Natural Space as Interface

Interaction Research at UCSB's Four Eyes Laboratory

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"Four Eyes" Lab
Imaging, Interaction, and Innovative Interfaces

Computer Science Department
University of California, Santa Barbara

Outline

- **Lab Overview**
- **Selected Research Projects**
  - Interactive Tools for Augmented Reality "X-ray vision"
  - HandVu: Hand gestures for mobile computing
  - Photorealistic Real-Time AR in Unprepared Environments
  - Multi-Flash Imaging
  - Facial Expression Analysis
  - Constraint-Based Interaction with RNA Molecules
- **Conclusions**

The Four Eyes Lab

M. Turk

- Research in the Four "I"s of Imaging, Interaction, and Innovative Interfaces
- 2000/01 Matthew Turk starts the "i-lab"
- 2002/03 Tobias Höllerer joins, new lab space, new name
- 2004 First PhD Student Graduates (Mathias Kölsch)
- 2004/05 Visiting Professors/Researchers
  June-Ho Yi,
  Hyoung Gon Kim,
  Ismo Rakkolainen

The Four Eyes Lab

- **Current Size:**
  - 2 Permanent Faculty
  - 2 Visiting Faculty
  - 1 Post-doctoral Researcher
  - 7 Ph.D. Students
  - 4 Masters Students
  - 3 Undergraduate Researchers

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The Four Eyes Lab

~20 Research Projects in

- Computer Vision Methods & Applications
- Perceptual & Multimodal Interfaces
- 3D Imaging and Interaction
- Augmented Reality
- Mobile HCI

Four Eyes Lab: General Motivation

Provide better, more compelling HCI technologies in a variety of important computing environments

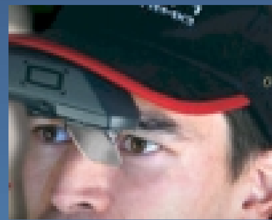
- Desktop, immersive, VR
- Mobile, ubiquitous, AR

…and for a variety of application areas

- Sciences, entertainment, digital art, visualization, …

Investigate fundamental issues in developing robust, real-time, working technologies for interactive systems

Augmented Reality



1) Blends real and virtual, in real environment
2) Real-time interactive
3) Registered in 3-D

Mobile Augmented Reality

- **Overlay information anywhere, anytime**
- **Many application areas**
  - Tourism, journalism, architecture, construction, maintenance, repair, military, training, medicine, entertainment, …
- **General purpose situated UI for wearable computers**
  - Navigational aids, communication aids, personal situated information DB, general UI for appliances

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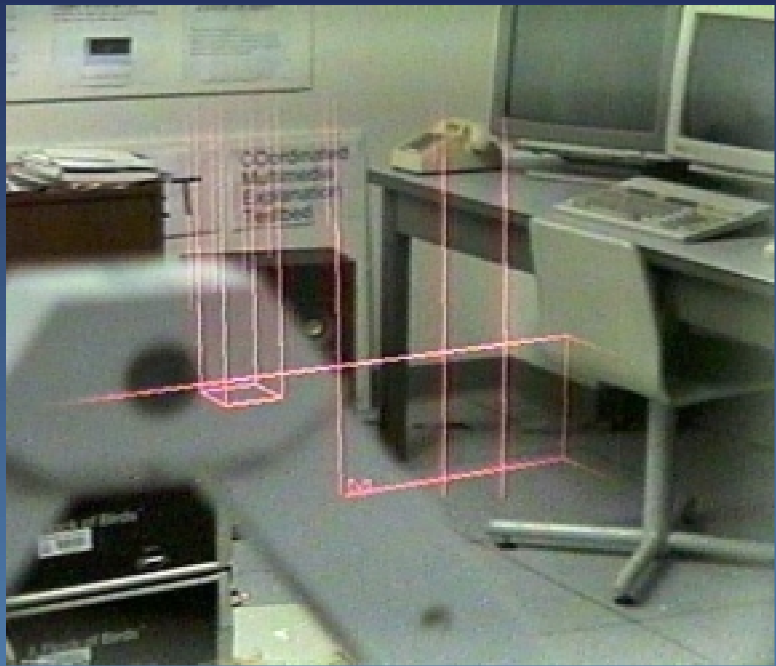
X-Ray Vision in AR



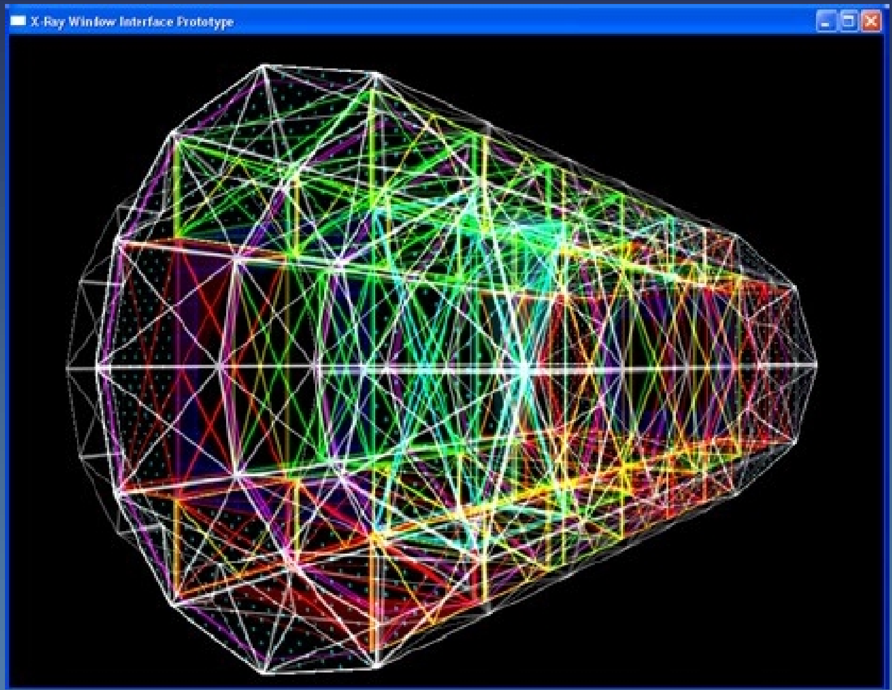
Architectural Anatomy

Feiner, Webster, Krueger, MacIntyre, & Keller, 1995

Augmented Reality Visualization for Laparoscopic Surgery

Fuchs, Livingston, Raskar, Colucci, Keller, State, Crawford, Rademacher

More Motivation



W. White (S. Illinois U., NASA Johnson Space Center)

X-Ray Window: Portable Visualization on the International Space Station,

Technical Sketch, SIGGRAPH '04

X-Ray Window Rendering of ISS *Destiny* Module, with Color-Coded Stowage and Equipment Components

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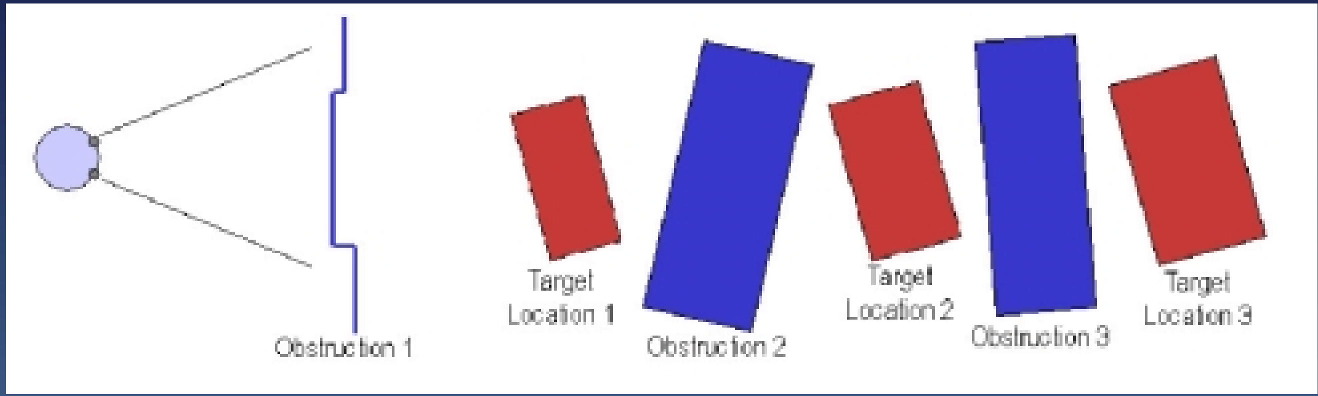
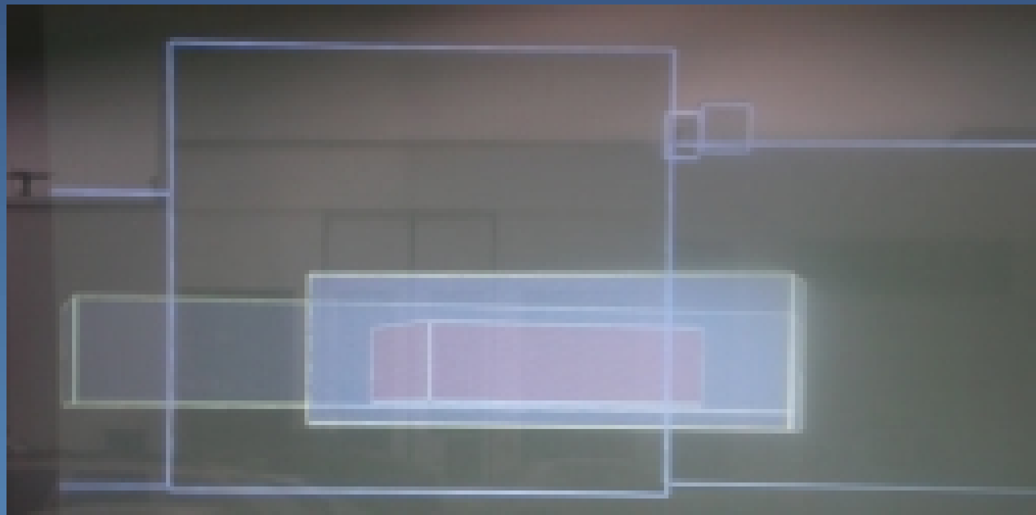
Direct Display Methods





Resolving Multiple Occluded Layers in Augmented Reality
Livingston, Swan, Gabbard, Höllerer, Hix, Julier, Baillot, Brown,
ISMAR ‘03

Tangible Interaction with Occluded Infrastructure

Provide *interactive tools* to explore occluded infrastructure from a mostly static vantage point.

Slice through the environment in front of you.

