Eye Tracking Technology and its Application Toward Image Analysis & Synthesis

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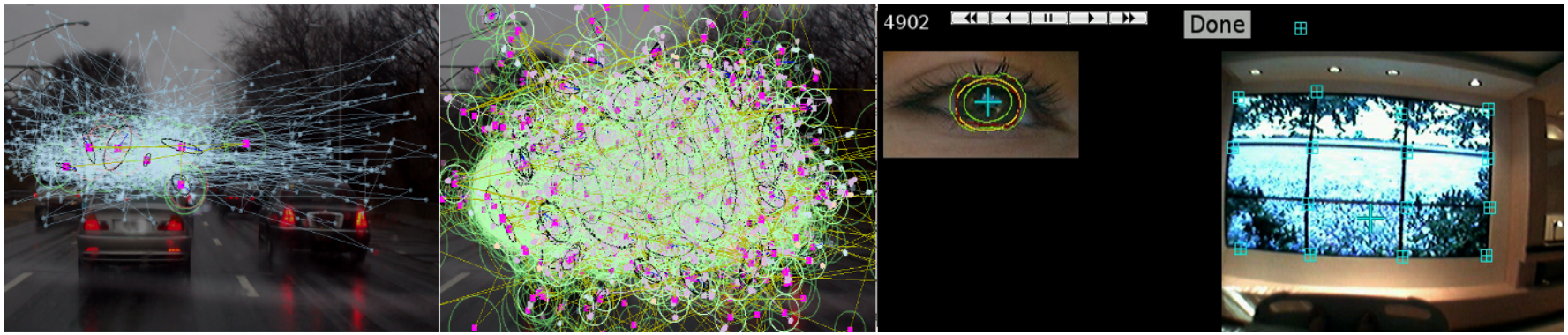


Abstract

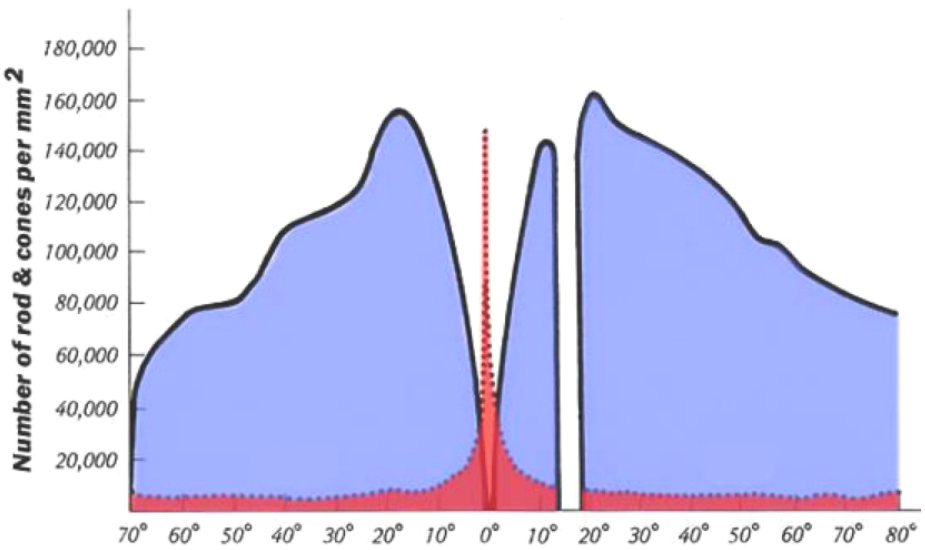
Eye movements provide a compelling record of the deployment of visual attention over imagery. Analysis and visualization of these scanpaths provides corroborative evidence of viewers' attention to direction embedded in synthesized media. Disagreement between intended foci of attention and actual fixations can guide image design, whether static or dynamic. Likewise, the comparison of automatically detected salient regions in imagery with fixated regions of interest can influence the refinement of computer vision algorithms.

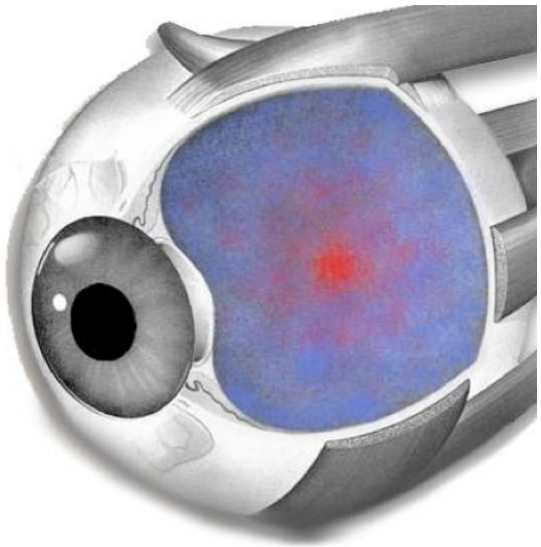
Outline:

- Overview: eye movements, technology, analysis
- Methodology: metrics, tasks, example, advanced analysis
- Couple of examples: image analysis
- Couple of examples: image synthesis

Overview: eye movements, technology, analysis

Eye Movements





Photoreceptor distribution and fovea

(from Pelz et al.'s (2005) CHI 2005 tutorial on eye tracking)

- Why do we move our eyes about?
- What is the dimension of the fovea?
- Types of eye movements?

