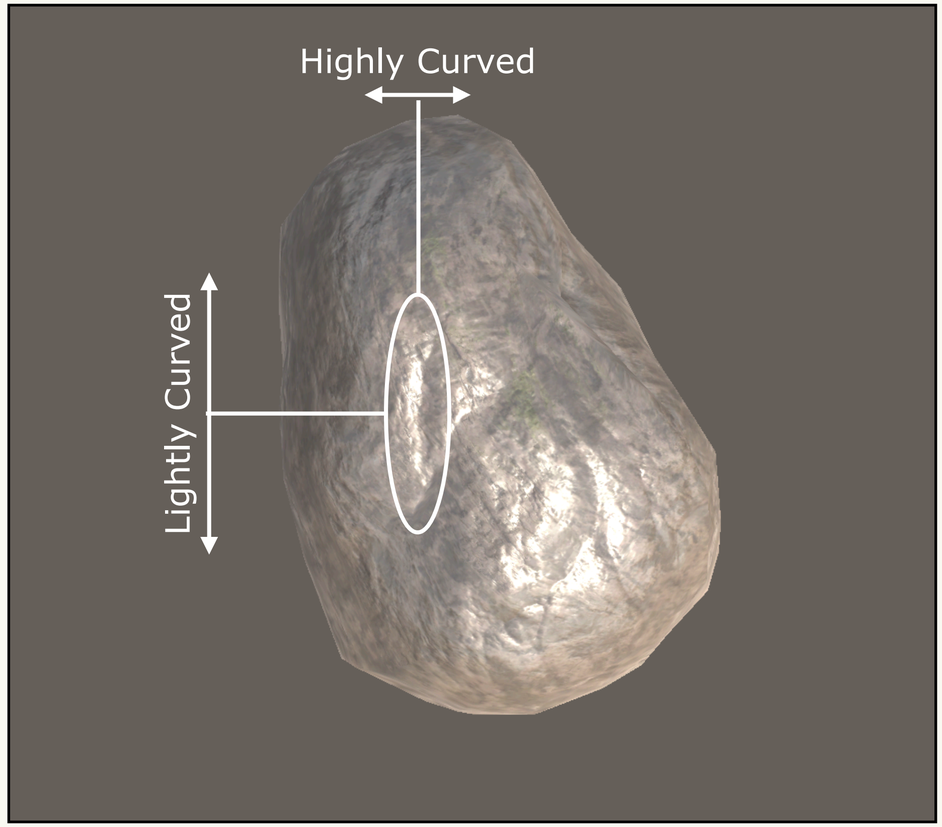




Lighting



- Human vision is somewhat biased to interpret scenes as lit from above and to interpret dark spots as indentations
- Specular highlights provide curvature clues

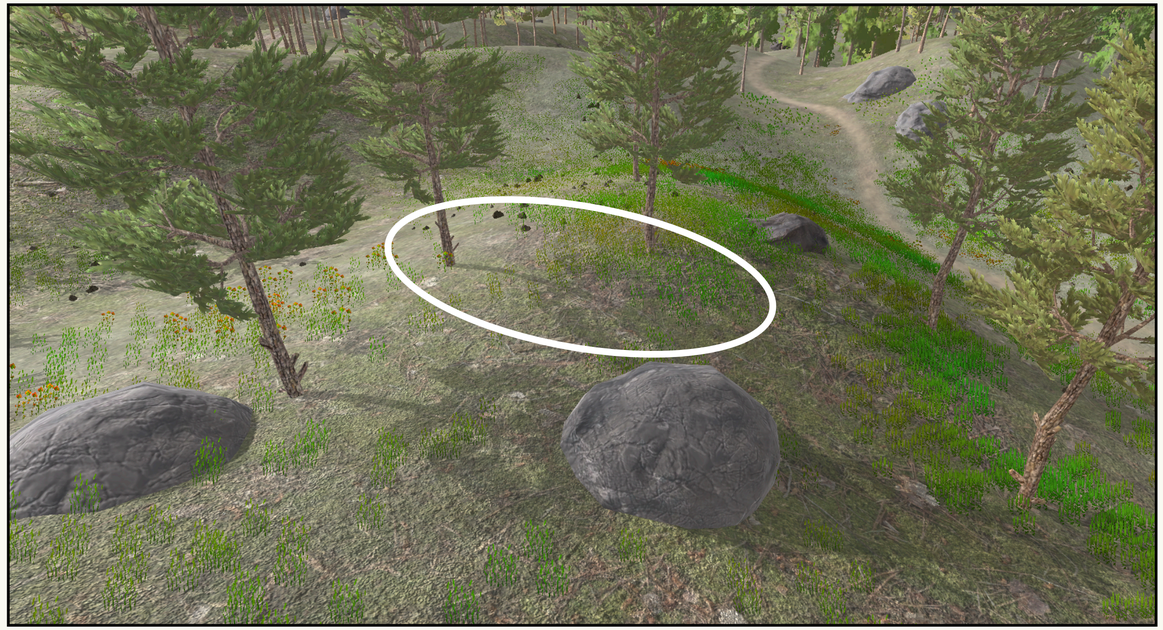


Shadows

- Do the shadows look geometrically correct in the image?

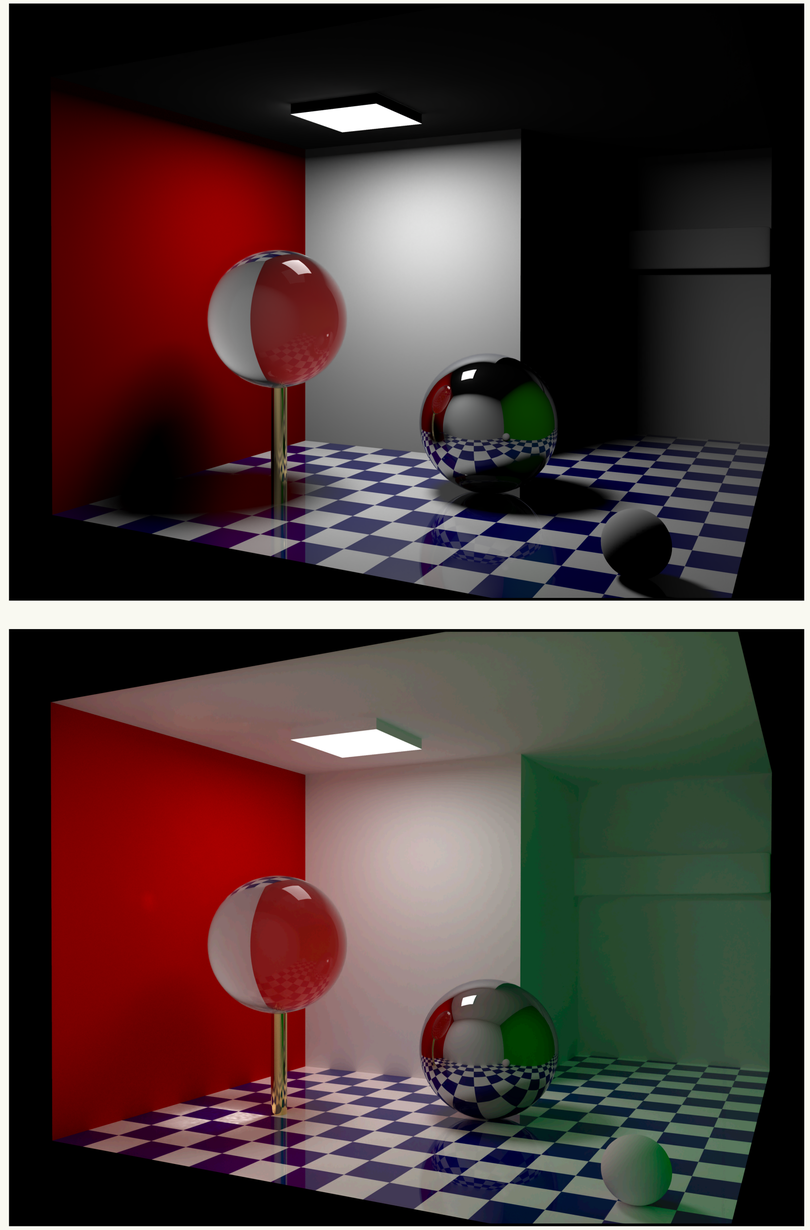
Shadows

- Shadows give strong positional clues and need to have soft edges
- Moderate inconsistencies in illumination directions and shadow directions are not immediately salient



Global Illumination

- Scenes are likely segmented in our perception into areas where illumination is perceived as mostly the same
- There is evidence that people mostly perceive influence from one or two light directions per object
- Diffuse to diffuse interactions (e.g. small color bleeding) may be less perceptually salient



