Developing VR Experiences

with the

Oculus Rift

Tom Forsyth

GDC Europe August 2014

facebook

- Palmer Luckey & John Carmack duct-tape prototype at E3 2012
- Oculus VR founded mid 2012
- Successful Kickstarter campaign Sept 2012
- First 10k dev kits shipped March 2013
- 55,000 DK1 dev kits made & shipped
- >50,000 DK2 on order (16k shipped as of Aug 8th)
- 70,000 developers on Oculus dev portal
- Acquired by Facebook July 2014

The Rift Technology

- Development Kit 2
- 1920x1080 OLED screen, half per eye
- Wide-angle circular lenses, 90-110 degree FOV
- GPU corrects distortion of lenses
- Low-persistence – each pixel is lit for <3ms per frame
- 1000Hz gyro tracks orientation
- 60Hz position tracking: external camera sees LED array on HMD
- SW fusion and prediction of orientation and position

Topics

- Be kind to your players
- VOR gain
- IPD and the neck
- Changing world scale
- How tall is the player?
- Transition animations
- Meathook avatars
- Maintaining framerate

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- Best Practices Guide contains what we know
  - Use it as a checklist of things to at least think hard about

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  - Over-intense VR makes it harder to follow plot & game mechanics

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- Make intense experiences optional
  - Fewer “in your face” particles & explosions
  - Less, slower movement
  - Maybe reduce the world scale (see later)

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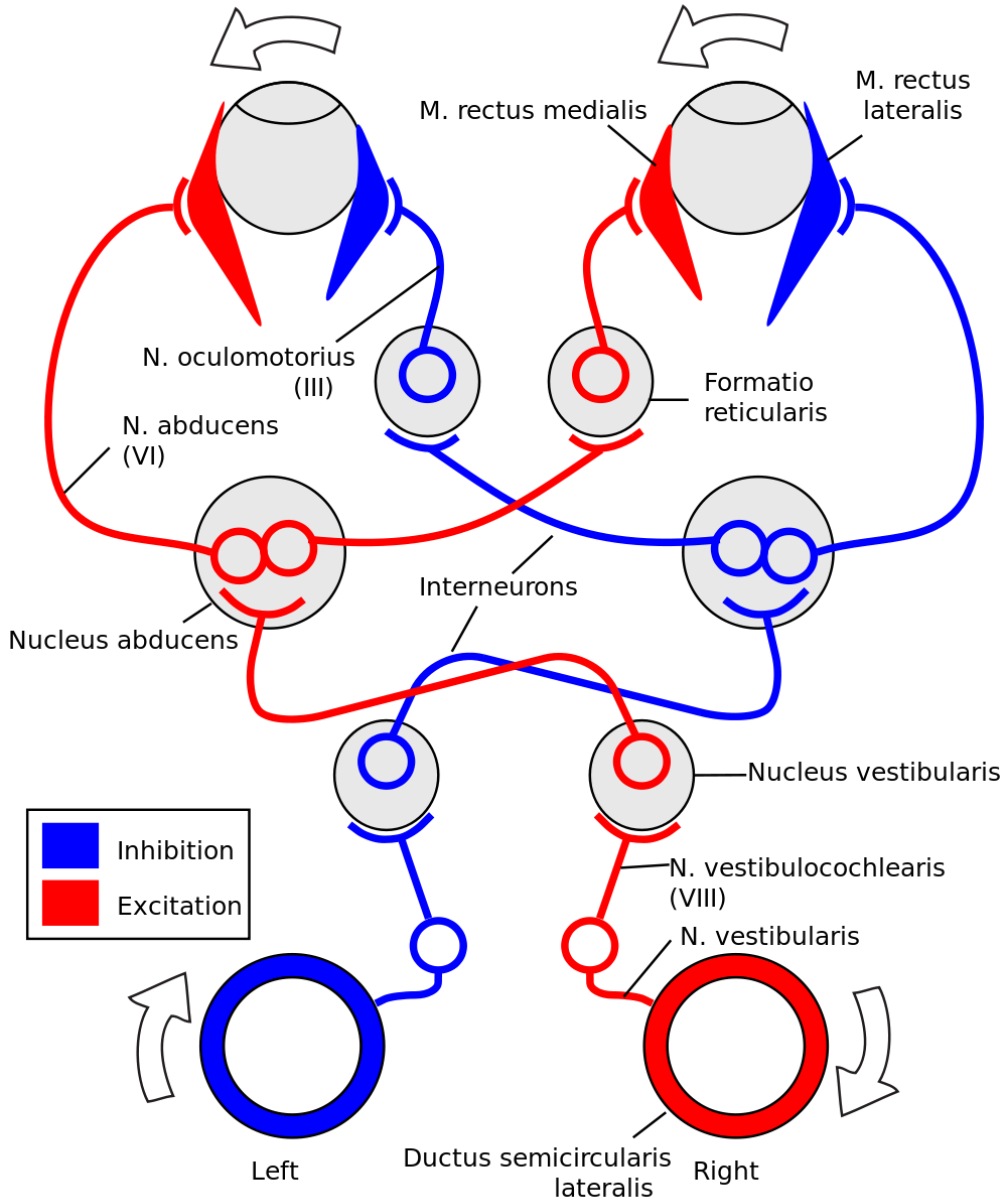
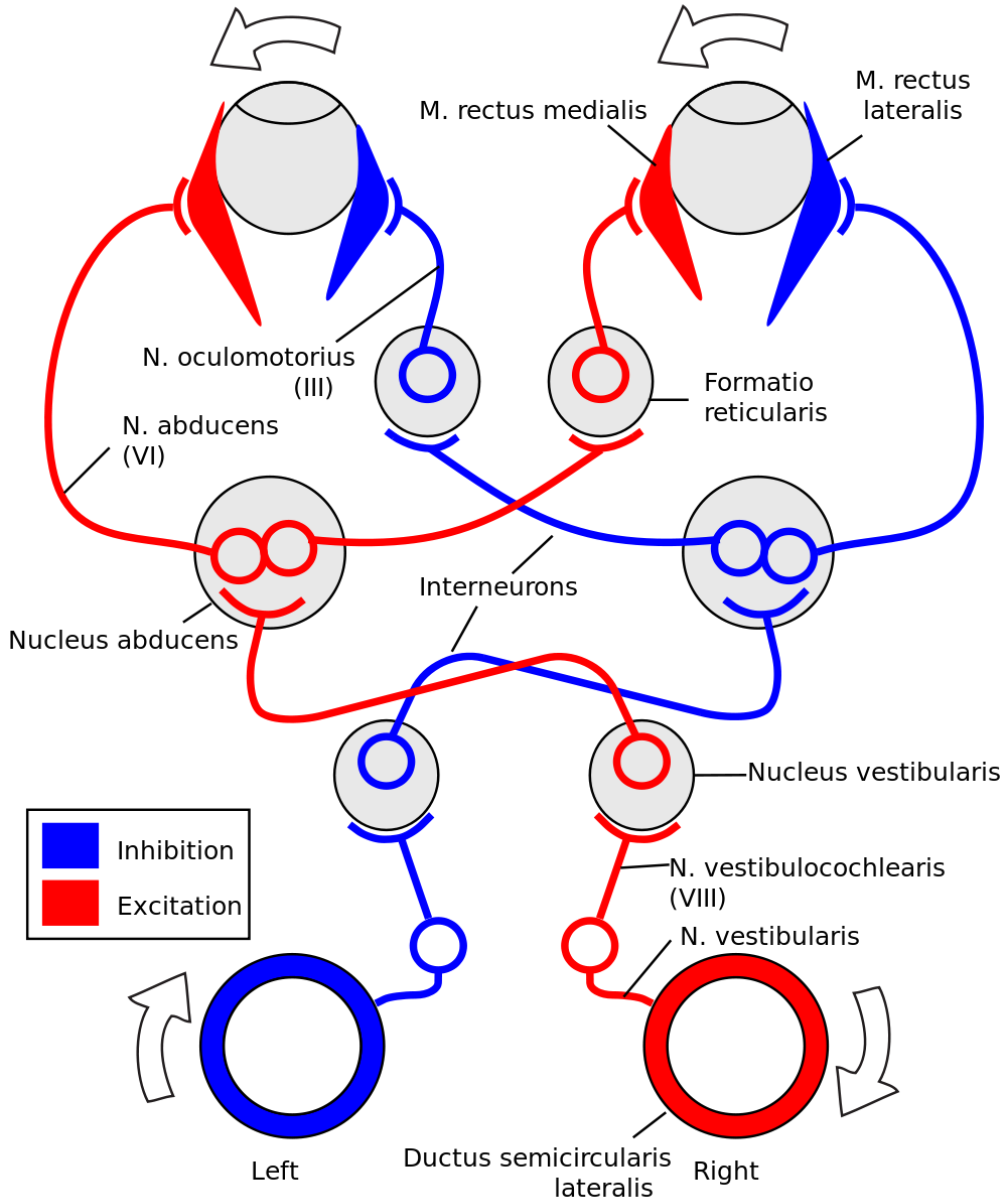
- Default low
  - Let more experienced VR people “opt in”, don’t make newbs “opt out”
- Make it easy to change any time
  - Allow dropping to lower intensity to actually play the game after the “VR hit”

Vestibulo-Optical Reflex



Vestibulo-Optical Reflex

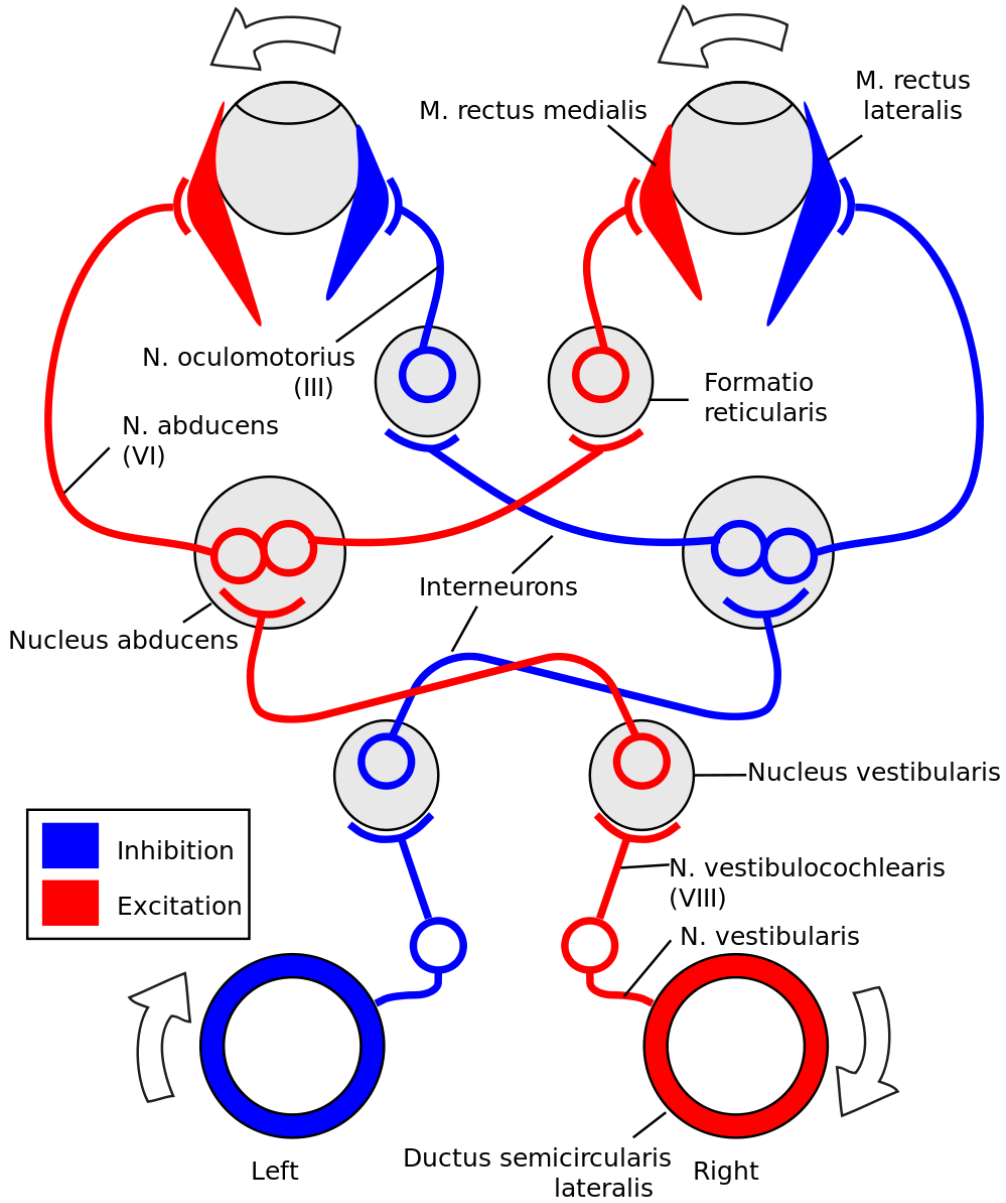
OMGWTH???



Vestibulo-Optical Reflex

Horizontal slice through the head

(just showing systems for yaw control)



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Horizontal slice through the head

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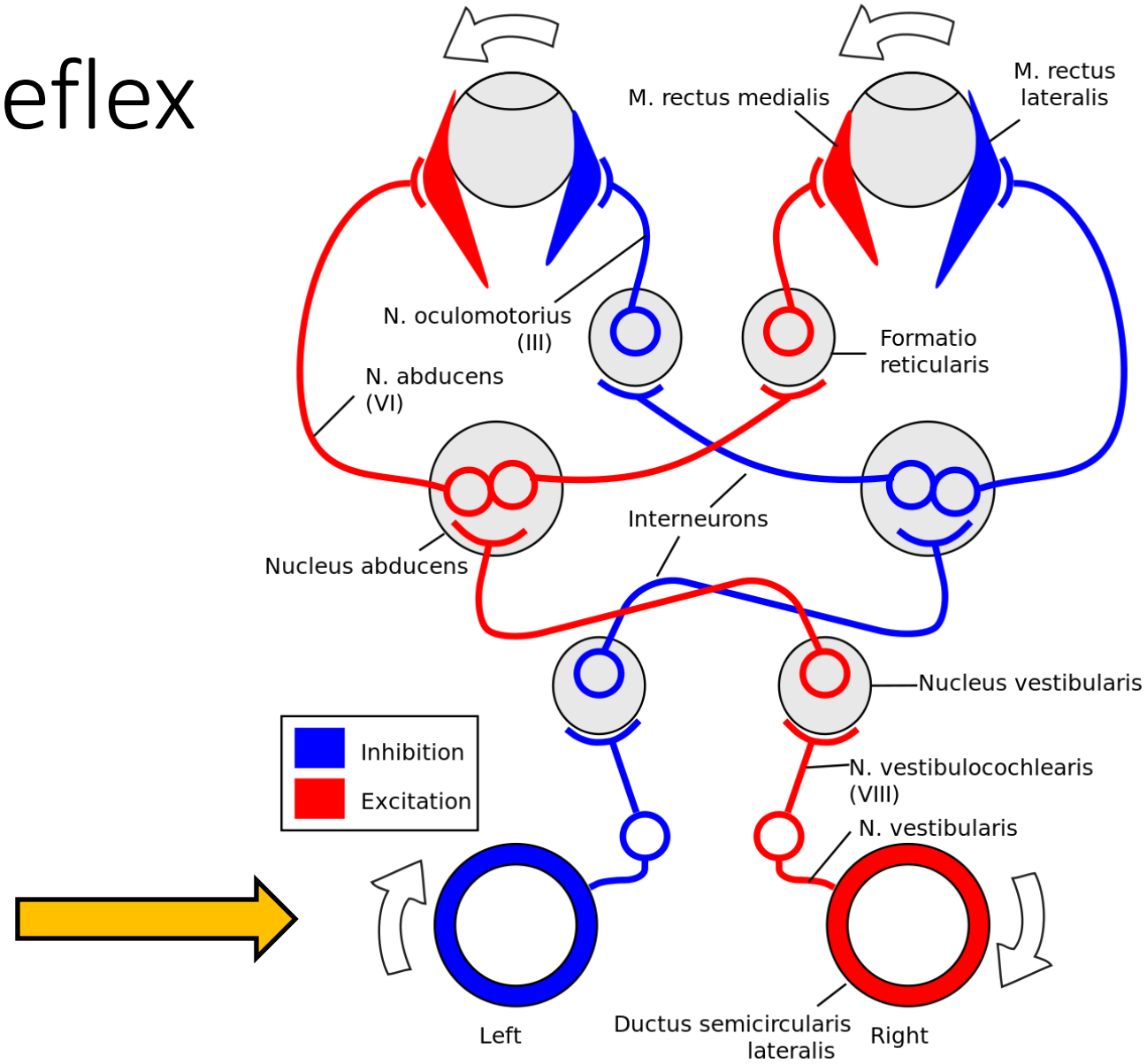
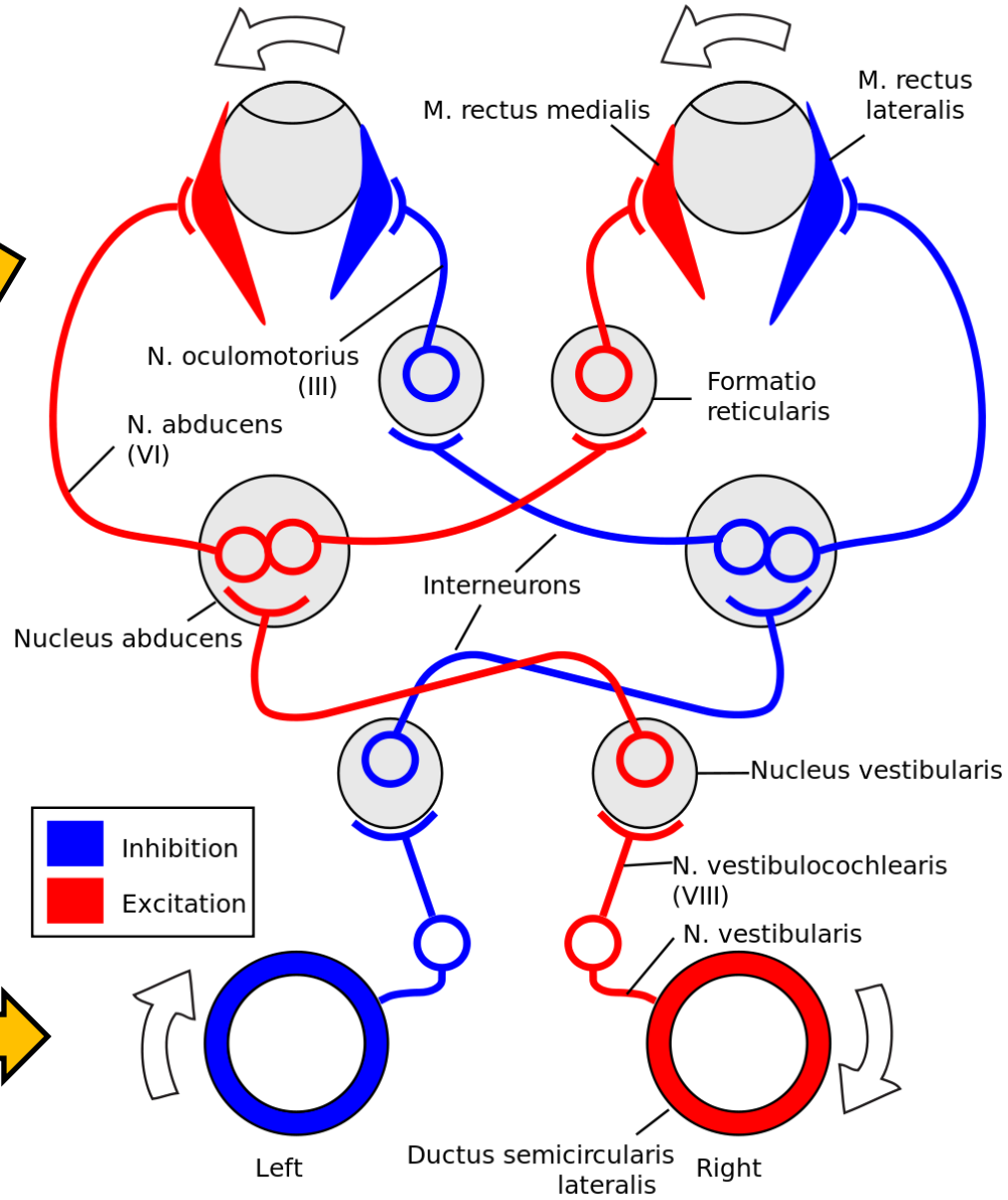
Semi-circular canals in the ears



