Cyber-Physical Virtual Reality

Greg WELCH

Pegasus Professor
AdventHealth Endowed Chair in Simulation

UNIVERSITY OF
CENTRAL FLORIDA
UCF

17 APR 2025
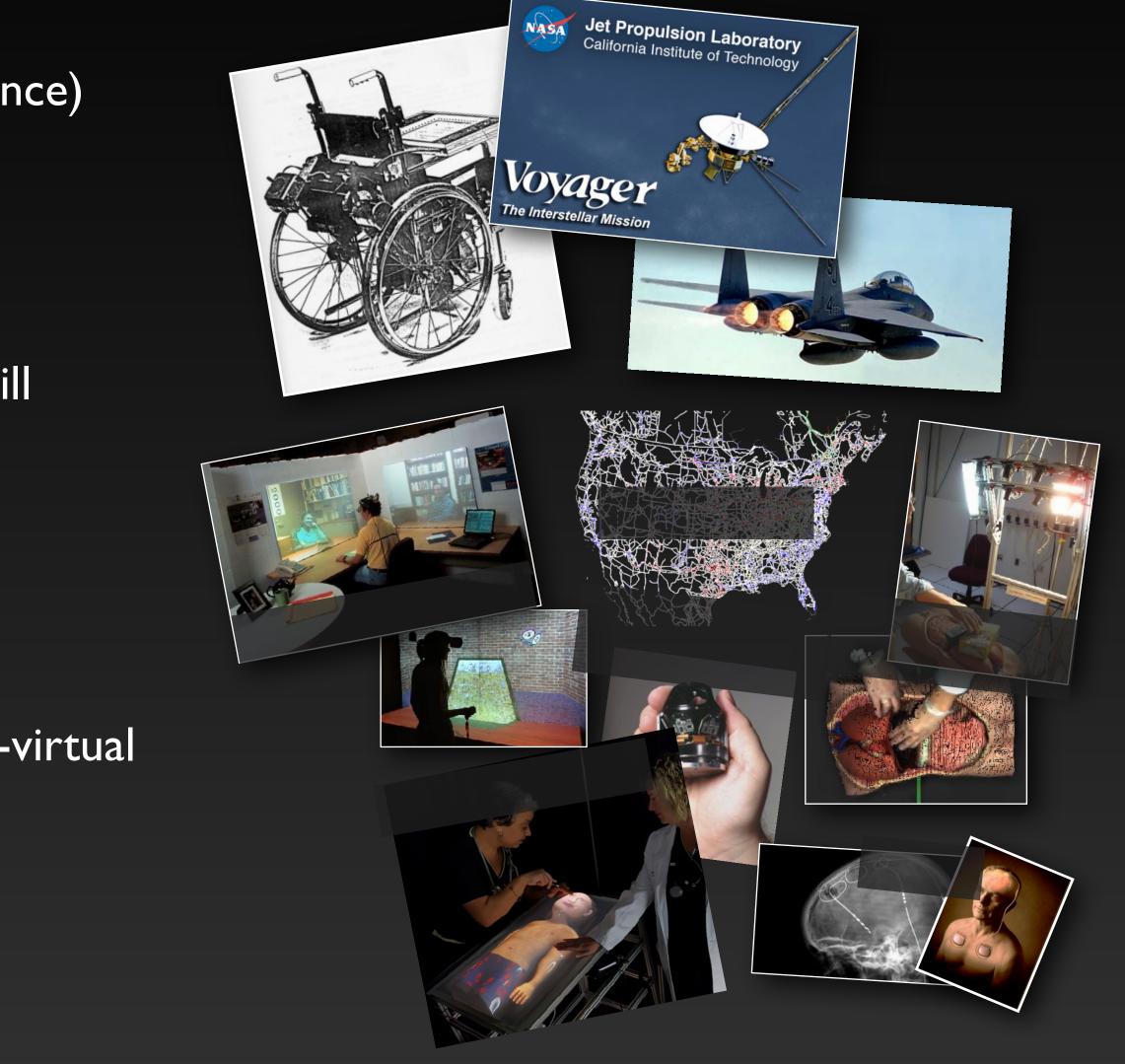
Background Summary

- **Academic** Background
  - Purdue University (B.S. Electrical Technology)
  - UNC Chapel Hill (M.S. & Ph.D. Computer Science)

- **Professional** Experience
  - NASA's Jet Propulsion Laboratory (Voyager)
  - Northrop-Grumman (Radar jammer)
  - The University of North Carolina at Chapel Hill
  - The University of Central Florida

- **Research** (Examples)
  - Motion sensing / tracking — the Kalman Filter
  - Virtual Reality (VR) & Augmented Reality (AR)
  - Human surrogates — real, virtual, and physical-virtual
  - Applications in healthcare and defense
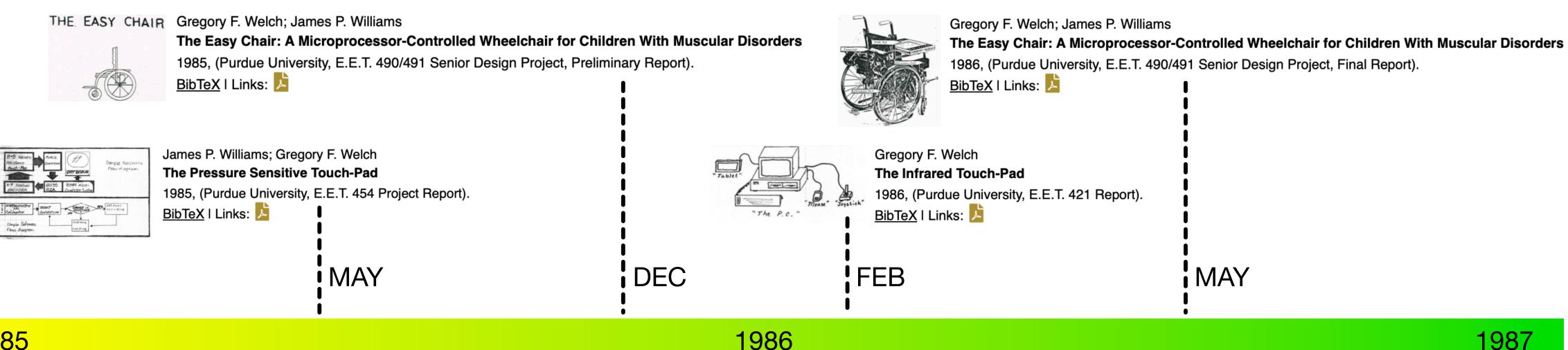
- **Expert Witness** — patent disputes

Purdue University (B.S. Electrical Technology)
Senior Design Project with Paul Williams

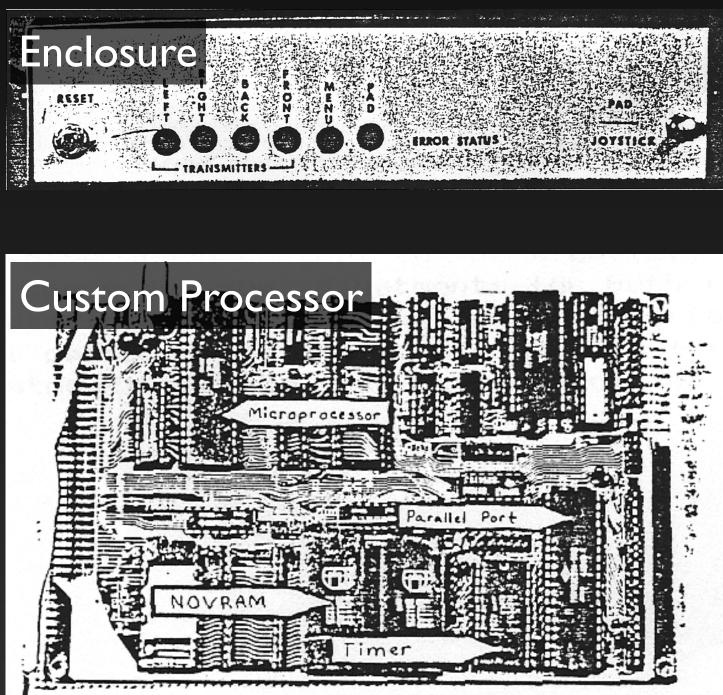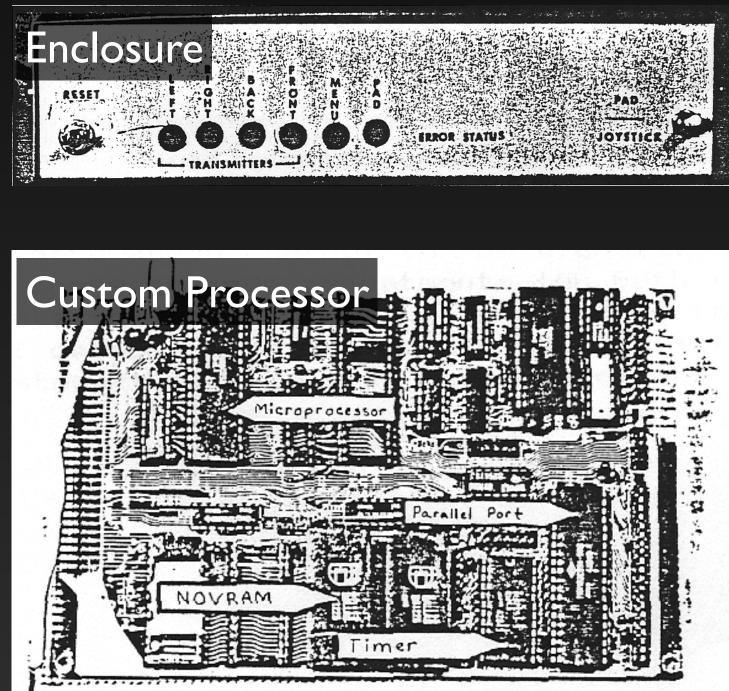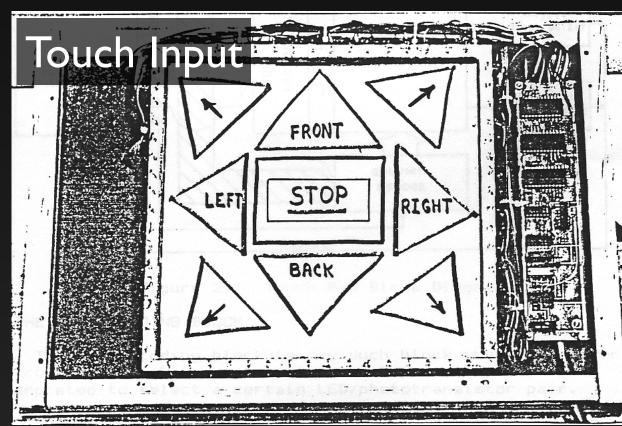The Easy Chair: A Microprocessor-Controlled Wheelchair for Children With Muscular Disorders