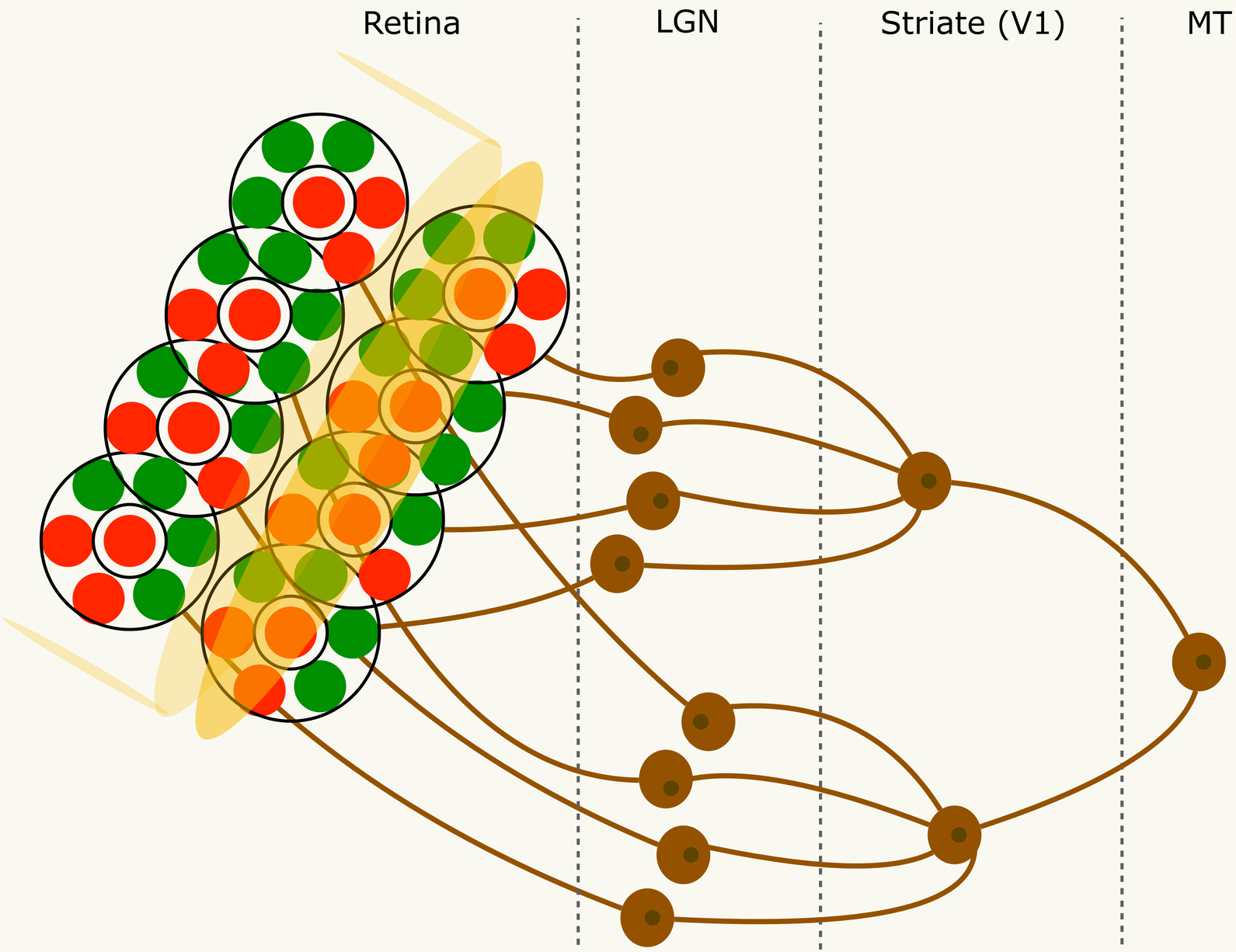
Perception of Motion

Perception of Motion

- Perceiving motion is one of the key goals of the visual system
- The system must account for object movement, subject own movement and eye movement
- Integration of data from several neural pathways is likely needed with magnocellular system being primary motion sensor
- Motion is often salient and routinely focuses attention when observed

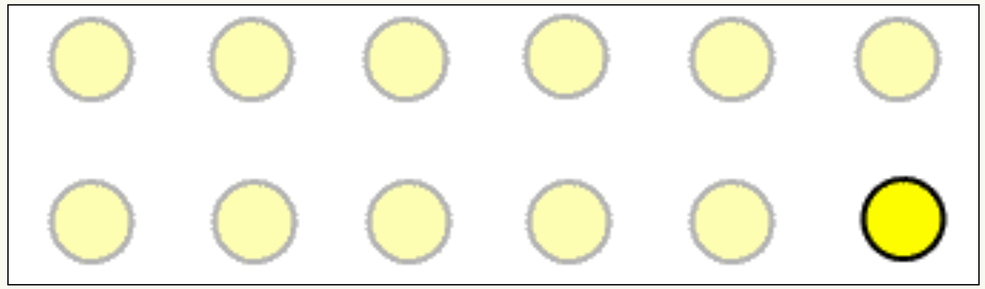
Oriented Edges

- Direction selective cells in MT area
- (V1 area contains orientation selection cells)



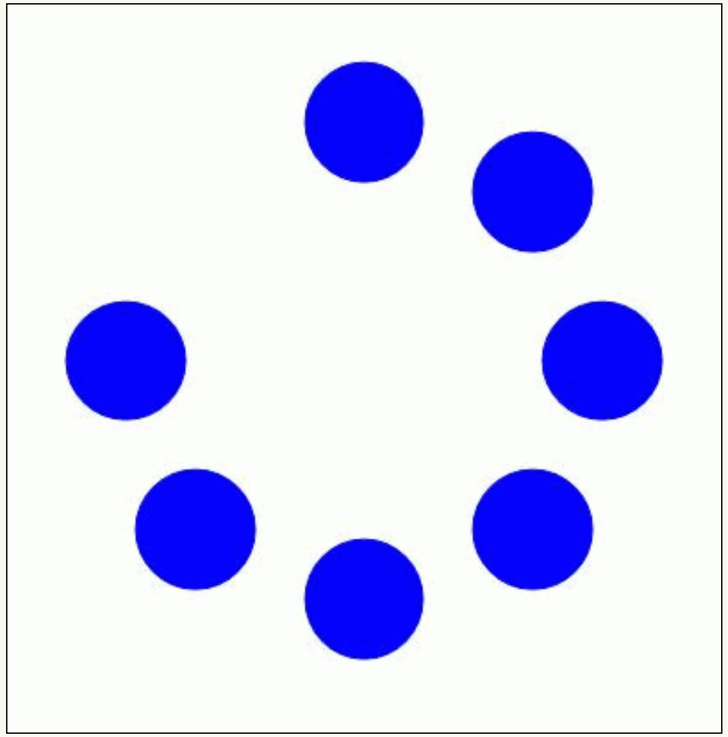
Apparent Movement

- Spatial and temporal changes in retinal illumination can be perceived as motion
- Perception of apparent motion is sensitive to timing and distances
- Beta motion - projection of a similar image nearby its previous location is perceived as motion
- This is the base for motion pictures and computer graphics



Phi Motion

- Depending on the timing and lightness of changes we can perceive a motion of an illusory shadow shape - phi motion
- Interestingly observers report perceiving shapes in intermediate positions for both beta and phi motions



Peripheral Drift Illusion

- Patterns with luminosity change may be interpreted as motion in peripheral vision likely due to eye movement (including micro-saccades)
- Motion is perceived as proceeding from dark to light areas

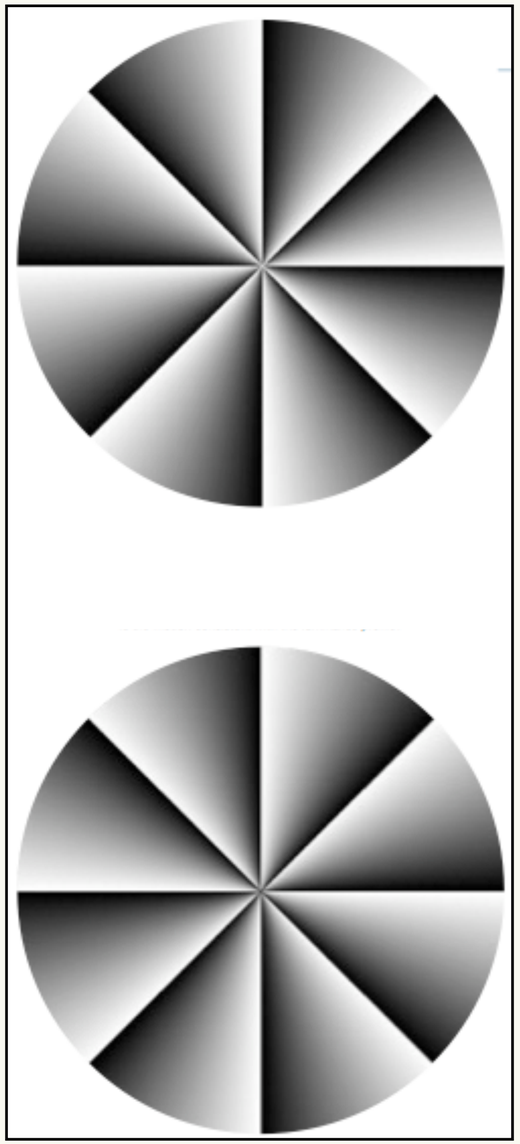


Image by Herbert and Faubert, CC BY-CA 3.0

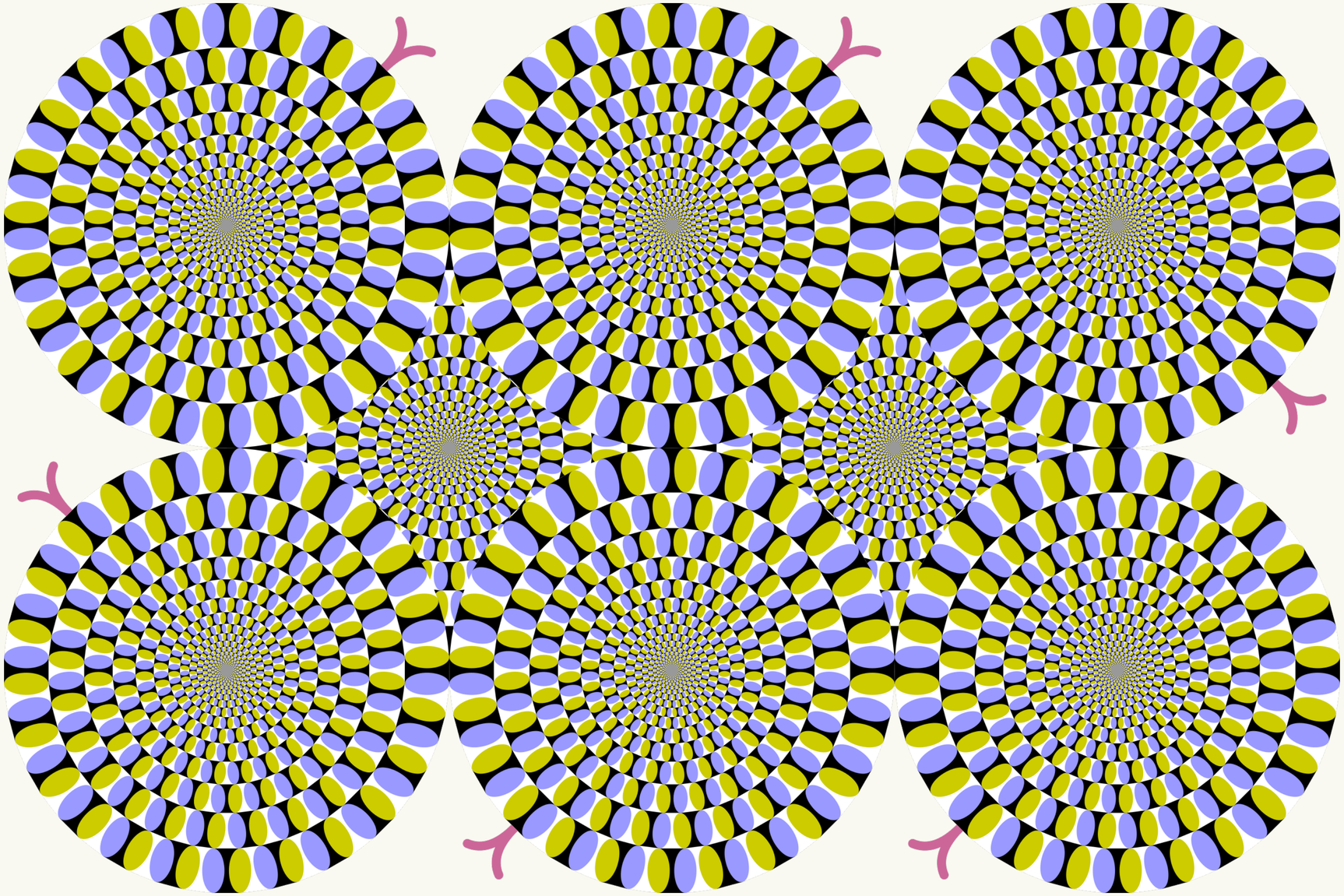


Image by Cmglee based on work by Kitaoka Akiyoshi, CC BY-SA 3.0

Inattentional Blindness And Change Blindness

- Very significant motion may remain unnoticed if attention is focused elsewhere
- There is also limited visual memory to these salient stimuli
- Large motion can mask smaller motion (likely due to shifting attention focus)

