Virtual Reality & Physically-Based Simulation
Introduction, Immersion, Presence, Fidelity

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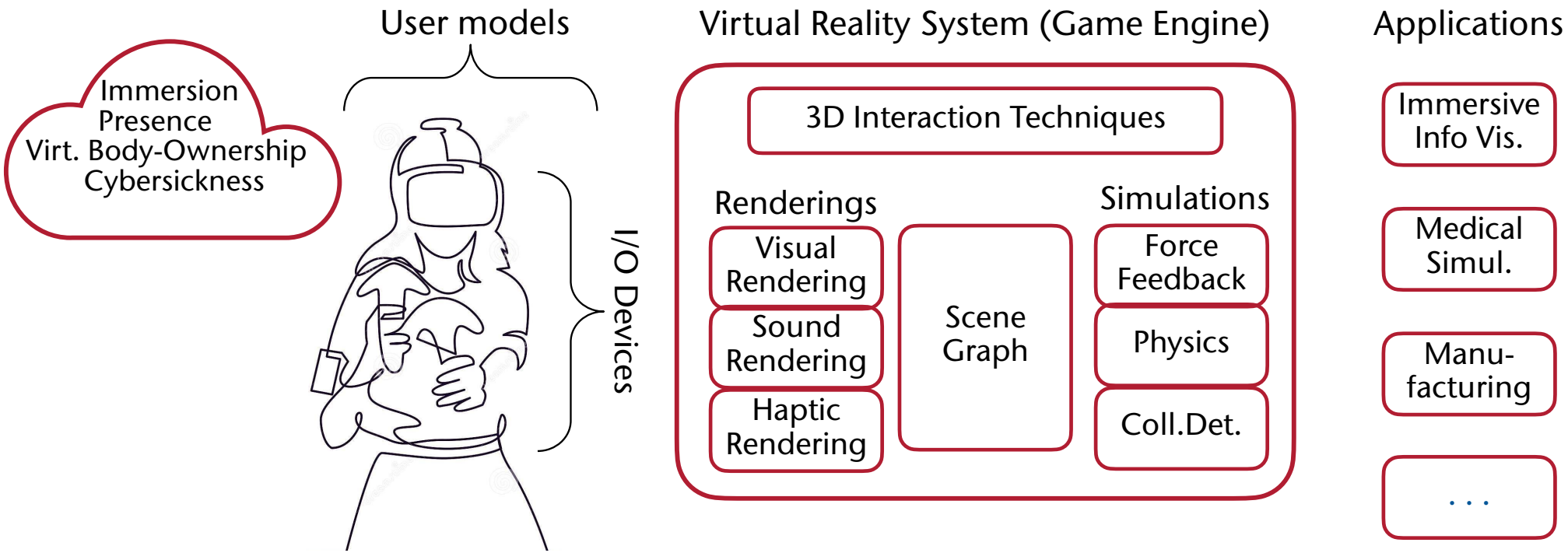
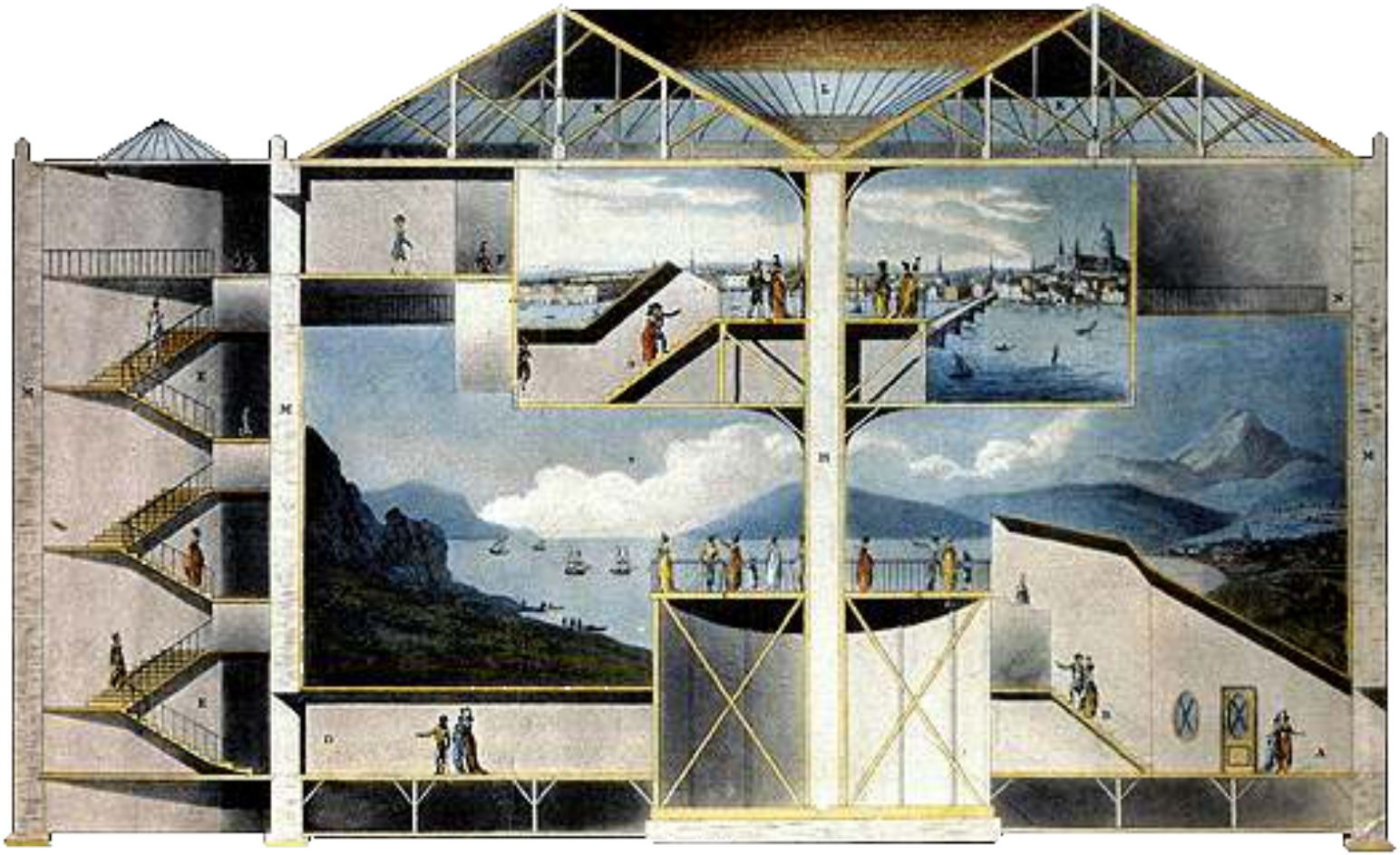
Overview of the Field of VR (and the Course)



- "[They] are among the happiest of contrivances for saving time and expense in this age of contrivances. What cost a couple of hundred pounds and half a year [...], now costs a shilling and a quarter of an hour. Throwing out of the old account the innumerable miseries of travel, [...] and the insufferable annoyances of [...] an Italian bed. [...] Now the affair is settled in summary manner."
- What does the author of the quote describe? ...
- The *Panorama* !
  [Blackwood's Edinburgh Magazine, vol. 15, pp. 472, 1824]



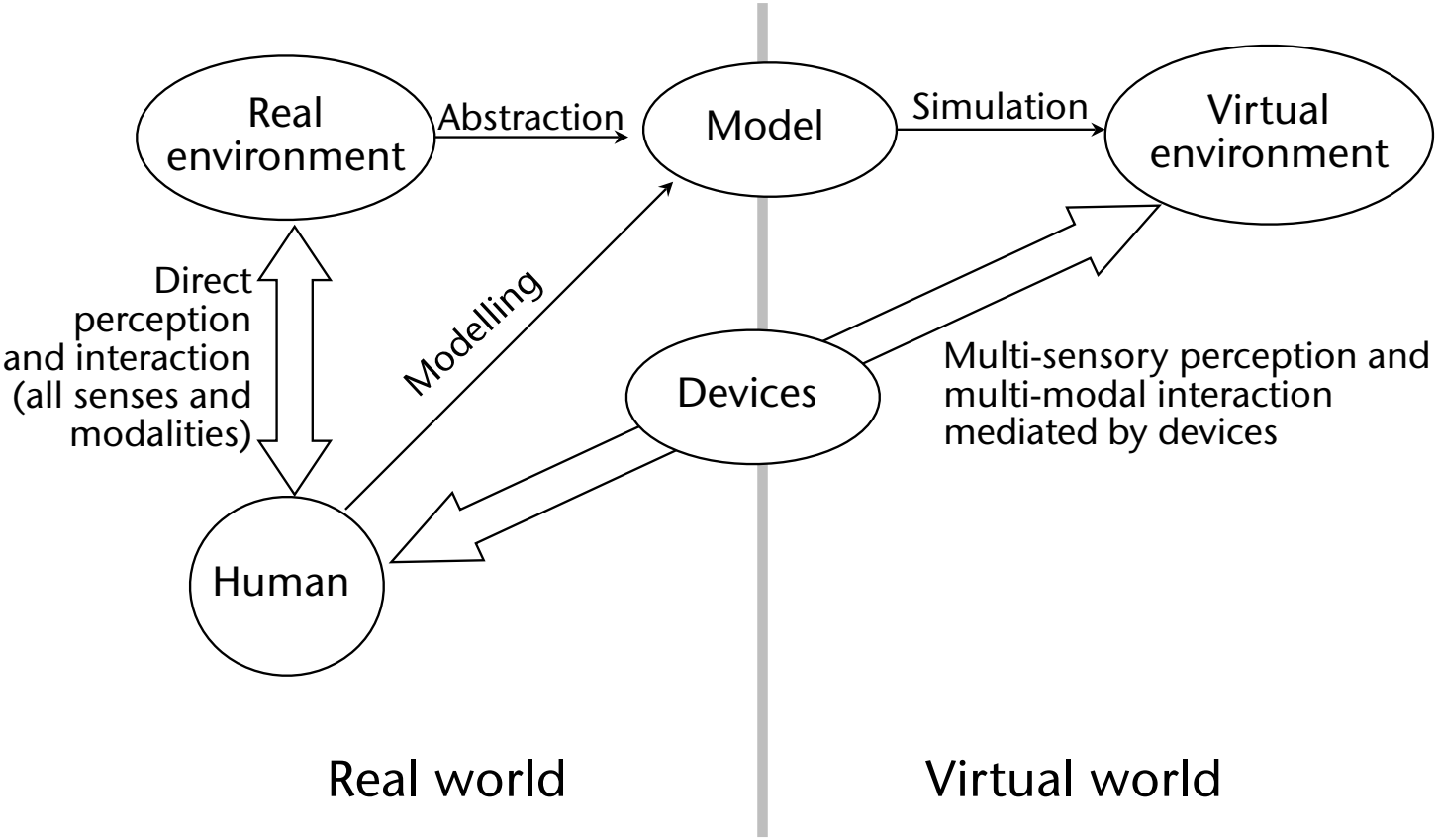
Cross section of Robert Barker's Panorama, Leicester Square, London,1789

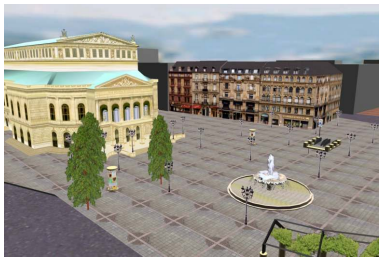
Bourbaki's Panorama in Luzern

VR is the Latest Technology for Virtualization

Walk, grab, ...

See, hear, feel, smell, ..



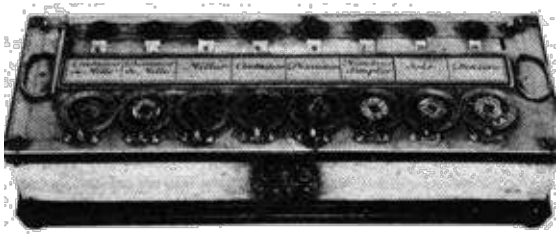


Inter-action meta-phors

See, hear, feel (?), smell ?, ..

A Few Words on Historical Context and the Future

I see two strands: first it happened in the arts, then technology took over



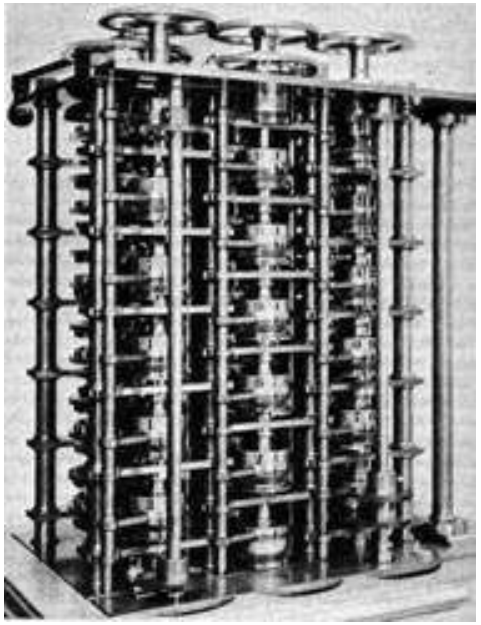
30,000 v. — Caves of Lascaux

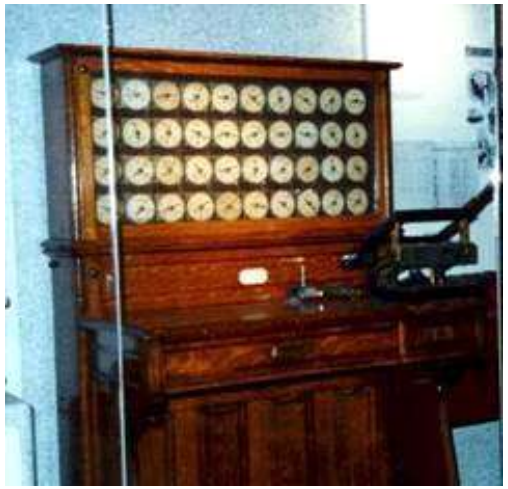
400 v. — Abacus

15. Jh. — Central perspective (Brunelleschi)

1642 — Mechanical calculators by Schickard & Pascal

1801 — Jacquard's loom with punched cards





1834 — Difference / Analytical machine (Babbage)

1854 — Boole "discovers" the binary numbers

1890 — Census in USA uses Hollerith's card tabulators

1924 — Founding of IBM

1929 — First flight simulator (Link trainer)

1936 — Turing maschine

1938 — Z1

1958 — Z60: precursor of CAD systems

1963 — Sutherland's "Sketchpad"

1962 Sensorama by Morton Heilig

Flight a a “ a generators" and motion platforms

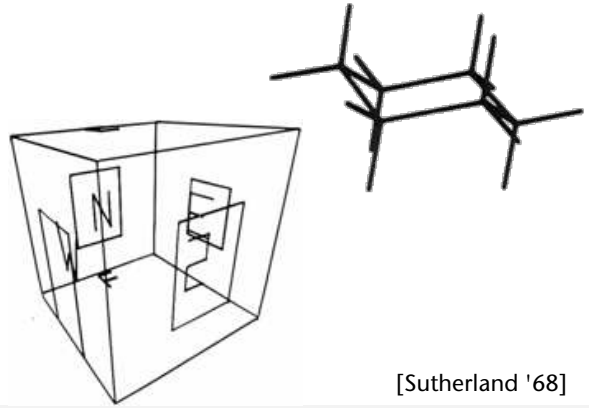
1981 Dataglove by Zimmermann

1983 First commercial HMD

1985 "Virtual Environment Display System" program of NASA

"The Ultimate Display .." or: Multimodal Rendering

- Quotes from the paper [1965]:
  - "If the task of the display is to serve as a looking-glass into the mathematical wonderland constructed in computer memory, it should serve as many senses as possible."
  - "I want to describe for you a kinesthetic [= force-feedback] display."
  - "Machines to sense and interpret eye motion can and will be built."
  - ".. We have little ability to have the computer produce meaningful sounds."
  - "The ultimate display would, of course, be a room within which the computer can control the existence of matter."
- First HMD [1968]



[Sutherland '68]

The "Sword of Damokles"

More Examples for Virtualization

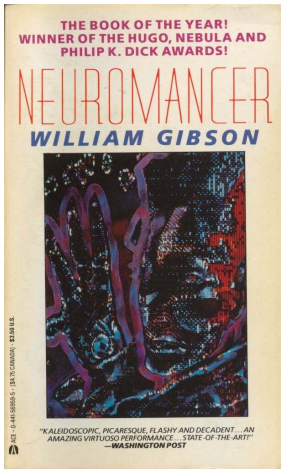
- Ca. 1900: Telephone
- Ca. 1950: TV
- Ca. 1980: MUDs (text-based multi-user adventures)
- Ca. 1990: erste Welle der Virtual Reality
- Ca. 2000: Shopping via internet
- Ca. 2005: "Social" platforms (Facebook, et al.)
- Ca. 2008: Second Life
- Ca. 2018: AltspaceVR, Mozilla Hubs, ENGAGE, ...
- Ca. 2017: holographic virtual companions (see *Gatebox, Virtual Home Robot*)
- 2020: Video-Conferencing (Zoom, etc.)

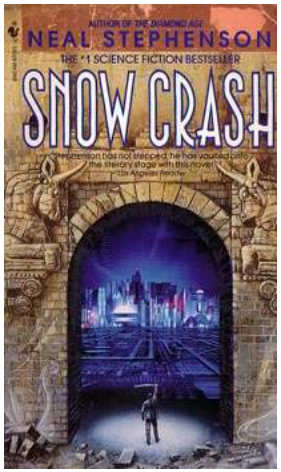
The Idea of VR is Not New

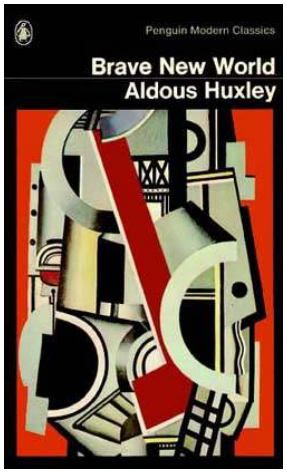
- Aldous Huxley: "Feelies" in *Brave New World,* 1932
- Vannevar Bush: *As We May Think*, 1945
- Ray Bradbury: *The Veldt*, 1950
- Morton Heilig: *El cine del futuro*, 1955
- Donald Sutherland: *The Ultimate Display*, 1965, Proc. Of IFIPS congress
- Many SciFi authors: Vernor Vinge, William Gibson, Neal Stephenson, ...
- Many movies: The Matrix, Lawnmower Man, Ready Player One, ...

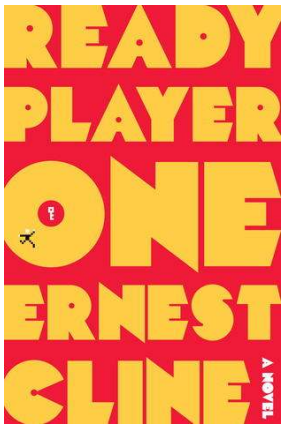
SciFi Literature Containing a Large Amount of VR

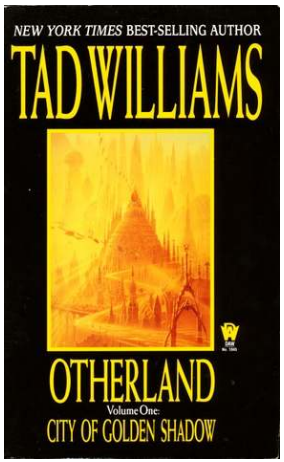
- Aldous Huxley: *Brave New World*, 1932
- William Gibson: *Neuromancer*, 1984
- Neal Stephenson: *Snow Crash*, 1992
- Michael Heim: The Metaphysics of Virtual Reality, 1994 [philosophy]
- Tad Williams: *Otherland*, 1996-2001
- Ernest Cline: *Ready Player One*, 2011
- Any important book missing? ...











