## Cyber-Physical Virtual Reality

### **Greg WELCH**

Pegasus Professor AdventHealth Endowed Chair in Simulation



UNIVERSITY OF CENTRAL FLORIDA

17 APR 2025



### Academic Background

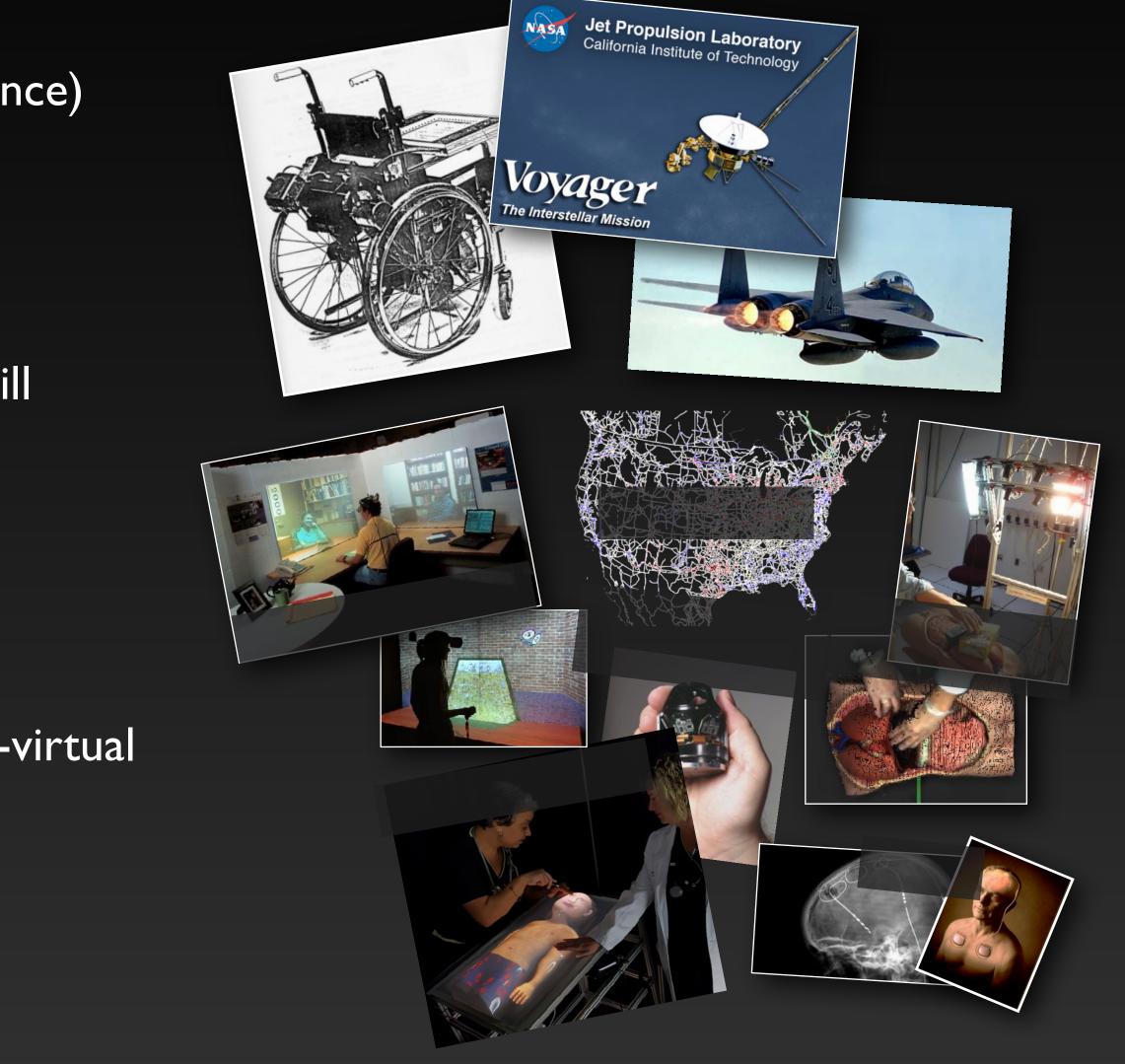
- Purdue University (B.S. Electrical Technology)
- UNC Chapel Hill (M.S. & Ph.D. Computer Science)

### 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



## Background Summary





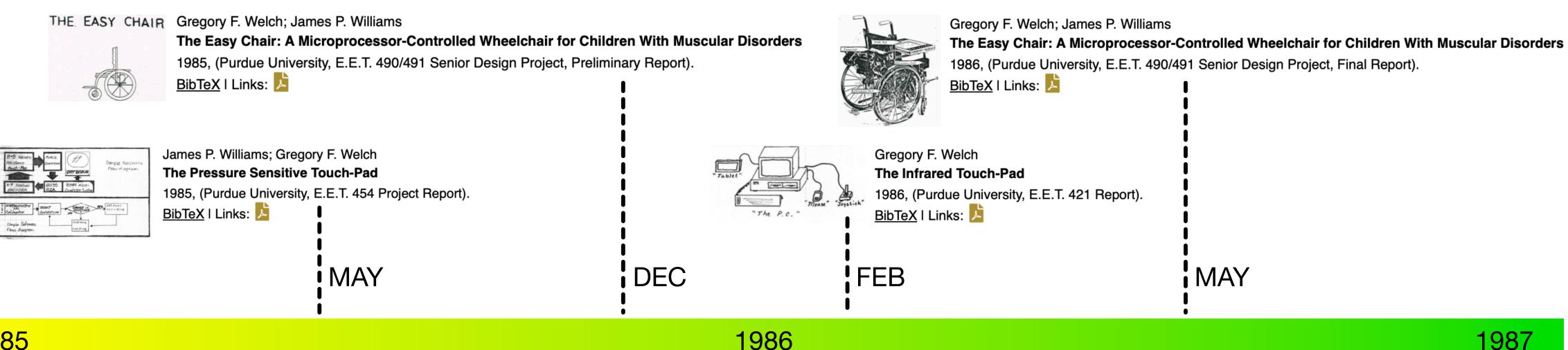






## Purdue University (B.S. Electrical Technology) Senior Design Project with Paul Williams

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



1985













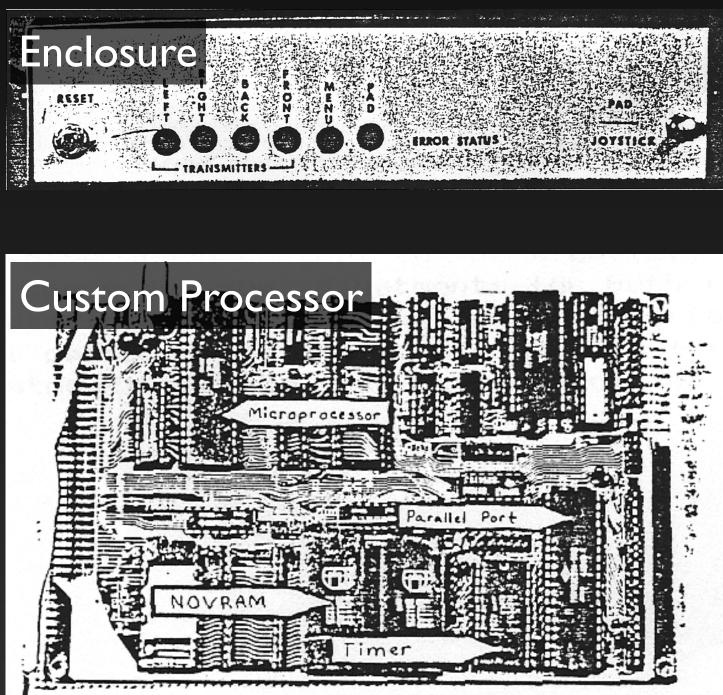


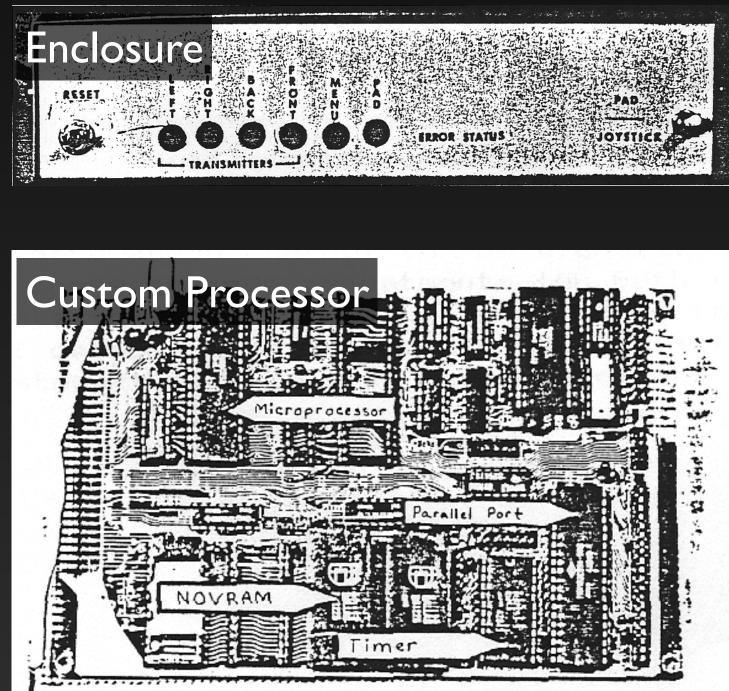
Technology

## Purdue University (B.S. Electrical Technology) Senior Design Project with Paul Williams (1985–1986)

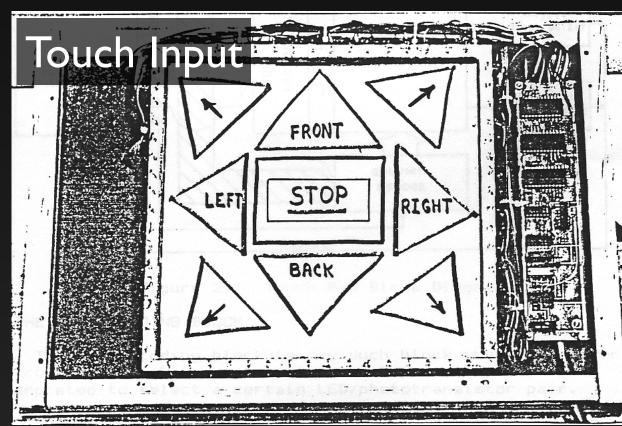
### The Easy Chair: A Microprocessor-Controlled Wheelchair for Children With Muscular Disorders