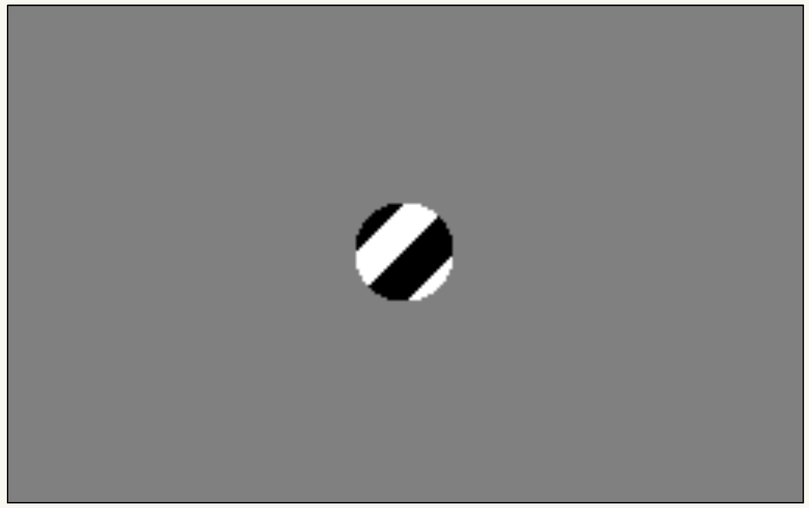
Image from Selective Attention Test, Simons and Chabris 1999

Second Order Motion

- Second order motion is not defined by luminance change but by texture, color or contrast change
- Generally second order motion is less apparent and likely carried and interpreted with the help of other neural pathways
- Color and motion is likely processed separately

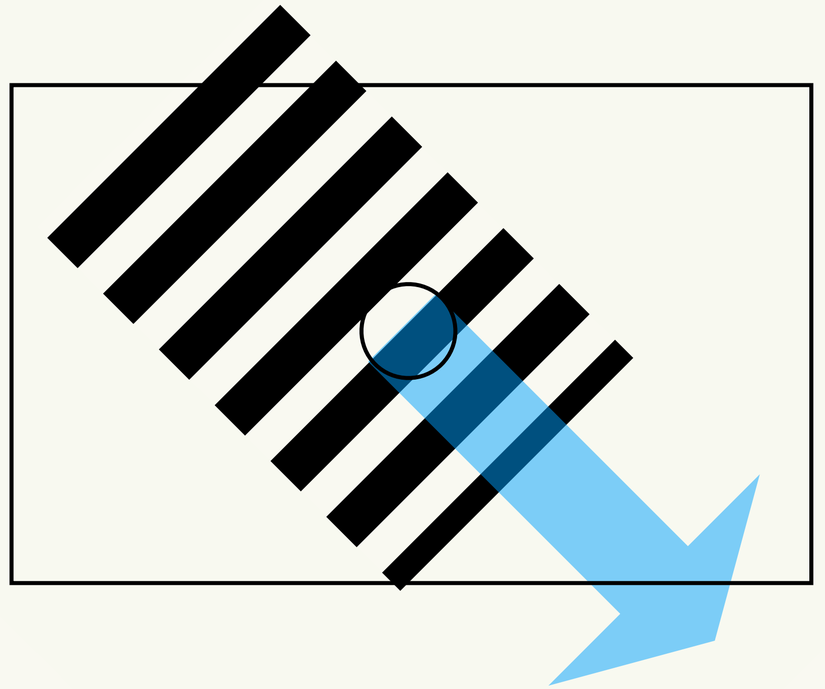
Motion and Shape Perception Challenges

- Use of beta motion aggravates existing visual system challenges:
  - Aperture problem: inability to identify motion direction
  - Correspondence problem: misidentifying subsequent state of an object observed earlier



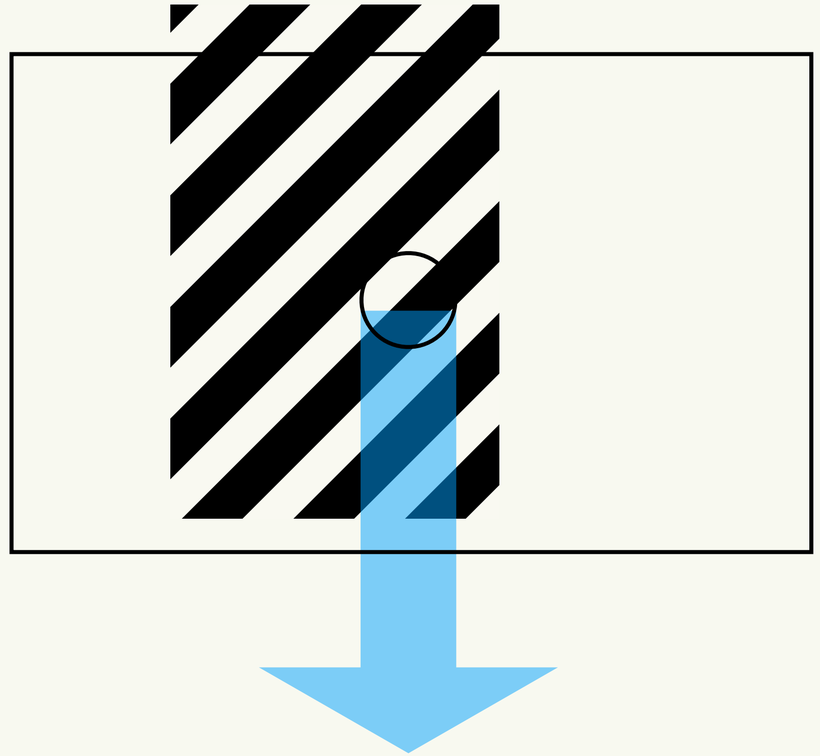
Motion and Shape Perception Challenges

- Use of beta motion aggravates existing visual system challenges:
- Aperture problem: inability to identify motion direction
- Correspondence problem: misidentifying subsequent state of an object observed earlier



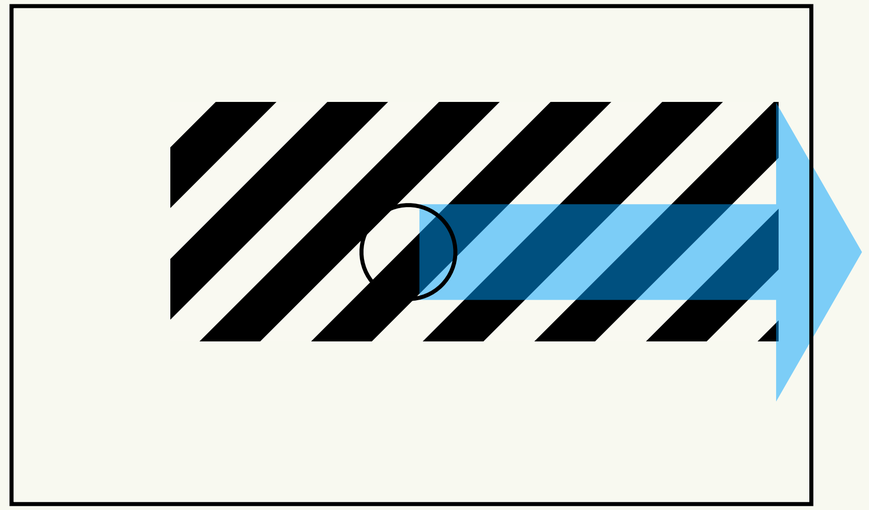
Motion and Shape Perception Challenge

- Use of beta motion aggravates existing visual system challenges:
- Aperture problem: inability to identify motion direction
- Correspondence problem: misidentifying subsequent state of an object observed earlier



Motion and Shape Perception Challenge

- Use of beta motion aggravates existing visual system challenges:
- Aperture problem: inability to identify motion direction
- Correspondence problem: misidentifying subsequent state of an object observed earlier



Neural Pathways

- Edge motion recognized in MT area
- Lesions in magnocellulare layers in LGN inhibit motion perception of large objects
- Motion after effects - perceived motion of stationary objects after prolonged exposure to moving stimuli

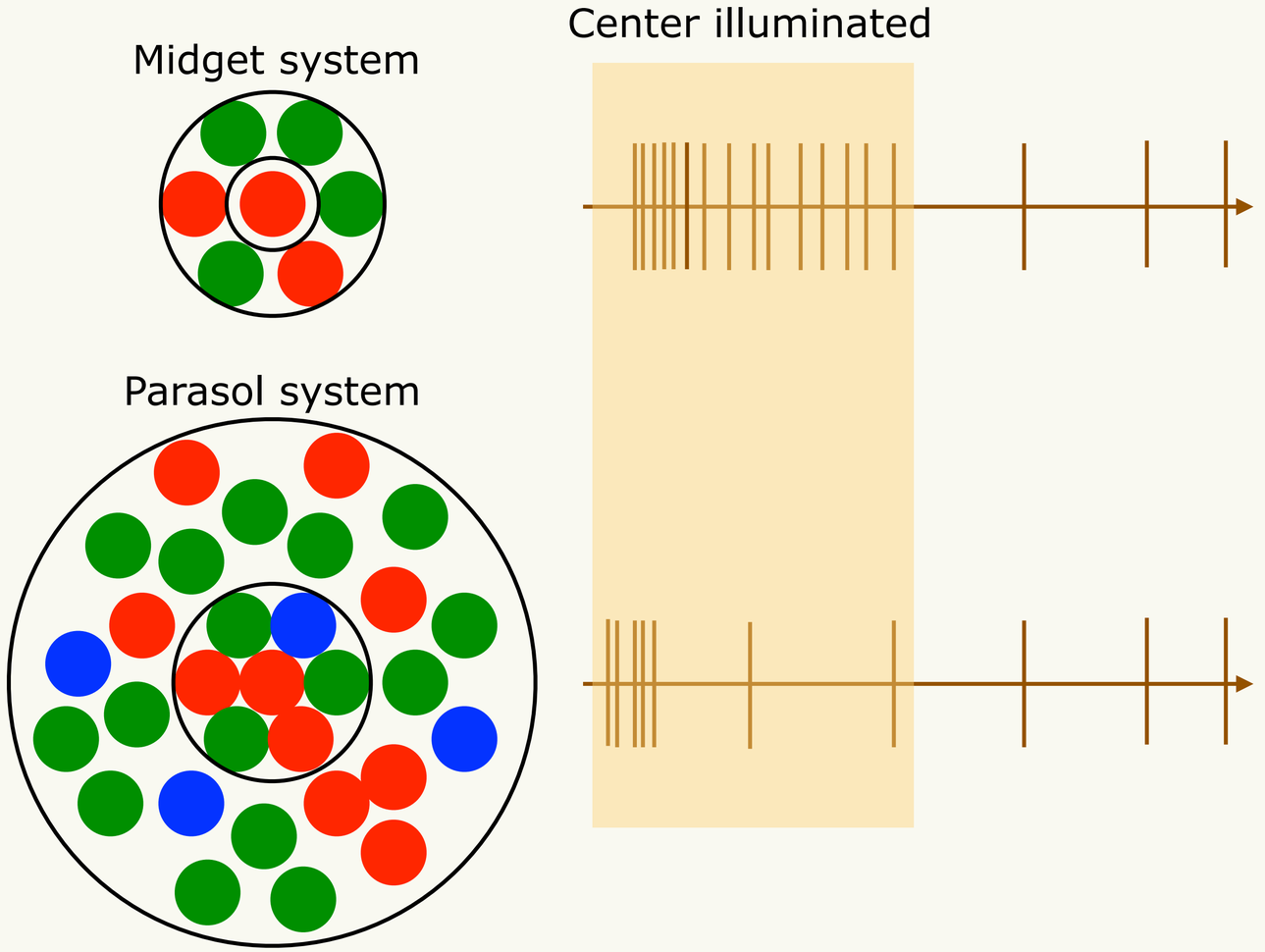
Why does it matter?