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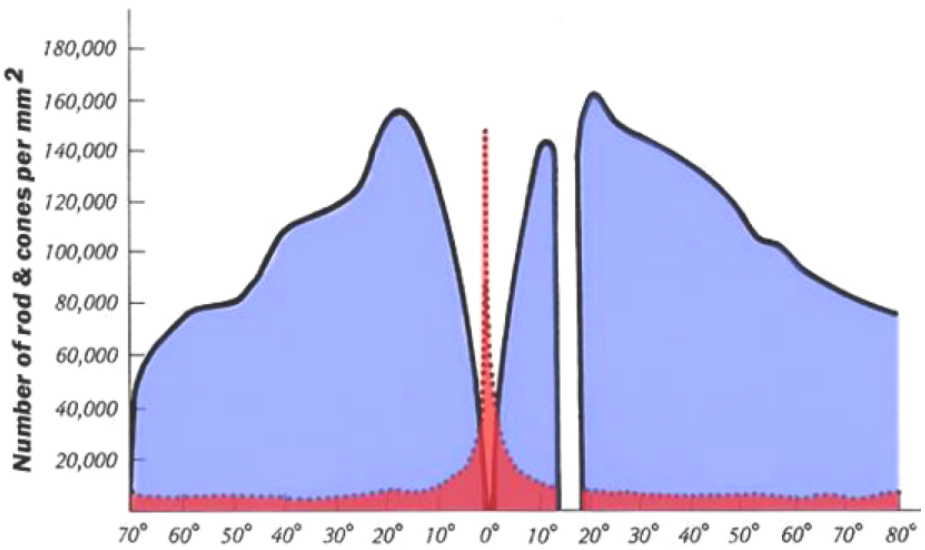

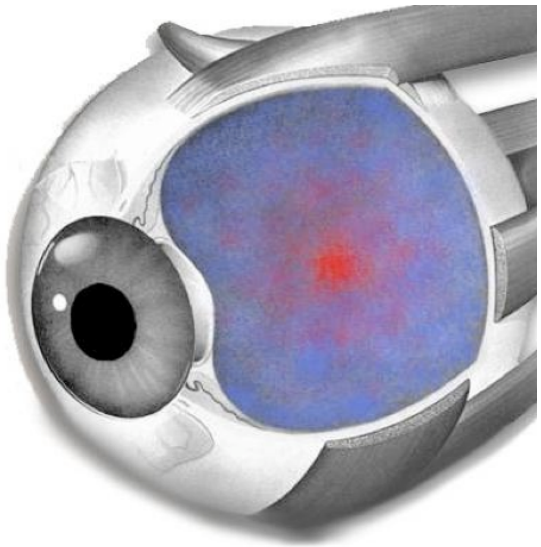

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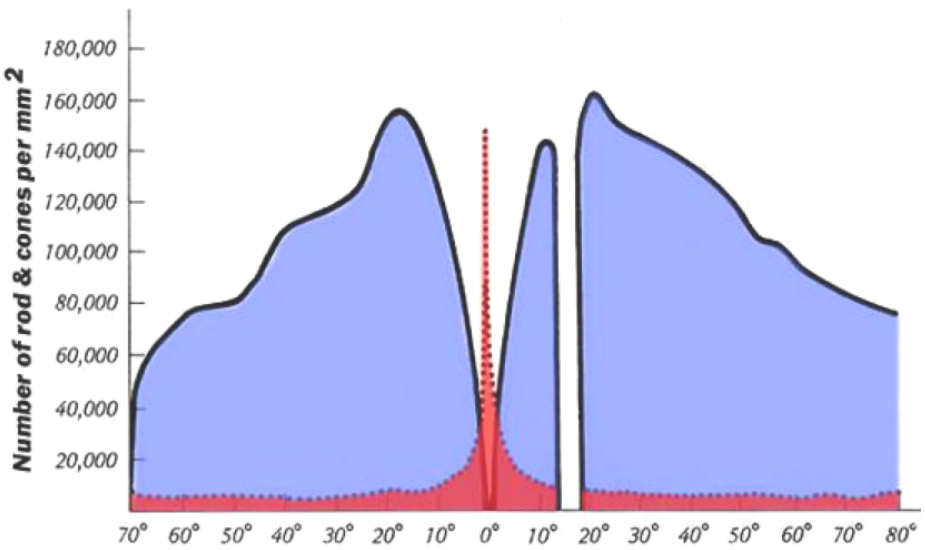

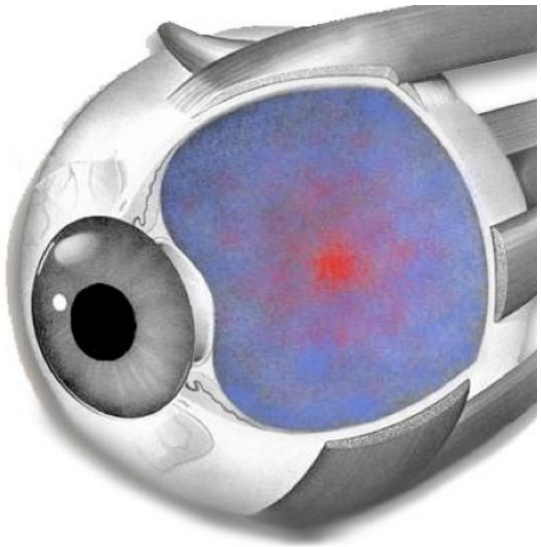

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On Wikipedia: <http://en.wikipedia.org/wiki/Eye_tracking>

- Users keep updating the Wikipedia “Eye Tracking” page.
- Hotspots represent the visual tendencies of several participants, superimposed over a magazine cover.
- Red and orange spots represent areas of high visual attention.
- Analysis of eye movements is needed to make sense of (meaningless) raw data.

