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Mobile Eye Pupil Tracking in Challenging Lighting

Thomas Kinsman, Dr. Jeff Pelz

MVRL, Multidisciplinary Vision Research Lab
CIS, Carlson Center for Imaging Science
RIT, Rochester Institute of Technology

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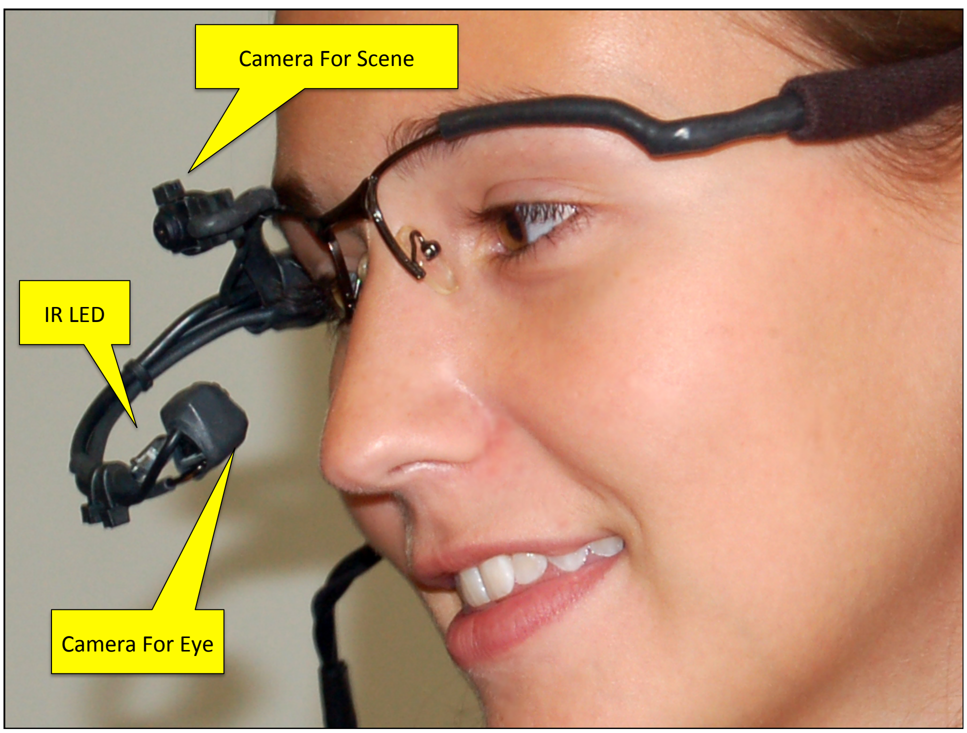
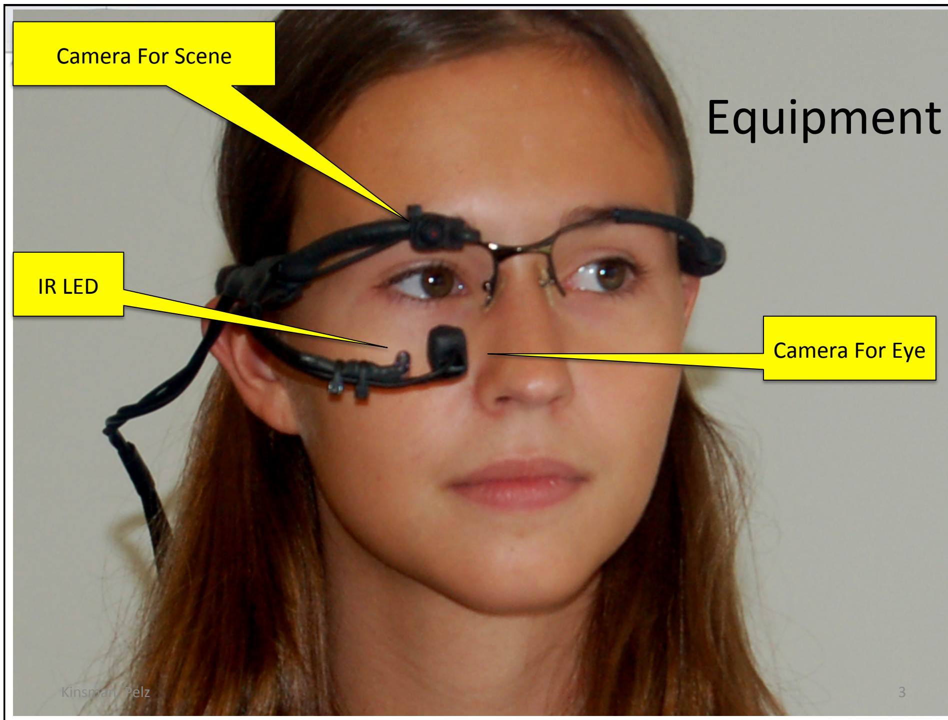


Equipment



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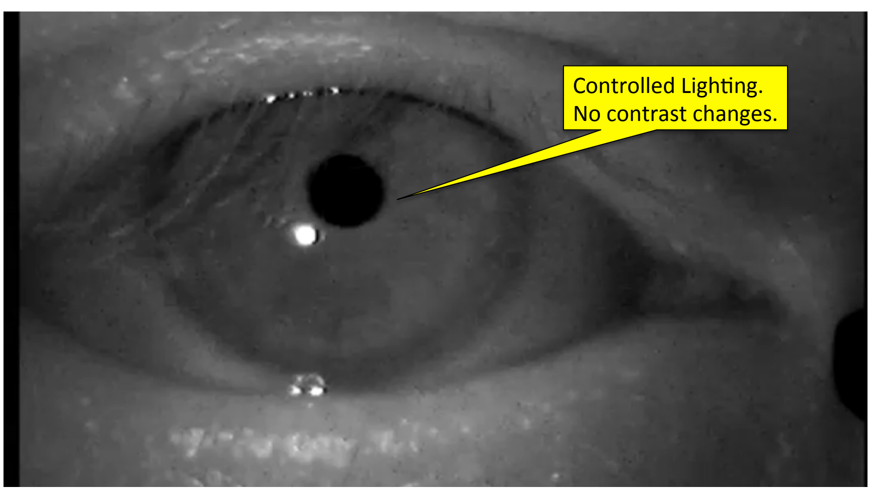
Example Eye Frame - Indoors



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Problem with Reality

- Bright sunlight
- Constricted Pupils
- Squinting
- Changing lighting
- Hair blowing in eyes
- Video processing requires manual frame-by-frame manual analysis