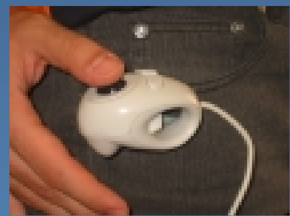
Integrate birds-eye overviews

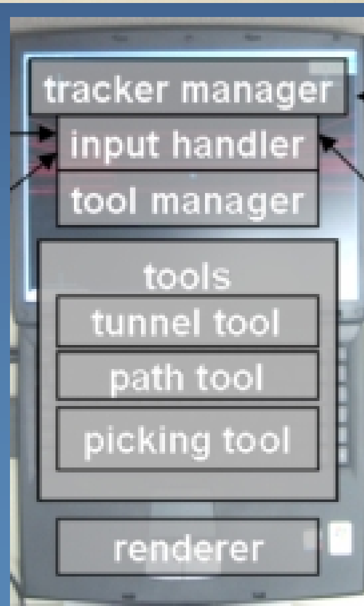
Implementing X-Ray Vision

Hardware Overview

Video See-Through AR
(Tradeoff: FOV / immediacy)

Focus on far-field AR,
Interaction from a relatively static viewpoint.





Running off a 2.2GHz laptop computer with NViDIA Quadro4 Go graphics.

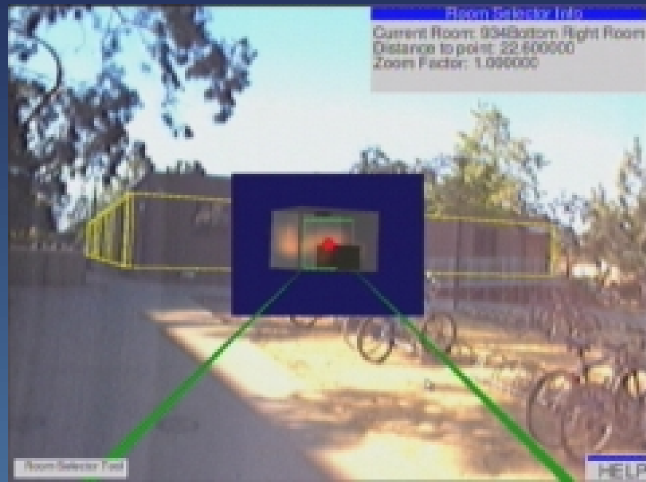
Implementing X-Ray Vision

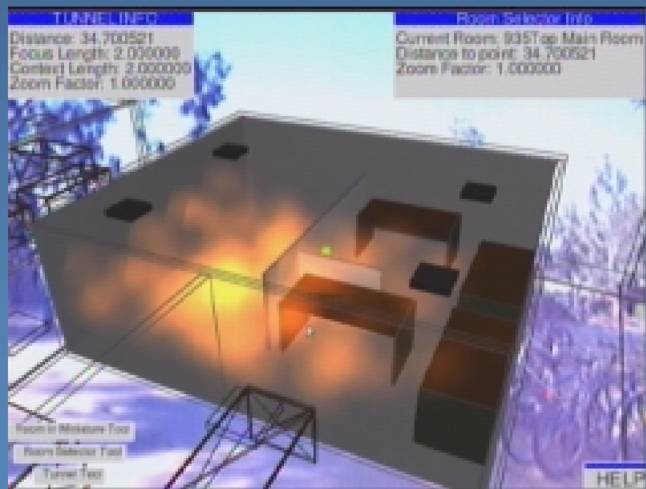
Software / UI Overview

Implements interactive techniques in the form of a small toolset.

First person tools use virtual lenses and three dimensional sliders

Third person tools allow users to control a virtual camera to view objects





The Toolset

The Toolset examines two main approaches: Volume based and Room based

- Volume tools work on general geometry
- Room tools assume that structures are modeled as collections of rooms, and allow the user to examine buildings on a room by room basis.

General idea: assume limited semantic information. Shifts burden to modeling.

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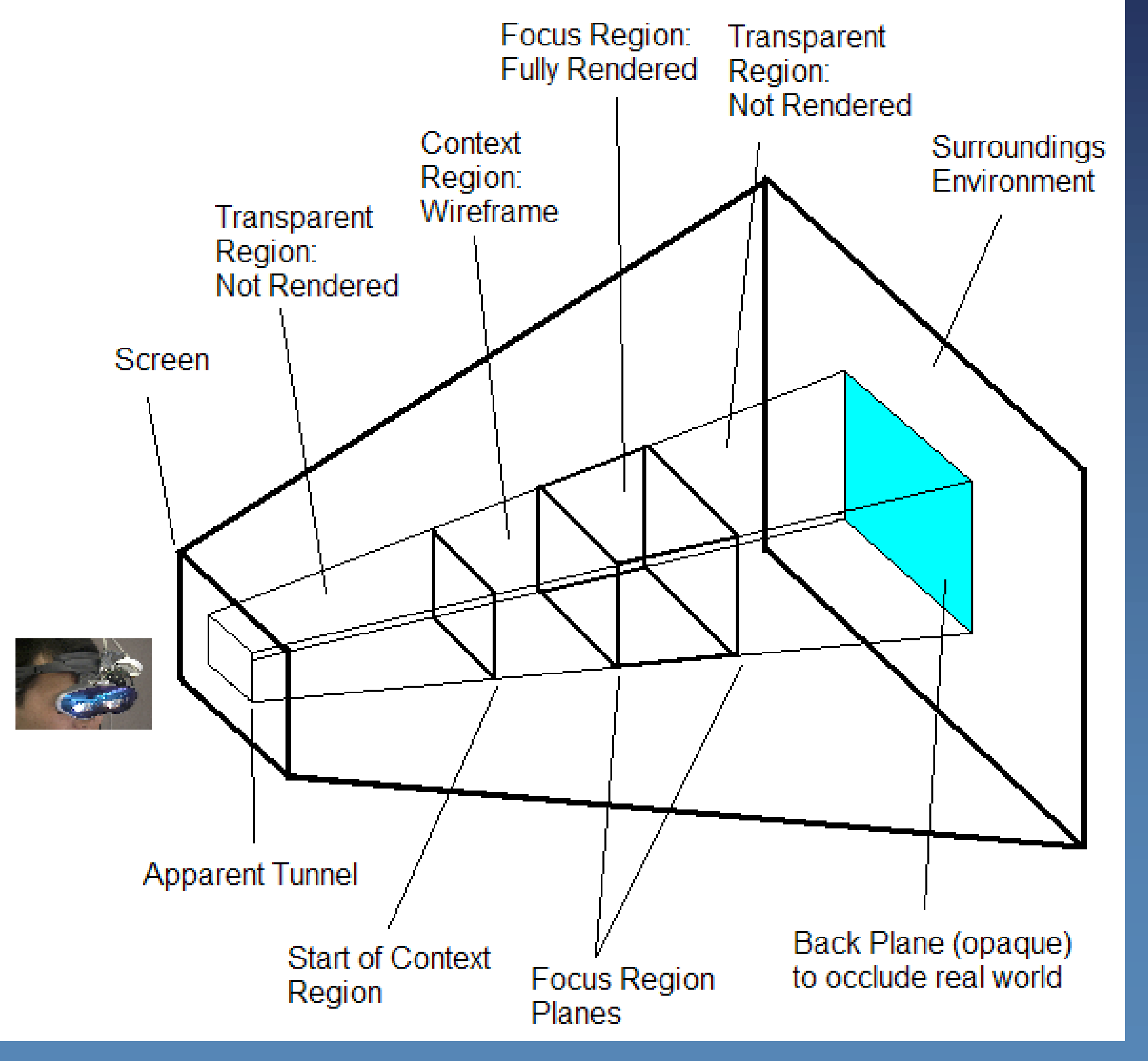
An “X-Ray Lens”: The Tunnel Tool



The Tunnel Tool

The Tunnel Tool

- Good for viewing data clouds (temperature, wireless connectivity, …)
- Good for viewing buildings whose main walls are aligned with, or orthogonal to, viewing direction
- Can be confusing when walls are cut at angles.

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The Room Selector Tool

- The Room Selector Tool is a room-based, first person tool
- Assumes rooms to be represented in the environment model
- Intuitive – This is what many people imagine "x-ray vision" looks like