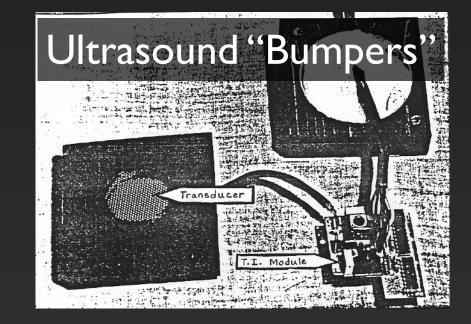












© 2025 Greg WELCH



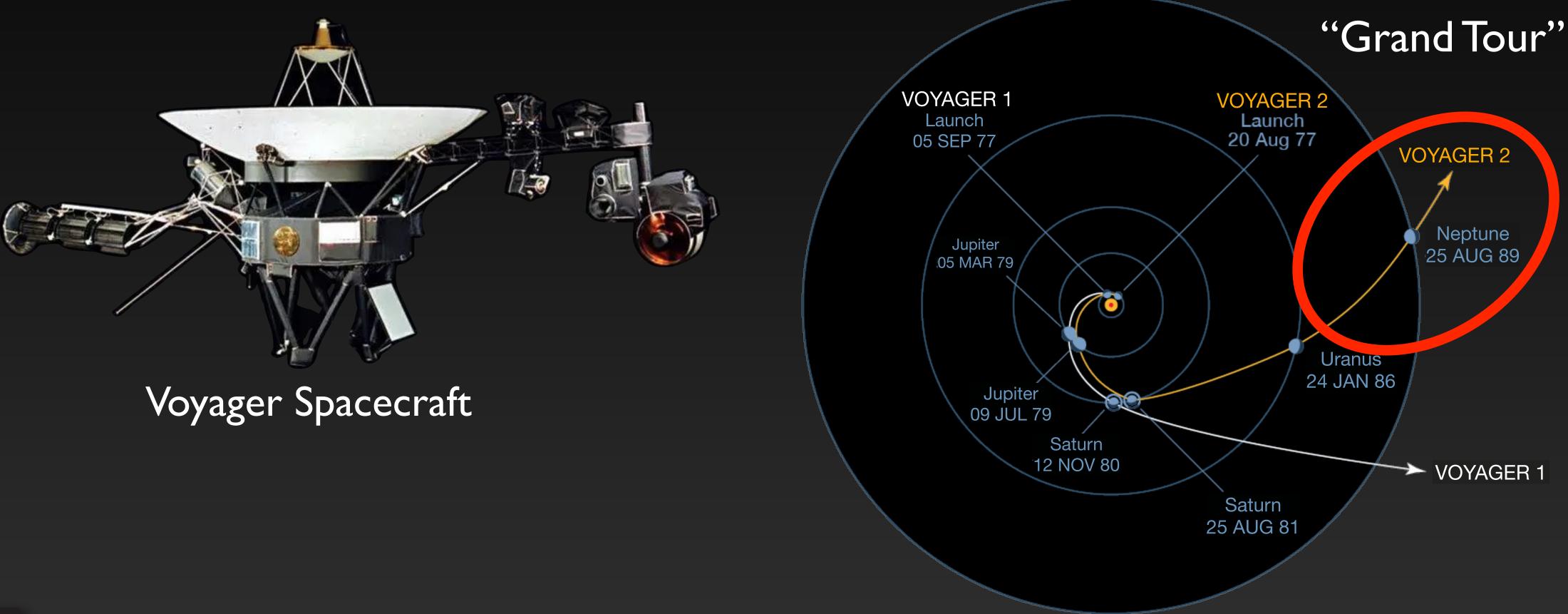




4









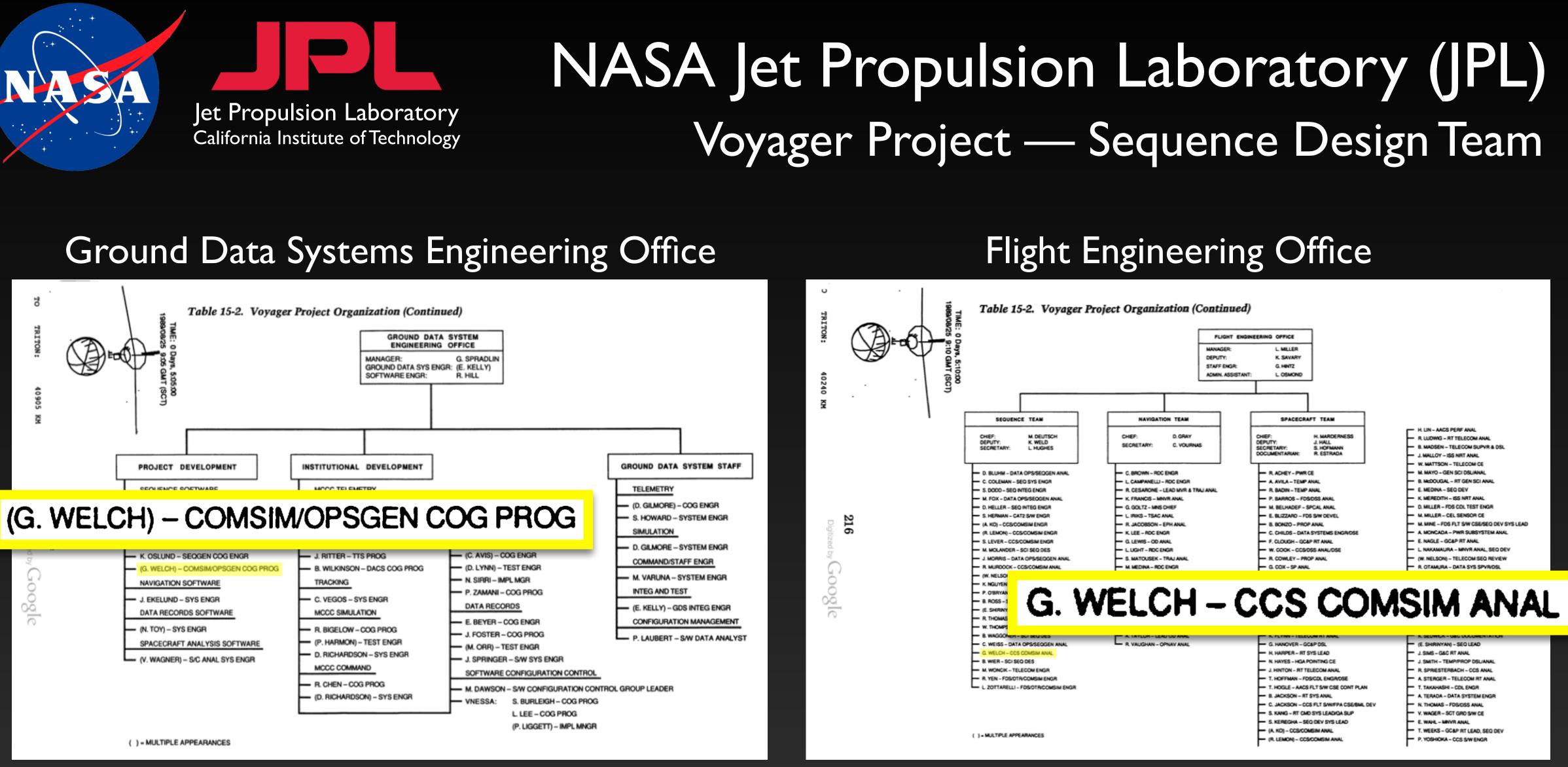
## NASA Jet Propulsion Laboratory (JPL) Voyager Project — Sequence Design Team















6



#### "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.

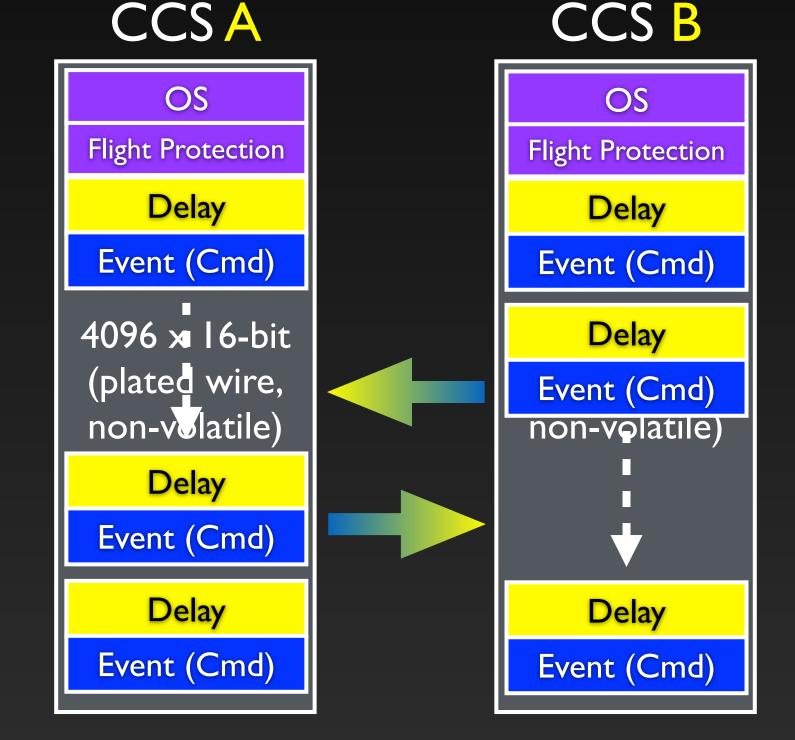
### 4KHbbzbituch Eetema fyz. Gypesseessors