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The Mojave Desert

Credit: Jeff Pelz,

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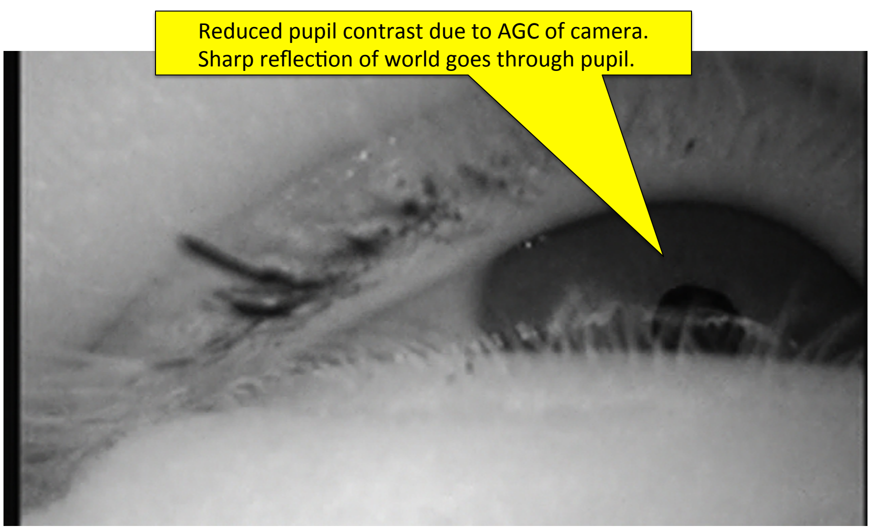
Example Eye Frame - Outdoors



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Example Eye Frame - Outdoors

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Problems:

1. Looking at the pupil through the cornea is like looking into a building though a window.
   A. At night when it is dark outside, this is easy.
   B. But, in the day, when it is bright outside, it is difficult.
2. Front surface reflections can make the center brighter than surrounding locations
3. The illumination on the iris changes considerably
4. The pupil ellipse parameters change, depending on where it is in the image

The following slides illustrate this...

