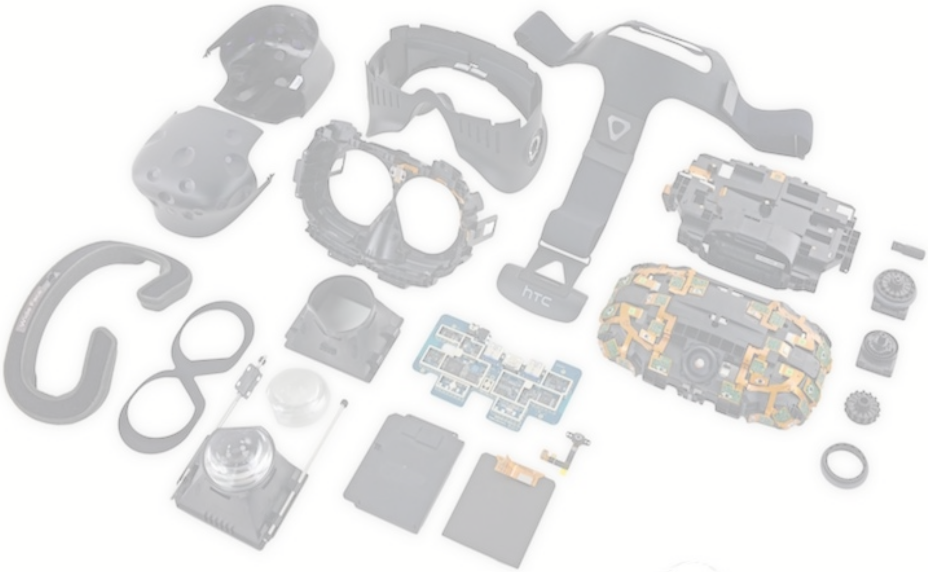
Frontiers of VR II

VR engines & Unity, latency, and eye tracking

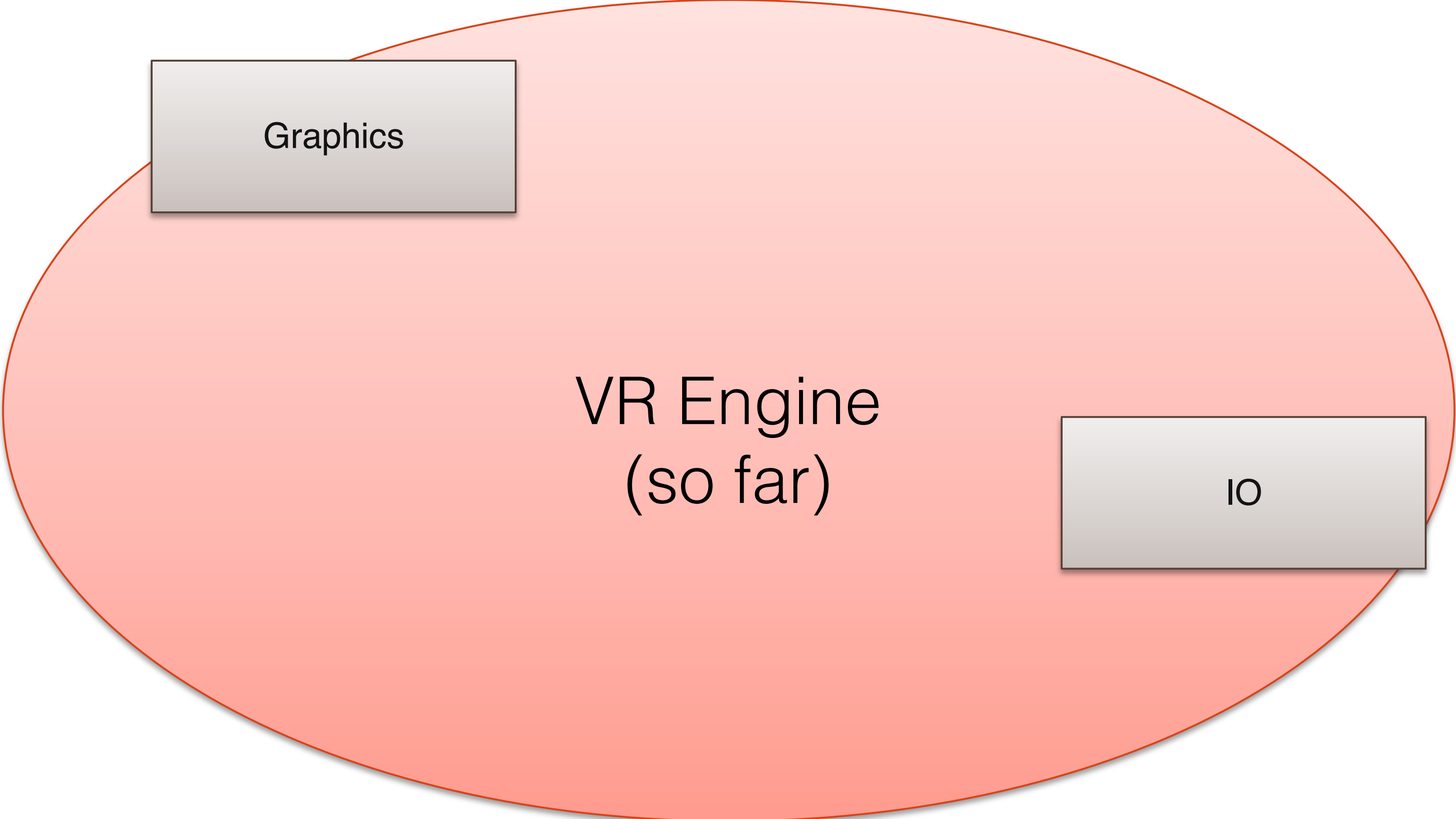


Gordon Wetzstein
Stanford University

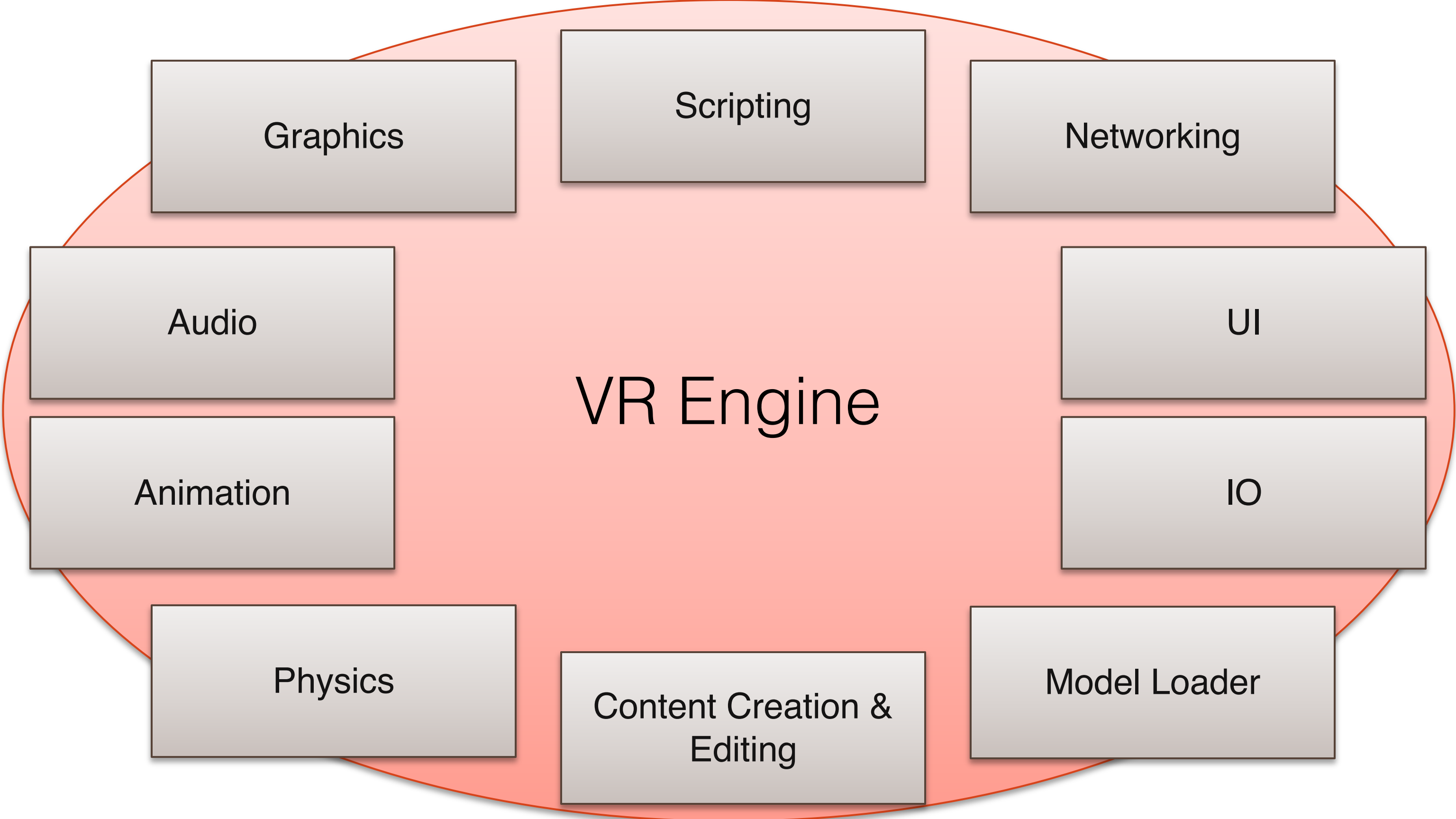
EE 267 Virtual Reality

Lecture 14

stanford.edu/class/ee267/



Graphics
VR Engine
(so far)
IO


Graphics
Scripting
Networking
Audio
VR Engine
UI
Animation
IO
Physics
Content Creation & Editing
Model Loader

VR Engines - Audio

- middleware – between audio card and application (e.g. game)

- usually provides functionality for:
    - loading different types of sound files
    - mixing and mastering
    - <u>3D sound</u>
    - occlusions, echoes, reverberation, …

VR Engines - Audio

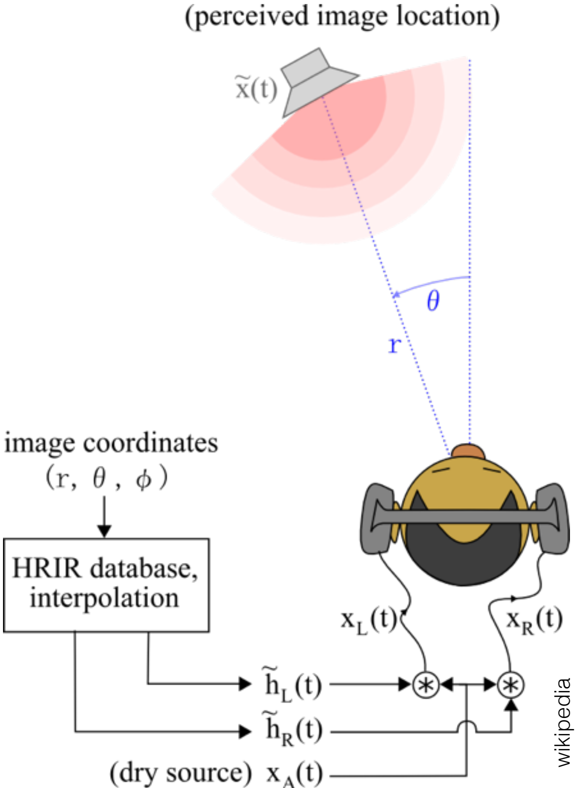
- examples:
  - FMOD - www.fmod.org
  - OpenAL - “OpenGL for sound”
  - SDL – provides basic functionality
  - …

VR Engines – 3D Audio

- start with mono sound $x_A(t)$
- head-related impulse response (HRIR) model time delay and attenuation via convolution

$$\tilde{h}_L(t) \qquad \tilde{h}_R(t)$$

- basically different temporal shift for each ear
- but HRIR also includes other effects created by shape of ear and other factors



wikipedia

VR Engines – 3D Audio

- sound, 3D sound, coupling sound and physics, accurate HRIR or head-related transfer function gets much more complicated

- Prof. Doug James in CS is working on physics & sound, check out his recent SCIEN talk if you're interested: "Physics-based Animation Sound: Progress and Challenges"

https://talks.stanford.edu/doug-james-physics-based-animation-sound-progress-and-challenges/

VR Engines - Physics

- framework to simulate:
    - rigid body dynamics (e.g. collision detection)
    - soft body dynamics (e.g. deformation, cloth, …)
    - fluid dynamics (water, smoke, fire, …)