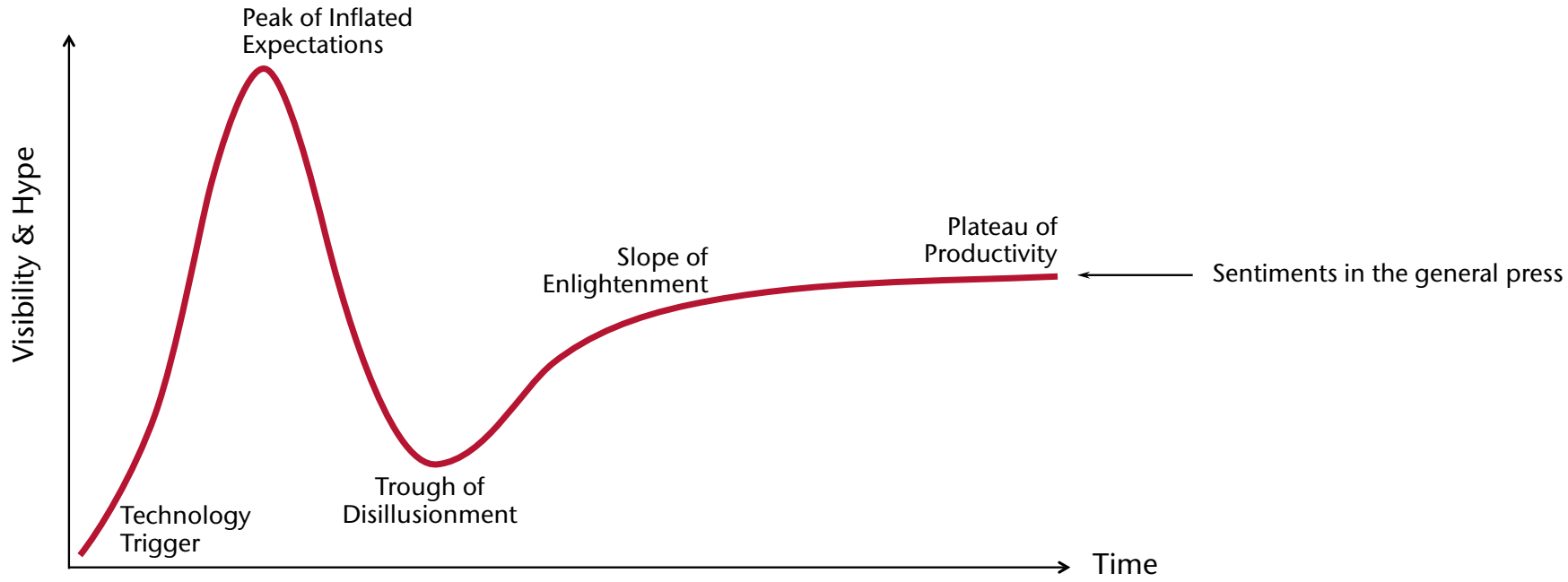
Gatebox - Virtual Home Robot

Excerpt from *Surrogates* (2009)

How far do we want to go with virtualizing our social lives?

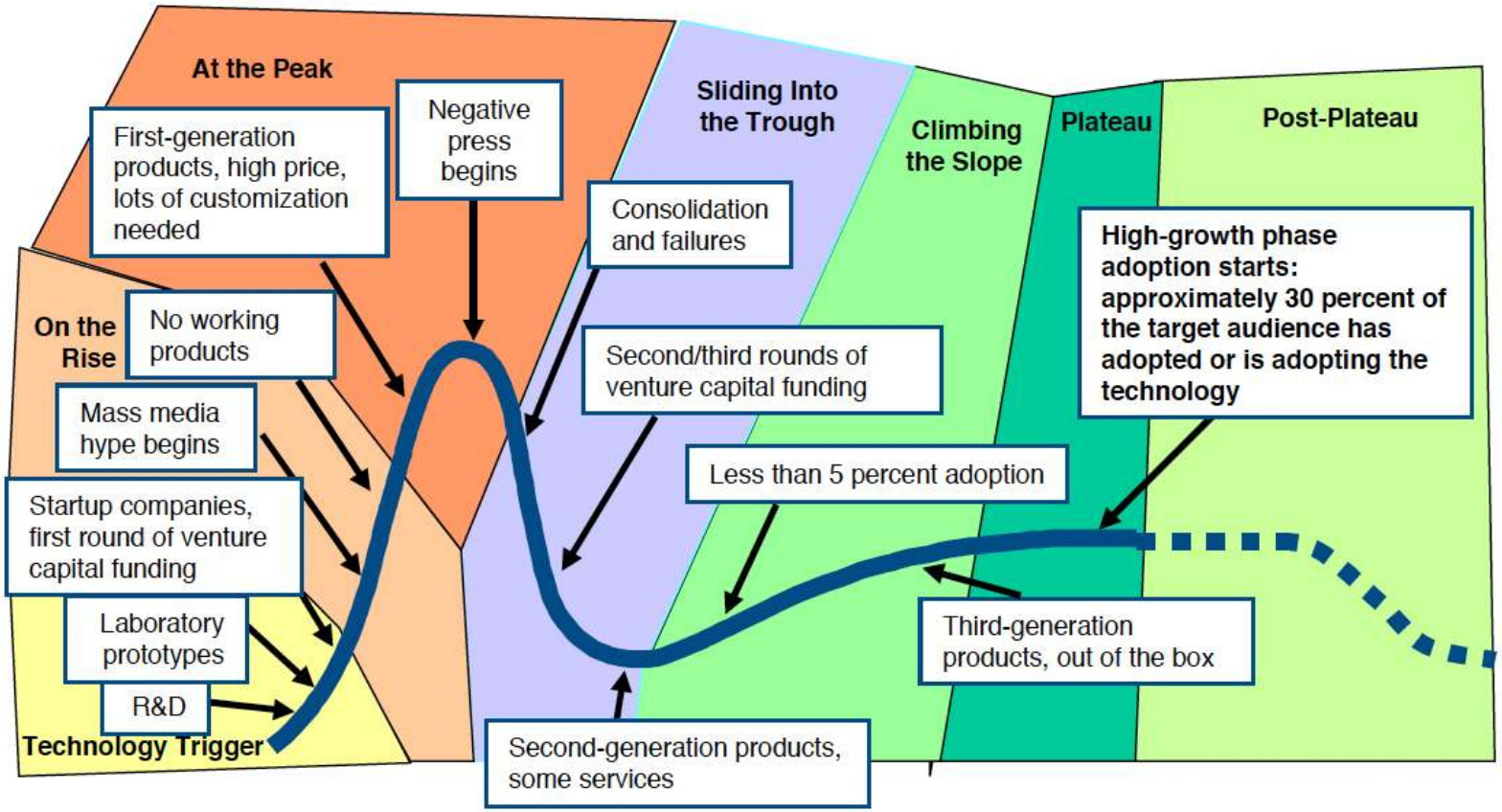
Gartner's Hype Cycle for Emerging Technologies

- Graphic representation of over-enthusiasm, disillusionment, and eventual realism that accompanies each new technology

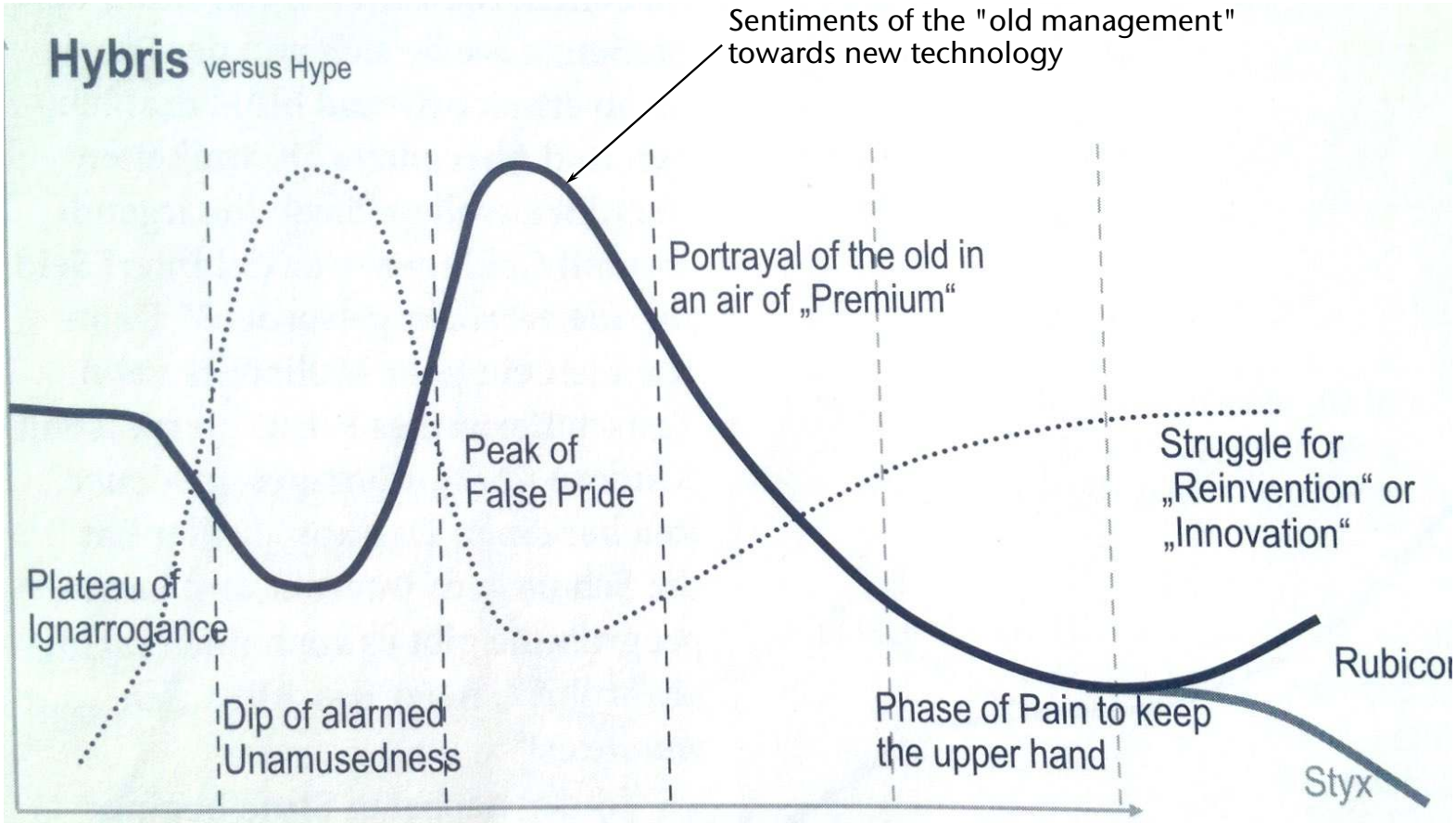


[Jackie Fenn, 1995]

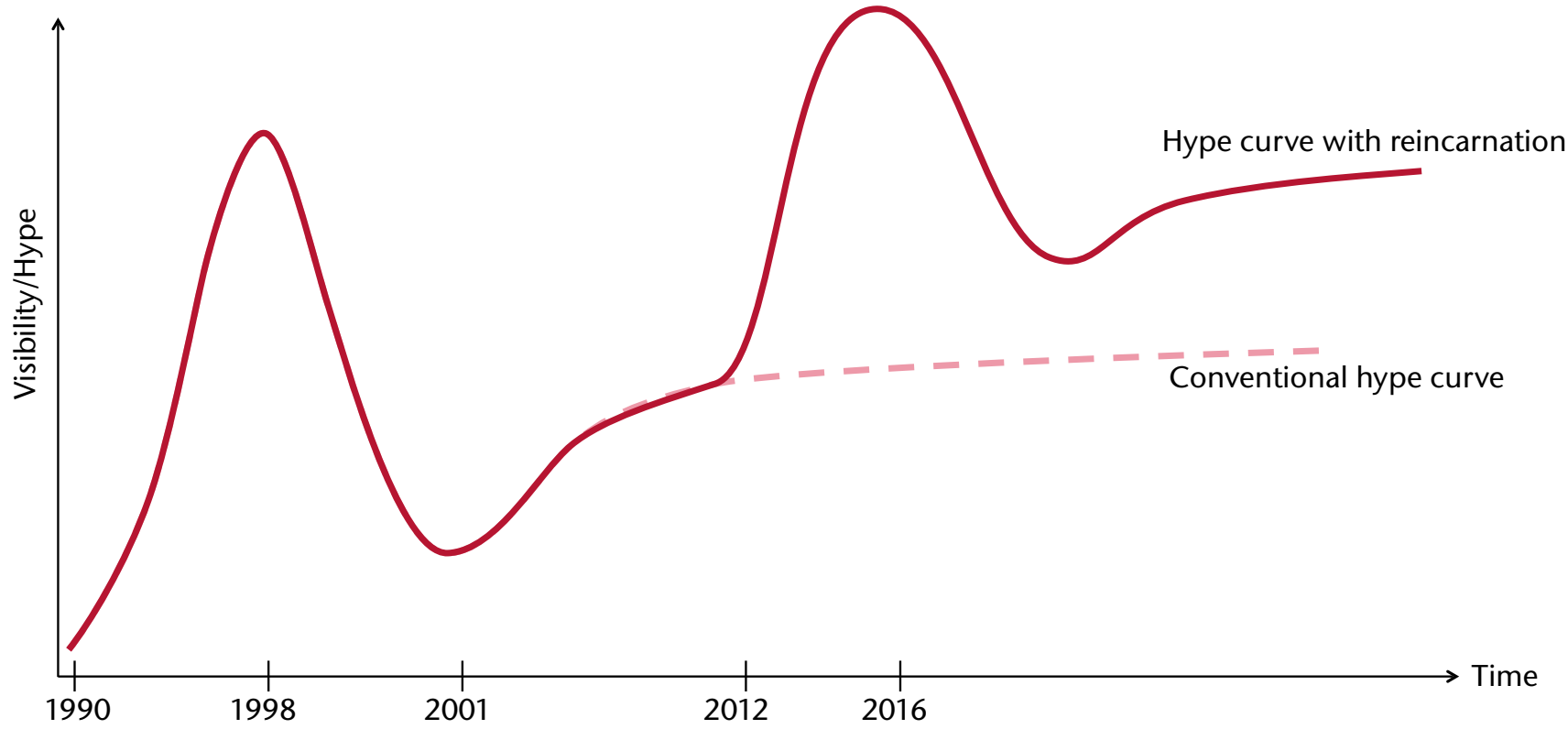
In More Detail



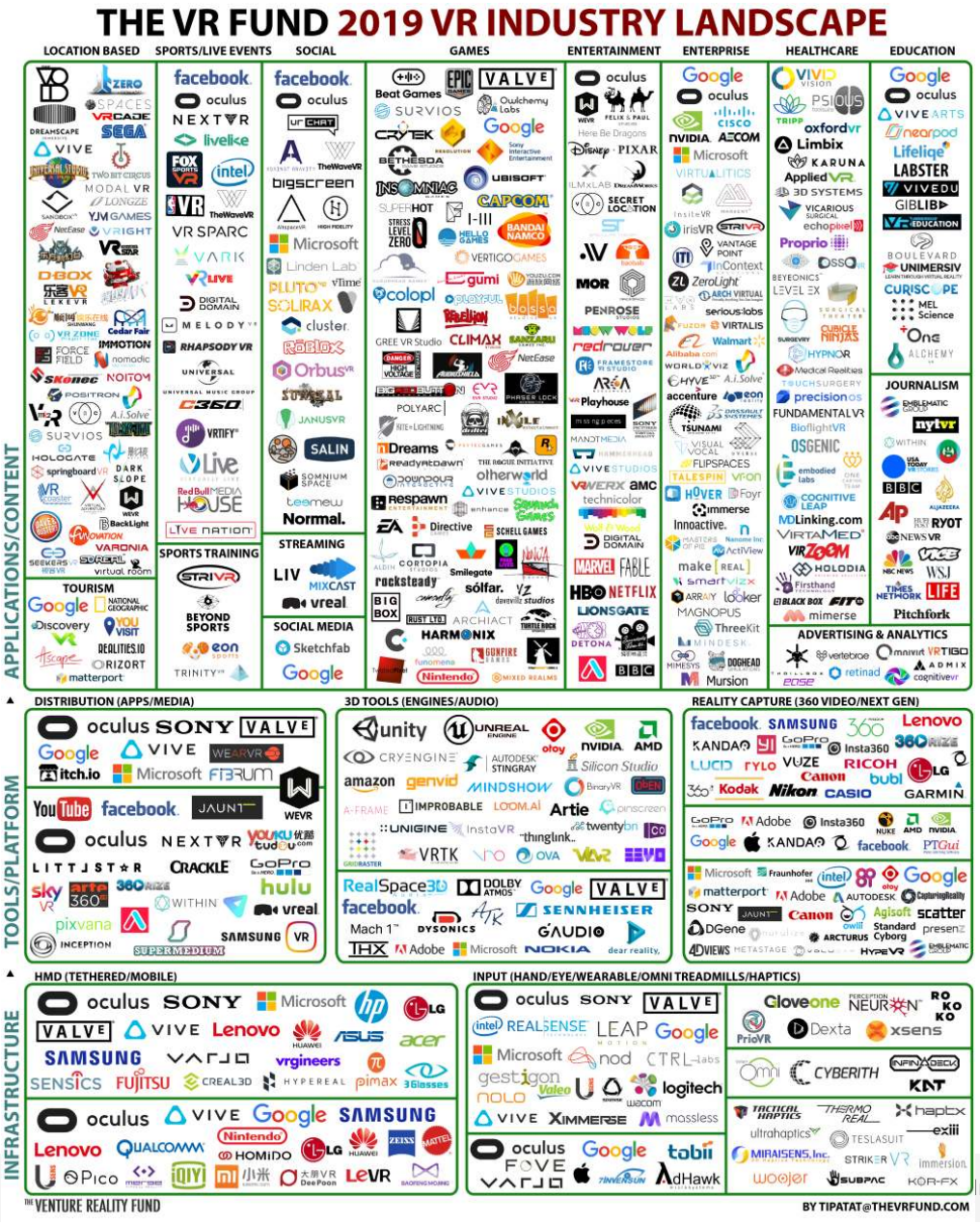
Gunter Dueck's Hybris Curve



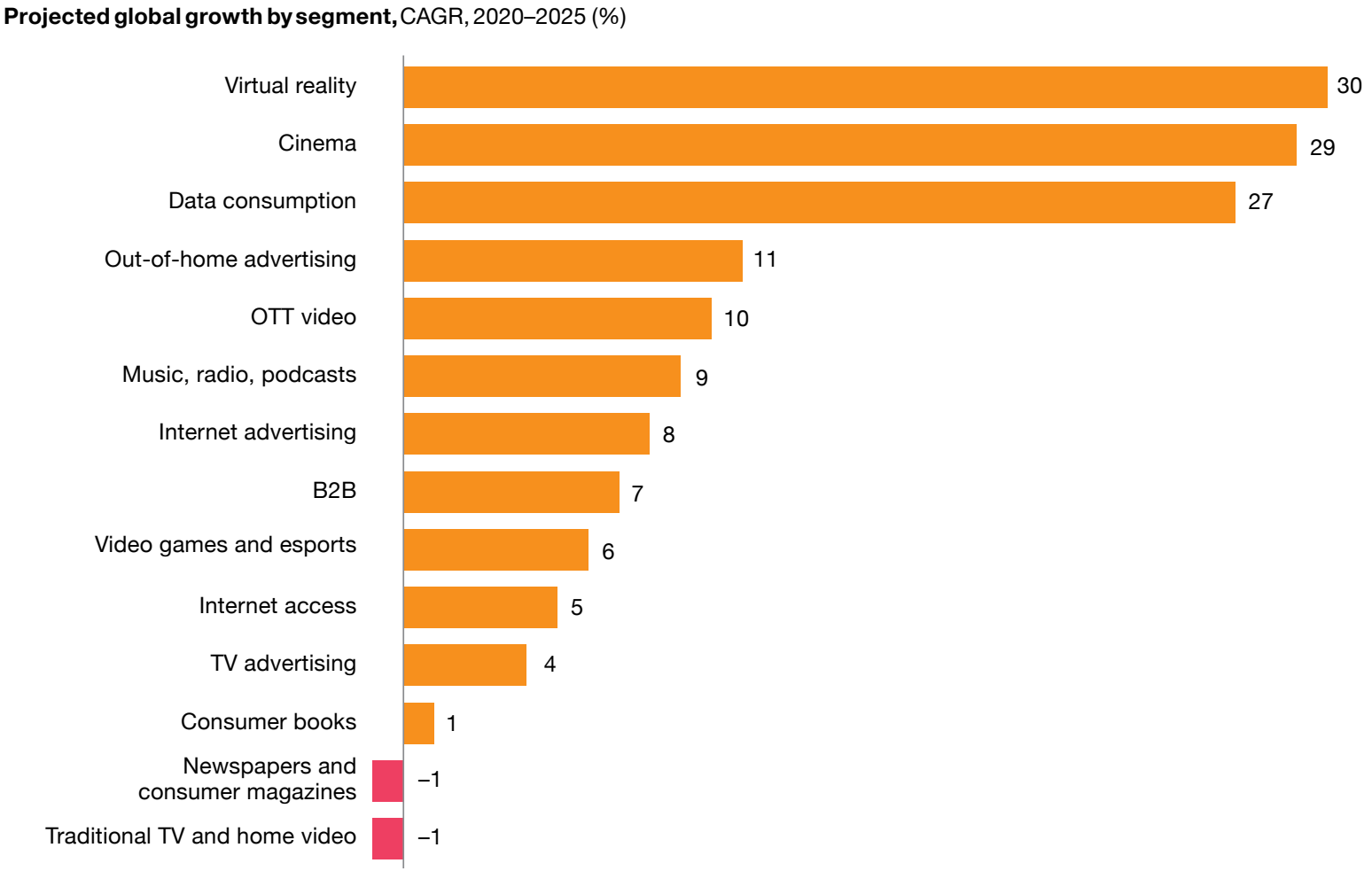
In VR, we See a "Curve of Reincarnation"