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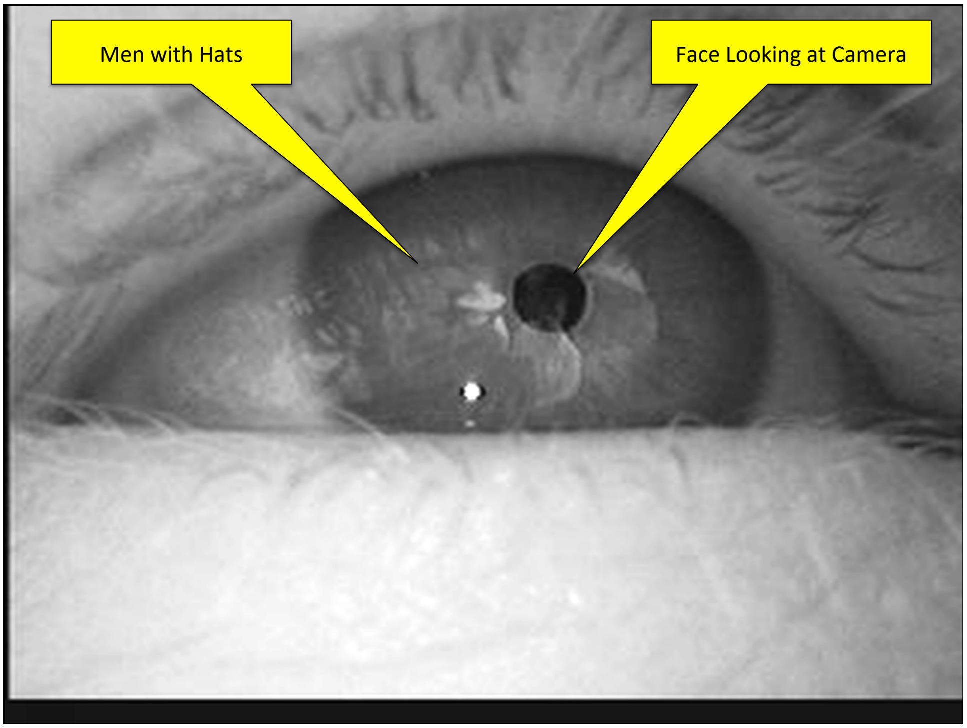
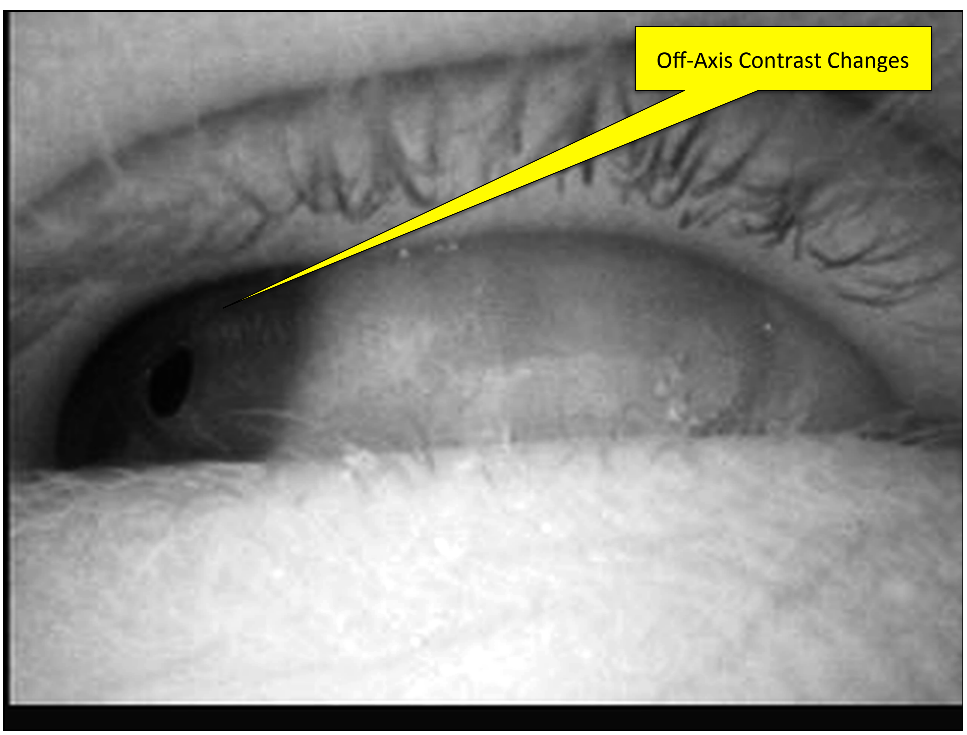
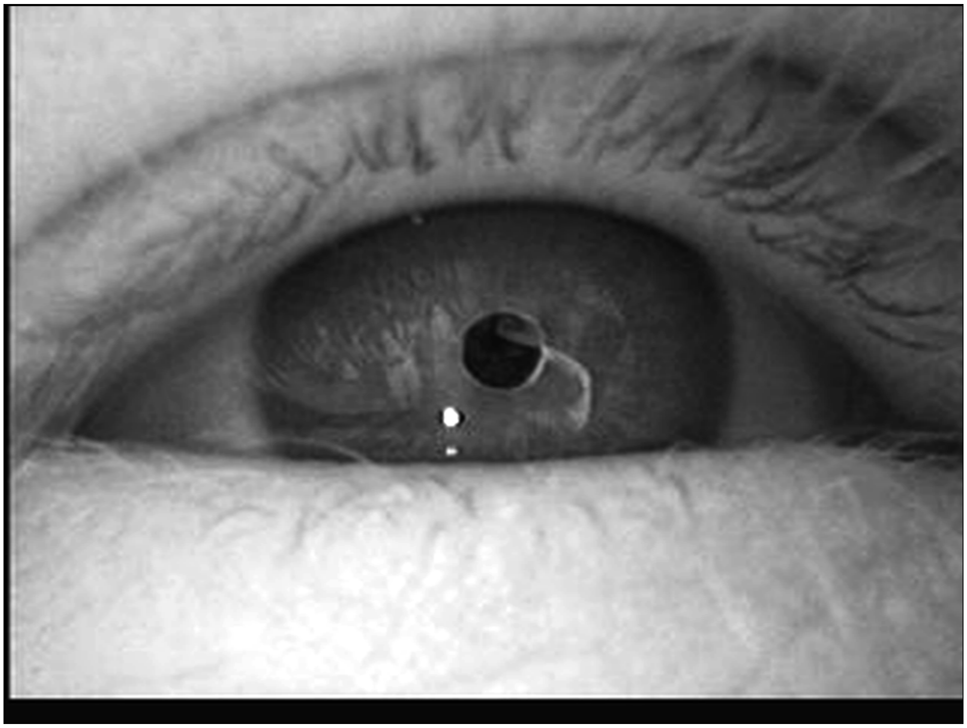
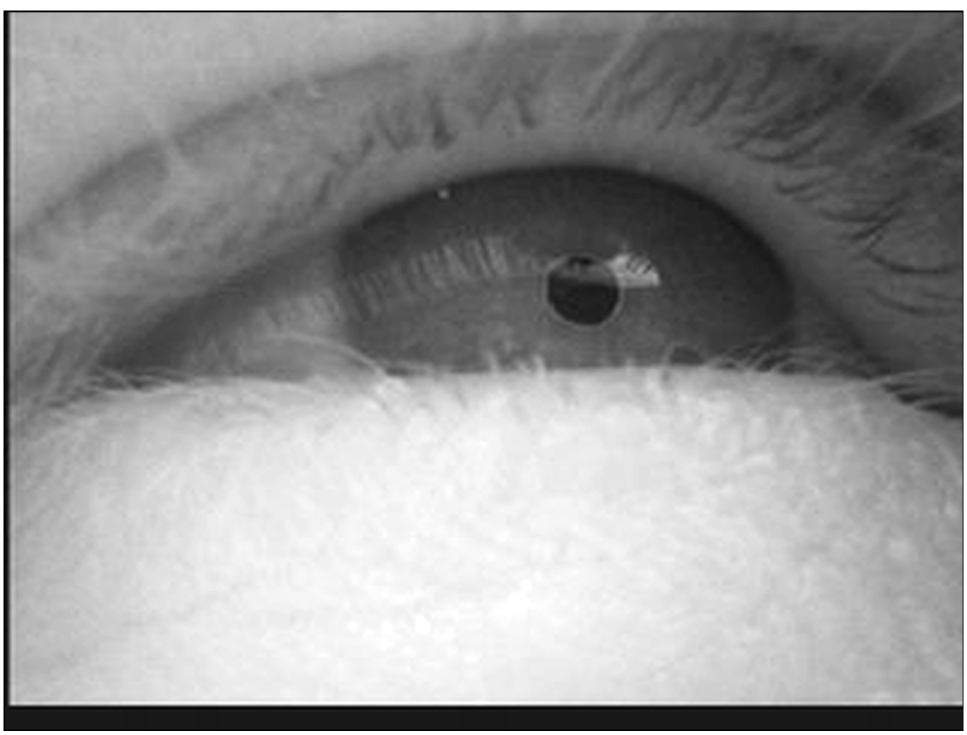
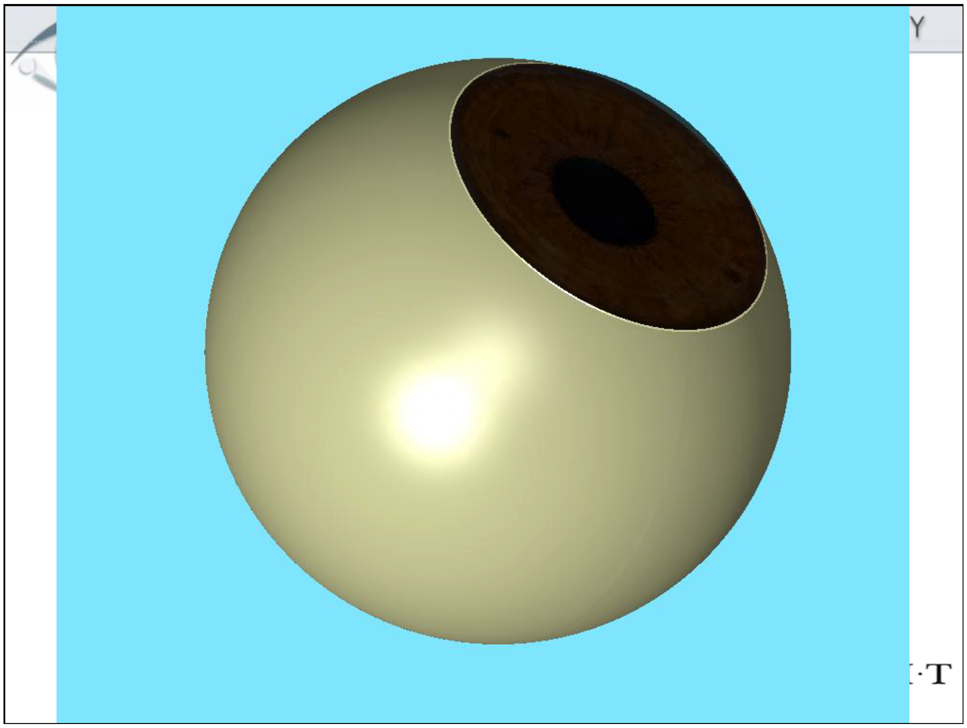
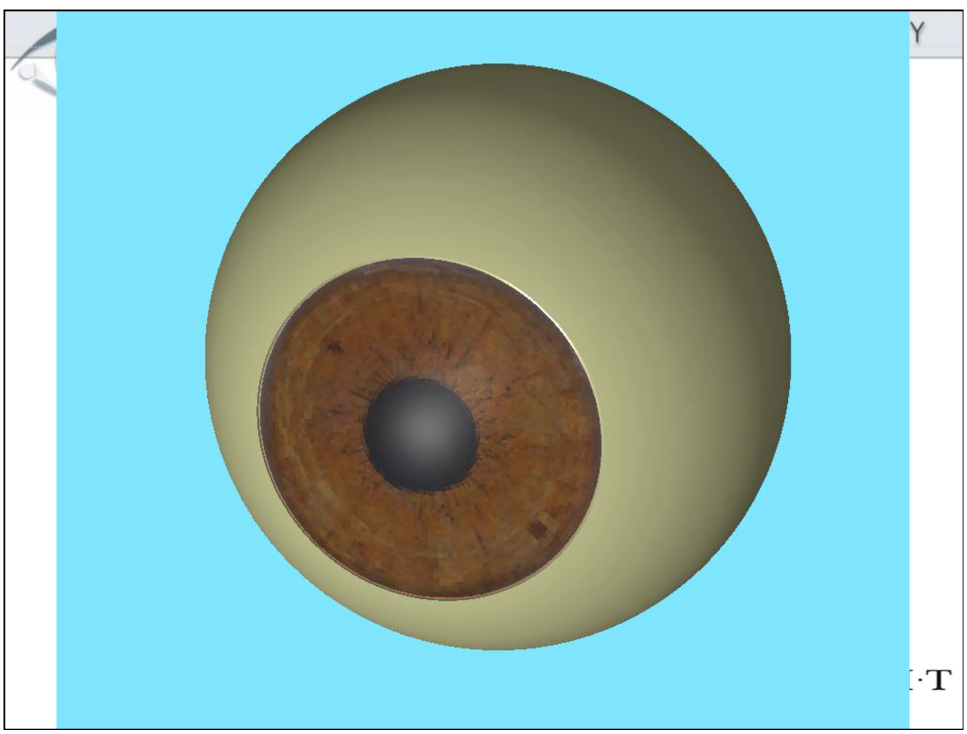

