Augmented Reality:
Applications and Current Research Issues

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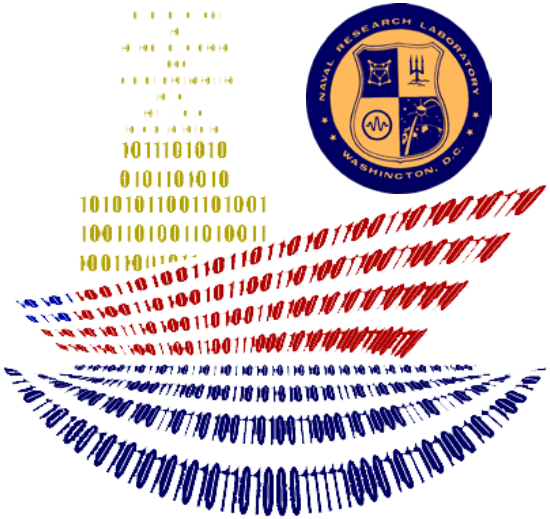


Outline

- Definition and Examples
- Basic components
- Applications
  - Military
  - Medical
  - Manufacturing / Maintenance
  - Consumer / Entertainment
- Research Issues
  - Improved components
  - Visualizations
  - Human factors

What is Augmented Reality?

- Informal
  - Merge synthetic stimuli into your view of the scene
- Formal
  - Must align those synthetic elements with real objects
  - Real-time and interactive
  - First-person perspective

Modalities of AR

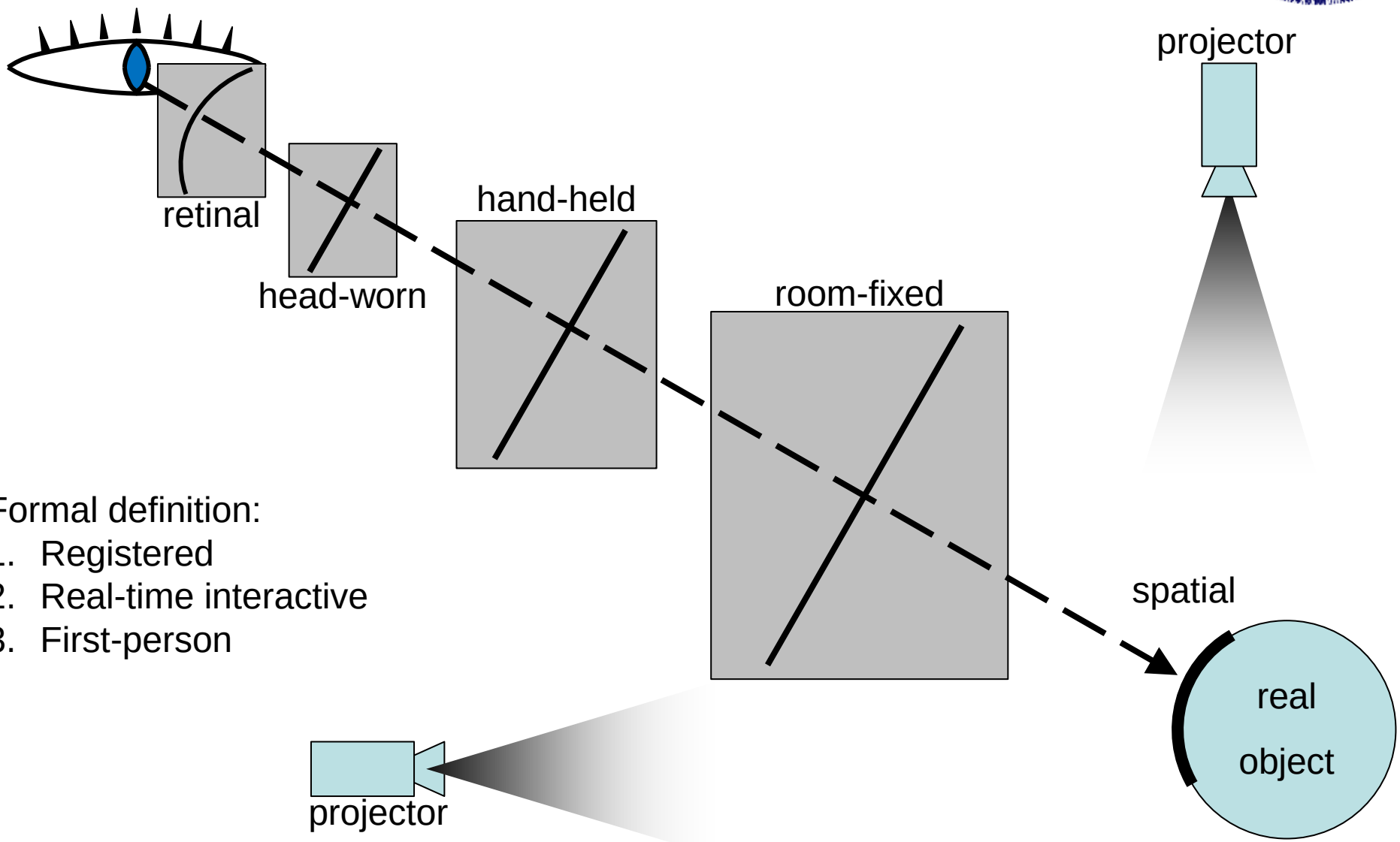
- Visual
- Aural
- Tactile
- Smell
- Taste

Technology for AR Systems

- Image generator (hardware/software)
  - Lots of commercial options
    - GPUs, game engines
- Display device
  - Many options
  - Some very expensive, some low quality
- Tracking system
  - A few commercial options (virtual reality)
  - Many technologies: optical/vision, ultrasonic, radio frequency, magnetic, mechanical, et al.

A Visual Display Taxonomy for AR

Bimber and Raskar, 2005



Formal definition:

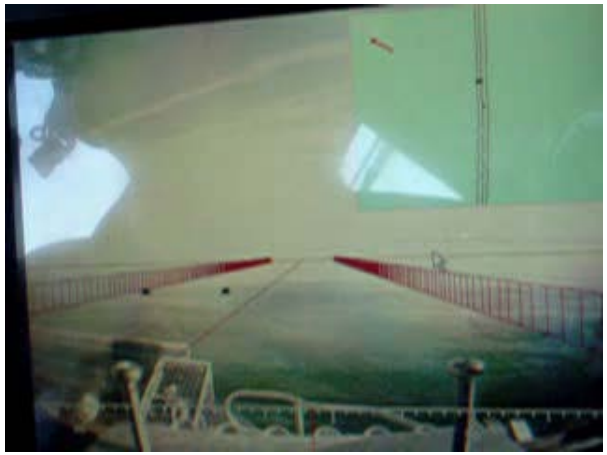
1. Registered
2. Real-time interactive
3. First-person

Some Technology Implications

- Image generator
  - How fast does it run?
  - How good does it look?
- Display device
  - Can the user really see and integrate real and virtual?
  - What is the right blending technology?
- Tracking system
  - How well are the graphics aligned?
- All
  - Mobility: indoor vs. outdoor

Military Applications of AR

- Situation Awareness/Navigation
  - Dismounted (NRL)
  - Boat pilots (TSI)
  - Air traffic control (DCS Corp.)
  - Unmanned vehicle interfaces (AFRL)
  - Law enforcement (FBI)

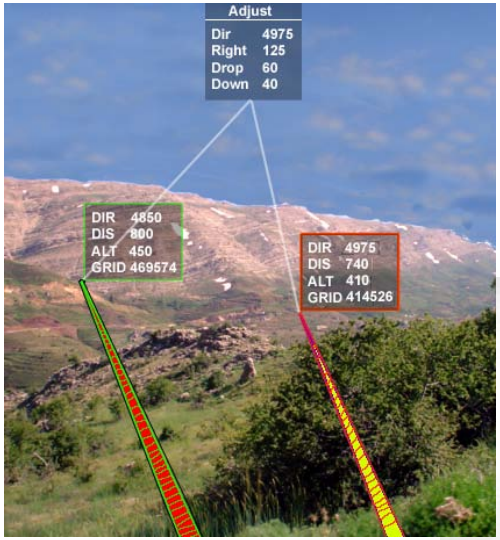


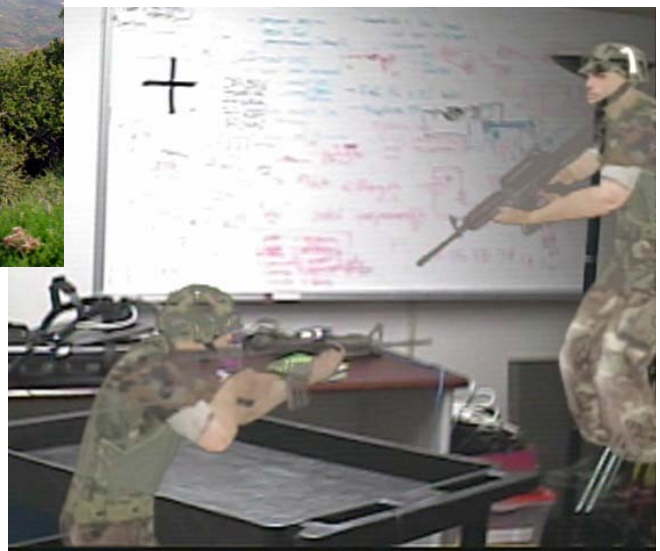
Chuck Benton, Technology Systems, Inc.

Jim Fulbrook, DCS Corp.

Military Applications of AR

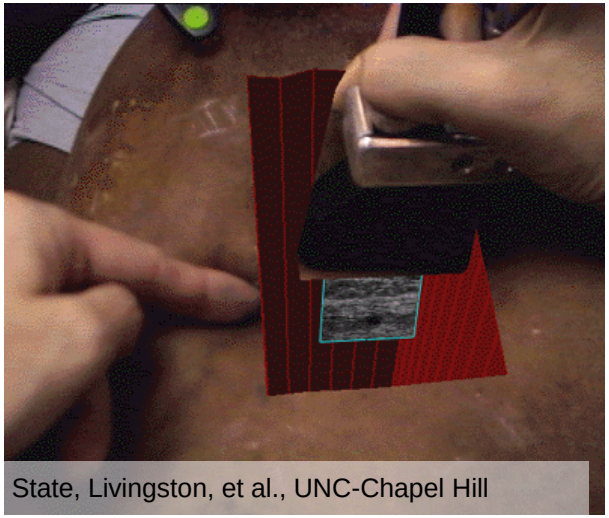
- Forward Observer
  - Operations
  - Training

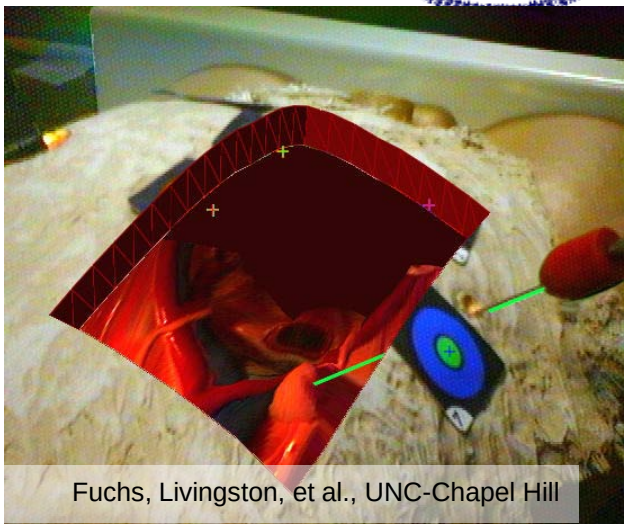


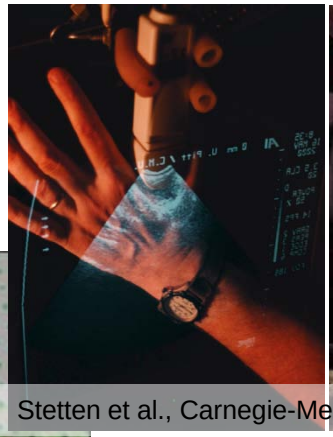


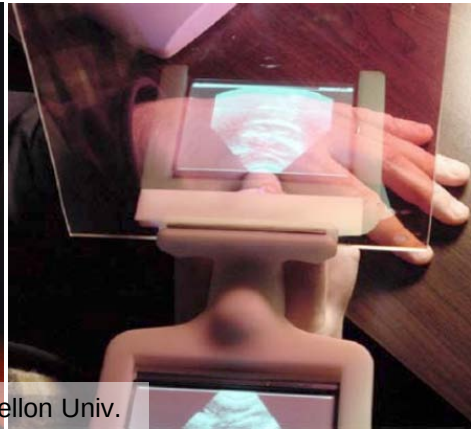
Medical Applications of AR

- Ultrasound
  - UNC, CMU
- Laparoscopic
  - UNC
- CT/MRI
  - Harvard/MIT/GE, TU-Munich


State, Livingston, et al., UNC-Chapel Hill


Fuchs, Livingston, et al., UNC-Chapel Hill




Stetten et al., Carnegie-Mellon Univ.