Gabriel Zachmann, 2016


THE VR FUND 2019 VR INDUSTRY LANDSCAPE
LOCATION BASED
SPORTS/LIVE EVENTS
SOCIAL
GAMES
ENTERTAINMENT
ENTERPRISE
HEALTHCARE
EDUCATION
APPLICATIONS/CONTENT
TOURISM
STREAMING
SOCIAL MEDIA
SPORTS TRAINING
JOURNALISM
ADVERTISING & ANALYTICS
TOOLS/PLATFORM
DISTRIBUTION (APPS/MEDIA)
3D TOOLS (ENGINES/AUDIO)
REALITY CAPTURE (360 VIDEO/NEXT GEN)
INFRASTRUCTURE
HMD (TETHERED/MOBILE)
INPUT (HAND/EYE/WEARABLE/OMNI TREADMILLS/HAPTICS)
THE VENTURE REALITY FUND
BY TIPATAT@THEVRFUND.COM

The VR Sector has Currently the Biggest Growth in E&M



The 2-Minute Introduction to VR

[www.not-for-wimps.org]

The Goal of Virtual Reality for Serious Appl's

- More efficient Human-Computer-Interaction (HCI) by "post-WIMP interfaces"
- Better user performance

Goals of VR for Customers

- Intuitive & pleasurable user experience (consumers)
- Shorter time-to-market (manufacturing)
- Helps non-experts with spatial understanding of designs at early stage (visualization, car design, architecture, etc.)
- Platform for communication among teams (CSCW)

Definitions of VR

Steve Bryson:

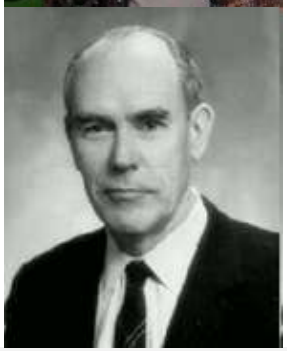
Virtual Reality (VR) refers to the use of three-dimensional displays and interaction devices to explore real-time computer-generated environments.

Carolina Cruz-Neira:

Immersive, interactive, multi-sensory computer-generated experiences.

Ivan Sutherland, 1966:

Indeed, in the ultimate display one will not look at that world through a window, but will be immersed in it.



Myron Krueger:

The promise of artificial realities is not to reproduce conventional reality, or to act in the real world. It is precisely the opportunity to create synthetic realities, for which there are no real antecedents, that is exciting conceptually, and ultimately important economically.

Lynne Dittmar:

VR emulates the information presented to the human visual (aural, tactile) system by the "real world".

In communication theory:

A medium for communication, consisting of synthetic spaces and people, both of which represent equal and integral components of a digital system.

What VR is *NOT*!

David Mizell:

Every computer graphics system after 1990. ☺

Manufacturing industries:

Interactive, 3D visualizations of simulations (e.g., crash simulation)

(a position held, in particular, by the executives in those industries)

Multimedia format, such as

QuicktimeVR

VRML

David Blatner:

Virtual Reality is a way for humans to visualize, manipulate, and interact with computers and extremely complex data

Business Week:

Virtual Reality is a new tool to amplify the mind

William Gibson (Neuromancer):

Cyberspace

My Definition

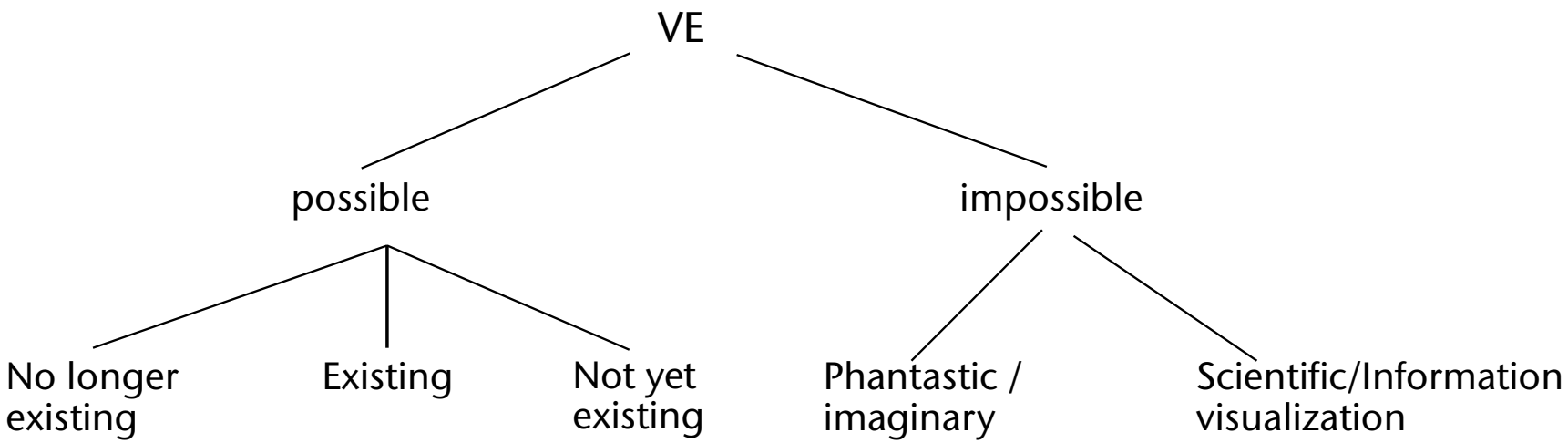
It is virtual reality, if the following criteria are met:

1. Rendering in real-time,
2. Simulation in real-time,
3. Interaction in real-time,
4. Intuitive interaction (usually involves post-WIMP input devices),
5. Immersion: stimulation of as many senses as possible by the computer,
6. Presence, possibly.

Ingredients of VR Systems (Ideal)

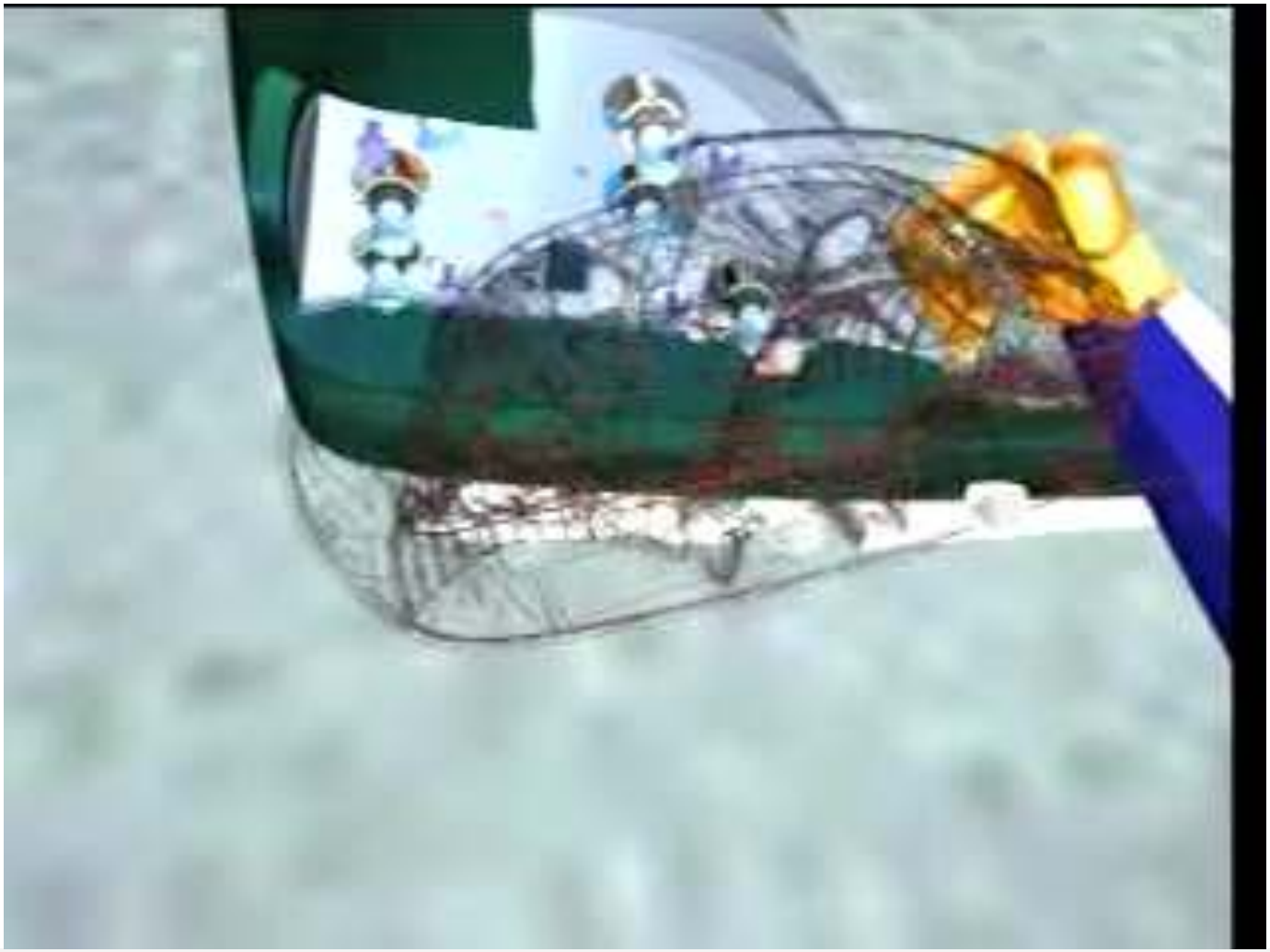
- In order to achieve that, you need:
- Post-WIMP, multi-dimensional input devices
- Visual displays that can present images with depth
- Haptic devices (force displays)
- Powerful graphics hardware (is a commodity today)
- Speech input & spatial sound output
- Algorithms!

Classification of Types of Virtual Environments / Appl's



Cultural Heritage Applications ("No Longer Existing VE")

Assembly Simulation Applications ("Not yet Existing")

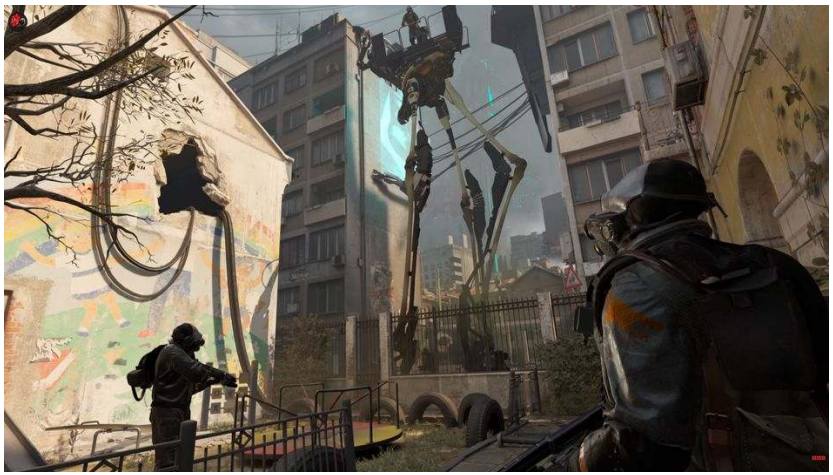


Creative Arts Applications ("Phantastic/Imaginary" VE's, Probably)

Quill, VR Drawing in the Production of Oculus Story Studio's New Movie, Inigo Quilez, Wesley Allsbrook, Oculus Story Studio, Siggraph 2016

Entertainment Applications

Aladdin's Magic Carpet VR Adventure, in operation 1998-2016, arguably one of the most persistent VR entertainment installations



Human Flight Simulators

Iron Man Flight Simu-lator

Icaros

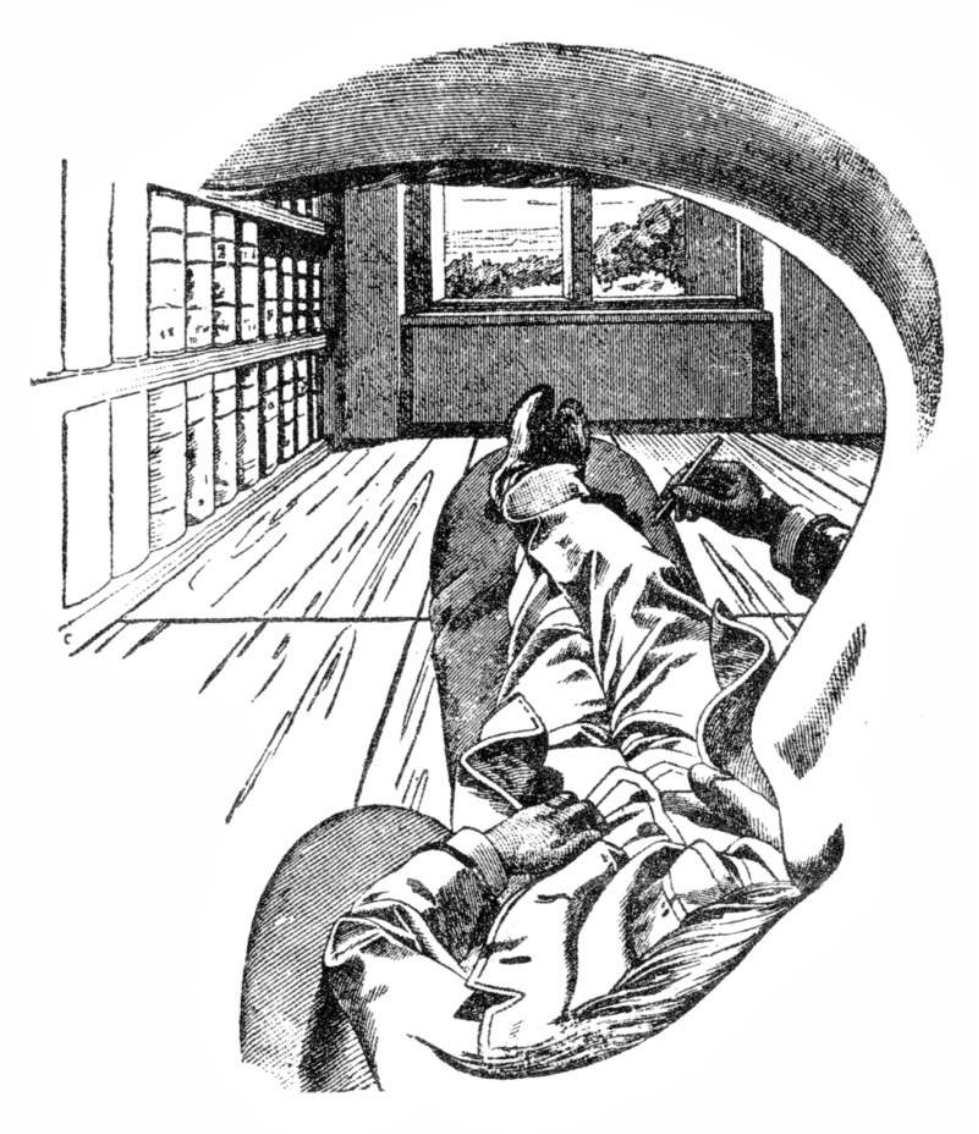
Birdly (Zürich University of Art and Design)
Types of feedback: visual, auditory, haptic, wind, smell

Virtual Reality and Games Have a Lot in Common

- Very high demands on rendering:
  - VR: 1. high polygon count, 2. high frame-rate, sometimes quality
  - Games: 1. high frame-rate, 2. special effects
- Interaction: efficient, "non-intrusive", natural,
- Object behavior:
  - Physically-based
  - Autonomous (aka. AI in games)
- Differences:
  - Size of market
  - Costs
  - Respective market segment targeted by each technology/industry

The technological differences have mostly vanished over the past few years!

They only hold when comparing applications of VR in industries with entertainment VR.



"The mind has a strong desire to believe that the world it perceives is real."

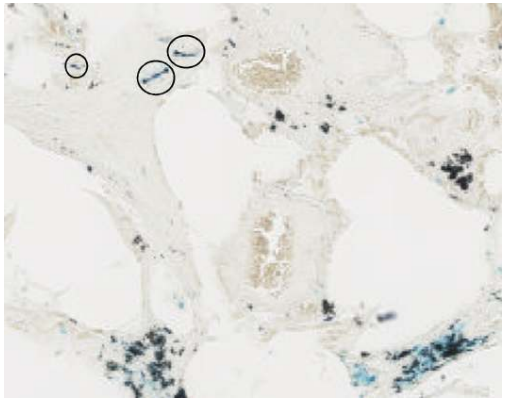
– Jaron Lanier

Immersion

- *Immersion* = "Eintauchen", borrowed from media theory
- Definitions of immersion:
  1. Complete immersion ⇔ all senses are stimulated consistently
  2. Complete immersion ⇔ user doesn't perceive real world any more
- Can be determined relatively easily:
  - Count number of senses that are stimulated by the computer
  - Count number of senses that are shielded from reality
- Unfortunately, there is no standard metric with which to *quantify* immersion!
- Caveat: Immersion ≠ Plausibility! (counter-example: SciFi virtual environment)

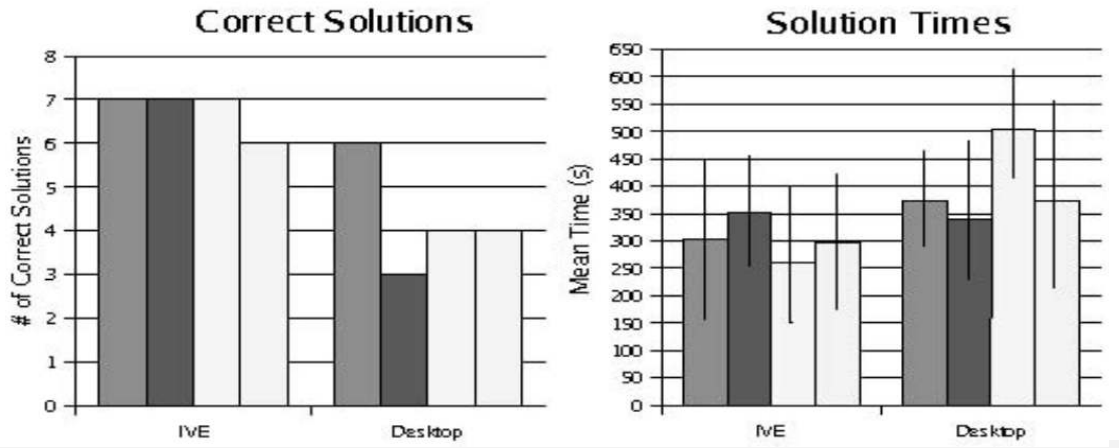
Benefits of Immersion

- Example: 2D search task
  - Three conditions (same input device):
    1. Standard monitor,
    2. Monitor with 130x70 cm,
    3. Large-screen projection with 300x130 cm,
  - Result: size is more important than resolution of the display
  - Task performance is 30% faster with large-screen projection than with (1) and (2)
- Immersive scientific visualization:
  - "positive impact on visualizing scientific data with complex 3D spatial relationships" [LaViola et al., 2009]
  - "Body-centric interaction appears to be another important component" [ibid.]