- Human ability to perceive motion in sequences of static images permit animated computer graphics
- Artefacts and misperception can occur particularly in peripheral vision
- There are spatial, temporal and attentional limits to this perception as well as boundary challenges (aperture and correspondence)

Frame Rate

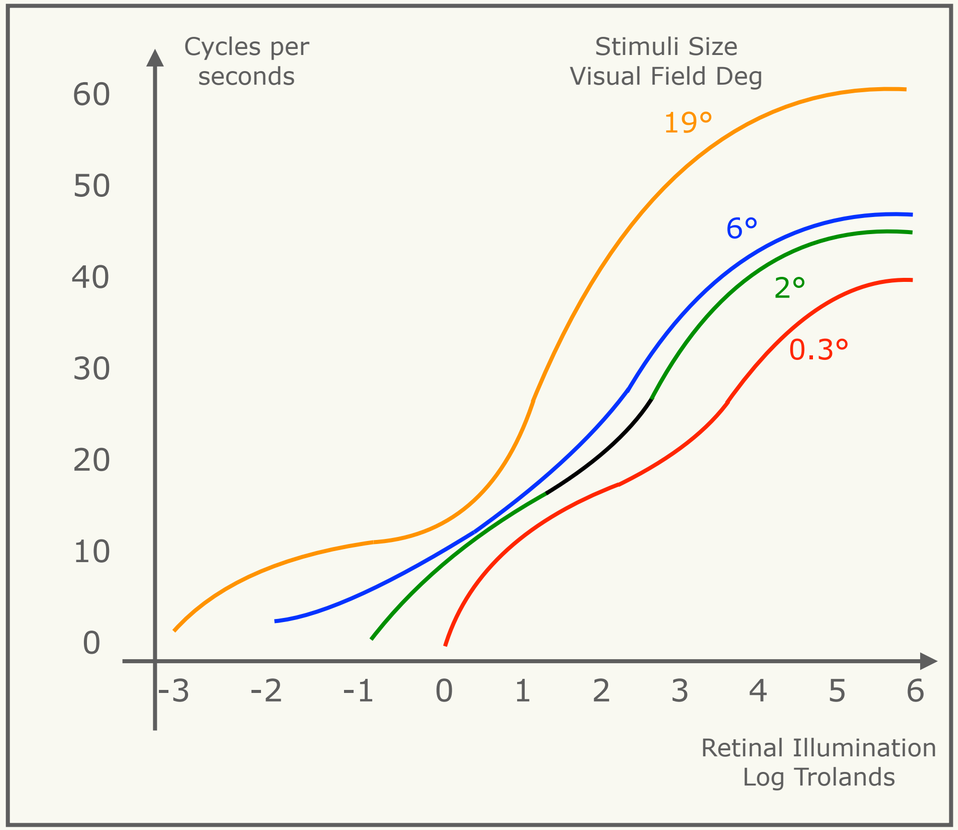
Frame Rate

- Primates have multiple parallel vision systems
  - Fine Detail, Color (Parvo?)
  - General shape and motion (Magno?)
  - Threat/flocking (Konio?)
  - Day/night cycle (Konio, photosensitive RGCs?)
  - Attention shift, eye movement
  - Pupillary Light Reflex
  - Color and lightness constancy
- All these have different temporal behavior
- We know that:
  - Detail vision, slow
  - Rough shape vision/motion perception, fast



Flicker Fusion Rate

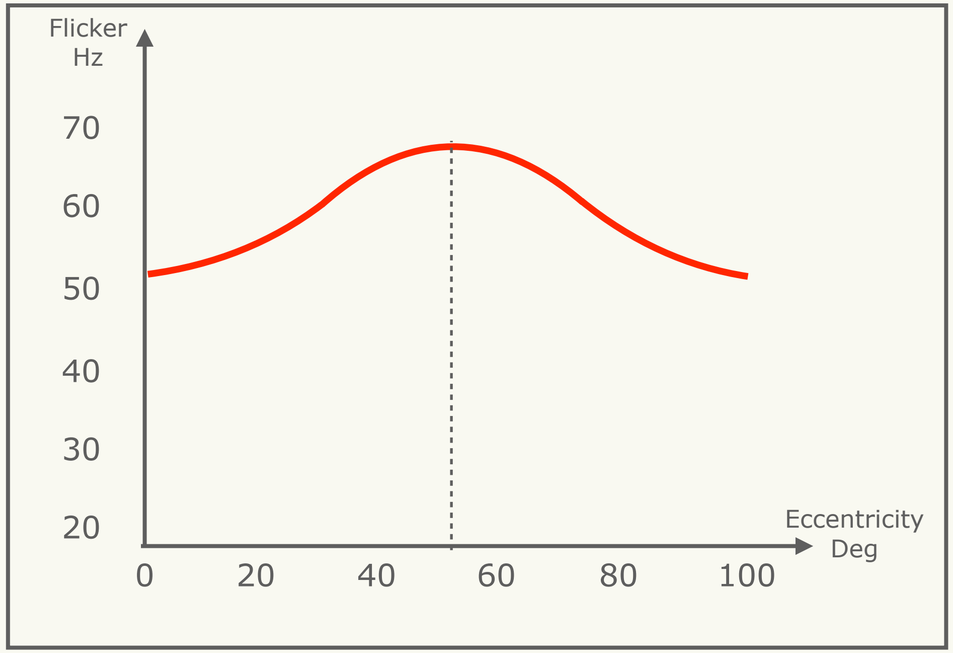
- Flicker fusion threshold depends on retinal illumination level and stimuli size
- Generally fusion happens somewhere between low 20hz and just under 60hz
- But, high intensity flicker can be felt (not necessarily perceived) even at 300+Hz
- LEDs in HDR TVs…



Adapted from Hecht and Smith, Intermittent stimulation by light, 1936

Flicker Fusion Eccentricity

- Central vision is less sensitive to flicker (slower midget RGCs?)
- Mid periphery appears the most sensitive (faster parasol RGCs?)



Adapted from Rovamo & Raninen, Critical flicker frequency and M-scaling of stimulus size and retinal illuminance, 1984

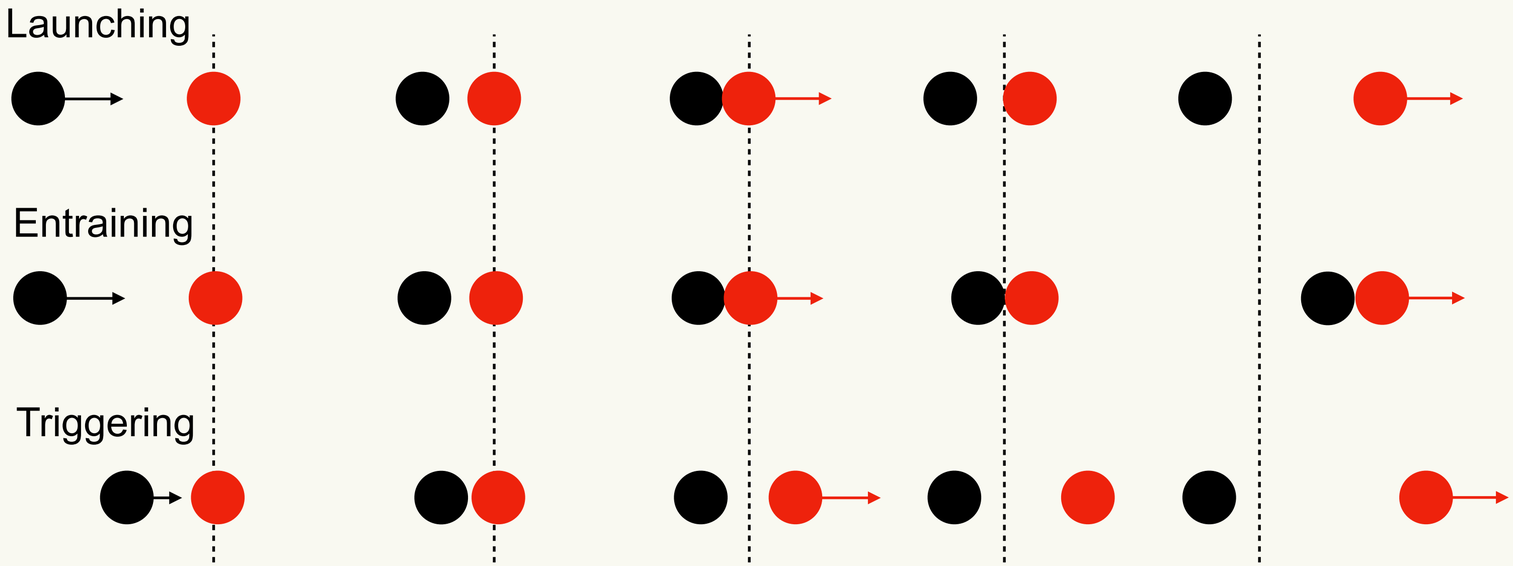
Why does it matter?