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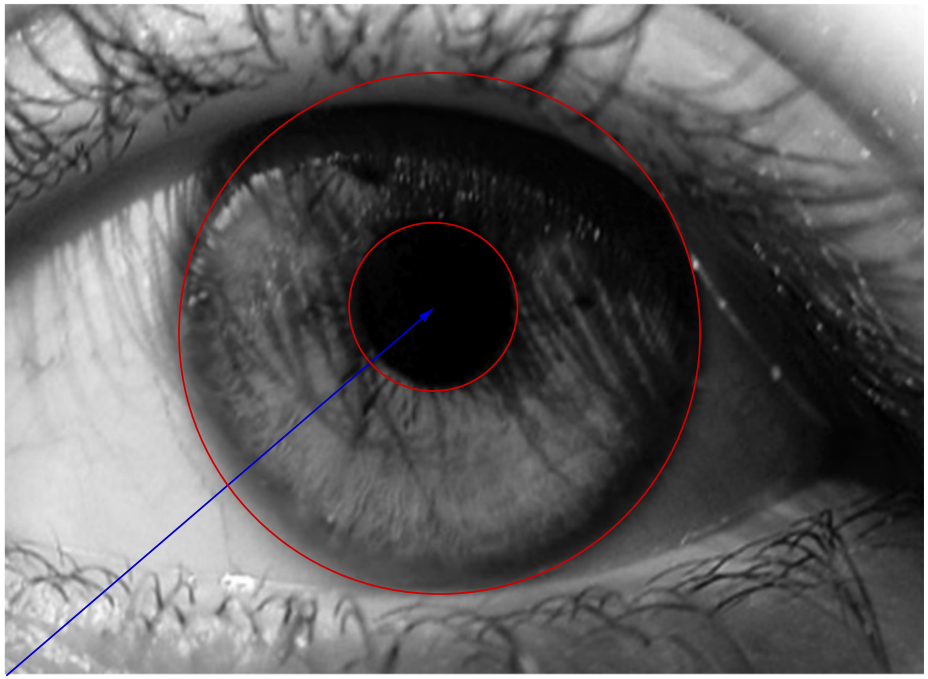

Pupil-Corneal Reflection (P-CR) approach (from Pelz et al. (2005))

- P-CR method (outgrowth of videooculography) is common.
- Need stable reference point and pupil center.
- Corneal reflection of NIR LED is often used.
- Other approach is model-based (based on Gullstrand's model).

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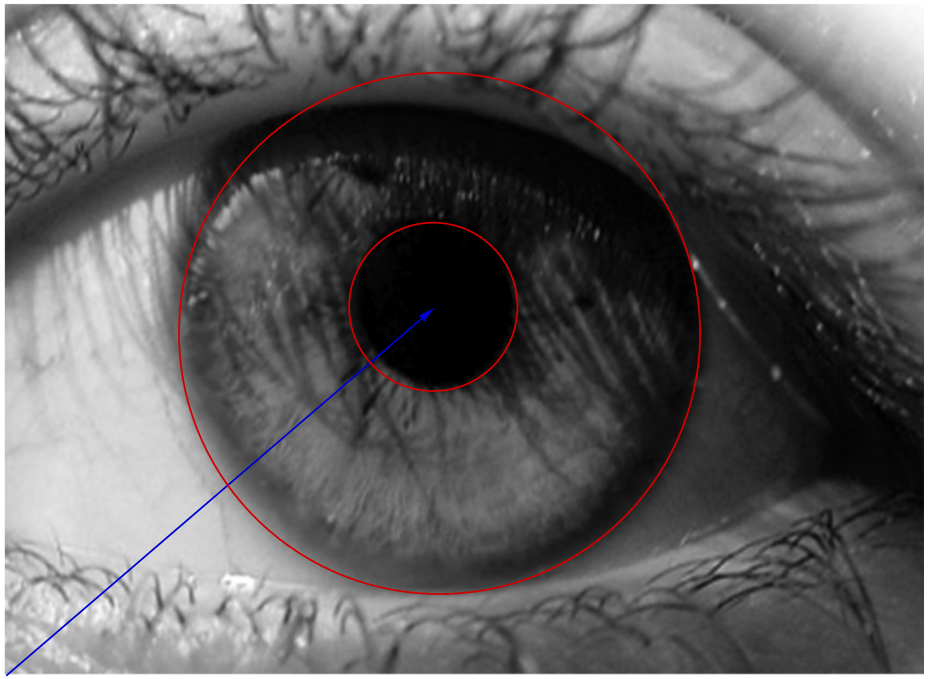