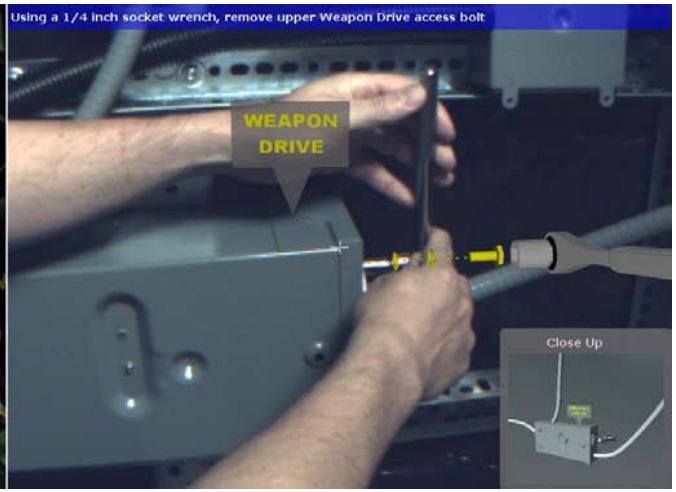
Navab et al., TU-Munich

Lorenson et al., MIT/Brigham&Women's

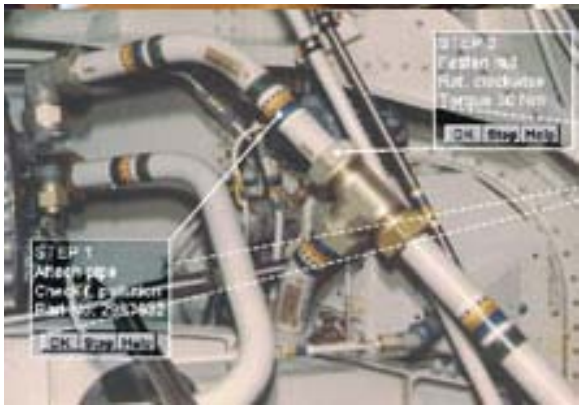
Manufacturing Applications of AR

- Wiring harnesses (Boeing)
- Office equipment (Columbia)
- Military vehicles (Columbia)
- Automotive engines (Honda)
- Automotive assembly (Daimler, BMW)

Honda Motor Corp.



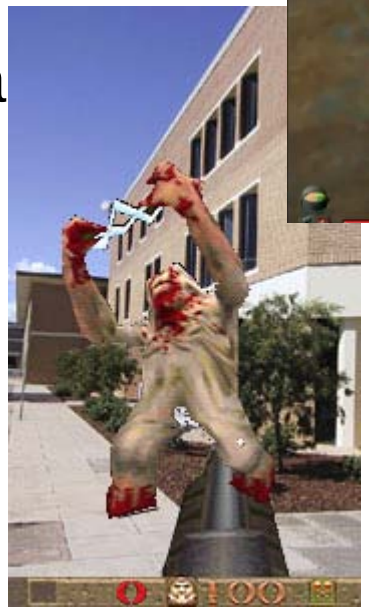
Henderson & Feiner, Columbia Univ.

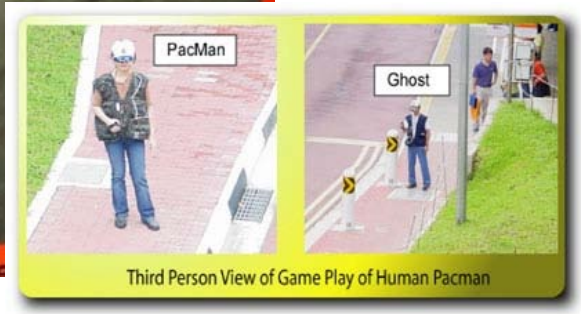


Steve Feiner, Columbia Univ.

Entertainment

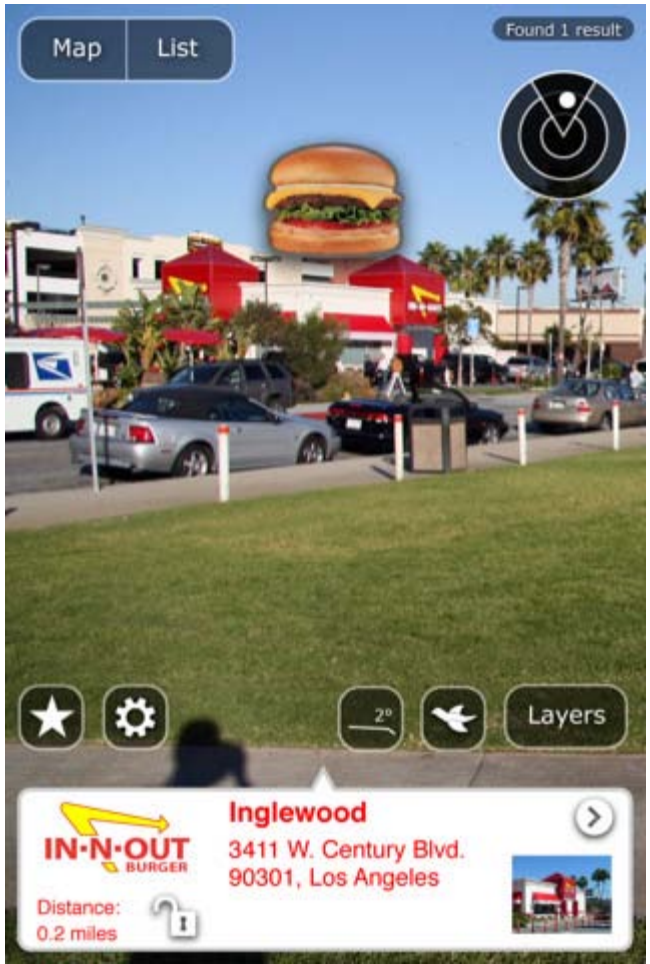
- Games
  - Univ. of Singapore
    Univ. of South Australia
    GaTech
- Marketing

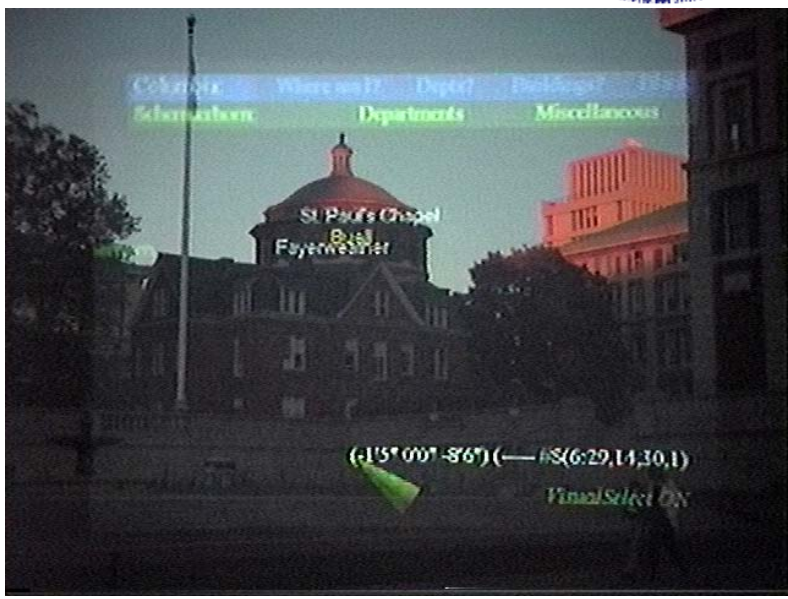




Consumer / Entertainment

- Tourism (Columbia)
- Maps / directions (Layar)





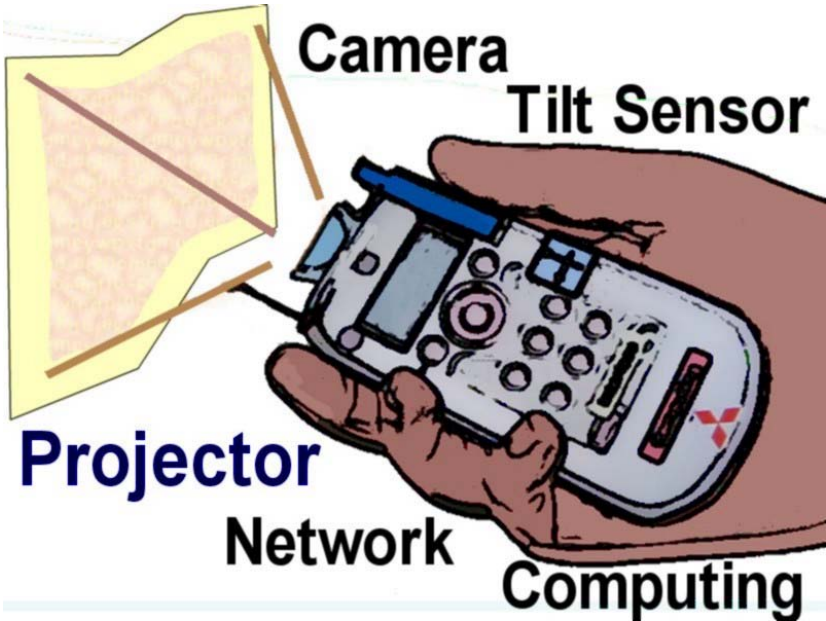
What Makes AR “Good?”

