Moving Through Virtual Reality
Without Really Moving?

Spatial orientation, self-motion perception,
& perceptually-oriented self-motion simulation in virtual reality

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23. April 2010, Locomotion Lab, SFU

My own background (Spatially)

Max Planck Institute for Biological Cybernetics, Tübingen, Germany,
www.kyb.mpg.de
Virtual Reality group of the Max Planck Institute for Biological Cybernetics in Tübingen, Germany

15 x 12m Free walking area
Kuka robot arm-based motion simulator
omnidirectional treadmill

A Morphable Model for 3D Face Synthesis
230° spherical/toroid projection screen
6DoF Stewart motion platform

Bernhard E. Riecke
Self-Motion Illusions (Vection)
SIAT, Simon Fraser Univ.
Since May 2008:

Simon Fraser University
Research Interest & Motivation

• Amazing technological and scientific progress in electronic media, HCI, & VR

• Novel opportunities for research, interface design & applications

• Novel challenges
  – Spatial disorientation, reduced task performance, insufficient transfer of training, unconvincing
  -> Reduced usability & user acceptance

Approach:
Fundamental research with an eye toward the applied
Old debate in experimentation

<table>
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<th>Naturalistic observation</th>
<th>Lab experiments</th>
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<tr>
<td>– Realistic stimuli/environment</td>
<td>– Full stimulus control</td>
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<tr>
<td>– naturalism &amp; ecological validity of stimuli</td>
<td>– Repeatability</td>
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<td>– natural interaction</td>
<td>– Flexibility</td>
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<td>– Closed action-perception loop</td>
<td>– Confound &amp; Error reduction</td>
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<td>– multimodal stimuli</td>
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Virtual Reality?

Do we perceive and behave similarly in real and computer-simulated environments?

“is virtual reality real enough?”

Overview

Part 1: Spatial orientation
Part 2: Self-motion illusions
Part 1: Investigating & Enabling Robust and Effortless Spatial Orientation in VR

VR: Disorientation
- even for simple navigation tasks
- lack of intuitive & robust spatial orientation, esp. if no landmarks → what is missing?
  → computationally expensive strategies
  → long response times
  → ineffective & unnatural behavior
  → impaired usability, user acceptance, and real-world transfer
  - Darken and Sibert 1996;
  - Darken and Peterson 2002;
  - Grant and Magee 1998;
  - Klatzky et al. 1998;
  - Lawson et al. 2002;
  - Péruch and Gaunet 1998;
  - Riecke & Wiener, 2006, 2007;
  - Ruddle and Jones 2001;
  - Ruddle et al. 1998

Real world: robust & effortless spatial orientation
- automatized and reflex-like “spatial updating”
  → minimal cognitive load

Approach: Basic research with an eye toward the applied

Basic research perspective: Multi-modal sensory integration & cues required for automatic spatial updating

Applied perspective: Enable robust & effortless spatial orientation & interaction in VR with minimal simulation effort

Applied goal: Natural, effective and unencumbered behavior in computer-mediated environments

Methodology: human in ecologically valid context

Theory: unifying framework, explanations & predictions

Approach: Experiments in real room & VR replica
Ecologically relevant task: Rapid pointing
**Methods - Setup**

- **Task:** After real/simulated self-rotations: Point accurately & quickly to targets outside of FOV
  - Ecologically valid
  - Reduced cognitive strategies

**Results**

- **Unrestricted FOV** improves spatial orientation performance
- **VR performance** ≈ **Real world** for same FOV
- Physical motion cues don’t improve performance
Results & Conclusions

- Small response times & high pointing accuracy
  - Spatial orientation was easy and intuitive, even in VR
- Response times independent of turning angle
  - Spatial updating occurred automatically *during* motion

  - **Natural, automatic spatial updating**
- VR performance ≈ Real world (if FOV matched)
  - Real-world like spatial orientation in VR *is* possible

  - Suggests real world transferability
  - Validates VR paradigm

- **Critical for research & applications**
  - Riecke et al., Psychological Research (2006)
  - Riecke et al., ACM Transactions on Applied Perception (TAP) (2005)

How far can we get with just optic flow?