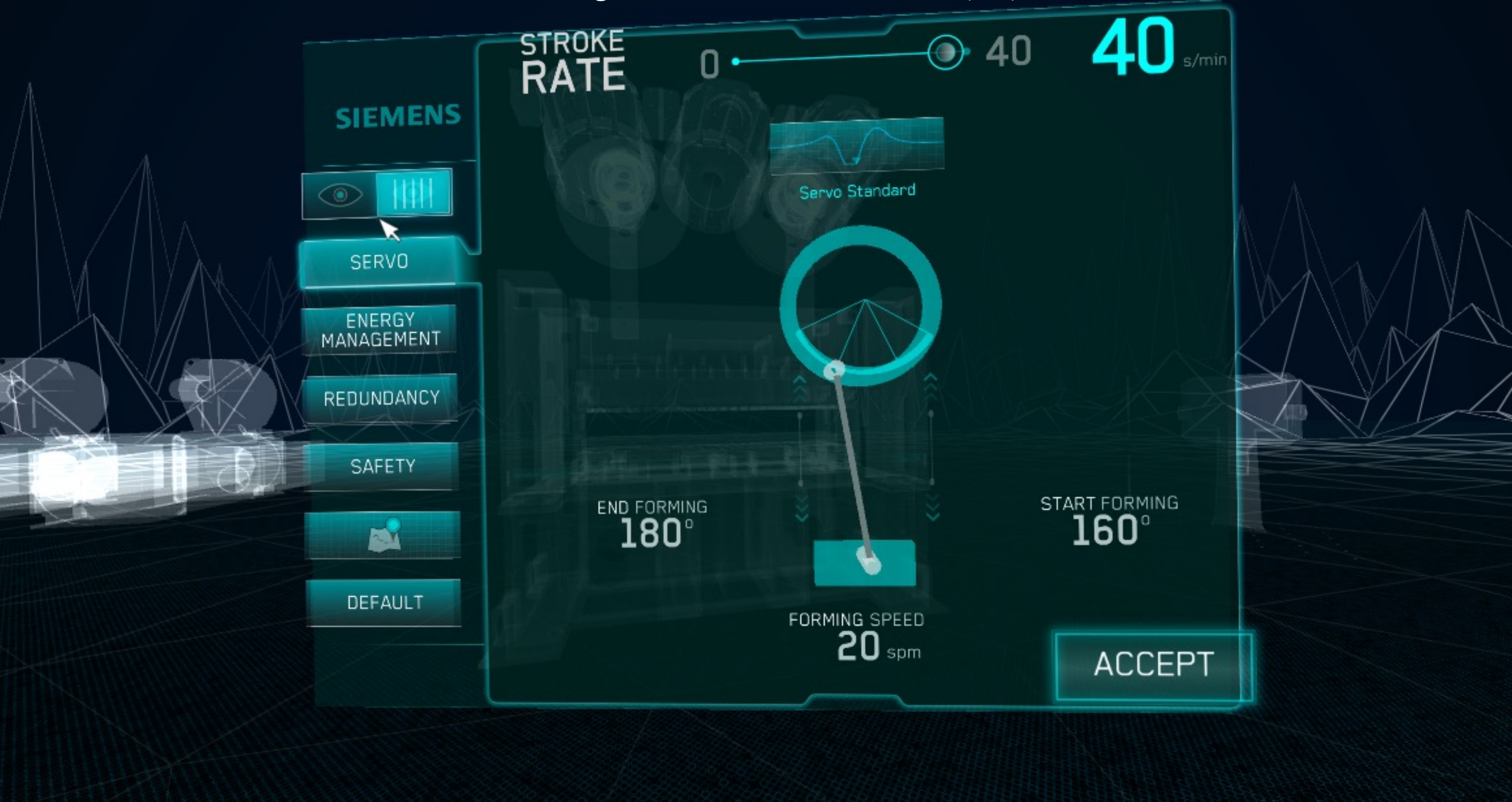
VR Engines - Physics

- examples:
  - Open Dynamics Engine (http://www.ode.org/): free ☺ but limited to rigid body dynamics & collision
  - Bullet Physics (http://bulletphysics.org/): free ☺, rigid & soft body dynamics, widely used
  - havok (owned by Microsoft) – not free ☹ but widely used, real-time rigid body dynamics

rendered in blender, bullet physics - https://www.youtube.com/watch?v=-6Sl5CCxp3Q

Early Tests

VR Engines – User Interface (UI)



VR Engines – User Interface (UI)

- concept is straightforward: widgets, menus, buttons, checkboxes, …
- types of UIs:
    - non-diegetic – lives in screen space (e.g. player status); doesn't work in VR (no screen space)
    - spatial UI – lives in the virtual world
    - diegetic – menus in world

images from unity

VR Engines - IO

- support for interfaces: keyboard, mouse, 3D mouse, standard haptic devices, …

- VR engine would provide functionality as well (e.g. Unity)

VR Engines – Content Creation

- 3D modeling programs / Computer-aided Design (CAD):
  - Maya (production)
  - 3ds Max (games)
  - Blender – free
  - SolidWorks – 3D printing & fabrication
  - Tinkercad: free & online

VR Engines – Content Creation

- what’s involved?
  - conceptual design
  - 3D modeling
  - animation and/or simulation
  - scripting behavior and artificial intelligence of characters
  - testing
  - … many different stages in application development …

VR Engines - Scripting

- core engine is usually designed for performance – C++
- developing applications should be easy! the user almost never wants to touch the C++ source but needs flexibilty
- provide a script-based interface to allow user to change anything they need for their application
    - create & manipulate objects
    - script behavior
    - change shaders (e.g. change camera or fragment shader art)

VR Engines - Networking

- manage low-level communication protocols (TCP/IP, UDP, …)
- ensure that character states, graphics, sound, and everything else is synchronized
- connect to application that's running as client
- network updates, messages, …

Popular VR/Game Engines

- Unity: cross-platform, Direct3D (Win), OpenGL (Mac & Linux), iOS & Android support, also came console APIs; personal license is free; seems to be the easiest to use so we'll use it for Lab 6 and HW 6
- Unreal: very popular, lots of awards, unreal engine 4 is free
- CryEngine: popular game engine, just announced support for VR; free for non-commercial use

Additional Information

- Unity game engine: https://unity3d.com/
- Unity tutorials: https://unity3d.com/learn/tutorials

Other Aspects of VR

Latency, Post-rendering Warp, Eye Tracking

Latency

- min acceptable: 20 ms
- interactive applications <20 ms (say target is 5 ms)

The latency between the physical movement of a user's head and updated photons from a head mounted display reaching their eyes is one of the most critical factors in providing a high quality experience.

- John Carmack

Latency – where does it come from?

- IMU ~1 ms
- sensor fusion, data transfer
- rendering: depends on complexity of scene & GPU – a few ms
- data transfer again
- display: LCD ~60 Hz = 16 ms; OLED <1 ms

Latency – how bad is it really?

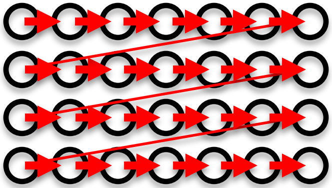
- example:
    - 16 ms (display) + 16 ms (rendering) + 4 ms (orientation tracking) = 36 ms latency total
    - head rotates at 60 degrees / sec (relatively slow)
    - 1Kx1K display over 100 degrees field of view

- in 36 ms, my head moved 1.92 deg ~ 19 pixels = size of thumb at arm's length! <u>too much</u>

Display Pixel Updates

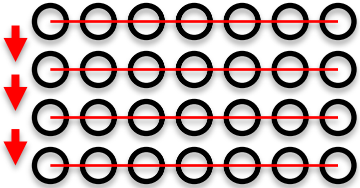
Raster Scan

(e.g. electron beam in CRT)



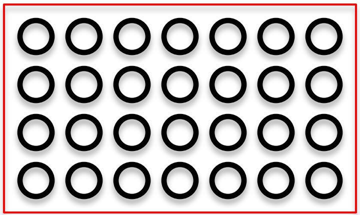
Rolling Update

(most LCDs)



Global Update

(some LCoS, DLP, other)

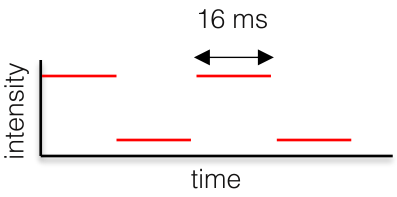


Display Pixel Switching - Persistence

- after the display pixel switched states, how long is it on?