- Perception of smooth motion depends on many factors: persistence of frames, retinal illumination, size of visual differences, presence of motion streaks etc.
- Flicker may be more apparent in far and mid peripheral vision compared to central vision

Motion and Timing

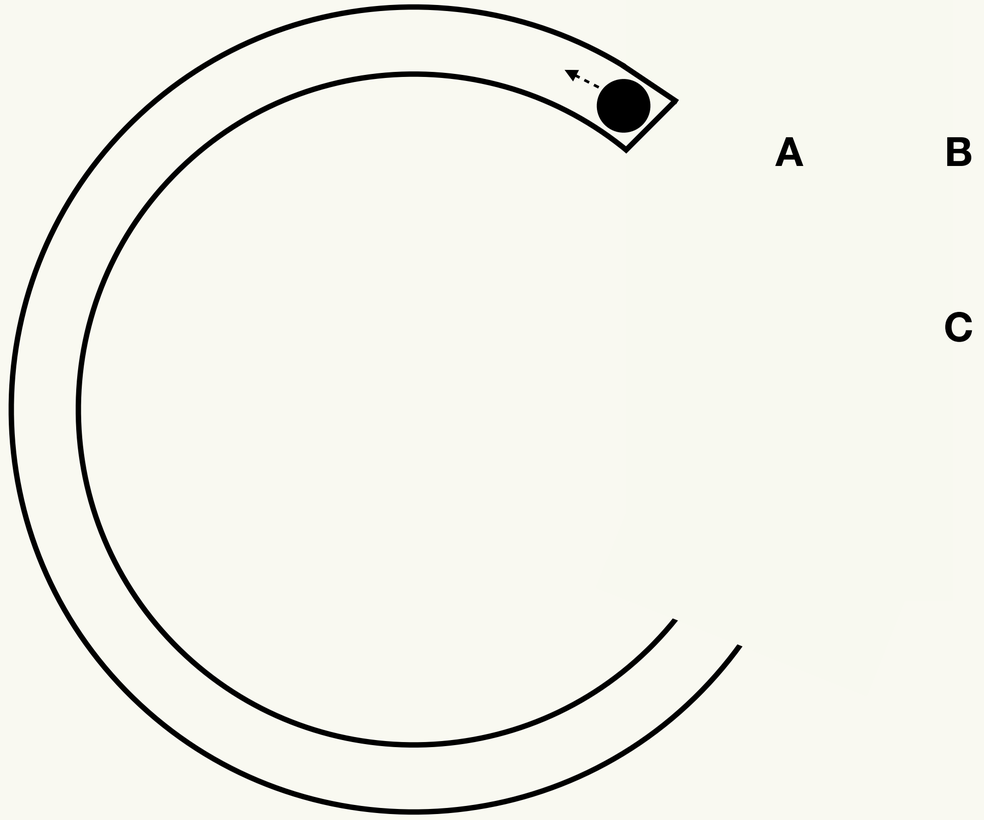
Types of Events

- An object needs to be set in motion no more than 200ms after interaction for there to be a perceived causation
- There needs to be directional correlation as well
- Resulting speed needs to be roughly the same, but not necessarily faster



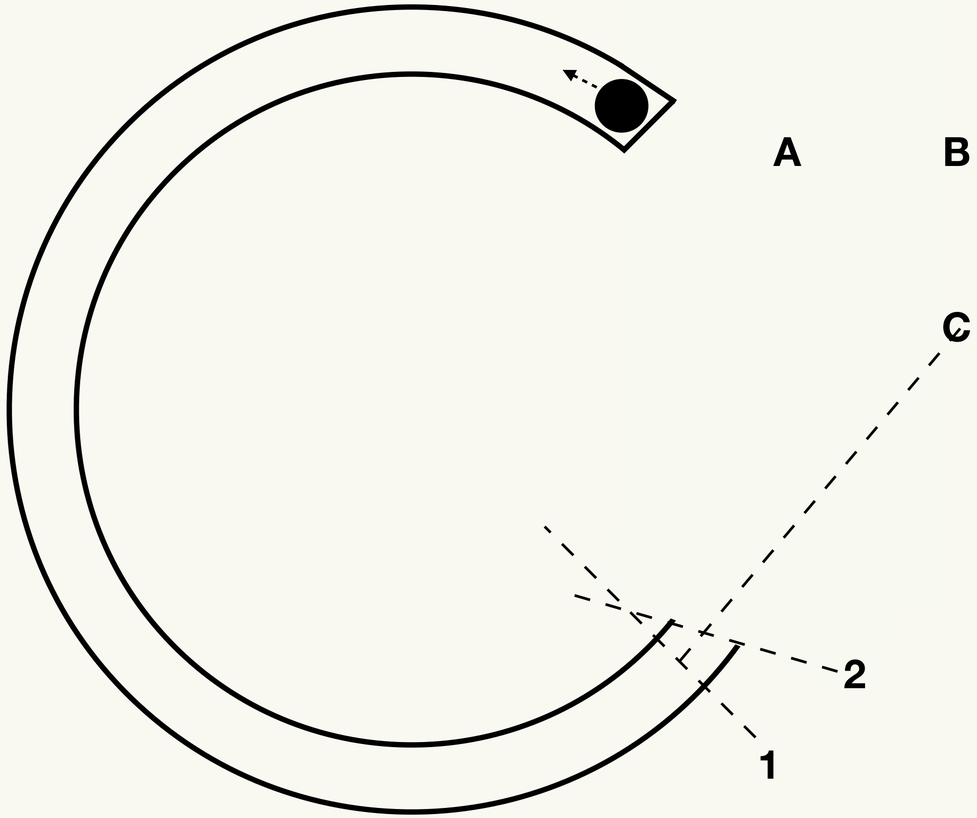
Motion Predictions

- Where to? A, B or C?



Motion Predictions

- It seems we use multiple heuristic to perceive the type of interaction between object
- Ricochet heuristic
- We may not be able to accurately judge mass involved in such interactions
- We may not be able to intuitively predict trajectories



Why does it matter?

- Perception of causality of interaction is time sensitive
- Generally humans have limited abilities to predict trajectories, mass or elasticity of objects interacting and use simple heuristics instead
- Fully physics-based simulation may not be necessary to portray plausible object interactions

Motion and Color

Motion and Color

- Motion perception is likely mostly independent of color perception:
  - Cerebral Achromotopsia - inability to see colors (but motion unaffected)
  - Cerebral Akinetopsia - inability to see motion (but color unaffected)
- Identifying motion of a foreground object equiliuminous with background is extremely complicated
- Note also that similarity of images is determined primarily by luminosity and not color (hence being able to use red/green glasses)

Color affecting Motion?

- Footsteps illusion: blue and yellow blocks appear to move at different speed
- Perception of movement can be different depending on the luminance of the stimuli

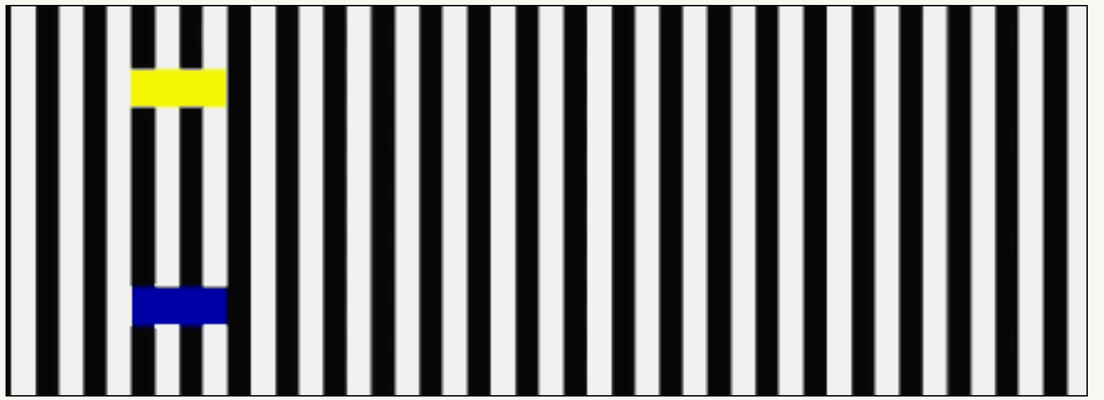
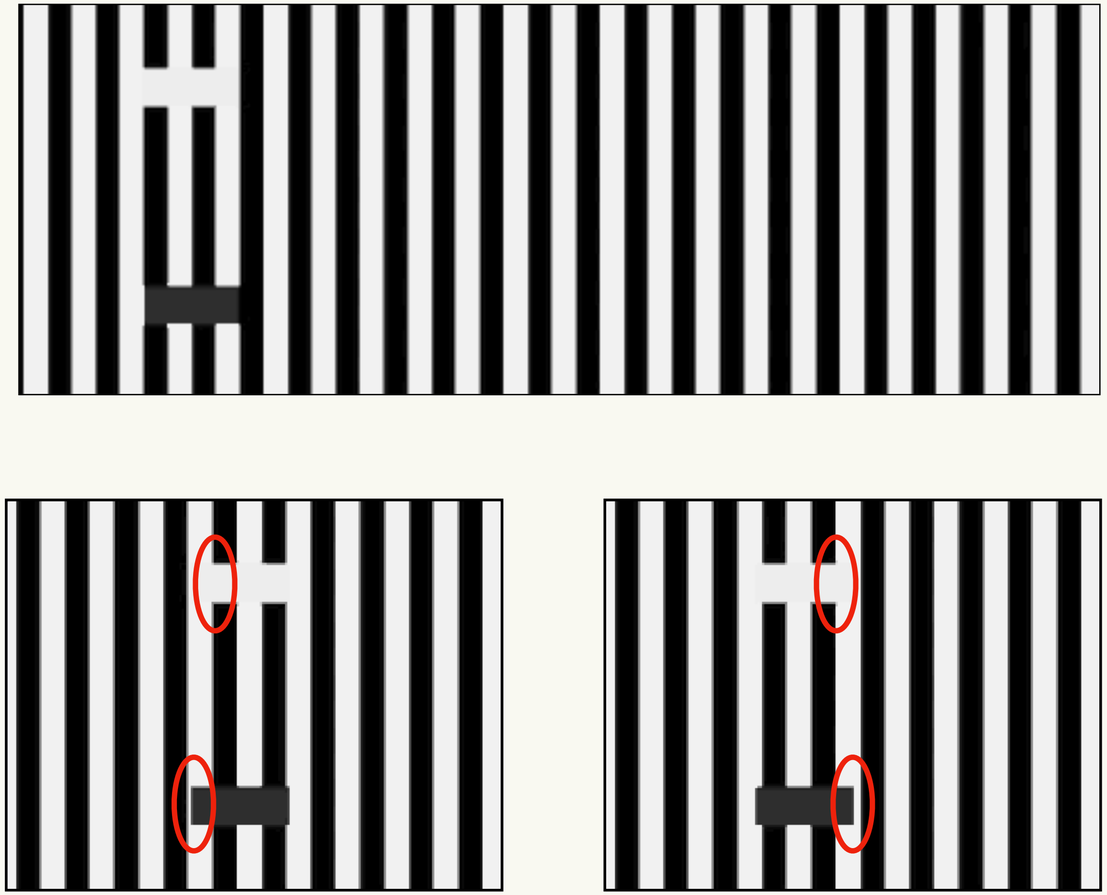