- Optic flow is heavily used in basic research (scholar.google.com: 14,000 hits)
- We can estimate all kinds of things from optic flow
  - “Optic flow is used to control human walking” (Warren et al., Nature 2001)
  - “Perception of self-motion from visual flow” (Lappe et al., TICS 1999)
  - “Heading” detection from optic flow” (Lappe & Rauschecker, Nature 1994)
  - “Humans can use optic flow to estimate distance of travel” (Redlick et al., Vision Res., 2001)
  - “Optic flow helps humans learn to navigate through synthetic environments” (Kirschen et al., Perception 2000)
  - “Path integration from optic flow and body senses in a homing task” (Kearns et al., Perception 2002)
  - “Visually induced illusion of self-motion” (Howard, 1982)

  - But: if optic flow specifies a self-motion: Do we have a clue where we are?

**Does optic flow enable natural, life-like spatial orientation?**

- use simplest non-trivial spatial orientation task: “point-to-origin”
Main question: How good is spatial orientation in VR given optic flow and no feedback training?

• Do participants have a natural “feeling” of where they are, just like in the real world? (qualitative errors)

• Approach: Use task that’s easy if natural spatial orientation (automatic spatial updating) works and else difficult
  – Point-to-origin after simple excursion (translation, rotation, (translation))
  – Similar to homing/triangle completion tasks in RW

General methods

• Passive motions, path integration using optic flow without landmarks

• Flat proj. Screen, FOV: 84° x 63°, 89cm distance, 1400 x 1050 pixel JVC D-ILA LCoS proj.; N=16

• Indep. Var.
  – Turning angles 0°, 30°, 60°, 90°, 120°, 150°, 170°, announced before each trial on screen
  – Turning angle left/right (alternating)
  – Length of first segment s1: 16m or 24m (s2 = 16m)
Example of individual subject data

• Top-down view:

Riecke & Wiener, APGV 2007: 2-segment encoding control exp., turn angles announced

• non-inverters (13/24)
Conclusions

• Despite expensive & immersive VR, people are still easily lost in VE…

• Standard VR visualization setups seem insufficient for enabling natural, accurate and intuitive, spatial orientation/updating based on visual path integration

• **Challenge:** How could we improve spatial orientation in VR?
  – Landmarks & naturalistic scene
    • (e.g., Riecke et al., 2002, 2005, 2006)
  – Active control? Maybe (not)
    • (e.g., Wraga et al., 2004)
  – FOV
    • (e.g., Arthur, 2000, Riecke et al., 2005)
  – Size of display
    • (Tan et al., 2003-6)
  – Display type & geometry
    • (e.g., Riecke et al., 2002, 2005)
  – Feedback training & thinking (but: still no intuitive spatial orientation)
    • (e.g., Gramann et al., 2005, Riecke et al., 2002)
  – Physical locomotion (or at least rotation), self-motion illusions?
    • (e.g., Klitzky et al., 1998, Riecke et al., 2005ff)

• **Outlook:** Rapid point-to-origin paradigm is simple yet powerful tool to
  – Evaluate perceptual & behavioral quality of VR setup
  – Capability of enabling natural & unencumbered spatial behavior and performance
Part 2: Self-Motion Illusions ("Vection") & Perceptually-Oriented Self-Motion Simulation in VR

- "Train illusion"
- Normally, the world doesn’t move… scene from Top Secret
What cues can induce vection?

- **Visual vection** (Flowing river; waterfall, train illusion)
  - Mach (1875), Helmholtz (1896), Fischer & Kornmüller (1930) Tschermak (1931) "linear/circular Vection"

- **Auditory vection**
  - 20-60% can perceive auditorily induced vection
    - Dodge, 1923; Hennebert, 1960; Lackner, 1977; Marmekarese & Bles, 1977; Larsson et al., 2004ff; Väljamäe et al., 2004ff, …
  - But: Much weaker than visual vection

- **Biomechanical** (stepping around) circular vection
  - Most (>90%) perceive it (e.g., Bles & Kaptelyn, 1977, Bles, 1981)
  - Vection onset time: ca. 20s (Becker et al., 2002, Bruggeman et al. (submitted))

![Vection intensity vs. time graph]

**Motivation:**

Why study self-motion illusions ("vection")?