Vestibulo-Optical Reflex

Eyeballs and muscles



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Reflex neurons

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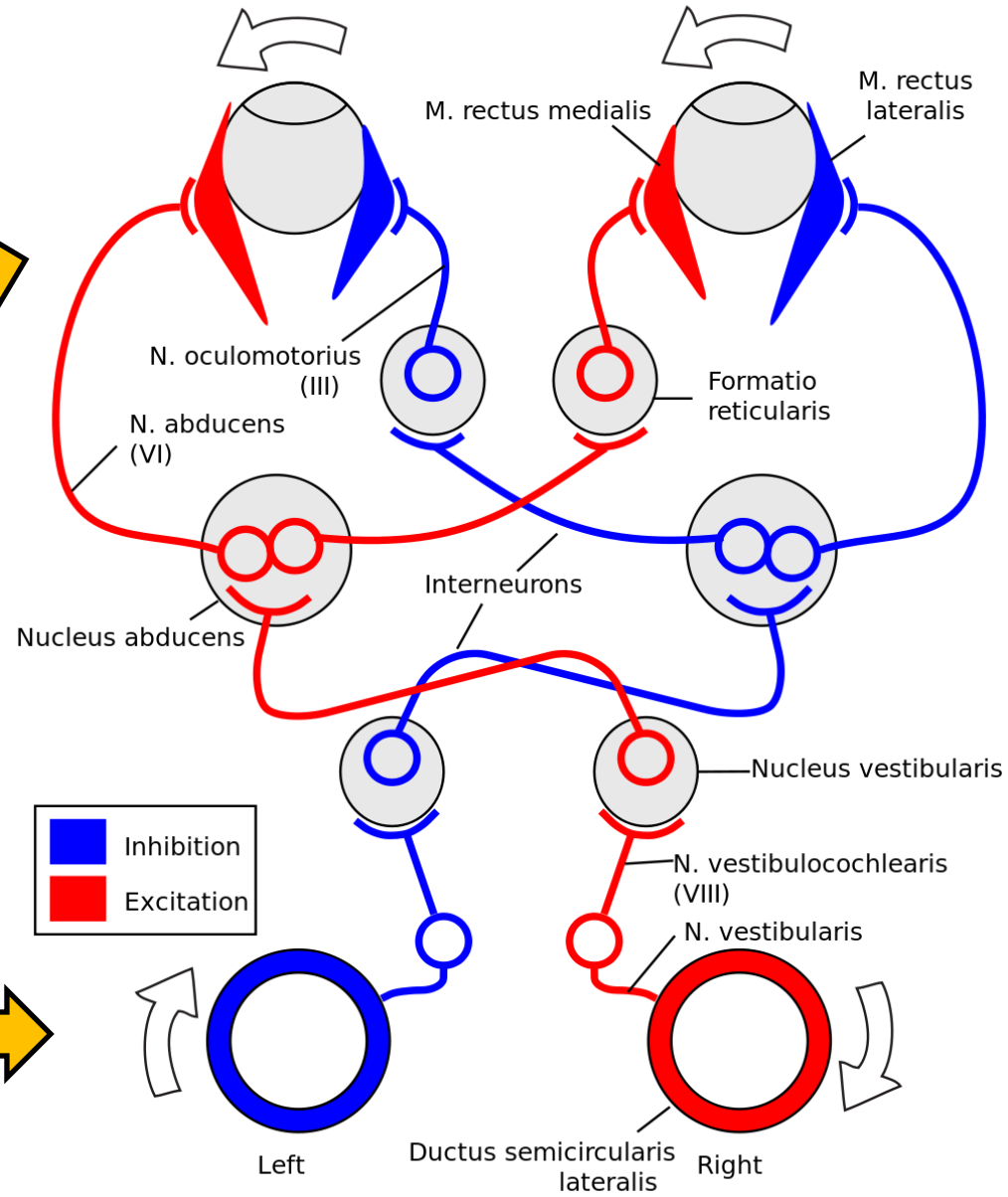
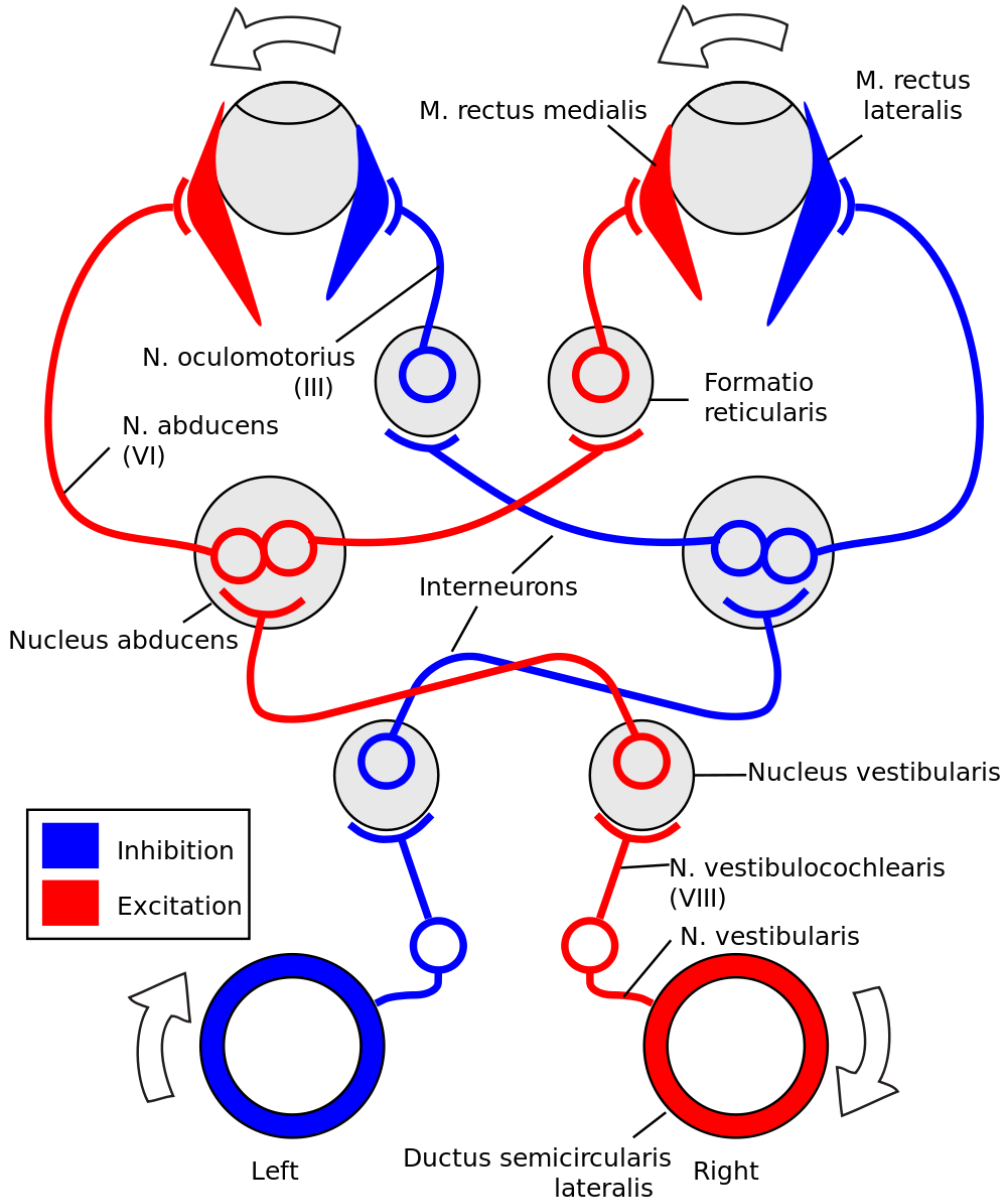


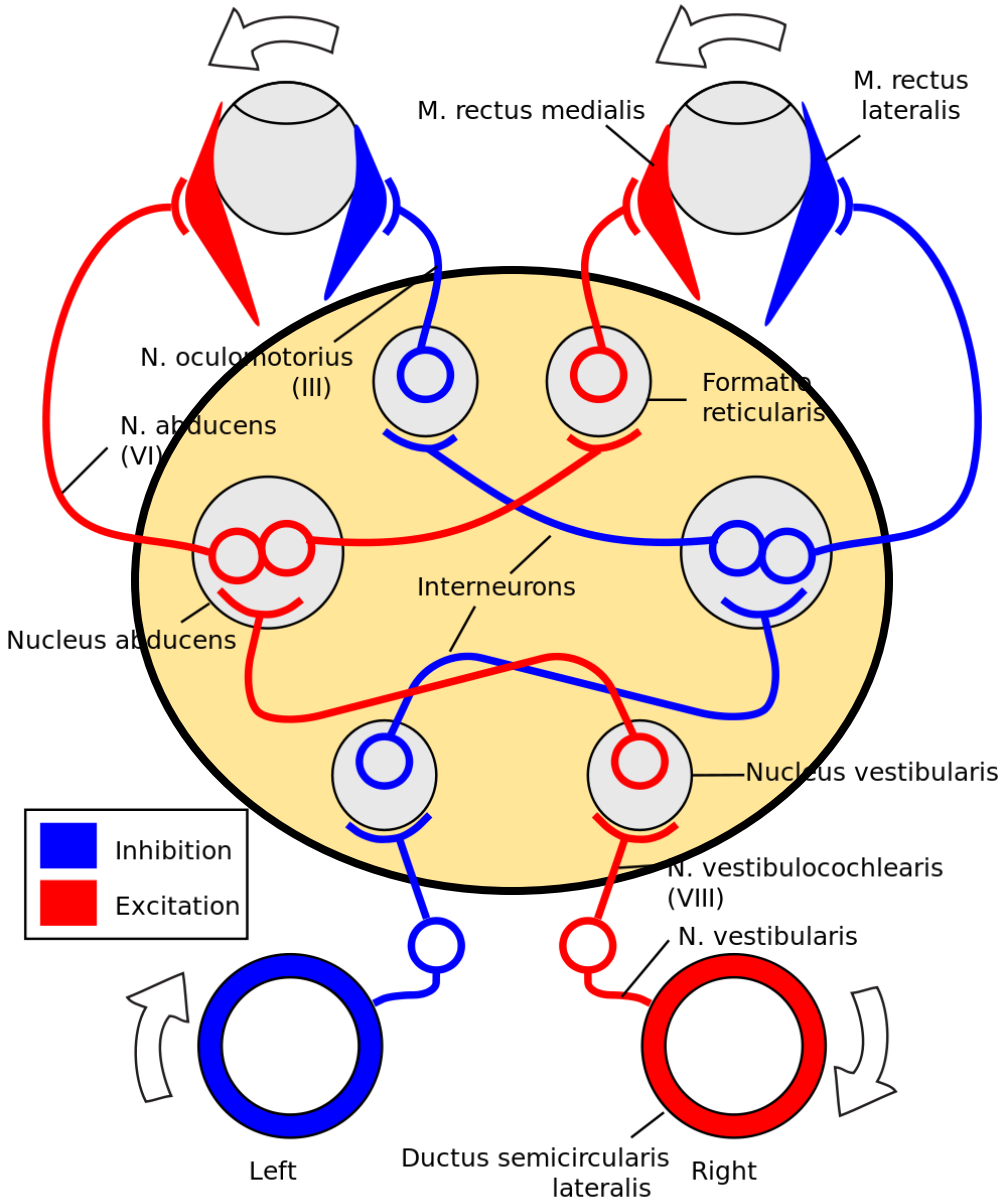
Vestibulo-Optical Reflex

- Used in “fixation”
  - Static object, moving head
- Head rotation detected by ears
- <10ms later, smooth eye rotation
- Not saccadic!
  - Very smooth
  - Excellent visual quality



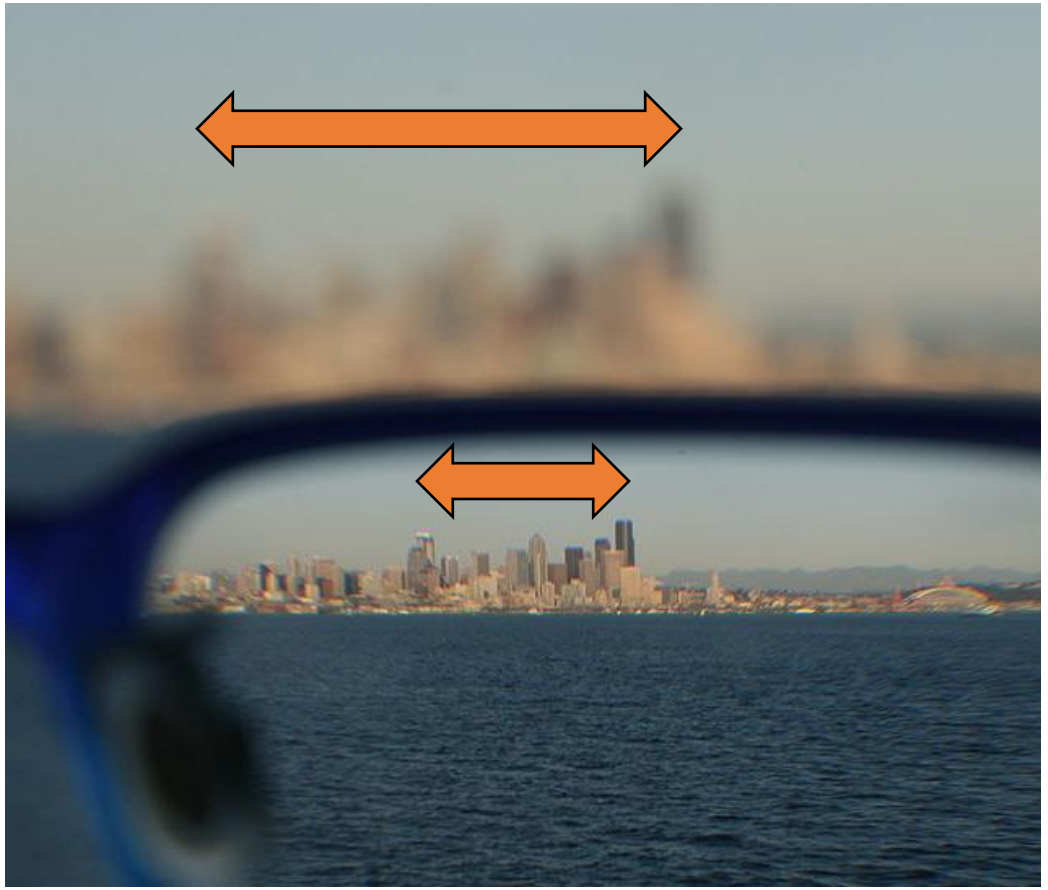
VOR gain

- VOR gain is the ratio between ear motion and eye response
- Usually gives 1:1 compensation
  - $+10^{o}$ head motion = -10^{o} eye motion
- Gain fine-tuned during fixation
  - Tries to produce zero “retinal flow”
- Tuning is extremely slow