THE EASY CHAIR
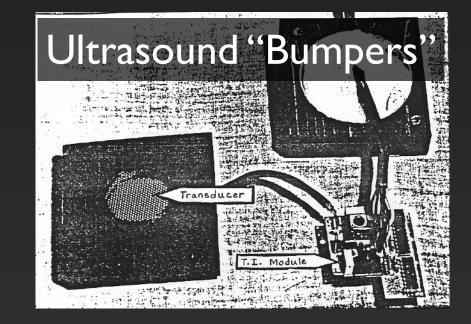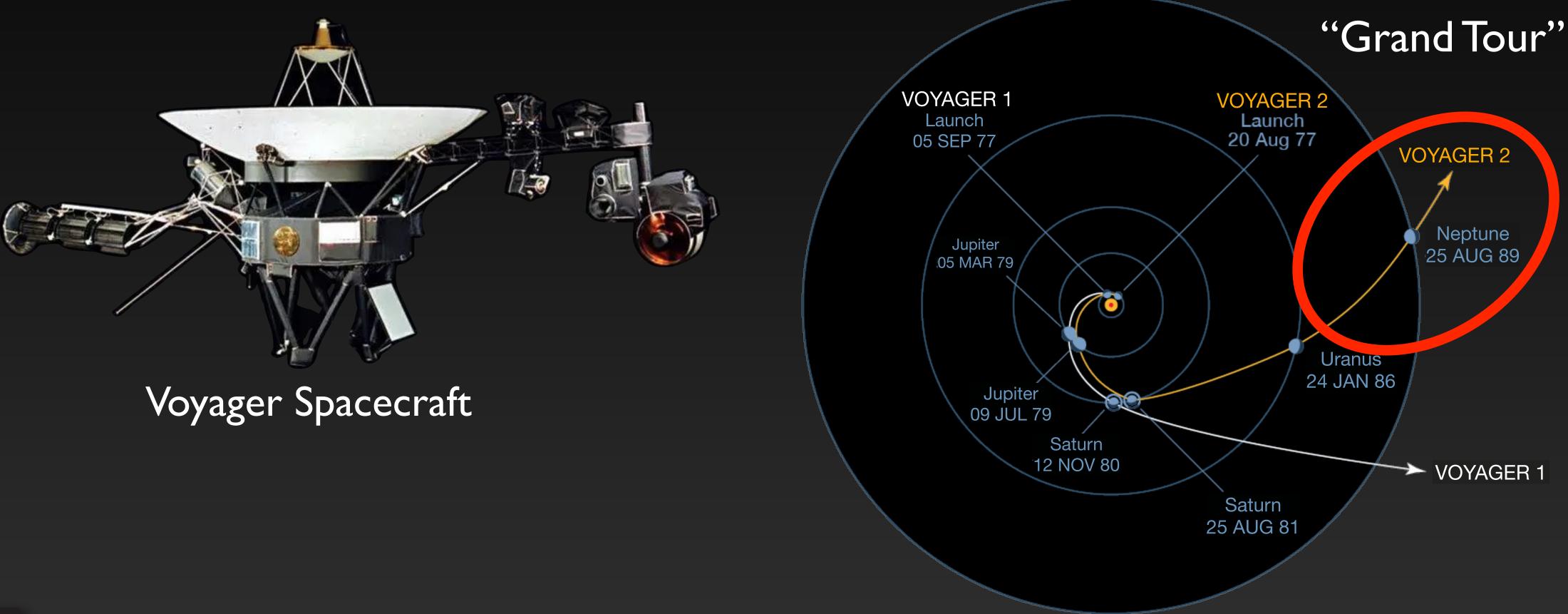
Gregory F. Welch; James P. Williams
The Easy Chair: A Microprocessor-Controlled Wheelchair for Children With Muscular Disorders
1985, (Purdue University, E.E.T. 490/491 Senior Design Project, Preliminary Report).
BibTeX | Links:

Gregory F. Welch; James P. Williams
The Easy Chair: A Microprocessor-Controlled Wheelchair for Children With Muscular Disorders
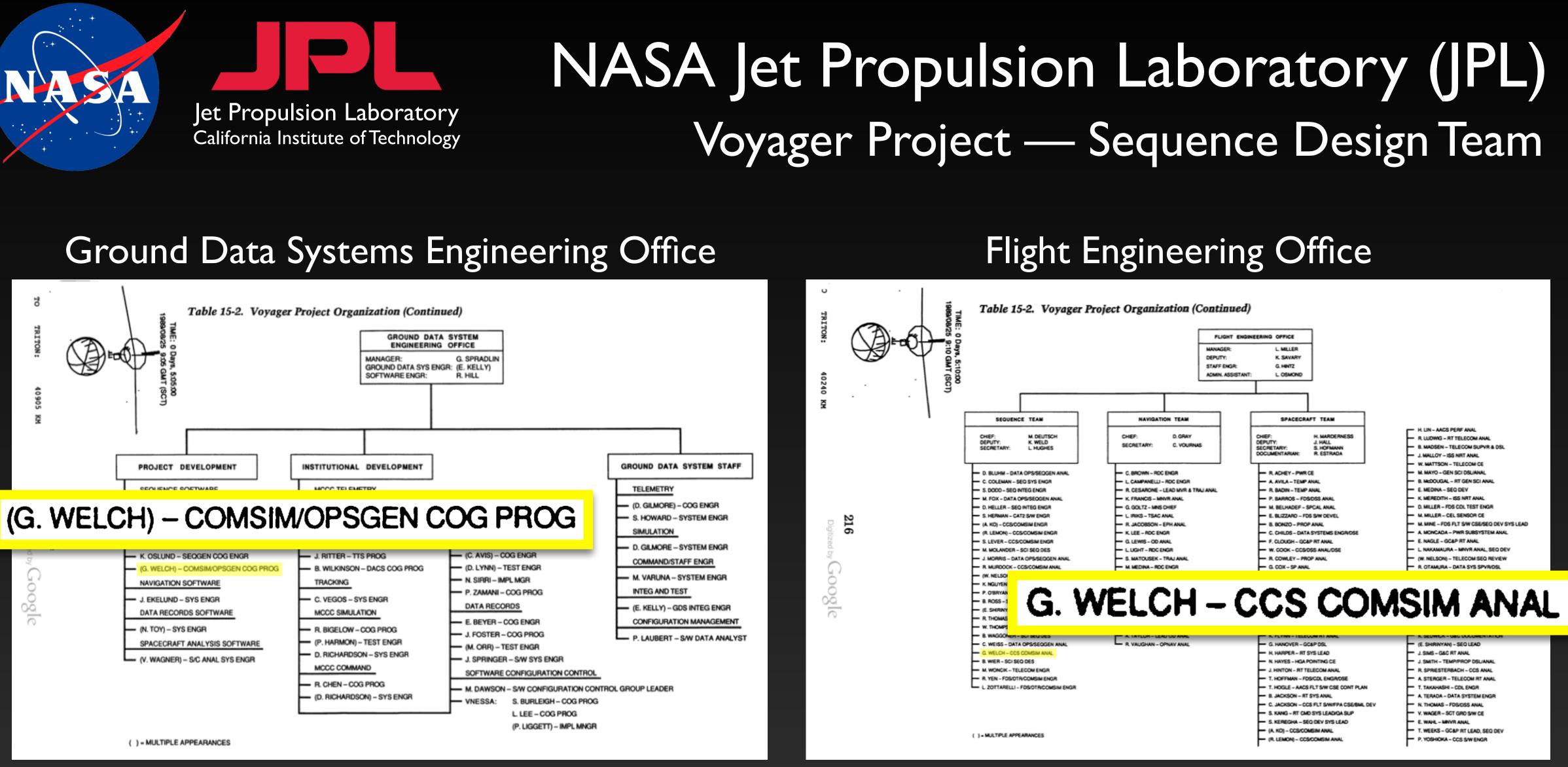1986, (Purdue University, E.E.T. 490/491 Senior Design Project, Final Report).
BibTeX | Links:

James P. Williams; Gregory F. Welch
The Pressure Sensitive Touch-Pad
1985, (Purdue University, E.E.T. 454 Project Report).
BibTeX | Links:

Gregory F. Welch
The Infrared Touch-Pad
1986, (Purdue University, E.E.T. 421 Report).
BibTeX | Links:

MAY   DEC   FEB   MAY

1985   1986   1987

Purdue University (B.S. Electrical Technology)

Senior Design Project with Paul Williams (1985–1986)

The Easy Chair: A Microprocessor-Controlled Wheelchair
for Children With Muscular Disorders

Award

THE EASY CHAIR
BY
Jim Williams
Greg Welch

Enclosure

Touch Input

Custom Processor

Ultrasound "Bumpers"

NASA Jet Propulsion Laboratory (JPL)
Voyager Project — Sequence Design Team

Voyager Spacecraft

"Grand Tour"

VOYAGER 1
Launch
05 SEP 77

VOYAGER 2
Launch
20 Aug 77

VOYAGER 2

Neptune
25 AUG 89

Jupiter
05 MAR 79

Jupiter
09 JUL 79

Uranus
24 JAN 86

Saturn
12 NOV 80

VOYAGER 1

Saturn
25 AUG 81

NASA Jet Propulsion Laboratory (JPL)
Voyager Project — Sequence Design Team

Ground Data Systems Engineering Office

Flight Engineering Office

NASA Jet Propulsion Laboratory (JPL)
Voyager Project — Sequence Design Team

Managing precious on-board memory

"The spacecraft was built in the 1970s, and so that's the technology that we had in those days. And we didn't have very much computer memory, so we had to be very careful and think through what we could do with this tiny amount of computer memory." (Linda Spilker)

Passant Rabie, "Keeping Voyager Alive: NASA's Project Scientist Faces Painful Choices as the Iconic Mission Nears Its End," Gizmodo, April 5, 2025.