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

Managing precious on-board memory















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

#### MEMMAN

Voyager CCS Memory Management Software

Software Description Document

Revised April 27, 1990

Jet Propulsion Laboratory

Gregory F. Welch

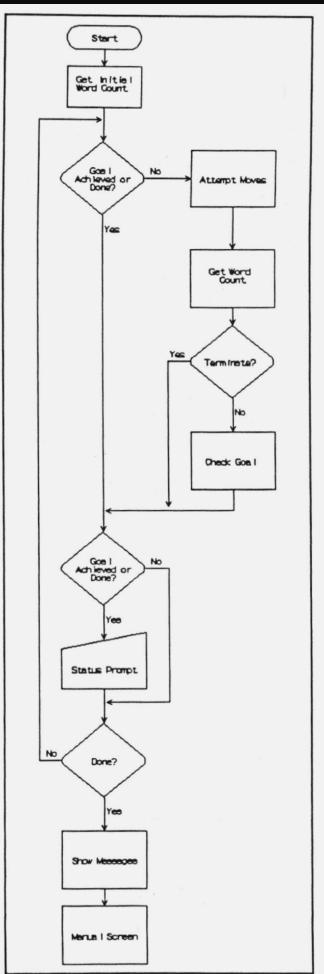


Figure 4: Automatic Management



### MEMMAN Memory Management Software

#### MEMMAN

Voyager CCS Memory Management Software

Software Maintenance Document

Revised May 3, 1990

Jet Propulsion Laboratory

MEMMAN

Voyager CCS Memory Management Software

Functional User's Guide

Revised May 15, 1990

Jet Propulsion Laboratory

Gregory F. Welch

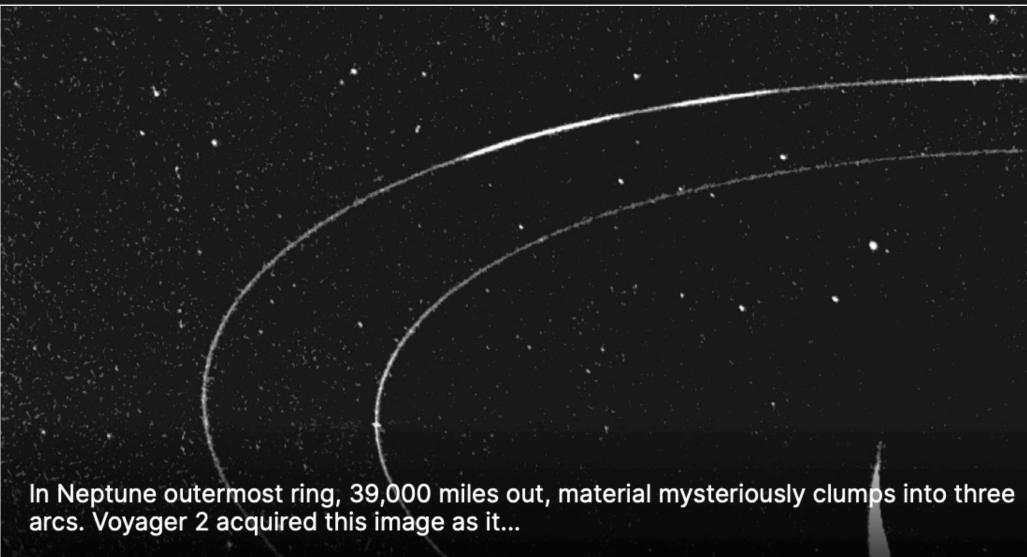
Gregory F. Welch

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









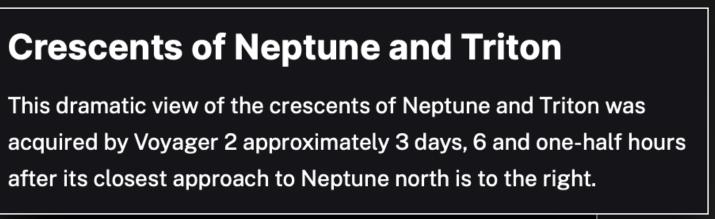


This false color photograph of Neptune was made from NASA's Voyager 2 images taken through three filters: blue, green, and...

**Crescents of Neptune and Triton** 

after its closest approach to Neptune north is to the right.









### **NORTHROP GRUMMAN**



#### USAF F-15 Eagle

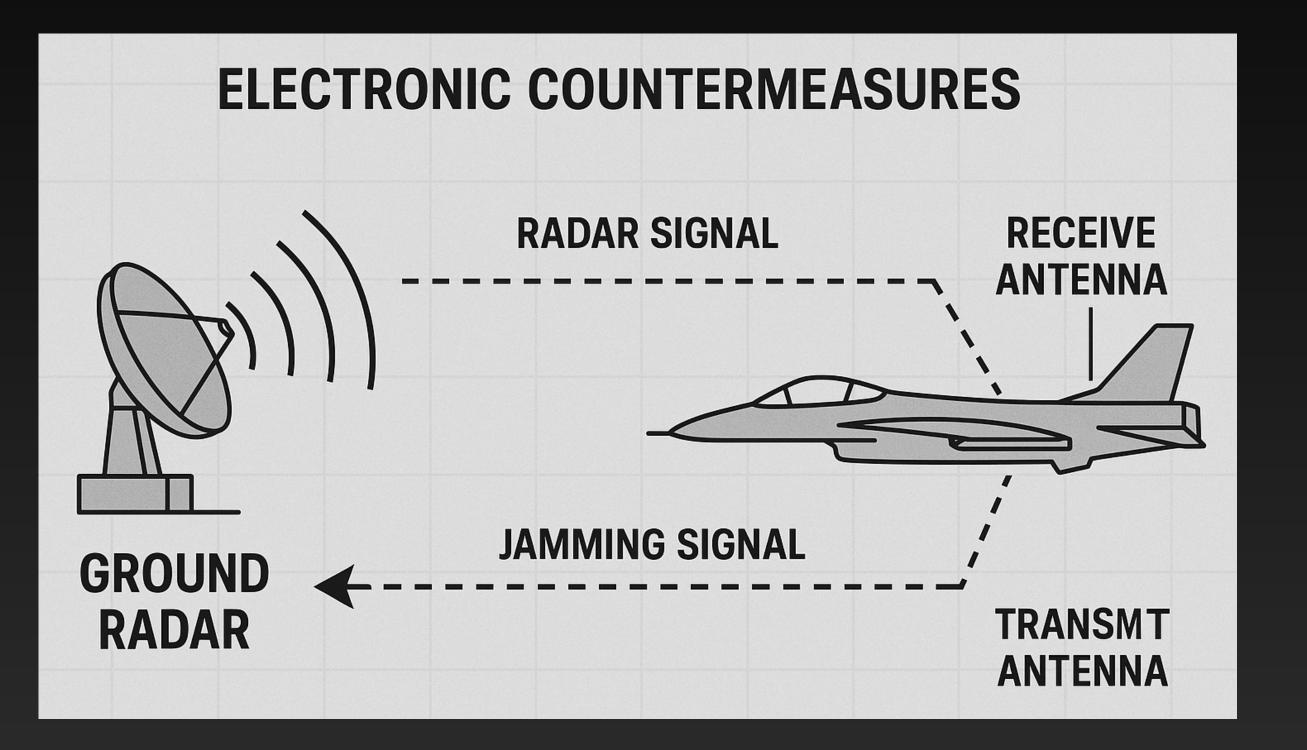




### AN/ALQ-135 Band 1.5 and Band 3



## Northrop Defense Systems AN/ALQ-135 Electronic Countermeasures













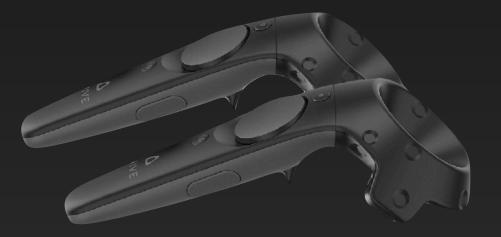
THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