- Formal Definition
  - Registered virtual objects
  - Real-time and interactive
  - First-person perspective
- Technology
  - Display
  - Tracking
  - Image generation
  - Application
  - Human factors

Display Research

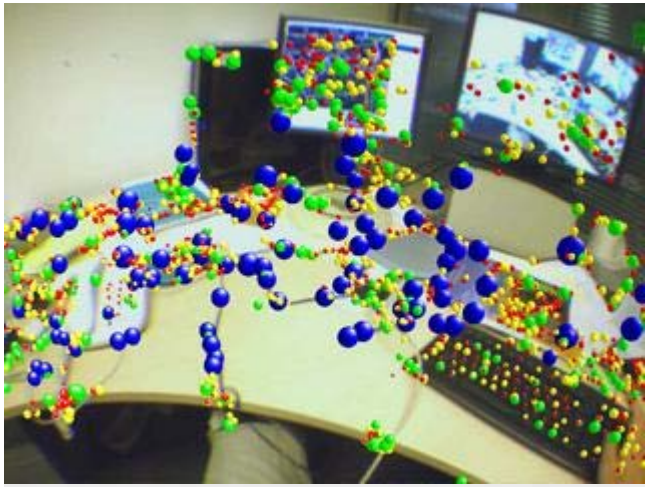
- Head-worn
  - Focus
  - Stereo adjustment
  - Field of view

- Head-worn and hand-held
  - Ergonomics
  - Outdoor use
- Projector
  - Geometric correction
  - Photometric correction



Tracking Research

- Video-metric tracking
- Indoor/outdoor
- High accuracy



Hybrid Tracking Research

Technology	Strengths	Weaknesses
Mechanical	Accuracy and precision Speed (usually) Immunity from environment	Range Cumbersome Difficult to use multiple devices
Magnetic	Robust to occluders, Speed Low latency, Inexpensive	Low range Distorted by EM environments
Ultrasonic	Scalable, Small, Inexpensive	Sensitive to environment Requires line-of-sight, Slow (sometimes)
GPS	Global range	Limited accuracy (commercial) Inter-reflections Two DOF (most receivers)
Inertial	Speed, Accuracy, Range	Error accumulation or drift Few degrees-of-freedom (dimensions)
Optical	Accuracy, Speed, Scalable	Require line-of-sight, Expensive Sensitive to lighting
Videometric	Accuracy Closed-loop system Inexpensive hardware	Require line-of-sight, Video speed Sensitive to lighting Computationally expensive

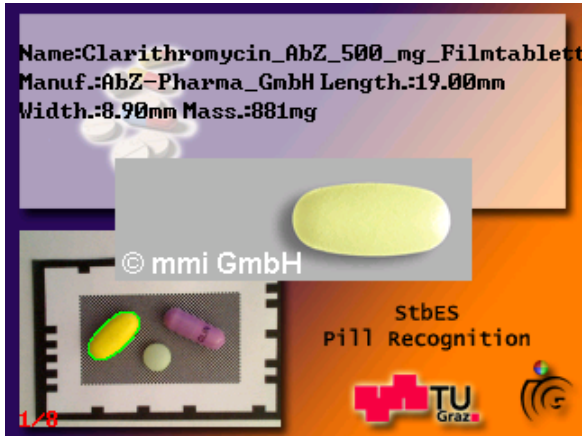
Interaction Research

- Gestures
- Voice
- Stylus (tablet displays)

- Metaphors?

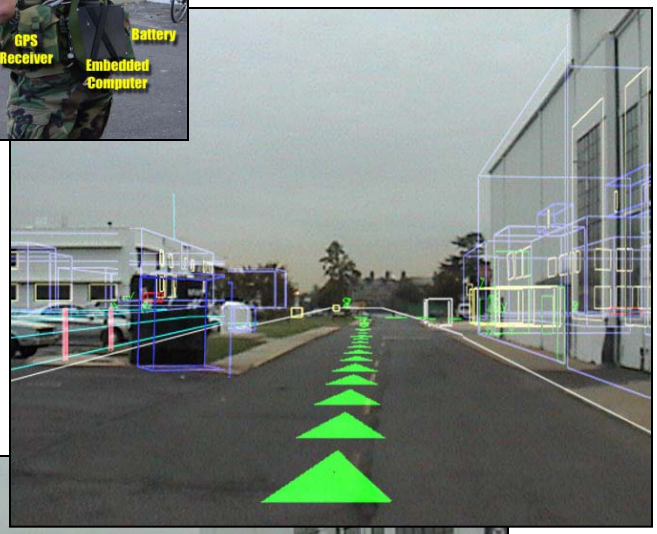
Applications Research

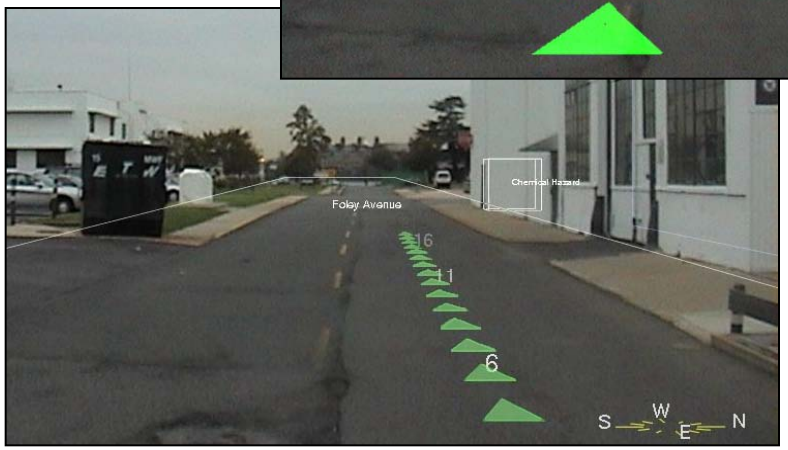
- Mobile Phone
  - Maps/directions
  - Museum guide
  - Medicine recognizer
  - Store/warehouse shelf guide



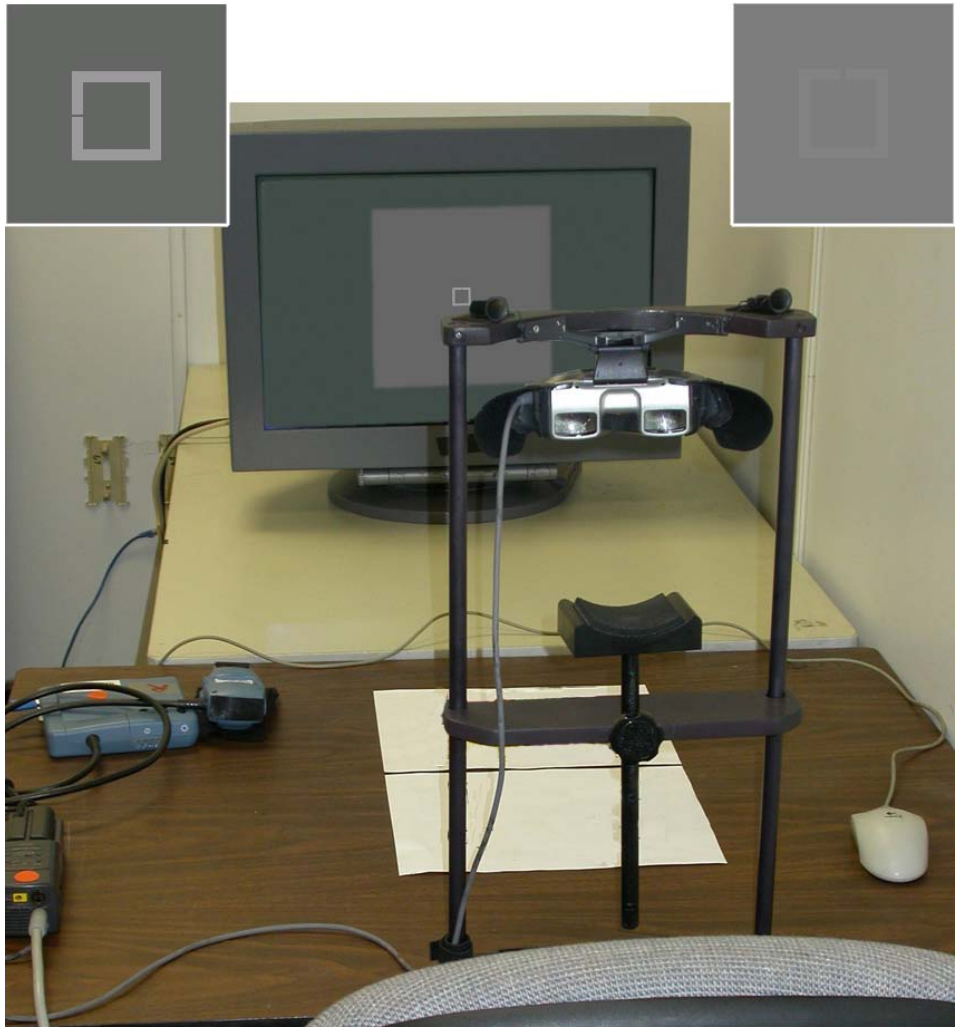
Human Factors Issues in AR

- Ergonomics
- Information overload
- Basic perception
  - Acuity/contrast
  - Color perception
- Depth perception
- Registration
- Effectiveness
  - Situation awareness
  - Training



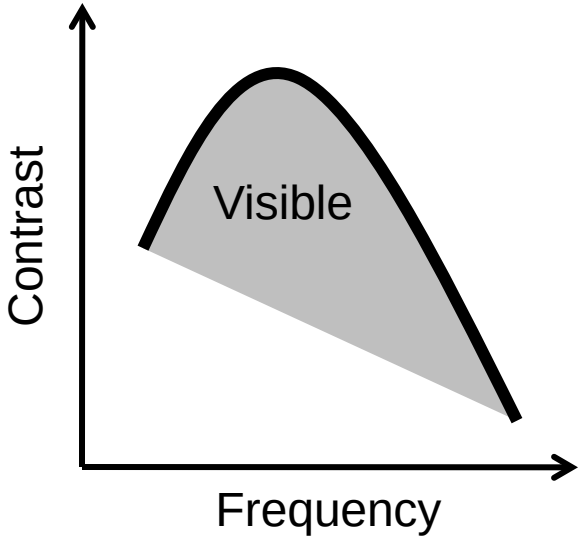


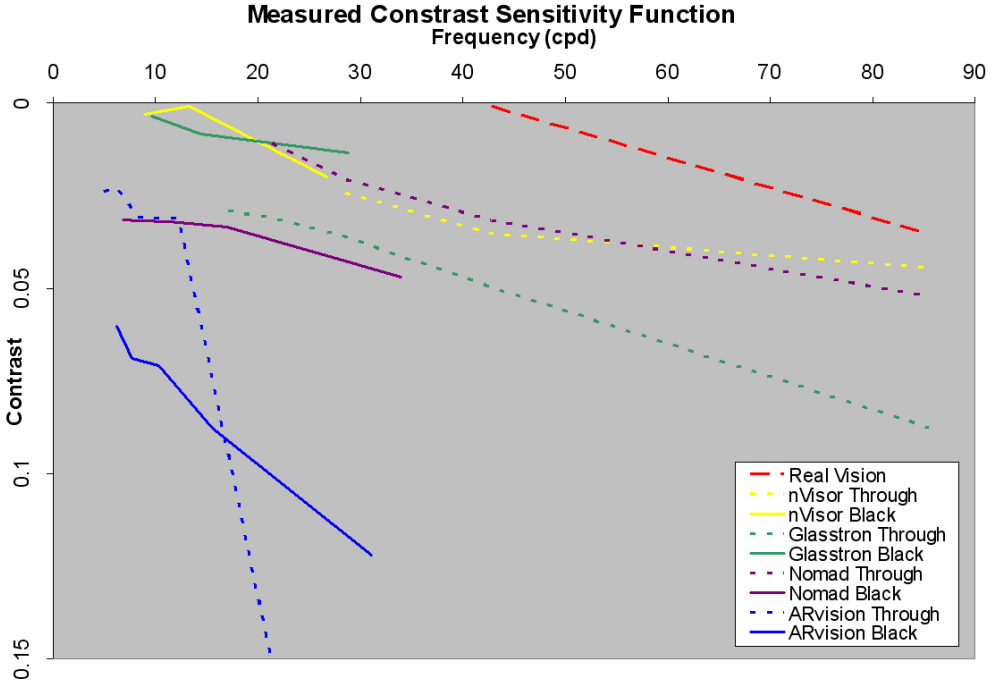
Visual Acuity/Contrast Experiment



Design Challenges

- Acuity and contrast sensitivity are not separable in human visual system
  - Size and contrast affect legibility
  - Need a lot of trials to cover a reasonable amount of data