Men with Hats
Face Looking at Camera


Off-Axis Contrast Changes









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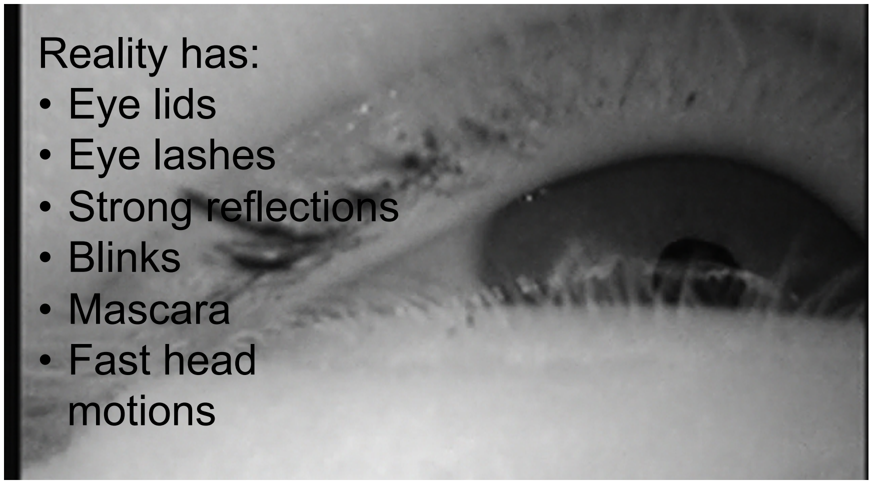
Another Reality Check



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Things that Don't Work

- Pupil is not the darkest local region
- Mean-shift
- Graph Cuts Segmentation
- Hough Circle Detector Finds:
  hairs, eyelashes, eyebrows, wrinkles...
- Starburst not tried – relies on segmentation
  - Reflections segment the pupil on the eye

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Key Insights on Pupils:

When the eye moves, the reflections do not move as fast as the pupil.

If the cornea was perfectly spherical, rotating about its center – then the reflections would not move at all.

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Solution Overview

- Have user select pupil to track
- Integrate over an annulus of temporal edges
- Break pupil into parts, and track the parts
- Compute a multi-frame motion estimation based on histograms
- Also find darkest region
- Use a decision tree
- Further stages is ellipse fitting

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First Clue: Difference Image

- Subtracting one frame from the next, gives a difference image
- Remember: eye motion does not change reflections as much as the pupil moves
- Eye motion nicely separates out pupil edges from edges of reflections

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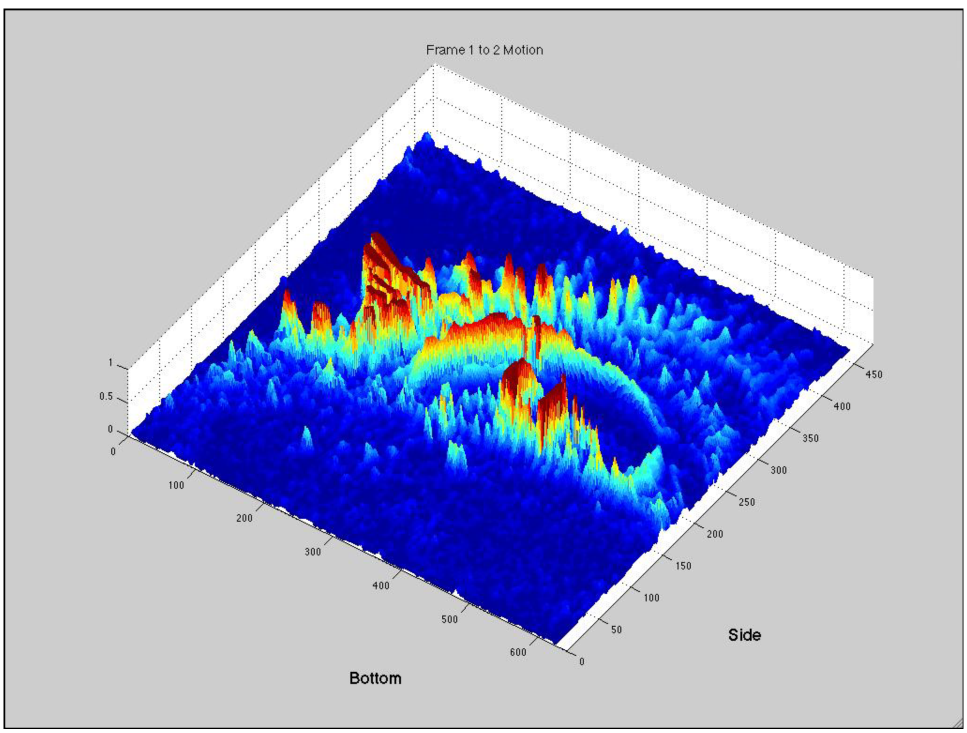

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First Clue: Difference Image

Subtracting one frame from the next,
gives a difference image

- ➢ Integrate the difference image over a circular region gives an expected object location
  - – Peak response indicates location object moved to

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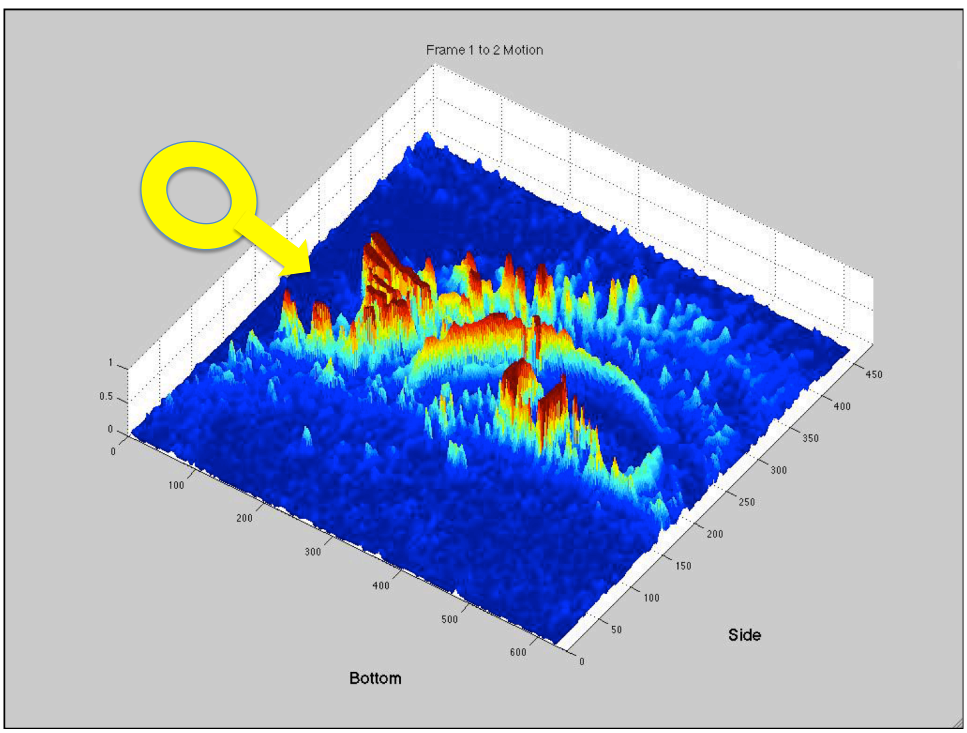

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Temporal Coherence

Does not always work if signal is small

Next Key Insight:

- Break up the pupil and track the parts.
- But need to know what the pupil looks like.