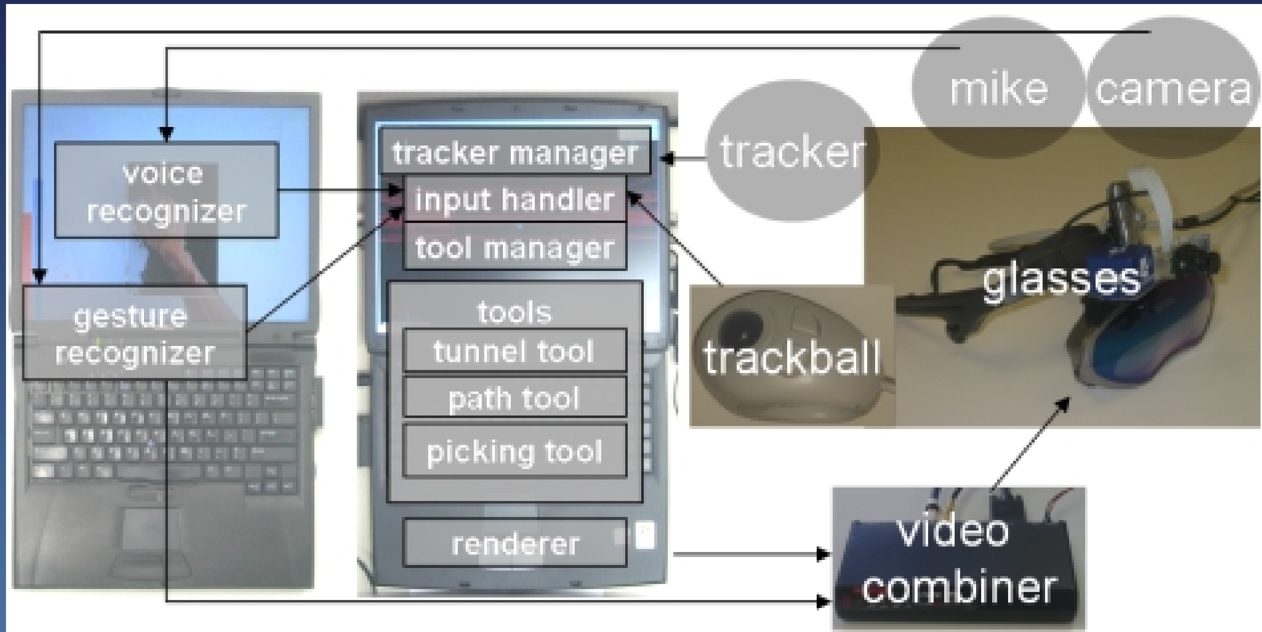
The Room Selector Tool

- **But what happens when objects in the room occlude other objects?**

Putting it all together

Video

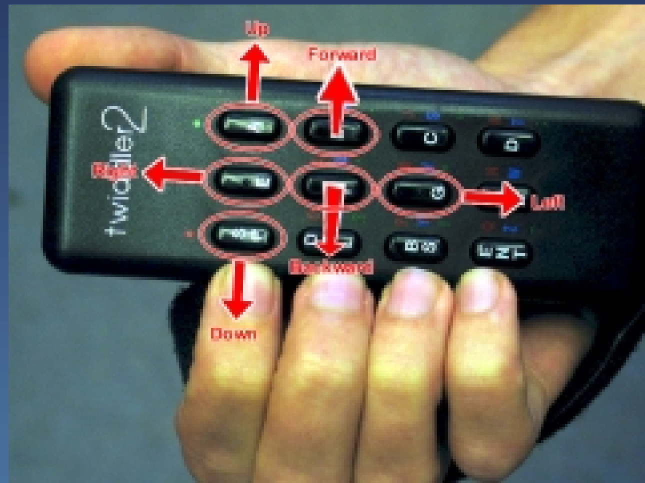
Architecture



Evaluation of Techniques for Interaction (3D Cursor Control) at a Distance

Four techniques tested

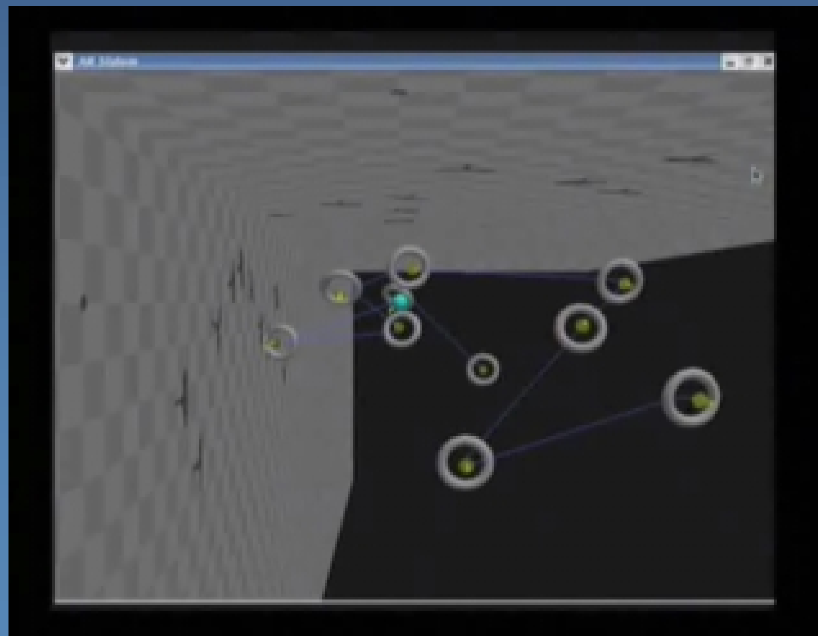
- T1 uses a Twiddler2 keyboard
- T2 uses a Rocket Mouse finger trackball
- T3 uses head orientation and two buttons
- T4 uses head orientation alone (plus a button to switch between modes)



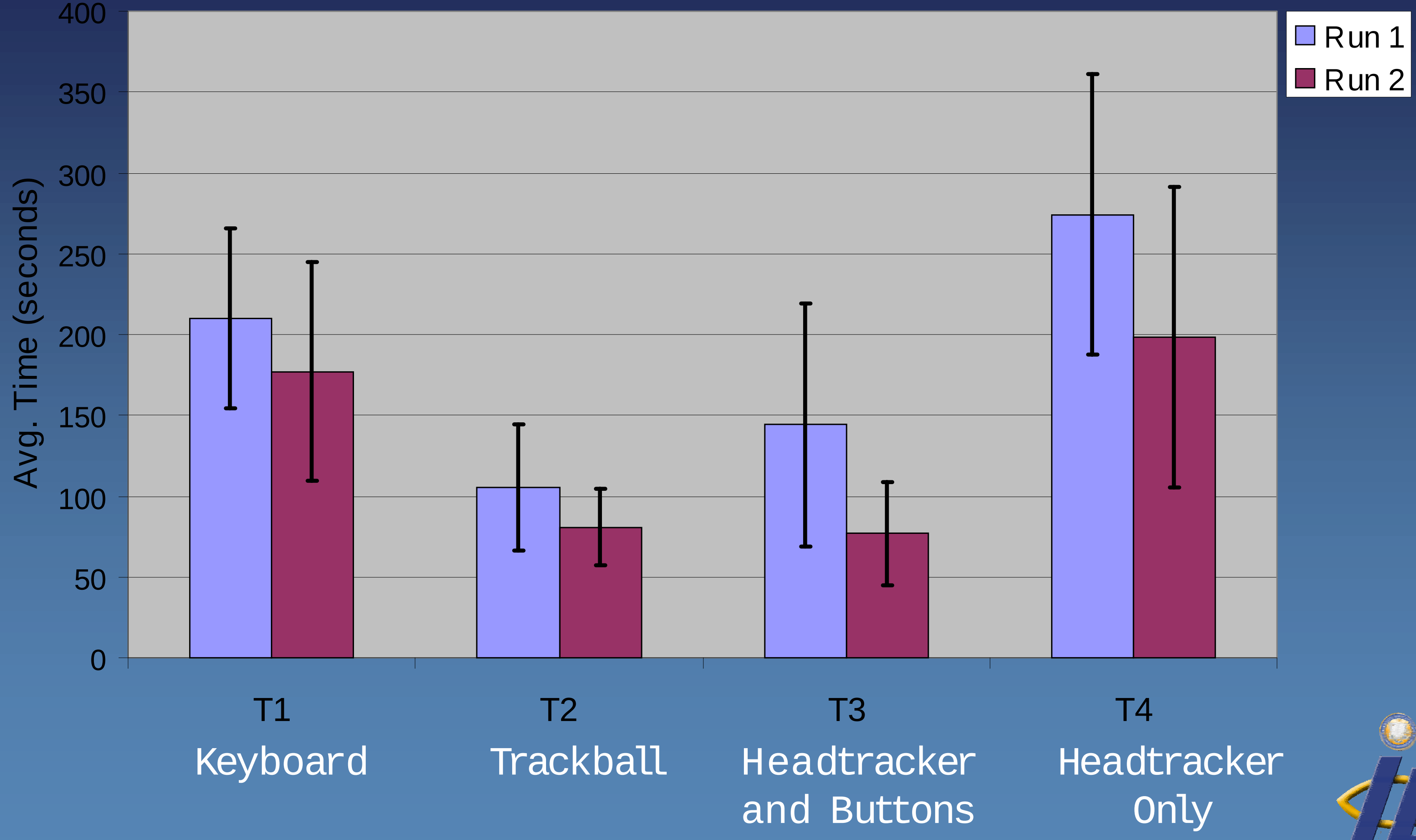
Study details

- Study in VR with users sitting
- 13 users – 9 male / 4 female
- 10 gate course

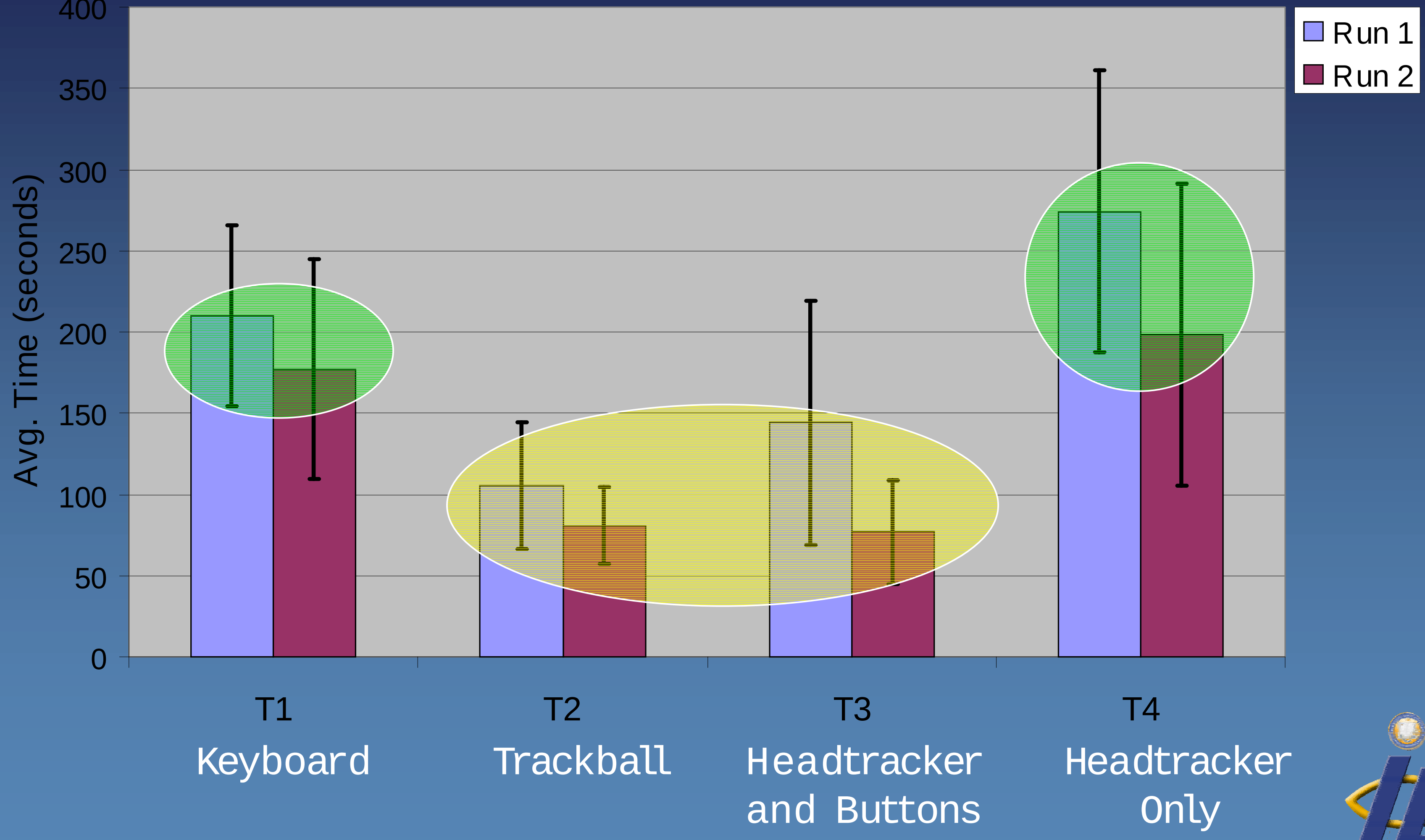
- Training session for each technique
- Two test-runs per technique
- Order of techniques was permuted between users



Study Results (Times)



Study Results (Times)