- Theoretically interesting: Cue combination
- Compelling ("embodied")

- Related to challenges in VR applications:
  - Convincingness and naturalism
  - Presence & immersion (Prothero, 1995; Riecke et al, 2005ff; Stanney, 2002)
  - Spatial orientation (Hypothesis by Riecke & von der Heyde, 2003)
**Fulfill vision of Virtual Reality:**
Computer-generated world accepted as alternate „Reality“
→ as compelling, immersive, & empowering as real world

**Research philosophy:** Human-centered,
perceptually- and behaviorally-oriented perspective

**Fundamental research perspective**
Goal: Understand human system
Self-motion perception
Multi-modal & higher-level contributions

**Applied perspective:** Goal: How can we simulate self-motions more effectively at minimal cost? → Empower humans to effectively & intuitively interact with comp./VR

**Methodology:** human in ecologically valid context whenever possible

**Theory:** unifying framework
→ deeper understanding, predictions, hypothesis-testing

**Approach:**
Perceptual/ behavioral experiments
in naturalistic, multi-modal VR

**VR as Enabling Technology:**
Multi-modal, naturalistic & immersive VR provides the unique opportunity to study human perception & behavior in reproducible, clearly defined & controllable experimental conditions in a closed action-perception loop

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**Visual Vection – Why use naturalistic stimuli?**
**higher-level influences**

*Main idea:* Scene scrambling should reduce global scene consistency, depth cues & spatial presence (higher-level factors) while hardly altering image statistics (bottom-up factors).
Demo & Experimental Design

Relaxed viewing without fixation

- Convincingness of motion [%]
- Presence questionnaire (Schubert et al., Presence 2001)

Global Scene Consistency
Vection Measures

Joystick timecourse (=vection intensity)

Vection time
Vection buildup time
Maximum vection intensity [%]

Vection onset time
Vection buildup time
Maximum vection intensity

Maximum vection intensity [%]

Vection onset time
Vection buildup time
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Global Scene Consistency
Presence Ratings

(Presence questionnaire by Schubert et al., Presence 2001)

Conclusions

• Stimuli depicting a consistent natural scene produce a faster, stronger, and more convincing sensation of illusory self-motion

• **Higher-level processes** (global scene consistency & pictorial depth cues) are important factors for ego-motion sensation

• Hypothesis: **stable reference frame** → “spatially presence” & involved
Can auditory cues facilitate biomechanical vection?

Bernhard E. Riecke
Daniel Feuereissen
John J. Rieser
&
Timothy McNamara

Setup
Methods – Auditory stimulus generation

• Binaural recording via in-ear mics
  - Core Sound Binaural Microphone Set

Methods – Auditorily induced circularvection

• Binaural display via headphones
  – Audiotecnica AT-7ANC active noise canceling headphones
**Time-course & measures of vection**

**Can auditory cues facilitate biomechanical vection?**

**Auditory vention**

**Auditory & biomechanical vention**

**Biomechanical vention**

- **Methods:**
  - 3 stimulus combinations x 2 directions (L/R) x 2 repetitions = 12 trials; N=19 currently
- **Questions:** Can auditory cues
  - Induce circular vection?
  - Facilitate biomechanical vection? (even if too weak to induce vection by themselves?)
Results

- Rotating sound field itself was hardly able to evoke circularvection.
- Yet, auditory cues significantly enhanced biomechanicalvection.

Role of auditory cues forvection:
  - facilitation/supporting other modalities?

Applied perspective:
  - audio is affordable & robust yet HiFi

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Self-Motion Illusions (Vection)
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Summary

Vection can be reliably induced and studied using a VR setup

Visual + auditory cross-modal facilitation
Adding spatialized sound of visual landmark (fountain) enhances vection & presence

- Moving headphone-based 3D audio rendering can induce vection
- "Acoustic landmarks" help
- Spatialization quality not critical for vection

Additional cross-modal benefits for adding matching

- Vestibular & proprio: self-generated motion cueing
  - Vestibular: Minimal motion cueing (jerks of a few cm)

- Audio + biomechanical cues (stepping on the treadmill)
  - Riecke et al., VRST (2006)
  - Riecke et al., Cyberwalk (2008)

- Audio + haptic and and or vibrations
  - Riecke et al., HCI (2005), IEEE VR (2005)