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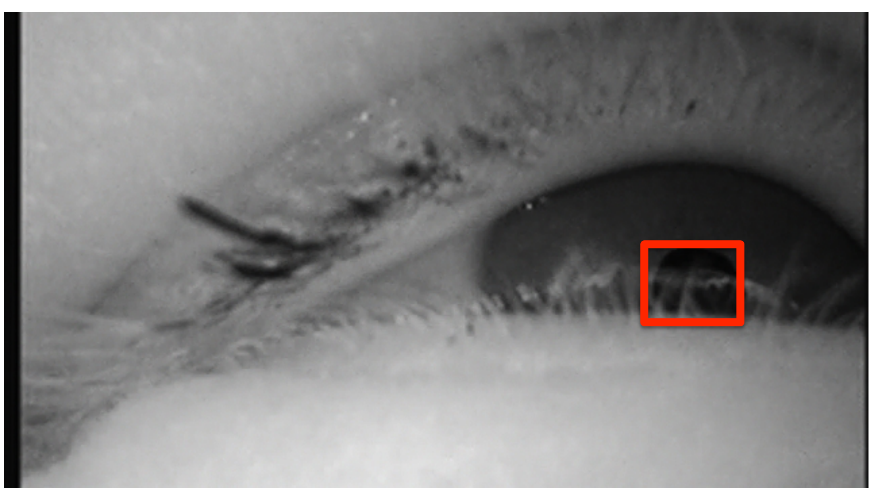
Semi-Supervised: one frame input



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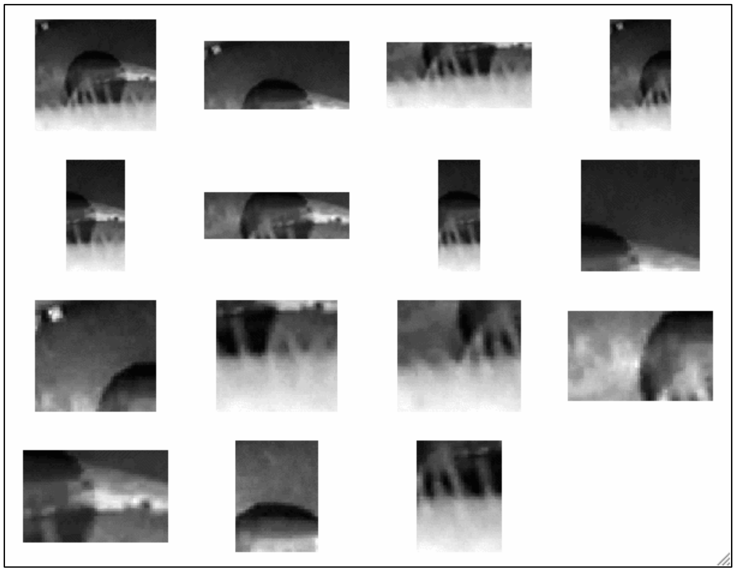
Location By Component Correlation



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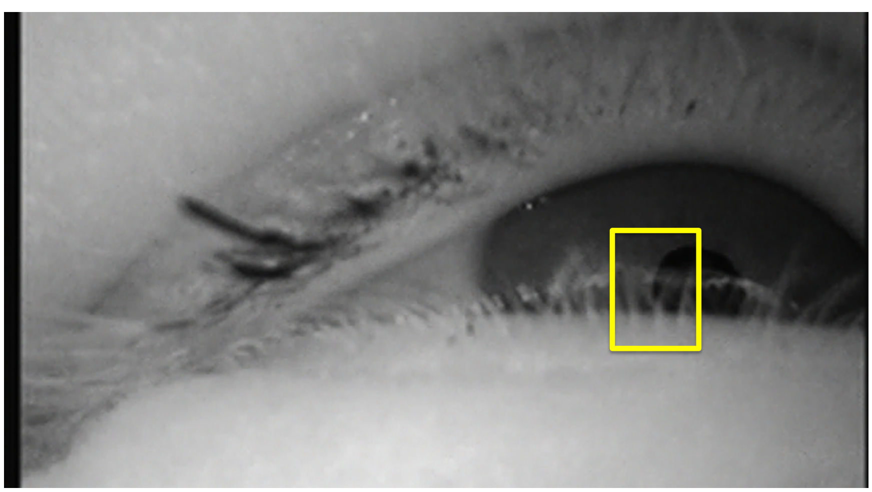
Location By Parts: Correlation



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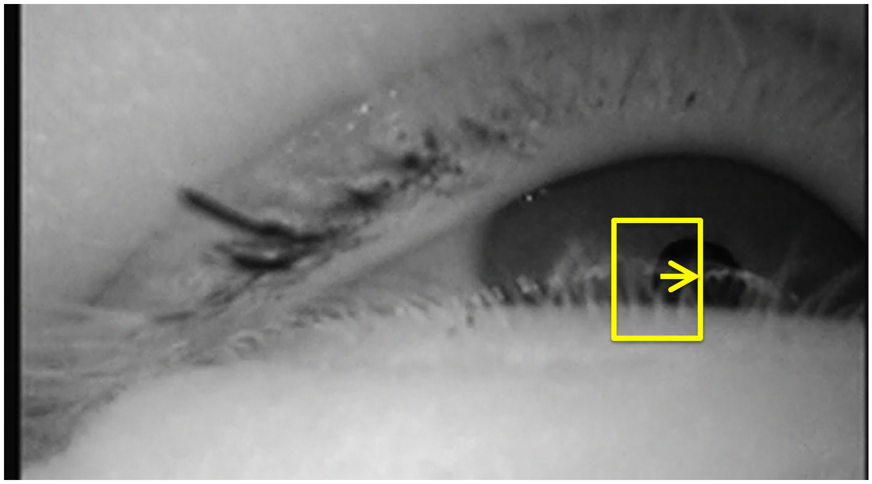
Offset Correlation