4K 16-bit words? Memory? Two processors

NASA Jet Propulsion Laboratory (JPL)
Voyager Project — Sequence Design Team

MEMMAN Memory Management Software
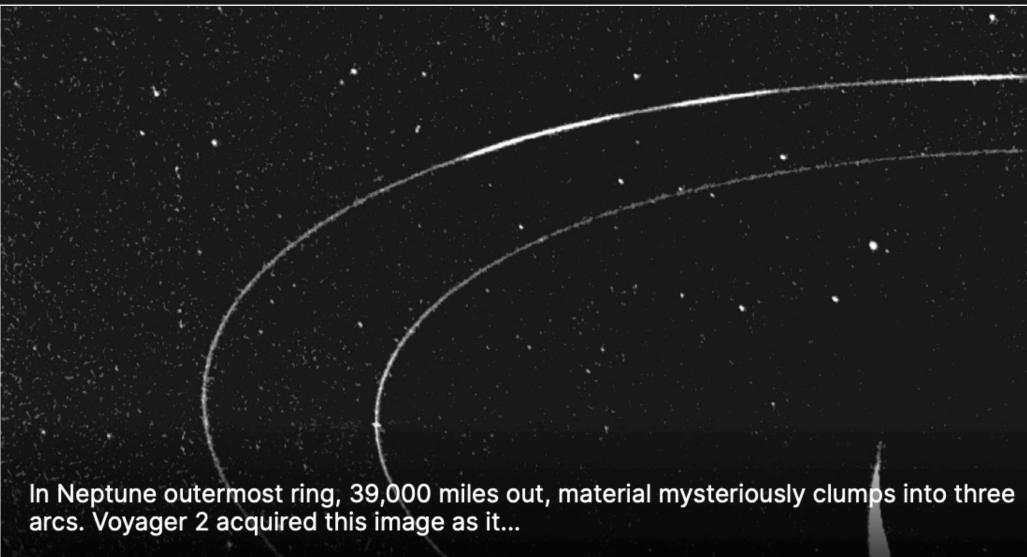
Optimized memory usage afforded extra scientific data during the Neptune encounter, e.g., additional images.

This picture of Neptune was produced from images taken by NASA's Voyager 2 in the summer of 1989 as it...
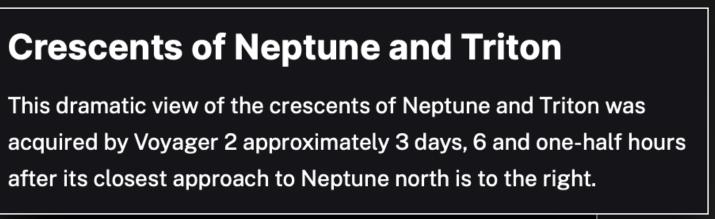
This false color photograph of Neptune was made from NASA's Voyager 2 images taken through three filters: blue, green, and...

In Neptune outermost ring, 39,000 miles out, material mysteriously clumps into three arcs. Voyager 2 acquired this image as it...

Crescents of Neptune and Triton

This dramatic view of the crescents of Neptune and Triton was acquired by Voyager 2 approximately 3 days, 6 and one-half hours after its closest approach to Neptune north is to the right.

This dramatic view of the crescents of Neptune and Triton was acquired by Voyager 2 approximately 3 days, 6 and...

Northrop Defense Systems
AN/ALQ-135 Electronic Countermeasures
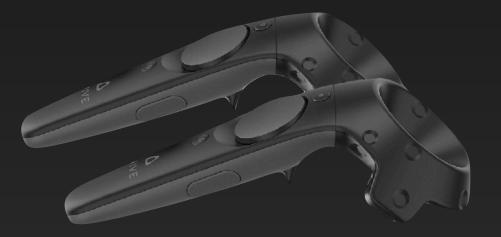
USAF F-15 Eagle

AN/ALQ-135 Band 1.5 and Band 3

ELECTRONIC COUNTERMEASURES

RADAR SIGNAL

RECEIVE ANTENNA

GROUND RADAR

JAMMING SIGNAL

TRANSMT ANTENNA

University of North Carolina at Chapel Hill

1992–1995 M.S. and Ph.D. in Computer Science
1995–2011 Research Professor (Assistant, Associate, Full)

$300–$1200

Ivan Sutherland (1960s)
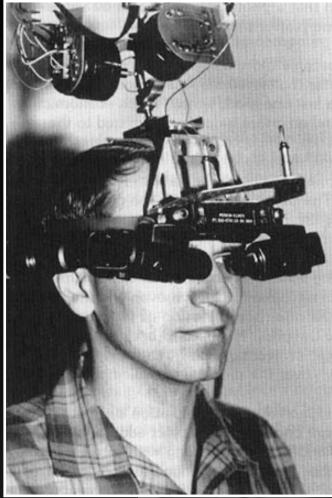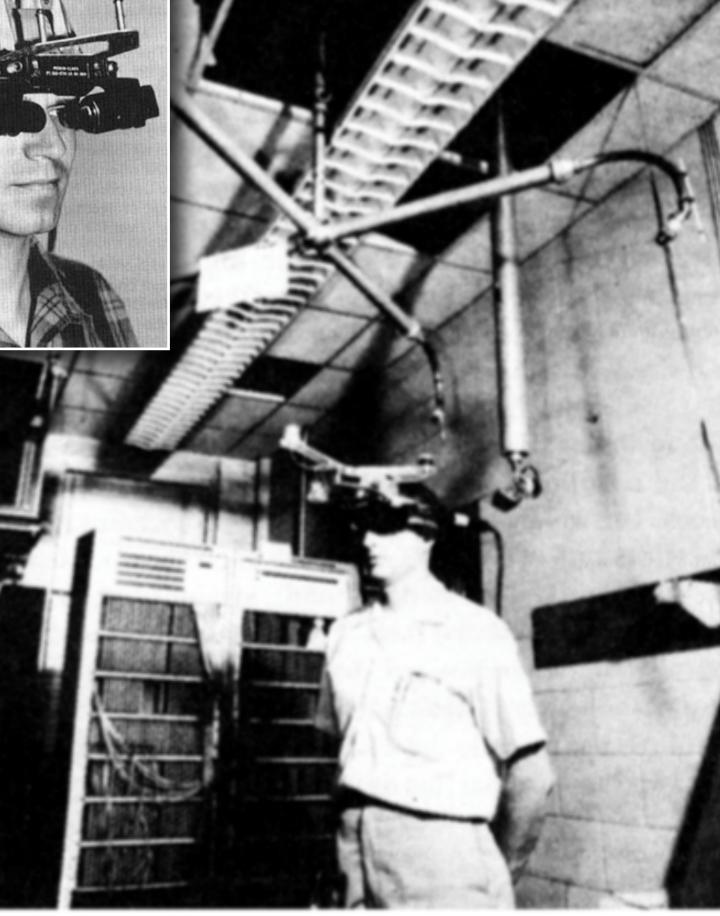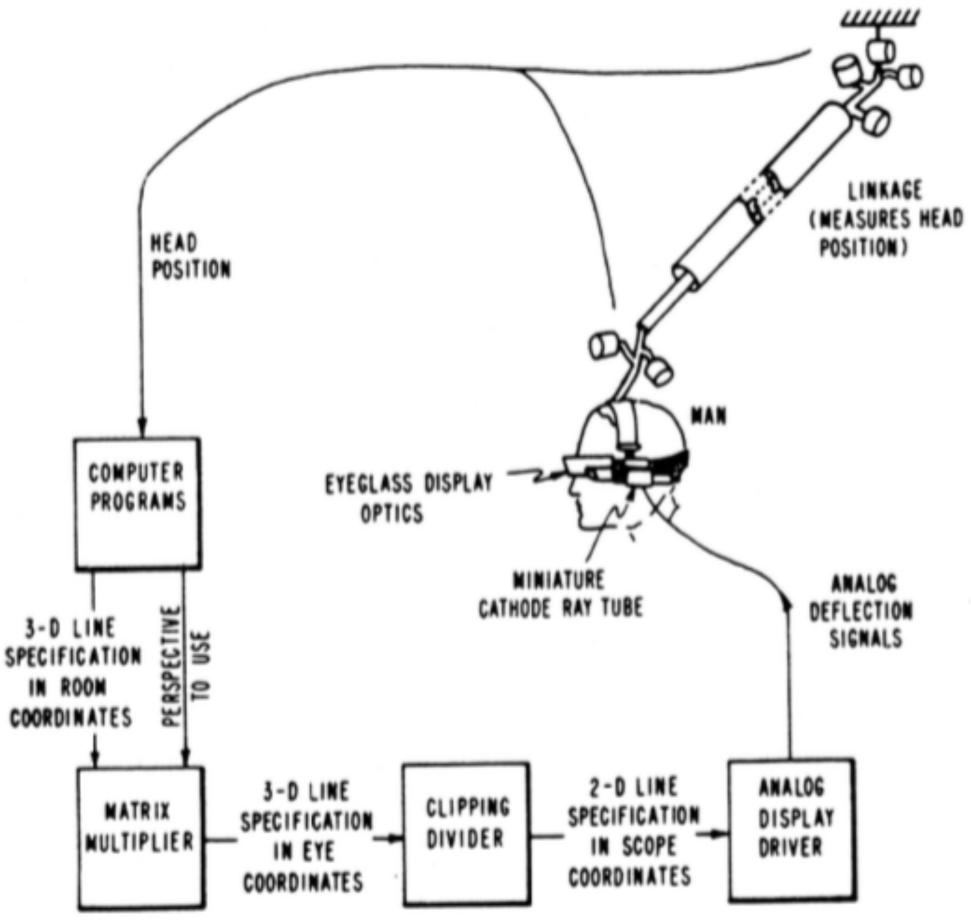
Ivan Sutherland's Head-Mounted Display (1968)