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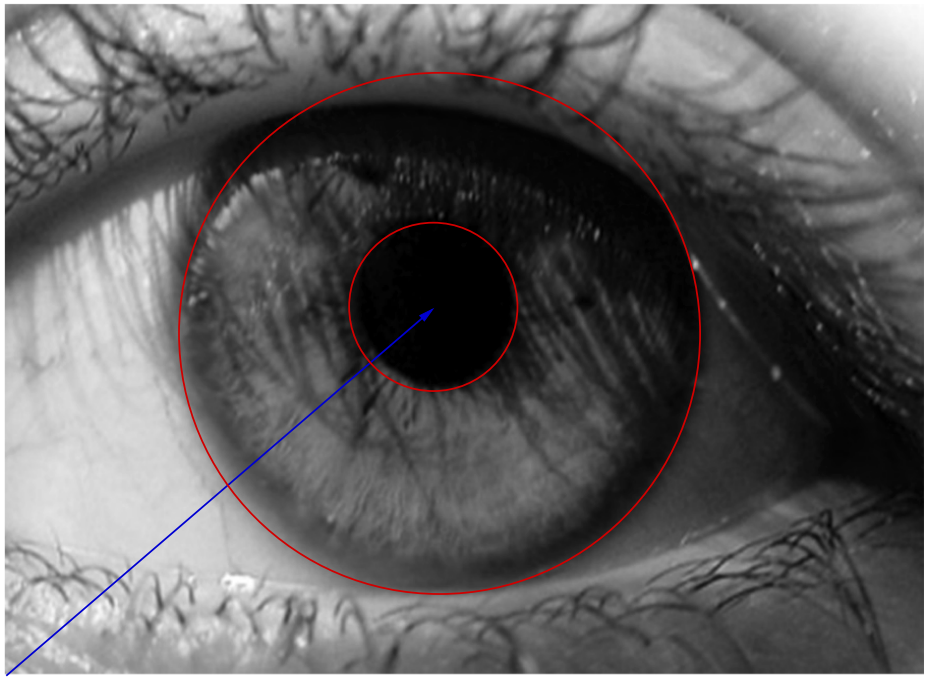

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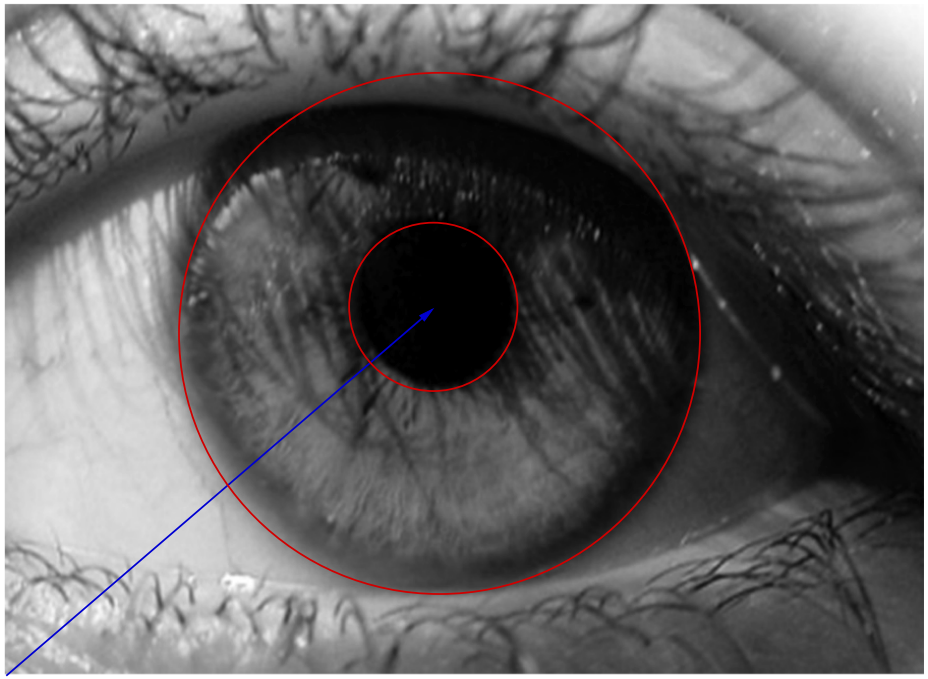

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Clemson's Eye Tracking Lab

- Three Tobii ET-1750s:
  - 50 Hz sampling rate, 1280×1024 17″ display,
  - 0.5° accuracy (about 10×10 pixels @ 50 cm).
  - 30 × 15 × 20 cm head movement volume.
- One ISCAN.
- Home-grown wearable.