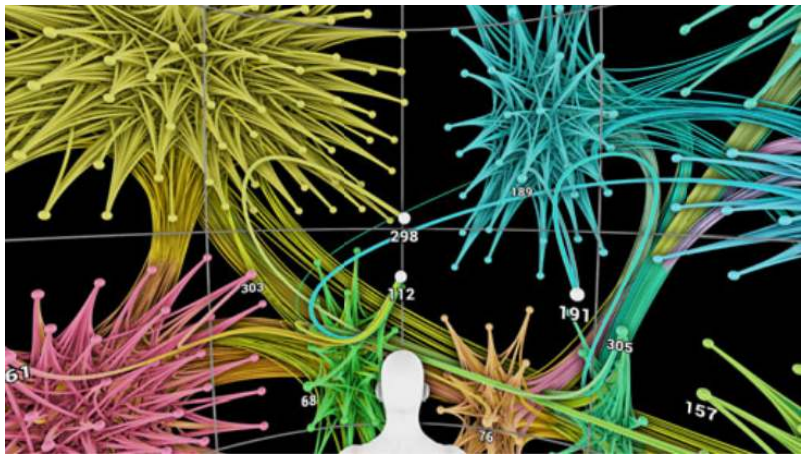


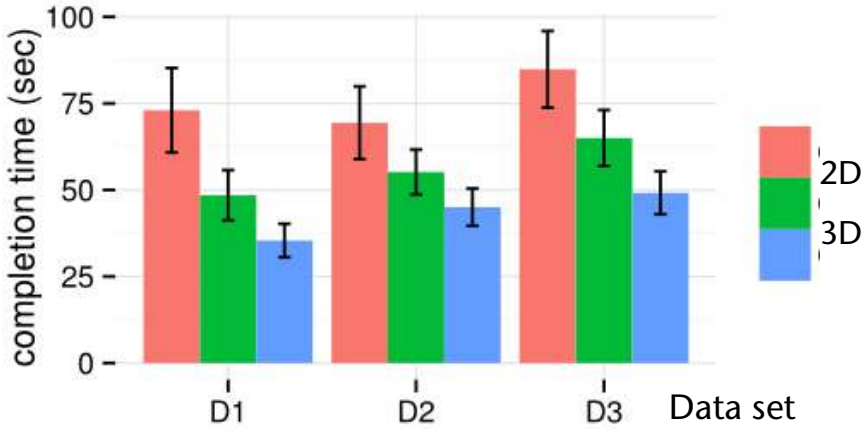
Benefits of Immersion

- Example: planning of oil well paths
  - 16 participants, 4 different tasks
  - Two conditions:
    1. immersive VE (cave)
    2. desktop
  - Number of correct solutions:
    9 of 16 participants had more correct solutions in VR,
    1 user had more in desktop cond.,
    6 had same number in both cond.
  - Task completion time:
    15 of 16 were faster in VR



- Example: graph visualization
  - Conditions:
    1. 2D graph layout
    2. 3D graph rendering
  - Tasks:
    3. Find highest degree node
    4. Find a path, and others
  - Data sets:
    5. small graph: 34 nodes, 78 edges
    6. large graph: 300 nodes, 2300 edges
    7. in between
  - Result: cond. 2 has significantly shorter task completion time and a significantly fewer number of interactions than cond. 1 for more difficult tasks





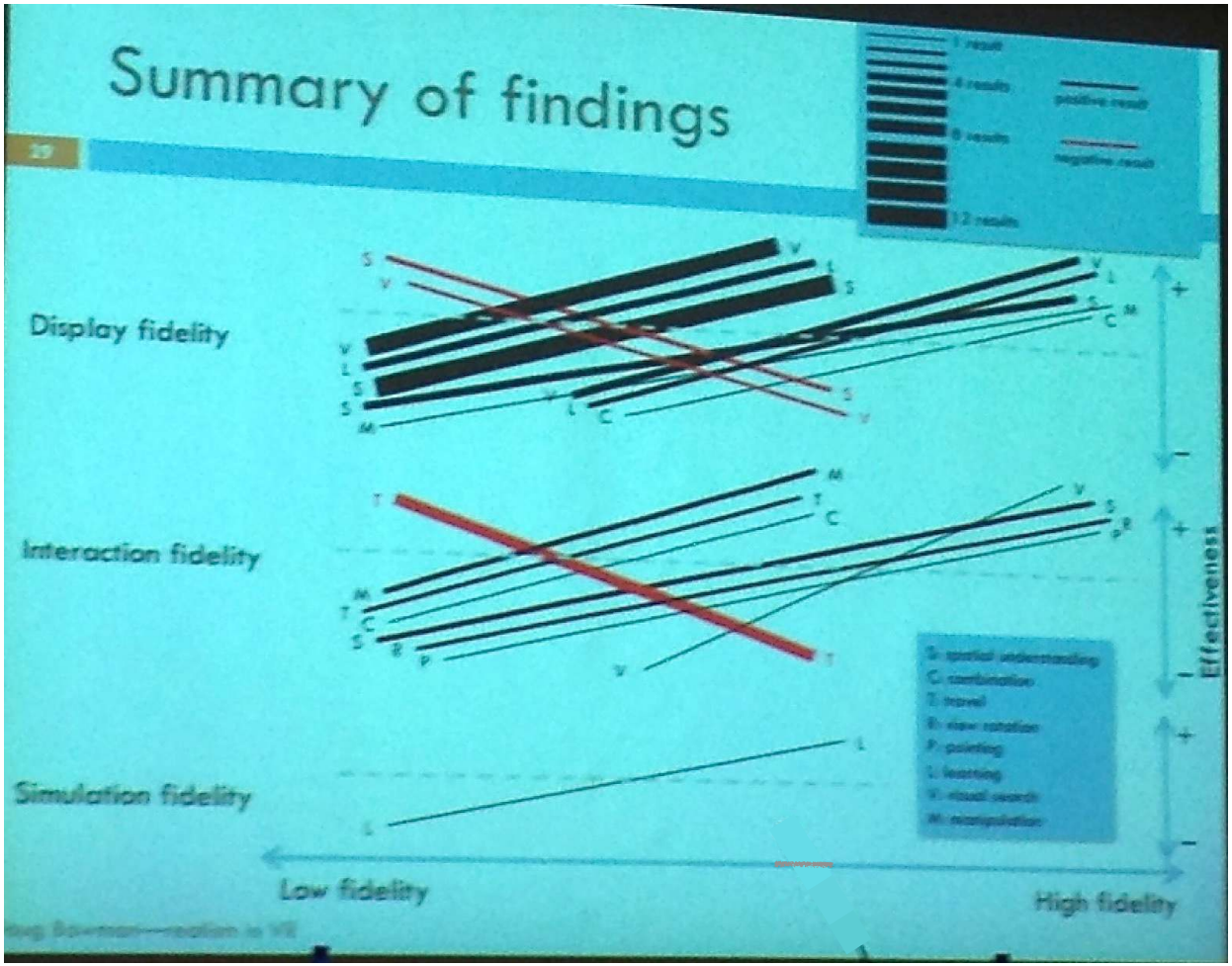
Fidelity

- *Fidelity* := objective level of realism of a virtual reality system
  - Ground truth, i.e., 100% fidelity = real world
- The three important components of the fidelity of a VR system:
  1. Rendering fidelity := level of realism of rendering
     - Visual rendering : image resolution, detailed textures, correct lighting, etc.
     - Haptic rendering : do rigid objects feel stiff? Forces on all fingers, or one handle only?
     - Auditory rendering : does the virtual room sound like real rooms?
  2. Interaction fidelity := level of realism of interaction with virtual objects
  3. Simulation fidelity := level of realism of behavior of virtual objects
     - E.g., does the cloak of a virtual character behave like real cloth?
- Note: higher fidelity does not necessarily imply higher user performance! (but maybe more motivation/fun = "hedonistic quality")

Factors Increasing Visual Fidelity

- Visual depth cues:
  - Occlusion
  - Perspective foreshortening
  - Stereo parallax (convergence of eyes)
  - Head motion parallax (german: Bewegungsparallaxe)
  - Accomodation (focussing of our eyes' lenses)
  - Color/contrast change with increasing distance
- Shadows: caused by (direct) light source and shadow caster
- Global illumination: simulation of light transport throughout scene
- Textures and other fine detail

Is More Fidelity Always Better?



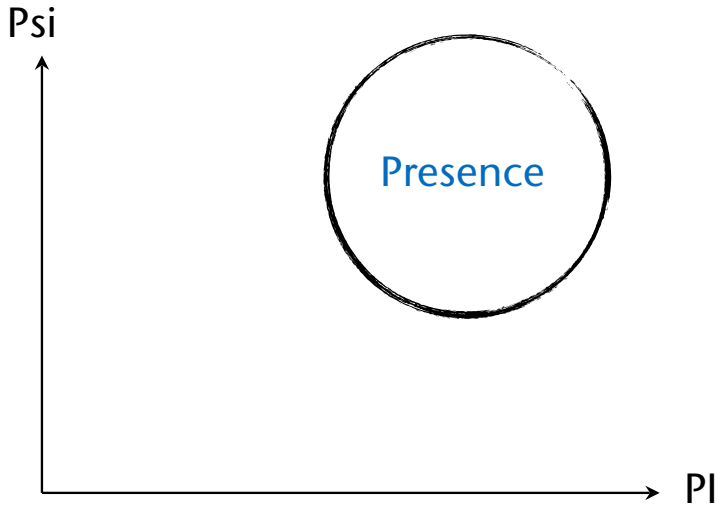
[Doug Bowman, JVRC'12]

Is More Fidelity Always Better?

- Higher fidelity (all 3 kinds) often results in higher effectiveness
- Sometimes, the effect is rather weak, or even not statistically significant
- Very few cases where higher fidelity is detrimental
  - Travel techniques are one strong case for **less** fidelity
- Best cases for high fidelity:
  - Difficult and complex visuo-spatial tasks
  - Learning and training
  - High-DOF interaction tasks

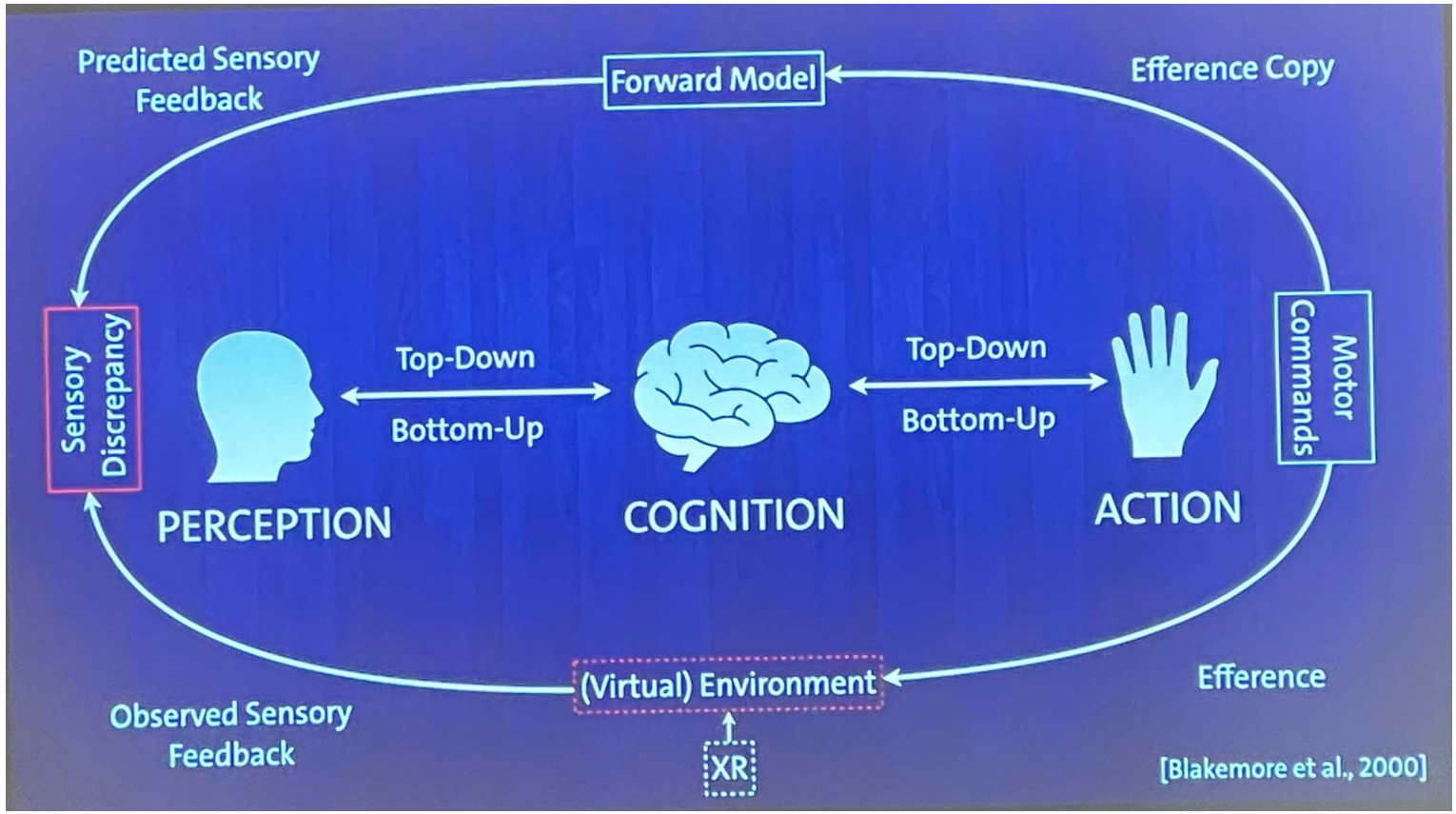
Presence (Much Harder to Define and Measure)

- Presence = *suspension of disbelief* (borrowed from literary studies)
- There are two orthogonal illusions at play
- Why are they called "illusions"?
- Place illusion (PI) = "being there" = illusion of "being in a place, in spite of the sure knowledge that you are not there"
- Plausibility illusion (Psi) = "this is really happening" = illusion of "what is apparently happening is really happening, in spite of the sure knowledge that it is not"



Why does the Illusion of Presence Even Occur?

- Current trend in neuroscience:
  - Our brain actively maintains an *internal model* ("simulation") of the body and the environment around it
  - Using that it tries to *predict* the sensory input to be expected in the immediate future
  - Simultaneously, it tries to minimize the amount of prediction errors (or ‘surprise’)
  - Called "Predictive Coding" in neuroscience
- Some evidence:
  - Mirror neurons
  - Canonical neurons


Predicted Sensory Feedback
Forward Model
Efference Copy
Sensory Discrepancy
Top-Down
Bottom-Up
Top-Down
Bottom-Up
Motor Commands
PERCEPTION
COGNITION
ACTION
(Virtual) Environment
Efference
Observed Sensory Feedback
XR
[Blakemore et al., 2000]

Neuroscientific Explanation of the Emergence of the Feeling of Presence

- During the execution of any action, outcome to be expected as sensory input is predicted, along with transmitting the actual motor commands
- Sensors (eyes, ears, ...) observe outcomes of the action
- Observation matches the brain's predictions → feeling of presence
- Observation and prediction mismatch ⟶ break in presence
  - Then, brain needs to focus attention on the discrepancy to deal with it

Corollaries

- Sensorimotor contingency: degree to which sensory feedback corresponds to the user's actions and matches their expectations, i.e., is consistent with reality
  - Frequent example: user moves head ⟶ visual percept changes (i.e., motion parallax)
  - Dito: walking, reaching for object, ...
  - Factors decreasing sensorimotor contingency:
    - Tracking errors, latency, low degree of agency, ...
- Multimodal consistency/congruency: degree to which sensory stimuli are consistent with each other
  - Example: virtual hand touches a virtual object ⟶ visual stimulus; if our real hand feels an obstacle at the same time ⟶ visuo-haptic consistency (a.k.a., visuo-haptic synchronicity)
  - Factors decreasing multimodal consistency: ....