VOR gain

- What if the view is compressed?
  - A new pair of glasses
  - Incorrect rendering scale in VR
- 10^{o} head motion now needs -5^{o} eye motion to maintain fixation



VOR gain

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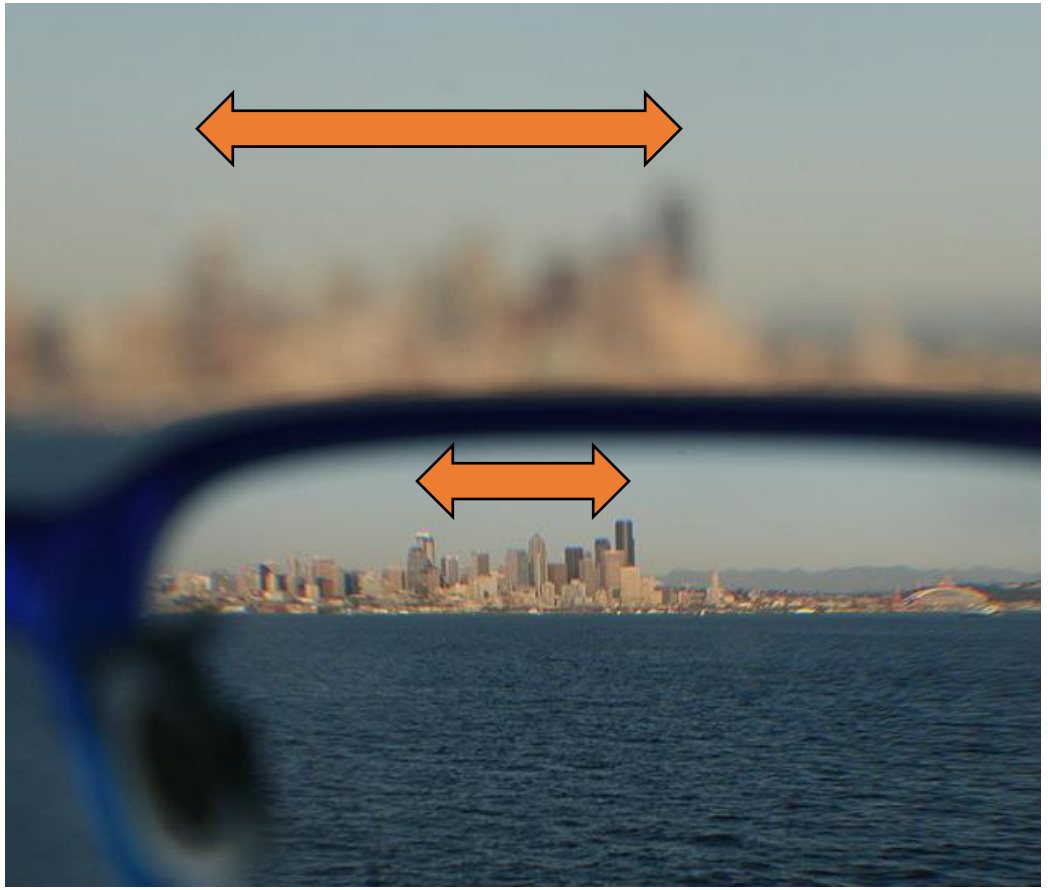
- 10^o head motion now needs -5^o eye motion to maintain fixation
- VOR gain now results in retinal flow
  - Causes disorientation
- Gain adaptation takes 1-2 WEEKS

  (assuming continuous use!)



Preserving VOR gain

- Games on a monitor often have a “FOV” slider
- Acceptable on a monitor – does not directly affect VOR gain
  - Monitor does not move with the head – no “virtual fixation” happening
  - Peripheral vision of room provides real-world optical flow reality check
  - …but even then it does cause problems for some

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  - …but even then it does cause problems for some
- In the Rift, the only things to fixate on are in VR
  - Retinal flow of VR objects must match real-world motion
- FOV scale in VR is not an arbitrary choice!
  - It must match the HMD+user characteristics
  - “Doctor it hurts my players’ brains when I do this…”

Preserving VOR gain

- The Rift display has a physical pitch, aka “pixels per visible degree”
  - Exact value depends on distortion, user’s head & eye position, etc.
  - Found with user configuration tool
- SDK will help you match this pitch precisely
  - For a given device & user size, it will give you the right FOV & scale
- Avoid any changing FOV or “zoom” effects
  - 10 degrees of head rotation must produce 10 degrees of optical flow
  - Even slight changes in pixels per degree will cause problems for most users

IPD, eye-relief, and the neck

IPD, eye-relief, and the neck

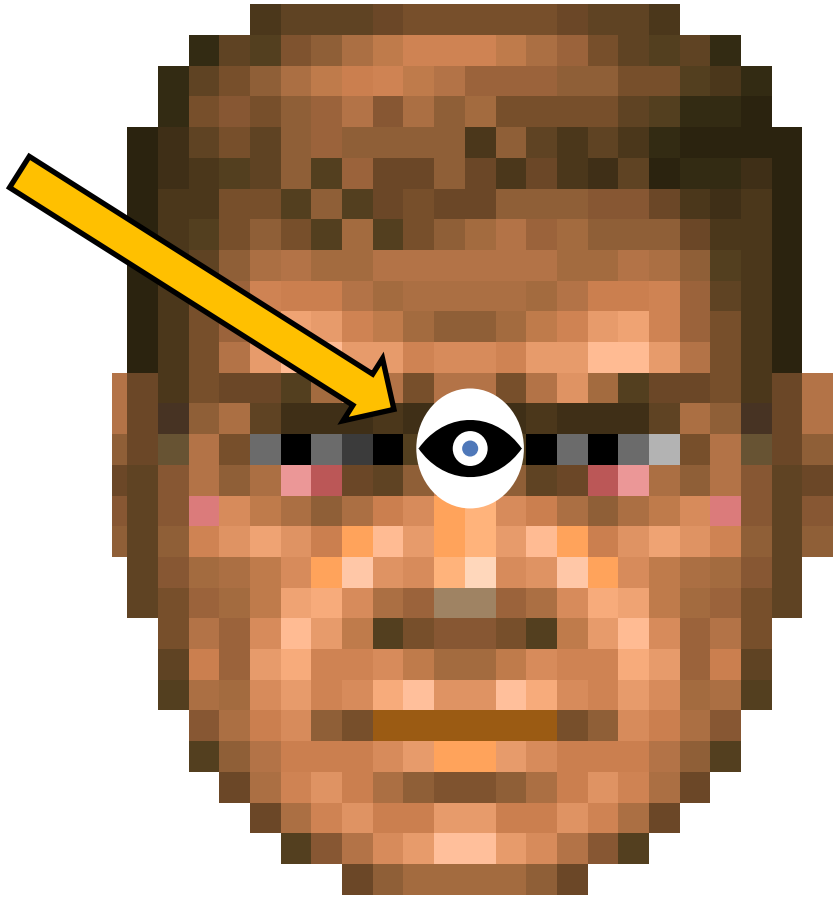
- IPD – Inter-Pupillary Distance
  - That’s all I need, right?

IPD, eye-relief, and the neck

- IPD – ~~Inter-Pupillary Distance~~
- Actually two components per eye
  - Nose-to-pupil – “half-IPD”
  - Eye-relief – distance from lens surface to pupil
  - NOT related to the dimensions of the HMD!
- Together form center-to-eye vector
  - Set during user configuration
  - Stored in user profile
- Rarely symmetrical
  - My eye reliefs differ by 2mm
  - This chap is 1 pixel different in nose-to-pupil

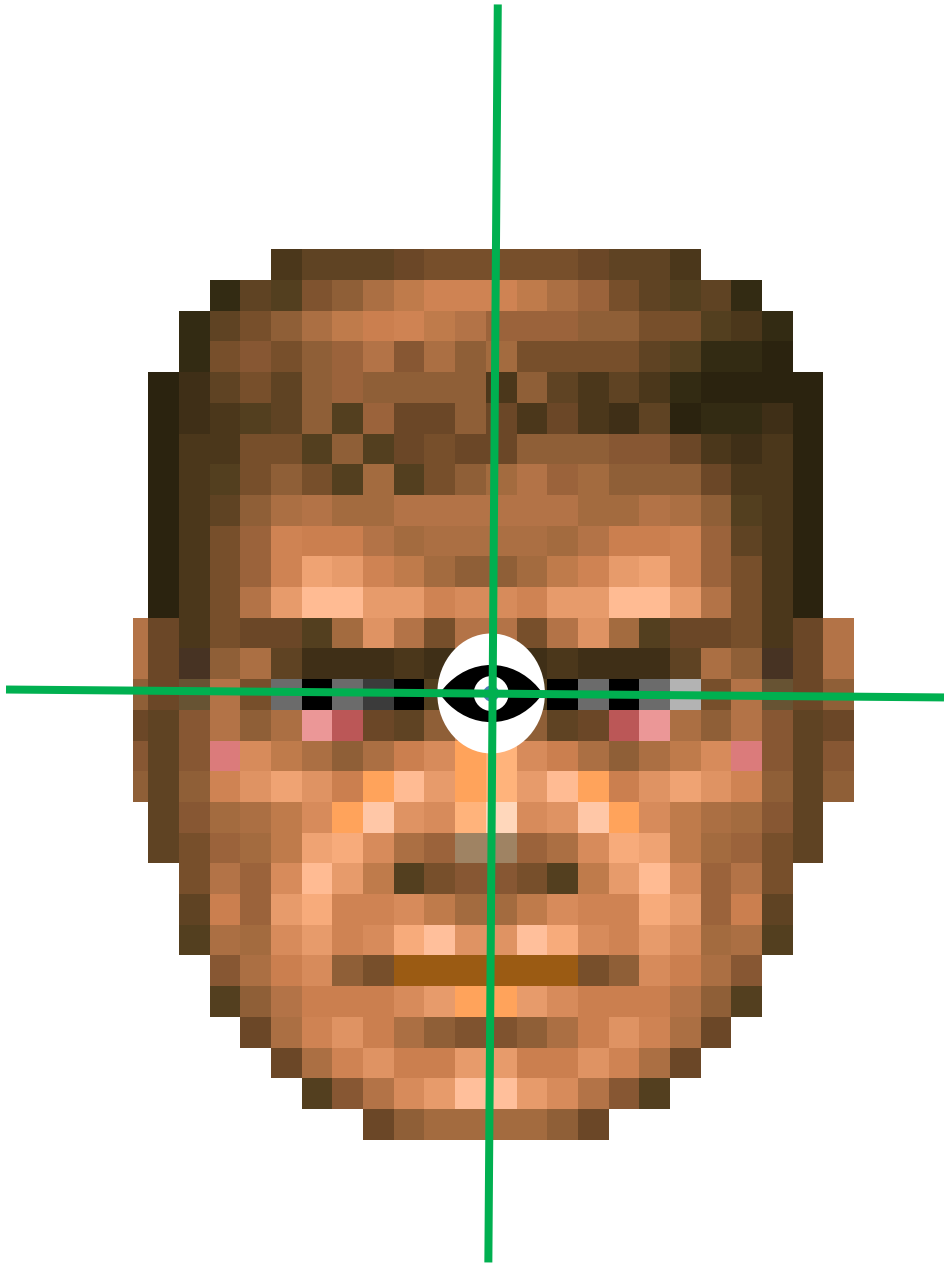
IPD, eye-relief, and the neck

- Center eye pupil - position reported by SDK
  - Centerline of the HMD
  - Average of left & right eye-reliefs
- Roughly where players “feel” they are
  - Audio listener position
  - Line-of-sight checks
  - Origin for reticle/crosshair raycast



IPD, eye-relief, and the neck

- Origin set by `sensor->Recenter()`
  - App should have a button to trigger this
  - Player sits in neutral forward pose to press it
  - Also defines “zero yaw”
  - Zero pitch & roll defined by gravity vector



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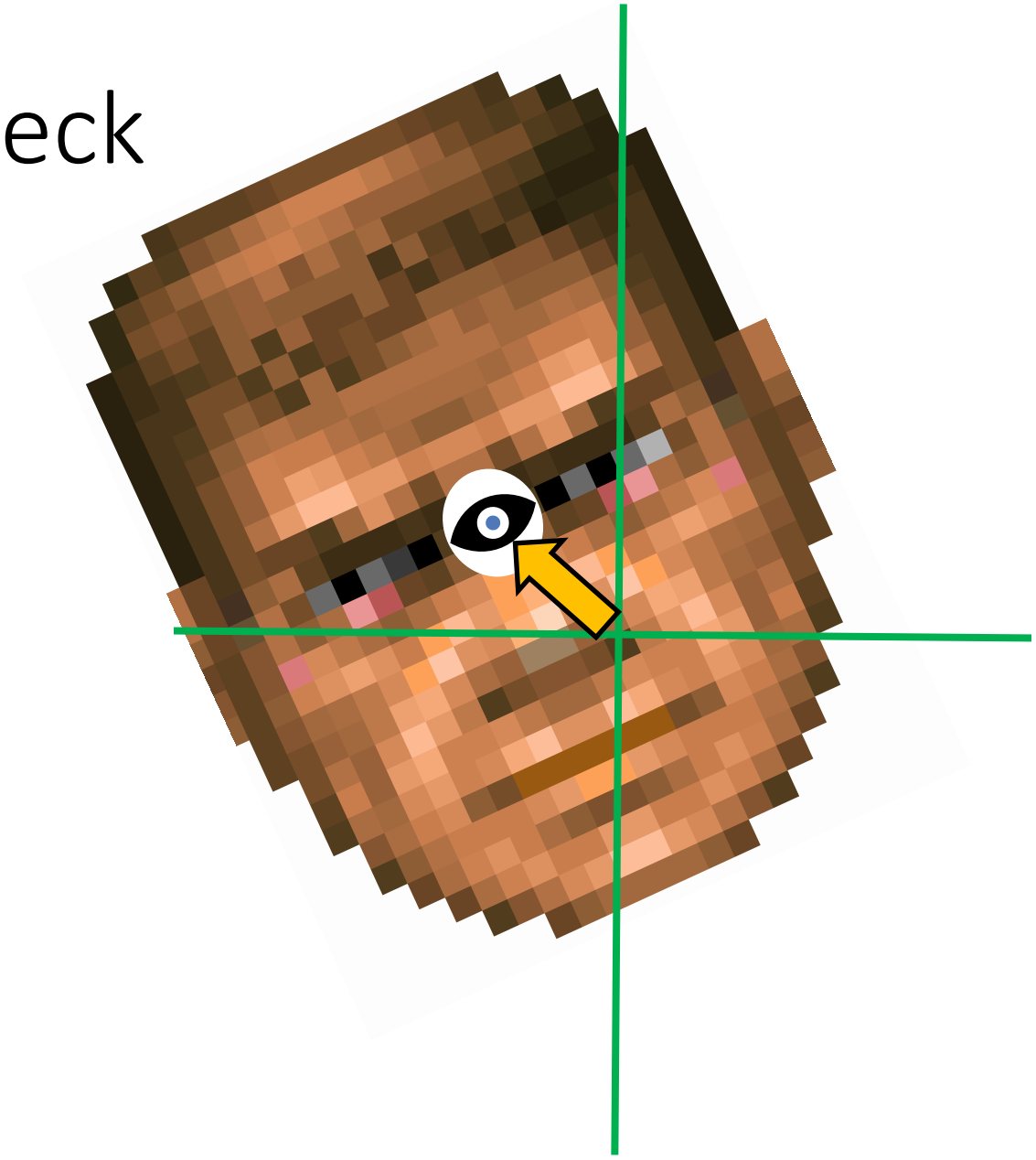