# University of North Carolina at Chapel Hill

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









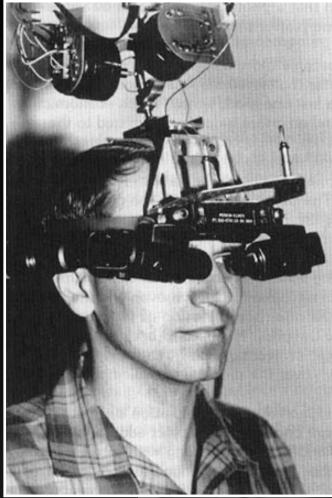
## Virtual Reality Today

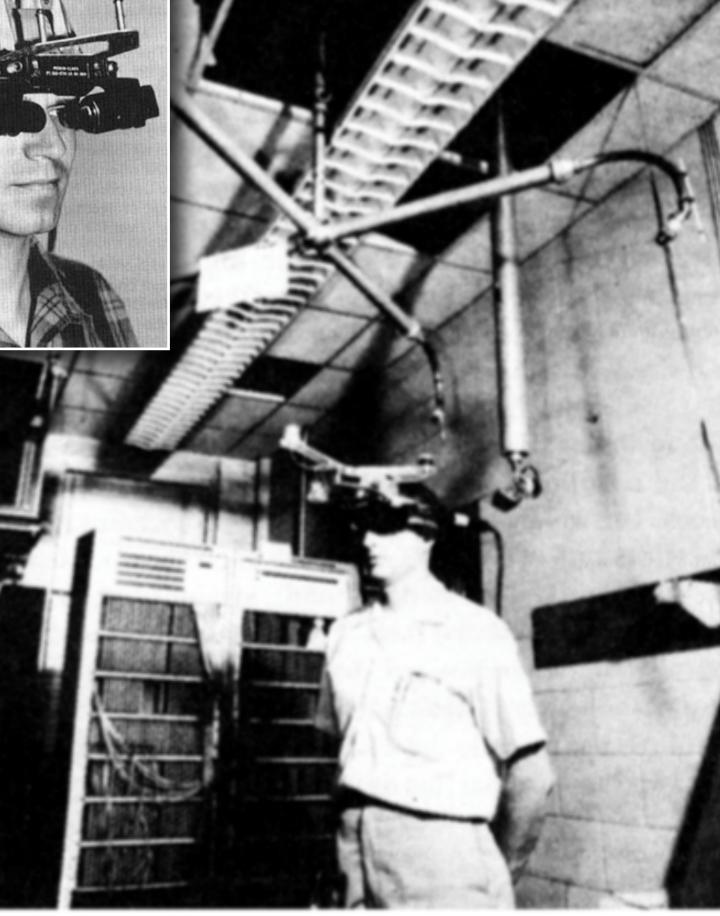


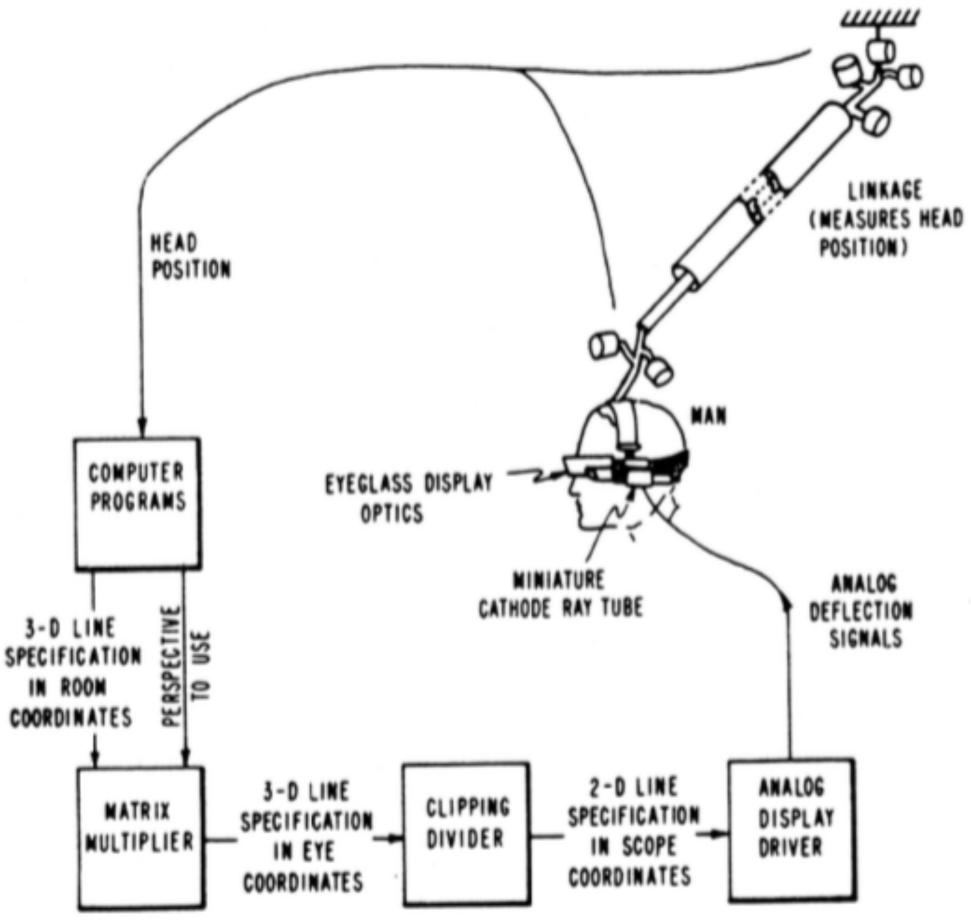














### Ivan Sutherland's Head-Mounted Display (1968)



## Ivan Sutherland (1960s)











## Ivan Sutherland (1960s)













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



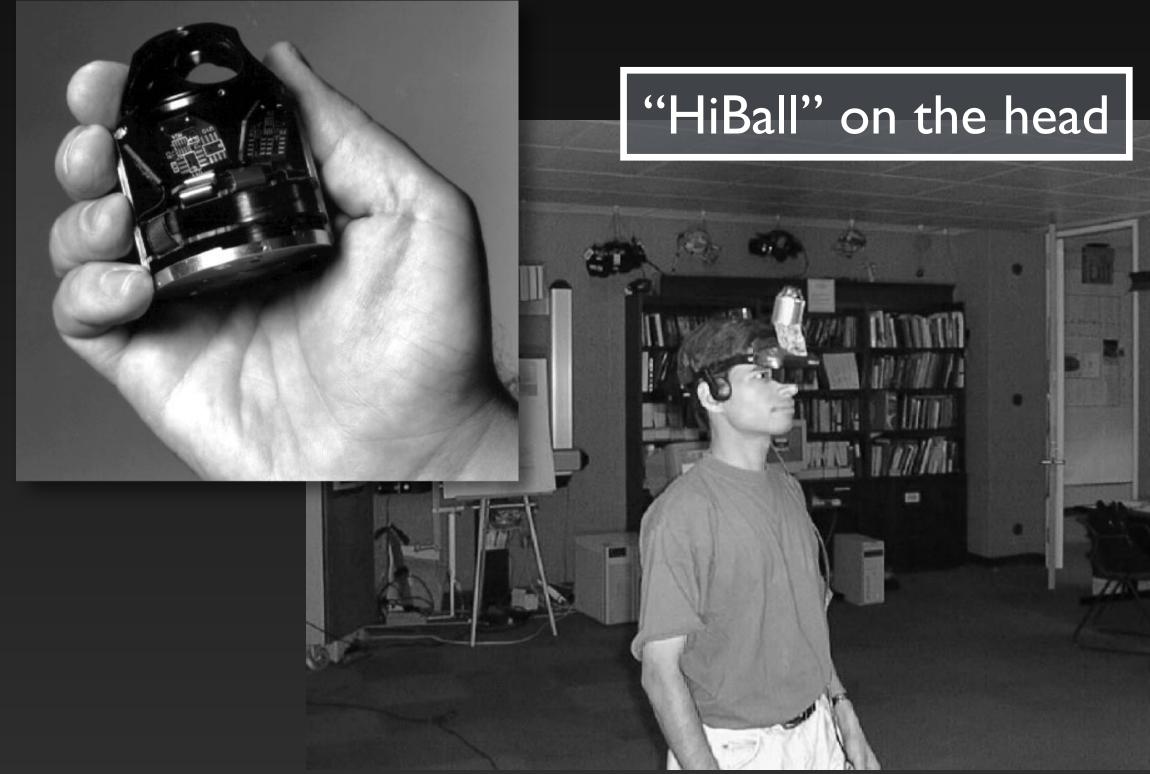




### Infrared LEDs installed in normal false-ceiling panels



# UNC Chapel Hill (late 1990s) The HiBall Tracking System







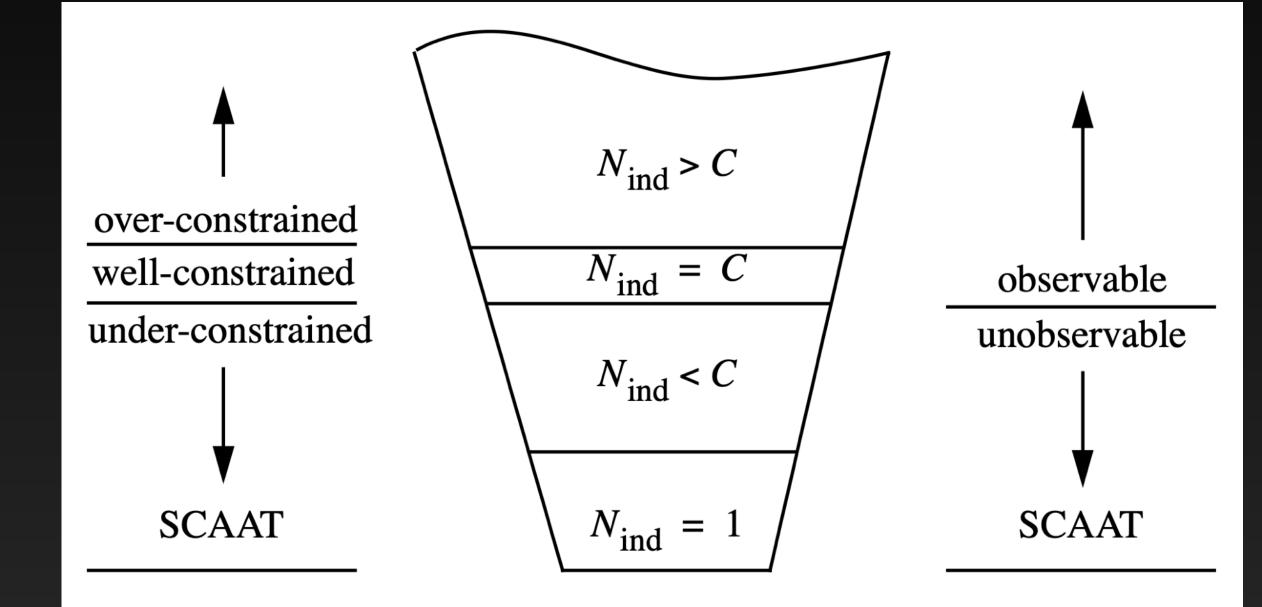




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## Single-Constraint-at-a-Time Tracking (Welch)







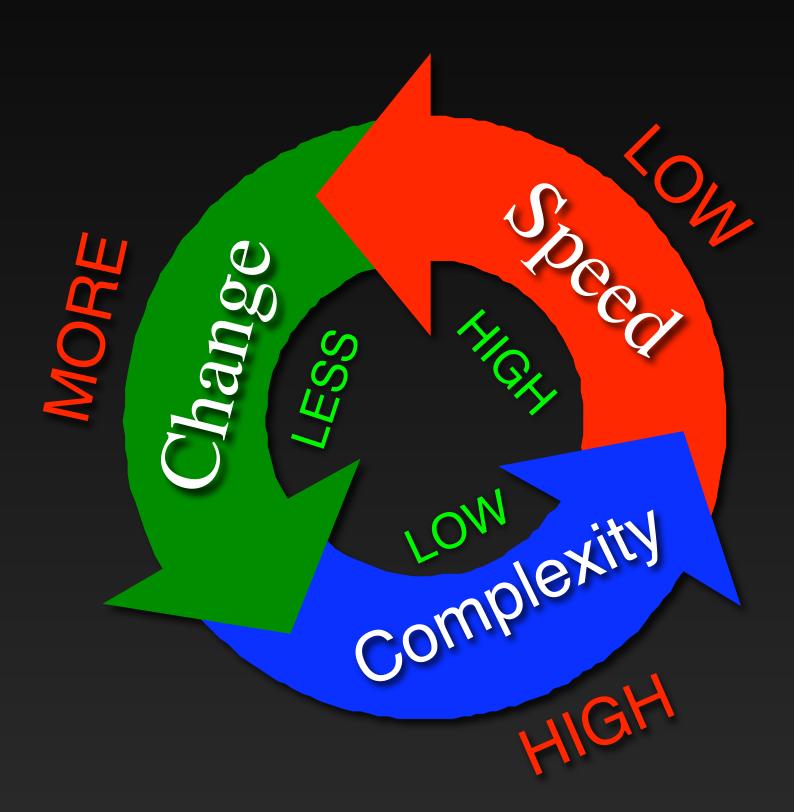






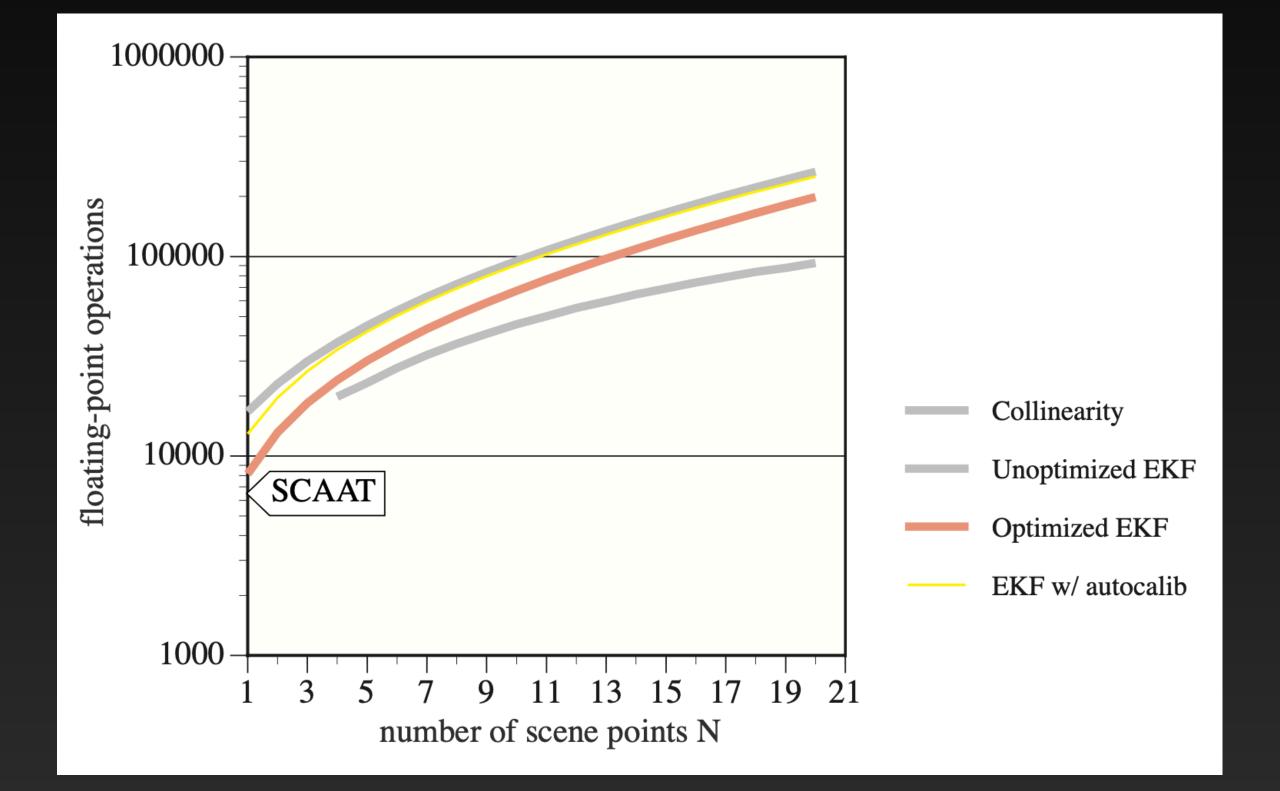
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## "Spiral of Goodness" (Bishop 1982)









# Commercial HiBall Tracking System (circa 2000)

. . .