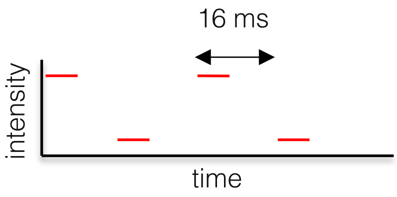
Full Persistence

(most LCDs)



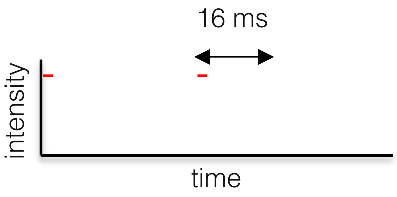
Half Persistence

(strobe backlight)



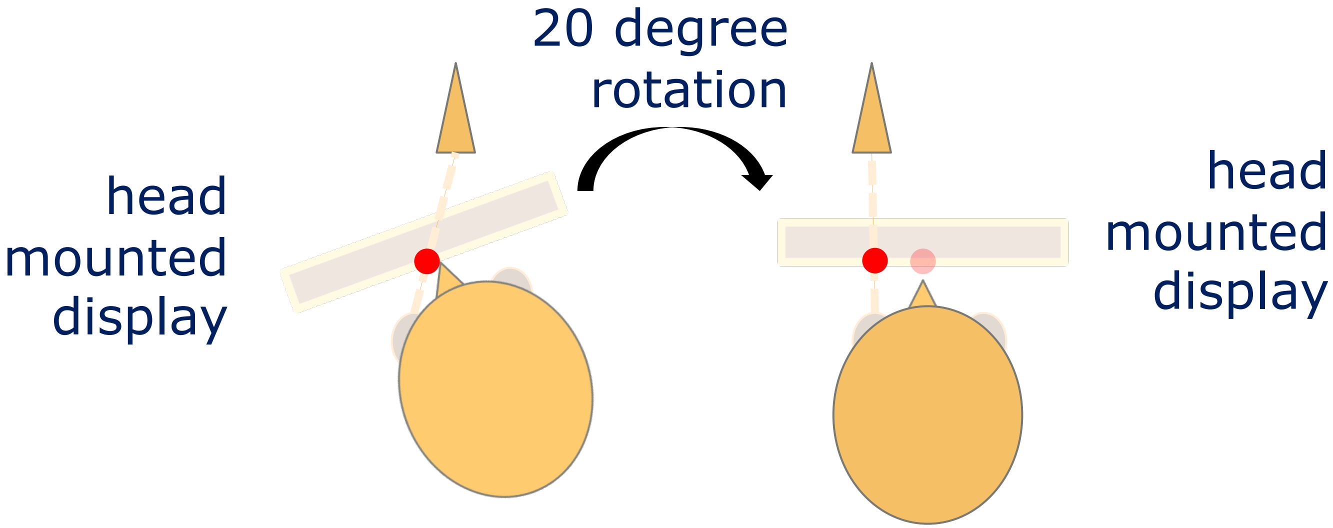
Low Persistence

(OLED, strobing)



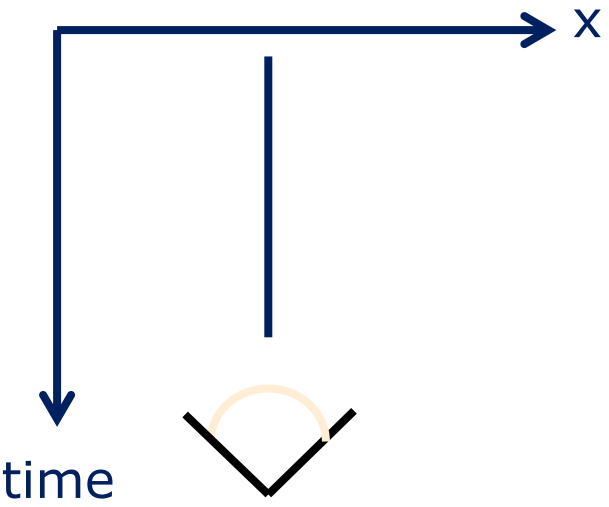
example: switch from white to black to white to black as fast as possible

Rapid relative motion



slides from Michael Abrash 2013

Space-time diagrams (static)



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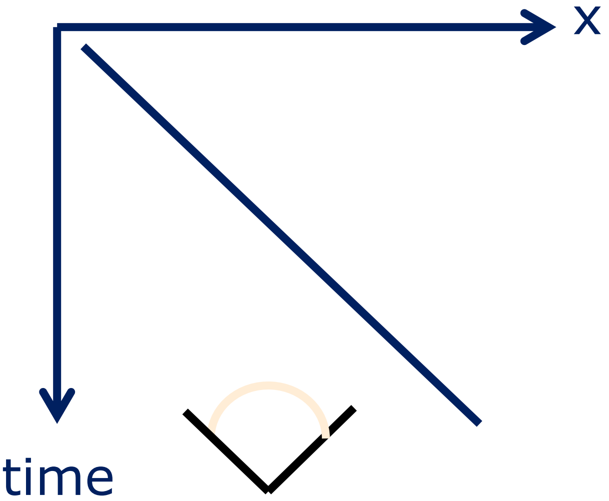
Spatial movement over time



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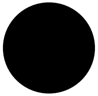

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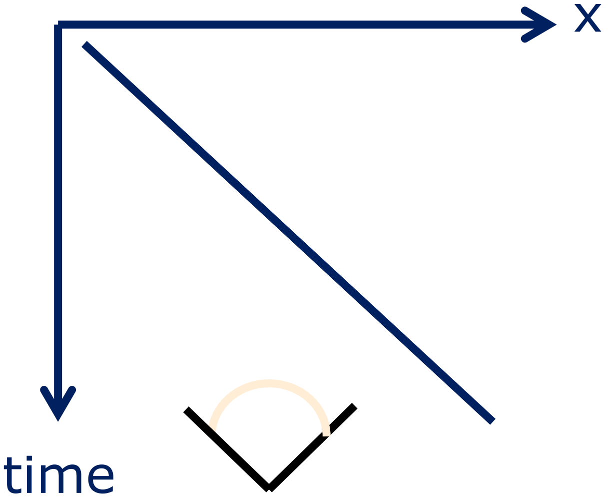

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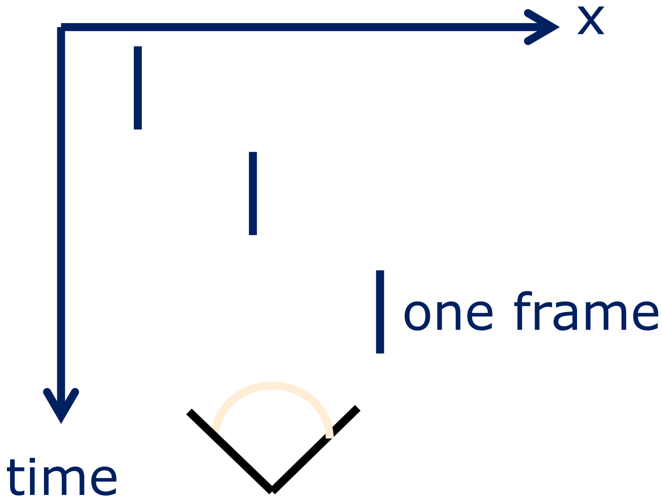
Pixel-based movement



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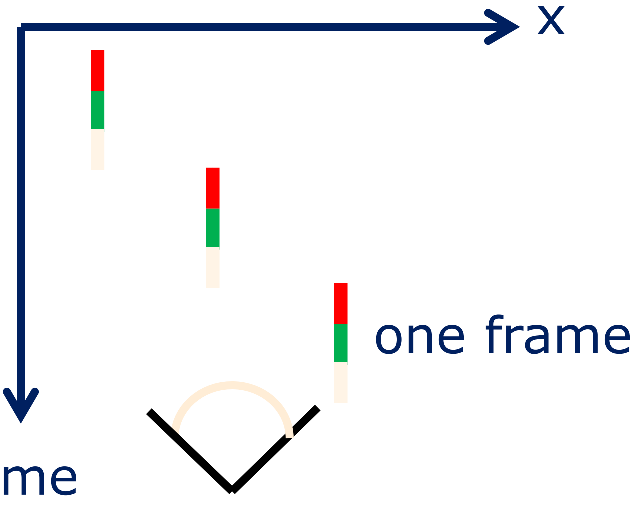
Sequential RGB display