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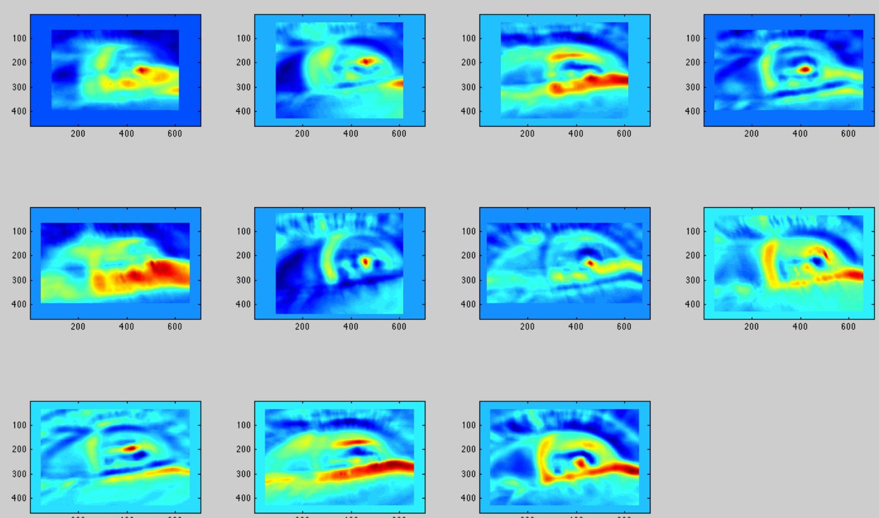

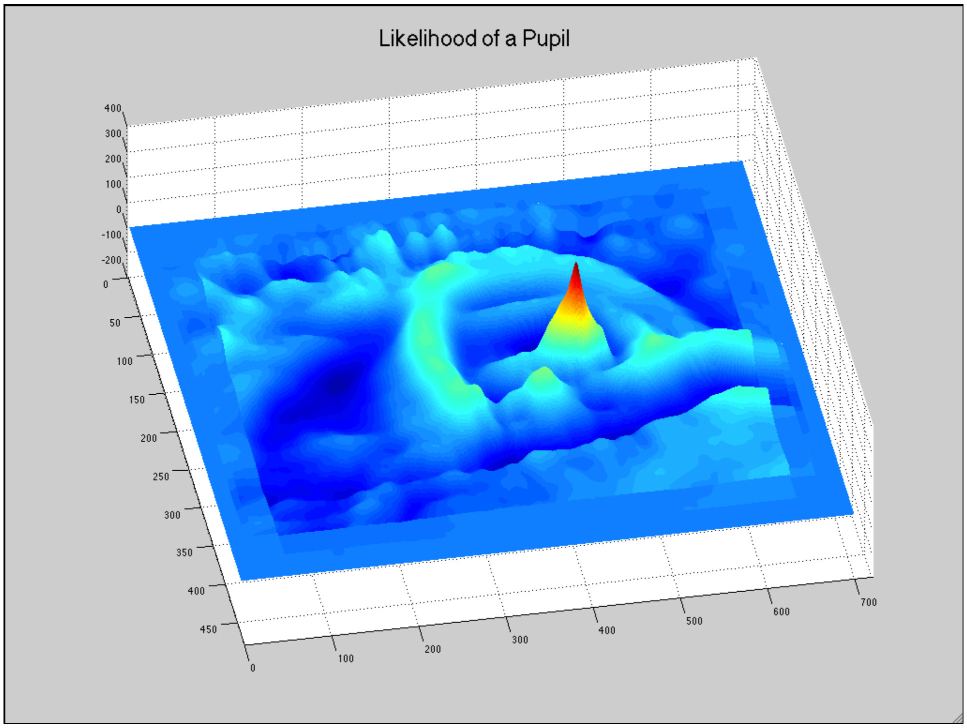

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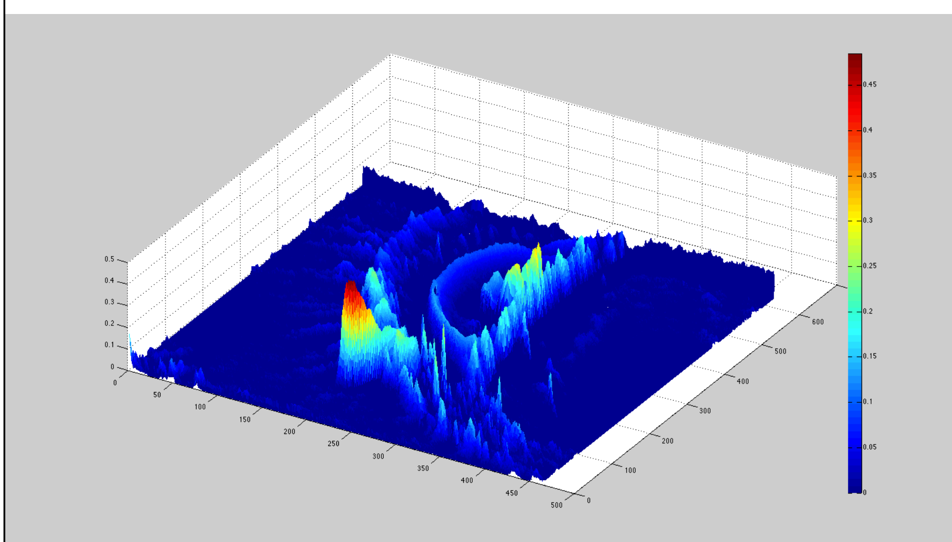
Dark Mascara



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Two Methods for Combining Sub-Model Correlations

- Each correlation computed
- Off by appropriate amount
- Weighted by its reliability
- Combined in two ways:

1. Adding ➔ logical OR
2. Multiplication ➔ logical AND

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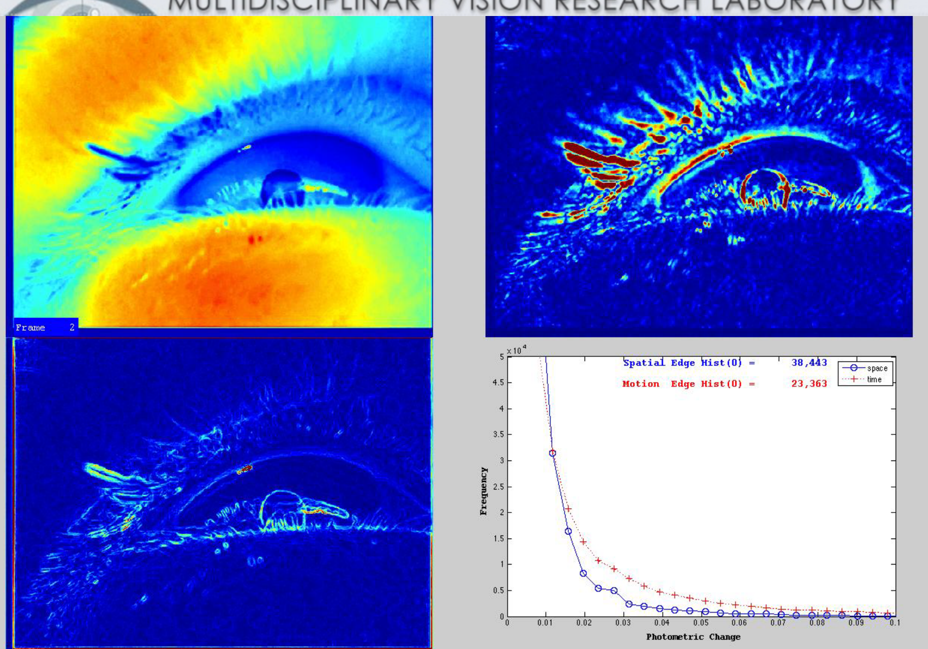