### 3rdTech / HiBall Tracker, Inc.

#### HiBall<sup>™</sup>-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-

tanteared sh LEDs in daisy-chained • Low tency solid, looth speed isor moti 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	า	
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 m	าร.	
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 UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

## University of North Carolina at Chapel Hill The Kalman Filter — Web Site and Paper



**The Kalman Filter** 

ome tutorials, references, and research related to the Kalman filter.

This site is maintained by <u>Greg Welch</u> in <u>Nursing</u> / <u>Computer Science</u> / <u>Simulation & Training</u> at the <u>University of Central Florida</u>, and <u>Gary Bi</u> <u>Department of Computer Science</u> at the <u>University of North Carolina at Chapel Hill</u>. Welch also holds an adjunct position at UNC-Chapel Hill. additions or comments

#### News & Events

- [STICKY] R. E. Kalman passed away on 2 July 2016. See the story on the University of Florida web site (local PDF), as well as the tribute at t once, but corresponded with him over the years, and felt connected to him.
- [STICKY] On 2 January, 2008, The U.S. National Academy of Engineering announced that Rudolf Kalman would receive the 2008 Charles Stark dissemination of the optimal digital technique (known as the Kalman Filter) that is pervasively used to control a vast array of consumer, health, co \$500,000 prize was presented in Washington, DC, on 19 February, 2008. More information is available here. See also the NAE press release. We have event, taken by Greg Welch.

**Quick Links** 



Courses

Non-English Material

Thank you to the people who made the following possible:

Salman Masoumi has created a Farsi translation of Kalman's biographical information

- Xuchen Yao, a Ph.D. student at Johns Hopkins University has taken our article "An Introduction to the Kalman Filter" and translated it into Chinese
- Ruben R. Raygosa has contributed a Spanish tutorial for the Kalman filter

Reference **Rudolf E. Kalman**  Biographical information • A little biographical information. The information is also available in Farsi, thanks to Salman Masoumi. More information, thanks to Eduardo Sontag, a former student of R.E. Kalman's Yet more information in Wikipedia • There is a nice article on Kalman in the IEEE History Center. • On 16 November, 2005, Kalman was awarded Columbia Engineering School Alumni Association's Egleston Medal for Distinguished Engin On 19 February, 2008, Kalman was awared the <u>Charles Stark Draper Prize</u> for "the development and dissemination of the optimal digital tech pervasively used to control a vast array of consumer, health, commercial and defense products." More information is <u>available here</u>. (See also Vladimir Tislenko wrote to tell us about two Kalman rivers connected to the Irtysh river in Siberia. • R F Kalman's seminal (1960) naner IAN-7A4HZV?OpenDocument" in a new tab behind the current one



**Greg Welch<sup>1</sup> and Gary Bishop<sup>2</sup>** 

TR 95-041 **Department of Computer Science** University of North Carolina at Chapel Hill Chapel Hill, NC 27599-3175

Updated: Monday, July 24, 2006

In 1960, R.E. Kalman published his famous paper describing a recursive solution to the discrete-data linear filtering problem. Since that time, due in large part to advances in digital computing, the Kalman filter has been the subject of extensive research and application, particularly in the area of autonomous or assisted navigation.

The Kalman filter is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of a process, in a way that minimizes the mean of the squared error. The filter is very powerful in several aspects: it supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modeled system is unknown.

The purpose of this paper is to provide a practical introduction to the discrete Kalman filter. This introduction includes a description and some discussion of the basic discrete Kalman filter, a derivation, description and some discussion of the extended Kalman filter, and a relatively simple (tangible) example with real numbers & results.

#### An Introduction to the Kalman Filter

#### Cited 12,228 times (Google Scholar, 15 APR 2025)

#### Abstract



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



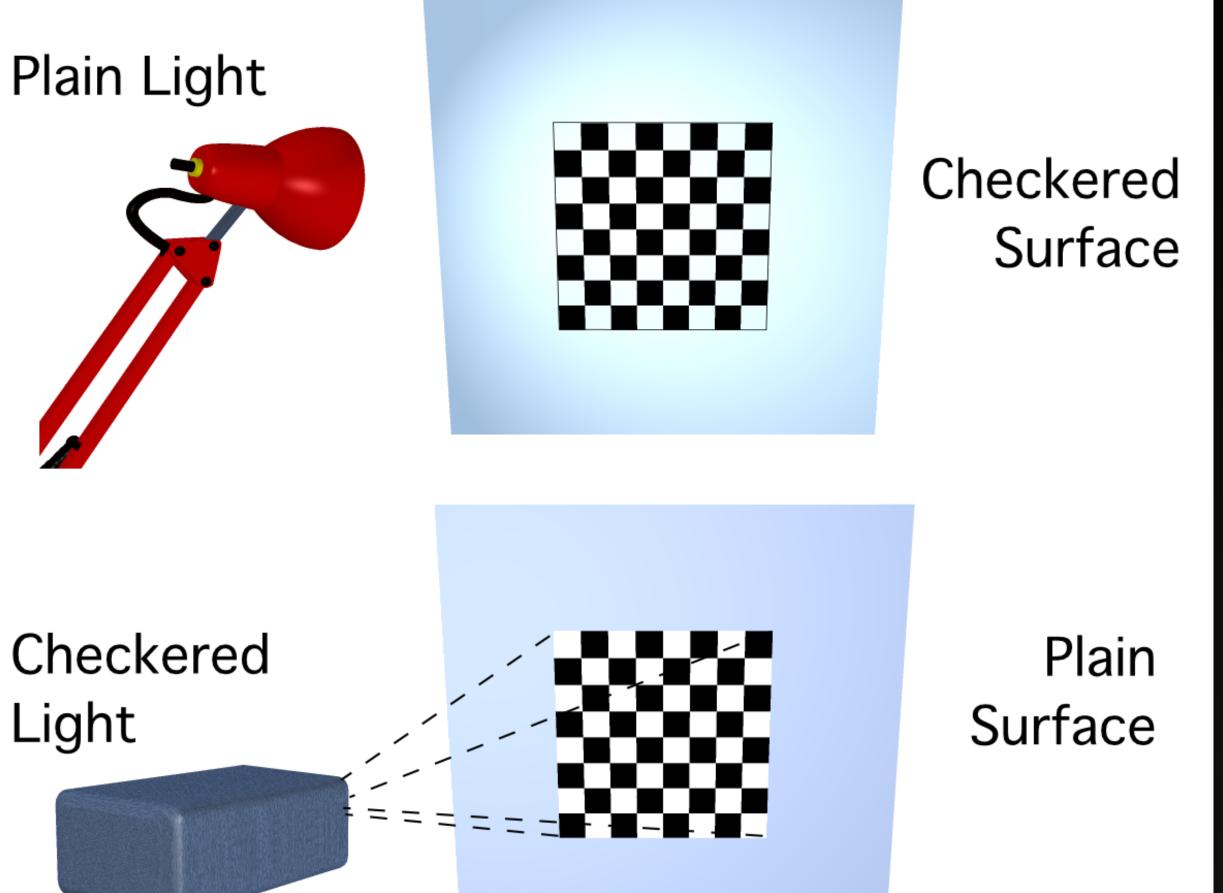


# Cyber-Physical Virtual Reality (UNC-CH)

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

- I 998 International Workshop on Augmented Reality
- "Long Lasting Impact Paper" award at ISMAR 2016





## Shader Lamps (1998)







### White physical models







## Spatial Augmented Reality (1998)

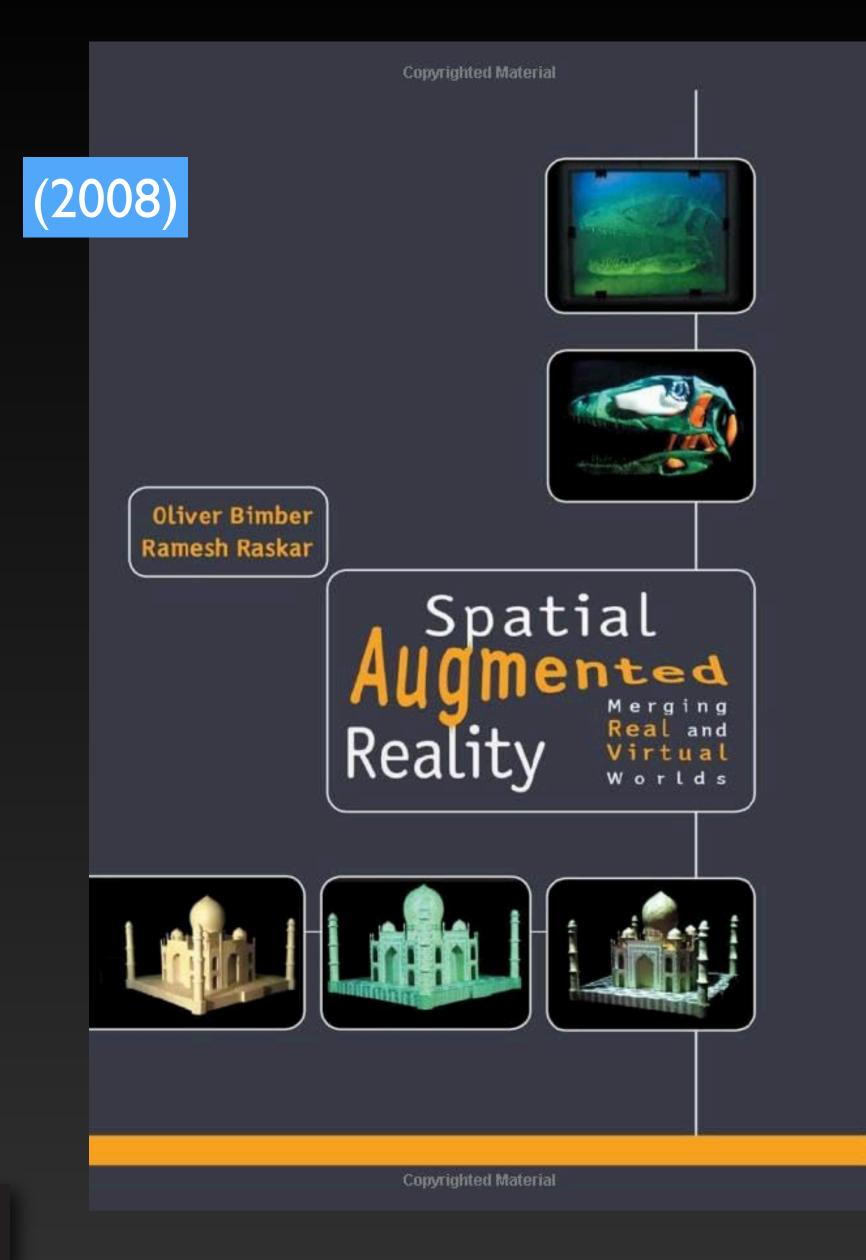
Models textured with projected light

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











## Ramesh Raskar (MIT)



#### Illii



#### Ramesh Raskar Associate Professor of Media Arts and Sciences

< People

#### **Camera Culture**

Overviev Updates

Projects

Archived Projects

Publications

Events

Contact Information: 🛛 raskar@media.mit.edu O Personal Website

Ramesh Raskar is an Associate Professor at MIT Media Lab and directs the Camera Culture research group. His focus is on Machine Learning and Imaging for health and sustainability. They span research in physical (e.g., sensors, health-tech), digital (e.g., automated and privacyaware machine learning) and global (e.g., geomaps, autonomous mobility) domains.