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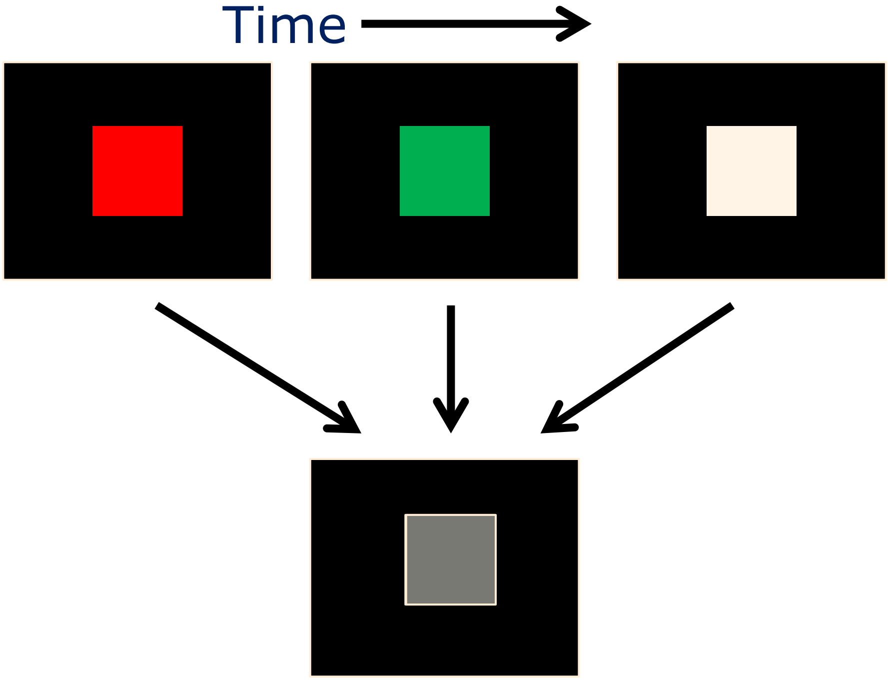

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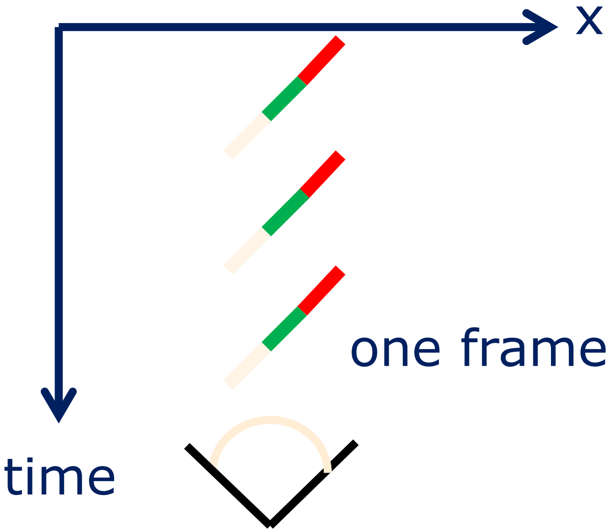
Sequential RGB with eyes moving



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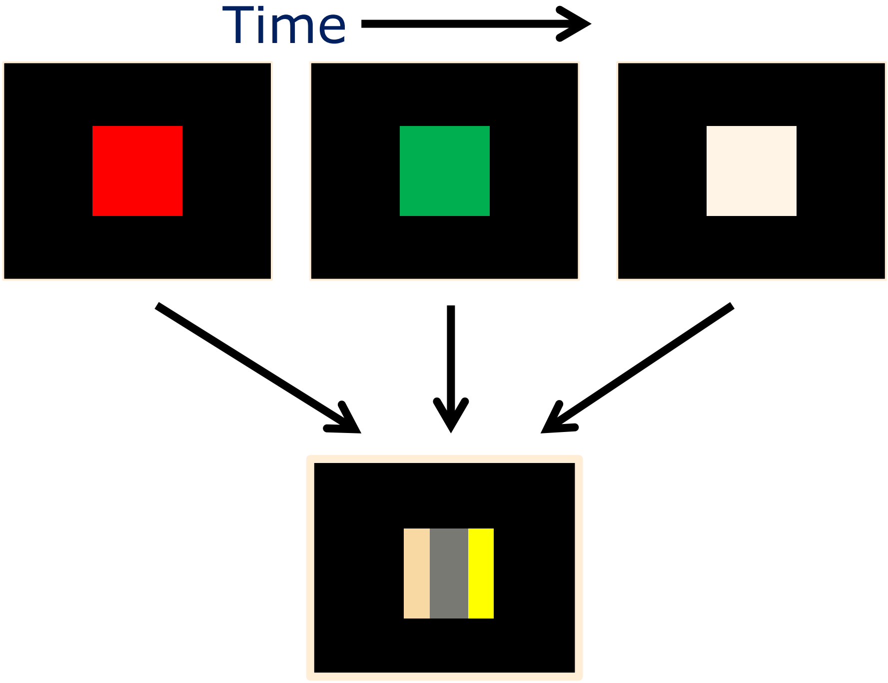

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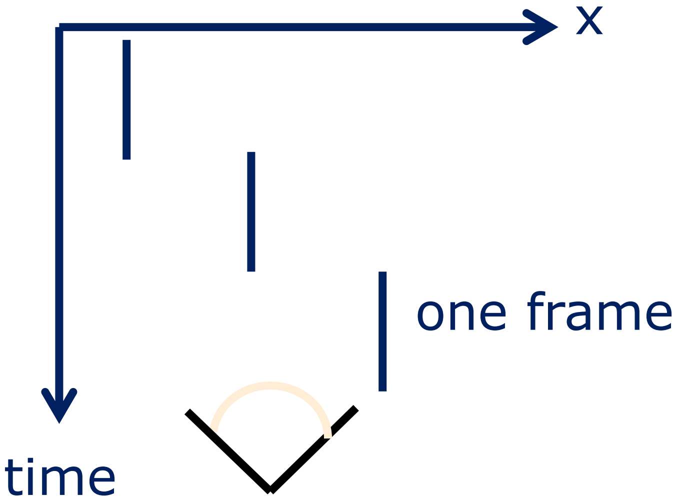
Full persistence



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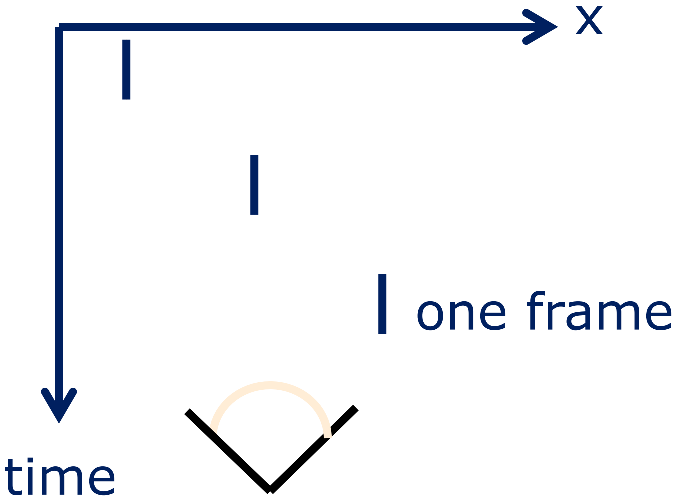
Half persistence