Summary of Results

- T2 (Trackball) and T3 (Headtracker and Buttons) performed nearly equally well
- Users found T2 (Trackball) more favorable than it objectively performed
- Times and error rates were not directly correlated

Interaction Design Recommendations

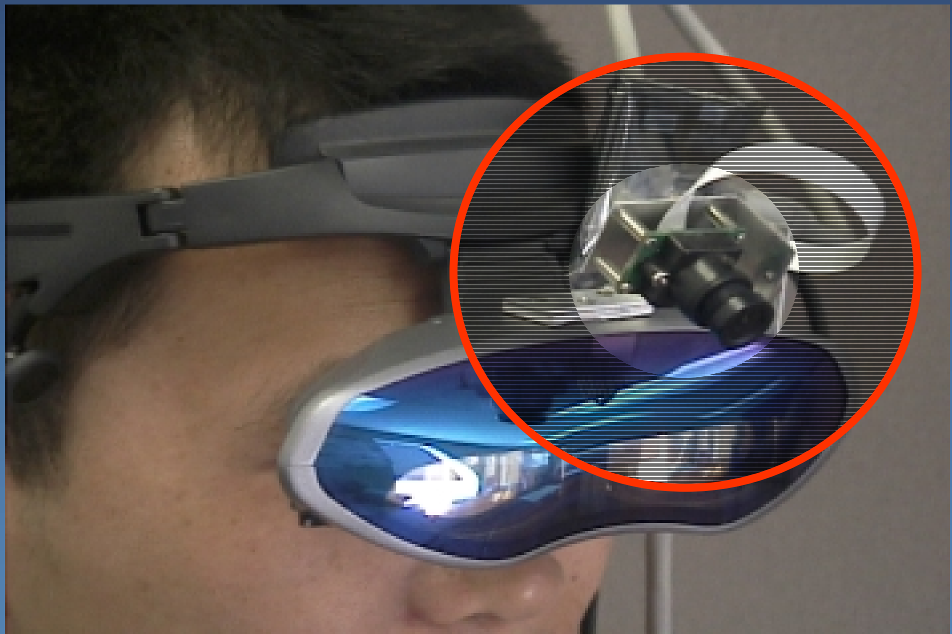
Trackball well suited for 3D cursor control from a distance

Head tracking can be a useful input technique in certain cases, particularly panning

Head tracking is commonplace in AR

Keyboard has low error rate, but slow times

Vision-based interfaces for mobility



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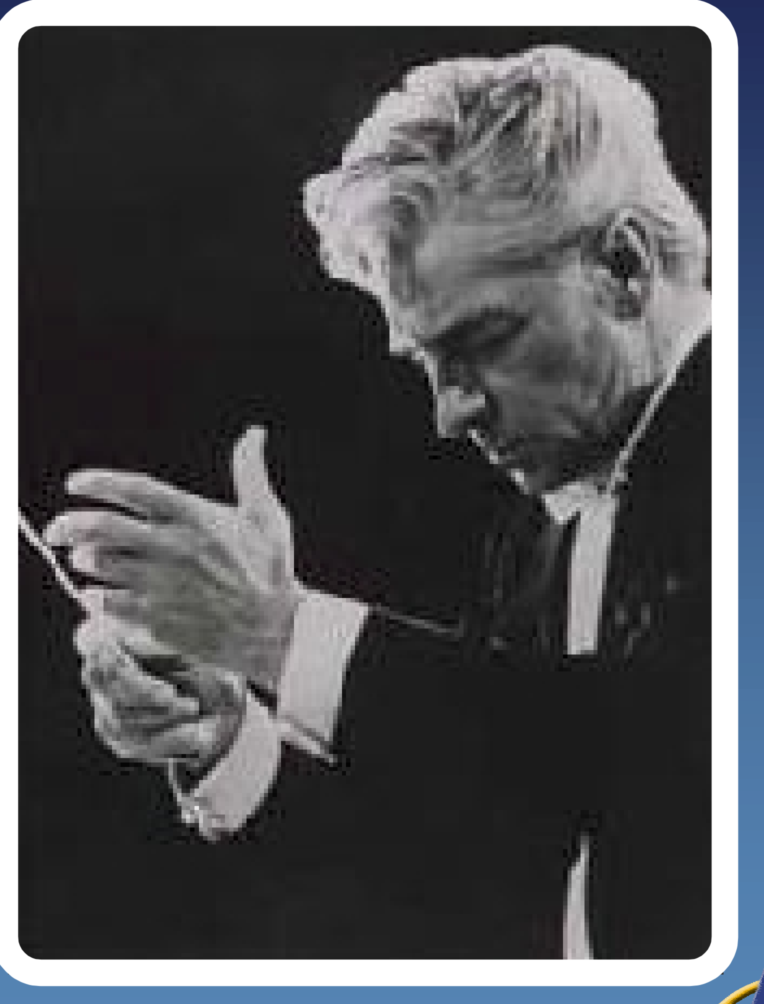
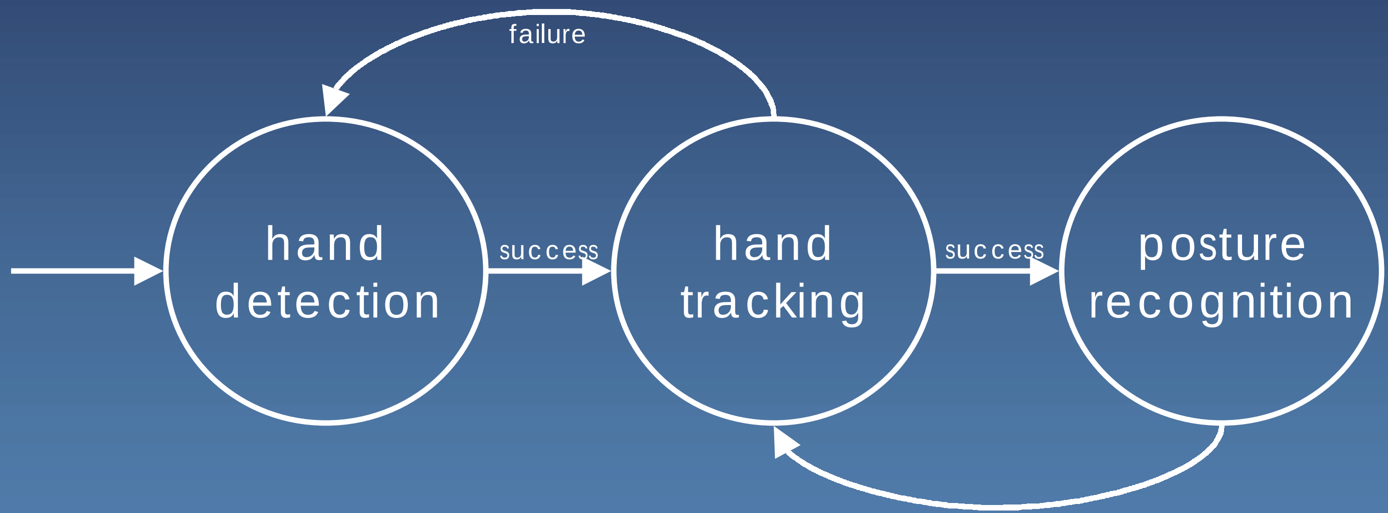
Hand gestures

- unobtrusive – no gloves or devices
- lightweight, mobile, wireless
- good for adverse environments
  - sand, moisture, silence, noise
- camera's versatile applications
- hardware advances and price drops

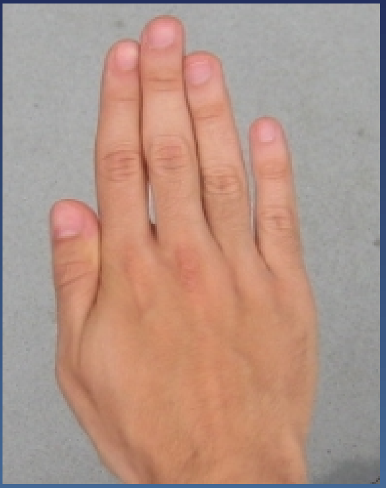


HandVu Vision-Based Interface Toolkit (M. Kölsch)



Robust hand detection

[Kölsch & Turk: Face and Gesture Recognition 2004]



extension to [Viola & Jones 2001]

detection rate: 92 %

false positive rate:

$1.01*10^{-8}$, or

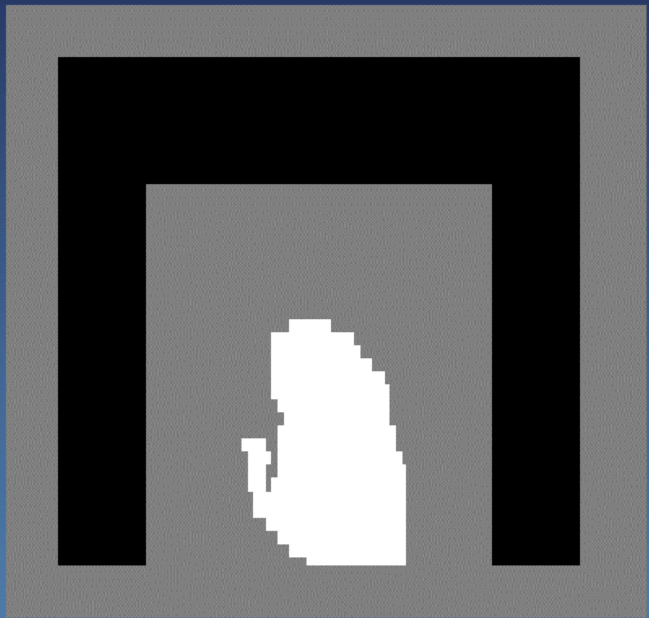
one in 279 VGA-sized image frames,

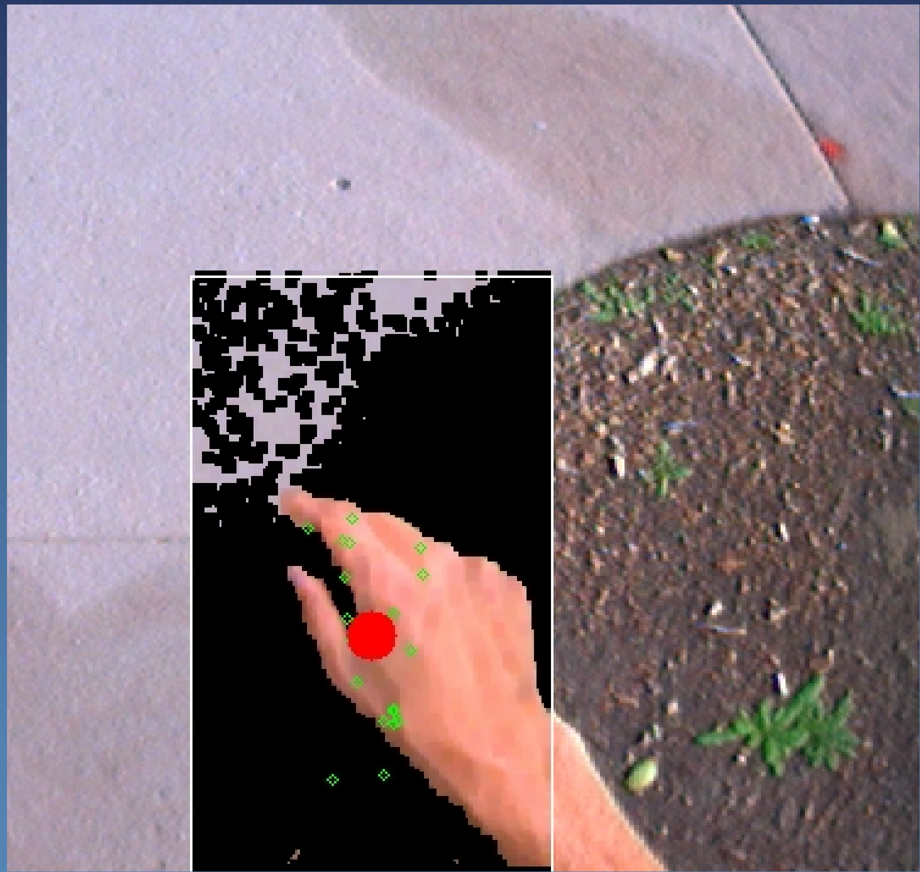
one in ~1500 in our 218x308-size area

with color verification:

few false positives per hour live video

Online learned hand color





Flock of Features: Fast 2D hand tracking

tracking of articulated objects

- location in 2D image plane
- no finger configuration

fast: 5-18 ms on 3GHz

robust:

- despite arbitrary backgrounds
- despite changing lighting conditions

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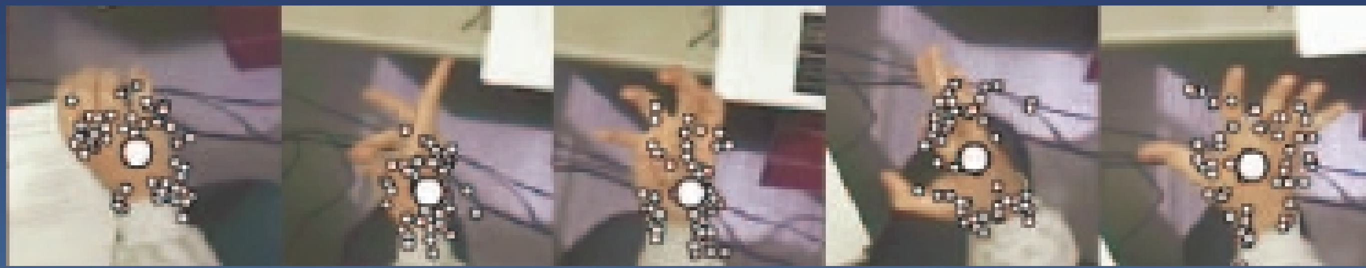
Flock of Features tracking

individual KLT features (grey level)



loose, global "flocking" constraints:

- not too close to another feature
- not too far from flock

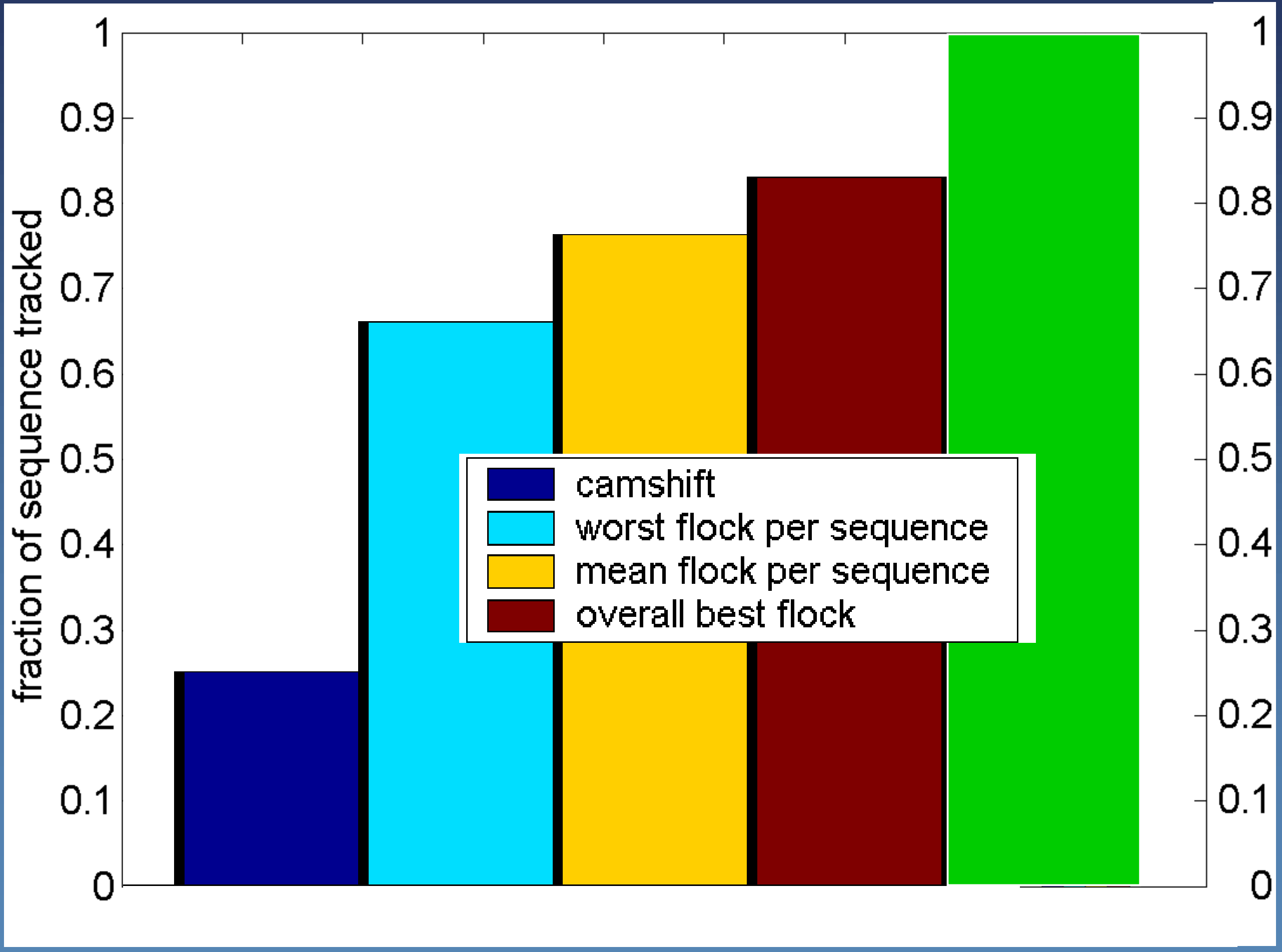
color probability for backup consultation

→ multi-cue integration

→ overcomes single-cue failure modes

Flock of Features tracking

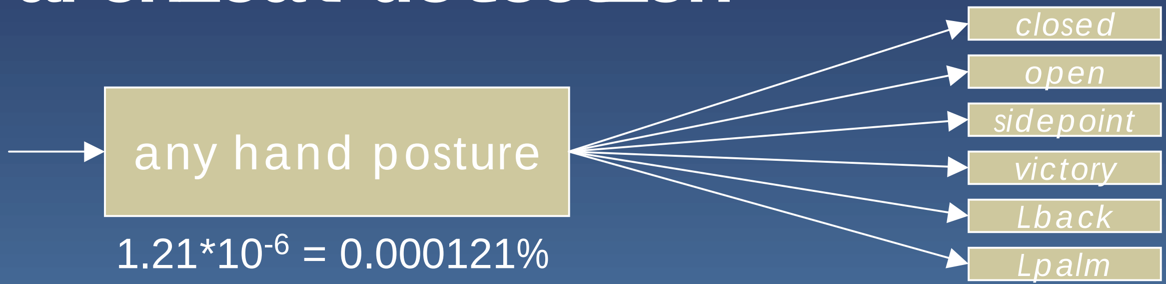
Flock of Features evaluation



[Kölsch & Turk: RTV4HCI (at CVPR) 2004]