At MIT, his co-inventions include camera to see around corners, femto-photography, automated machine learning (auto-ML), private ML (split-learning), low-cost eye care devices (Netra, Catra, EyeSelfie), a novel CAT-Scan machine, motion capture (Prakash), long distance barcodes (Bokode), 3D interaction displays (BiDi screen), new theoretical models to augment light fields (ALF) to represent wave phenomena and algebraic rank constraints for 3D displays(HR3D).

In his recent role at Facebook, he launched and led innovation teams in Digital Health, Healthtech, Satellite Imaging, TV and Bluetooth bandwidth for Connectivity, VR/AR and 'Emerging Worlds' initiative for FB.





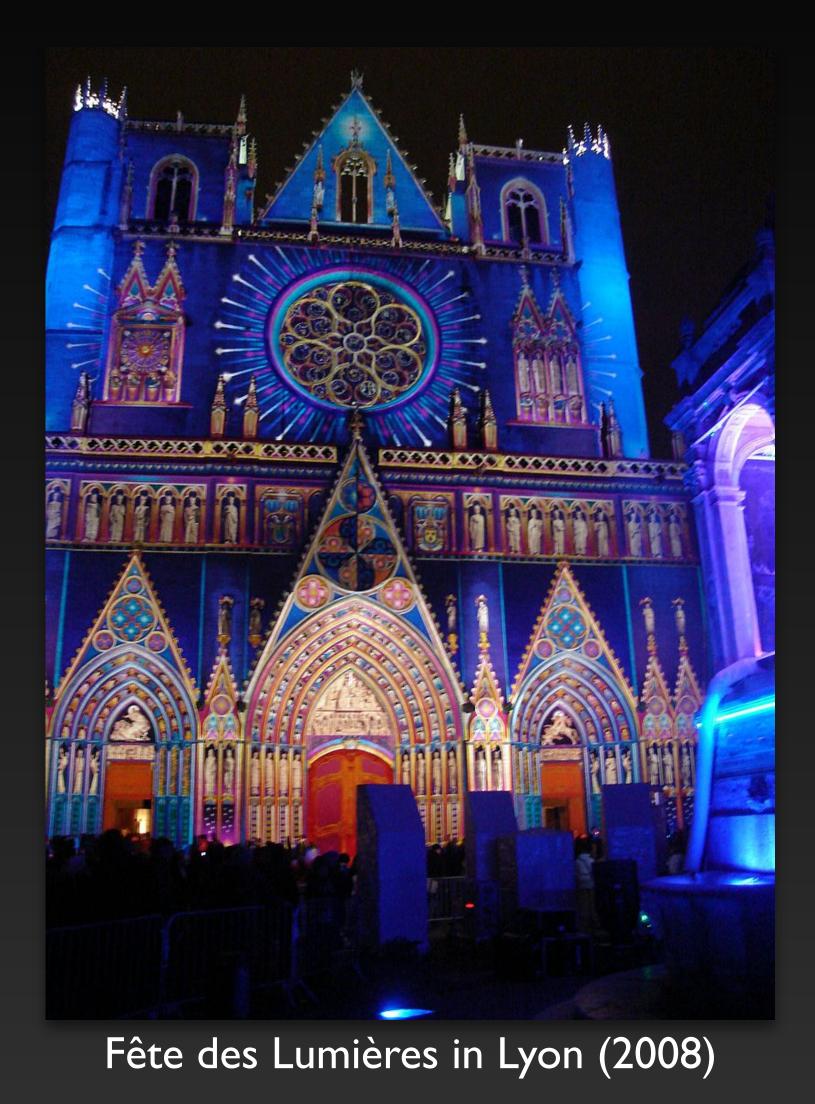




Cinderella's Castle at Walt Disney World



## "Projection Mapping"









# 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.



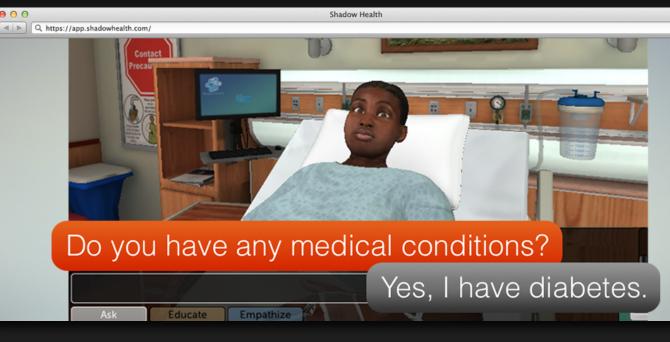






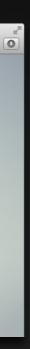
## Patient Simulators

### Physical Patient ("Mannequin")



### Virtual Patient (Computer)









# A Physical-Virtual Head for Hands-On Healthcare Training (2015)

Jason Hochreiter Salam Daher Arjun Nagendran Laura Gonzalez Greg Welch



UNIVERSITY OF CENTRAL FLORIDA



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















## Stroke Diagnosis Example (Adult)

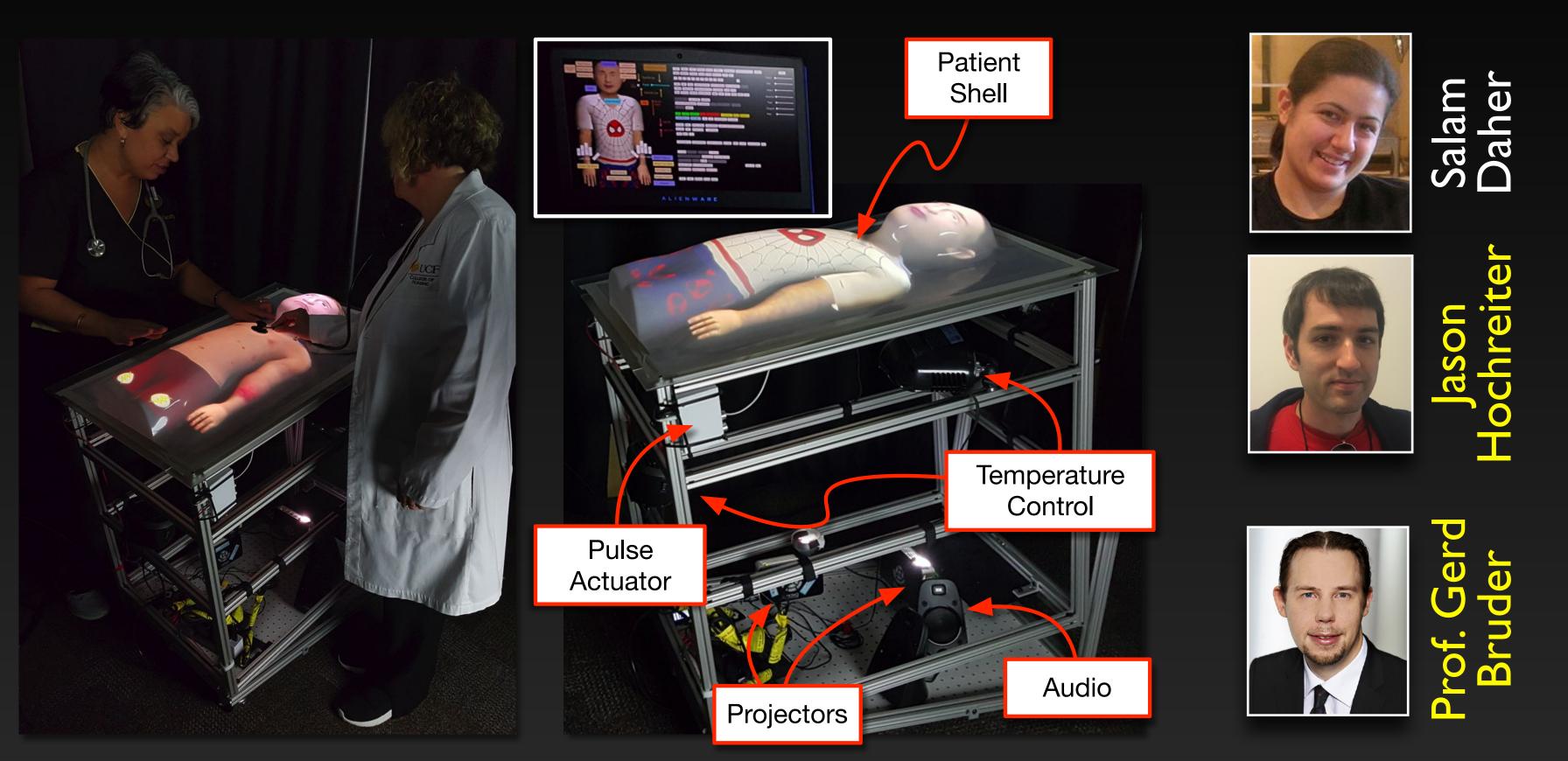
## Normal patient







# Physical-Virtual Child — Pediatrics (2020)



Desiree Diaz, PhD, RN-BC. UCF Medicine: Juan Cendan, MD.