Example of Importance of Visuo-Haptic Consistency

Multi-Sensory Integration

- Our brain tries to combine all the sensory input from different channels and form one common, consistent percept
- Some senses have priority over others, e.g., seeing over feeling ⟶ multi-modal consistency does not have to be perfect in VR
- Example:

[EPFL-IIG]

A Different Categorization of Types of Presence

- Spatial Presence:
  1. A.k.a. the "I-am-Here" hypothesis of our brain, i.e., your mind believes that you are *part of a virtual/remote environment*
     - VR with presence creates a *"suspension of disbelief that they are in a world other than where their real bodies are located"* (Slater & Usoh).
  2. *It* is here
     - "Objects we see are *really* here"
     - Ex.: Car body style reviews in a virtual showroom

Co-located collaborative virtual environment (CVE)

- Social presence:
  - Sense of *being with another* (human, virtual being, AI)
  - Often important in collaborative virtual environments (e.g., meta-verses)

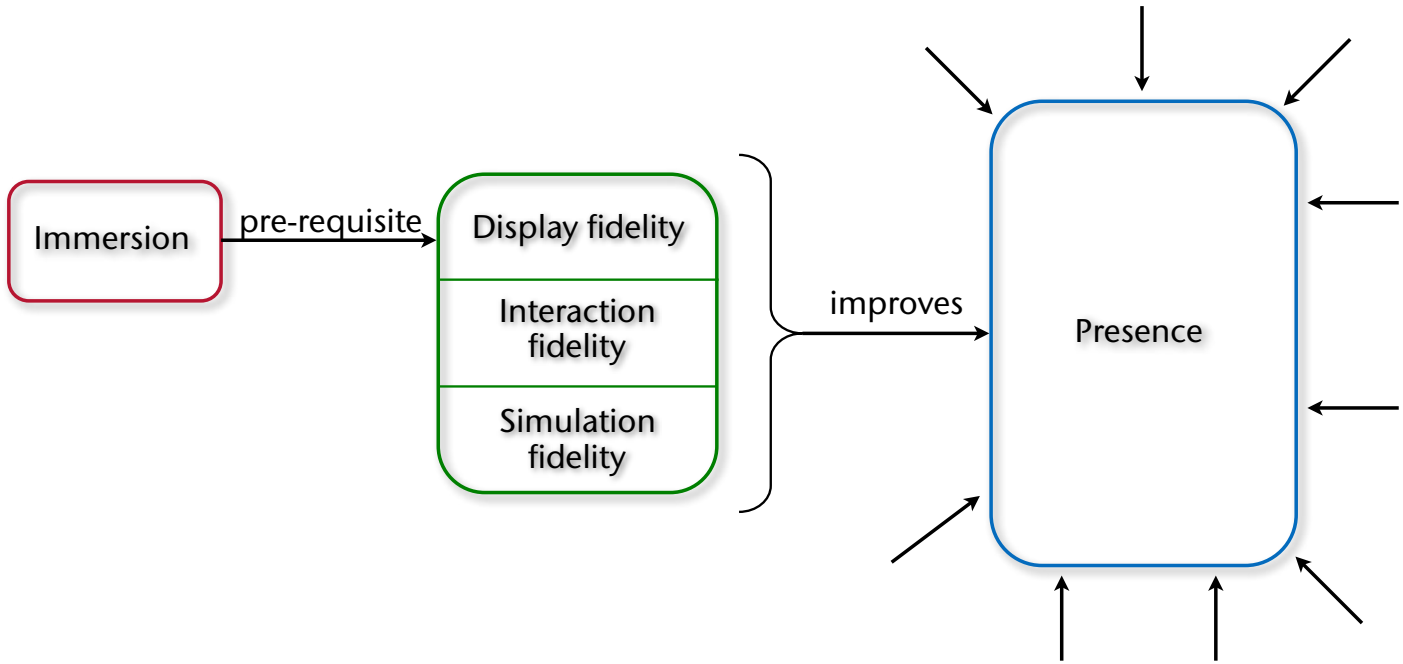
Distributed CVE

- Self presence (aka. "This-Is-Me" hypothesis, aka. virtual body ownership):
  - "It is really **ME** who is experiencing things"
  - Sensory input to your brain comes always from your body (or, rather, the sensors embedded in your body)
  - Examples:
    - Rubber hand illusion
    - Tools become a part of your body (there is neuronal evidence, i.e., some neurons appear to represent the tools the person currently uses)
    - Virtual hand illusion: the brain adopts the virtual hand as its own (again with neuronal evidence)

Tele-Presence: a Different(?) Kind of Presence

Big Bang Theory

Relationship Between Immersion, Fidelity, and Presence

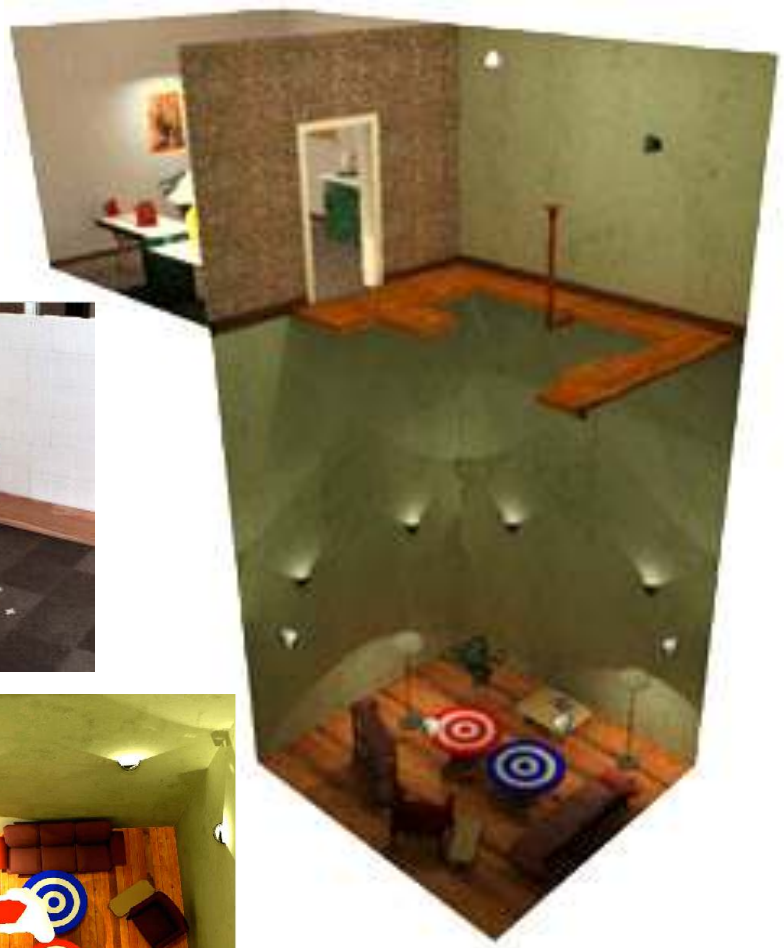


Factors Causing Presence

- Stereo vision
- Haptic feedback (consistent w/ vision!)
- Acoustics
  - Directional (3D) audio
  - Room acoustics
  - Soundscape
  - Personal footsteps
- Graphics frame rate
- Low system latency
- Large field of view
- Realistic (i.e., global) illumination
- Head tracking
- Natural locomotion: walking
- Control of events
- Dynamics (simulation of virtual object behavior, e.g. gravity)
- Virtual body ownership
- Isolation from surrounding reality (i.e., immersion)
- High cognitive load (my hypothesis ⟶ thesis?)
- Emotions (two-way influence)

Example: the "Pit Experiment"

- Subjects start in a real room, then put on an HMD, see the real room in the virtual environment, walk through the real=virtual door, and are then in the virtual "pit room"
- Conditions:
  1. Real walking
  2. Flying by joystick
  3. Virtual walking (virtual camera moves up & down)
- Results: high sense of presence *when really walking*
- Reasons:
  - Real walking (sensorimotor congruence)
  - Low latency (dito)
  - Stereopsis, spatial audio, passive haptics
  - Visual fidelity of the detailed, textured, radiosity-lit scene ? ...



Importance of Visual Fidelity for Presence?

- Seems inconclusive
- Experiment with 5 levels of visual fidelity: wireframe, ..., photo-realistic
  - No influence on anxiety when standing in front of pit
- Experiment with/without dynamic elements (shadows, reflections)
  - *With* dynamic elements (i.e., more realistic) increased anxiety!
-

More is *Not* Always Better - Sometimes There Are Exceptions

- Example: Beat Saber game in VR
- Conditions: with / without haptic vest
- Result: **no** statistically significant difference in ...
  - Sense of presence, and
  - Player experience
- Contradicts other experiments (with different settings)
- Explanation? ...

TactSuit, bHaptics

Beat Saber, Beat Games

The Importance of Presence

For treatment of phobias, e.g. fear of heights

For rehabilitation (?)

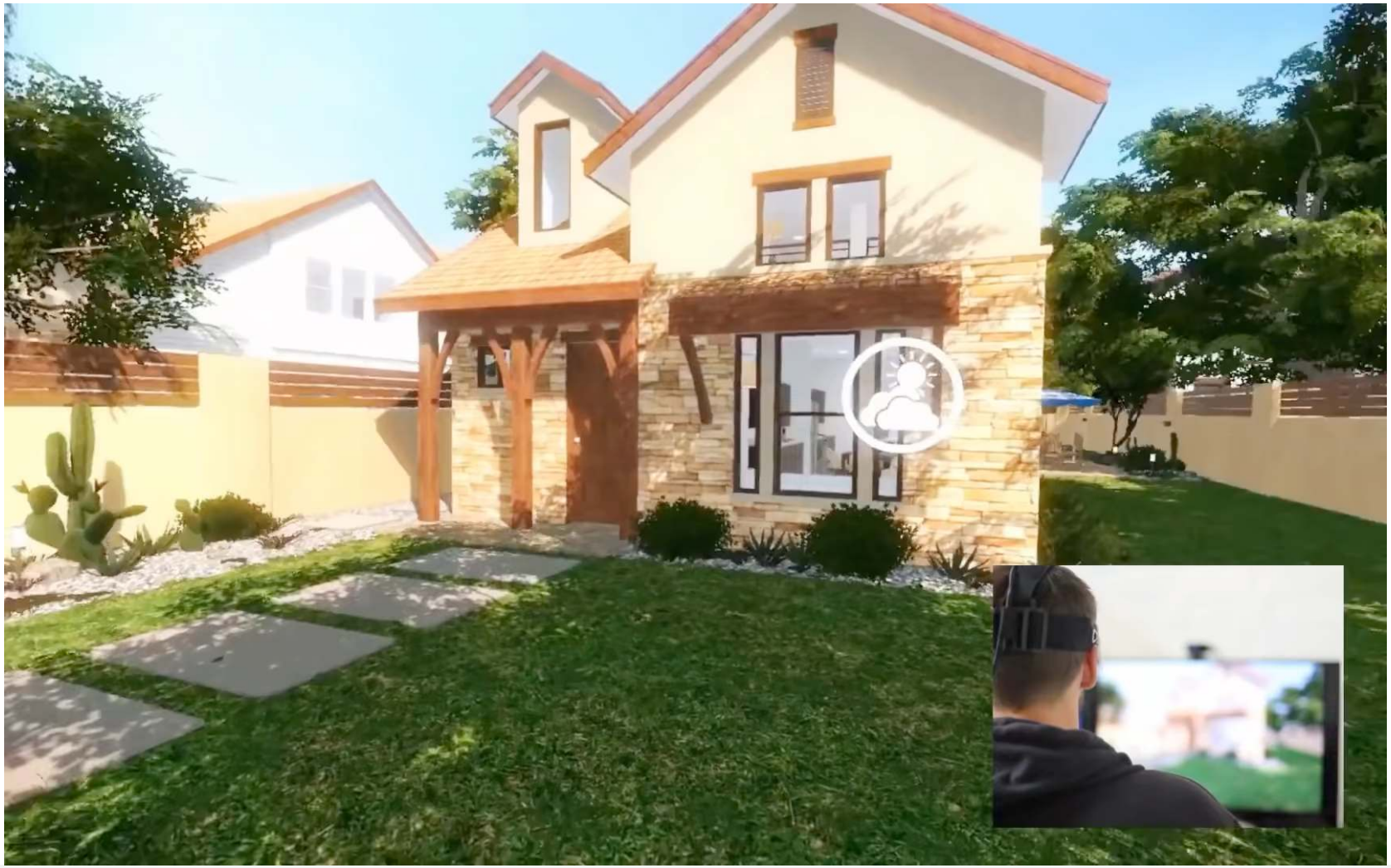
[Bandai Namco project "I Can"]

[Christou t al., 2018]

For performing user studies on usability / user experience

- Advantages: easier reconfiguration of the UI
- Prerequisite: high level of presence (and all its prerequisites)
  - Otherwise, the findings from the user study are probably not valid for RL

For Architectural Walk-Throughs



Viewport AU,
Fremantle,
Western Australia

Training Performance

- Task: learn building model airplane ⟶ procedural skill
- Conditions:
  - Instructional video (passive)
  - Fully immersive (HMD), actually trying to build the plane (experiential learning)
- Results:
  - No significant differences in task performance (task completion time, errors, and product quality) between the 2D video and VR!
  - But, participants who experienced a higher sense of presence scored better in all three performance metrics!

How to Measure Presence

- Presence is subjective = user's psychological (and/or physiological response?) to the system ⟶ hard to measure!

1. Mostly using questionnaires:
   - *Igroup Presence Questionnaire* (IPQ): 13 items, validated, wide-spread use
   - *Spatial Presence Experience Scale* (SPES): 8 items, spatial presence = 2 dimensions
   - Witmer-Singer Presence Questionnaire: very long (24/32 items)
   - Slater-Usoh-Steed Questionnaire (SUS): simple, maybe too simple
   - Networked Minds Social Presence Inventory
   - Game Engagement Questionnaire (GEQ): presence is one of 4 components

- Recommendation in general: try to use a **validated** questionnaire

The IPQ

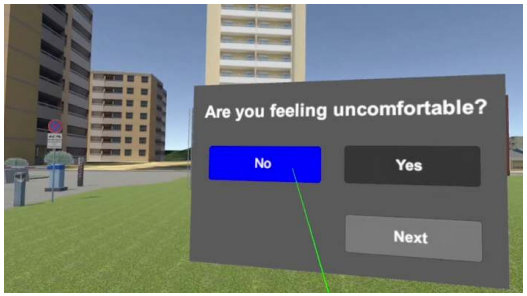
- 14 items (= questions) in total
- Factors:
  1. Spatial presence: 5 items
     - "In the computer generated world I had a sense of *being there*.
     - "I felt like I was just perceiving pictures."
  2. Involvement: 4 items
     - "I still paid attention to the real environment."
  3. Realness (could be called fidelity today): 3 items
     - "How much did your experience in the virtual environment seem consistent with your real world experience ?"
     - ...
  - Presence (second-level)

The Case for In-VR Questionnaires (?)

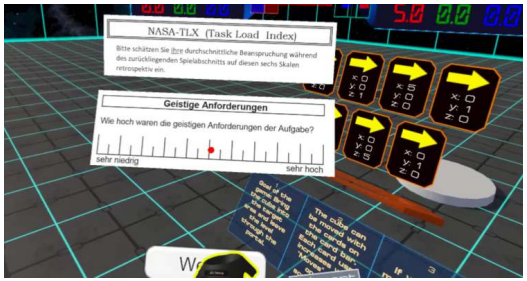
- In-VR questionnaire = user does not take off HMD, questions are presented *in* VR
- Design choices:
  - Presentation: heads-up display, world-anchored billboard, 3D object(s), ...
  - Interaction: laser-pointer, controller's trackpad, buttons, ...
  - Environment: within scene, separate virtual "office", "home screen",
- Results so far:
  - No difference in presence levels measured between In-VR and Out-VR questionnaires
  - Less variance (spread) of answers with In-VR questionnaires
  - User preference for In-VR
  - Fewer potential biasing cues from experimenter
  - Reduced study time/effort, good for participants

Virtual office Real office

Billboard in scene



Anchored on hand/controller



More Ways to Measure Presence

2. A "mid-experience" question, delivered *during* the VE (e.g., virtual character):
   - "How much do you feel present in the virtual environment right now?"
3. Physiological indicators:
   - Heart rate variability, skin conductance, skin temperature, breathing, ...
   - Mixed results
4. Behavioral indicators:
   - Response to virtual objects / reflexes
     - E.g., startling reflex when virtual objects fly or suddenly appear into private space
   - Driving patterns

Examples how to elicit a potential startling reflex

Example of a Strong Reflex During a VR Experience

- A simple test for presence: does the user show reflexes?
- Is the following reaction proof of presence?

Application "Behavior Change" Using VR

- Two-way influence between presence and emotions [Baños et al. 2007; Riva et al. 2006]
- Influence of perspective-taking in VR on behavior:
  - Pro-social behavior [Rosenberg et al. 2009]
  - Reduction of racial bias [Peck et al. 2013]

- Message framing on behavior change [Ahn et al. 2015]
  - Scenarios: cutting down trees, or growing trees
  - Positive framing leads to more environmentally conscious intentions

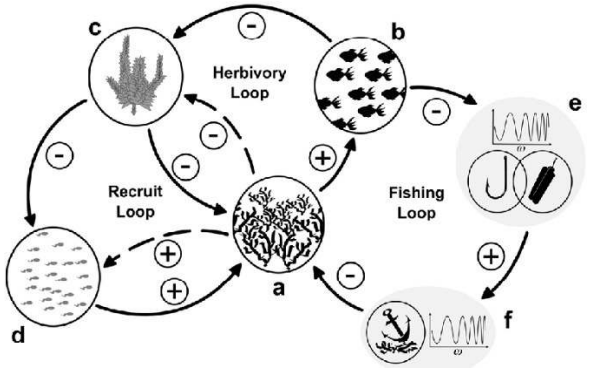
Application: Behavior Change - Example Coral Reefs

93% of the entire Great Barrier Reef is now bleached because of the climate crisis [Conservation Project International]

95% of reefs from Cairns to Papua New Guinea are now severely bleached. [National Coral Bleaching Taskforce, 2016]

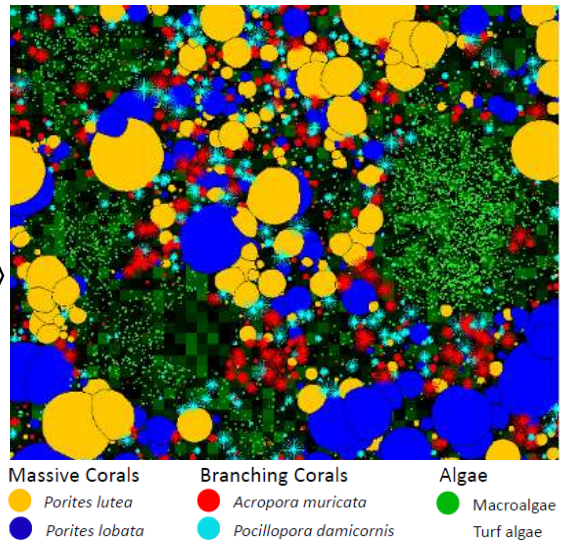
Simulating a Living Virtual Coral Reef

Multi-agent system

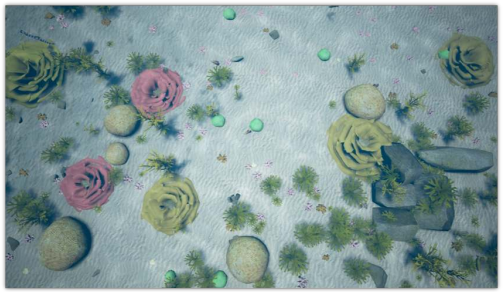


Multi-threaded implementation running in a separate process

ZMT



VR System



Create and grow 3D shapes at runtime

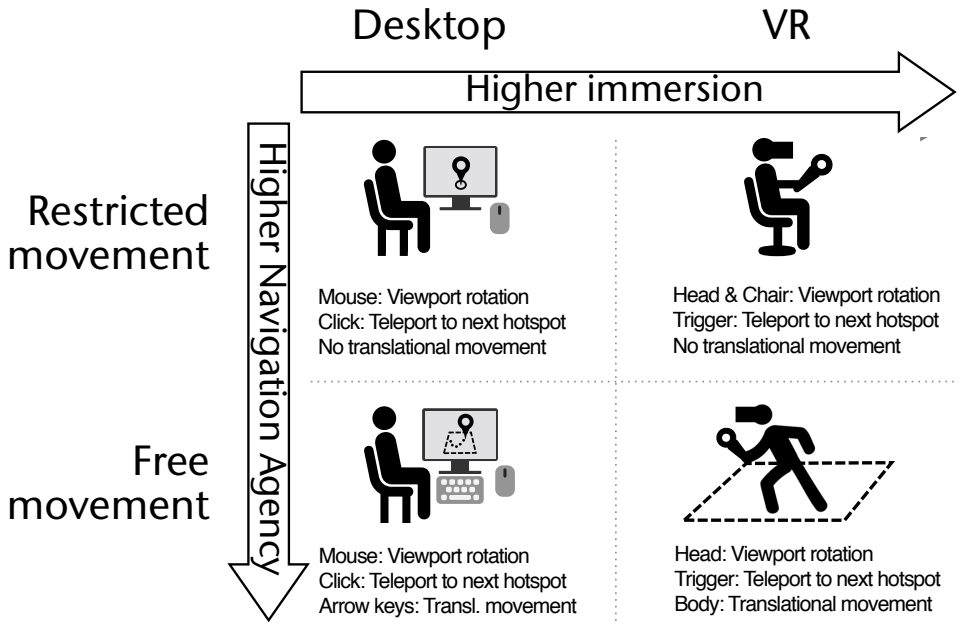
Simulate animals and swarms

Allow user to interact with the VE and system

U Bremen

Setup of the User Study

- Two-factorial design, between subjects
- Participants: $N = 224$, average age 24 years (std ≈ 6)
- Pre- and post-questionnaires
  - Own questions regarding environmental behavior and change intentions
  - Presence measured using IPQ
- Seven-minute experience showing the dying coral reef over 500 years



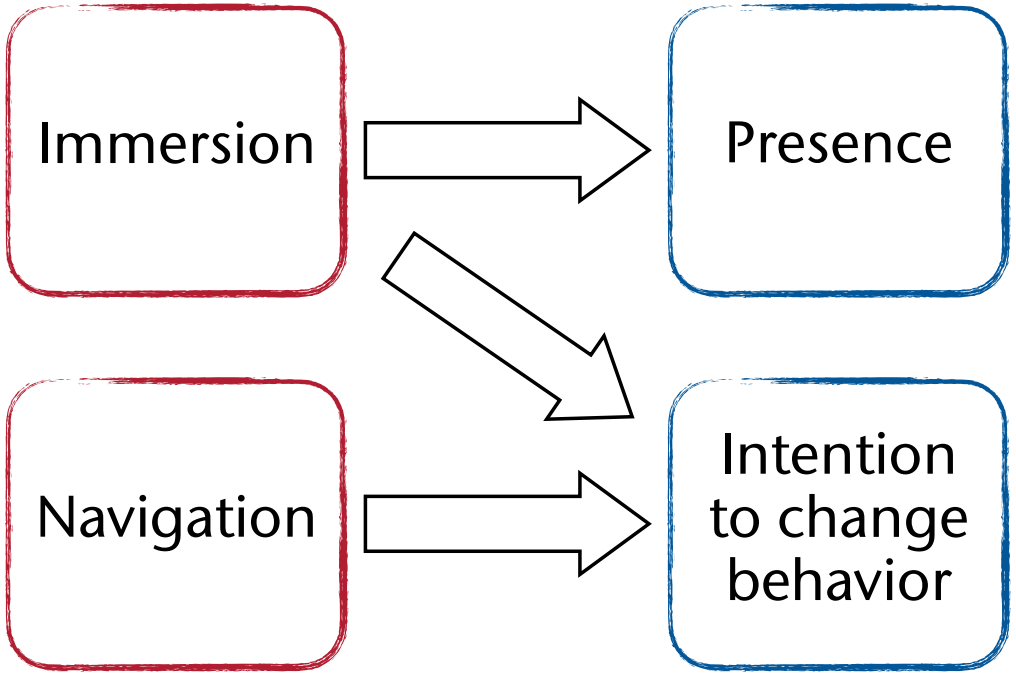
Our Findings, Based on Statistical Analysis

1. No habituation effects, i.e., even after years of VR experience, higher immersion leads to stronger emotions

2.