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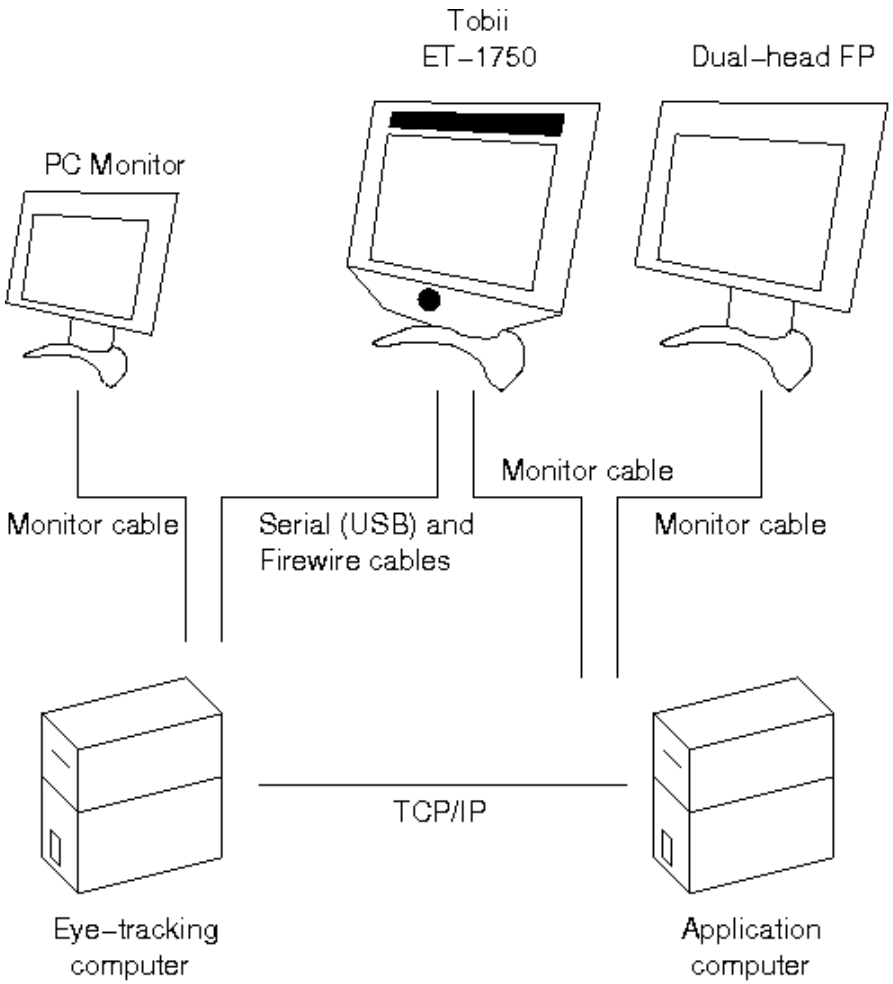
Tobii Eye Tracking Workstation



Infrastructure Specs

- Older technology is, by today's standards, truly cumbersome.
- Current eye tracking stations consist of:
  1. Sun W2100z server running Windows XP (dual 2.0 GHz AMD Opteron 246 CPUs, 2GB RAM),
  2. Sun Ultra 20 client running Linux (2.2 GHz AMD Opteron 148 CPU, 1GB RAM, NVidia GeForce 7800 GTX).
- All machines are connected to 1Gb/s Ethernet subnet.
- Tobii's SDK and TCP/IP client/server model makes Linux development much simpler than before.
- Example Linux C/C++ software available at `<http://andrewd.ces.clemson.edu/tobii>`.

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Data Formats

- Basic data tuple is (raw) gaze point: (x, y, t).
- Goal is to identify fixations (just boolean label).
- Most commercial software can output both raw and analyzed data.
- One has to be careful about what algorithm is used for analysis.
- For example, Tobii's ClearView software exports these data files:

`AOI`	fixation duration in AOIs
`AOIL`	list of AOIs
`CMD`	combined data (gaze point, fixation, camera)
`EFD`	gaze data (raw data)
`EVD`	event data (mouse clicks, image index)
`FXD`	fixation data (incl. duration)
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Example EFD Data File

```
Data properties:

Recording date:  11/13/2008
Recording time :  15:36:06:000 (corresponds to time 0)
Study:  physics
Subject:  S01
Recording:  R01
Screen resolution:  1280 x 1024
Coordinate unit:  Pixels

Timestamp Found GazepointX GazepointY

11 None -1280 -1024
31 None -1280 -1024
51 Both 766 371
71 Both 760 385
91 Both 751 352

...
```

Eye Movement Analysis

- Basic approaches to fixation identification:
  - position-variance,
  - velocity-based,
  - Hidden Markov Models (HMMs).
- Position-variance assumes radius and no. of samples (e.g., 30 pixels, 5 samples [@ 20 ms = 100 ms]).
- Velocity-based assumes speed threshold (e.g., saccade $>$ 150 deg/s).
- HMMs—I've no idea how this works (state-based?).
- Whatever is used, one must report specific parameters used.
- `C++` example from LC Technologies on my course web page: `<http://andrewd.ces.clemson.edu/courses/cpsc412/>`.

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Methodology: metrics, tasks, example, advanced analysis

Methodology

- Given goals of eye movement collection and analysis, what next?
- Need to set up basic empirical methodology.
- Want quantitative comparison of gaze data *process metrics*:
  - number of fixations,
  - fixation durations (ms),
  - saccade amplitude (deg),
  - see also Goldberg and Kotval (1999) and Jacob and Karn (2003).
- Gaze data supports and corroborates *performance metrics*:
  - reaction time (speed),
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- Can combine with subjective evaluation as well (questionnaires).