Design Challenges

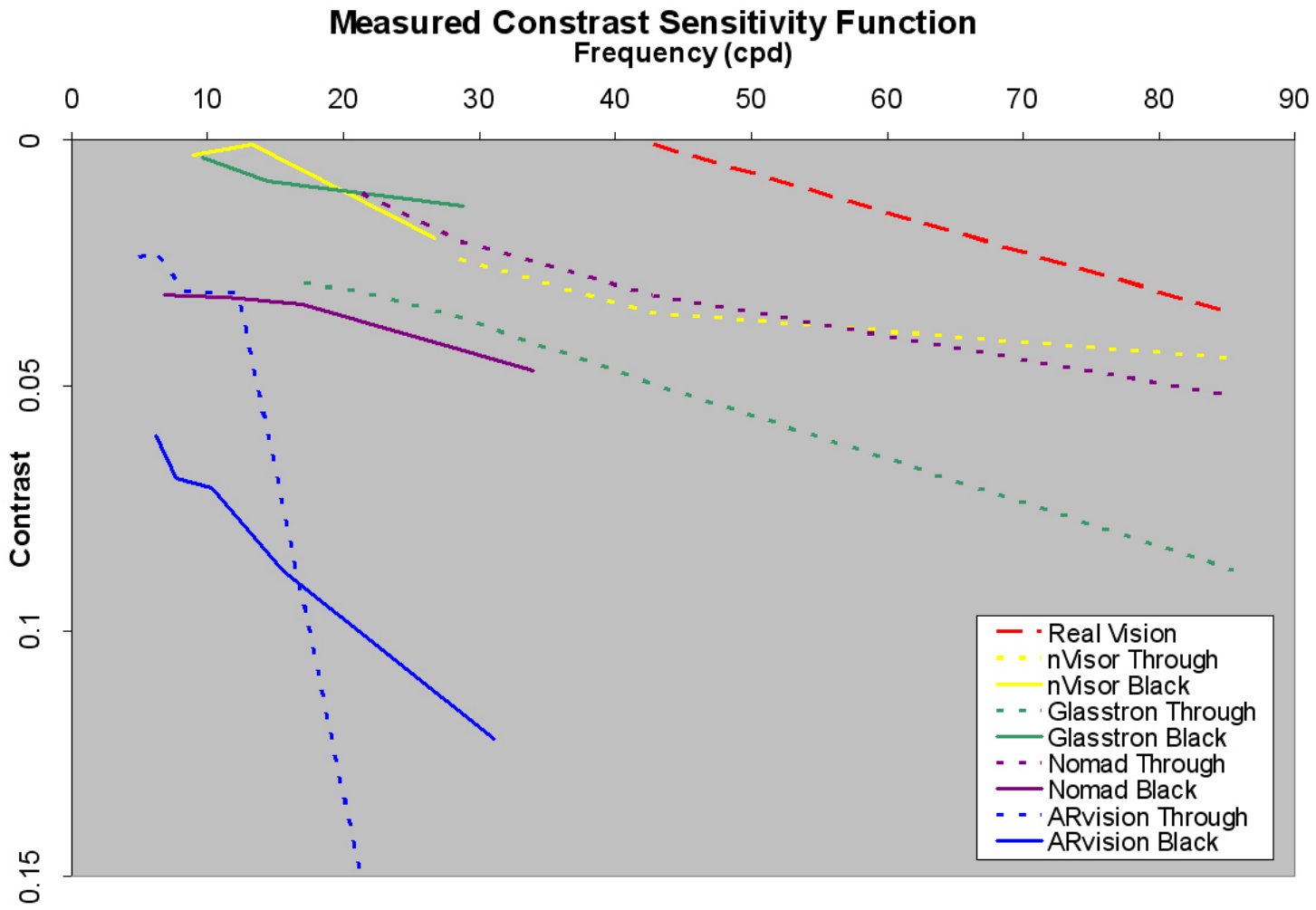
- Resolution of displays is discrete and low compared to human vision
  - What makes for a useful test?
  - How do anti-aliasing methods interact?
- Hard to compare displays directly

Display	Res	h-FOV	Pix/°	Min/Pix	Snellen
Monitor	UXGA	18.7°	85.5	0.70	20/15
nVisorST	SXGA	48.0°	26.7	2.25	20/45
Nomad	SVGA	23.7°	33.8	1.78	20/35
Glasstron	SVGA	28.1°	28.5	2.11	20/42
ARvision graphics	SVGA	24.9°	32.1	1.87	20/38
real	NTSC	24.9°	25.7	2.33	20/47

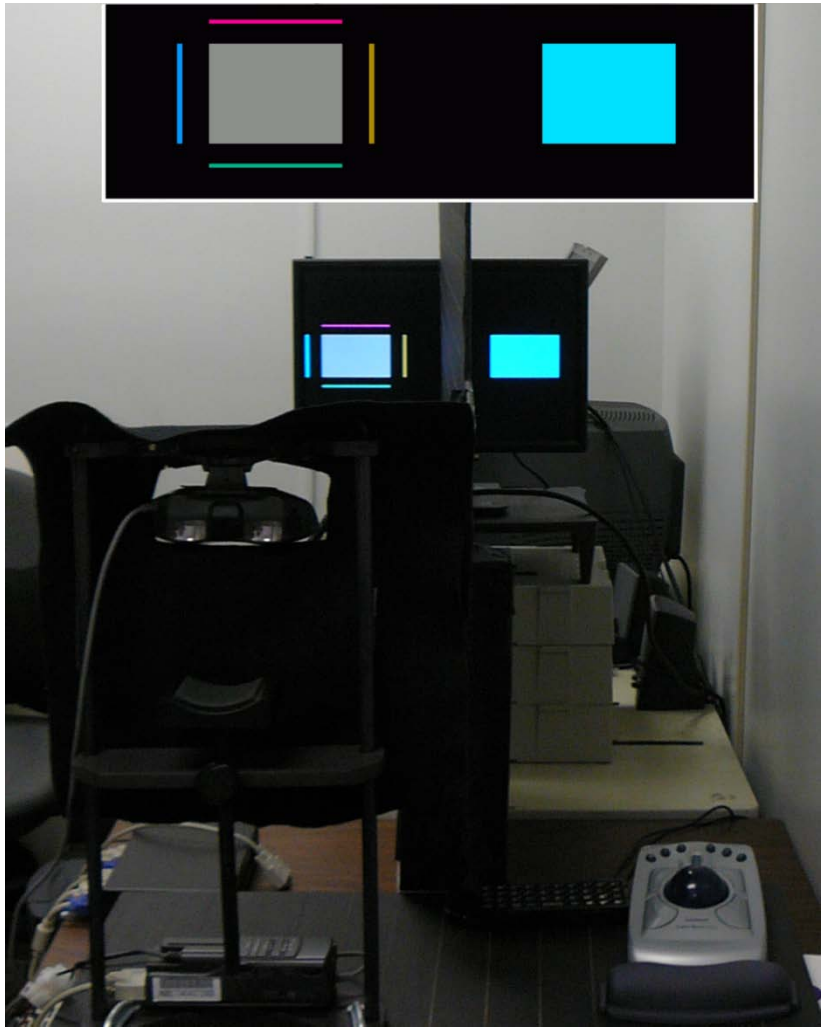
Strategies Employed

- Discretize continuous variables
  - Reduces parameter space
  - Makes analysis a little easier
- Cover the range of values
  - Makes experiment more applicable
  - Guides how you might set up a follow-up experiment
- Mimic how experiment is done in real world

Acuity/Contrast Findings



Color Perception Experiment

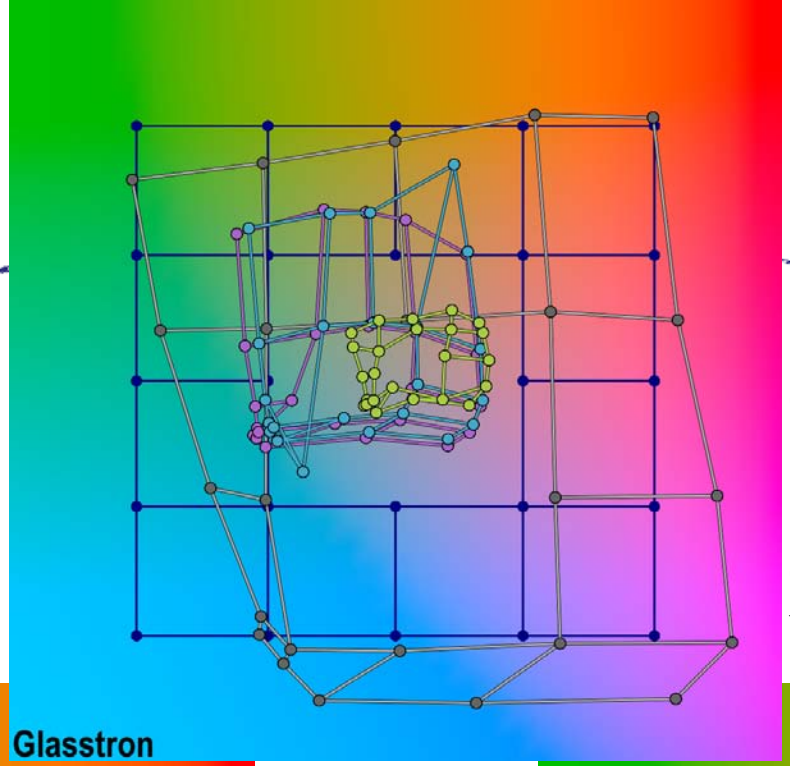


Design Challenges

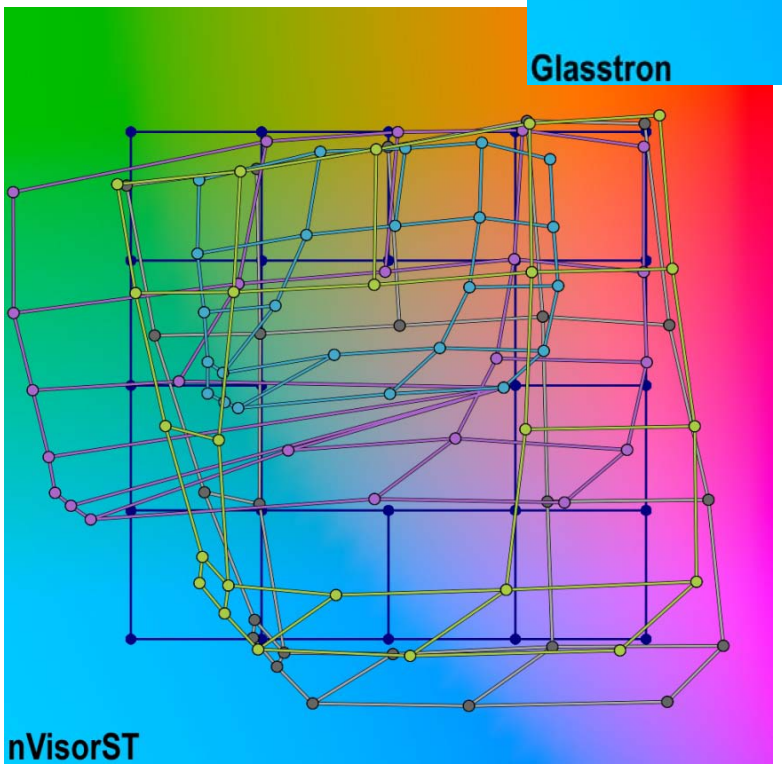
- Far too many parameters to search space exhaustively
- No clear guidance on an analogous real-world test
  - Color-blind tests like Ishihara or Farnsworth don’t really express the nature of the issue in AR
  - Very different displays might not be able to use the same test