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- SDK reports pos & orn of center eye
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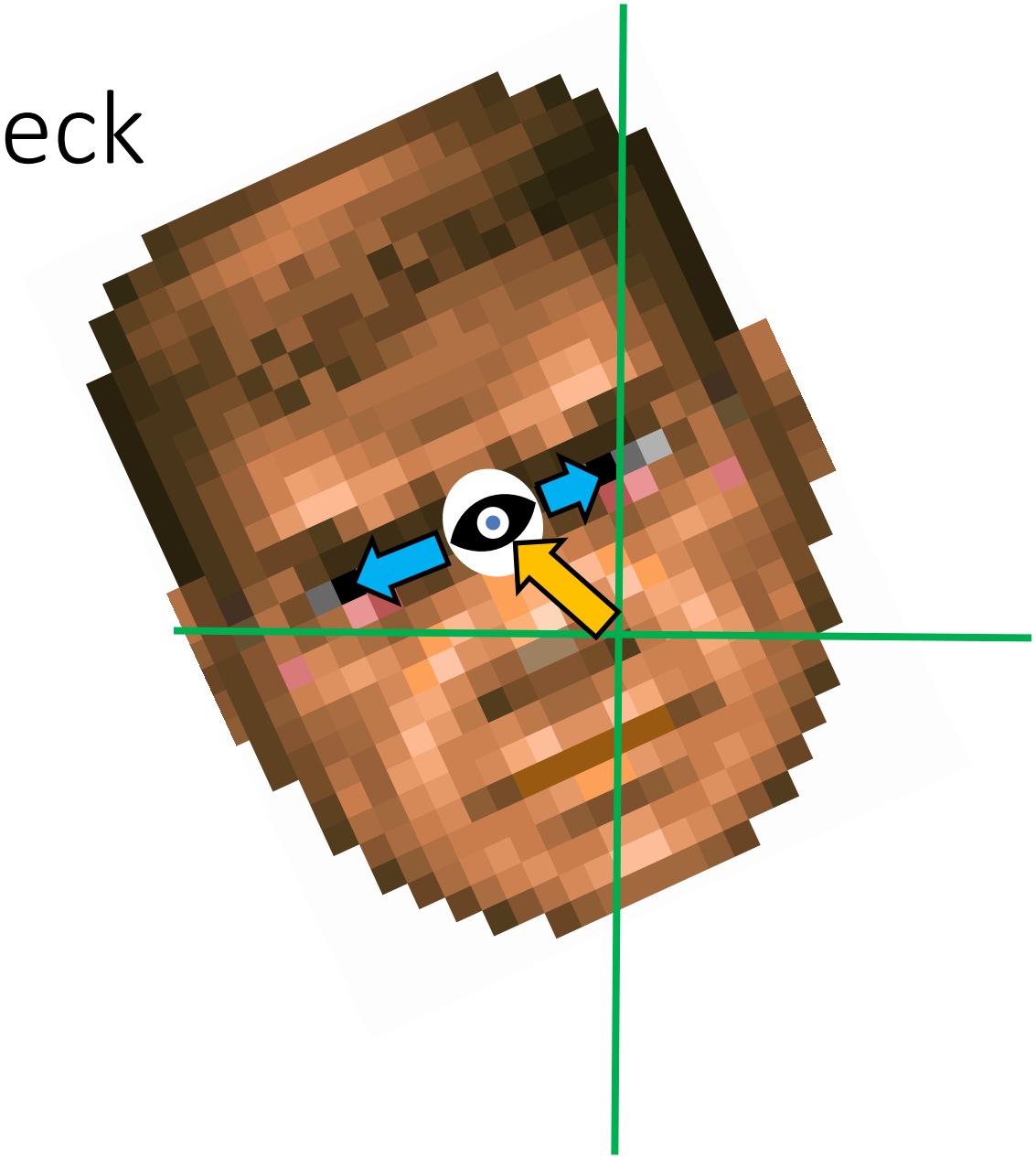

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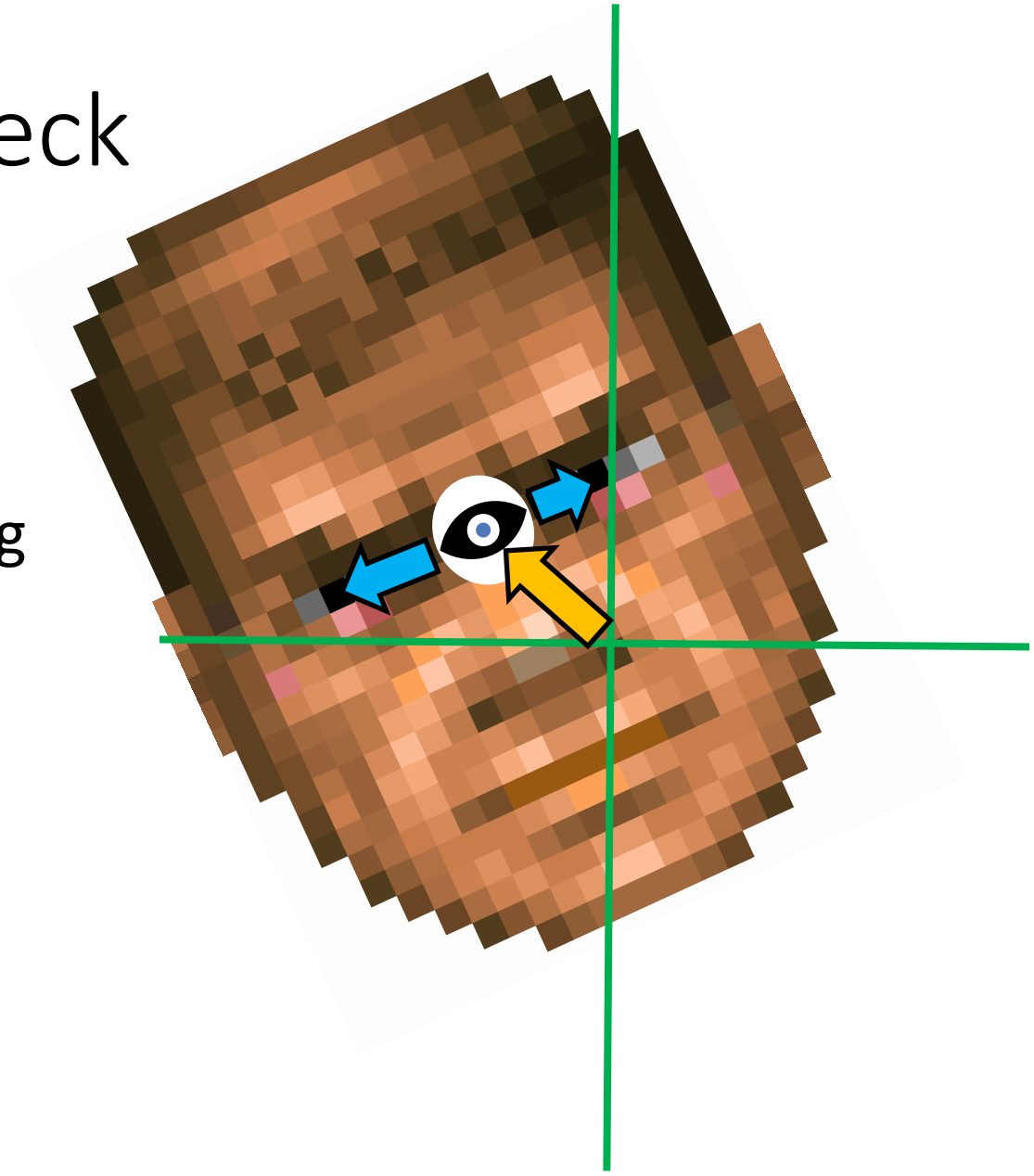

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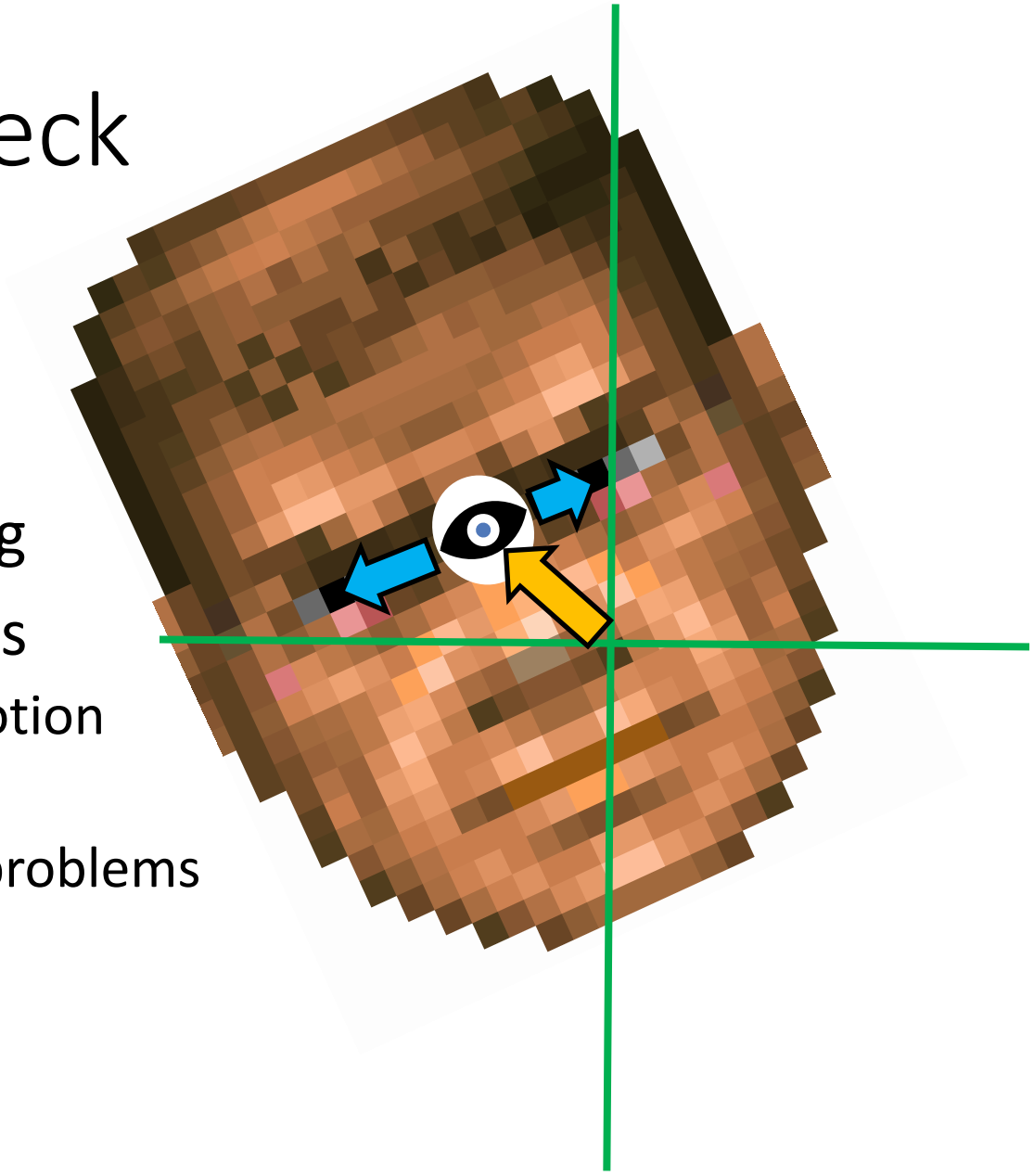
  - They are real player dimensions and motion
  - They are not your free artistic choice!
  - Changing them can very quickly cause problems



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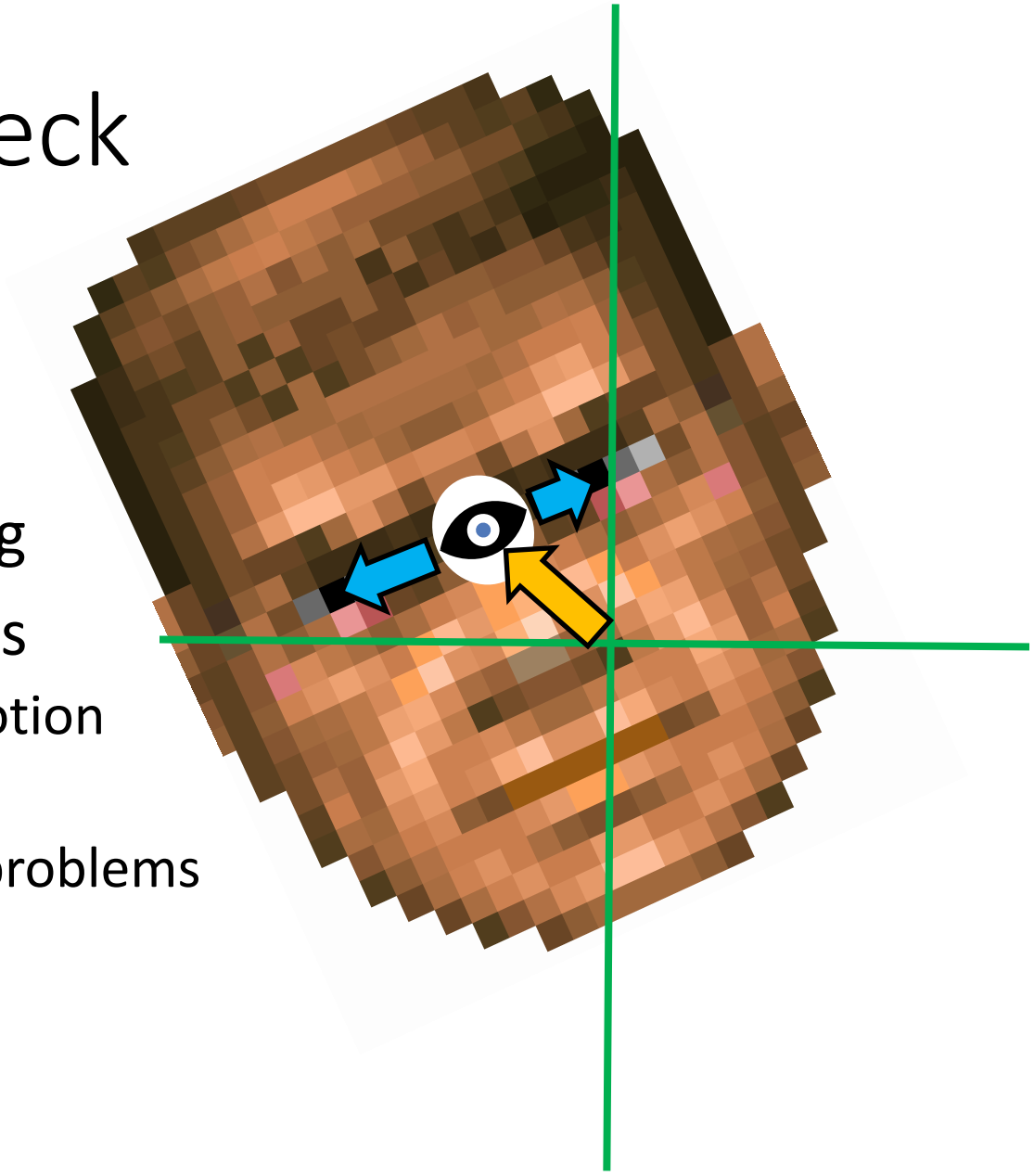
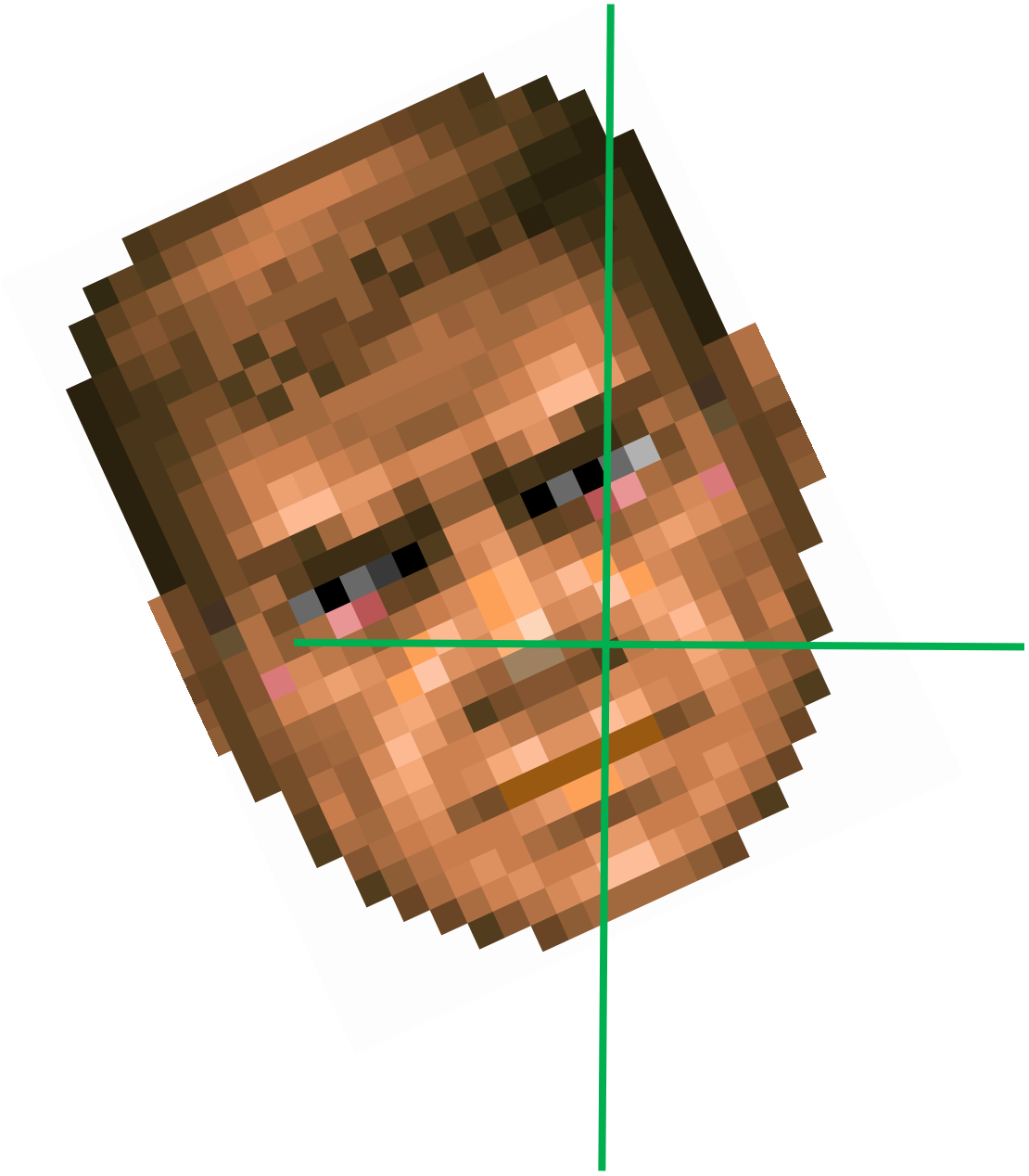
  - …but there is one thing you can do…