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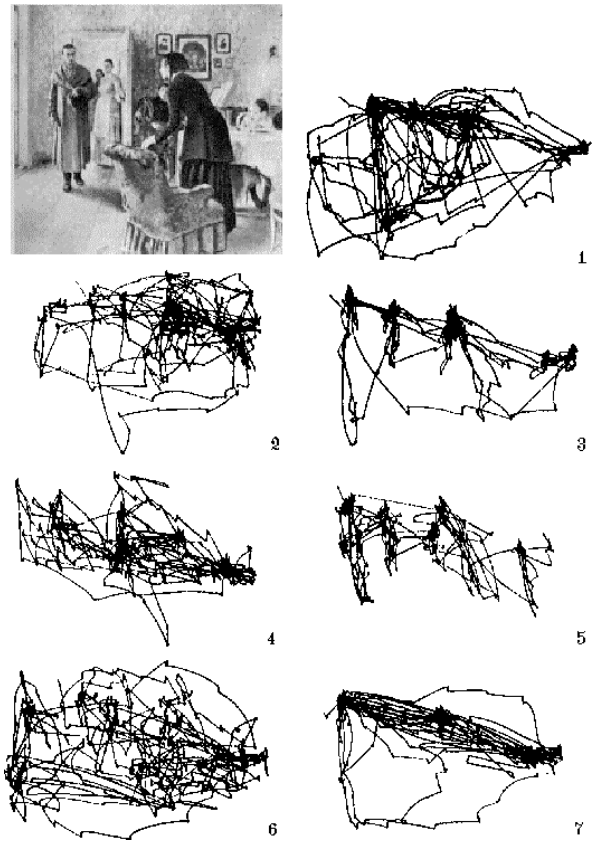

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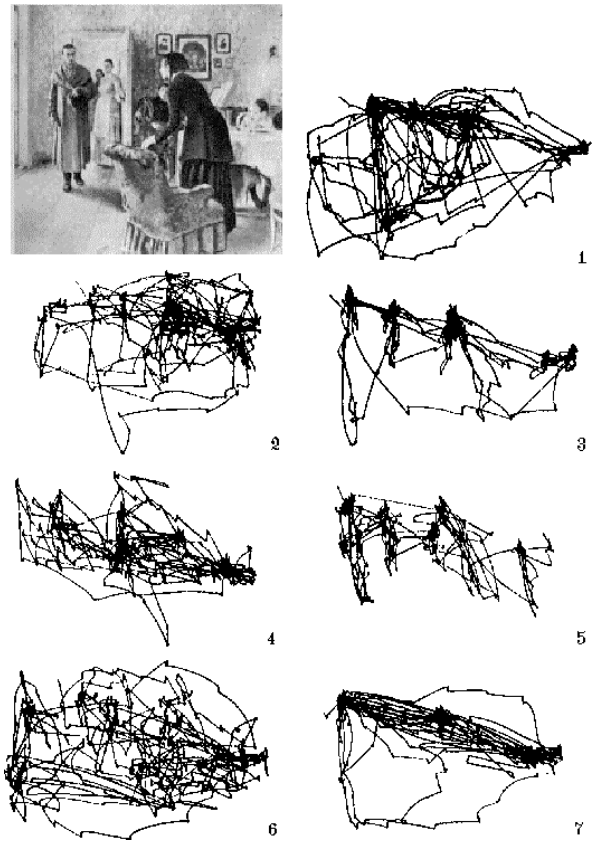

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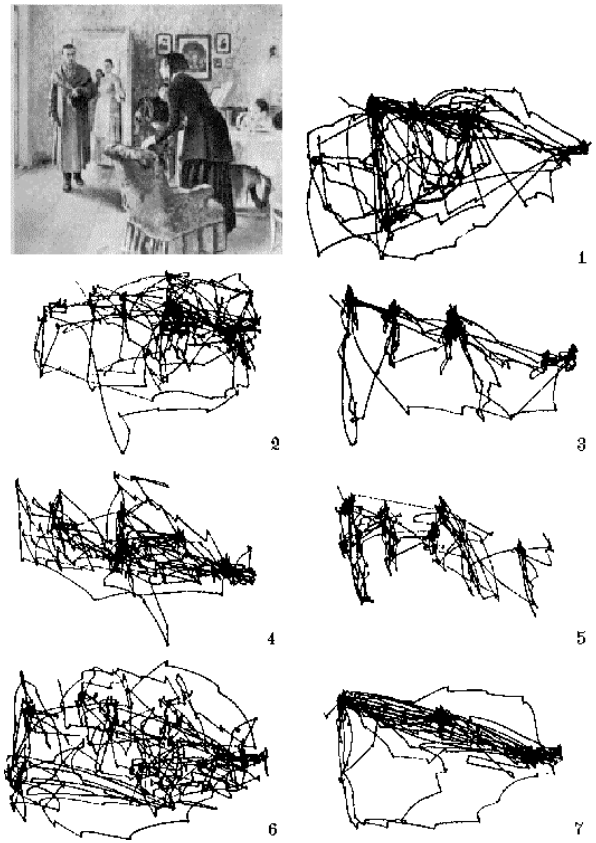