# UCF Nursing: Laura Gonzalez, PhD, ARNP; Mindi Anderson, PhD, ARNP and

US National Science Foundation 1564065







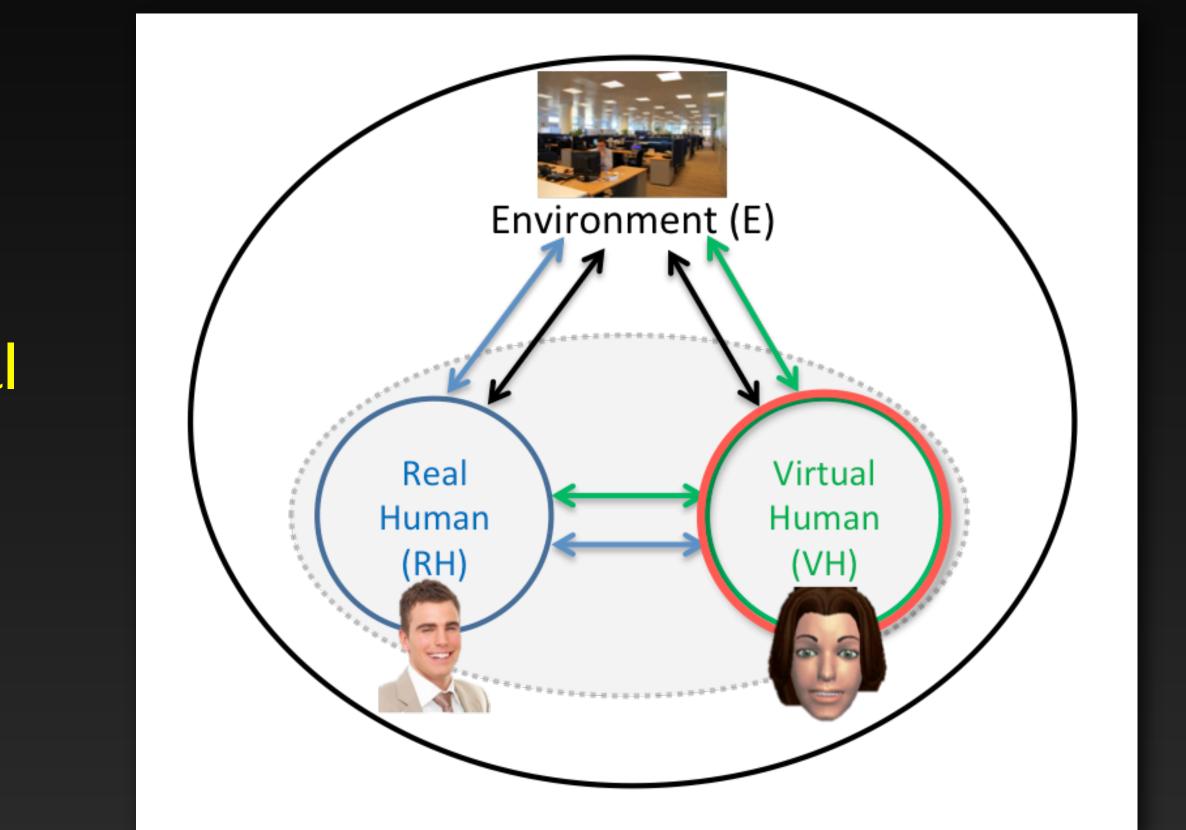
## Cyber-Physical Virtual Humans and Environments

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

## Co/Social Presence—Indirect Effects

What features can we add to the surrogate, environment, or interaction to strengthen co/social presence in the user and elicit plausibly realistic behavior?











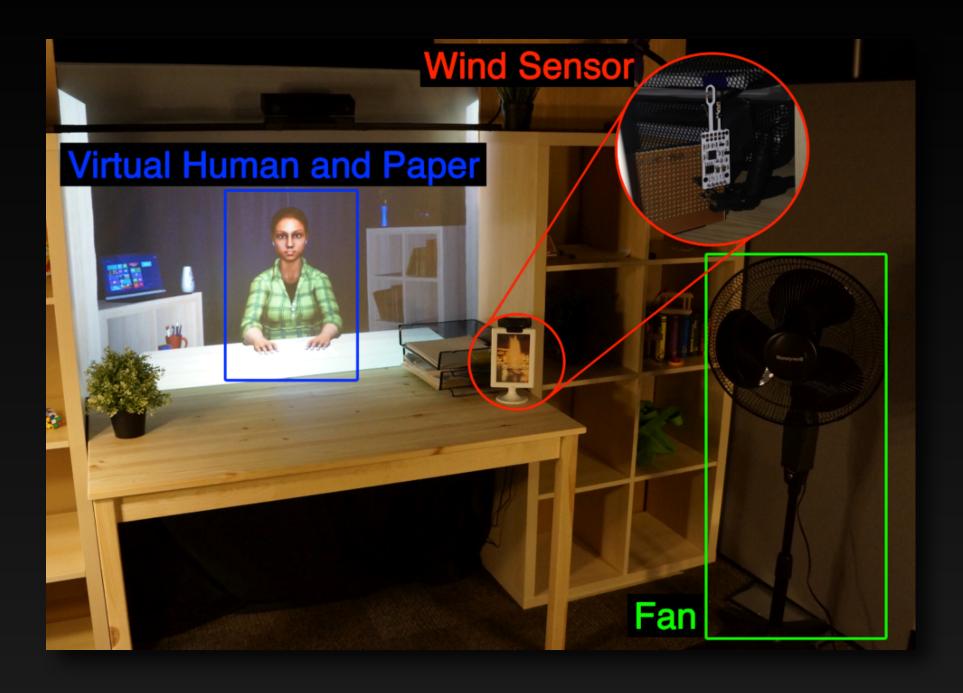
### (Lee, Kim, Daher, Raij, Schubert, Bailenson, and Welch, 2016)



# The "Wobbly Table"











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

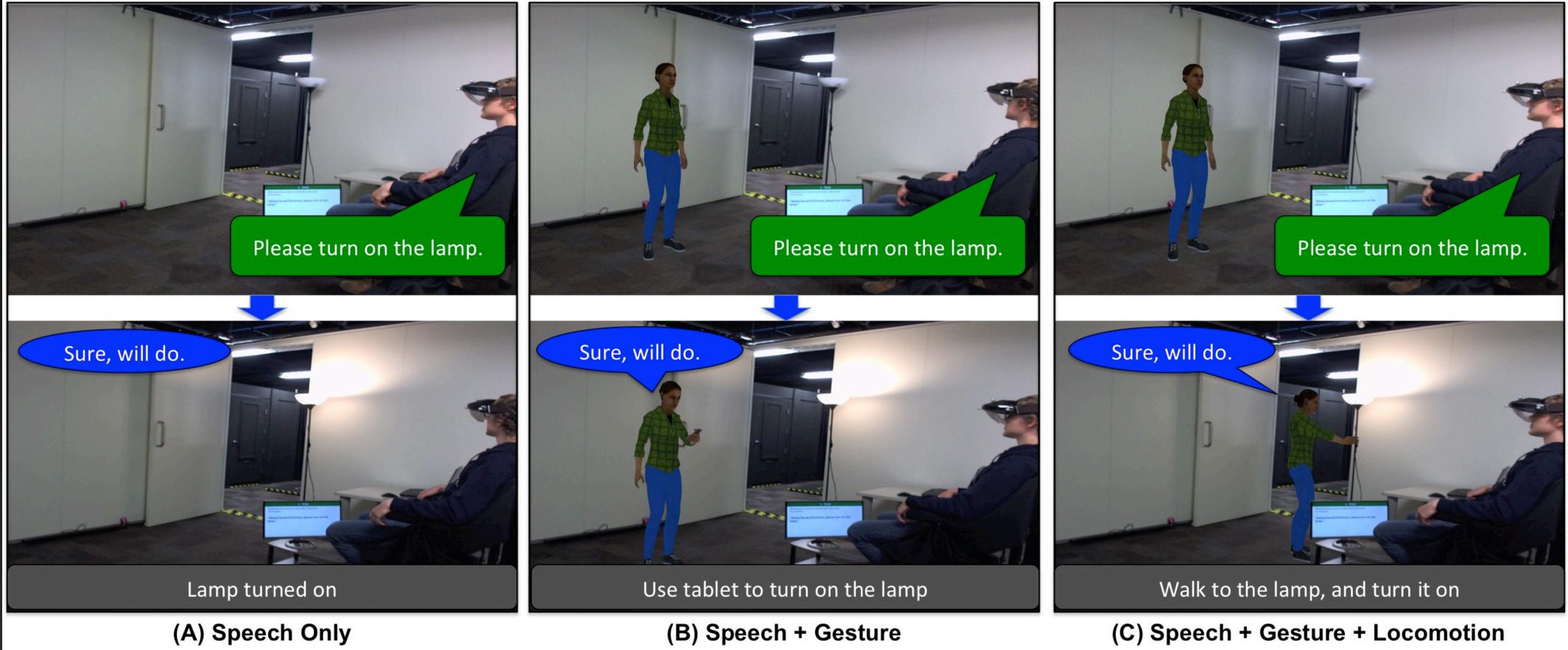
Flutter

Still

Aware



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





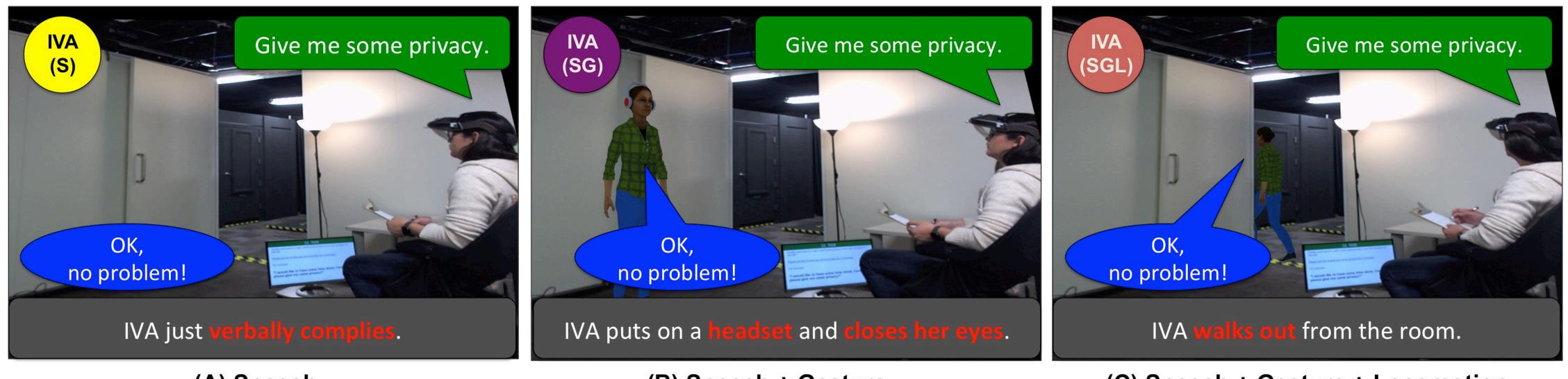
© 2025 Greg WELCH







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



#### (A) Speech



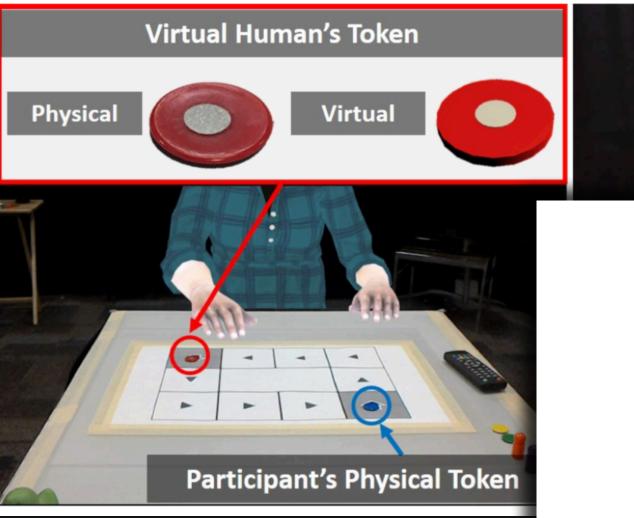
#### (B) Speech + Gesture

(C) Speech + Gesture + Locomotion









Increased Co-P Increased expension physical objects Improved the u





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

#### **Optical tracking system**



#### Magnet-patched game piece

#### Tabletop

Two-axis motorized translation stage

### uzi, Bruder, Wisniewski, and Welch, 2019)



#### Best Paper Award

his certificate is awarded to Lee, Nahal Norouzi, Gerd Bruder, J. Wisniewski, Gregory F. Welch

for the paper titled firtual Table: Exploring the Effects of hysical Influence on Social Interaction"

the 24<sup>th</sup> ACM Symposium on ity Software and Technology ecember 1, 2018, Tokyo, Japan

> symposium General Chair Shigeo Morishima









## The Virtual Experience Research Accelerator (VERA)



Virtual Experience Research Accelerator



UNIVERSITY OF CENTRAL FLORIDA







# 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

### U.S. focus for now ....

• ... but international use is planned through various mechanisms, including eventual growth or replication





**Community Infrastructure for Research** in Computer and Information Science and **Engineering (CIRC)** 

**View guidelines** 23-589

#### Exact for more funding opportunities Search for more funding

#### Important information for proposers

All proposals must be submitted in accordance with the requirements specified in this funding opportunity and in the NSF Proposal & Award Policies & Procedures Guide (PAPPG) that is in effect..