Ivan Sutherland (1960s)

UNC Chapel Hill (circa 1990)
The "Ceiling" Tracker

Array of Infrared LEDs in precisely machined ceiling

"Cameras" on the head

UNC Chapel Hill (late 1990s)
The HiBall Tracking System
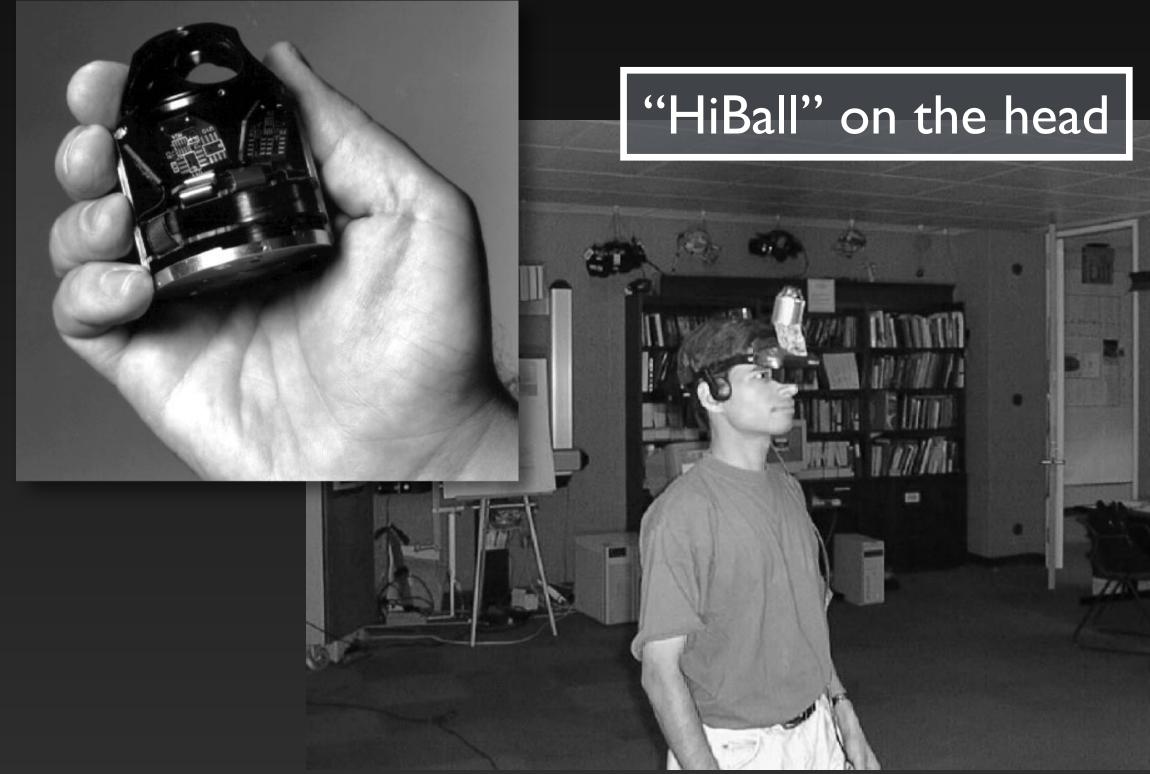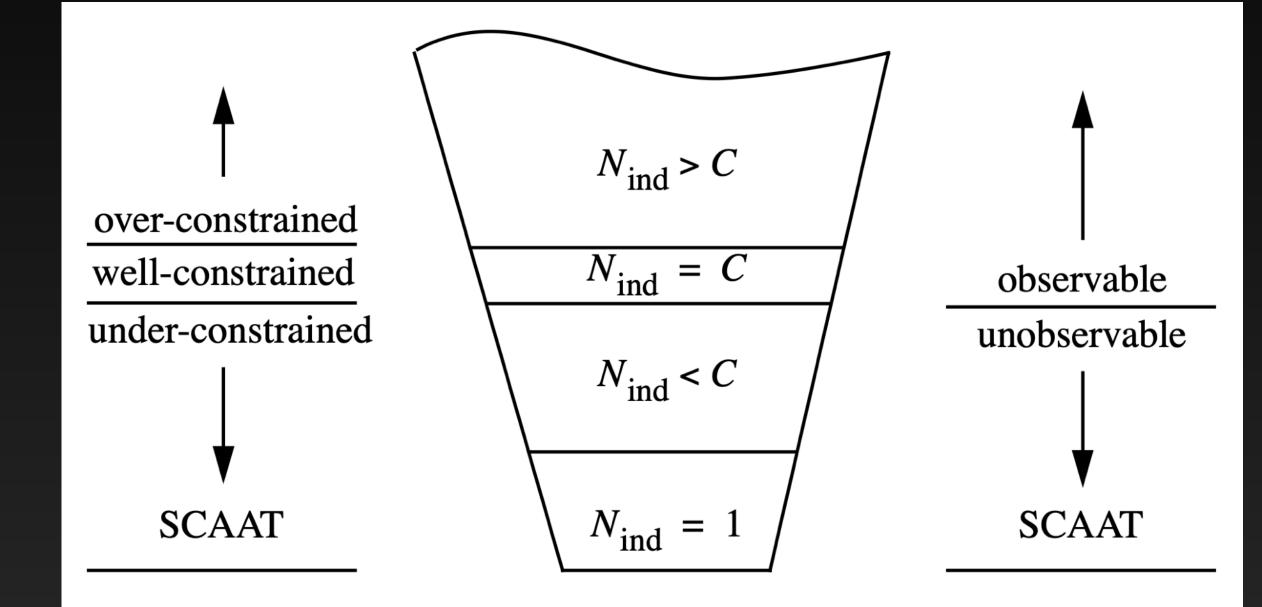
Infrared LEDs installed in normal false-ceiling panels

"HiBall" on the head

over-constrained
---
well-constrained
---
under-constrained

SCAAT

$N_{ind} > C$

$N_{ind} = C$

$N_{ind} < C$

$N_{ind} = 1$

observable
---
unobservable

SCAAT
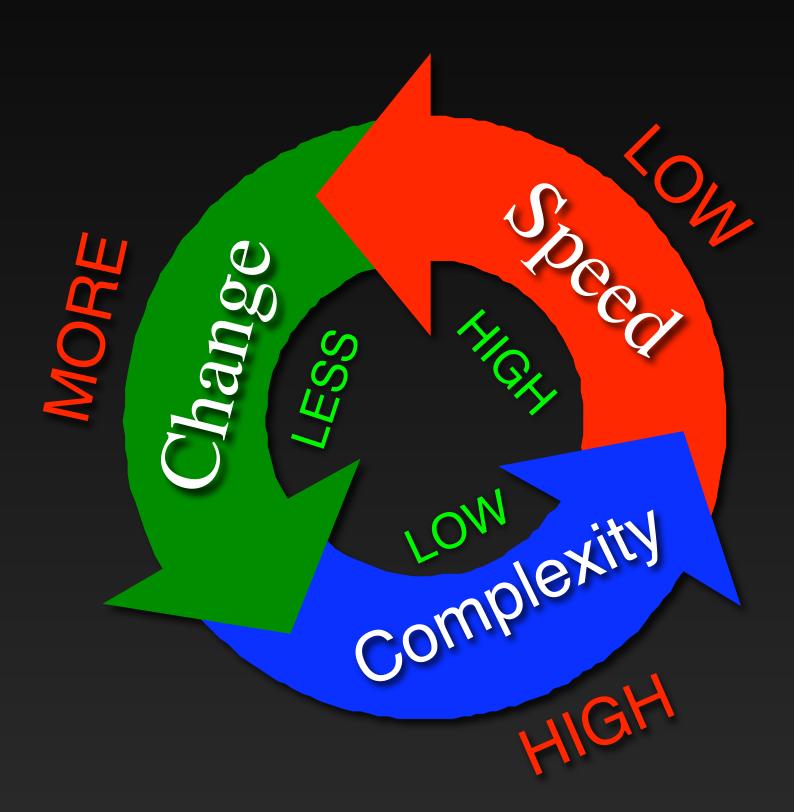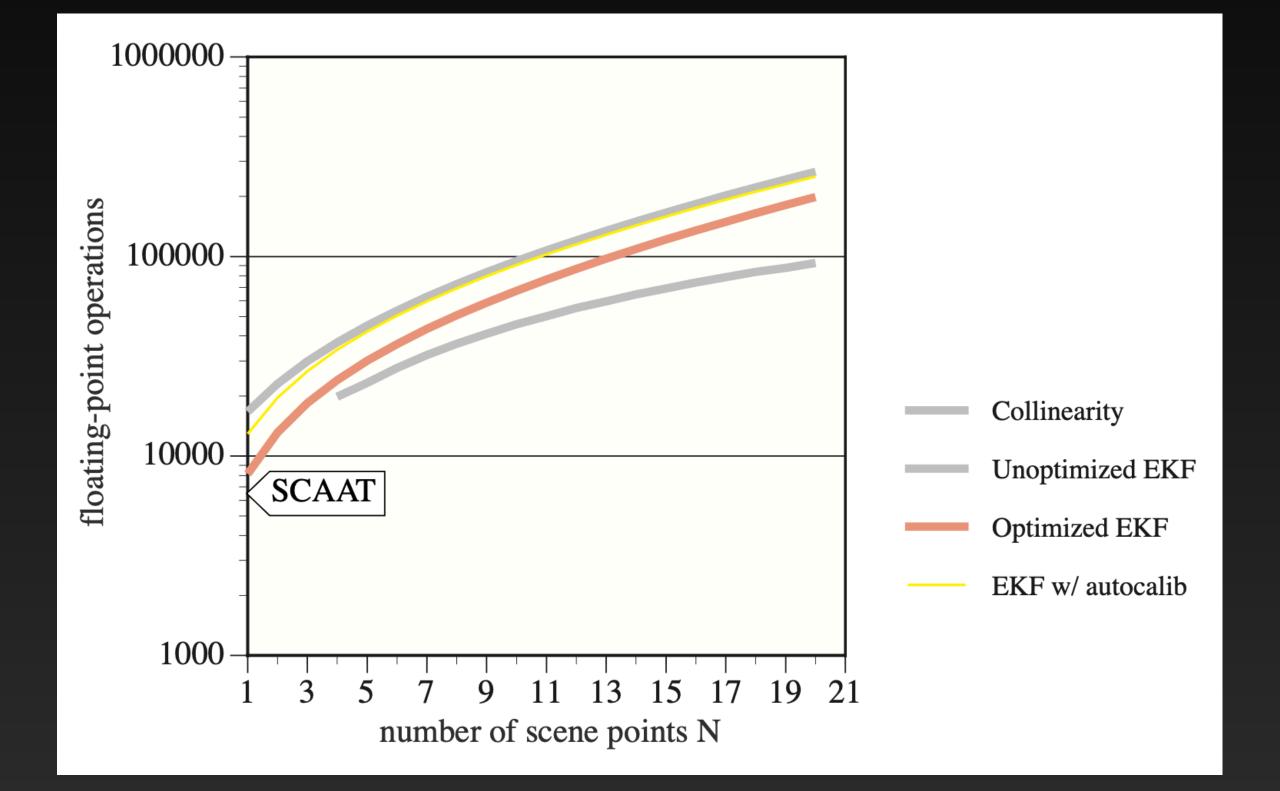
Commercial HiBall Tracking System (circa 2000)