Image by Rinuraeni, CC BY-CA 4.0

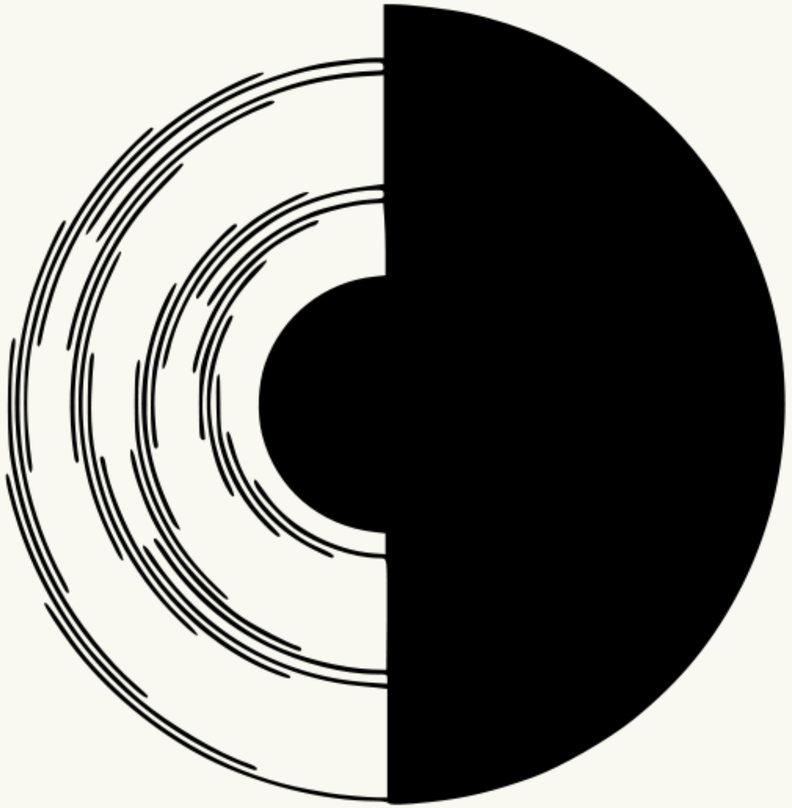
Contrast Points

- Footstep illusion works in back and white
- Relationship of contrast points that we use to build an interpretation of shapes

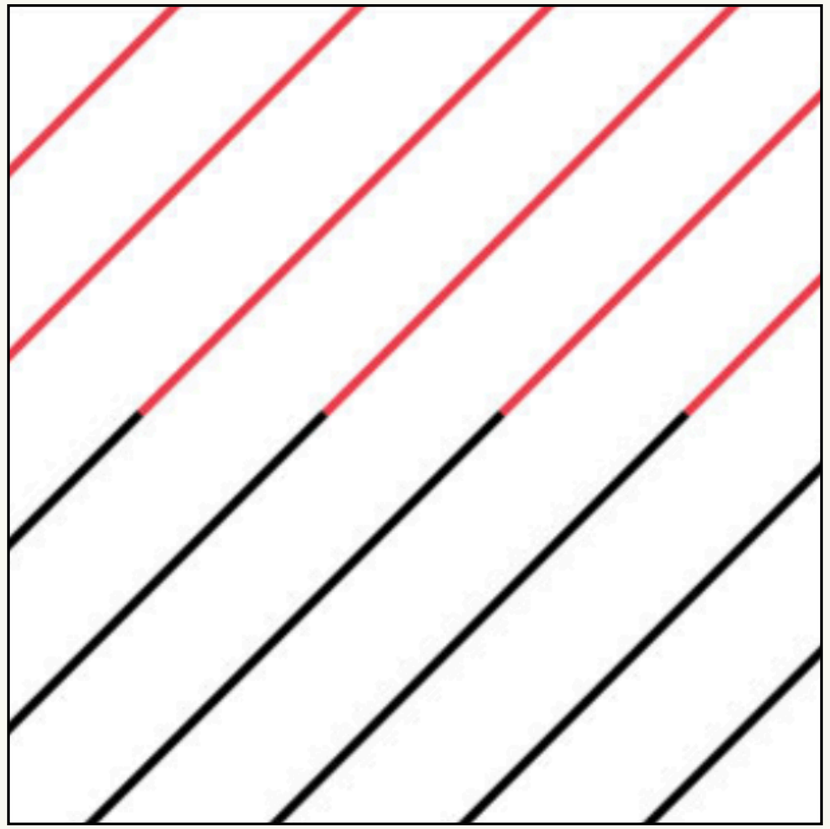


Motion affecting Color

- Some achromatic stimuli in motion can trigger perception of color
- Benham’s top



Public domain image



Why does it matter?

- Motion perception is affected by luminance and contrast of objects
- Key contrast points are very significant for both shape and motion perception
- Fast motion may produce fine color artefacts

Visual System and Motion Blur

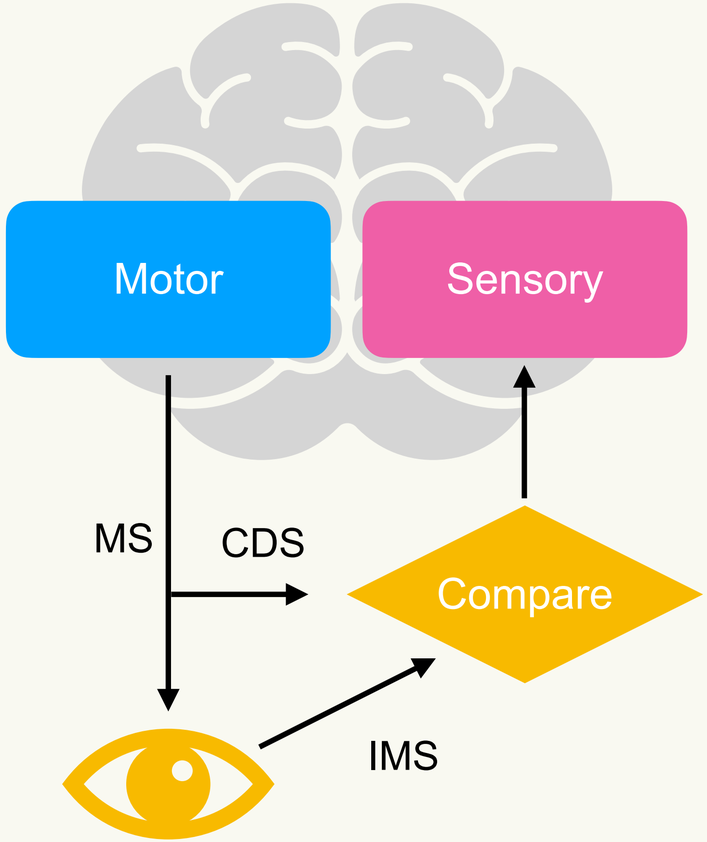
Low Perception of Blur

- A static stimuli can persist for 100-120ms - hence fast moving objects or fast head movement should be producing a significant blur - however this is not normally perceived
- Smooth pursuit eye movement helps but insufficiently
- Saccadic suppression also help

Image by EO1, CC BY-CA 2.0

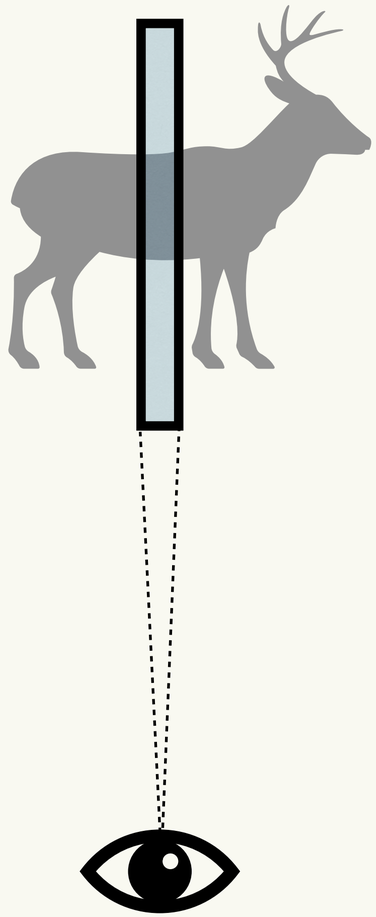
Corollary Discharge

- Motion signal is sent to eye muscles
- Corollary Discharge (a copy of motion signal is sent to the comparator)
- Image motion signal is subtracted from corollary discharge to compute stable world image
- Damage to medial superior temporal area upsets the mechanism — results of perception of movement of stationary targets
- (Close one eye, press on the other, perceive motion as there is no corollary discharge to compensate)



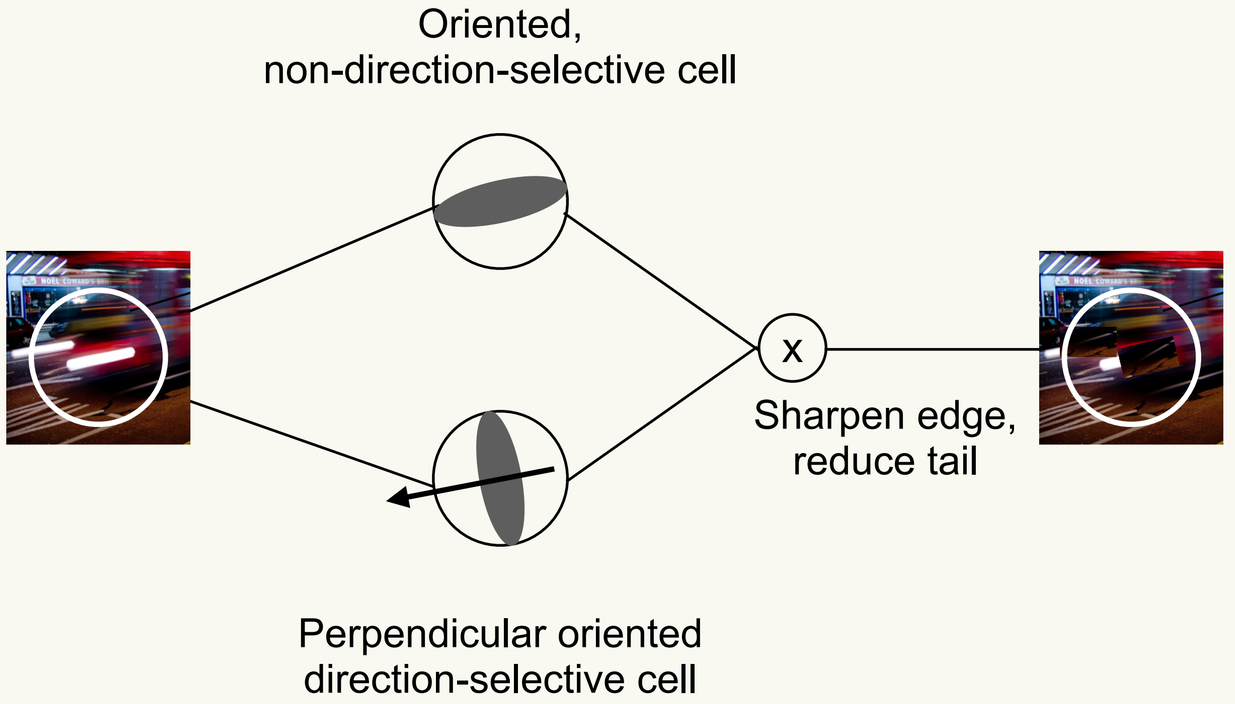
Anorthoscopic Perception

- Anorthoscopic perception
- Ability to reconstruct a shape in motion through a slit may be using a somewhat similar mechanism to that of deblurring
- Percepts quite different from retinal image