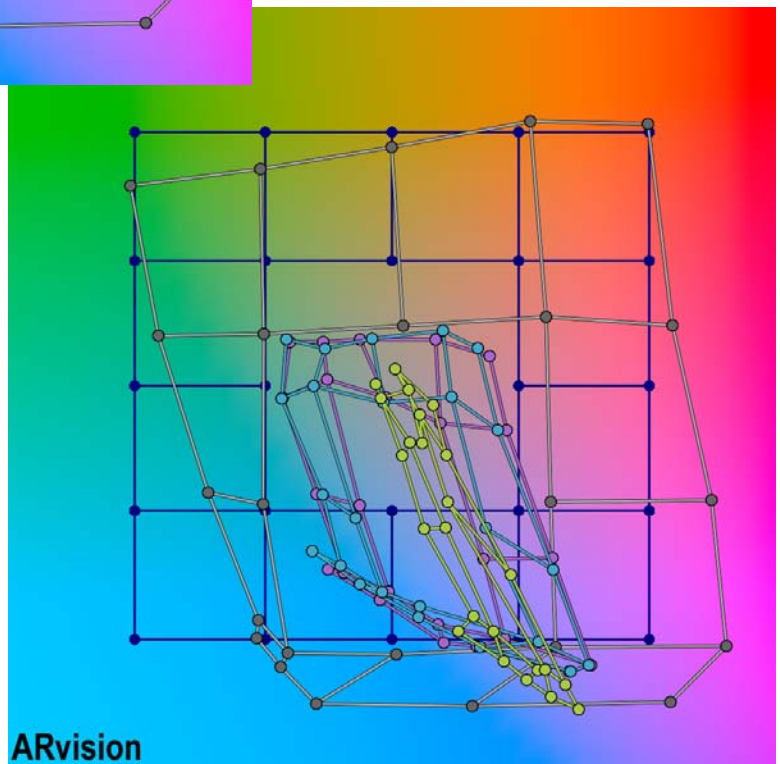
Design Challenges

- Helps to understand color spaces
  - Perceptually uniform space (CIElab) improved experimental design
  - Makes displaying results more meaningful
- Unique AR situation
  - See-through to real world
  - Look at virtual
  - Requires a lot of data to gather objective measurements



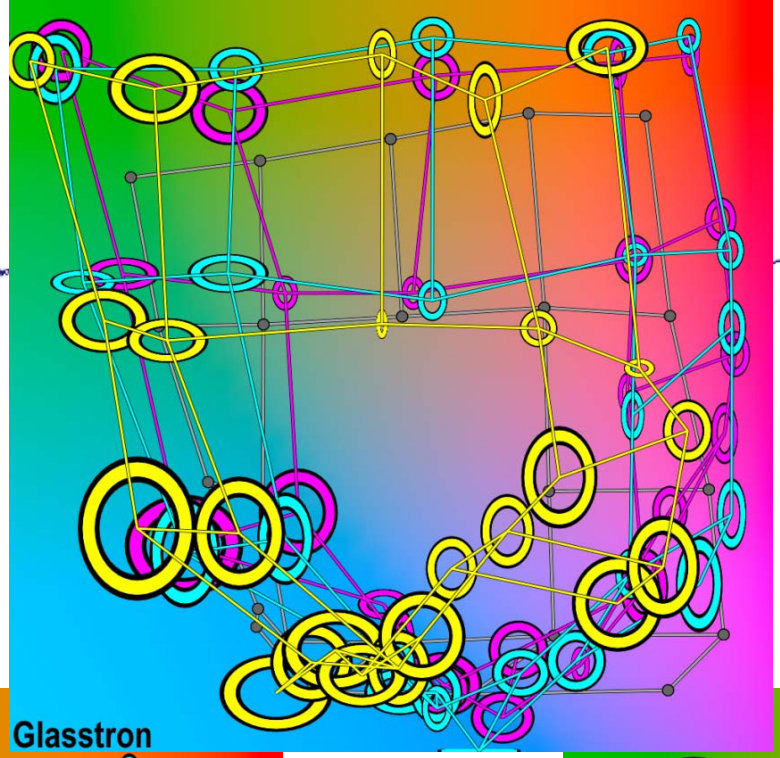
Blue = color meter
Gray = real
Magenta = Black background
Cyan = White background
Yellow = See-through





Strategies Employed

- Drastically reduce parameter space
  - Well below “useful” amount
  - Makes analysis tractable
  - Reduces applicability of experiment
- Plan a series of coordinated experiments
  - Explore one variable at a time
  - Reuse code and design
  - Enables a meta-analysis of multiple results from the series of experiments



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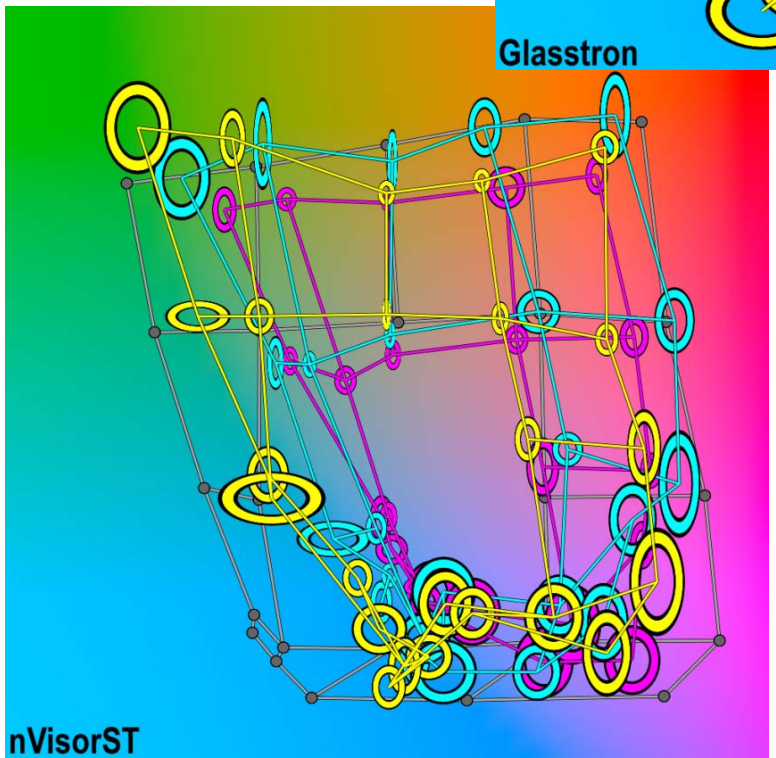
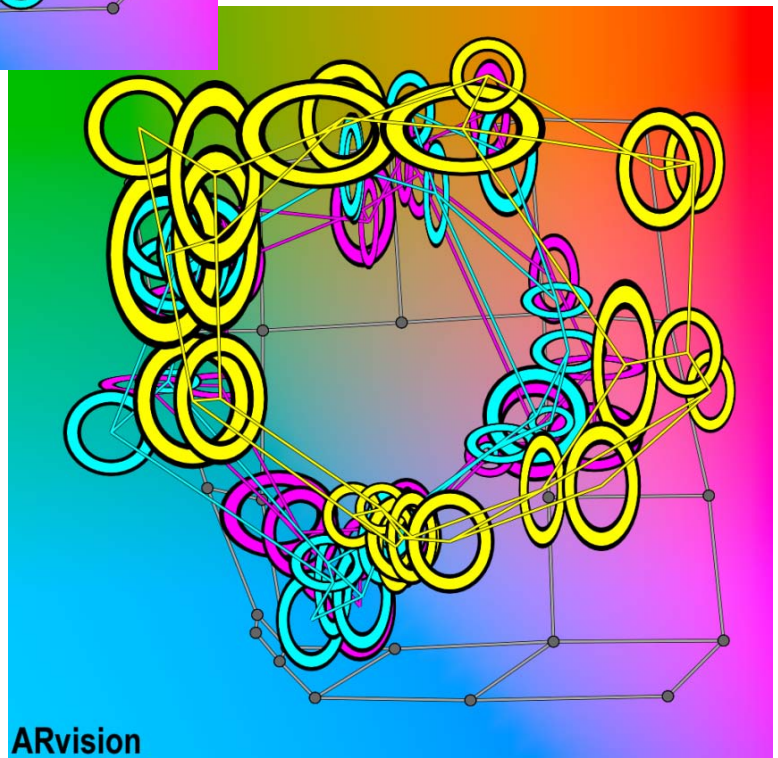
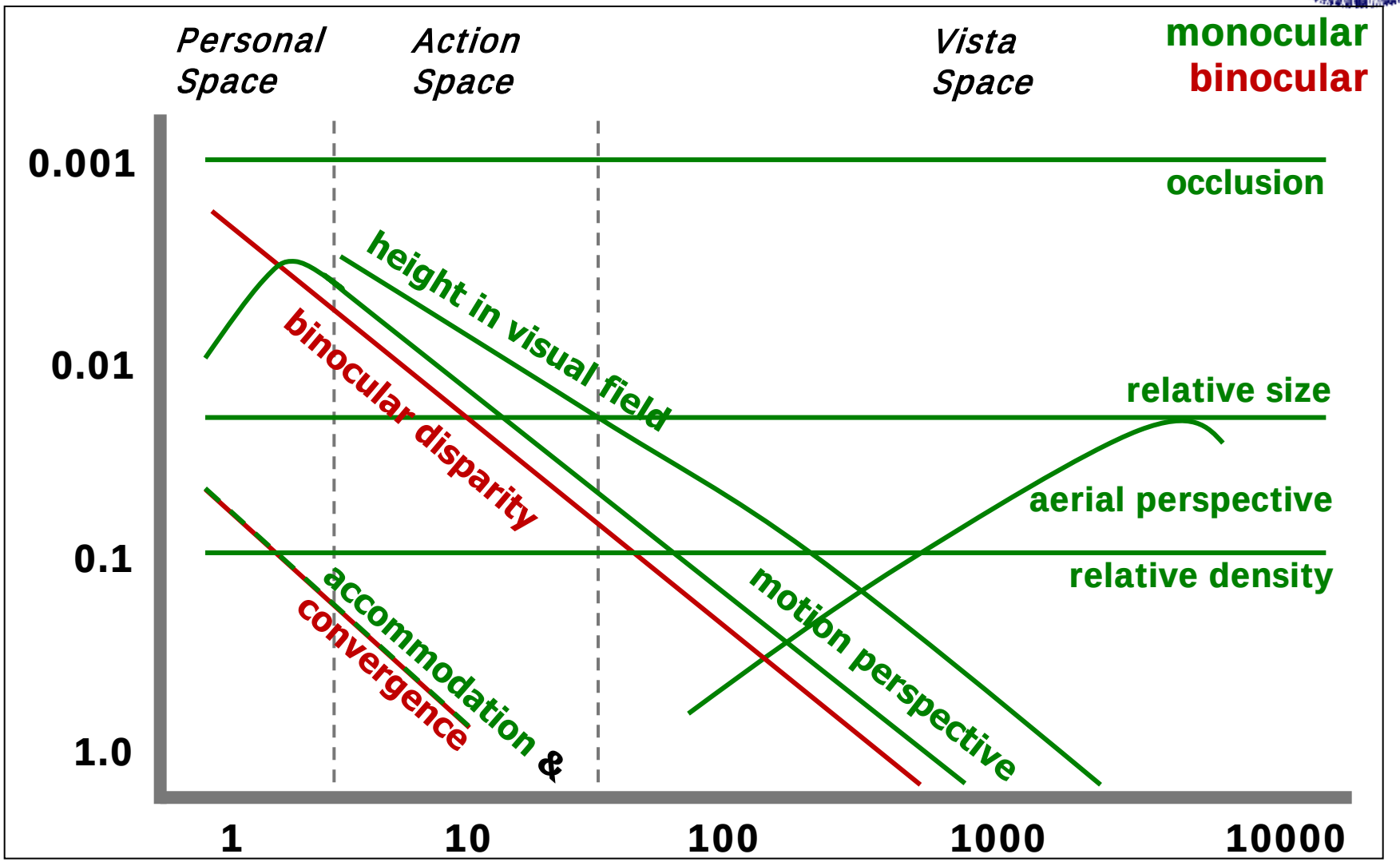