Hand posture recognition

hierarchical detection



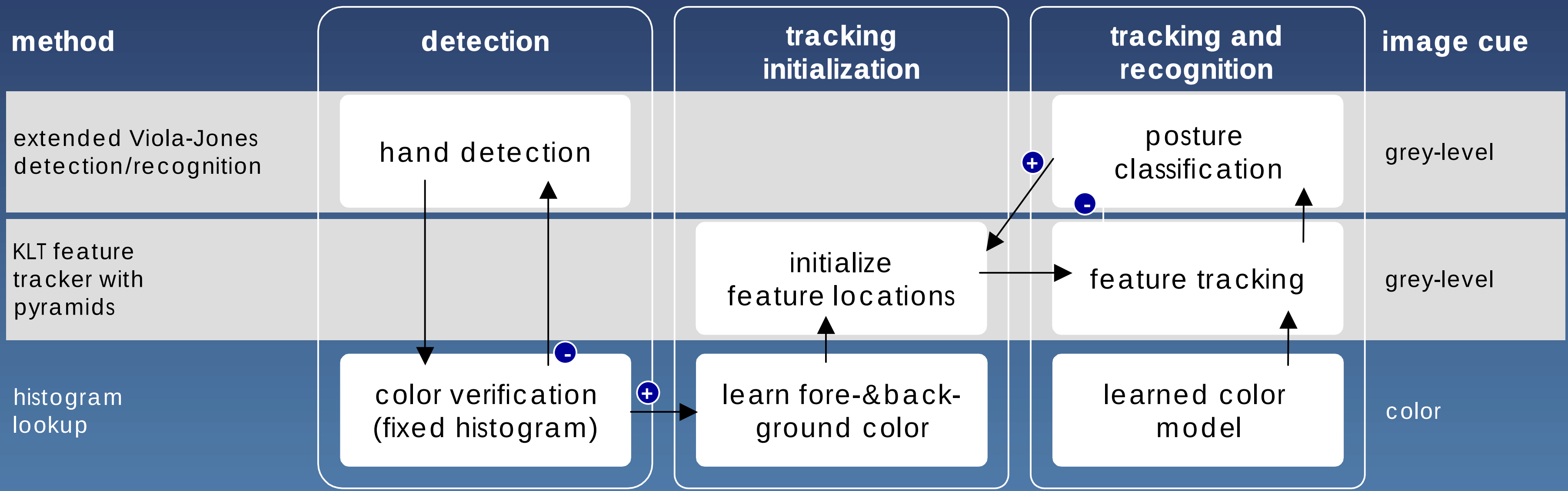
$1.21*10^{-6} = 0.000121\%$

distinguishes six postures

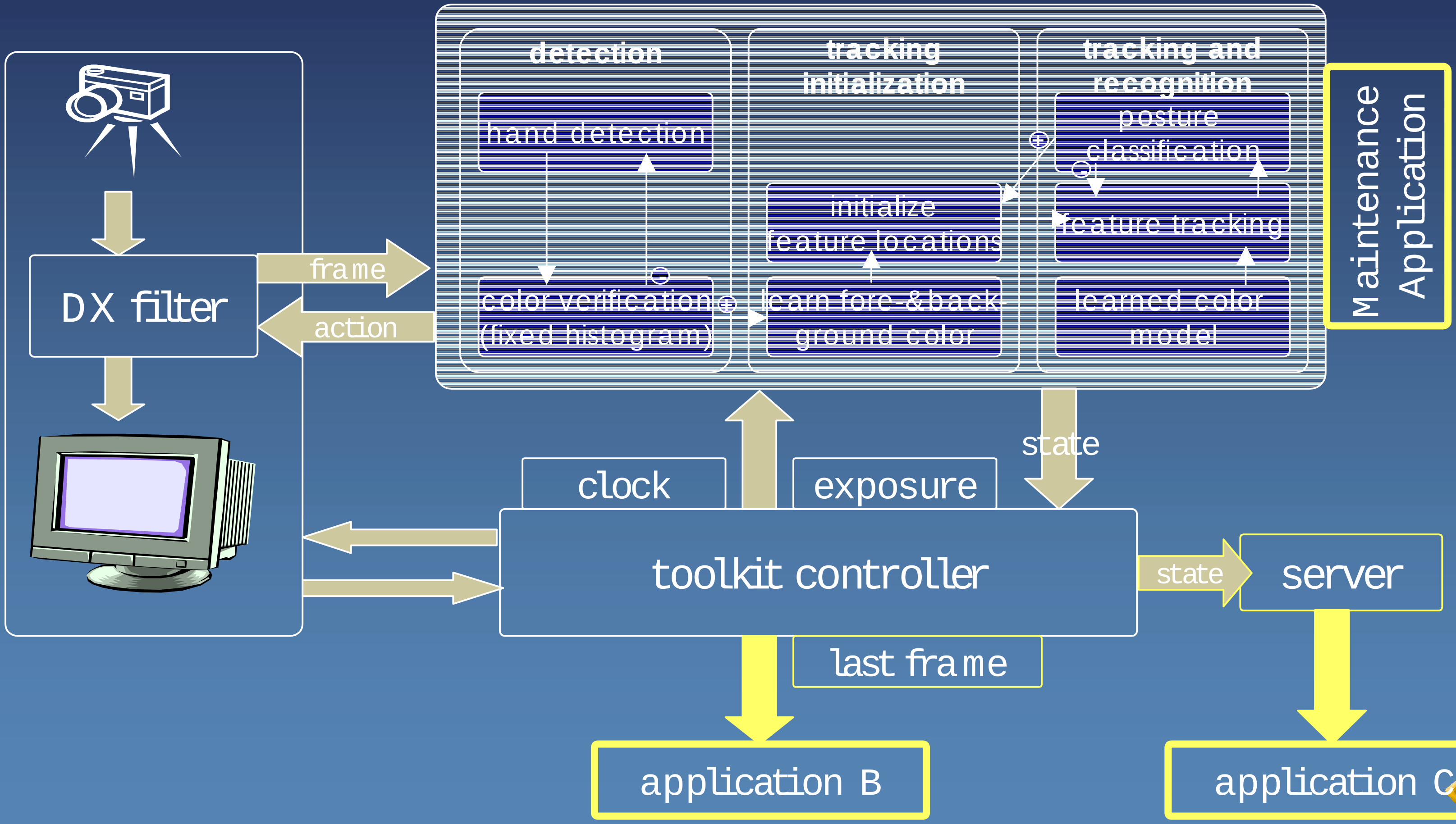
re-initialization of tracking

- learn color model
- set feature locations

HandVu's vision methods



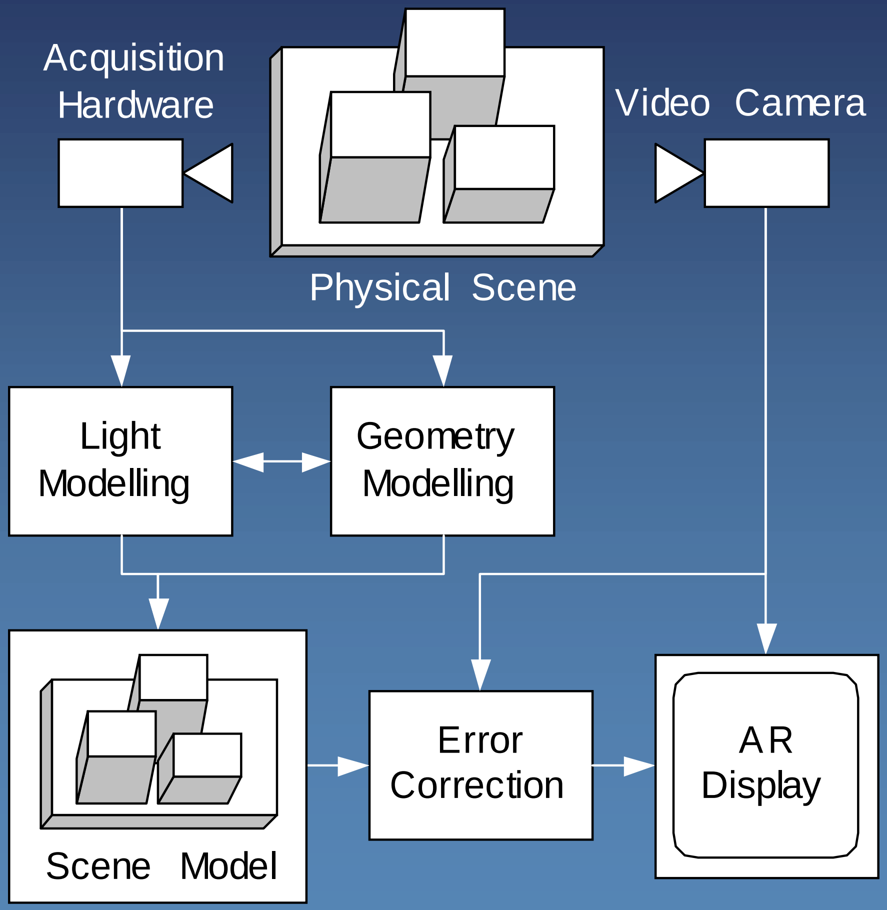
HandVu toolkit



Photorealistic Real-Time AR in Unprepared Environments (S. DiVerdi, T. Höllerer)

- Seamless integration of virtual and physical worlds is a goal of AR.
- Good integration requires accurate geometric registration, as well as consistent illumination.
- Existing realistic mixed reality systems require extensive start up costs - calibration, scene modeling, instrumentation, etc.

Photorealistic Real-Time AR in Unprepared Environments



- System will use a variety of data acquisition hardware.
- Aggregated light and geometry information must be stored in unified scene data structure with low incremental update cost.
- Video input will be used for error correction and video see-through display.

Photorealistic Real-Time AR in Unprepared Environments

http://www.middlebury.edu/stereo/

Approximate Geometry Acquisition

- Physical geometry necessary for lighting and shadows.
- Dynamic response to geometry changes requires (semi-) automatic acquisition techniques.
- Stereo vision algorithms for automatic updates.
- Interactive (marker sweep, line markup) intervention for semi-automatic updates.

Photorealistic Real-Time AR in Unprepared Environments

© P. Debevec. Rendering Synthetic Objects Into Real Scenes, SIGGRAPH 98. http://www.debevec.org/Probes

Lighting and Shadows

- Dynamic response to lighting environment changes requires automatic acquisition techniques.
- Tracked light probe provides partial information.
- Currently, shadows from IBL are only done with offline rendering techniques → turn interactive
- Process light probe to find small number of bright area light sources for shadow generation.
- Real-time environment map

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Photorealistic Real-Time AR in Unprepared Environments

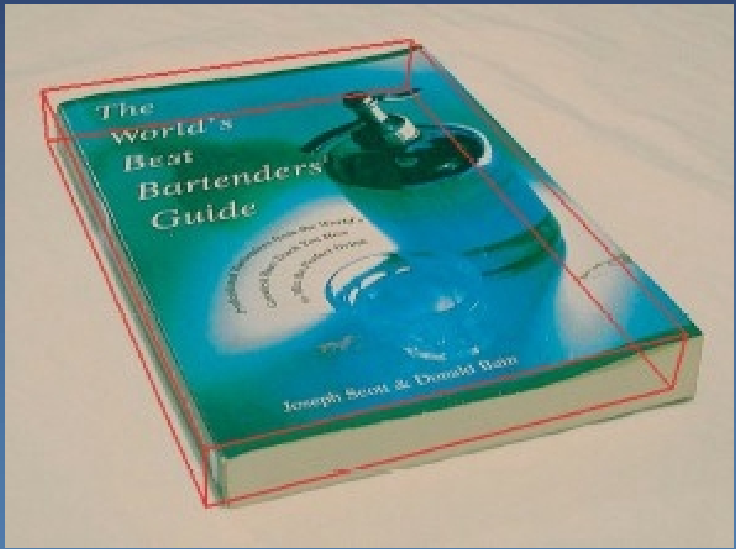


Image-Based Error Correction

- Applying virtual lighting and shadows requires pixel-perfect registration. Errors in registration are easily detectable near edges.
- Registration errors are difficult to eliminate, especially with automatic geometry acquisition techniques.
- Video of scene can be used to correct errors by making rendered lighting edges correspond with depth discontinuities

Multi-flash imaging for depth discontinuities

SIGGRAPH 2004 and CVPR RTV4HCI 2004

Joint work with MERL, MIT

General idea:

- Take *N* images with *N* differently located flashes
- Reason about the cast shadows to determine depth discontinuities

Applications:

- Non-photorealistic rendering
- Finger spelling (for sign language recognition)

Depth Discontinuity Detection

(R. Feris w. R. Raskar (Mitsubishi Electric Research Labs) and M. Turk)

Source object, no shadows

Multi-Flash Camera

Multi-Flash Imaging

(R. Feris w. R. Raskar (Mitsubishi Electric Research Labs) and M. Turk)