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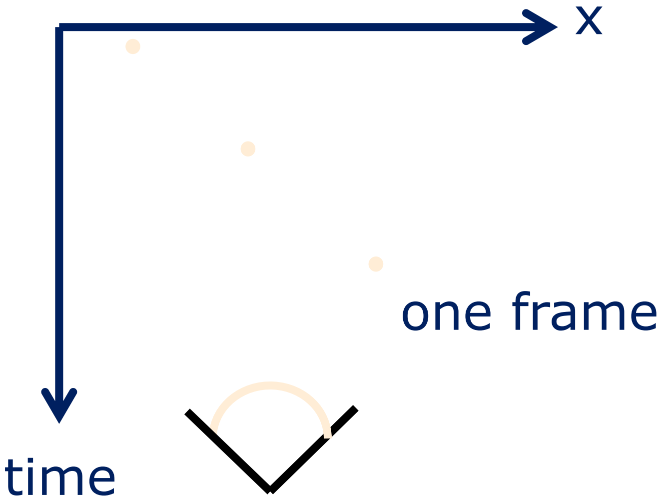
Zero persistence



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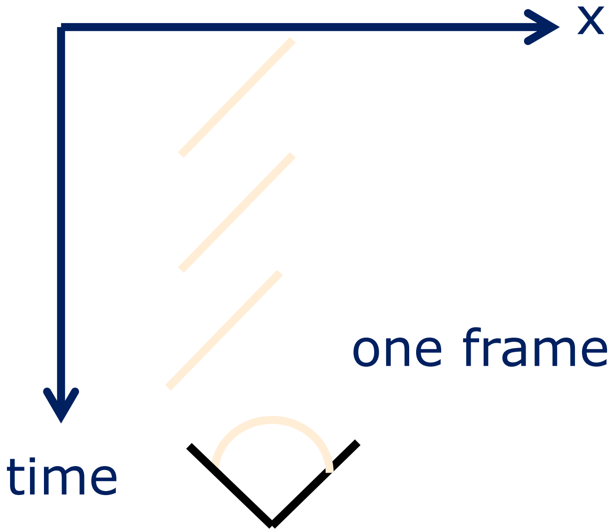
Full persistence + head rotation



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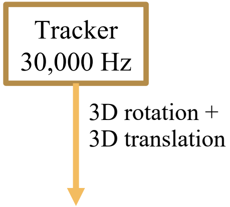
297
274


Post-rendering Image Warp

- also called time-warp by John Carmack
- minimize end-to-end latency
- original paper from Mark et al. 1997, also Darsa et al. 1997
- overview:
    1. get orientation from IMU, perhaps also position
    2. render scene into off-screen buffer (larger than screen)
    3. read latest orientation from IMU
    4. warp rendered image with latest orientation
- 2D image translation v 2D image warp v 3D image warp

End-to-End Low-Latency Optical See-Through AR Pipeline



slides from Zheng et al. 2014

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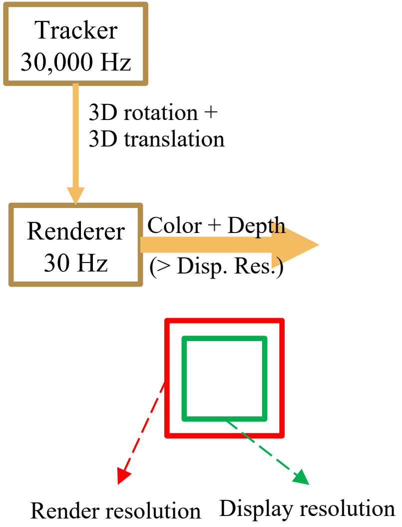

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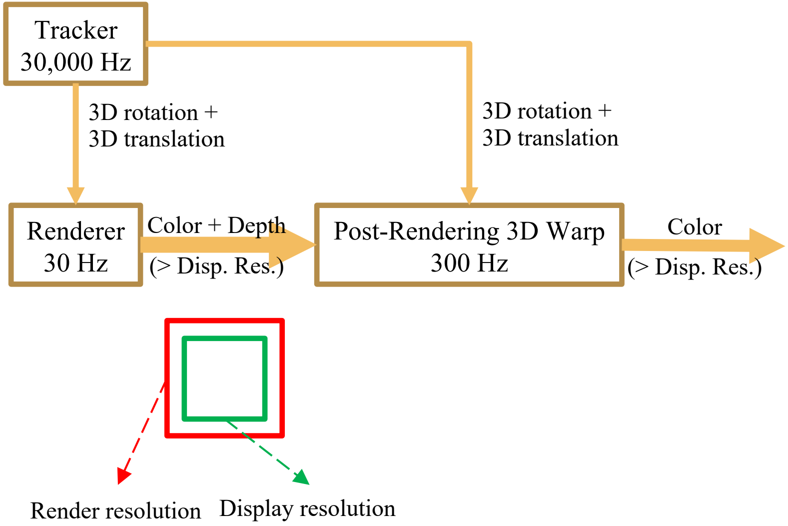

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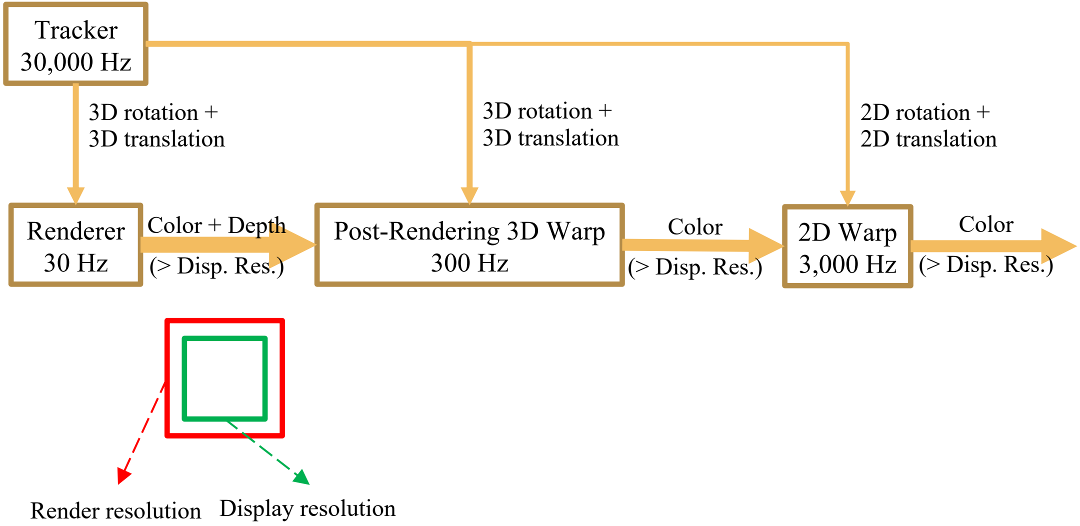