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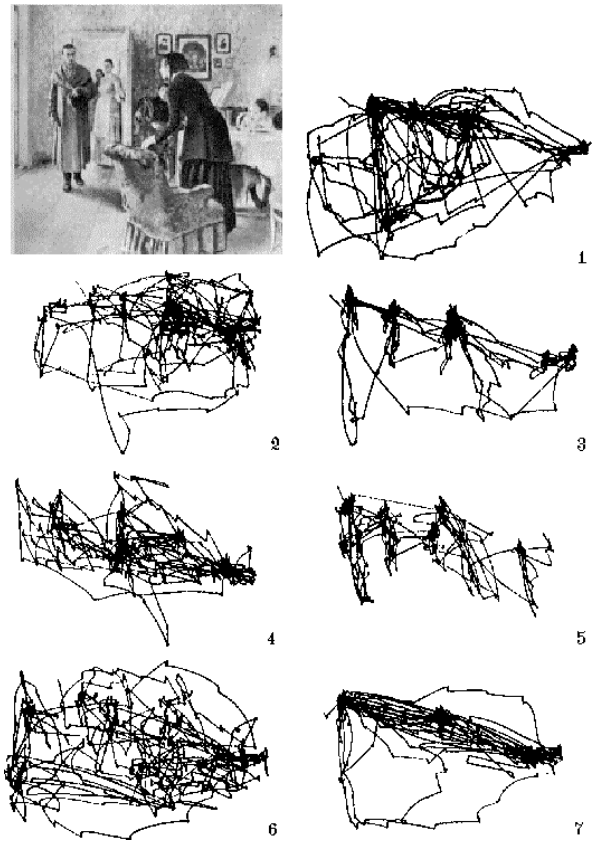

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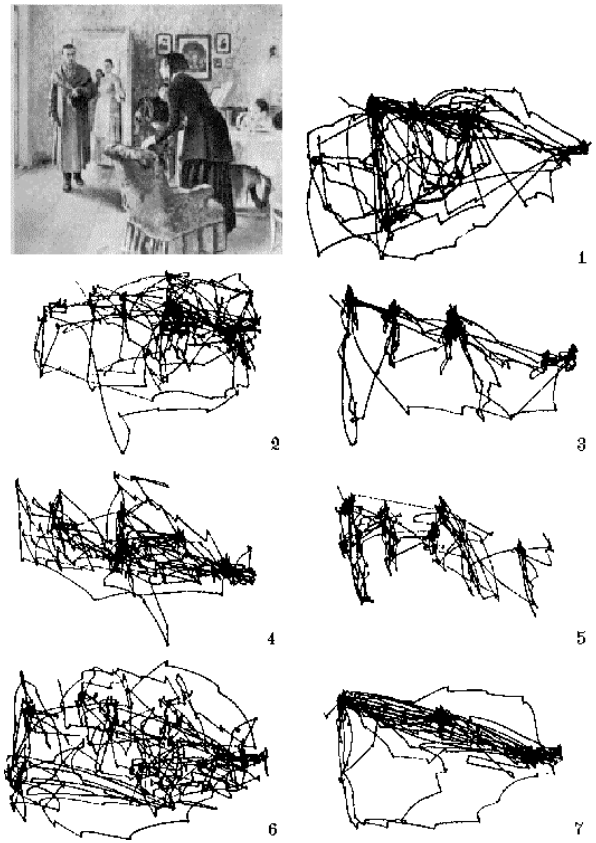