Depth Perception Studies

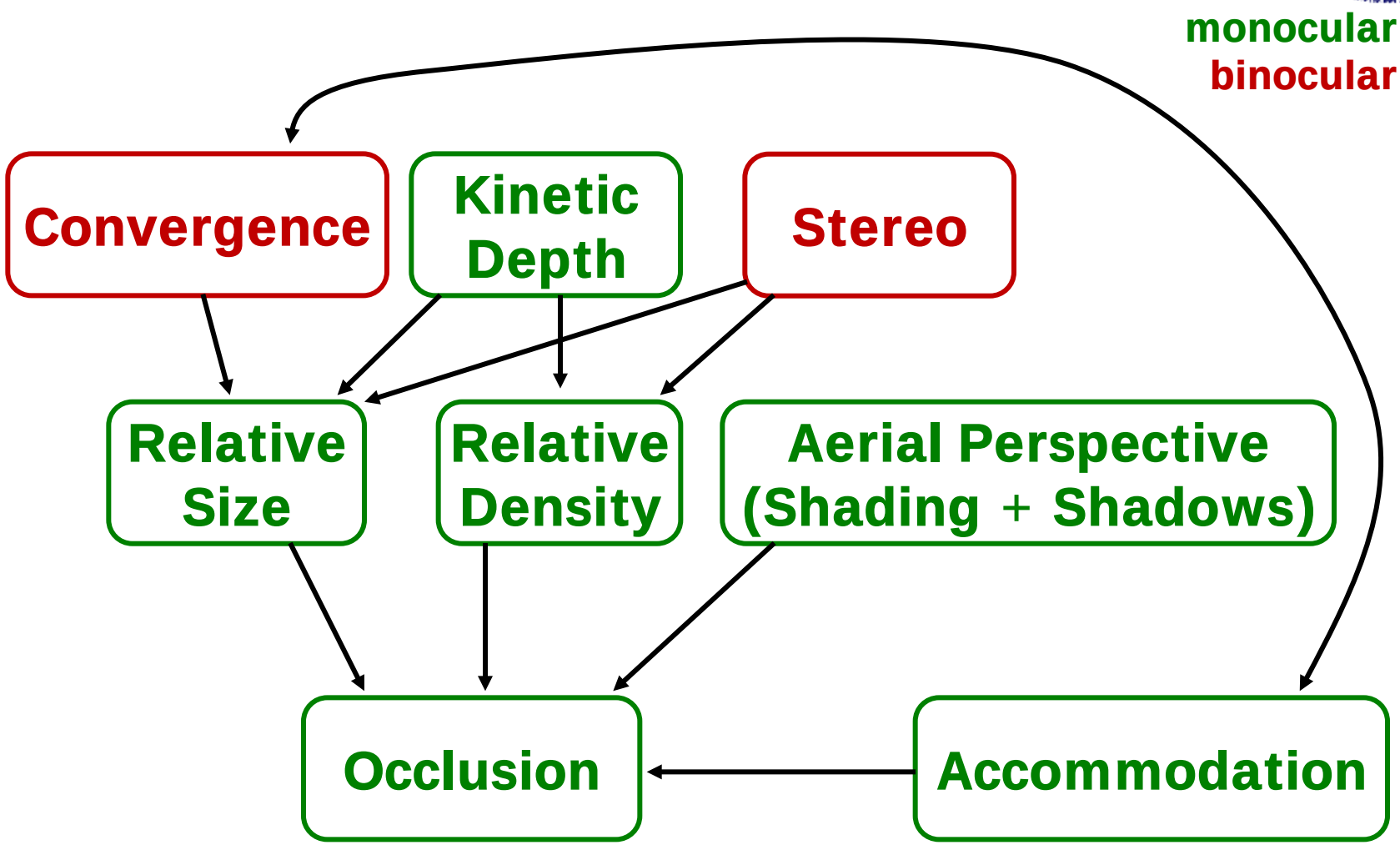
- Started with an ecological problem
  - Wanted to understand real-world location of other AR users amongst occluding 3D infrastructure
  - Had designs from previous work to consider
  - But creates a “superhuman” capability
- Needed to study perception literature

Depth Cues



Graph after [Cutting03]

Depth Cue Dependency



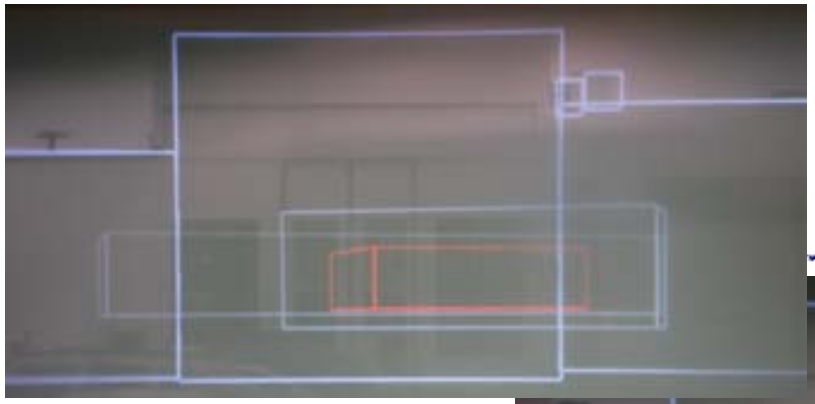
Graph after [Ware04]

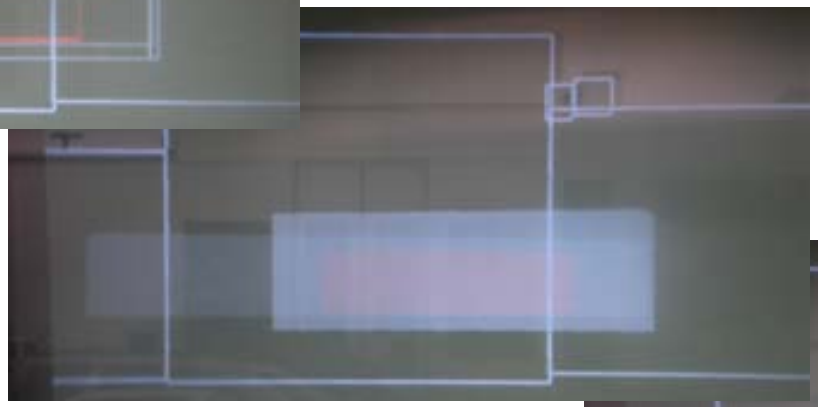
Studying AR Depth Perception

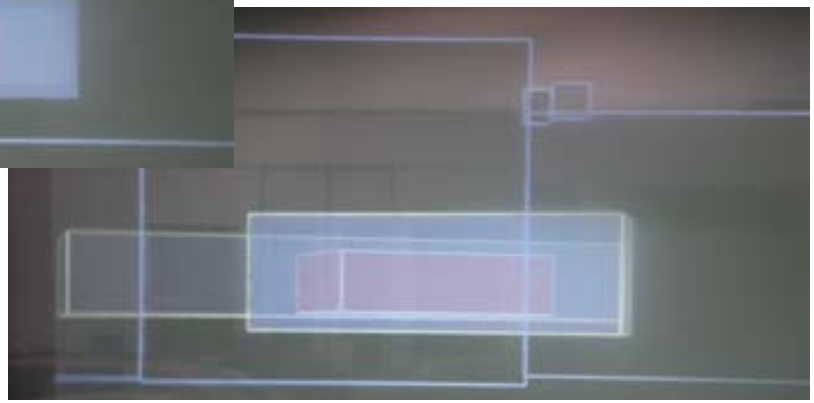
- Nuance: Studying Depth Perception or Presentation of Occluded Objects?
  - First is a scientifically interesting question
  - Second is ecologically useful
  - But they are not quite the same problem

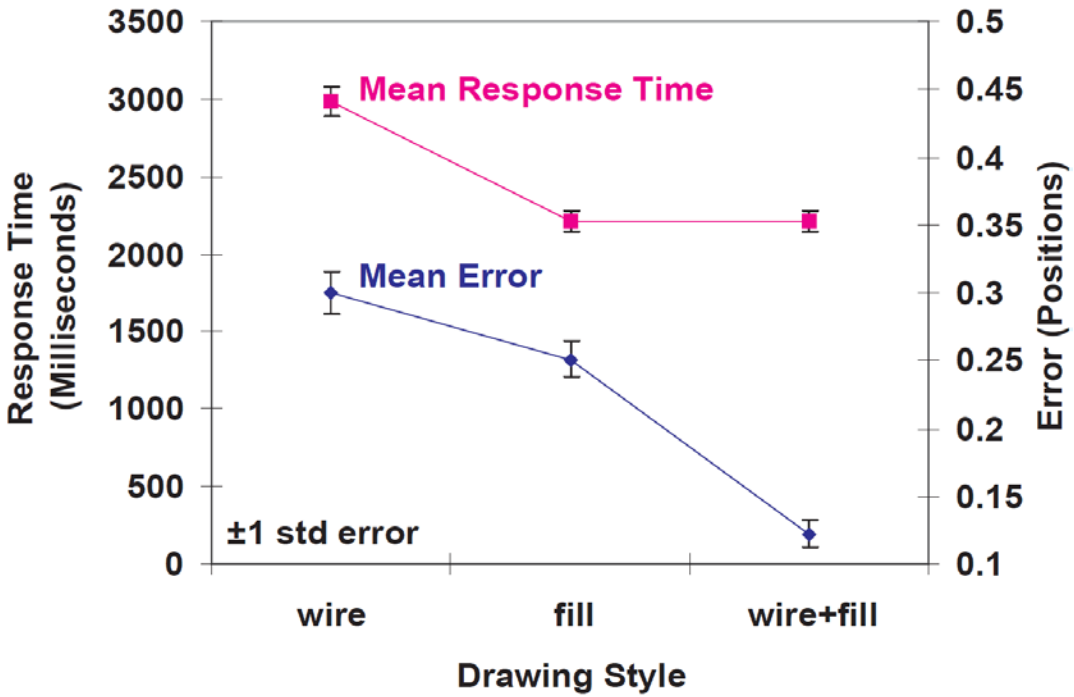
Studying AR Depth Perception

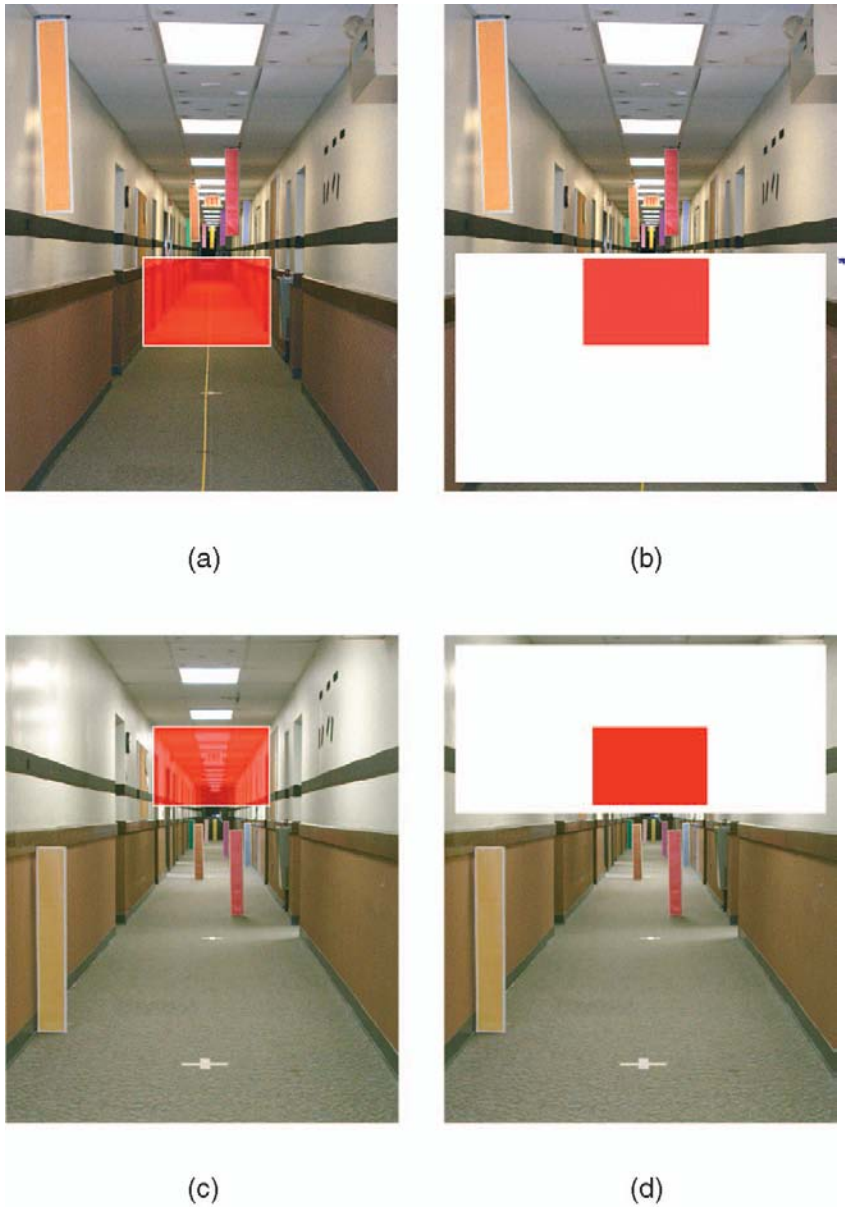
- Began with occlusion problem
  - Several authors have studied this
  - Easy to justify for our domain experts
- Shifted to depth perception
  - Thought it would help us understand the problem space
  - Easier to design and build off of perception literature for valid tasks