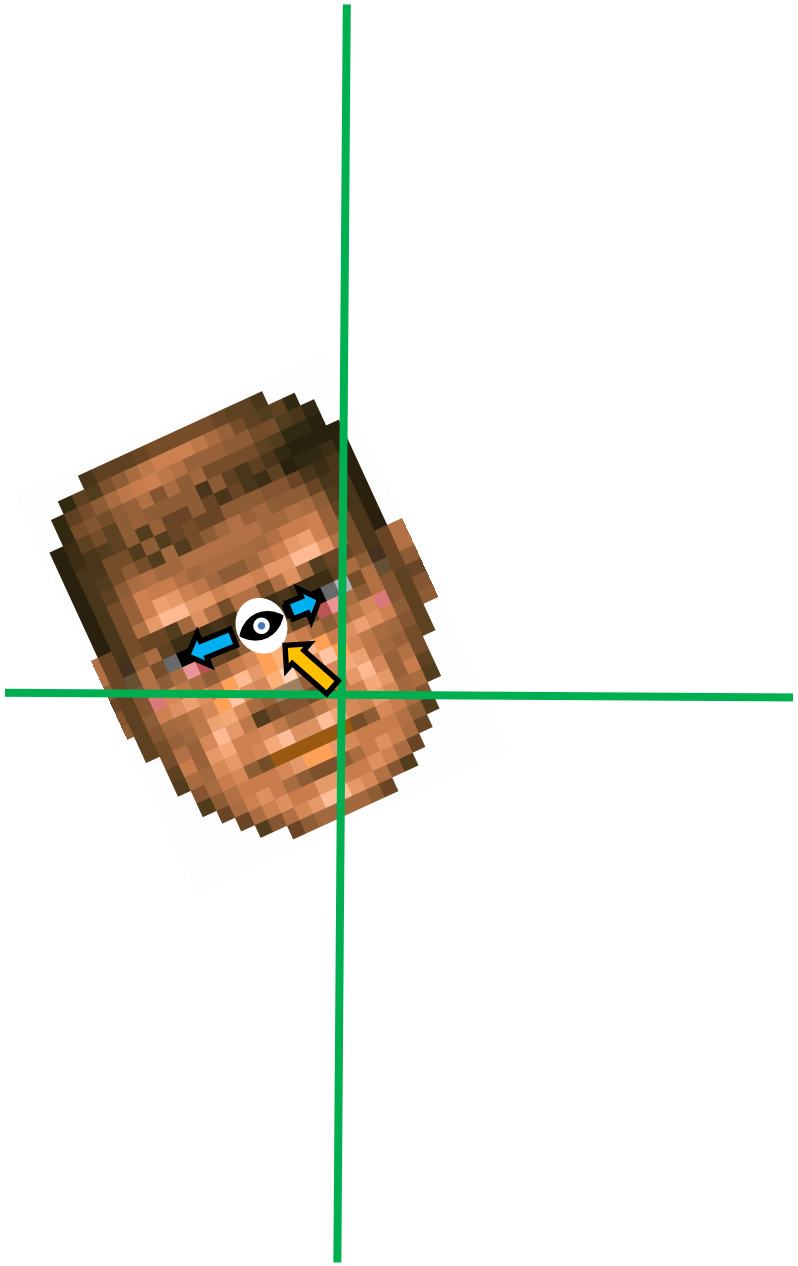


Changing World Scale



Changing World Scale

- You can apply a consistent scale to all three
  - Scale center-to-eye and head motion identically



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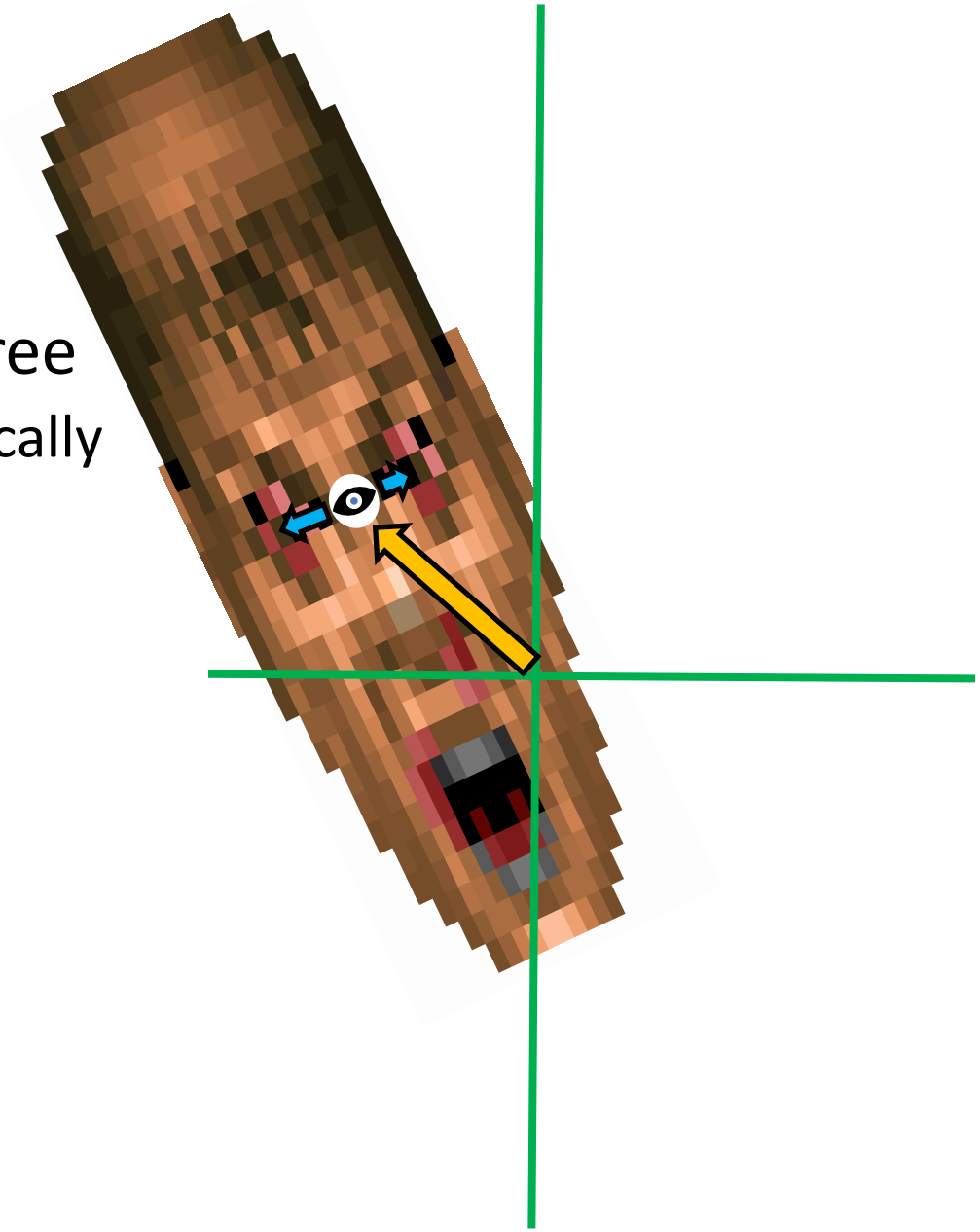

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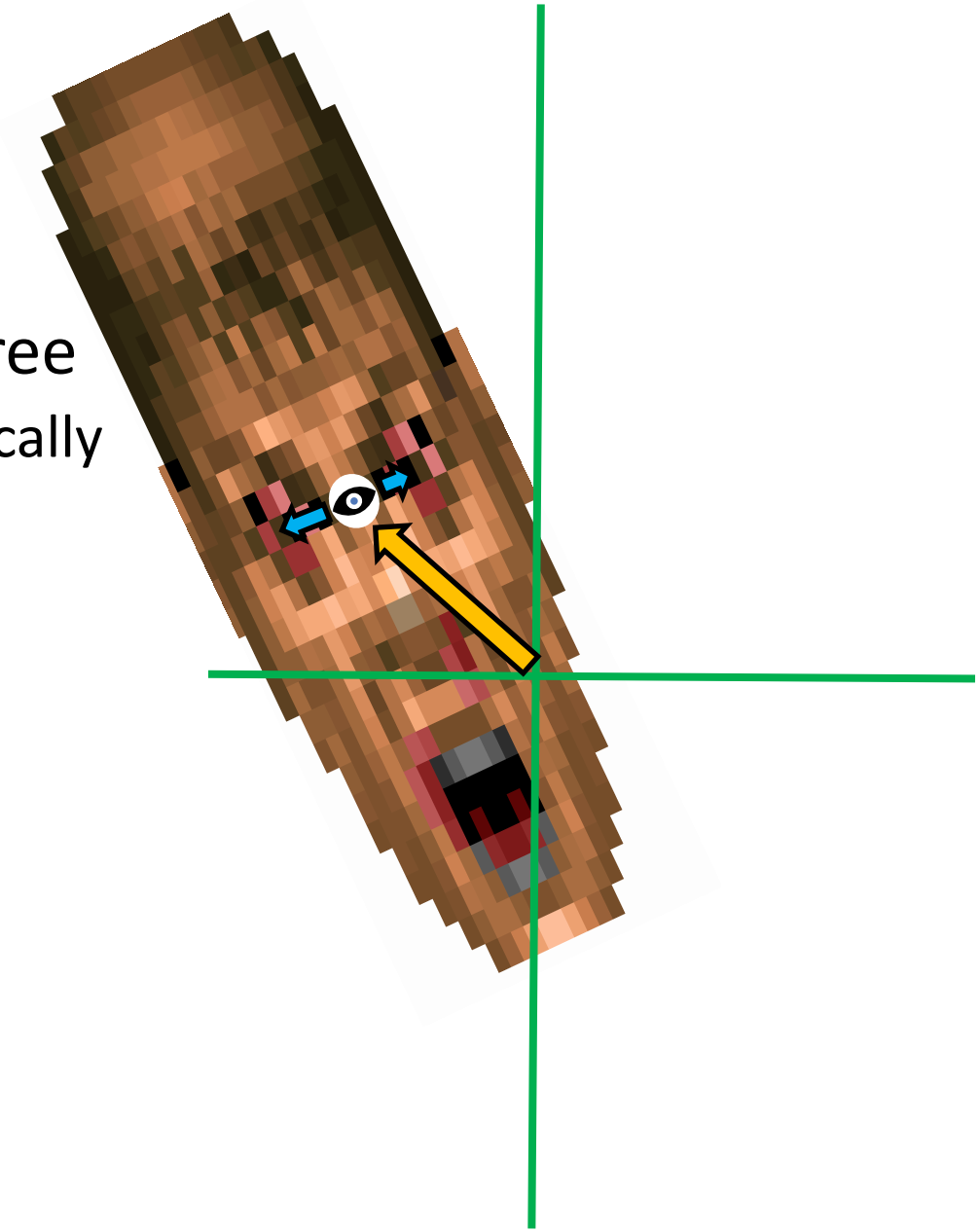
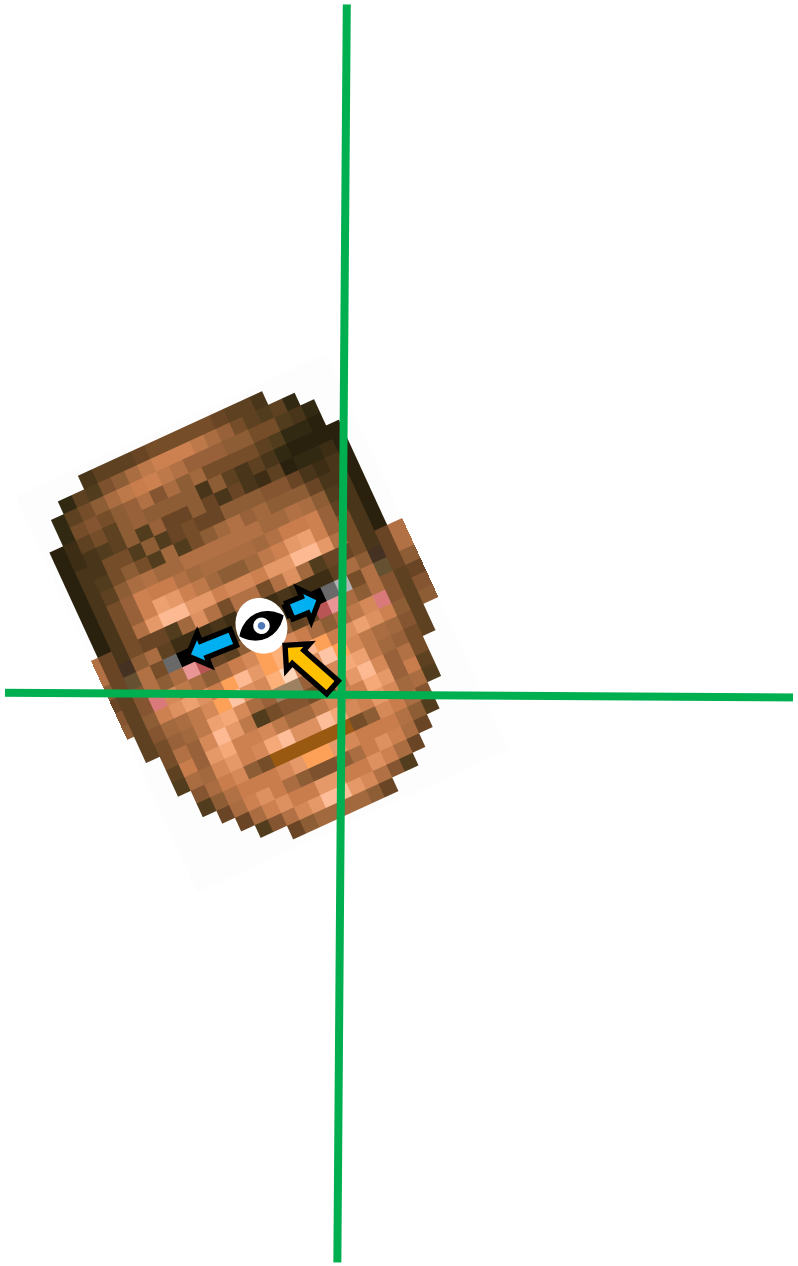
Identically

No VR giraffes!