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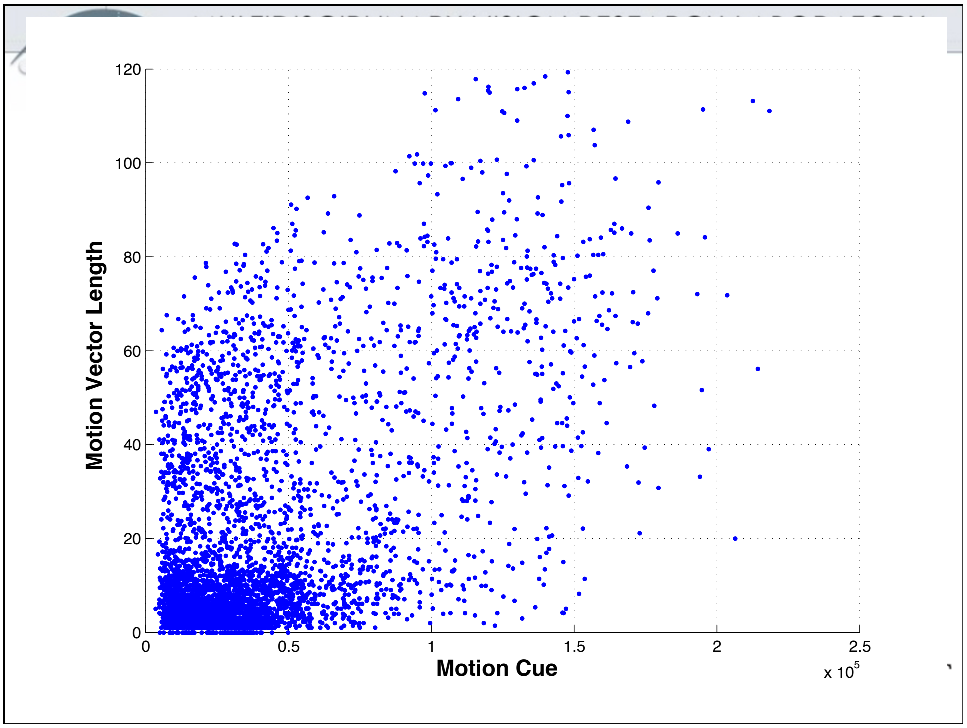
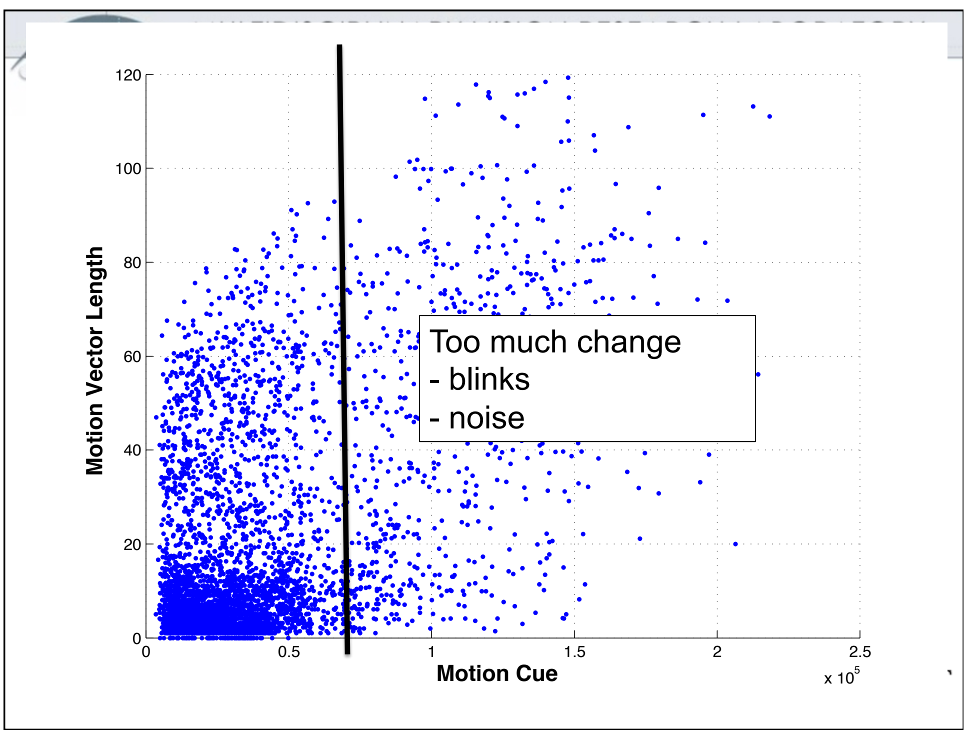
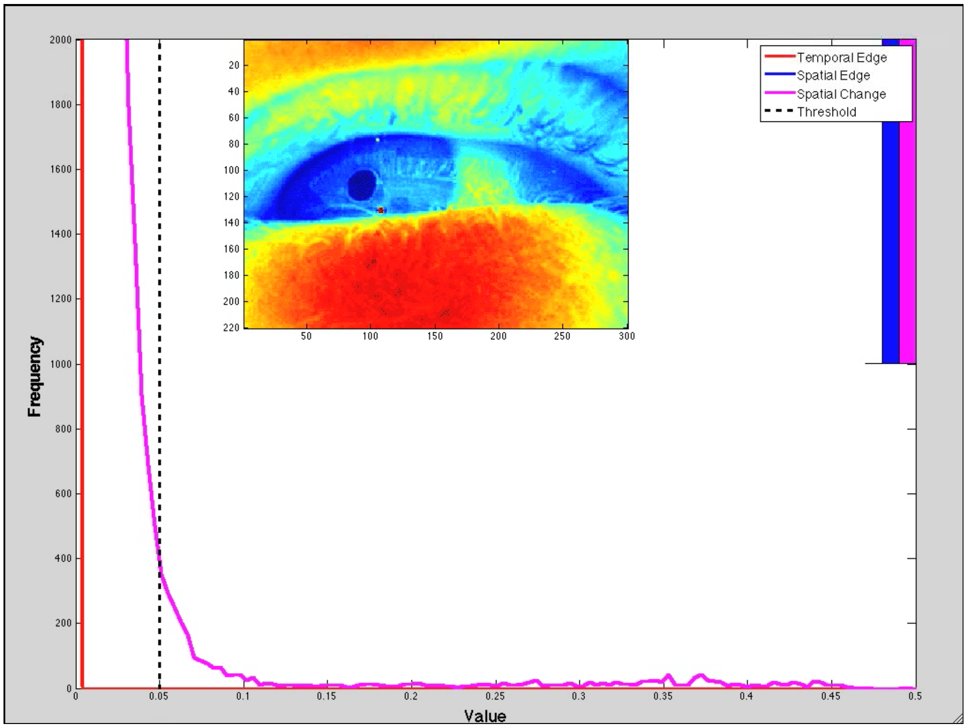

Motion Vector Length
Motion Cue
x 10^5
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5


Too much change
- blinks
- noise
Motion Vector Length
Motion Cue
x 10^5
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5