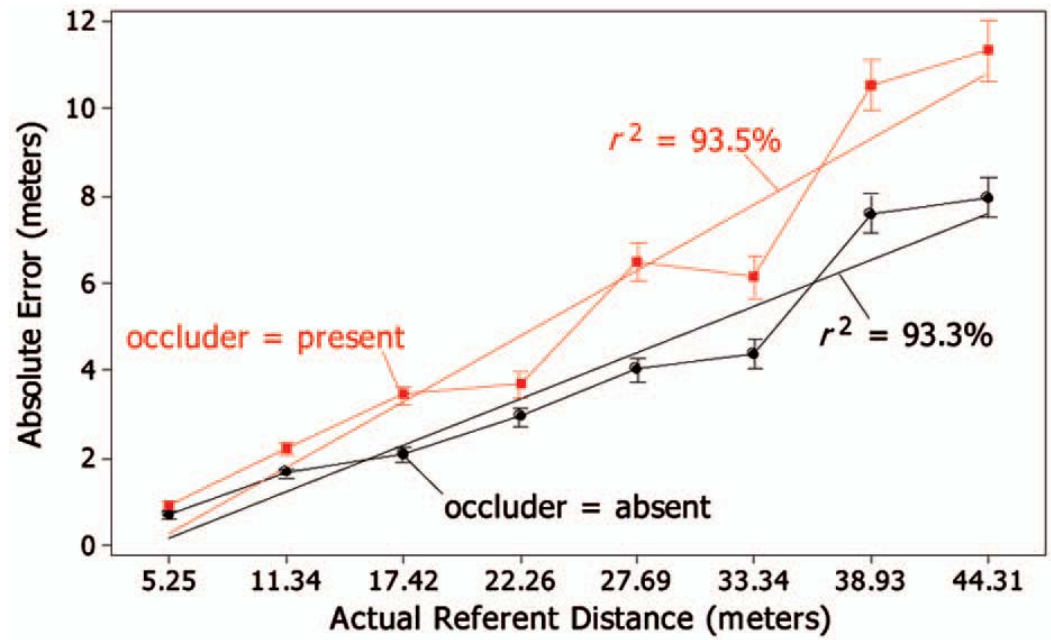


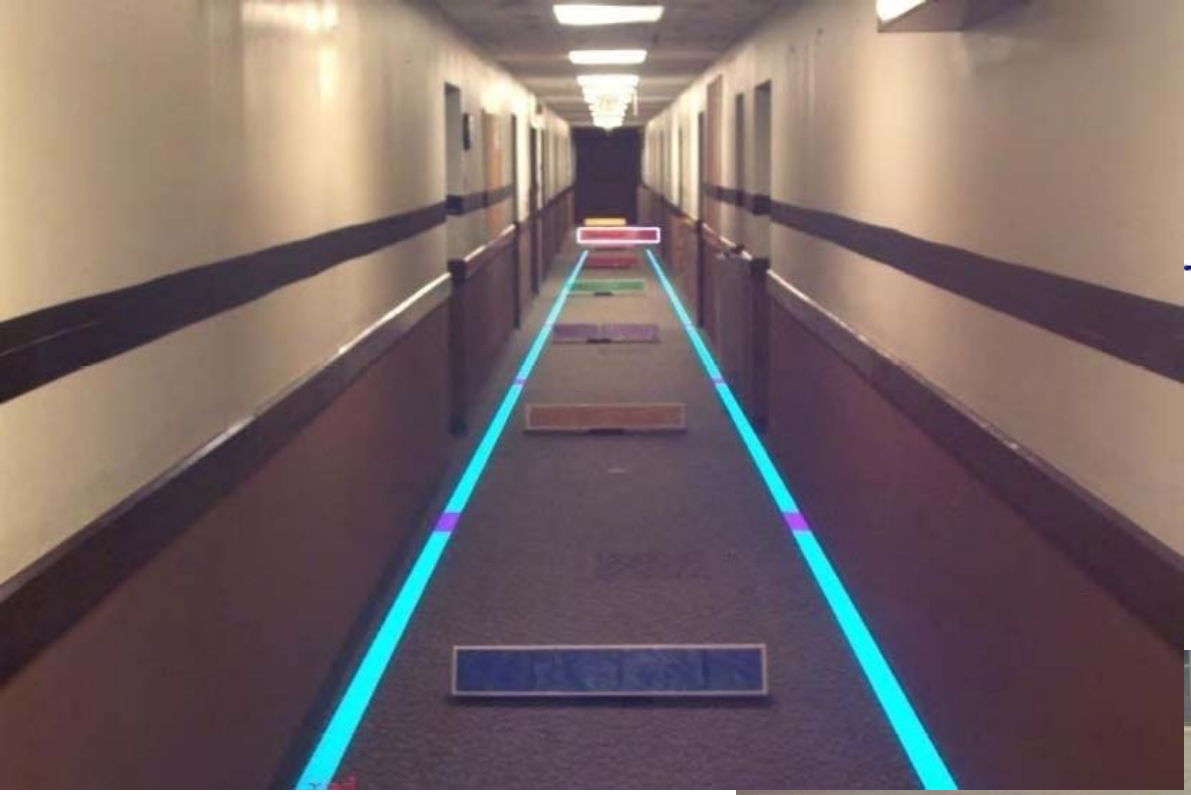


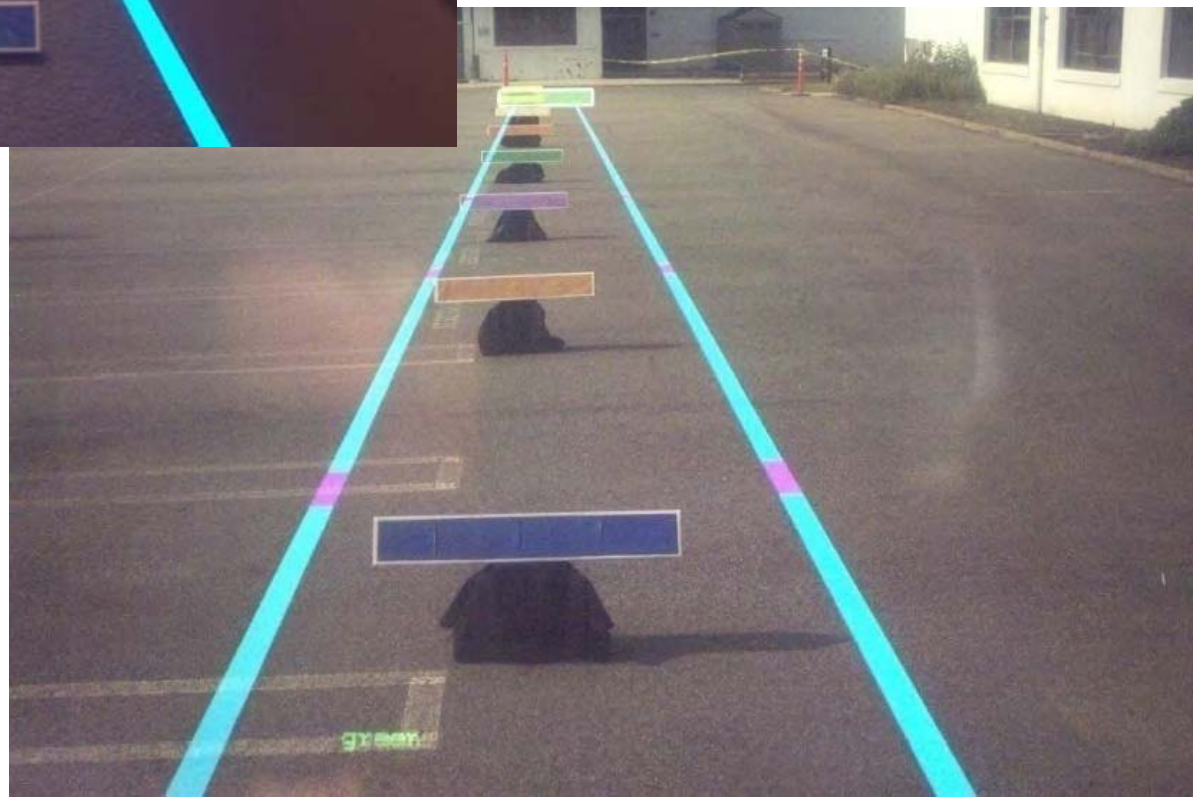


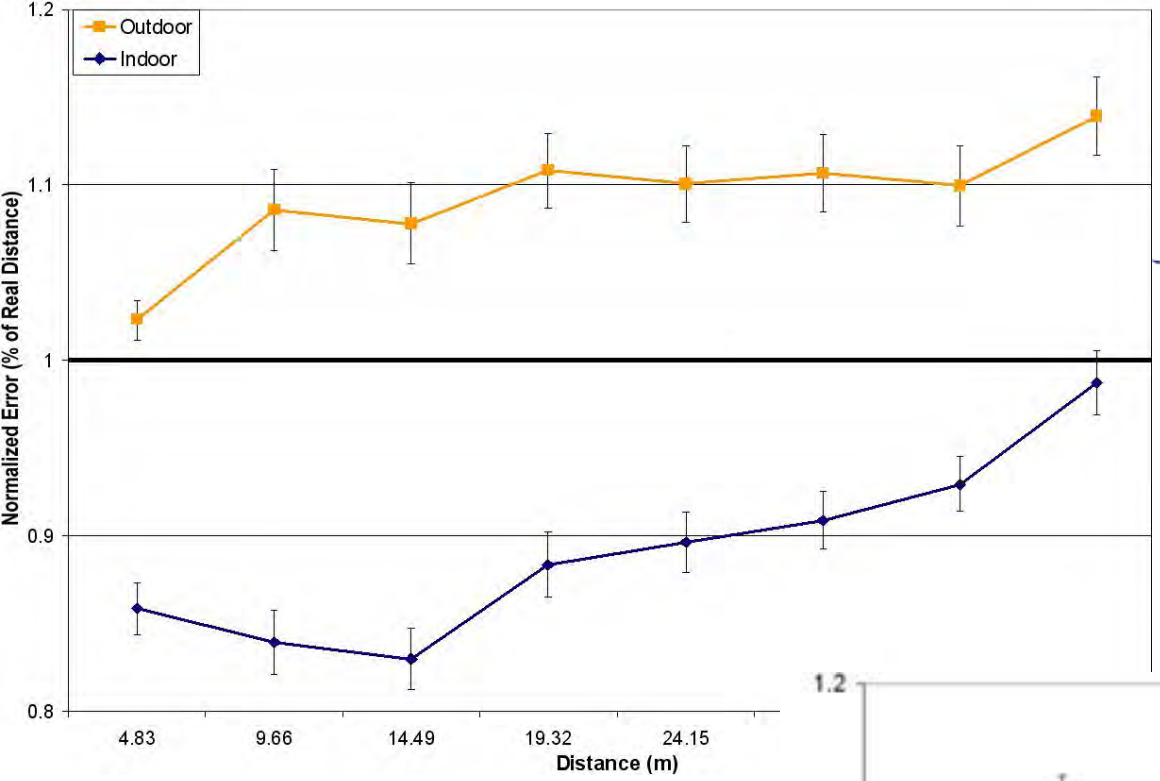

Mean Response Time
Mean Error
±1 std error
Response Time (Milliseconds)
Error (Positions)
3500
3000
2500
2000
1500
1000
500
0
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
wire
fill
wire+fill
Drawing Style