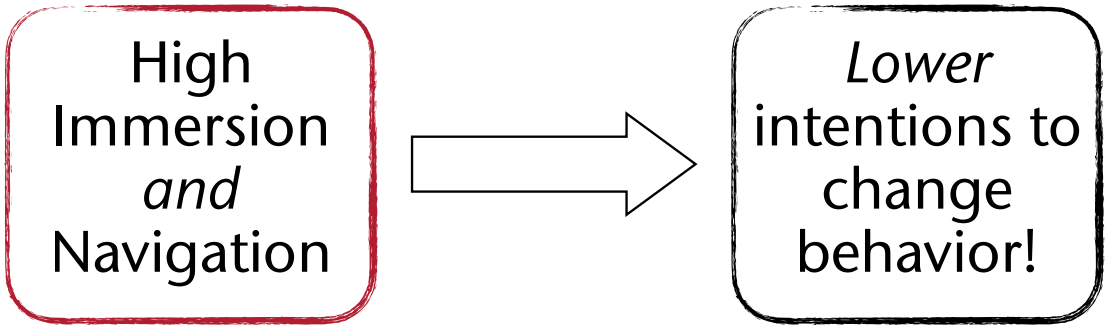
3.

4.



Surprising Findings

5.

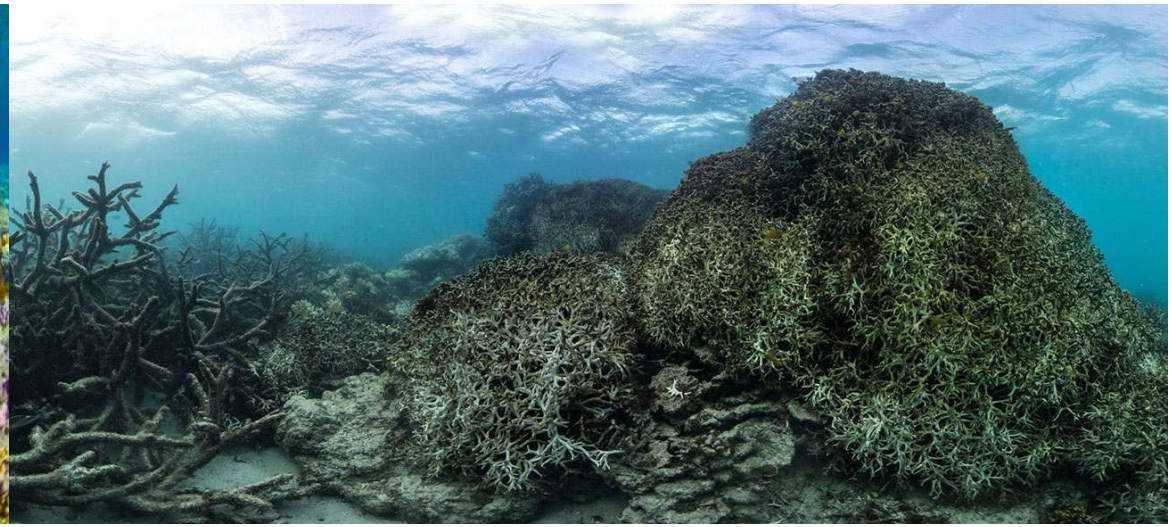


"More is Not always better"

6.

Don't let this ...

... turn into this!



Ethics of User Studies

- Depending on the "intrusiveness" or psychological stress, studies should be approved by the university's ethics review board
- Make participation voluntary, with informed consent (get signature)
- Avoid pressure to participate
- Let them know they can stop at any time
- Stress that you are testing the system, not them
- Make collected data as anonymous as possible
- Try to gather groups of participants that are as inclusive as possible (try to avoid the "young white male" problem)
-

Note on System Usability

- Presence questionnaires (or cybersickness) do *not* yield direct information about the usability of a VR system!
- Depending on the context and goal, other questionnaires are more relevant:
  - SUS (System Usability Score): 10 items, still very popular
  - UMUX (Usability Metric for User Experience): 4 items, high correlation with SUS
  - AttrakDif (pragmatic and hedonistic aspects): 28 items
  - UEQ (User Experience Questionaire): very quick
  - NASA TLX (Task Load Index): 6 items (plus subjective weightings)
  -

Avatars (Self-Representations, Virtual Bodies)

- Avatar in VR = representation of a user in the virtual environments
- Possible representations:
  - Virtual mannequin, ideally deformable / articulated
  - Just the virtual hand (ideally, deformable)
  - Just a cylinder with eyes
  - ...
- Borrowed from Indian philosophy & religion

- Occurs, for instance, in the "Book of Tea" by Kakuzo Okakura (1906):
  The heaven of modern humanity is indeed shattered in the Cyclopean struggle for wealth and power. The world is groping in the shadow of egotism and vulgarity. Knowledge is bought through a bad conscience, benevolence practiced for the sake of utility. The East and the West, like two dragons tossed in a sea of ferment, in vain strive to regain the jewel of life. We need a Niuka again to repair the grand devastation; we await the great Avatar. Meanwhile, let us have a sip of tea. The afternoon glow is brightening the bamboos, the fountains are bubbling with delight, the soughing of the pines is heard in our kettle. Let us dream of evanescence, and linger in the beautiful foolishness of things.

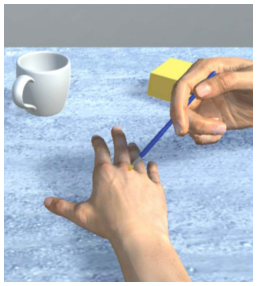
The Illusion of Virtual Body Ownership (IVBO)

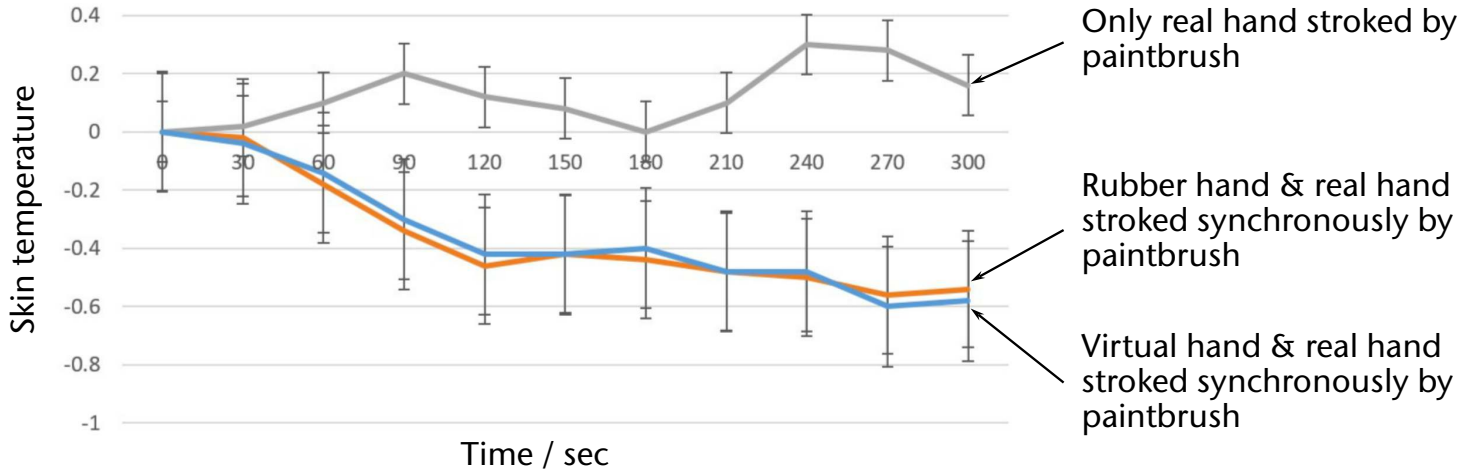
- Definition Illusion of Virtual Body Ownership (IVBO):
  Users accept virtual body parts (or the whole self-avatar) as their own
- A.k.a. self-presence
- One of the mechanisms for IVBO: visuomotor synchrony and visuotactile synchrony
  - Proprioception matches visual percept
  - Tactile perception matches visual percept

The Rubber-Hand Illusion (Body Ownership)

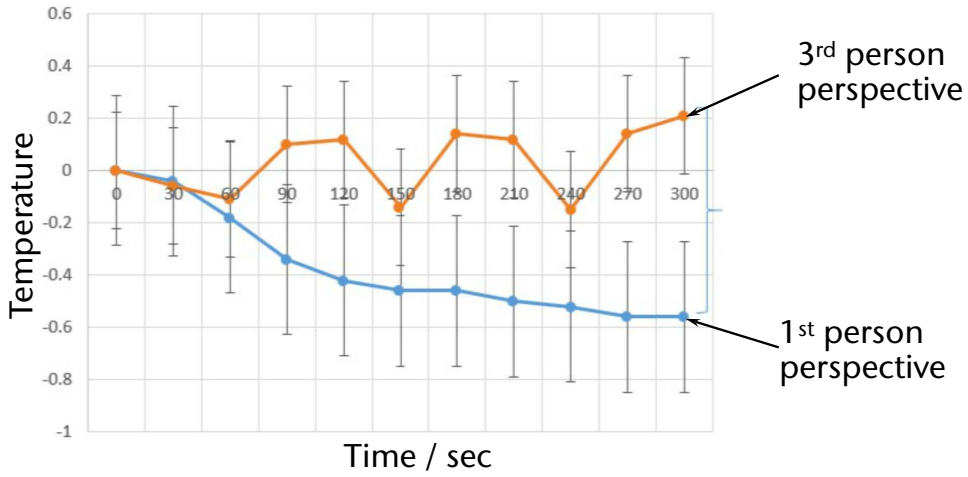
Measuring Virtual Body Ownership Illusion [2017]

- What are good, objective measures?
  - Skin conductance: probably not. Evidence is inconclusive, whether skin conductance is a reliable indicator of arousal (e.g., under stress)
- Apparently better: skin temperature (!)
  - Drop indicates: brain adopts virtual body (does not matter where it is measured)
- Experiment 1: *virtual*/rubber hand illusion



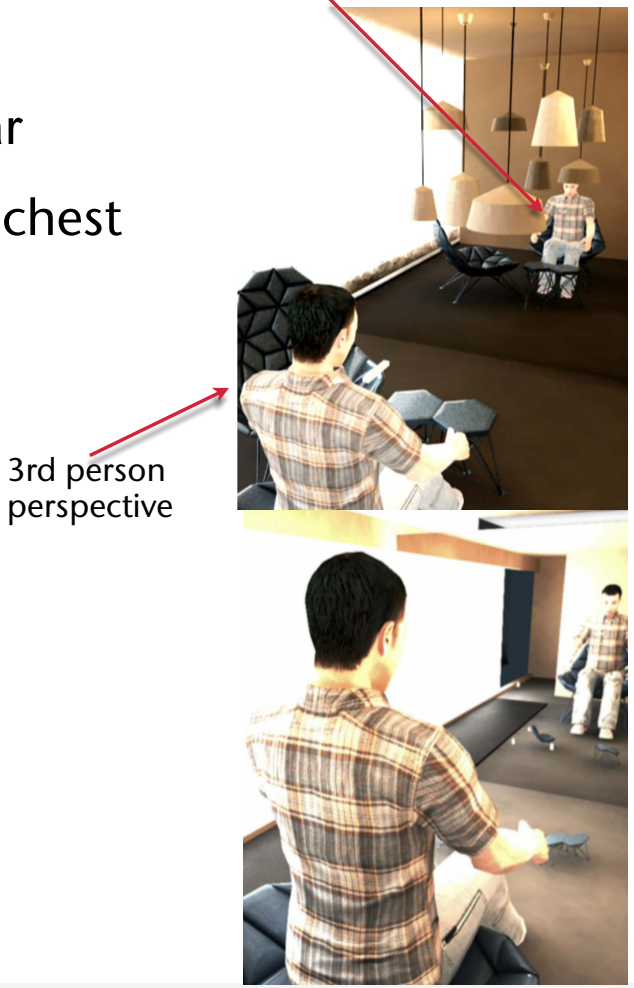


- Experiment 2 on full body ownership illusion:
  - First and third person perspective of virtual (self-) avatar
  - Synchronous stroking of both real and virtual body on chest



  - Works even with different virtual body sizes
    - Virtual body size = 140 cm, ..., 500 cm

Whole virtual room, including the self-avatar, can be seen in a (virtual) wall-sized mirror

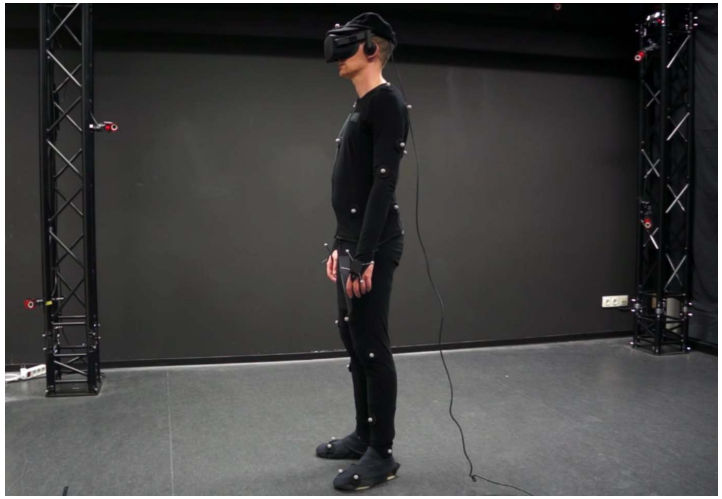


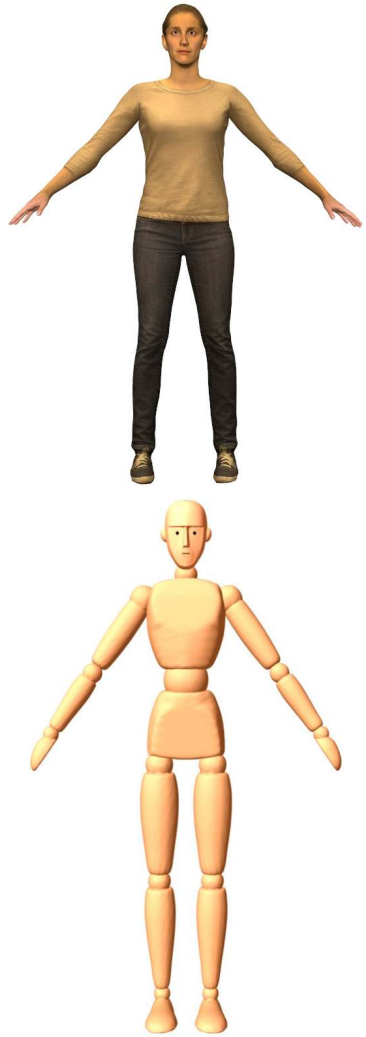
The Design Space of Self-Avatars and IVBO

- Which features of the self-avatar, and how much can we change them, such that users still accept the avatar as their own?
  - Realism?
  - Agency?
- Definition visual anthropomorphism:
  Visually perceived human resemblance of the self-avatar
- Question: does the level of visual anthropomorphism (realism) influence the level of IVBO?

Importance of Realism of Self-Avatar

- Experiment:
  - Wooden avatar, or personalized (scanned) self-avatar
  - Complete body tracking
  - Participants perform several movements, actions, and postures in front of a virtual mirror





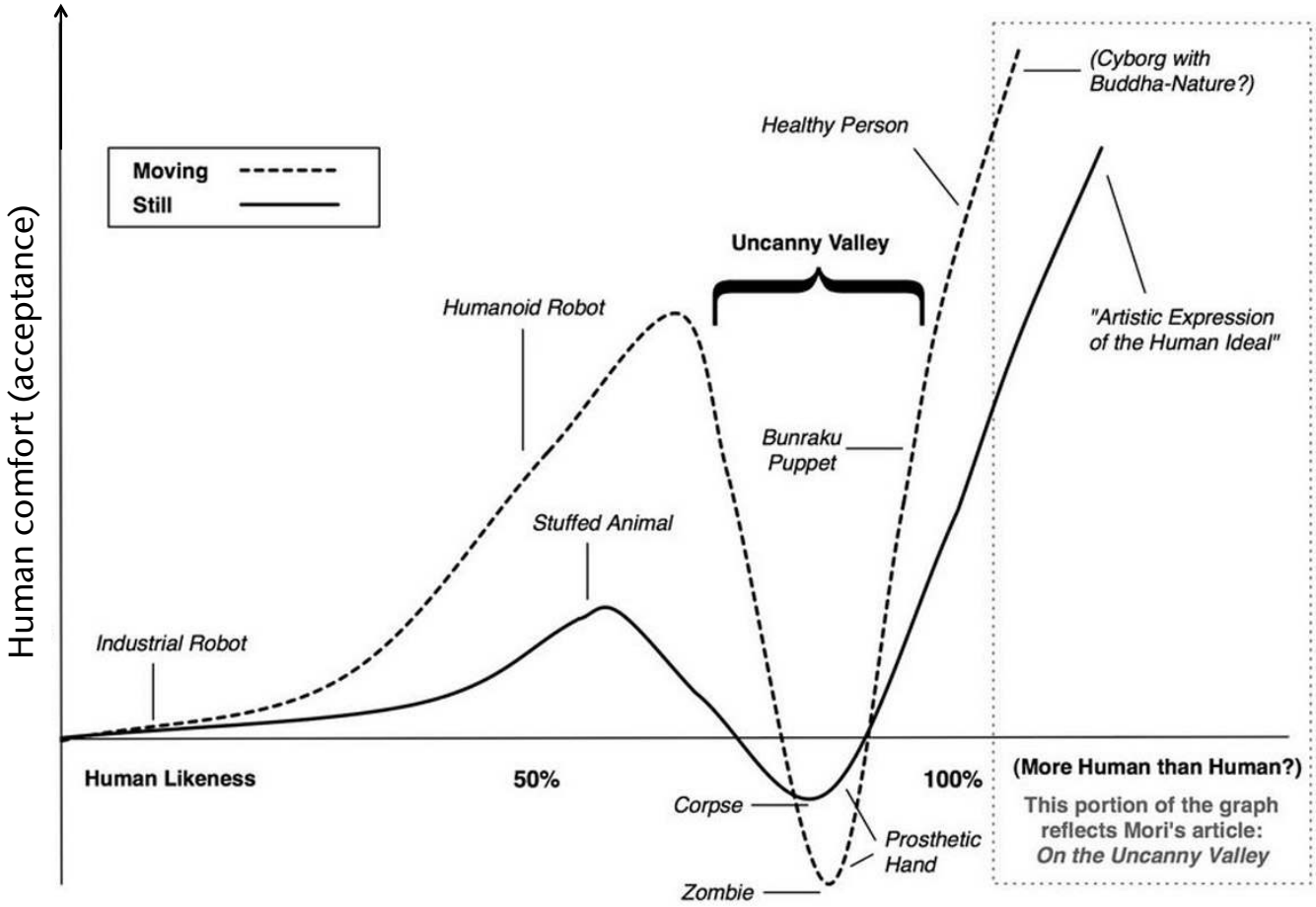
[Lugrin, Latt, Latoschik, VRST 2017]

Findings from the user study

- Personal, scanned avatars looked more realistic and human-like than "woody" (as expected)
- Potential uncanny valley effect for realistic avatars
  - *Eeriness* slightly higher for the realistic avatar, *attractiveness* higher for woody
  - Maybe because of missing face tracking
- Much higher IVBO with the realistic avatar
  - End-to-end latency was <150 msec for both woody and realistic avatar

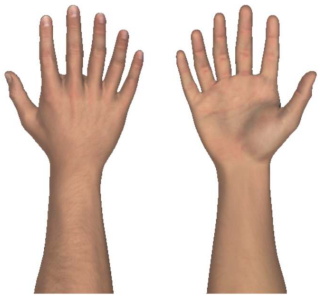
The Uncanny Valley

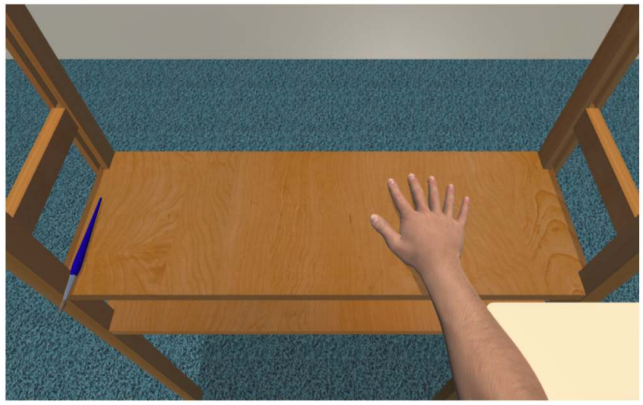
Hypothesis: "When human replicas look and act almost, but not perfectly, like actual human beings, it causes a response of revulsion among human observers."