3rdTech / HiBall Tracker, Inc.

HiBall™-3100 Wide-Area Tracker and 3D Digitizer

6 DOF Position and Orientation with Unparalleled Precision and Performance

Highest-Performance Tracking

The HiBall-3100 Tracker creates a new standard of performance for wide-area tracking. Fast, accurate, steady, consistent – you've never used a tracker like this. Based on results of the wide-area tracking research project of the Department of Computer Science of the University of North Carolina at Chapel Hill — the HiBall-3100 optical tracker delivers:

● Low latency and high update rate – solid, smooth tracking even for high-speed sensor motion.

Infrared LEDs in daisy-chained strips that clip to the ceiling

Performance		
Degrees of Freedom	6 per HiBall Sensor	
Max Update Rate (position and orientation)		
1 HiBall Sensor	2000 Hz	
2 HiBall Sensors	1000 Hz each	
4 HiBall Sensors	500 Hz each	
Resolution		
Position (X/Y/Z)	0.2mm RMS	
Orientation (Rx/Ry/Rz)	0.01˚ RMS	
Absolute Accuracy/Stability		
Position (X/Y/Z)	0.4mm RMS	
Orientation (Rx/Ry/Rz)	0.02˚ RMS	
Latency	Less than 1 ms.	
Max Tracking Volume	Greater than 40' x 40' x 10' (200 Beacon Array Modules)	
Angular Range	± 180˚ azimuth; 0-90˚ elevation	
Environment		
Operating Temperature	0 - 45˚ C	
Power	110-130 VAC, 60 Hz	

*specifications subject to change without notice

The Kalman Filter — Web Site and Paper

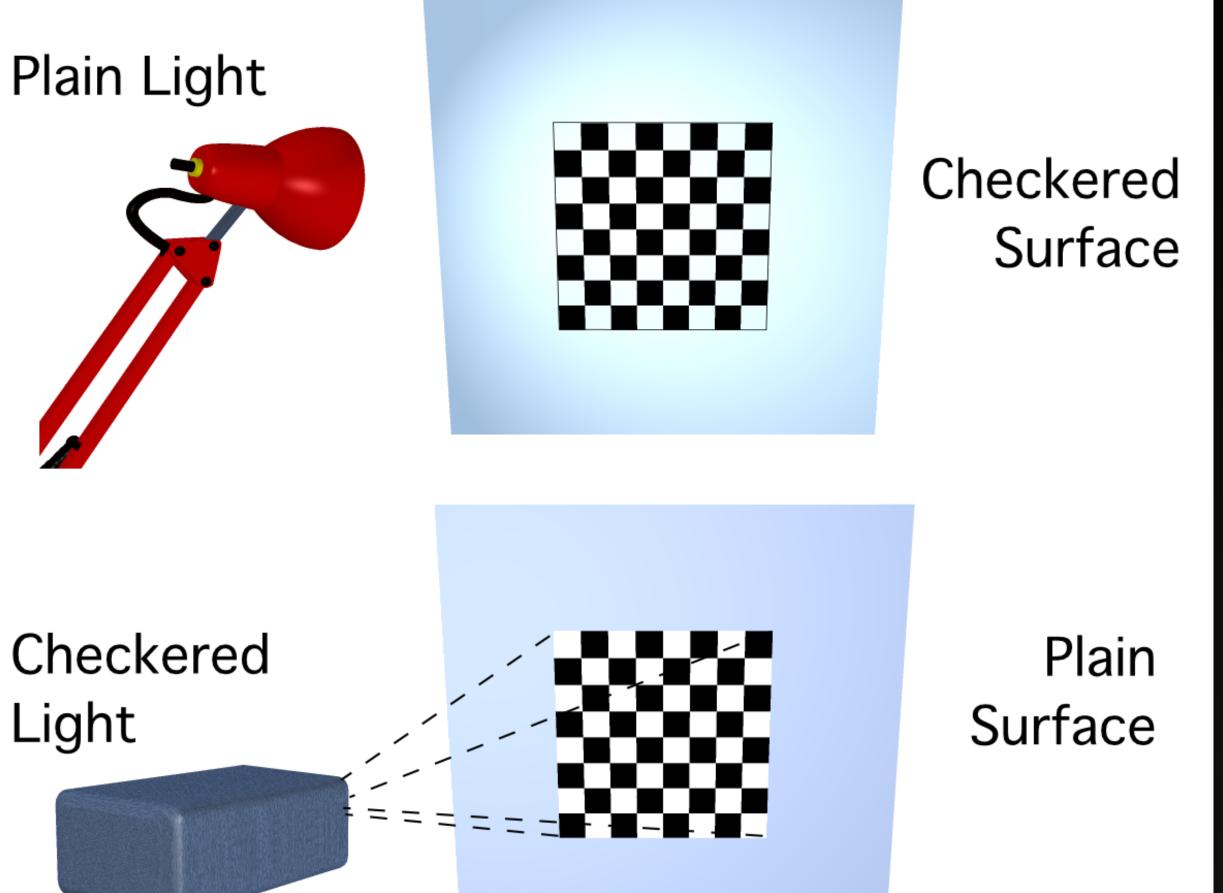2008 NAE Charles Stark Draper
Prize to R.E. Kalman

Cyber-Physical Virtual Reality (UNC-CH)

Virtual experiences that are deeply connected to, responsive to, and capable of influencing the physical world through sensing and actuation.

Ramesh Raskar, Greg Welch, and Henry Fuchs

- 1998 International Workshop on Augmented Reality
- "Long Lasting Impact Paper" award at ISMAR 2016

Spatial Augmented Reality (1998)

White physical models
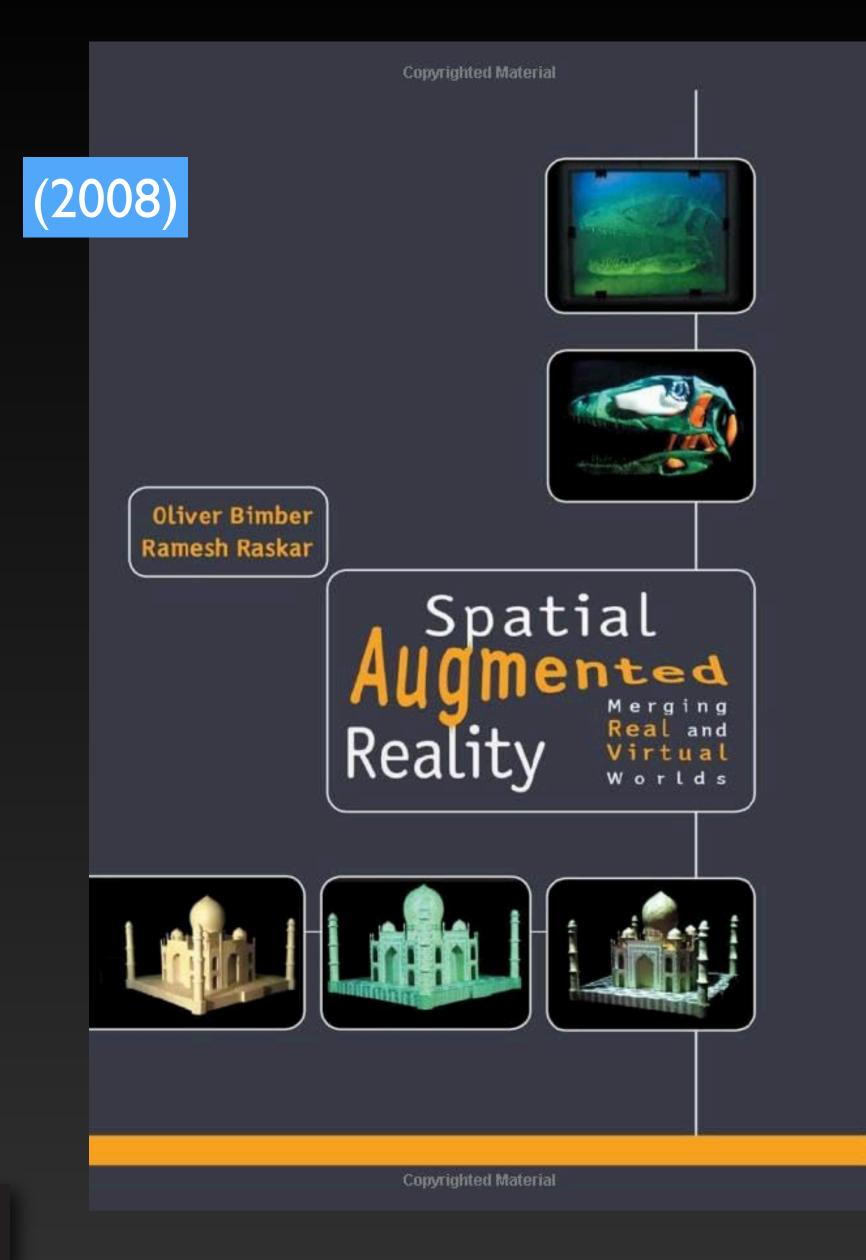
Models textured with projected light

Ramesh Raskar, Greg Welch, Henry Fuchs, et al.