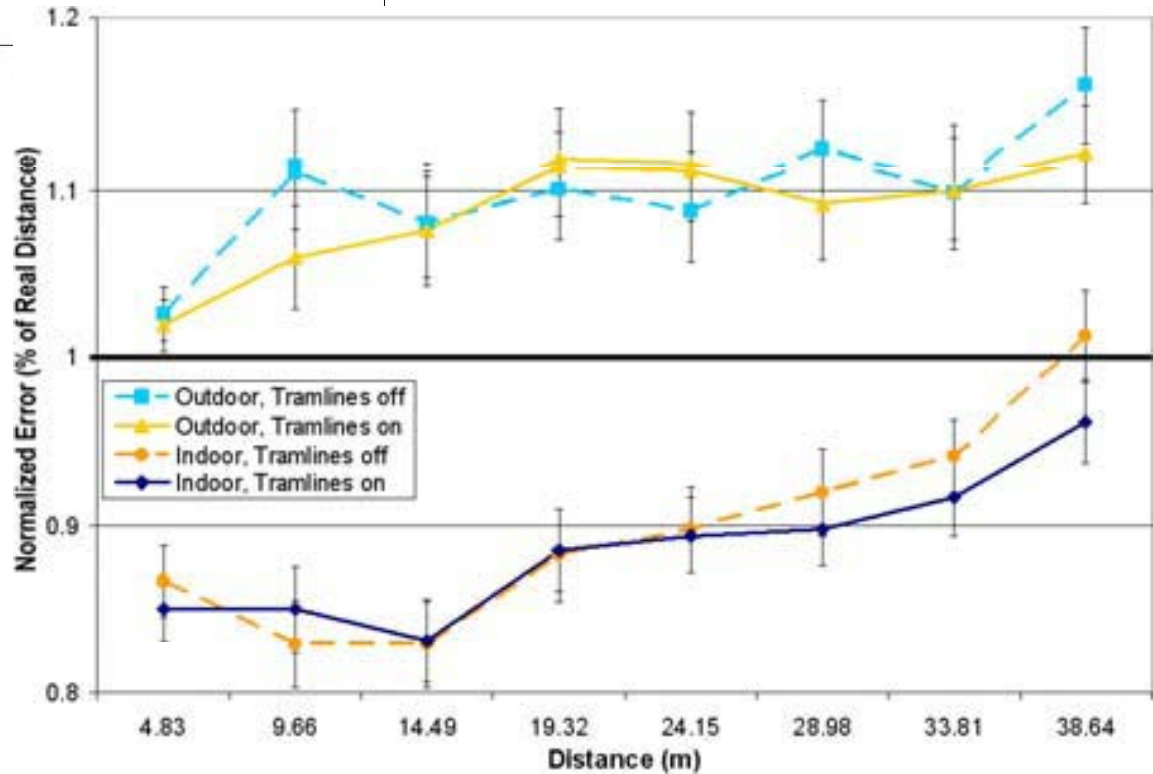

(a)
(b)
(c)
(d)


Absolute Error (meters)
0
2
4
6
8
10
12
r^2 = 93.5%
r^2 = 93.3%
occluder = present
occluder = absent
5.25
11.34
17.42
22.26
27.69
33.34
38.93
44.31
Actual Referent Distance (meters)






Outdoor
Indoor
Normalized Error (% of Real Distance)
1.2
1.1
1
0.9
0.8
4.83
9.66
14.49
19.32
24.15
Distance (m)


Normalized Error (% of Real Distance)
1.2
1.1
1
0.9
0.8
Outdoor, Tramlines off
Outdoor, Tramlines on
Indoor, Tramlines off
Indoor, Tramlines on
4.83
9.66
14.49
19.32
24.15
28.98
33.81
38.64
Distance (m)

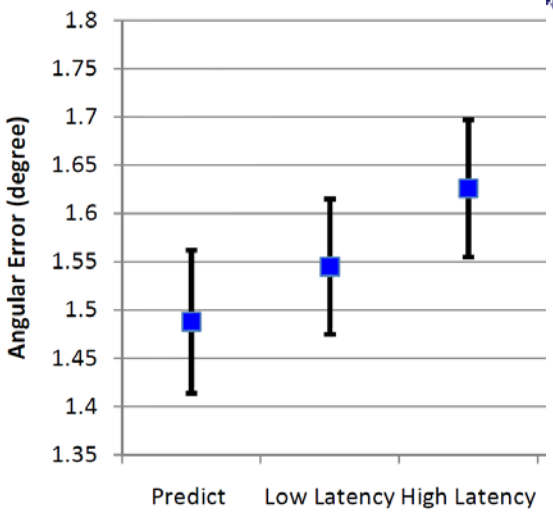
Registration Error

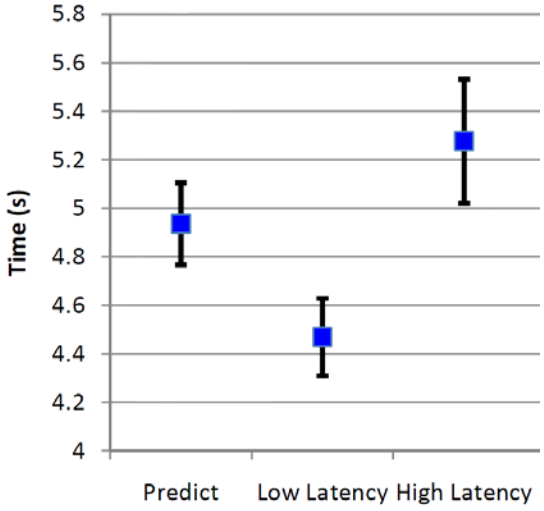
Registration Matters

- Underlying assumption of almost every MR & AR application
- Can be very noticeable that something is inconsistently registered – i.e. dynamic errors
  - Jitter
  - Latency
  - Dynamic position error
  - Dynamic orientation error

Some Results on Registration

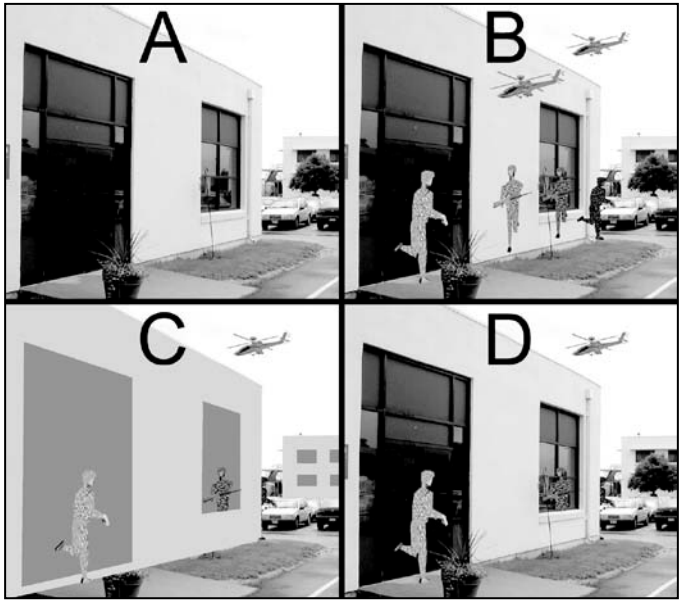
- Latency really matters
  - Understanding association of graphics and real
  - Not getting headache
- Noise is very annoying
  - … but might not detract from task performance





Urban Skills Training

- Bridge to SAF system to include virtual friendly and enemy forces or civilians
- Room clearing task
  - Need to model environmental geometry and light
  - Issue of model fidelity
- Task: Room clearing
- Does training against virtual characters lead to better training than learning techniques in empty rooms?

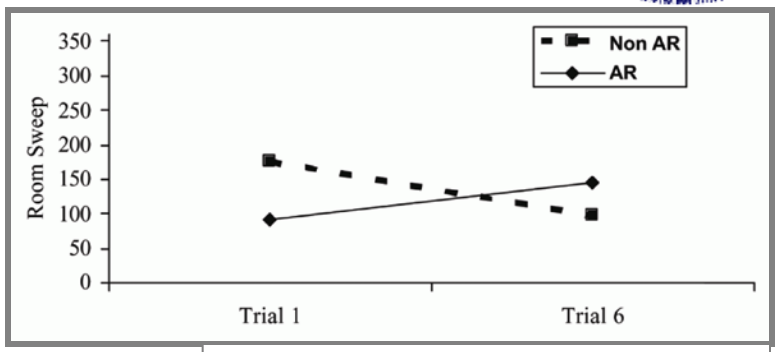


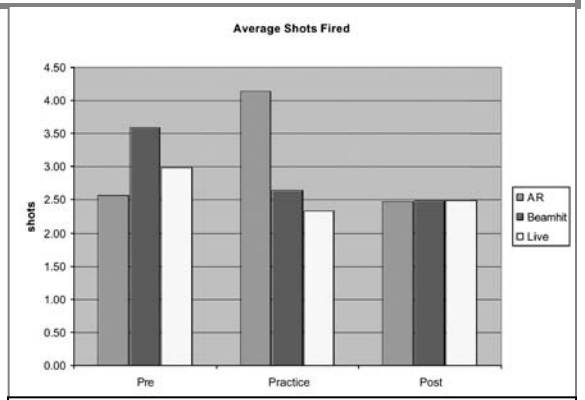
Evaluation Strategy

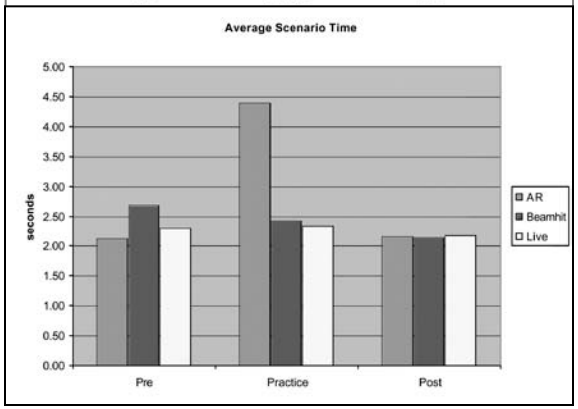
- Use One-SAF Testbed to control computer-generated forces
- Two test groups: novice (scientists) and Corporals/Lance Corporals at MCB Quantico
- Pre-test &post-test against live forces; training type (AR, empty rooms) varied
- Single person “team” with threats placed in his area of responsibility within each room

Training Effectiveness Results

- Novices who trained against AR entities learned to look at the whole room; those who trained against empty rooms learned to look at less of room
- Experts fired more shots and took a little longer when training against AR
  - But only trends (p=0.080 for time and p=0.092 for shots), not a statistically significant result







Subjective Feedback

+ Liked the idea
+ Enjoyed it, as a game
+ Could use customary target system and training facilities
− Difficulty sighting the AR rifle
− Hard to get HMD to fit and hard to see through it
− Worried about walking into walls
− Poor depth perception

Conclusions

- AR is ready to move out of the lab … again
  - Mobile phone applications might be the “killer app”
  - Industrial applications are making some advances
  - Displays and tracking hardware have a long way to go
  - Interaction techniques need improvement
  - Human factors require deeper understanding to make these systems that people really want to use
- Potential is high and (once again) matched by the hype

NASA Applications?

- Ames Research Center
  - Steve Ellis is a major contributor on depth perception
  - Resiman et al. (SIGGRAPH,2009) “AR for Air Traffic Control Towers”
- Johnson Space Center
  - Maida et al. proposed use of Space Vision System for learning robotic manipulation (AR or MR?)
- European Space Agency
  - Wearable AR on ISS for step-by-step instruction guides for difficult, lengthy procedures

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