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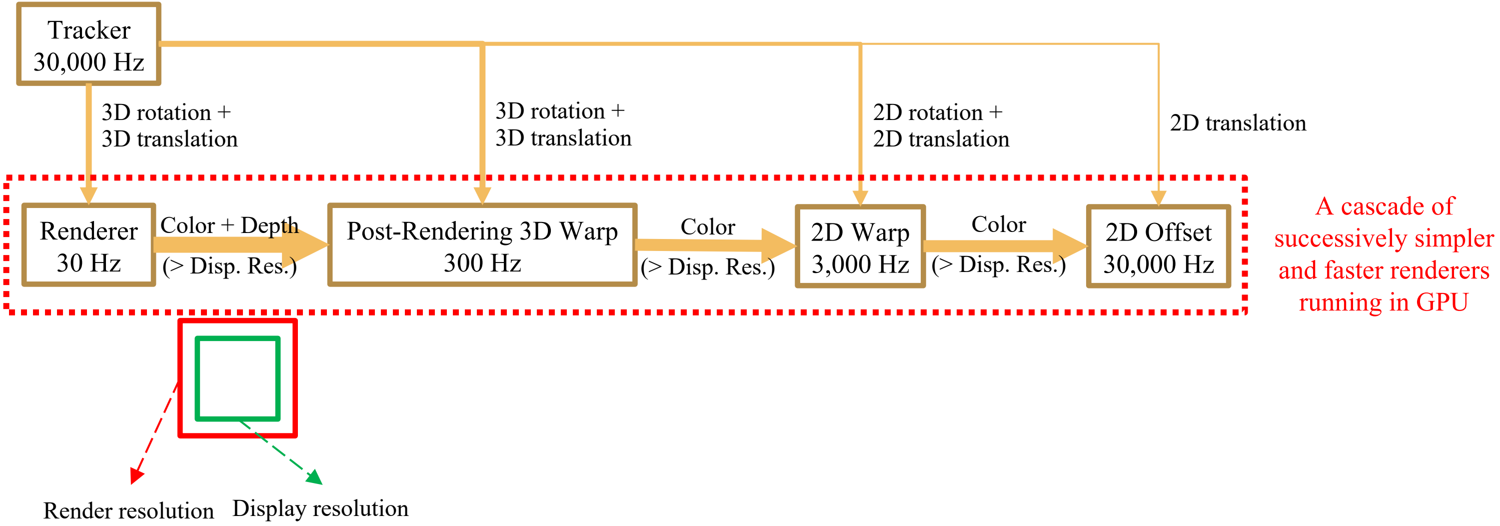
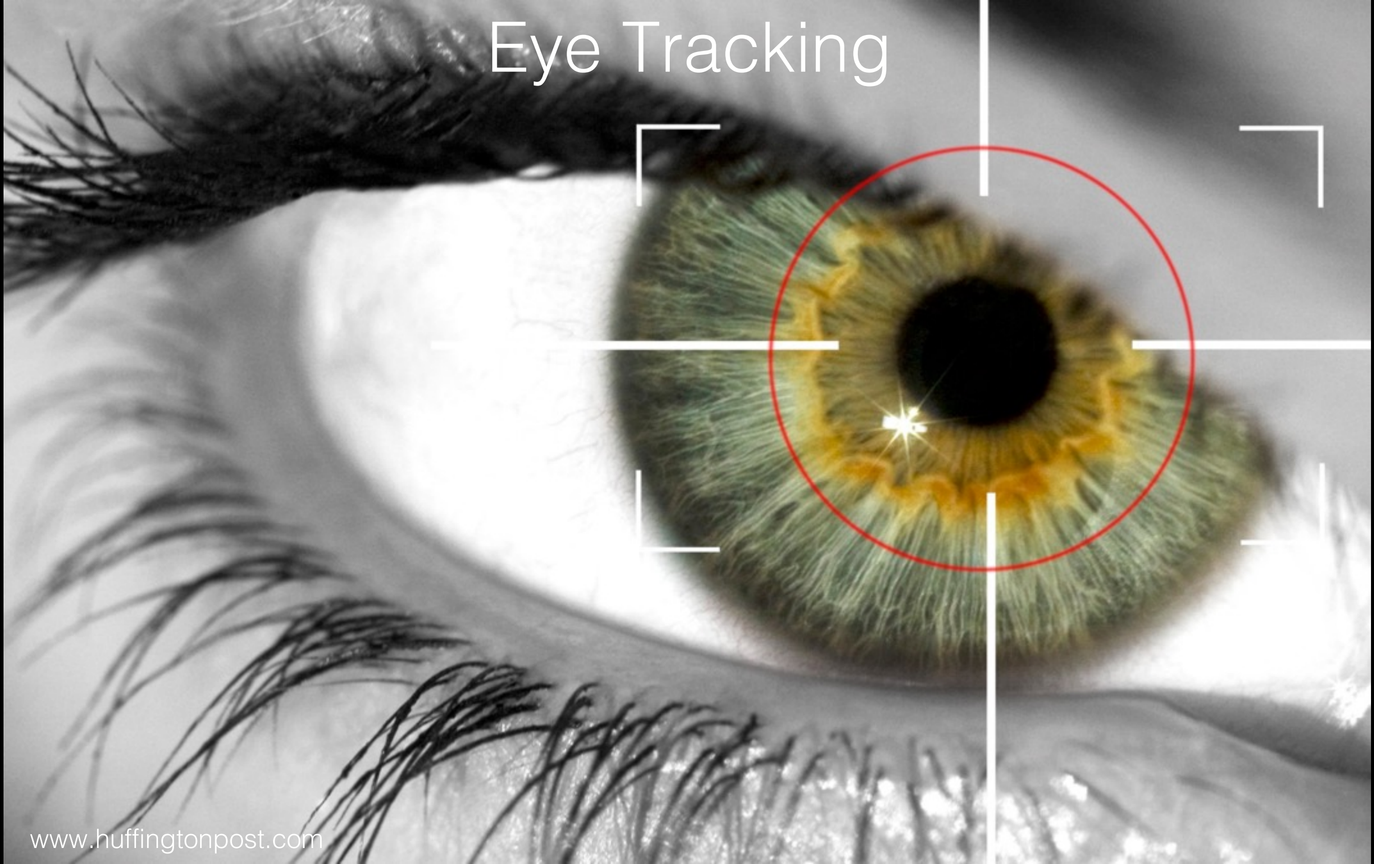


slides from Zheng et al. 2014

Summary: Latency, Persistence, etc.

- predictive tracking (e.g. LaValle ICRA 2014)
- post-rendering warp
- design and build really great hardware & algorithms
- use OLED displays or strobing backlights for low persistence
- design some type of a device to actually measure latency!

Eye Tracking



www.huffingtonpost.com

Eye Tracking

- necessary for gaze-contingency paradigm (foveated rendering, gaze-contingent rendering, gaze-contingent focus, …)
- interaction
- eye contact
- …

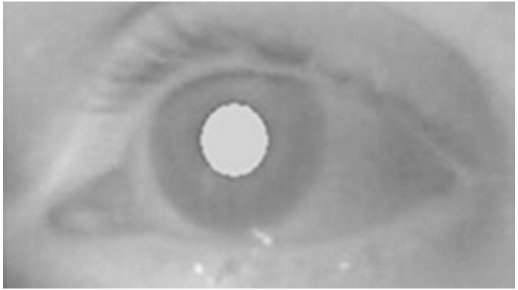
Eye Tracking

- many different techniques:
    - electro-oculography
    - contact lens tracking
    - video-oculography
    - pupil / corneal reflection tracking
    - dual Purkinje image