(2008)

"Projection Mapping"

Cinderella's Castle at Walt Disney World

Fête des Lumières in Lyon (2008)

Cyber-Physical Virtual Patients (UCF)

Virtual humans that are deeply connected to, responsive to, and capable of influencing the physical world through sensing and actuation.
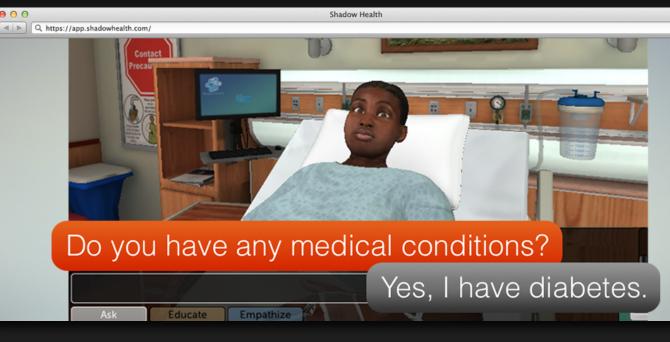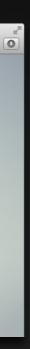
Standardized Patient
(Human)

PediaSim

Physical Patient
("Mannequin")

Do you have any medical conditions?

Yes, I have diabetes.

Ask   Educate   Empathize

Virtual Patient
(Computer)

Touch Sensing on Non-Parametric Rear-Projection Surfaces:
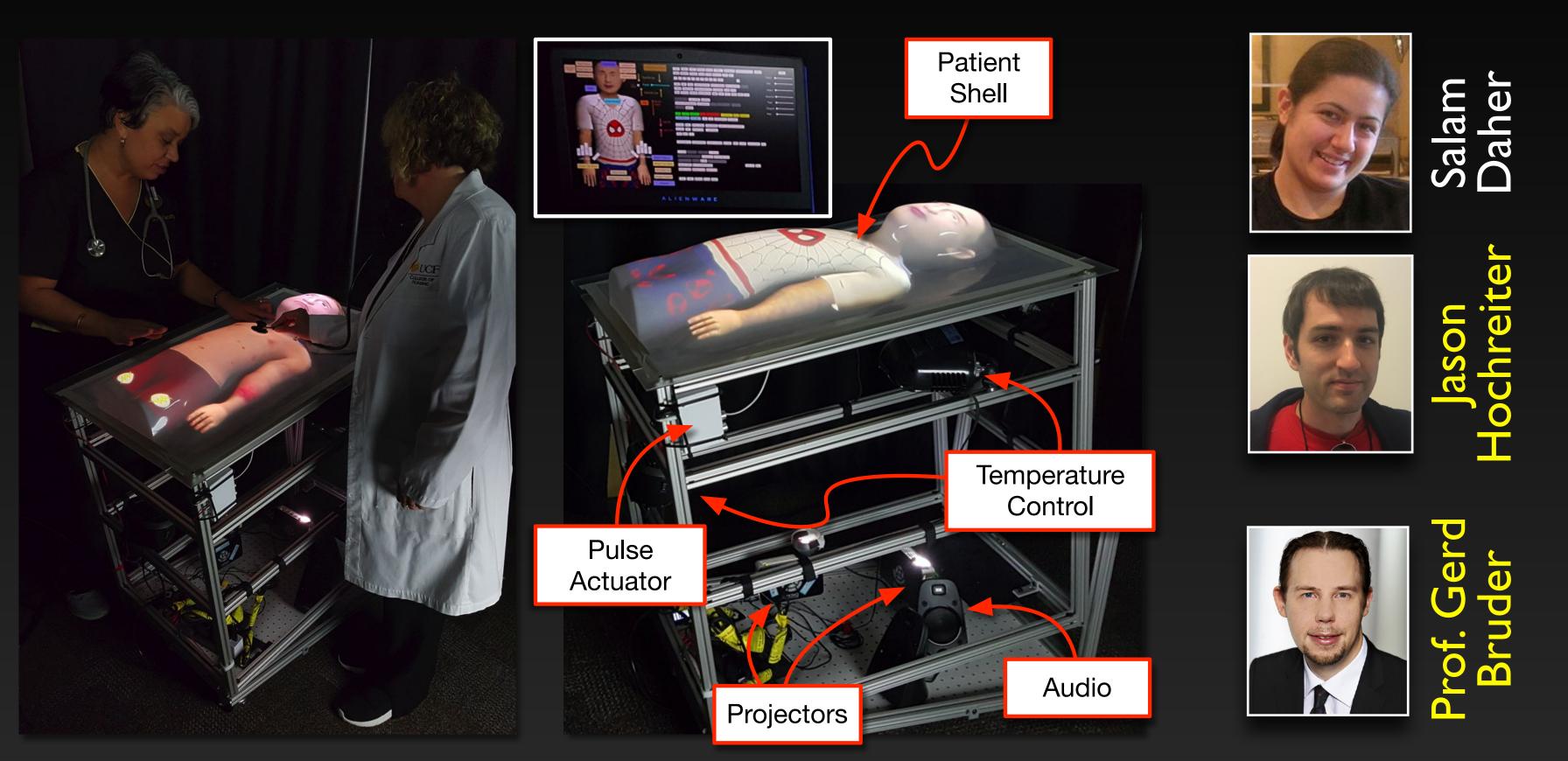A Physical-Virtual Head for Hands-On Healthcare Training

Jason Hochreiter
Salam Daher
Arjun Nagendran
Laura Gonzalez
Greg Welch

UNIVERSITY OF CENTRAL FLORIDA

Stroke Diagnosis Example (Adult)

Normal patient

Physical-Virtual Child — Pediatrics (2020)

Patient Shell

Temperature Control

Pulse Actuator

Projectors

Audio

Salam Daher

Jason Hochreiter

Prof. Gerd Bruder

UCF Nursing: Laura Gonzalez, PhD, ARNP; Mindi Anderson, PhD, ARNP and Desiree Diaz, PhD, RN-BC. **UCF Medicine:** Juan Cendan, MD.
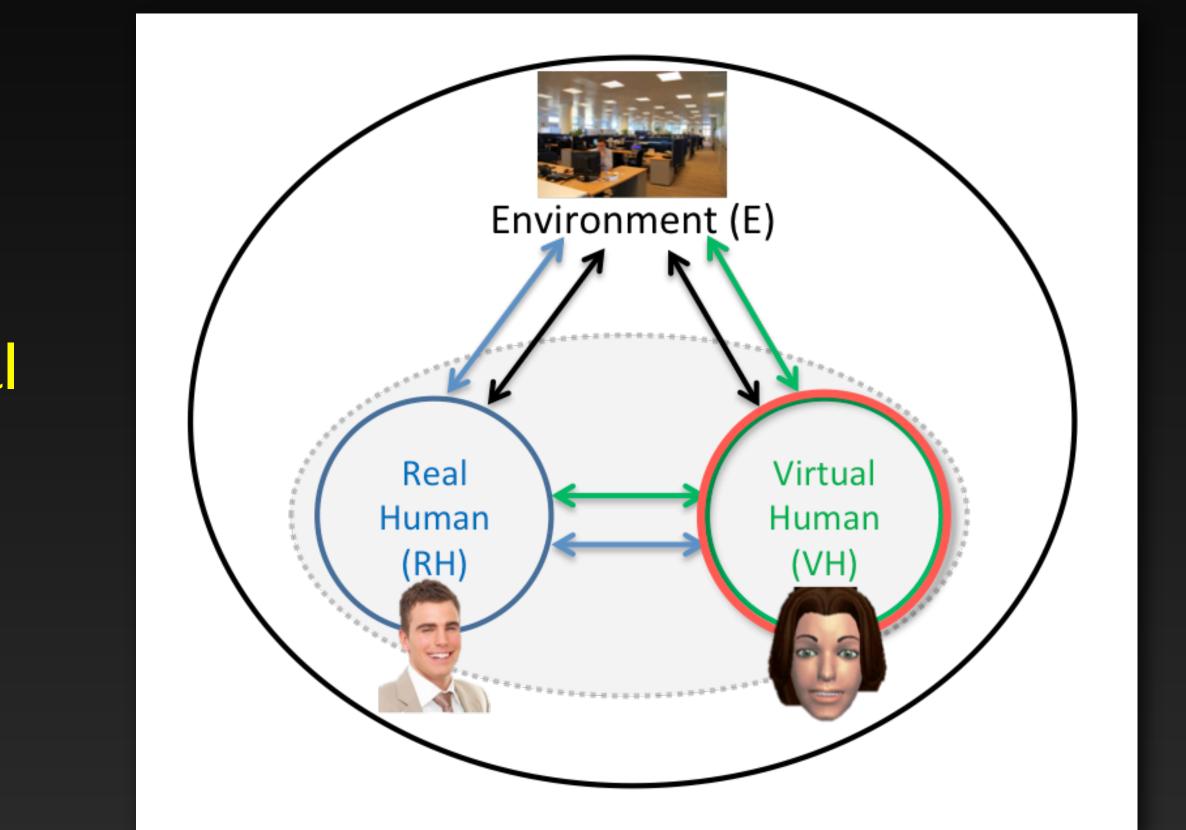
Cyber-Physical Virtual Humans and Environments

