Announcements

- **MP4**, Nov 11, Nov 18 @11am

**Final project upcoming deadlines:**

- Nov 15, short video of your project
- Dec 12, 7:00-10:00pm, Final project presentation

**Second Midterm:** Dec 7, 7:00-8:30pm

**Grades are out for:**

- MP2
- MP3
More Challenges for Rendering in VR

A perfect VR system:

- Head Motion
- Eye moves
- Viewpoint update
  - Chain of transformation update
  - Recomputation done with no delay
  - Shading update for all pixels
- Photon generation

Oracle provides values $O_5$ with no delay

Perfect simulation

Screen update

$O_5$ Screens are next gen! fast/high res
Challenges for Rendering in VR: Latency

Motion-to-photon latency: the amount of time it takes to update the display in response to head motion (change in current position and orientation).

Latency = key obstacle of past-generation VR!

Next topic:
Motion in VR:
- Math. models
- Vestibular system
- Motion-tracking

Some current methods for latency reduction:
1. Lower the complexity of the virtual world.
2. Improve rendering pipeline performance.
3. Remove delays along the path from the rendered image to switching pixels.

Problem: ALL OF THE ABOVE NEED TO WORK FOR MUCH HIGHER RES AND MORE FPS SCREENS!

Reducing "effective" latency:
4. Use prediction to estimate future viewpoints and world states.
5. Shift or distort the rendered image to compensate for last-moment viewpoint errors.

LaValle, 2013
Oculus blog

Carmack, 2013, Alt.Dev Blog
Mathematical Modeling of Motion

Why?

1. The physics of both real and virtual worlds impact VR experiences.

2. Physics engines may model the motions of dynamic bodies in the virtual world, but not the motion of the virtual world itself.

3. Tracking methods rely on accelerations and velocities.

4. Human vestibular organs rely on accelerations and velocities.
How to Display the World Right?

- Only one display

- Two sensory organs for motion

- Optical flow

- Result of contradicting T cues
<table>
<thead>
<tr>
<th>Sense of motion</th>
<th>Vestibular system</th>
<th>Vision</th>
<th>Example</th>
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<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>No</td>
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<td>Mismatched</td>
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Motion Detection Circuitry

https://www.youtube.com/watch?v=vAY50UqY-_Q

https://lh3.googleusercontent.com/-0OFBVGsCDpc/Ts5vhIRNPUl/AAAAAAAACMM/EriRwqu2pb8/w497-h373/HitchcockZoom_Micael_Reynaund.gif
1D Motion

How do I find out $y(t)$?

- Sensor for $y(t)$ would be nice.
- Otherwise: sensor for $v(t)$.

$$v(t) = \frac{dy(t)}{dt}$$

constant $v(t)$:

non-constant $v(t)$: numerical solution only
1D Motion

$y(T) = y_0 + \int_0^T v(t) \, dt$

sensor for \( r(t) \) \rightarrow \text{odometer}

numerical solution

Example:

$\Delta t = \frac{s}{\text{for 1000 Hz}}$

$N$-error is

$m
\Rightarrow$ numerical error \( \dot{y}_N = \frac{m}{s} \)

$y > \text{Im}$ if $N >$
1D Motion

Sensor for $a(t)$ only $\Rightarrow$ accelerometer

$$v(t) = \frac{dy(t)}{dt}$$

$$a(t) = \frac{dv(t)}{dt}$$

Numerical solution:

Example: $(\text{0 m/s}) (N_0 + N_1 + N_2 + \ldots + v_{N-1} + v_N) \cdot \Delta t$
Tracking Systems in VR: Estimating 2D Orientation

How do I find out $\Theta(t)$?

- Sensor for $\Theta(t)$ would be nice

Otherwise: sensor for $\omega(t)$

$$\omega(t) = \frac{d\Theta(t)}{dt}$$

$$\Theta(T) = \Theta_0 + \int_0^T \omega(t) \, dt$$

numerical solution

$$\Theta(T) = \Theta_0 + \sum_{i=0}^{N} \omega_i \cdot \Delta t$$
1D Motion

Sensor for \( \vec{r}(t) \rightarrow \text{odometer} \)

Numerical solution

\[
\begin{align*}
y(T) &= y_0 + T \int_0^T \vec{v}(t) \, dt \\
y(T) &= y_0 + \sum_{i=0}^{N} \vec{v}_i \Delta t
\end{align*}
\]
Tracking Systems in VR: Estimating 2D Orientation

How do I find out $\theta(t)$?

- Sensor for $\theta(t)$ would be nice

Otherwise:

$\omega(t) = \frac{d}{dt} \omega(t)$

$\theta(T) = \theta_0 + \int_{0}^{T} \omega(t) \, dt$

numerical solution

$\theta(T) = \theta_0 + \sum_{i=0}^{N} \omega_i \cdot \Delta t$
Human Vestibular System

Only one display

two sensory organs for motion

senses optical flow

result of contradictory cues
Human Vestibular System

- **Semicircular canals:**
  - Anterior
  - Posterior
  - Lateral

- **Semicircular ducts of the membranous labyrinth**

- **Membranous ampullae:**
  - Anterior
  - Lateral
  - Posterior

- **Utricle**

- **Saccule**

- **Vestibule**

- **Cochlear nerve**

- **Cochlear duct**

- **Apex of cochlea**

- **Connection to cochlear duct**
Human Vestibular System

- Rest or constant velocity
- Linear acceleration
- Tilt

\[ \vec{F}_{\text{spring}} \]
\[ m\vec{g} \]
\[ \vec{a} \]
\[ \vec{F}_{\text{spring}} \]
Human Vestibular System

- Semicircular canals: Anterior, Posterior, Lateral
  - Semicircular ducts of the membranous labyrinth
- Membranous ampullae: Anterior, Lateral, Posterior
  - Connection to cochlear duct
- Utricle, Saccule, Vestibule
- Cochlea, Cochlear duct, Apex of cochlea
  - Cupula

Acceleration direction

Fluid