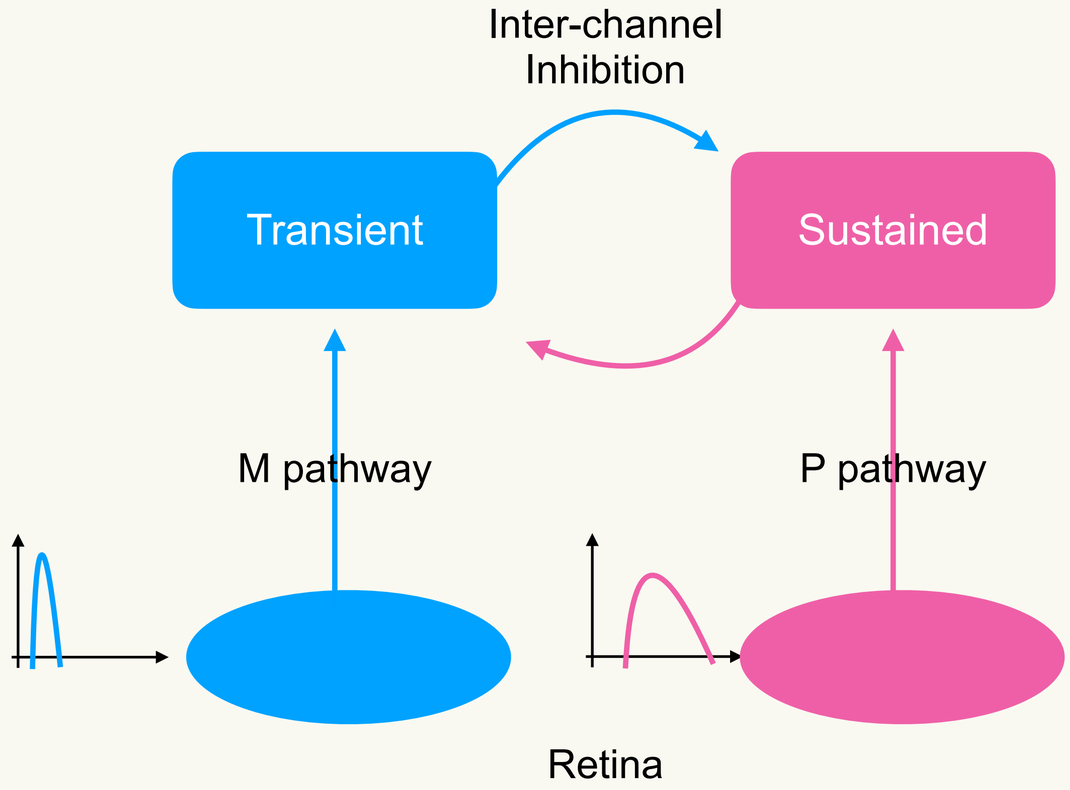
Deblurring

- A single object appearing for a short duration in motion produces a larger motion blur compared to a more complex object
- Objects in motion may appear sharper!
- Response of cells parallel to their preferred orientation (rather then perpendicular)



Transient Suppression of Sustained Response

- Parvo network is producing sustained response while Magno is transient
- Some evidence of transient suppression of sustained response
- Masking!



Motion Induced Blindness

- A likely related mechanism may also eliminate perception of objects altogether
- Motion induced blindness
- Generally considered different from attention blindness

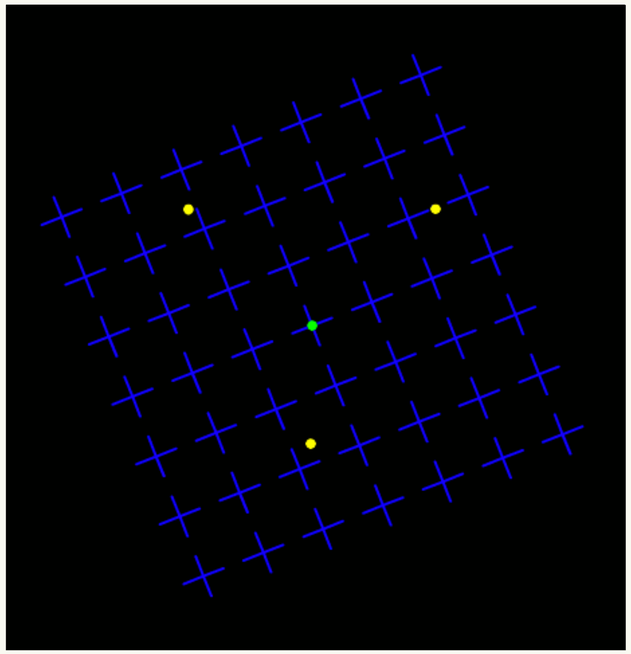
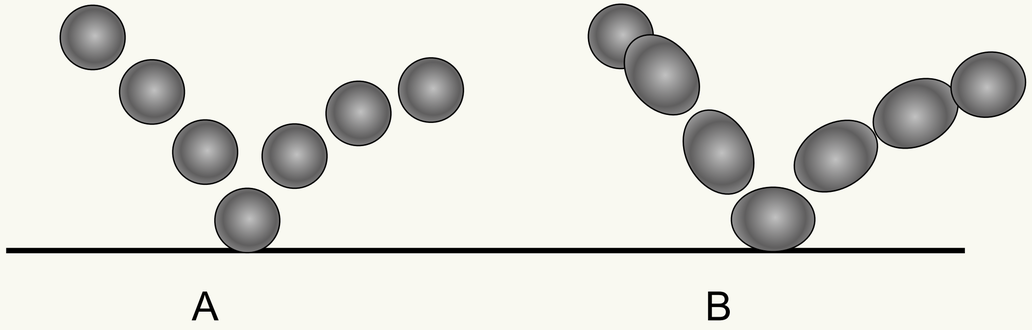


Image by Mlechowicz, CC BY-CA 3.0

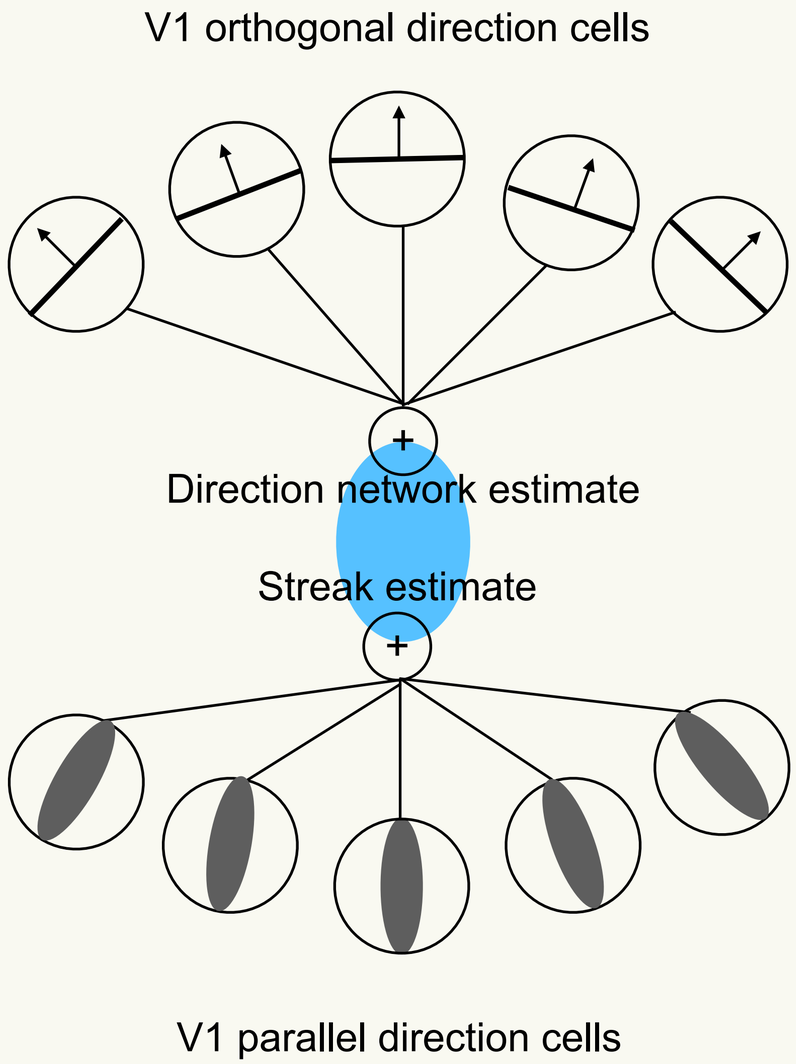
Motion Streaks

- Motion streaks provide intuitive sense of motion and of direction of motion
- Object elongation may serve a similar purpose



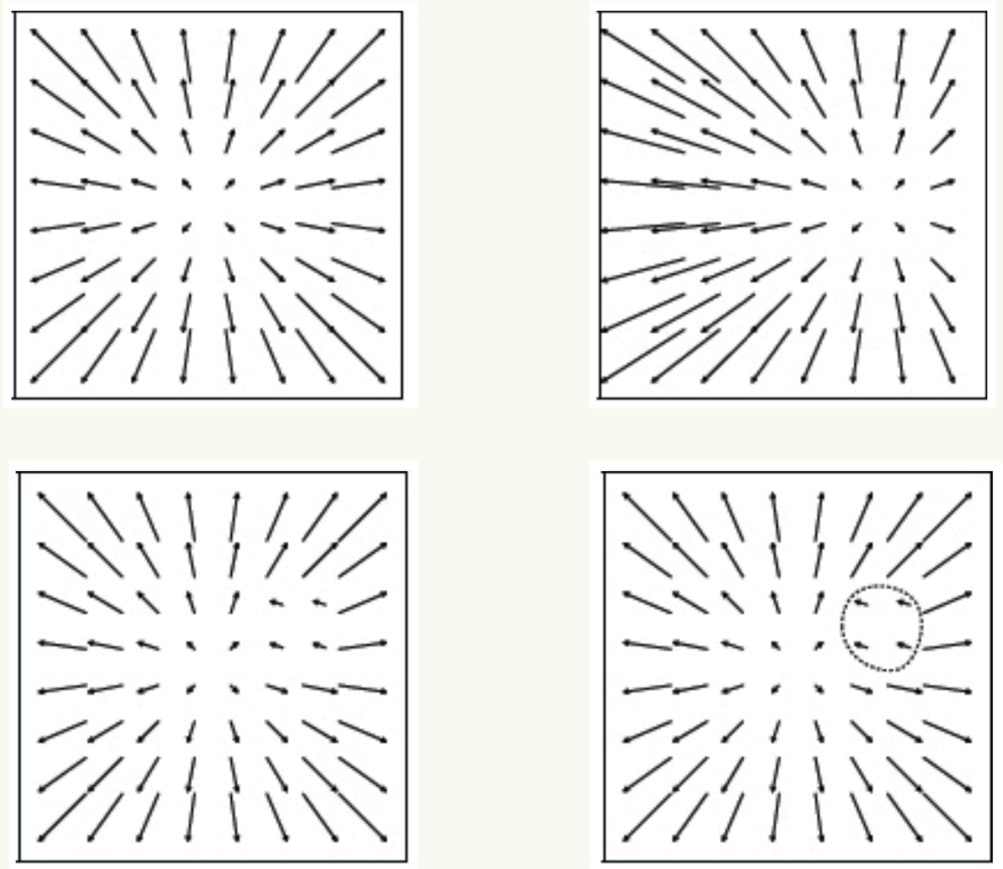
Neural Circuitry

- Motion streaks may be perceived by cell networks sensitive to streak directions
- These may augment information from the network of simple cells that are sensitive to edge movements



Optical Flow

- The pattern of apparent motion of objects
- Center of expansion of the flow indicates the direction of movement
- Used for detection of imminent collision
- Discontinuity in the flow may indicate a moving object
- Vection illusion of self-motion
- Generally motion in VR may produce mismatched optical flows



Why does it matter?