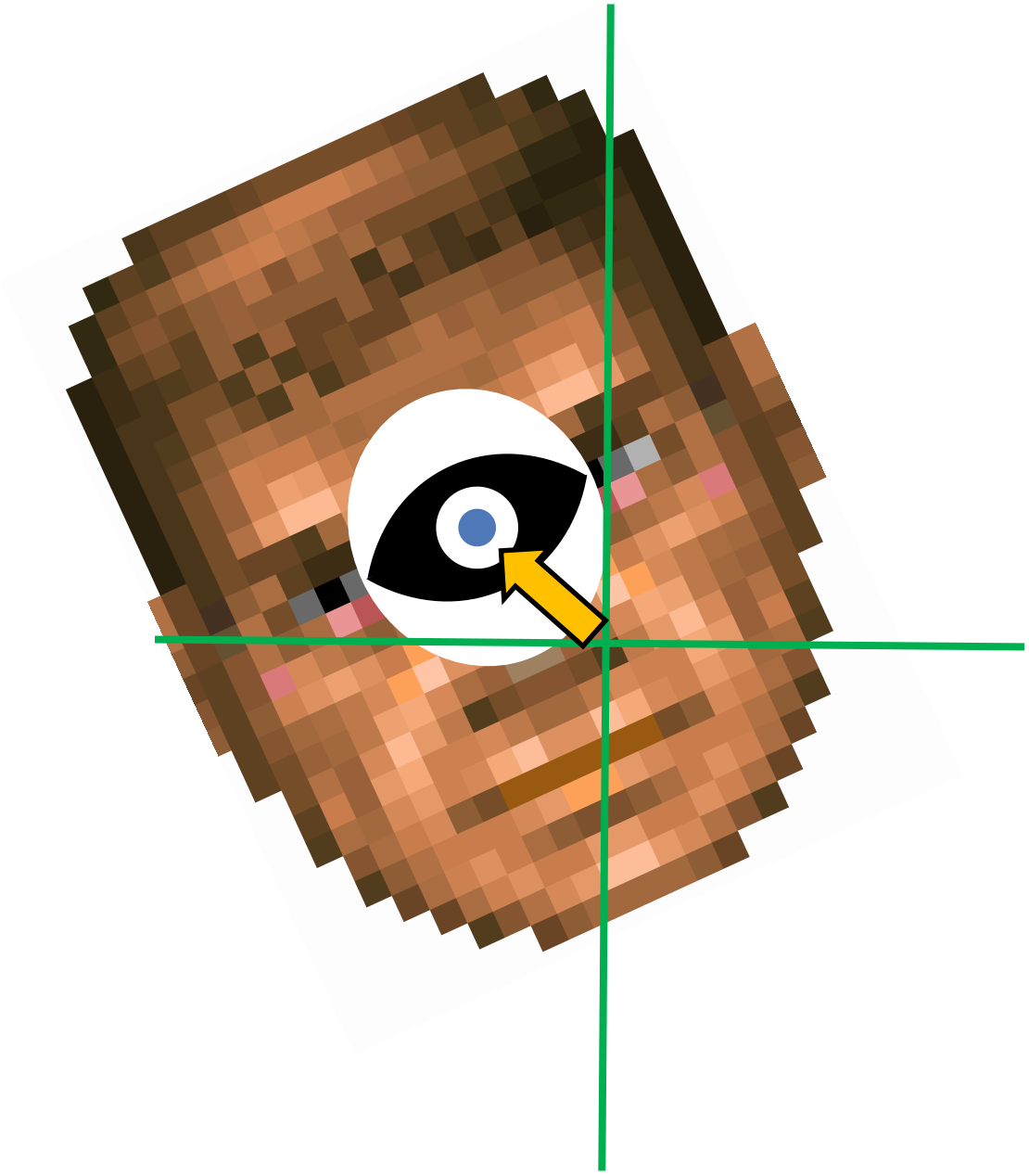
Changing World Scale

- You can apply a consistent scale to all three
  - Scale center-to-eye and head motion **identically**
- Same effect as scaling the entire world
  - Very compelling sense of being larger or smaller
- Reducing world scale can help reduce intensity for some people
  - Scales down all motions, accelerations, etc
  - Don’t shrink too small or convergence gets tricky



Changing World Scale

- Monocular mode – IPD of zero
  - An extreme case of scaling mismatch
- Studied in some older research
- Our testing results: it doesn't work
  - It's either neutral or bad
  - In some cases, it's awful



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- Monocular mode – IPD of zero
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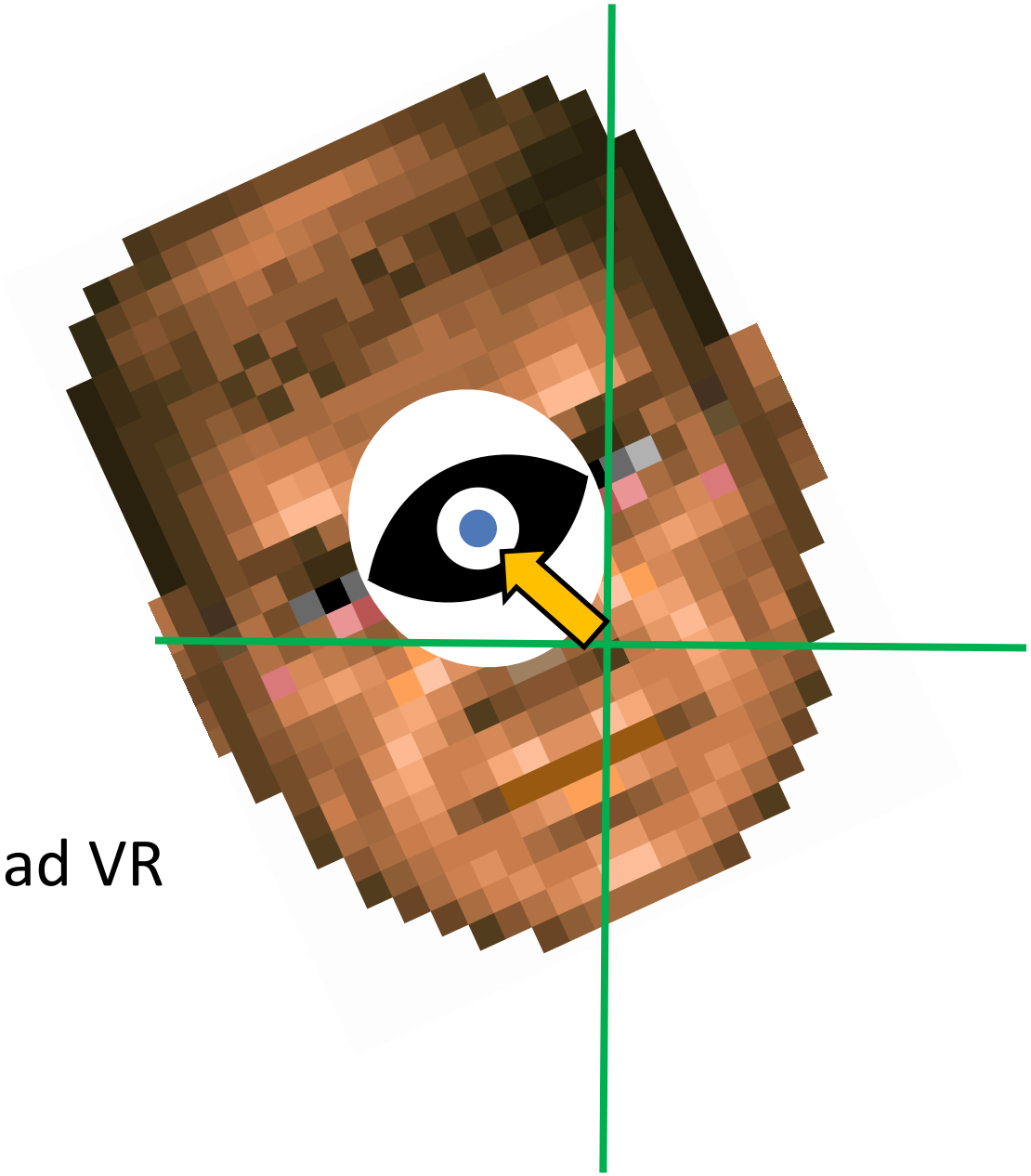
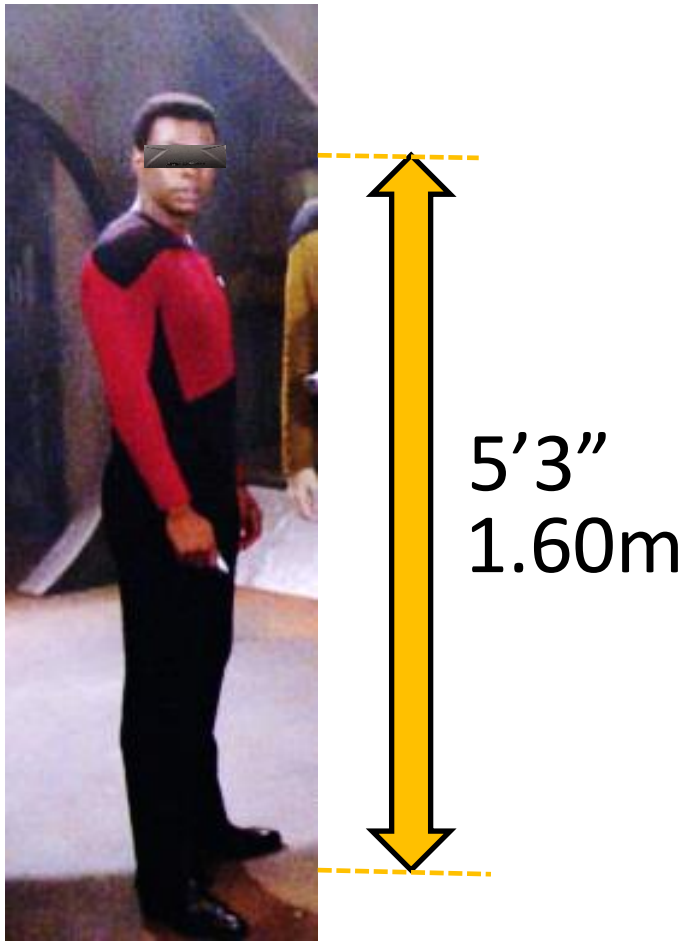
- Studied in some older research
- Our testing results: it doesn't work
  - It's either neutral or bad
  - In some cases, it's awful
- Many older studies were done with bad VR
  - Maybe it just makes bad VR less bad?
- We strongly urge you not to do this!



How tall is the player?

- Player profile has their actual height
  - SDK calculates eye-height-off-ground

Real world



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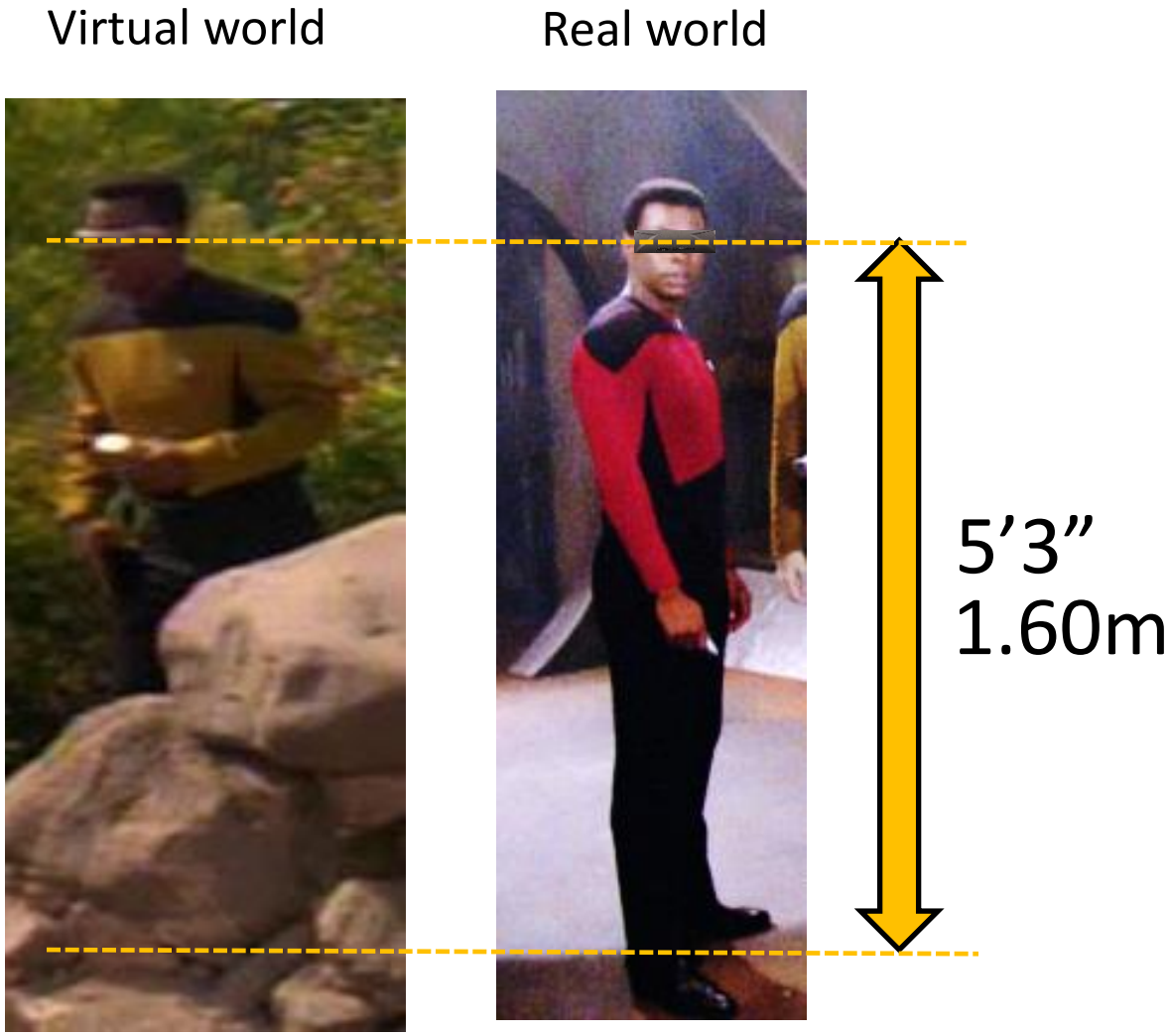
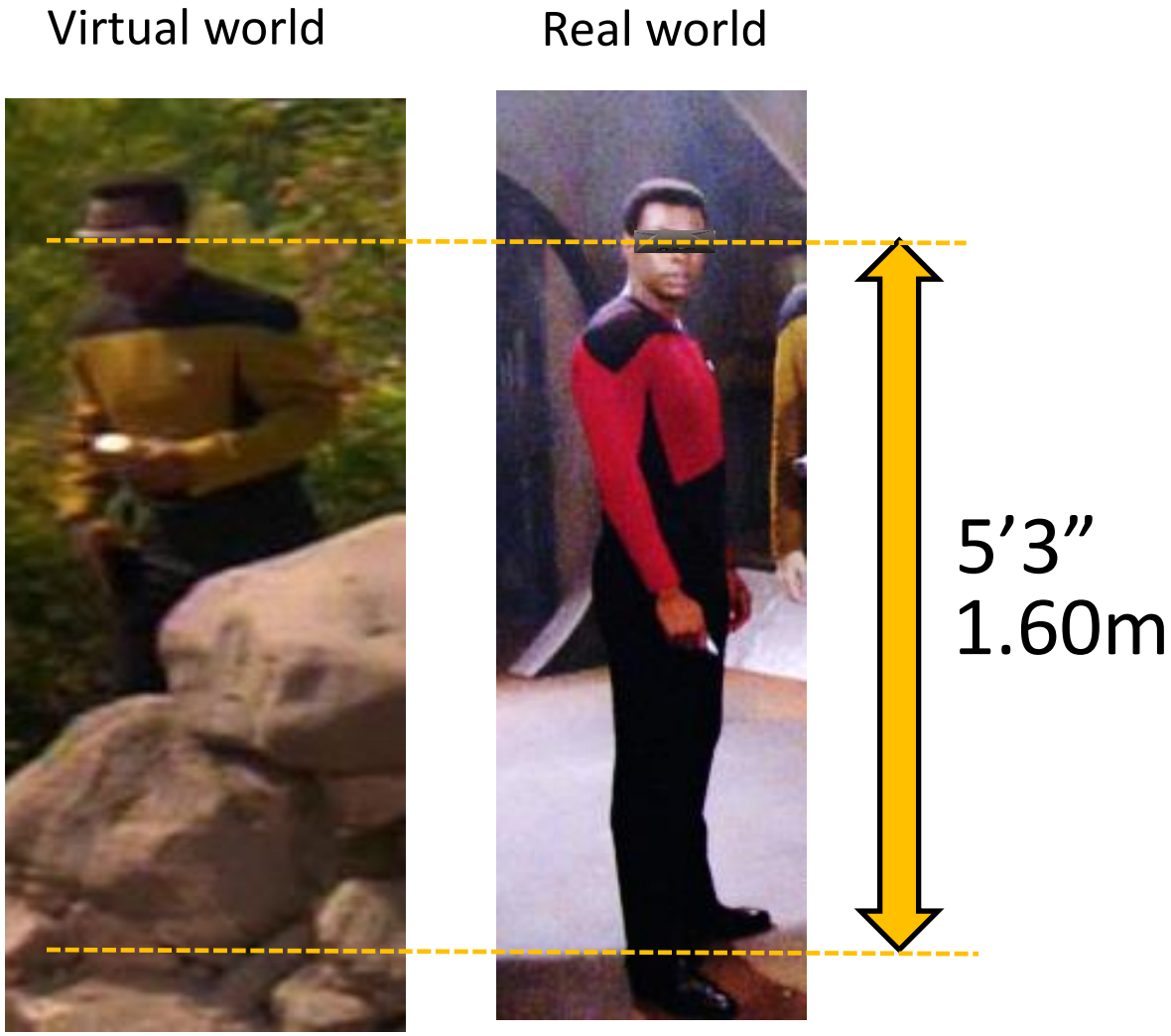
- If playing themselves, use that
  - Exploring an environment
  - Virtual tourism
  - Gives people a known metric & scale



How tall is the player?