Direct Multi-Flash Result

Canny Edge Detector

Multi-Flash Application: Finger spelling recognition

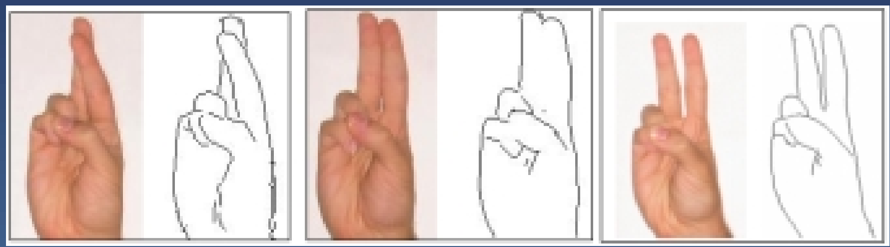
Vision-based finger spelling recognition using depth discontinuities

Part of sign language

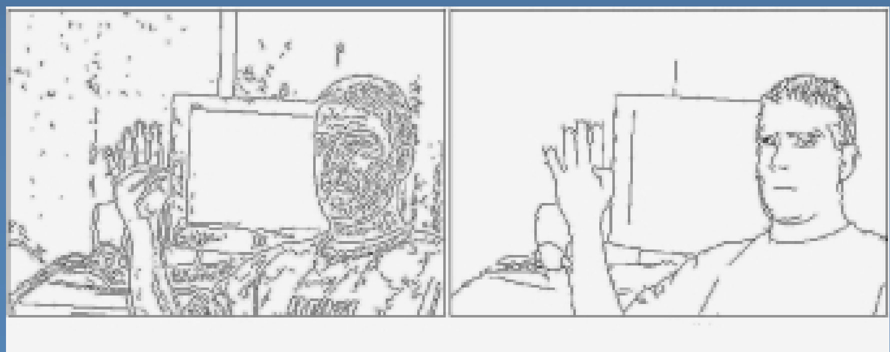
- Lots of occlusion!

Recognition

Worst cases reported by a glove-based system

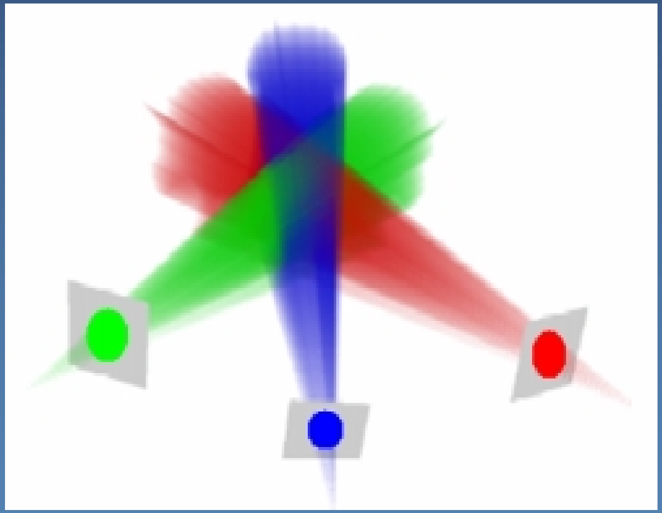


Clutter Removal



96% of correct matches, compared with 88% with Canny edges

Ongoing work: Exploit variable wavelength



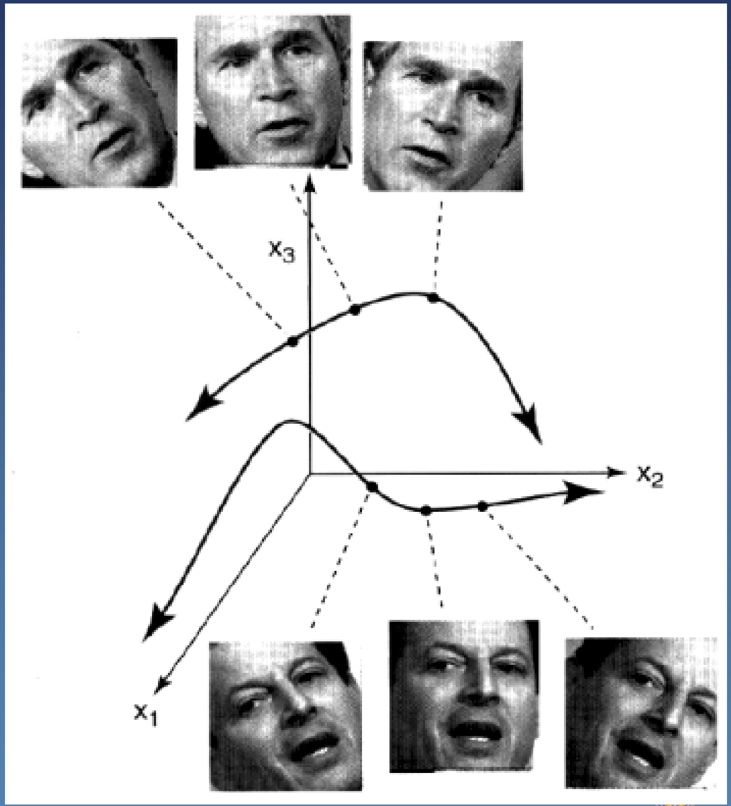
Facial expression analysis
(Y. Chang, M. Turk)

Facial expression <u>representation</u> and <u>visualization</u>

Use non-linear manifolds to represent dynamic facial expressions

Intuition:

- The images of all facial expressions by a person makes a smooth manifold in (high-dimensional) image space, with the "neutral" face as the central reference point

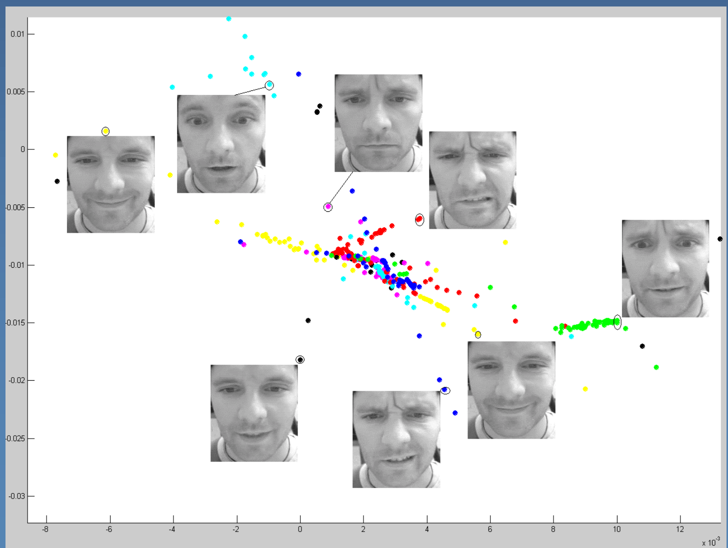


Expression analysis: Non-linear manifold

The manifold is embedded in the high dimensional image space

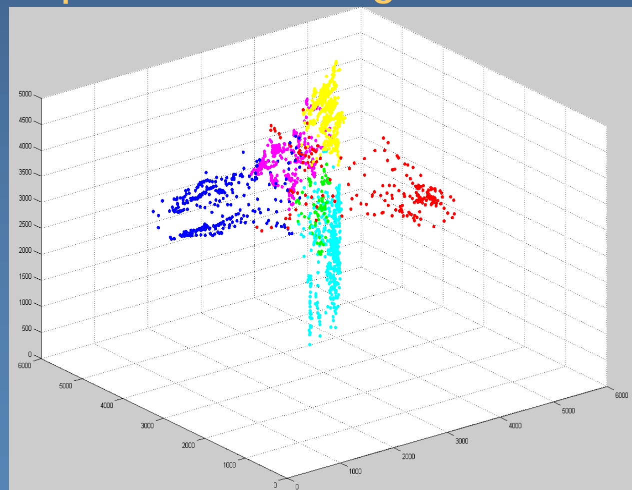
Two techniques:

- Locally linear embedding, Lipschitz embedding



First two dimensions of LLE

Expression = angle of manifold



First three dimensions of Lipschitz embedding: Good clustering for similar facial expressions

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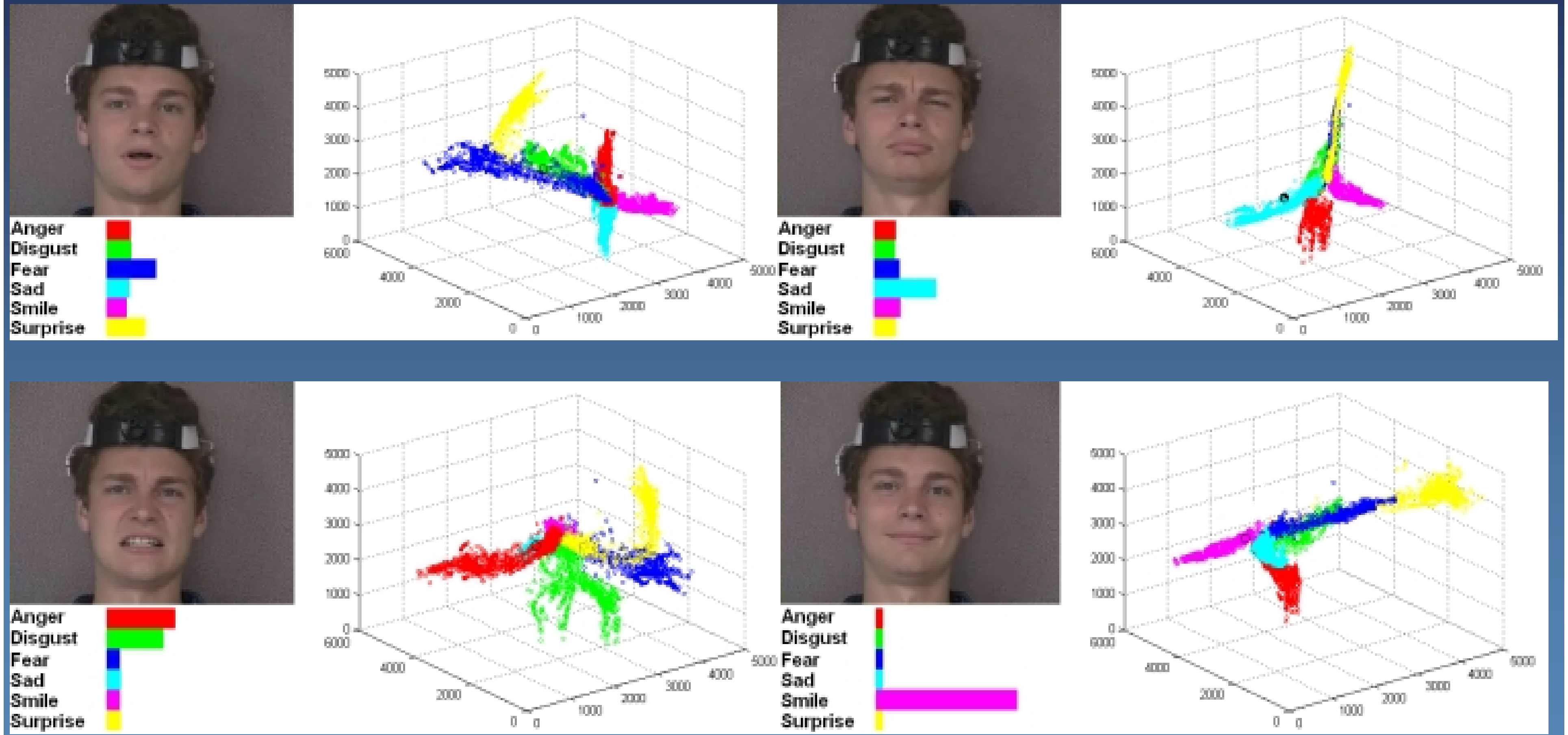
Manifold visualization of expression