Virtual humans aware/affected by the environment
Virtual humans able to Influence the environment

What features can we add to the surrogate, environment, or interaction to strengthen co/social presence in the user and elicit plausibly realistic behavior?
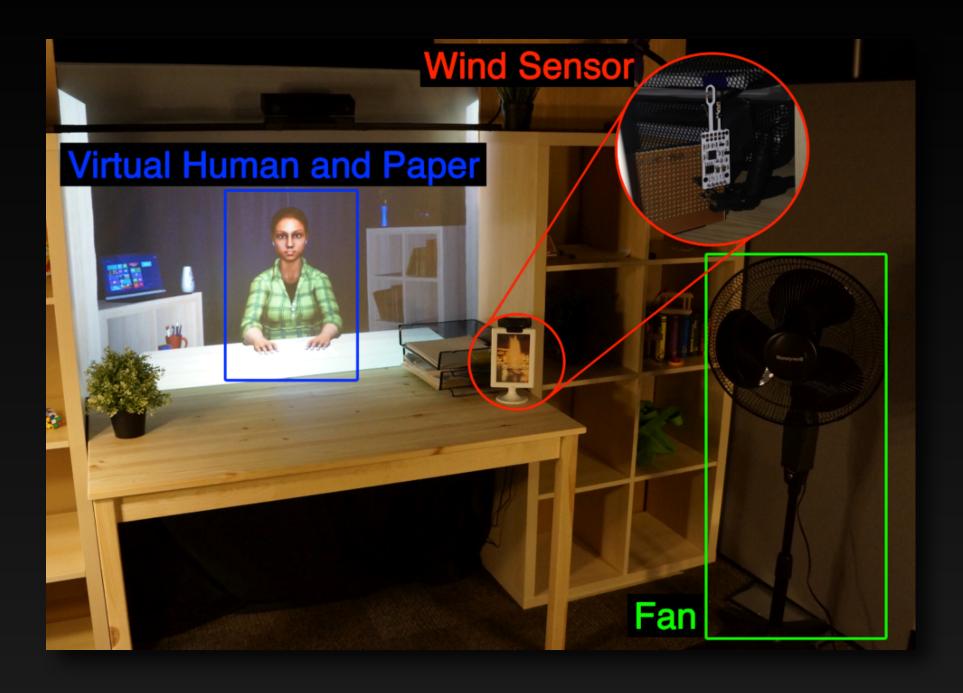
The "Wobbly Table"
(Lee, Kim, Daher, Raij, Schubert, Bailenson, and Welch, 2016)

Wind Sensor

Virtual Human and Paper

Fan

VRST 2018
Honorable Mention

Blowing in the Wind
(Kim, Bruder, Schubert, and Welch)

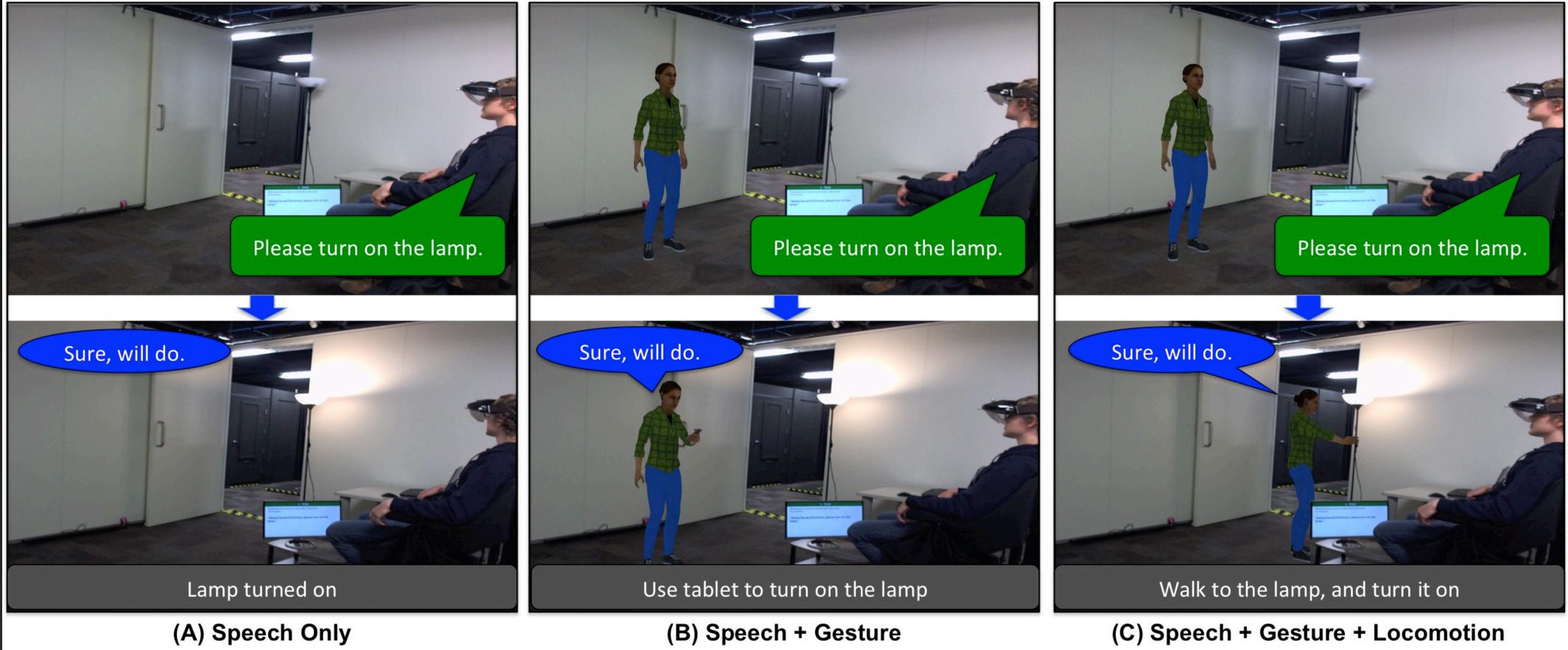Still   Flutter   Aware

Does a Digital Assistant Need a Body?
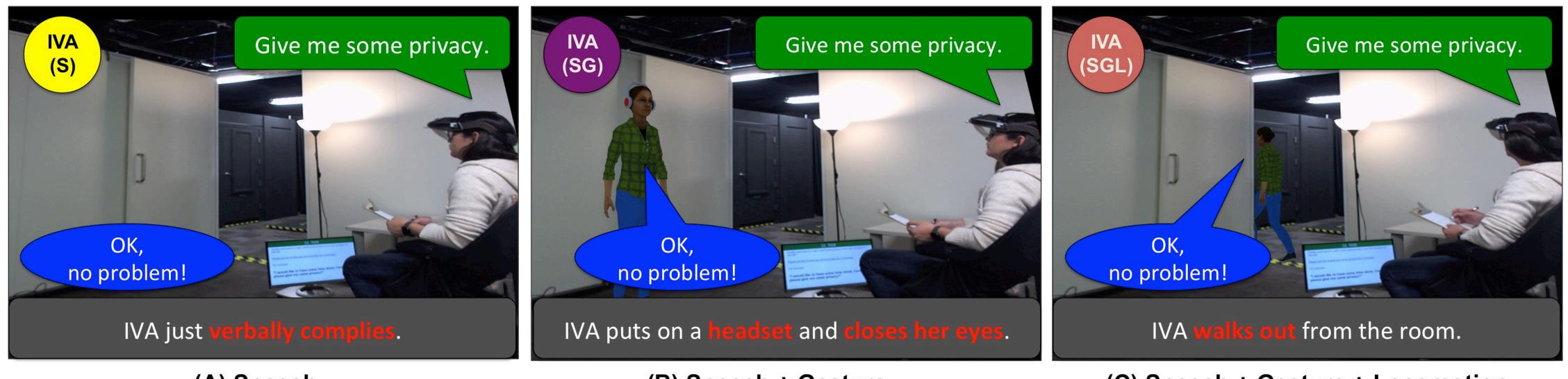## (Kim, Boelling, Haesler, Bailenson, Bruder, and Welch, 2018)

(A) Speech Only

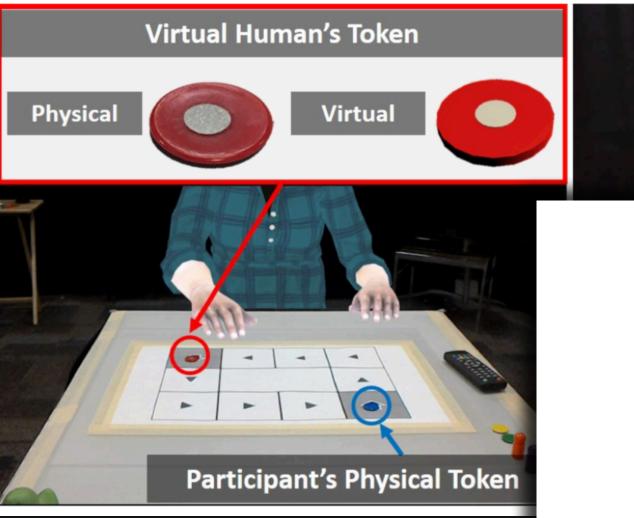(B) Speech + Gesture

(C) Speech + Gesture + Locomotion

Does a Digital Assistant Need a Body?
(Kim, Boelling, Haesler, Bailenson, Bruder, and Welch, 2018)

(A) Speech (B) Speech + Gesture (C) Speech + Gesture + Locomotion

The Physical-Virtual Table: **Effects of A Virtual Human's Physical Influence**

(...uzi, Bruder, Wisniewski, and Welch, 2019)

- Increased Co-P...
- Increased expe... physical objects...
- Improved the u...