- Player profile has their actual height
  - SDK calculates eye-height-off-ground
- If playing themselves, use that
  - Exploring an environment
  - Virtual tourism
  - Gives people a known metric & scale
- But if playing another character?
  - e.g. Cmdr Riker is much taller



How tall is the player?

Real world

5’3”
1.60m

How tall is the player?

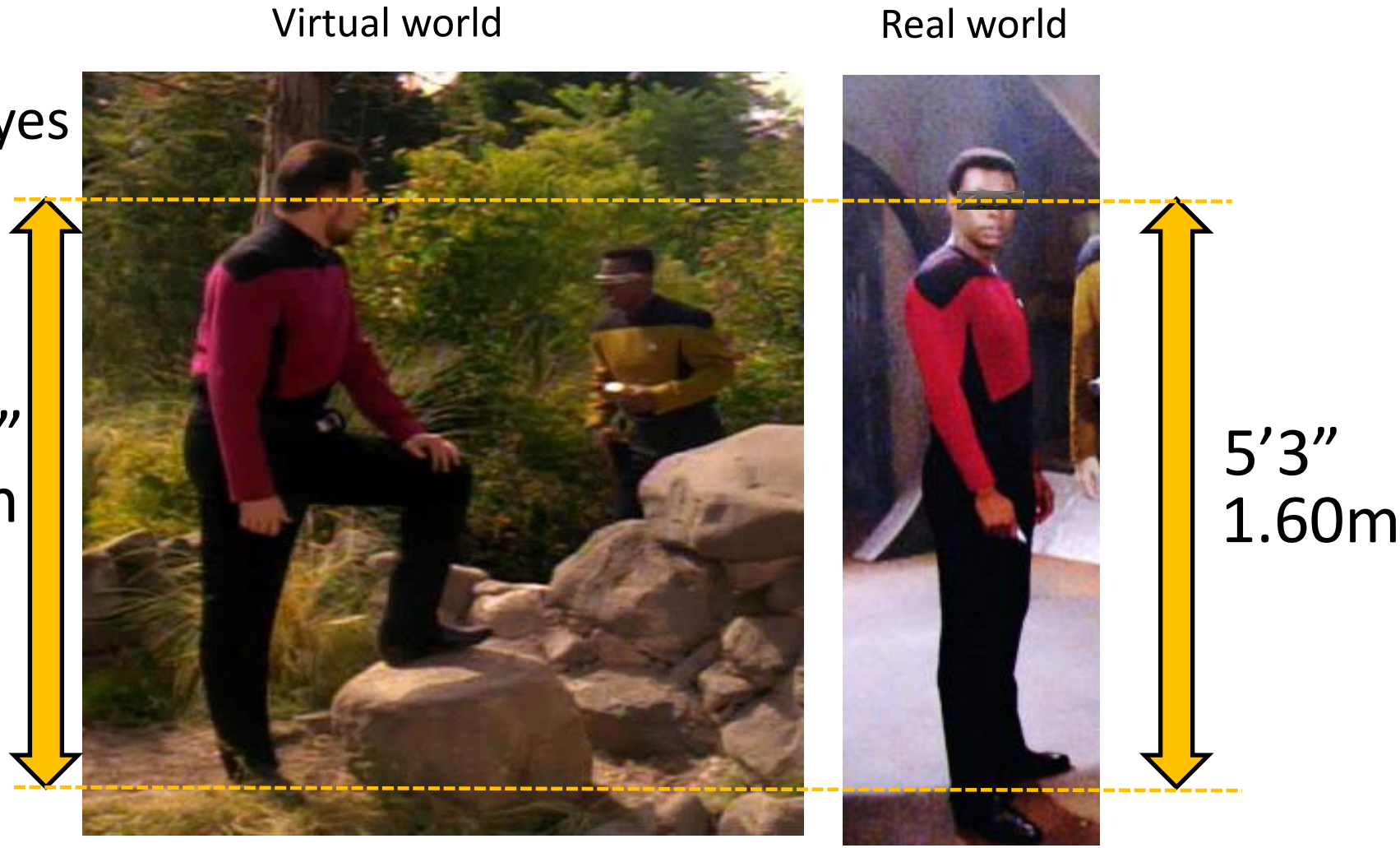
8’6”
2.60m

Real world

5’3”
1.60m

How tall is the player?

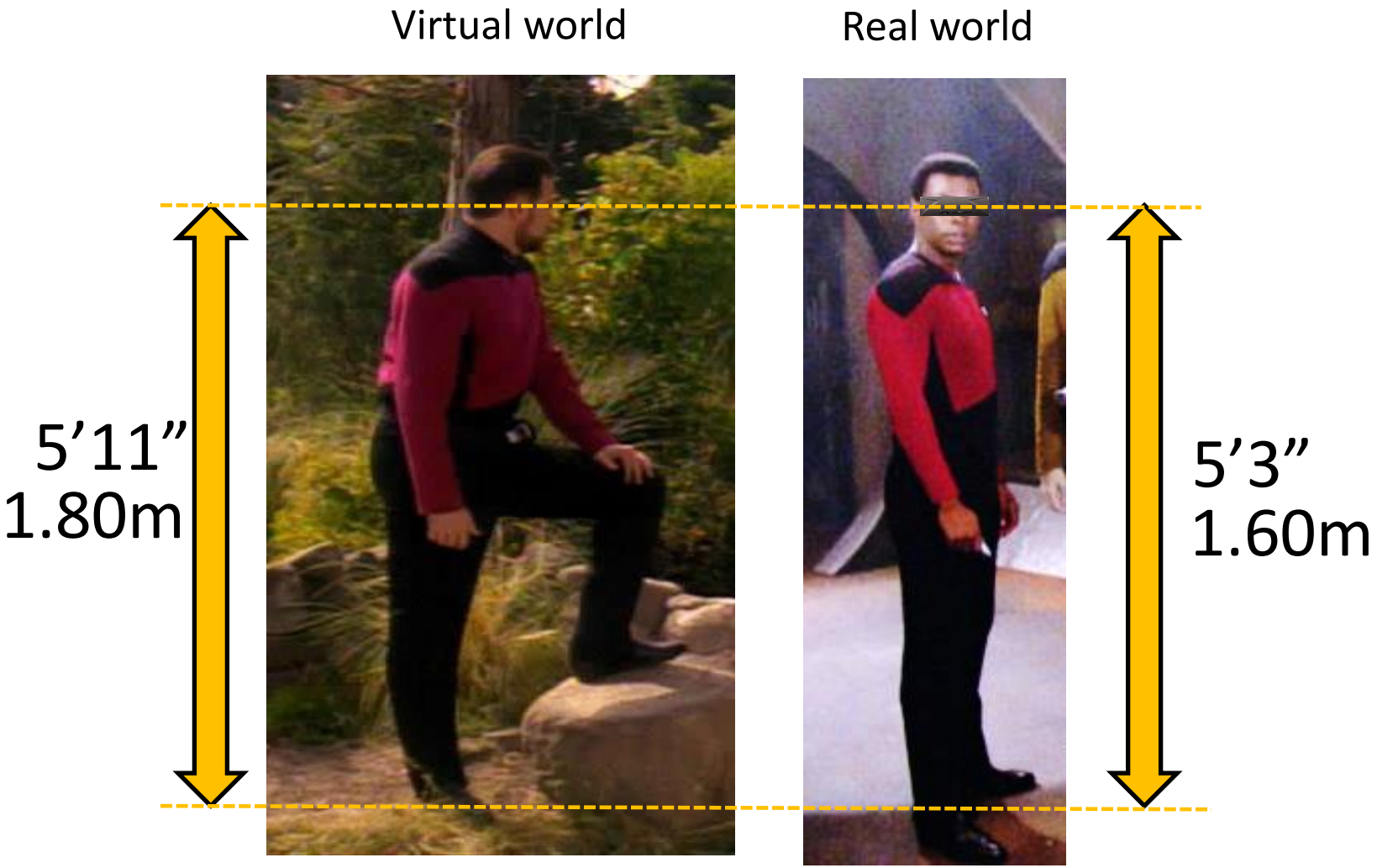
- Move the player's eyes to match the height of the character



How tall is the player?

- Changing eye height seems to be an aesthetic decision
  - No need to change world scale as well
  - Does not seem to cause disorientation (unlike other physical values)
- Player playing themselves – use their real height
  - Gives people a known metric to measure objects against
- Player playing a specific character – use height of character
  - Often necessary for gameplay reasons – sight lines, framing, etc

Perceived World Size – Floor-Dragging



Perceived World Size – Floor-Dragging

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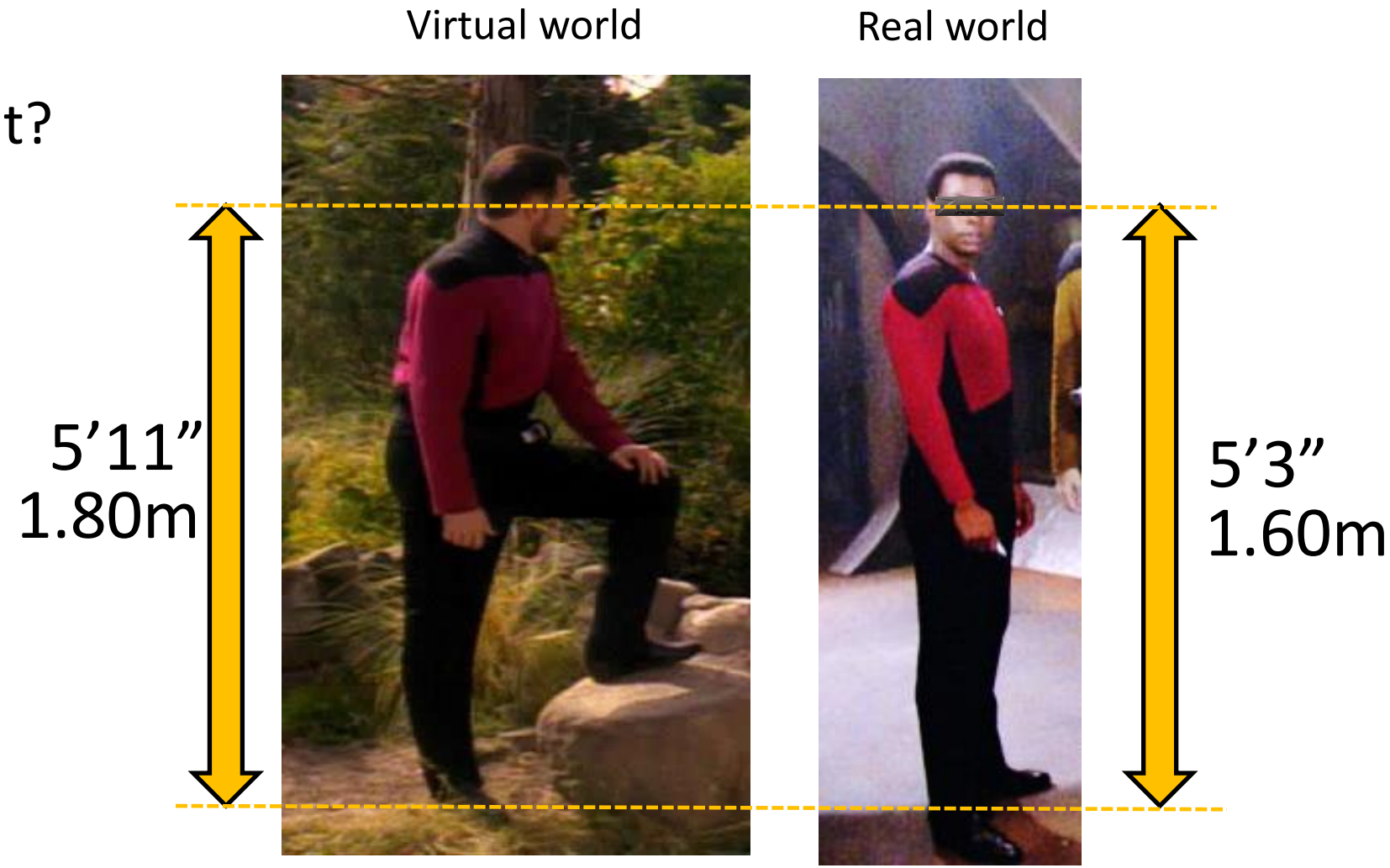

Perceived World Size – Floor-Dragging

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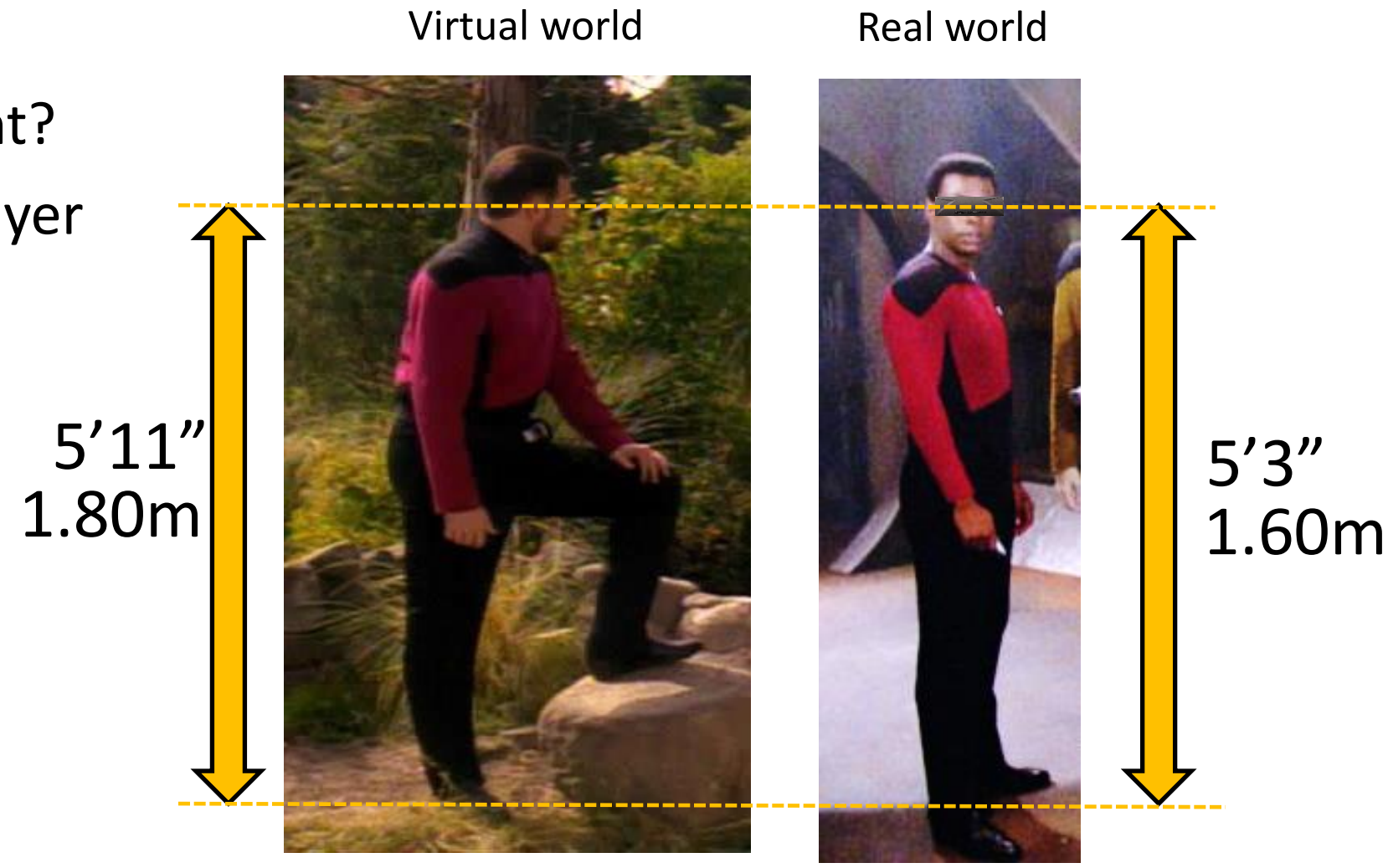
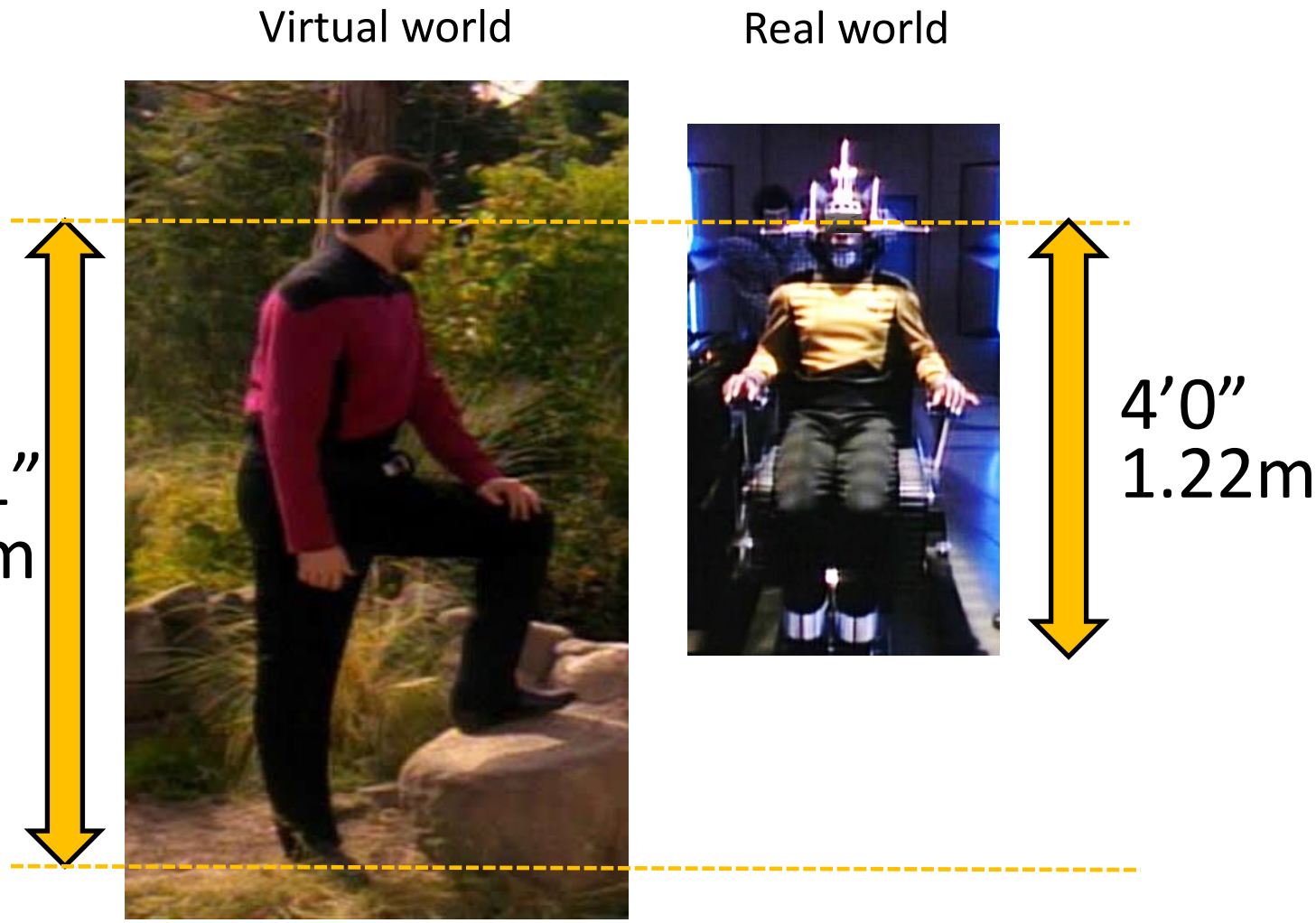
- But the real-world player isn't standing up