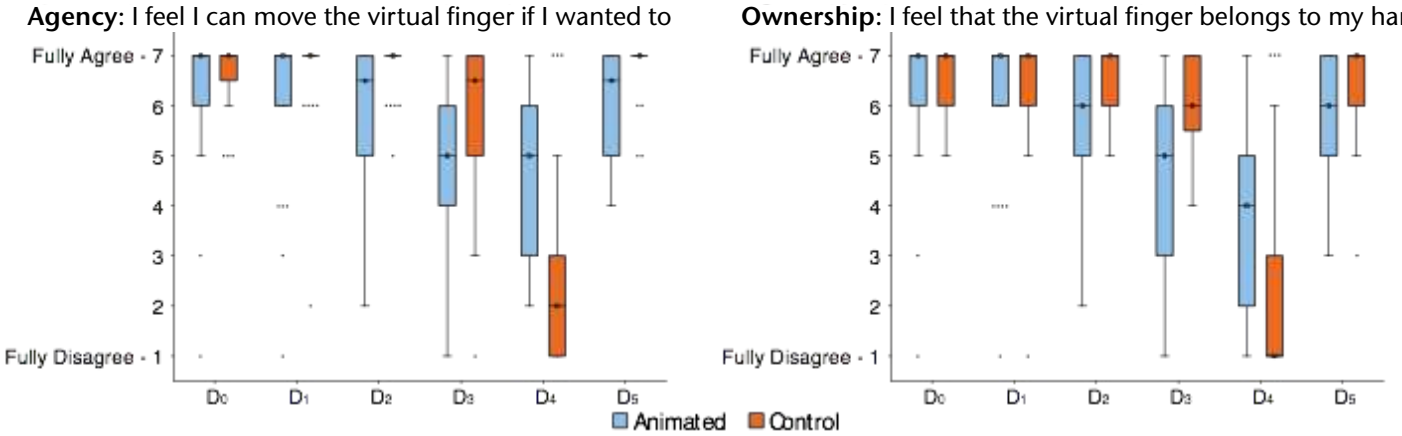


How Elastic is IVBO: the 6-Fingered Hand

- Do people accept virtual self-avatars as their own, even if it is notably different (for instance, a structural change, such as 6 fingers)?







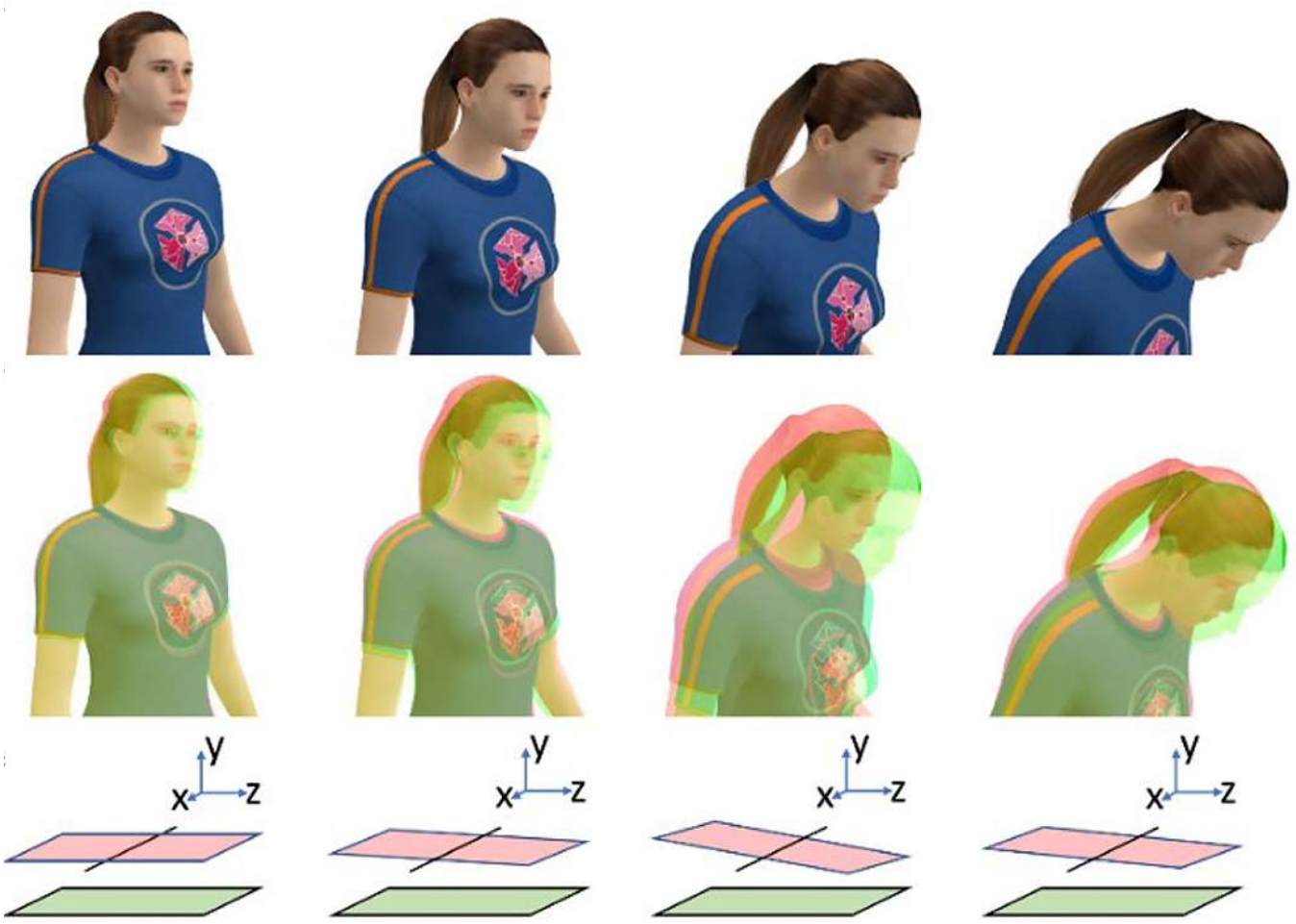
Cybersickness / Simulator Sickness / Motion Sickness

- Can sometimes occur with prolonged stay in flight simulators / virtual worlds
- Simulator sickness = more or less of the following symptoms:
  - Nausea (including vomiting), eye strain, dizziness, drowsiness, blurred vision, headache, fatigue
- Cybersickness = visually induced motion sickness, i.e. "simulator sickness without motion platform" (often used synonymously with simulator sickness)
- Motion sickness = response to the motion's stimulation of the vestibular system, e.g. at sea, in a car

Common Hypotheses

1. Sensory conflict hypothesis: Inconsistent sensory input to the brain, e.g., mismatch between vision and vestibular organ (sensor for motion and equilibrium)
   - One possible cause: difference in the user's virtual and physical head pose (e.g., induced by motion-to-photon lag), leading to a "wobbly" (non-stationary) VE
2. Poison (Evolutionary) hypothesis: nausea and vomiting due to sensory cue conflicts are an indirect by-product of an ancient evolutionary adaptation as a poison defense system that is being accidentally triggered
3. Postural instability hypothesis: primary behavioral goal of humans is to maintain postural stability, and thus as postural instability increases, motion sickness develops
4. Sensory input outside normal limits, e.g., apparent motion is too fast
5. Rest frame theory: mismatch in sensed gravitation and perceived up-direction
   - Observation: superimposing a fixed grid decreased symptoms

Illustration of the effect of motion-to-photon lag (hypothesis #1a):

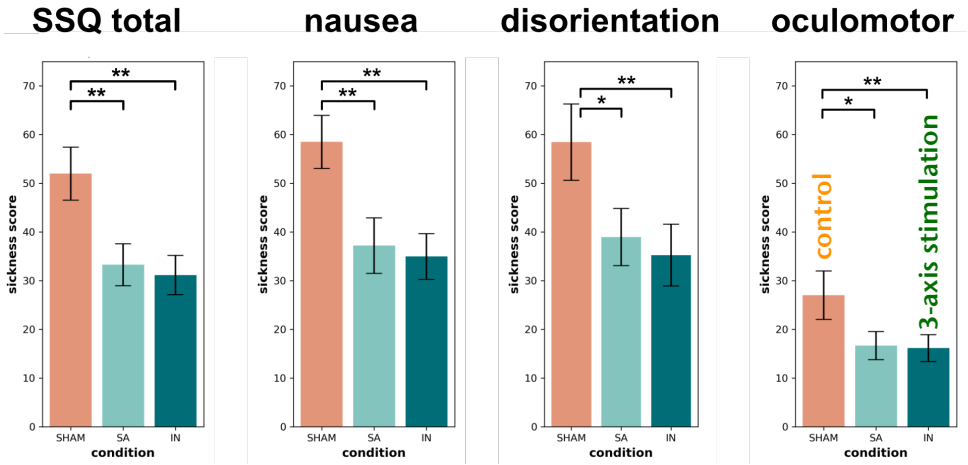


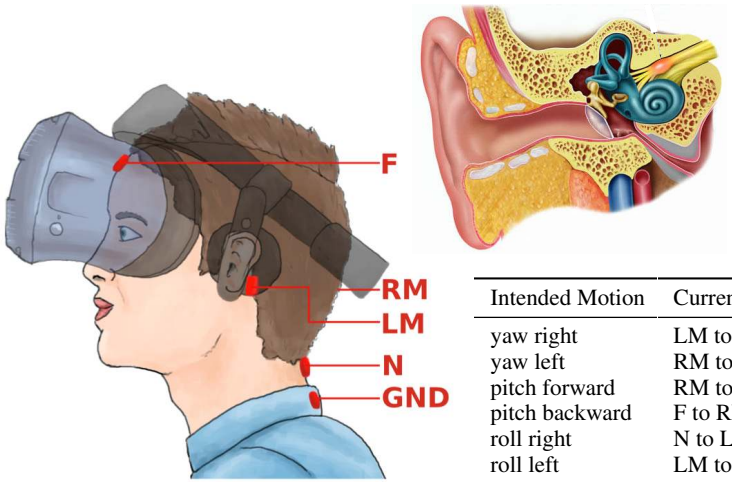
- Correlation between presence and cybersickness:
  - Many studies show *negative* correlation, some show *positive* correlation
  - Hypotheses for the mechanisms:
    - Higher immersion ⟶ higher presence *and* higher sensory mismatch
    - Higher presence ⟶ more attention is turned away from sensory conflicts
    - Higher cybersickness ⟶ lower presence
- Frequency:
  - 20-80% of the population [Rebenitsch and Owen, 2016]
  - 20-40% of jet pilots (probably based on flight simulators of the '90s)
    - Occurs more frequently with experienced pilots than novices [sic]

- Other cases:
  - When staying below deck for a prolonged time
  - In flight simulators with latency between motion of platform and rendering
- Other observations with mismatching sensory inputs:
  - In a rotating field when walking forward, people tilt their heads and feel like they are rotating in the opposite direction
  - If a person is walking on a treadmill holding onto a stationary bar and you change the rate the visuals are passing by, it will feel to the person like the bar is pushing or pulling on their hands

Mitigations of Cybersickness

- Increase frame-rate, reduce latency
- Restrict FoV, or blur peripheral vision
- Galvanic vestibular stimulation
  - Apply combined currents to stimulate 3 vestibular axes to match arbitrary visual rotations





Intended Motion	Current Flow Direction
yaw right	LM to RM
yaw left	RM to LM
pitch forward	RM to F || LM to F
pitch backward	F to RM || F to LM
roll right	N to LM || RM to N
roll left	LM to N || N to RM

Measuring Cybersickness

- Physiological measurements: skin conductance, heart rate, blood pressure, ..
  - Literature reports mixed success
- SSQ questionnaire
  - Predominant so far, but validity questionable!
  - 16 items load onto 2 factors:
    nausea and oculomotor symptoms
  - Factors are distinct, but correlated
    (Pearson r=0.56, p<0.001)
- Maybe better:
  Virtual Reality Sickness Questionnaire (VRSQ),
  Cybersickness Questionnaire (CSQ),
  Fast Motion Sickness Scale (FMS, can be administered in-VR)

	Dizziness	Difficulty focusing
Headache	.50	.
Eyestrain	.	.58
Difficulty focusing	.	.89
Nausea	.84	.
Fullness of head	.	.55
Blurred vision	.	.81
Dizziness (eyes open	.89	.
Dizziness (eyes closed)	.99	.
Vertigo	.54	.

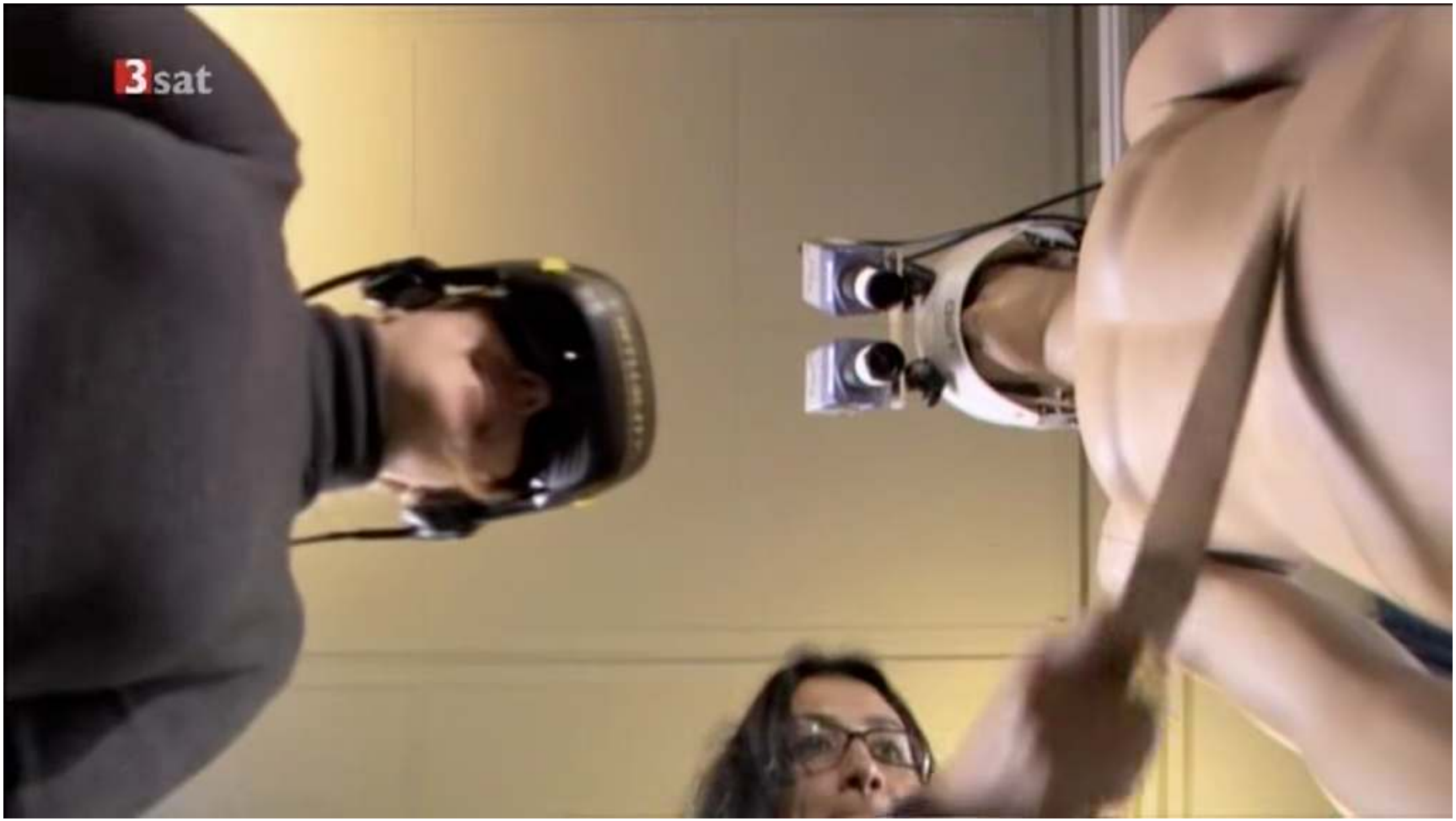
[William Bruce Stone III, 2017]

More Illusions Around One Own's Body

- The 3 hypotheses, under which the brain operates at all times (it has to!), namely:
  - Congruency hypothesis (Multimodal consistency/congruency, Sensorimotor contingency)
  - "This is me" hypothesis (virtual body ownership)
  - "I am here" hypothesis (spatial presence)

  ... leads to all kinds of illusions

Induced Body Ownership



[3sat: Die Macht des Unbewusstseins, 2014]