- Vibrations

Further info: www.siat.sfu.ca/faculty/Bernhard-Riecke/
www.poems-project.info

Riecke et al., TAP (2009)
Larsson et al., Presence (2005)
Riecke et al., APGV (2008)
Lepecq et al. (1995)
Wright et al. (2006)

# Cognitive & higher-level influences
# multi-modal spatio-temporal consistency

Natural, globally consistent scene & depth cues enhance visually-induced vection & presence

Percentage of trials with vection
43.4 93.4 90.8
Just Sound Sound & Platform Just Platform

Vection intensity [%]
76.7 64.7 46.5
Just Sound Sound & Platform Just Platform

Estimated vection onset time [s]
64.9 16.1 23.9
Just Sound Sound & Platform Just Platform

Percentage of trials with vection
64.9 45.4 0
Just Sound Sound & Platform Just Platform

Realism of actually rotating in room [%]
60 45.4 10
Just Sound Sound & Platform Just Platform

Overall vection intensity [%]
76.7 64.7 46.5
Just Sound Sound & Platform Just Platform

Role of auditory cues for vection:
- facilitation/supporting other modalities?

Applied perspective:
- audio is affordable & robust yet HiFi

Results

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Role of auditory cues for vection:
  – facilitation/supporting other modalities?

Applied perspective:
  – audio is affordable & robust yet HiFi
**Long-term vision:** Understanding & enabling effective spatial perception and behaviour in VR, and use this knowledge to design novel, more effective human-computer interfaces/interaction paradigms

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<th>Fundamental research perspective</th>
<th>Applied perspective</th>
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<td>Understand human multi-modal perception/interaction with real/virtual env.: what constitutes natural, robust, intuitive, &amp; embodied human perception &amp; behavior?</td>
<td>Empower humans to effectively &amp; intuitively interact with computers/computer-generated environments</td>
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**Exploit multi-modal self-motion illusions**

**Leverage spatial updating**

**minimize reference frame conflicts**

**VR as Enabling Technology:**

Multi-modal, naturalistic & immersive VR provides the unique opportunity to study human perception & behavior in reproducible, clearly defined & controllable experimental conditions in a closed action-perception loop.
Systems Engineering

- Rotating Rings
- Frame & Supports
- Motors
- Drive Train

Mechanical Engineering

- Frame Design and Analysis
  - Stress Analysis
  - Displacement Analysis
Mechanical Engineering

• Drive Train

Inner Disk & Foot Ring
Double Flanged Bearings
Ball Bearing
Synchronous Belt Sheaves
Drive Shaft

Overall Goal

The overall goal of this research program is to investigate what constitutes effective, robust, and intuitive human spatial orientation and behavior. This fundamental knowledge will be applied to design novel, more effective human-computer interfaces and interaction paradigms that enable similar processes in computer-mediated environments like virtual reality (VR) and multi-media.

iSpacer's
Daniel Feuereissen (MSc)
Dinare Moura (PhD)
Mechatronics CoOp's
Etienne Naugle
Adam Hoyle
Anton Brosas
Soon:
Lonnie Hastings (PhD)
Jay Vidyarthi (MSc)
Rances Narvaez (PhD)
Moving headphone-based 3D audio rendering can inducevection. "Acoustic landmarks" help spatialization quality not critical for vection.

Adding spatialized sound of visual landmark (fountain) enhances vection & presence.

- Natural, globally consistent scene & depth cues enhance visually-induced vection & presence.
- Vestibular: Minimal motion cueing (jerks of a few cm).
- Vestibular & proprioctic self-generated motion cueing.
- Audio + biomechanical cues (stepping on circ. treadmill).
- Audio + infrasound or vibrations.

- Visual + auditory cross-modal facilitation.

- Auditory

- Possibility of actual motion.

- Cognitive & higher-level influences

- Multi-modal spatio-temporal consistency

- \#Cognitive & higher-level influences

- \#Multi-modal spatio-temporal consistency

- Summary


- Multi-modal spatio-temporal consistency.

- Riecke et al., TAP (2009), Lepecq et al. (1995), Wright et al. (2006).

- Riecke et al., VRST (2006).


- Auditory

- Possibility of actual motion.

- Further info: www.siat.sfu.ca/faculty/Bernhard-Riecke/ber1@sfu.ca