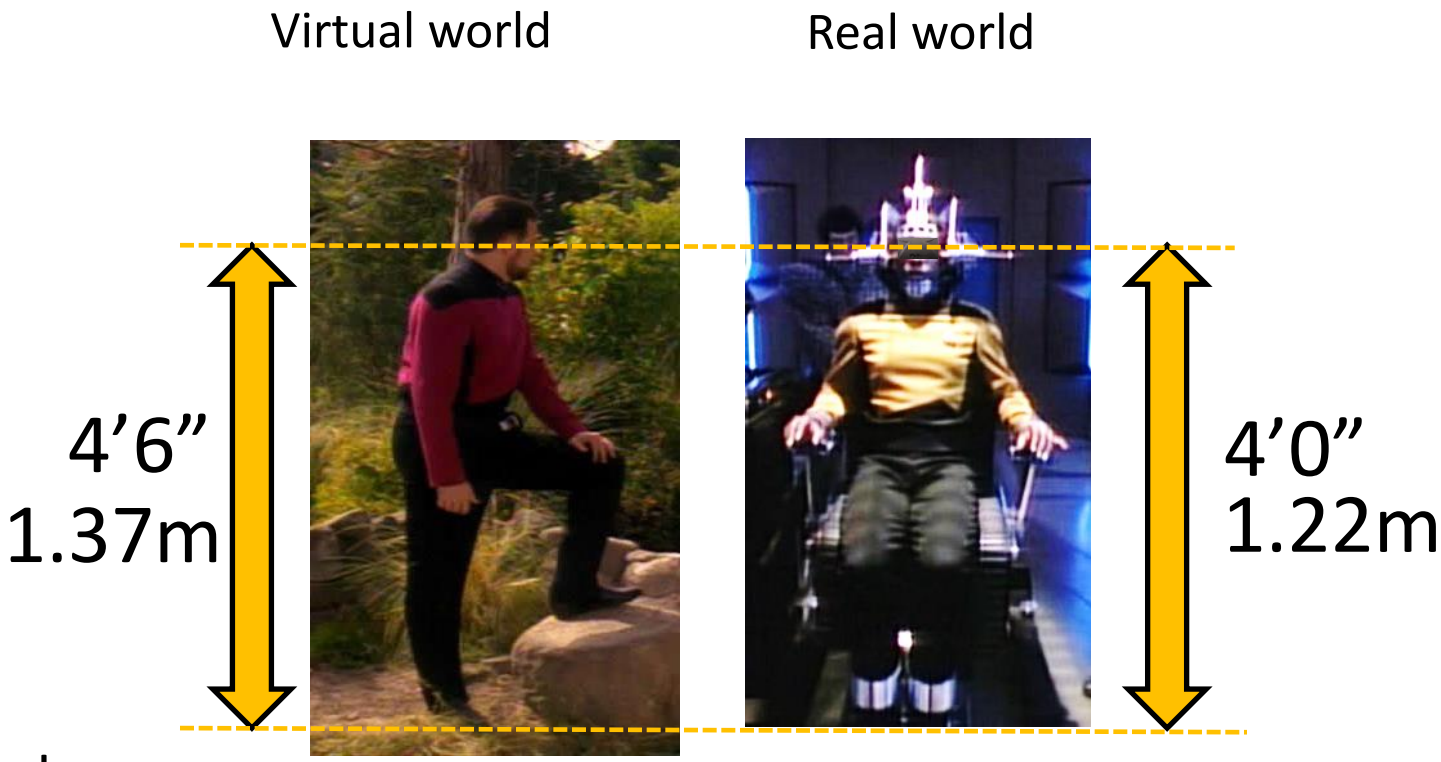
Perceived World Size – Floor-Dragging

- This should work, right?
- But the real-world player isn't standing up
  - They're seated
  - With feet on the floor
- So the brain can FEEL where the floor is



Perceived World Size – Floor-Dragging

- This seems fine, right?
- But the real-world player isn't standing up
  - They're seated
  - With feet on the floor
- So the brain can FEEL where the floor is
  - Scales the visible world to match
- Now the world is smaller
  - Riker is now shorter than Troi!



Perceived World Size – Floor-Dragging

- Real-world player is sitting down, with feet on the floor
  - The brain knows where the floor is, it can feel it!
- The brain scales the visible virtual world using the floor as reference
  - With a standing avatar, will cause the world to shrink
- Scaling appears to be higher-level cognitive effect
  - Conflicts with low-level stereoscopy and parallax cues
  - Effect comes and goes depending on focus

Perceived World Size – Floor-Dragging

- No one-size-fits all solution

Perceived World Size – Floor-Dragging

- No one-size-fits all solution
- Use seated avatars?
  - Works great for driving & flying sims
  - Papers Please VR Edition?

Perceived World Size – Floor-Dragging

- No one-size-fits all solution
- Use seated avatars?
- Scale the world larger to compensate?
  - Limited success, you now have even **more** conflict between sensory inputs
  - Stereo effect magnified, may be too intense for some

Perceived World Size – Floor-Dragging

- No one-size-fits all solution
- Use seated avatars?
- Scale the world larger to compensate?
- Give in and scale the world smaller to match?
  - Now everyone is an Oompa Loompa
  - But at least the visual cues don’t conflict with the physical ones
  - More relaxing, more immersive

Perceived World Size – Floor-Dragging

- No one-size-fits all solution
- Use seated avatars?
- Scale the world larger to compensate?
- Give in and scale the world smaller to match?
- Make players sit on bar stools?
  - Or any other way of getting feet off the floor
  - Heel rests, “ankle stirrups”, sit cross-legged

Perceived World Size – Floor-Dragging

- No one-size-fits all solution
- Use seated avatars?
- Scale the world larger to compensate?
- Give in and scale the world smaller to match?
- Make players sit on bar stools?
- More research needed
  - …and this is where we'd love feedback from devs

Transition animations

- In general, never take control of the camera
  - Always keep head-tracking on & faithful
  - Causes significant problems for many users
  - If you must do it, do it FAST – teleport rather than fly

Transition animations

- In general, never take control of the camera
- But sometimes, transitions need to happen for story/world
  - Getting into/out of vehicles
  - Getting into/out of bed
  - Standing up after knockdown
  - Picking an object off the floor

Transition animations

- In general, never take control of the camera
- But sometimes, transitions need to happen for story/world
- Most people find these too intense in VR
  - Especially orientation changes

Transition animations

- In general, never take control of the camera
- But sometimes, transitions need to happen for story/world
- Most people find these too intense in VR
- Option: show your avatar doing the action
  - Be careful of the 1st to 3rd person transition
  - Try a ghostly/transparent avatar

Transition animations

- In general, never take control of the camera
- But sometimes, transitions need to happen for story/world
- Most people find these too intense in VR
- Option: show your avatar doing the action
- Option: use a dissolve or fade-through-black
  - Needs to be live rendering, not a screenshot
  - Maintain head-tracking all the time - let the player look around

Transition animations

- In general, never take control of the camera
- But sometimes, transitions need to happen for story/world
- Most people find these too intense in VR
- Option: show your avatar doing the action
- Option: use a dissolve or fade-through-black
- Option: use a “blink”
  - Fuzzy-edged black borders top & bottom
  - Close, teleport, open
  - If ~300ms, some players don’t even “see” them!

Animated avatars

- Highly animated 1st-person avatars are awesome
  - Amazing sense of immersion and presence
  - TF2 examples:
    - High fives
    - Yelling “medic” – hand comes to face
    - Sniper’s bird – Sir Hootsalot / Steel Songbird

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- Constraints:
  - Virtual camera should always move with player’s real head
  - Virtual camera and avatar’s head should coincide for best immersion
  - …but those conflict!

Solution:

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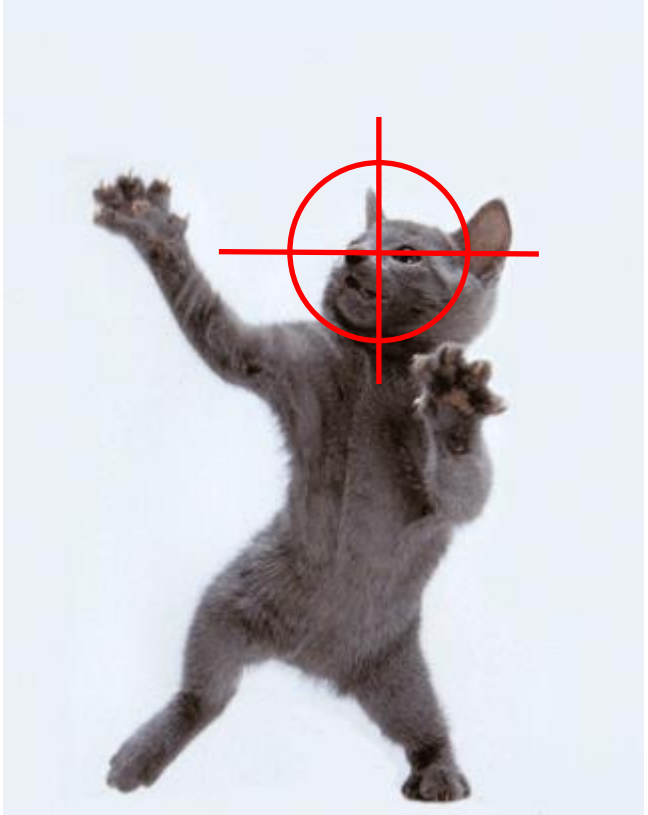
Meathook avatars

Meathook avatars

- Play animation on the avatar

Meathook avatars

- Play animation on the avatar
- Find avatar’s animated head position
  - May need to add a “center eye” bone to the skeleton

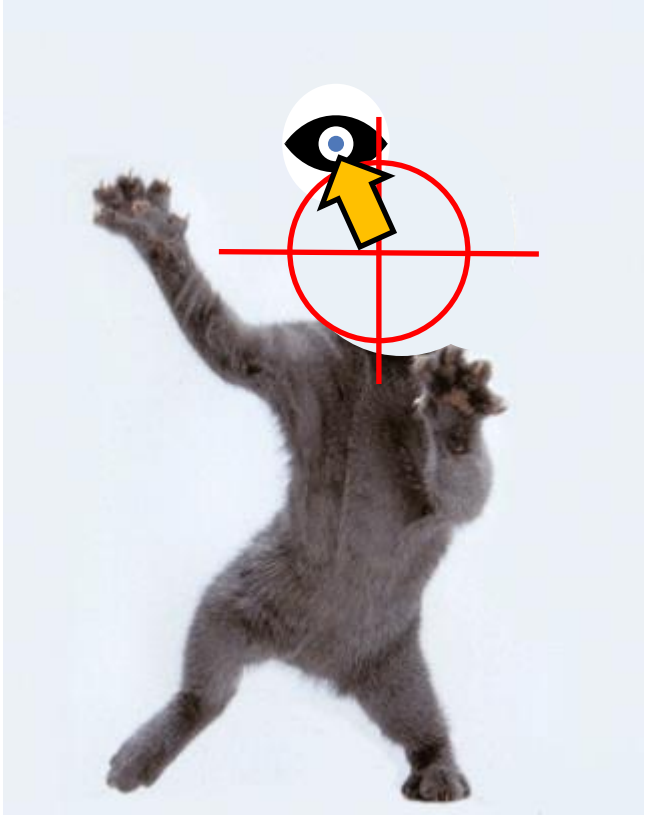


Meathook avatars

- Play animation on the avatar
- Find avatar’s animated head position
- Decapitate
  - e.g. shrink the head bone to zero size
  - Otherwise you see teeth & eyeballs from the inside

Meathook avatars

- Play animation on the avatar
- Find avatar’s animated head position
- Decapitate
- Find player’s virtual camera position
  - Standard head-tracking data from the SDK



Meathook avatars

- Play animation on the avatar
- Find avatar’s animated head position
- Decapitate
- Find player’s virtual camera position
- Hang the avatar on the hook
  - Fix head position to player’s position
  - Retain existing orientation

Meathook avatars

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- Find player’s virtual camera position
- Hang the avatar on the hook
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  - Retain existing orientation
  - Body thrashes around underneath with animations
  - Result in external debug camera is really quite gruesome
  - But it works great in VR!

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Maintaining framerate

- Presence is a fairly binary thing – you have it or you don’t
- Rock-solid, high FPS vital to sense of presence in VR
- Stereo display at 75FPS is challenging
  - Aggressively drop details and effects to maintain framerate and low latency
  - Maintaining presence gives far more player enjoyment than extra effects
- Main costs are draw calls and fillrate

Maintaining framerate – draw calls

- Twice as many eyes, so twice as many calls
- New APIs should make multi-submission cheaper
  - Mantle, DX12, etc
- Some things only need doing once
  - Culling – use a conservative frustum that includes both eyes
  - Animation
  - Shadow buffer rendering
  - Some distant reflections/gloss maps/AO renders – but not all!
  - Some deferred lighting techniques

Maintaining framerate – fill rate

- Change size of the virtual camera renders, NOT the framebuffer size
  - e.g. with DK2, framebuffer is always 1080x1920 – don’t change this!
- But camera-eye renders typically 1150x1450 per eye
  - Depends on shape of user’s face & eye position – set by profile & SDK

Maintaining framerate – fill rate

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- But camera-eye renders typically 1150x1450 per eye
  - Depends on shape of user's face & eye position – set by profile & SDK
- Scaling this render is absolutely fine
  - Distortion correction pass will resample & filter it anyway
- Scaling it dynamically every frame is also fine – nearly invisible
  - If you have lots of particles/explosions that frame, drop the size
  - Use the same RT, just use a smaller part of it
  - SDK explicitly supports this use case

Lessons learned

- Be kind to your players
  - Default to low intensity, let the brave ones pick MUCH WOW mode
- VOR gain
  - FOV scale is not an arbitrary knob to play with – follow the player's profile
- IPD and head motion
  - Keep them in sync – follow the player's profile
- Changing world scale & how tall is the player?
  - Aesthetic choices, odd perceptual effects, but fortunately few disorientation problems
- Transition animations
  - Try to avoid, but if you must, a teleport is better than continuous motion
- Meathook avatars
  - Gruesome in debug cams, looks great from the inside
- Maintaining framerate
  - Scaling the virtual eye renders looks surprisingly fine

Further reading, search for

“Oculus VR Best Practices Guide”

www.OculusVR.com

Tom.Forsyth@oculus.com

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Oculus VR

Rest in peace

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