VERA is an NSF Research Infrastructure Project

- U.S. National Science Foundation (NSF)
  - ~$5M over four years

- CIRC grants
  - Not for basic research
  - Are for infrastructure to be used by "the community" for basic research

- VERA Community ➜ XR Community

- U.S. focus for now …
  - … but international use is planned through various mechanisms, including eventual growth or replication

VERA Principal Investigators

Greg WELCH (Lead)
UNIVERSITY OF CENTRAL FLORIDA

Tabitha PECK
DAVIDSON

Valerie Jones TAYLOR
RUTGERS

Gerd BRUDER
UNIVERSITY OF CENTRAL FLORIDA

Jeremy BAILENSON
Stanford University

Shiri AZENKOT
CORNELL TECH
XR Access
Virtual, Augmented, & Mixed Reality for People with Disabilities

John MURRAY
UNIVERSITY OF CENTRAL FLORIDA

VERA Area Investigators

Jonathan BEEVER
Ethics and Privacy

UNIVERSITY OF CENTRAL FLORIDA

Center for Ethics

Rui XIE
Statistics and Data Science

UNIVERSITY OF CENTRAL FLORIDA

Carolina CRUZ-NEIRA
Sustainability and Partnerships
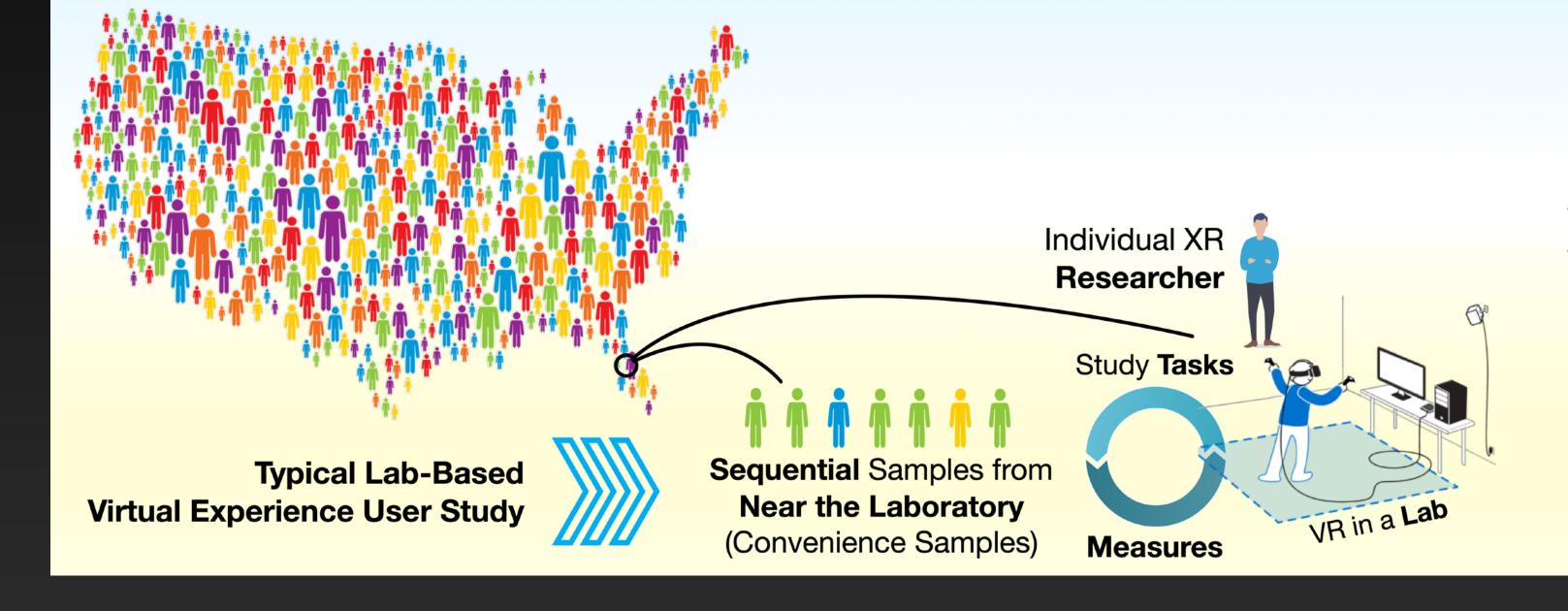
UNIVERSITY OF CENTRAL FLORIDA

Nicholas COLES
Big Team Science

UF | UNIVERSITY of FLORIDA

Typical Lab-Based Virtual Experience User Study

Sequential Samples from **Near the Laboratory** (Convenience Samples)

Individual XR **Researcher**

Study **Tasks**

Measures

VR in a **Lab**

Time
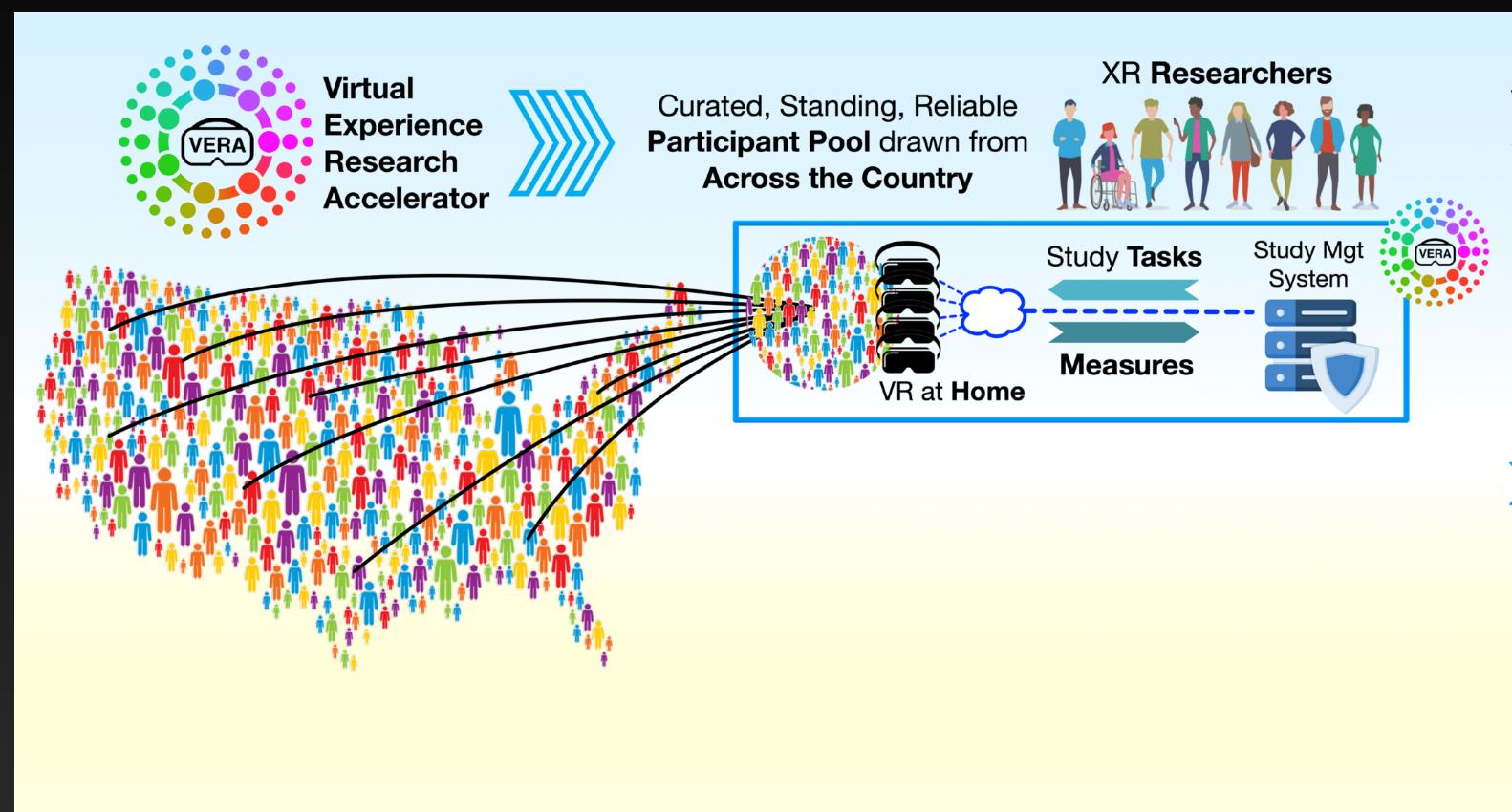
Relatively **slow**, **sequential** studies, **fewer** studies, **smaller** samples, **uncontrolled demographics**, difficult to **replicate** or study **over time**.

Virtual Experience Research Accelerator

Curated, Standing, Reliable **Participant Pool** drawn from **Across the Country**

XR **Researchers**

Study **Tasks**

Study Mgt System

Measures

VR at **Home**

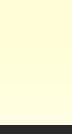Relatively **fast**, **concurrent** studies, **many** studies, **very large** samples, **controlled** demographics, supports **replication** and **longitudinal** studies.

Time

Development and Operations

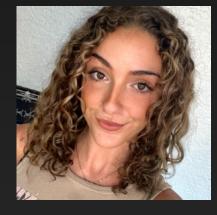Director of Development and Operations — Dr. Ali HASKINS LISLE

Software Development — Dr. John MURRAY

Development Project Manager — Chloe BEATO

XR Access Lead — Dylan FOX

Partnering with Public Libraries

FOR OUR LIBRARIES.

The Library Marketplace: Exhibits, Stages & Resources is where innovation meets opportunity!

Connect with expert exhibitors and authors, explore cutting-edge resources, and discover tools that will help innovate your library. Immerse yourself in a variety of engaging activities, grab free books, and so much more! It's not just an exhibit hall—it's a chance to fuel your mission and have a great time doing it!

Learn More

- Recruit VERA Participants from library patrons
- Allow VERA Participants to do Experiments using existing VR systems
- VERA could support the purchase of a VR system if needed
- Appropriate financial support for the library

Disseminate Knowledge ➡ Generate Knowledge

Thank you!

Questions or thoughts?

Virtual Experience Research Accelerator

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welch@ucf.edu