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Consensus Among Experts

- Temporal Coherence:
  - If the motion cue is small,
    use the temporal coherence
- Otherwise, use Probabilistic Coherence:
  - If the OR and AND detectors agree,
    use their average location
- Otherwise, use Energy Minimization:
  - Combine all experts

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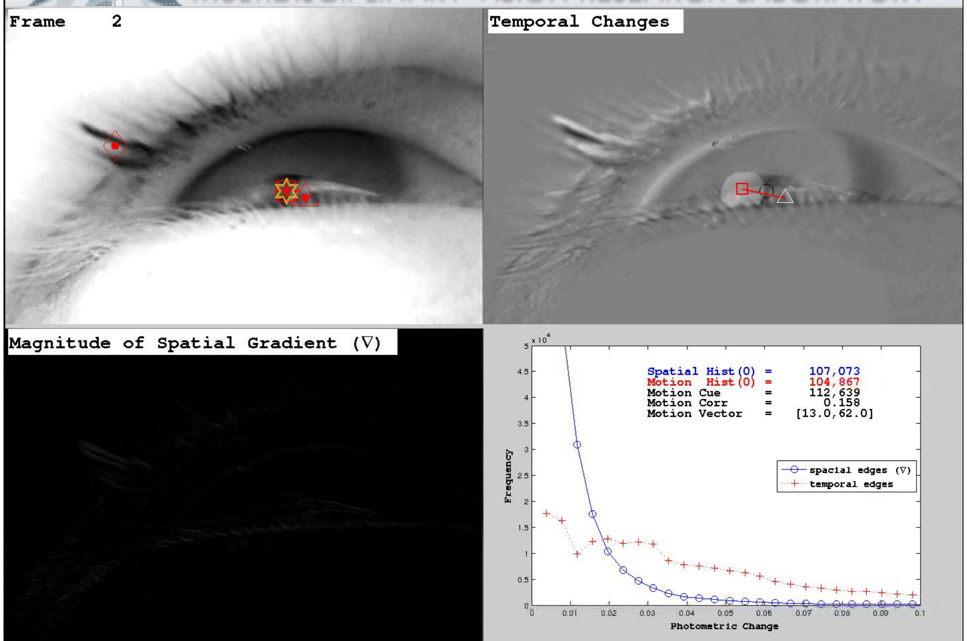

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Recommendations w/in 2 pupils:

Analyst	Don't Care	Correct	Incorrect
A	6.8%	86.4%	6.8%
B	6.7%	85.5%	7.8%
Average	6.8%	85.9%	7.3%

92 % close enough once we discount "don't care"

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Future Directions

These results leave two questions:

1. How do you detect blinks?
2. How do you improve the Hough Circle detector?

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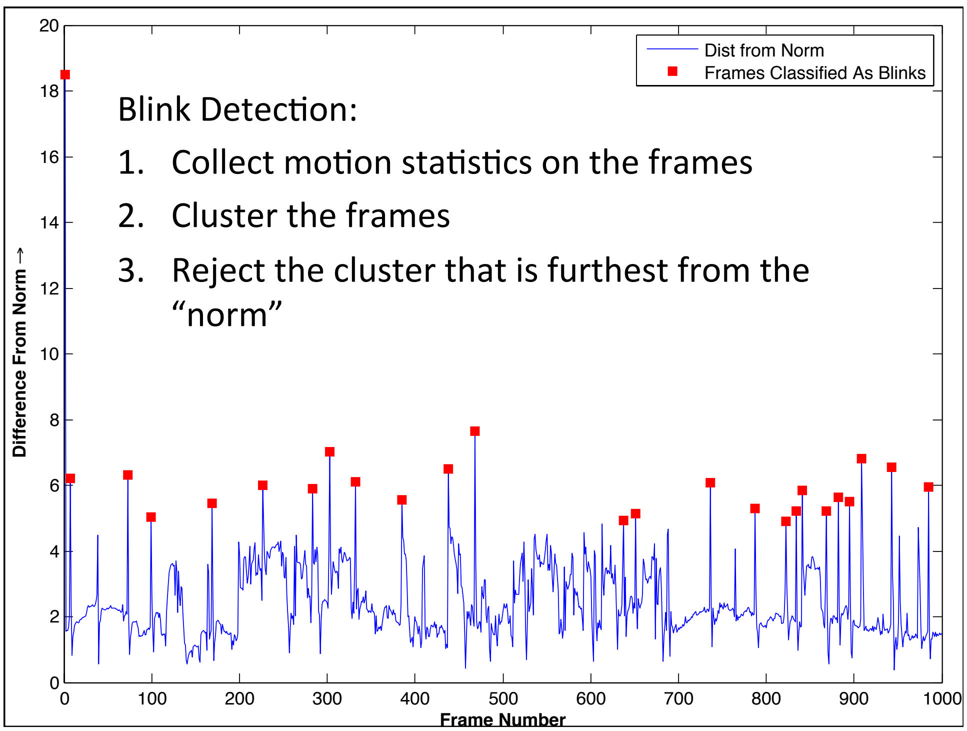
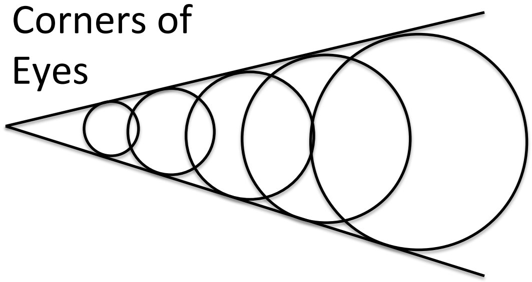
Blink Detection:

1. Collect motion statistics on the frames
2. Cluster the frames
3. Reject the cluster that is furthest from the "norm"



Hough Circle Detector Problems

1. Any detected edge votes in all directions
2. Noise votes as well as signal
3. Accumulators to accommodate any possible radius take up much memory
4. Large accumulators mean slow processing
5. Corners of Eyes



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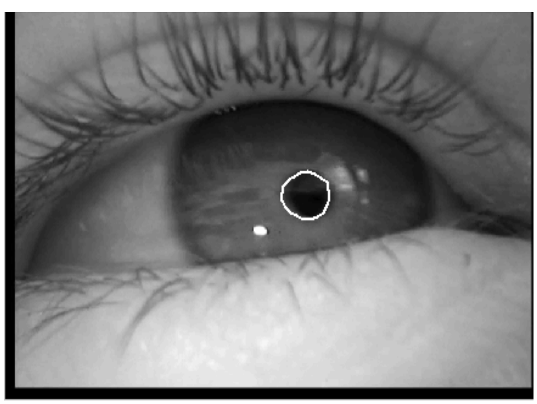
Future Directions - Contour Tracking



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Closing

- We know that given an approximate location of the pupil, an elliptic RANSAC works much faster.
- By combining spatial, temporal, and photometric cues, we are able to zero in on these approximate pupil locations.
- This is work is being integrated into a program for finding pupils in eye videos captures under difficult lighting conditions.

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Acknowledgements

We thank Valentina Staneva of Johns Hopkins University for help with segmentation.

We also thank Lech Swirski from the University of Cambridge for discussion of issues, and providing his source code for testing.

Thank you to anonymous reviewers.

Funded in part by United States NSF Grant 0909588.

Some imagery courtesy of:
- Dr. Jeff Pelz, RIT
- Lindsay Quandt, RIT

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