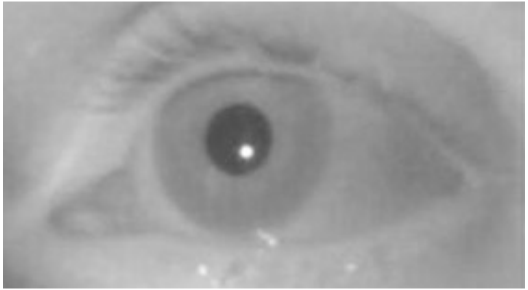
Eye Tracking

- some interesting properties one can exploit:
  - pupillary light reflex doesn’t work in near infrared (IR)
  - red-eye effect with co-axial camera - light source
  - purkinje images for off-axis illumination

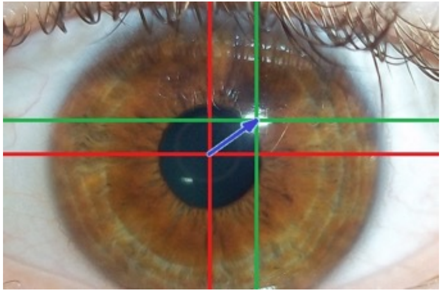
co-axial IR illumination



off-axis IR illumination



purkinje image

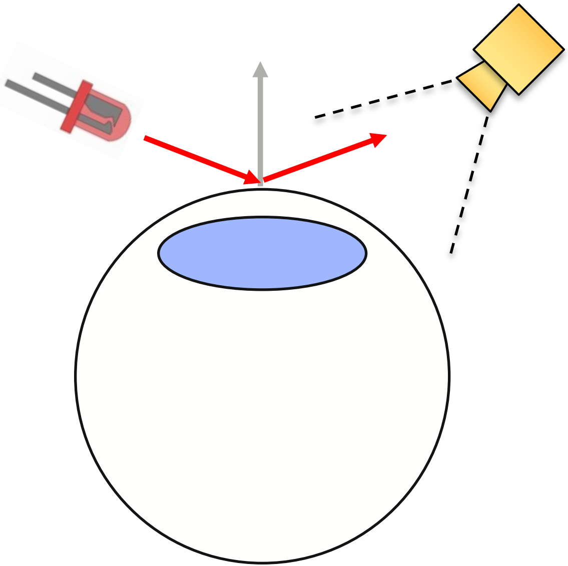


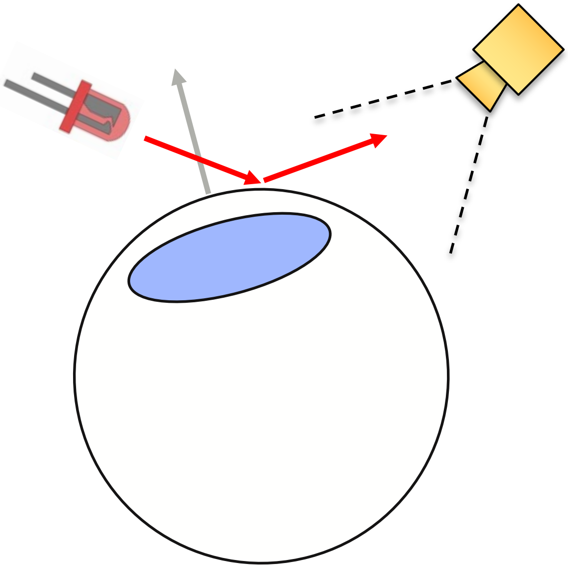
wikipedia

Eye Tracking – Pupil / Corneal Reflection

Eye Tracking – Pupil / Corneal Reflection

- corneal reflection stays constant, pupil center moves relative!





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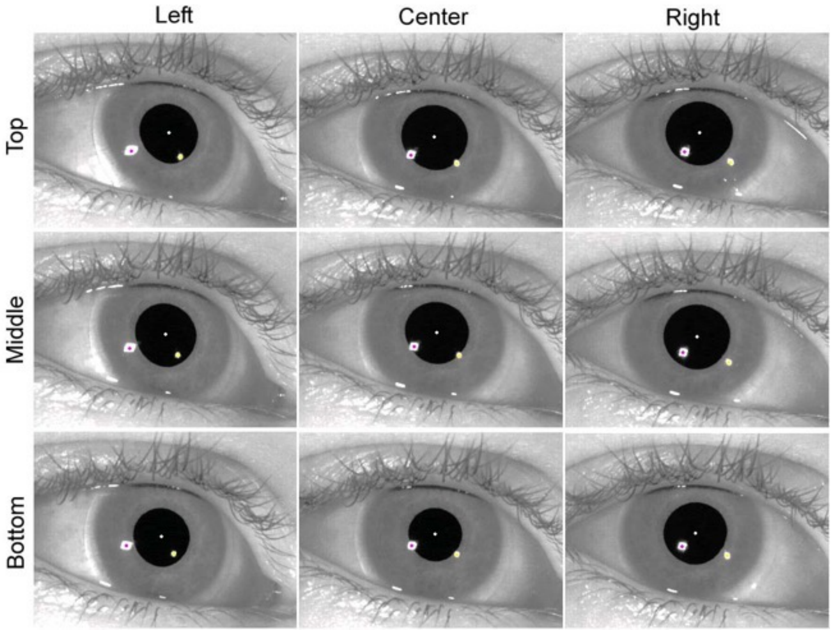
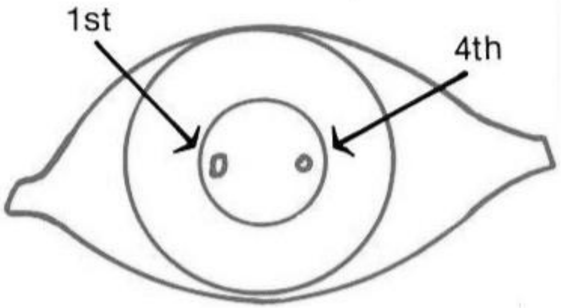
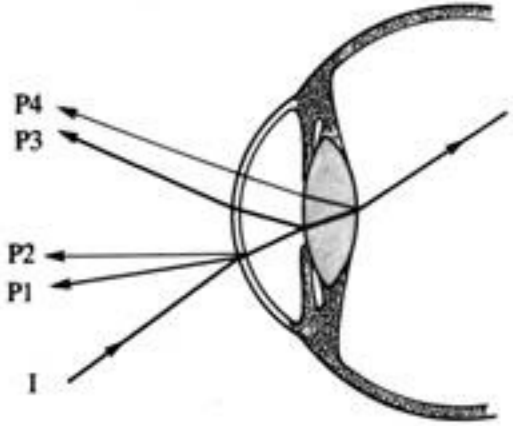


Eye Tracking – Dual Purkinje

- track relative location of Purkinje images





http://ppw.kuleuven.be/home/english/research/lep/resources/purkinje

Eye Tracking

- where am I looking? what am I looking at?

http://www.getbusymedia.com/small-business-insights-eye-tracking/

References and Further Reading

- Google Project Tango: https://developers.google.com/project-tango/
- Post-rendering warp:
  - W. Mark, L. McMillan, G. Bishop "Post-Rendering Warping," Proc. Symposium on Interactive 3D Graphics 1997
  - L. Darsa, B. Costa, A. Varshneyz “Navigating Static Environments Using Image-Space Simplification and Morphing“, 1997
  - John Carmack “Time Warp”, 2013 (blogs)
- Latency:
  - F. Zheng, T. Whitted, A. Lastra, P. Lincoln, A. State, A. Maimonek, H. Fuchs “Minimizing Latency for Augmented Reality Displays: Frames Considered Harmful”, ISMAR 2014