- Multiple neural mechanisms work to minimize perception of blur
- Motion streaks (blurred high contrast points) are shown to help perception of movement
- Discontinuities in retinal flow images help both motion perception and movement detection

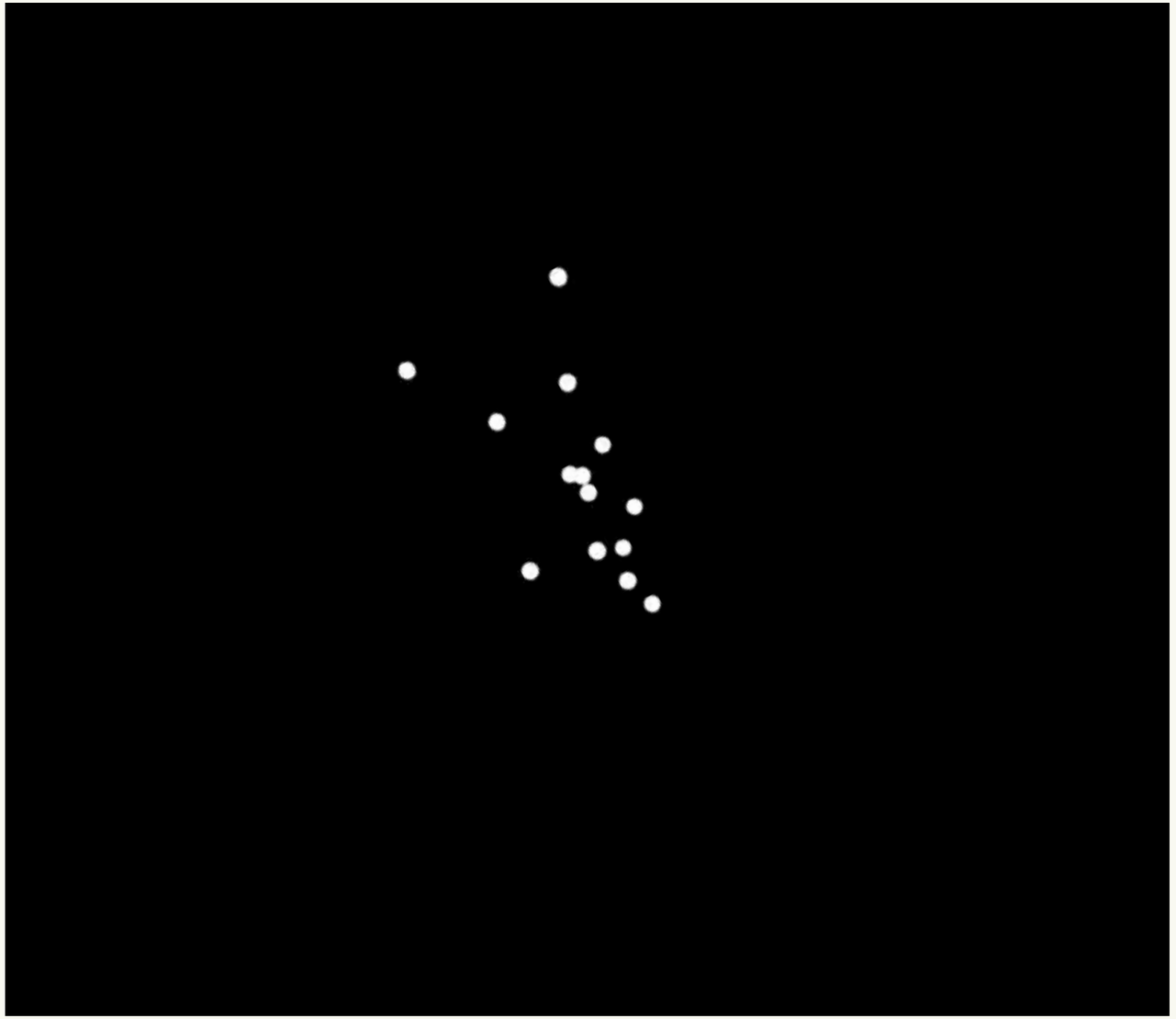
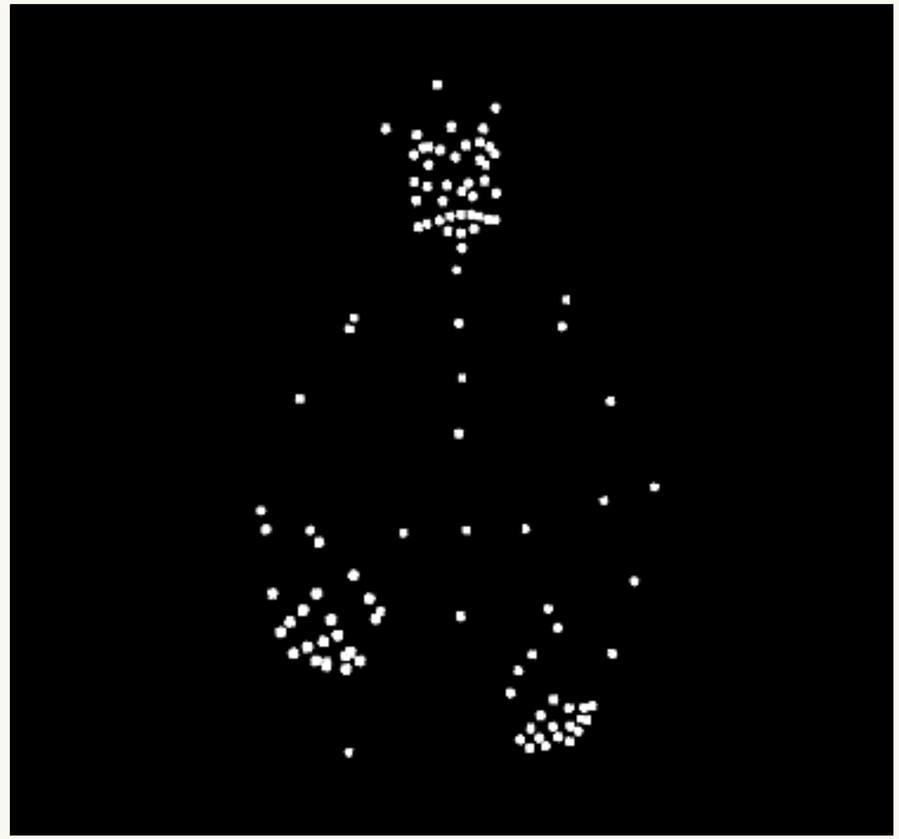


Image by Mlechowicz, CC BY-CA 3.0

Biological Motion

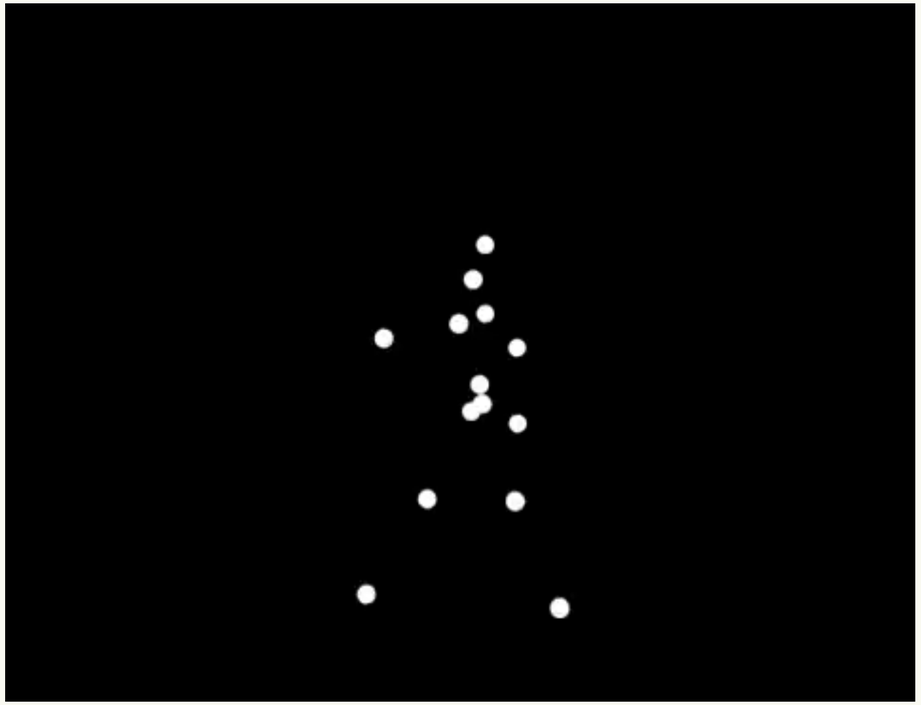
Point Light Displays

- Humans can recognize biological objects movement in very rudimentary displays



Orientation Sensitive

- Similarly to special circuitry related to face recognition (Fusiform Gyrus) we posses dedicated brain areas to recognize biological movement (STS - Superior Temporal Sulcus)



Scrambled Motion

- Scrambling trajectories still permit recognition of movement (but primarily in upright state)
- When direction is ambiguous it is judged to be toward the observer
- High contrast points may help perception

Why does it matter?

- Humans have dedicated circuitry to perceive biological movement even when extremely schematic
- This perception may resist some degree of scrambling and it is orientation sensitive

Thanks!

Questions?

sergei.savchenko@bethesdastudios.com