Example

Constraint-based Interaction with RNA Molecules (Helly Kwee, T. Höllerer, L. Jaeger)

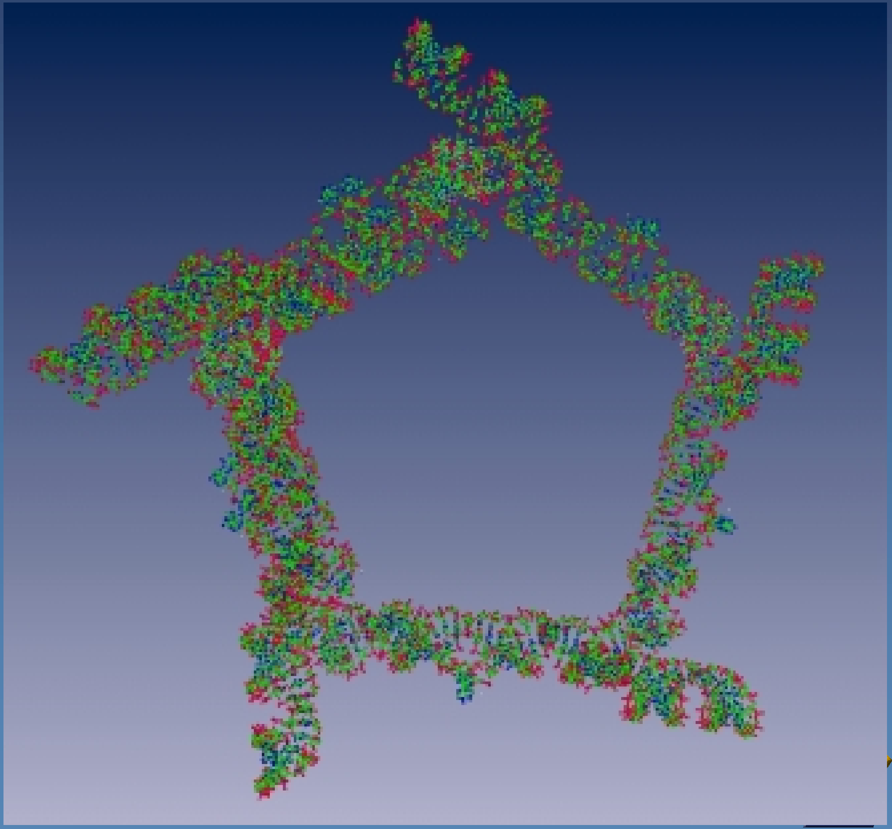
Long-Term Goal:

Assemble new shapes from RNA motifs

"Playing Lego with Biomolecules"

Interaction Research:

- Simulation Environment for RNA molecule assembly
- How to communicate biochemical constraints in interaction?



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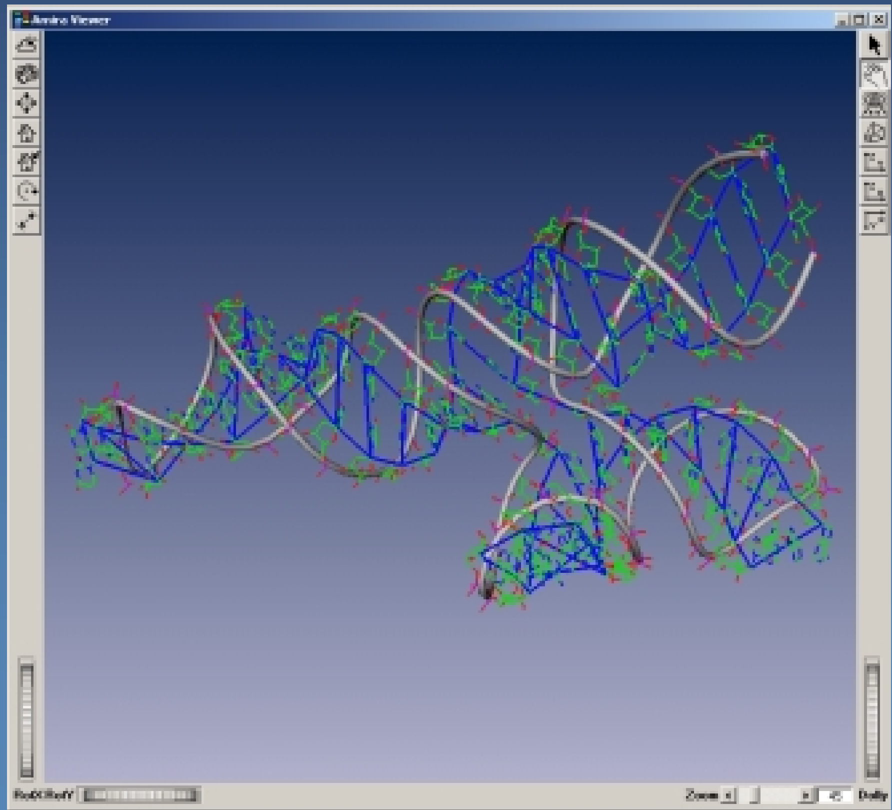
Constraint-based Interaction with RNA Molecules (Helly Kwee, T. Höllerer, L. Jaeger)

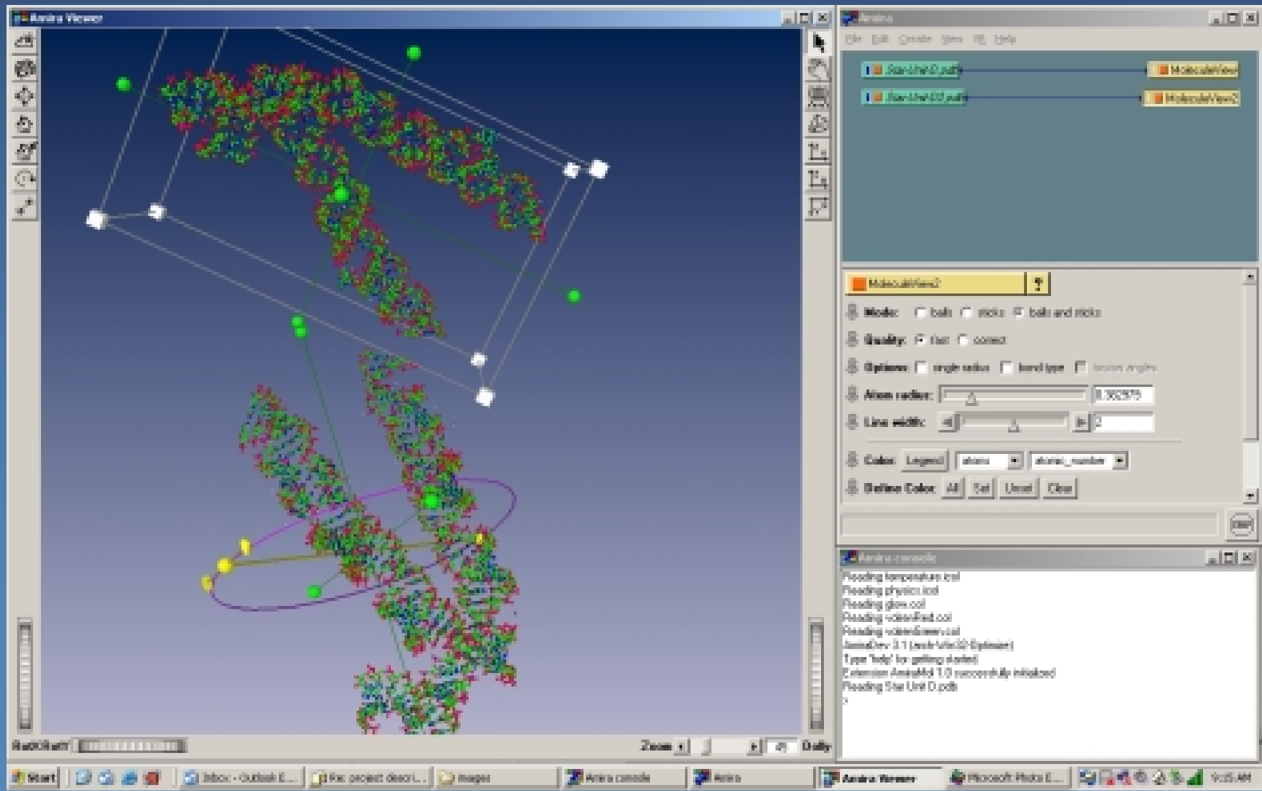
- Emulating Forces as Visualization Constraints
- Compare to Haptic Feedback (Sensable Omni, Delta)
- Interactive Drag'n'Drop 3D Databank of Motifs
- Novel Visualizations



Constraint-based Interaction with RNA Molecules (Helly Kwee, T. Höllerer, L. Jaeger)

International Collaboration with ZIB Berlin, Germany

Integrating new interaction, simulation, and visualization techniques into TGS/Mercury Amira



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  - Interactive Tools for AR “X-ray vision”
  - HandVu: Hand gestures for mobile computing
  - Photorealistic Real-Time AR in Unprepared Environments
  - Multi-Flash Imaging
  - Facial Expression Analysis
  - Constraint-Based Interaction with RNA Molecules
- **Conclusions**

Conclusions

- Overview of just 6 projects of currently about 20
- Tangible Space very much at the center of our research
- The computer has to be tought how to enhance rather than dominate a space.
- Take into account people's way of interacting with each other

Four Eyes Lab – Summary

General motivation

- Provide better, more compelling HCI technology in many computing environments

Technologies and research

- Fundamental issues in developing robust, real-time, working computer vision technologies for interactive systems
  - Multidisciplinary approach
- Multimodal integration
  - Speech, sound, haptics, user modeling, gestures, visualization
- Main application areas
  - General HCI, entertainment, digital art, visualization,

Ubiquitous Computing, Our Version

… Next comes ubiquitous computing, or the age of *calm technology*, when technology recedes into the background of our lives … (M. Weiser, 1991)

Making UIs ubiquitous:

- Electronically enhance the physical environment
- Electronically enhance the user's perception of the environment
- Enhance the computer's perception of the user