Barbie-Doll Illusion

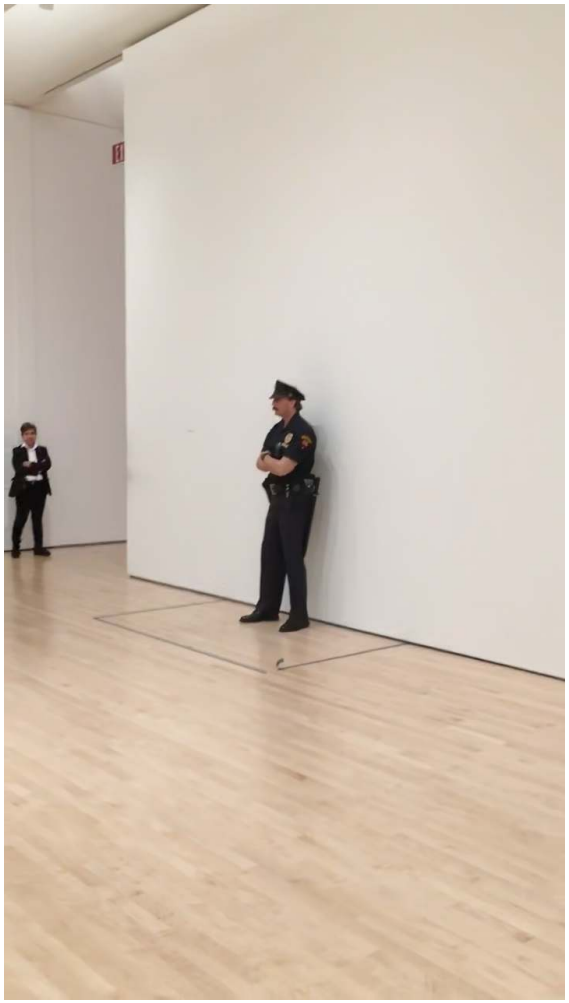
van der Hoort, Guterstam, Ehrsson, 2011, Karolinska Institutet

An Out-of-Body Experience

[H. Henrik Ehrsson, Karolinska Institutet; BBC Horizon]

More Examples of Uncanny Valley Effects (IMHO)

Biennale Venice 2015



Duane Hanson

Ex Machina (2015)

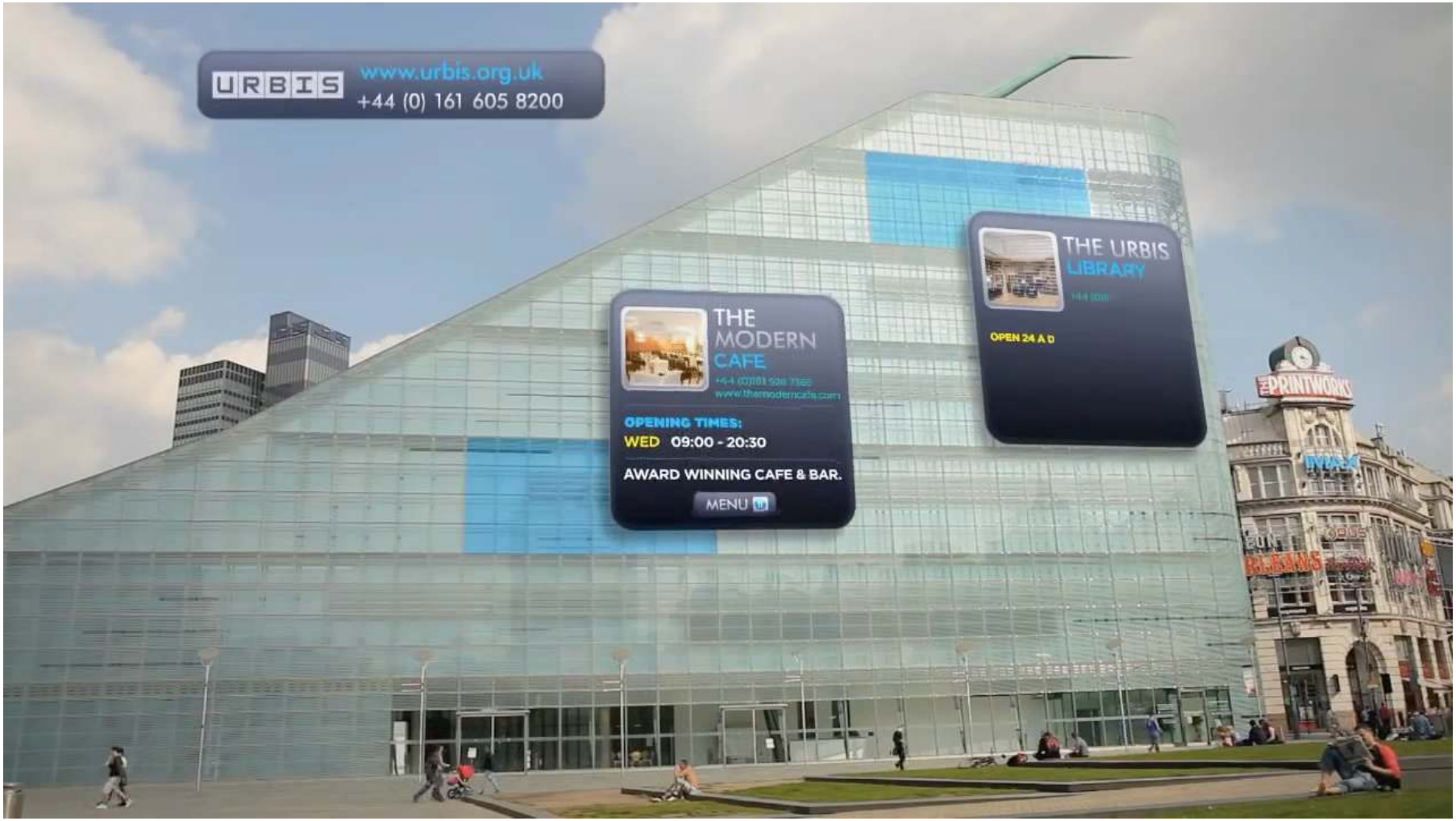
Digital Humans: Are We Getting Beyond the Uncanny Value?

Digital Human "Doug" by Digital Domain

Augmented Reality: Just Mentioning it Here

- Augmented Reality's goal: *consistent coexistence* of real as well as virtual objects in the same perceived space
- Approaches:
  - Overlay real imagery with computer-generated images
  - Project computer-generated imagery onto real-world objects
- Some devices:
  - Optical see-through displays (e.g. Google Glass)
  - Video see-through displays
  - Smartphones & tablets
- Unfortunately, we cannot cover AR in this course

Examples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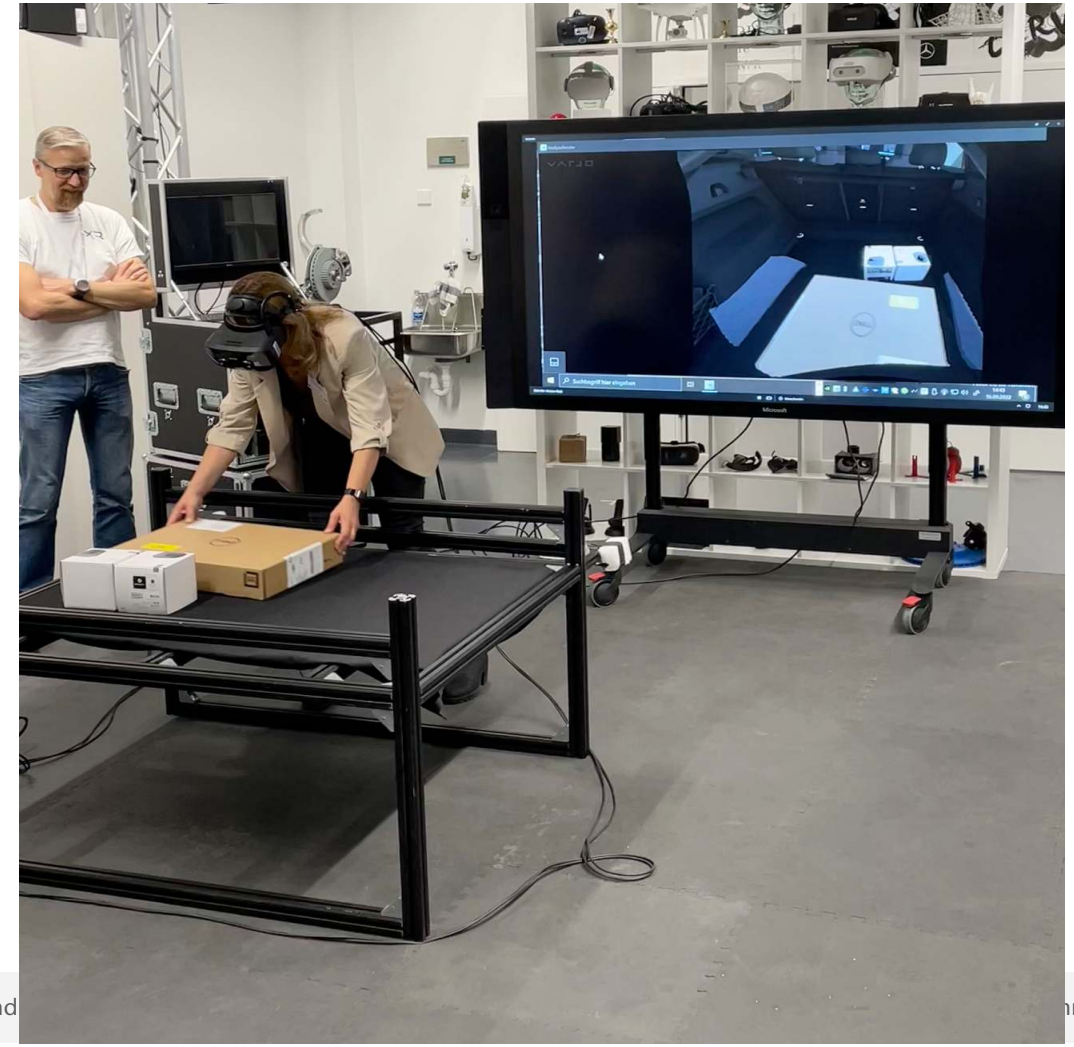
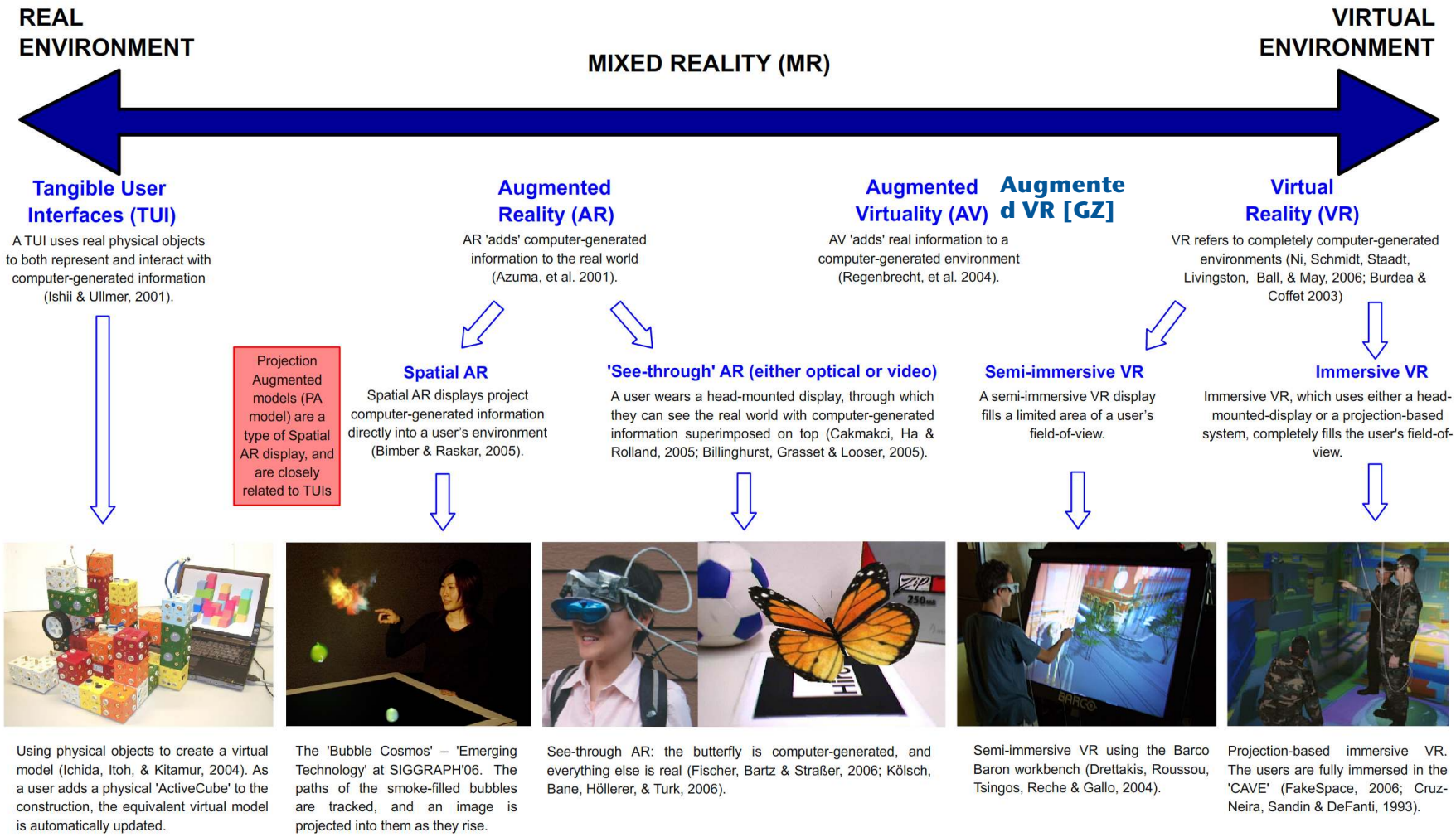
Product Testing Application



Handheld AR Application: Verification of Manufactured Parts

Milgram's Reality–Virtuality Continuum (XR)



Example of Augmented VR

David Nahon

Example of Projection/Spatial Augmented Reality

https://arsandbox.ucdavis.edu/

An Application? the See-Through Airplane

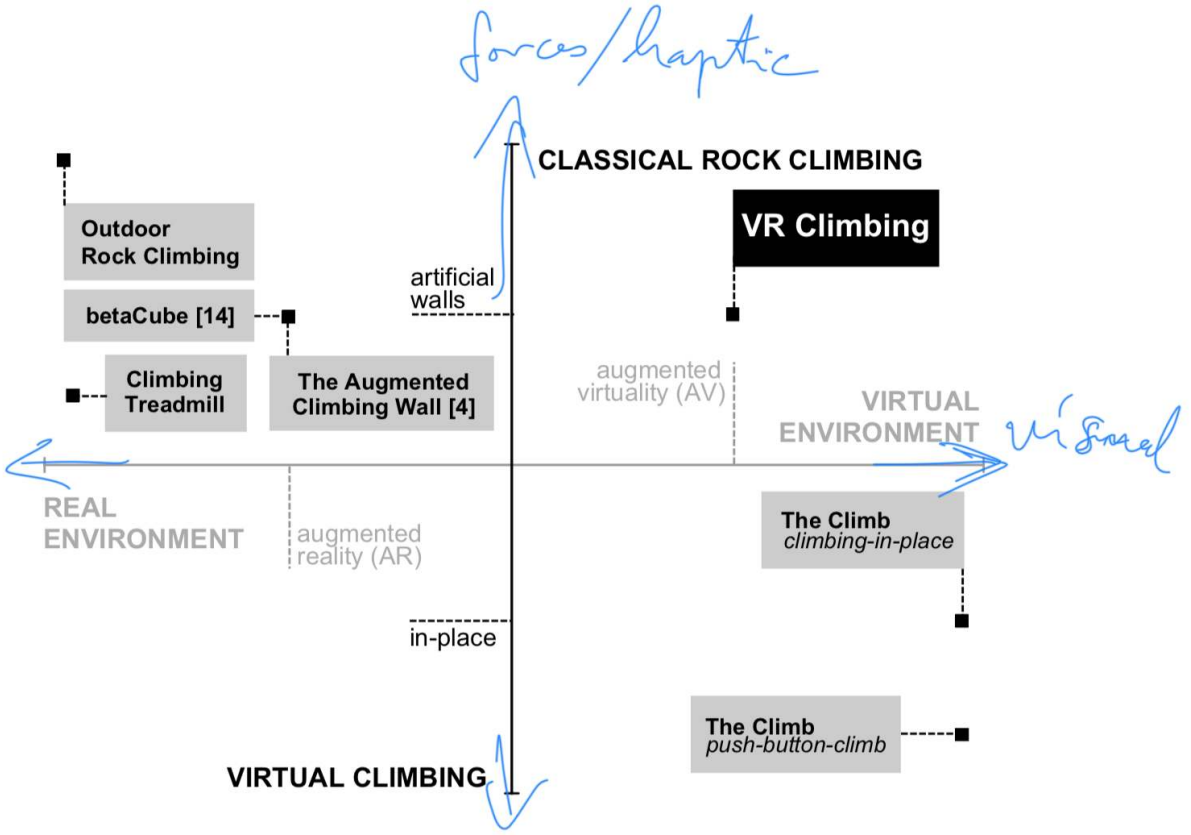
© CPI

Virtual Rock Climbing (Mixed Reality Climbing)

[Antonio Krüger et al: Exploring Rock Climbing in Mixed Reality Environments, CHI 2017]

Higher-Dimensional Continuums (Continua)

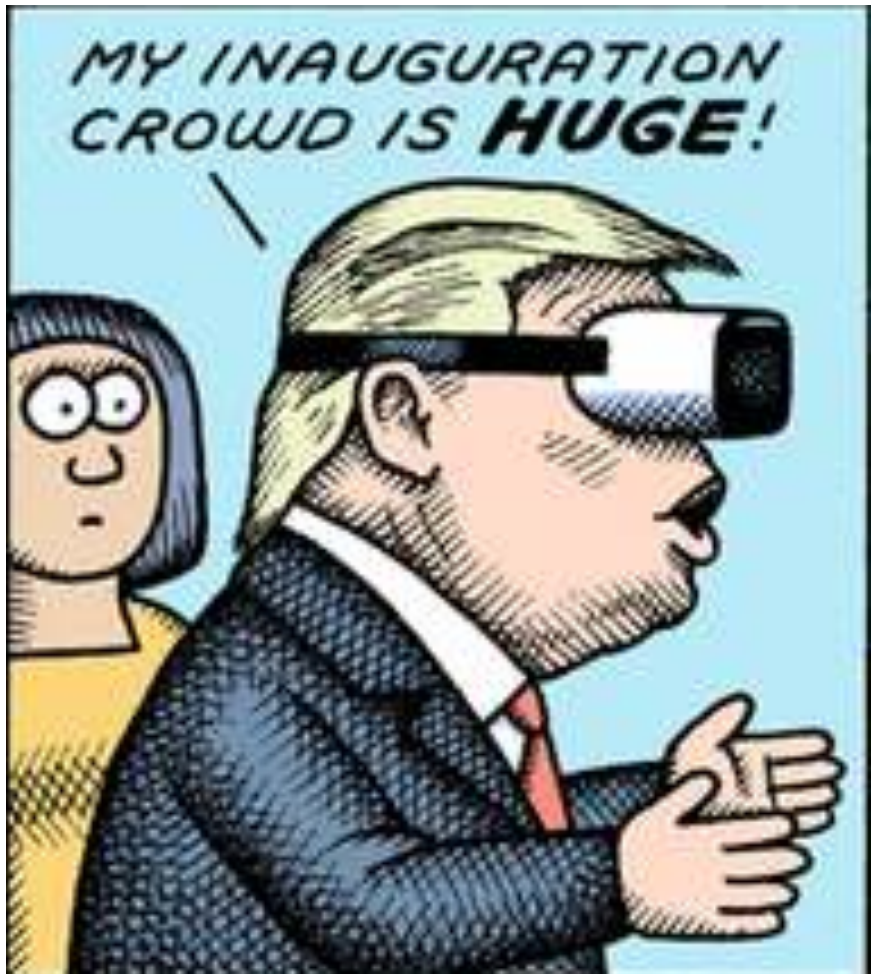
- For each additional immersive sensory input, you probably have to add another dimension to the continuum:



Call to Consider Ethical Questions w.r.t. VR

- Cybersickness
- Overuse / Escapism
  (like computer games)
- Violence?
- Delusions

See also the paper
The Ethics of Realism in Virtual and Augmented Reality
on the course home page!
[Slater et al., 2020]



The Bigger Societal Question: Where do We Want to Go?

There could be many other potential paths for our society!

Most of our lives spent in a purely virtual metaverse
(the "Matrix" path)

Most of our lives spent at home with physical surrogates representing us outside
(the "Surrogates" path)

How do we, as a society, want to live in the future?