#### Synopsis

The Community Infrastructure for Research in Computer and Information Science and Engineering (CIRC) program drives discovery and learning in the core disciplines of the three participating CISE divisions [Computing and Communication Foundations (CCF), Computer and Network Systems (CNS), and Information and Intelligent Systems (IIS)] of the Directorate for Computer and Information Science and Engineering (CISE) by funding the creation and enhancement of world-class research infrastructure. This research infrastructure will specifically support diverse communities of CISE researchers pursuing focused research agendas in computer and information science and engineering. This support involves developing the accompanying user services and engagement needed to attract, nurture, and grow a robust research community that is actively involved in determining directions for the infrastructure, as well as management of the infrastructure. This should lead to research infrastructure that can be sustained through community involvement and

#### Expand +

#### Program contacts

<b>Deepankar (Deep) Medhi</b> Program Director CISE/CNS	dmedhi@nsf.gov	(703) 292-2935	CISE/CNS
<b>Mimi McClure</b> Program Director, CISE/CNS	mmcclure@nsf.gov	(703) 292-8950	CISE/CNS

#### Upcoming due dates

Full proposal

2024

September 13 2024 - Deadline date C Second Friday in September, Annually Thereafter

#### **Program guidelines**

#### Award information

annually, subject to the availability of funds.

#### Estimated number of awards

10 to 25 - With up to 10 Planning awards, up to 3 **Dev** awards, up to 12 Medium awards, and up to 3 Grand awards in each

competition. Planning awards will be for up to one and one-half years and in the \$50,000 - \$100,000 range per award for Planning-C category and up to two years in the \$100.001 - \$250.000 range per award



### Greg WELCH (Lead)

UNIVERSITY OF CENTRAL FLORIDA





### Gerd BRUDER

UNIVERSITY OF CENTRAL FLORIDA



#### Shiri AZENKOT CORNELL TECH





# VERA Principal Investigators



### Tabitha PECK DAVIDSON



### Valerie Jones TAYLOR Rutgers



### Jeremy BAILENSON Stanford University



### John MURRAY

UNIVERSITY OF CENTRAL FLORIDA UCF







### Jonathan BEEVER *Ethics and Privacy*



UNIVERSITY OF CENTRAL FLORIDA Center for Ethics



### Carolina CRUZ-NEIRA Sustainability and Partnerships



UNIVERSITY OF CENTRAL FLORIDA



# VERA Area Investigators





Rui XIE Statistics and Data Science



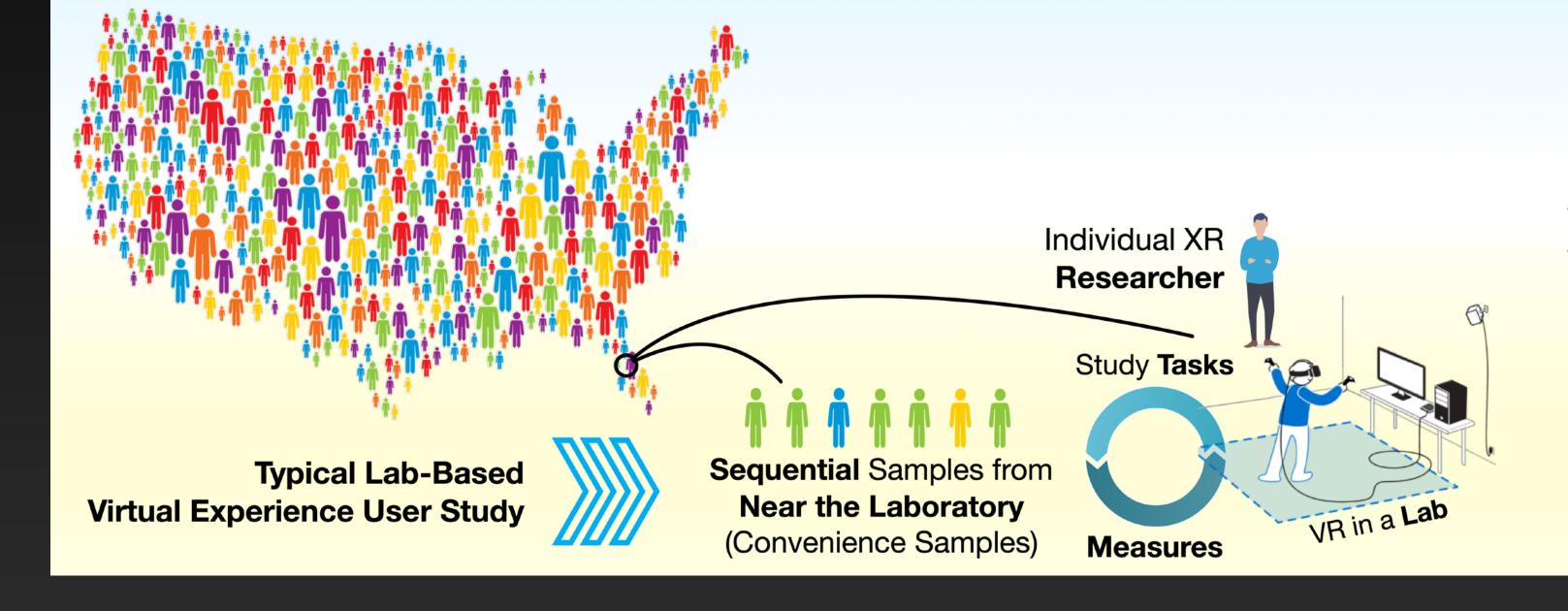
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Nicholas COLES Big Team Science

UF FLORIDA







## Lab-Based User Studies



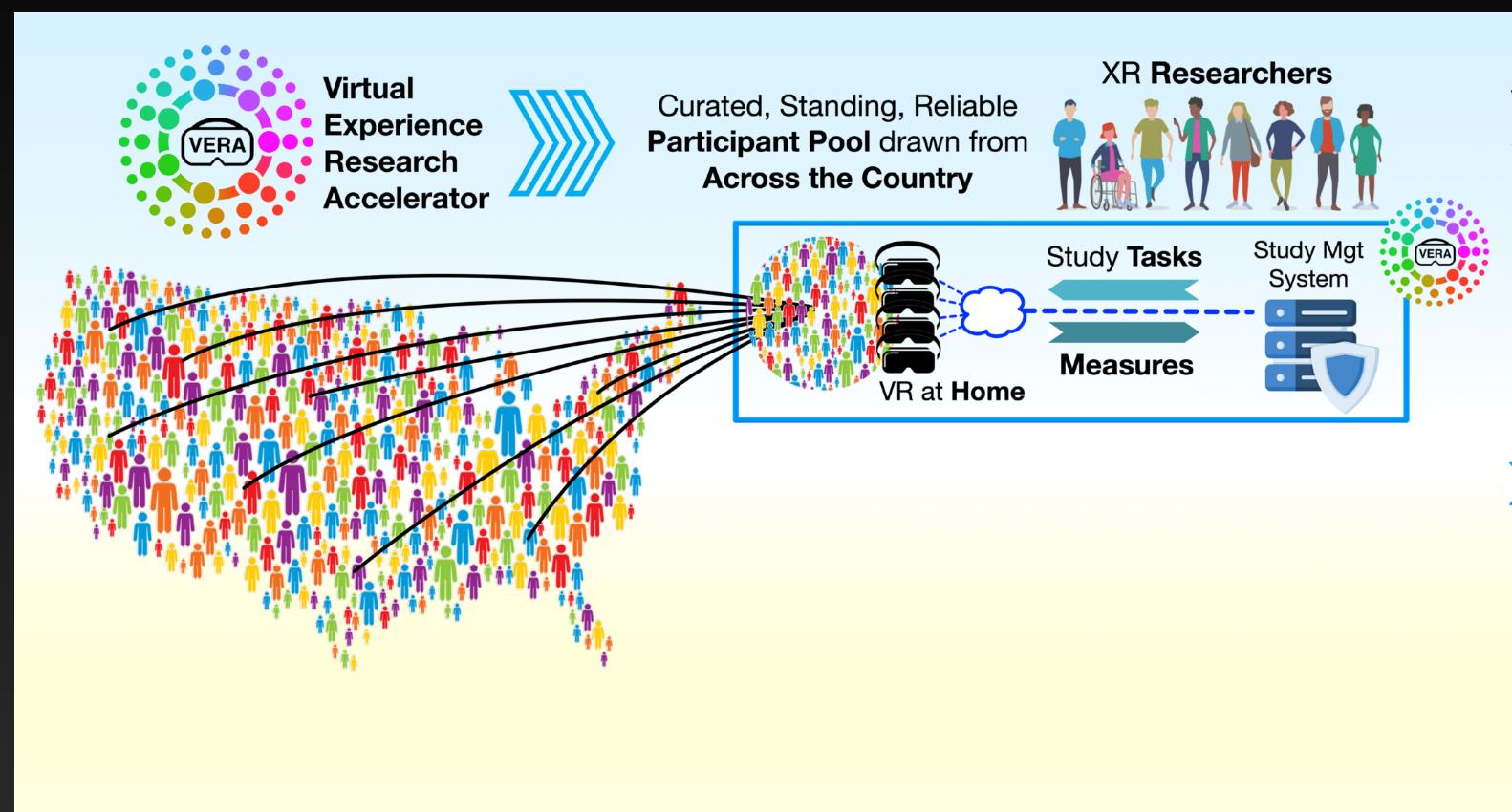
## 

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











# VERA User Studies



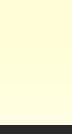
Relatively **fast**, **concurrent** studies, **many** studies, **very large** samples, **controlled** demographics, supports **replication** and **longitudinal** studies.



Time











# Development and Operations

### **Director of Development and Operations — Dr. Ali HASKINS LISLE**







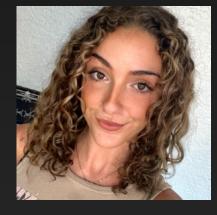


### Software Development — Dr. John MURRAY



### **Development Project Manager — Chloe BEATO**





### XR Access Lead — Dylan FOX









# ALA 25 Annual **Conference & Exhibition**

#### PHILADELPHIA • JUNE 26-30

**ALAAmericanLibraryAssociation** 

# Partnering with Public 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 $\implies$ Generate Knowledge





### **FOR OUR LIBRARIES.**







# Thank you!



Virtual Experience Research Accelerator





# Questions or thoughts?

### welch@veraccel.org welch@ucf.edu