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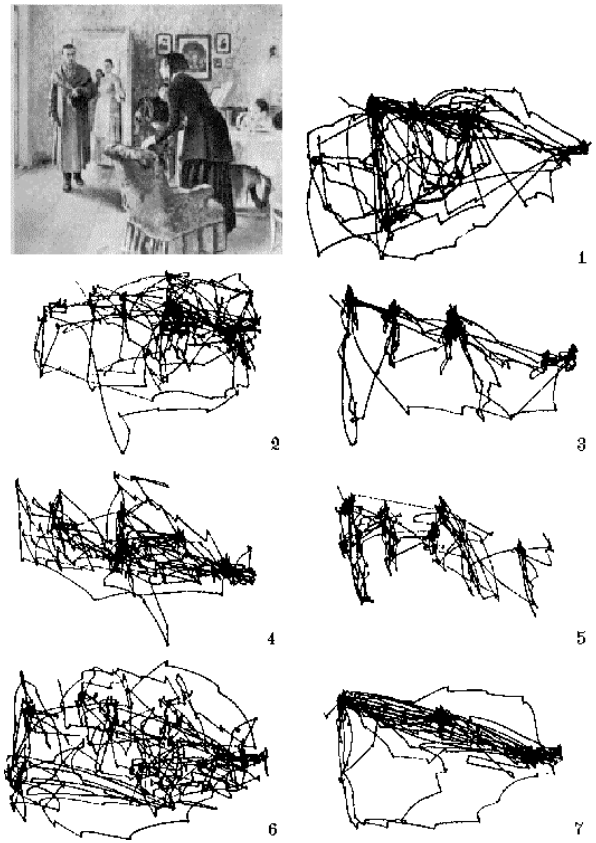
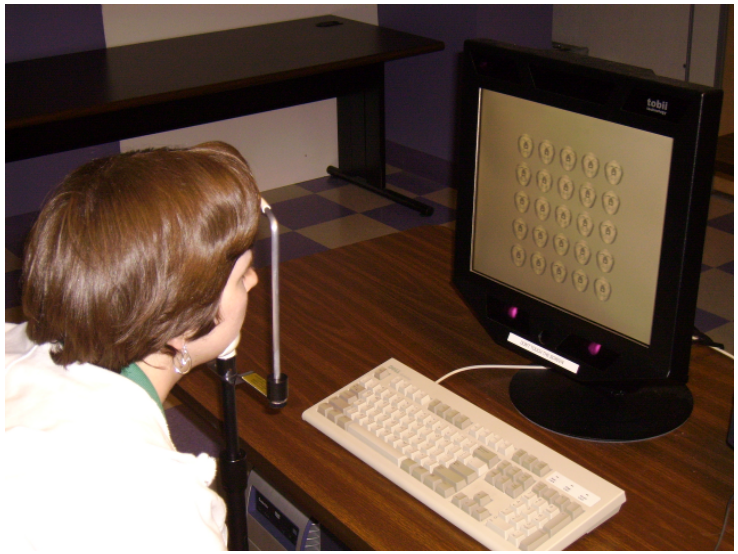
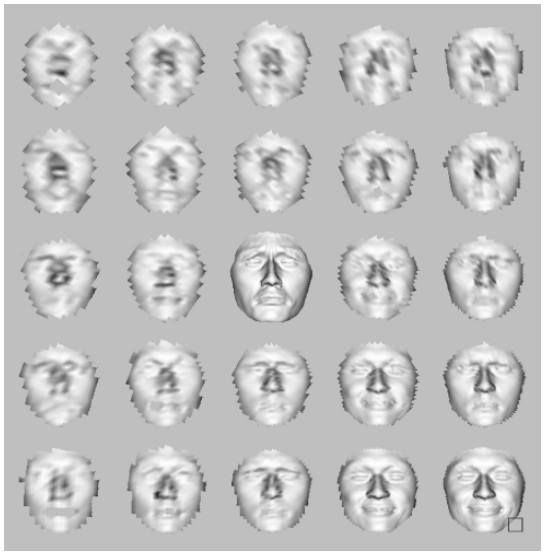
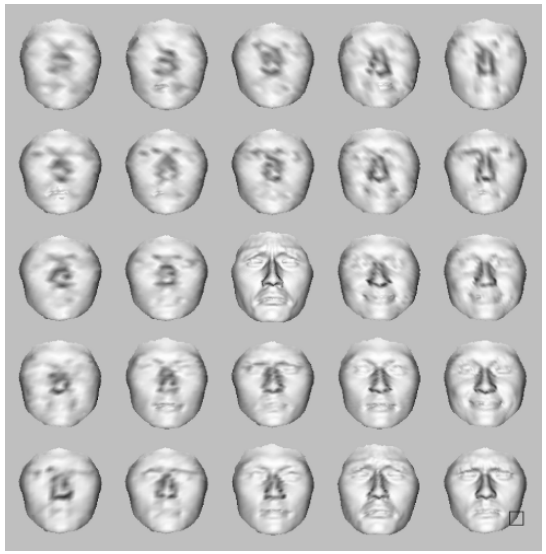


Example Study: Gaze-Contingent Window

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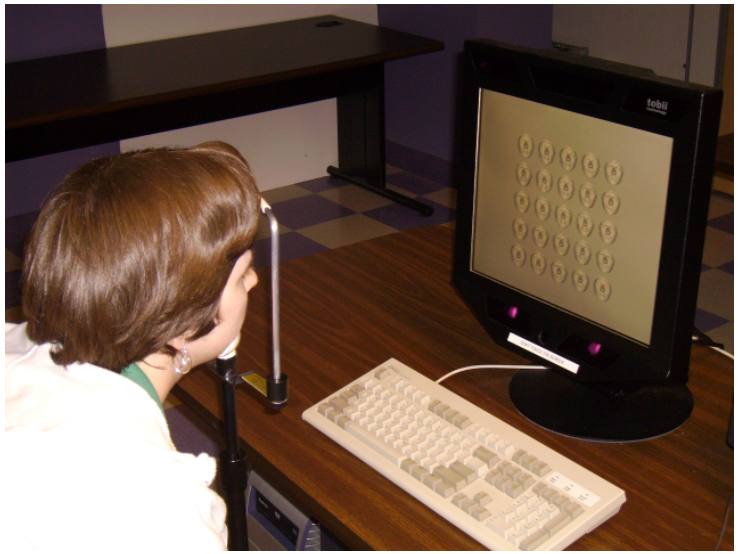
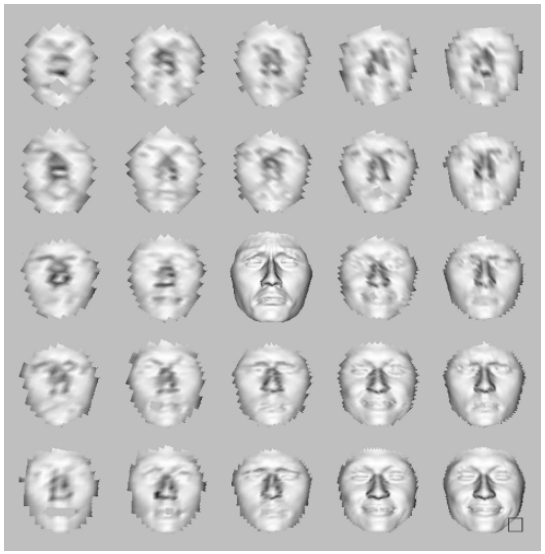
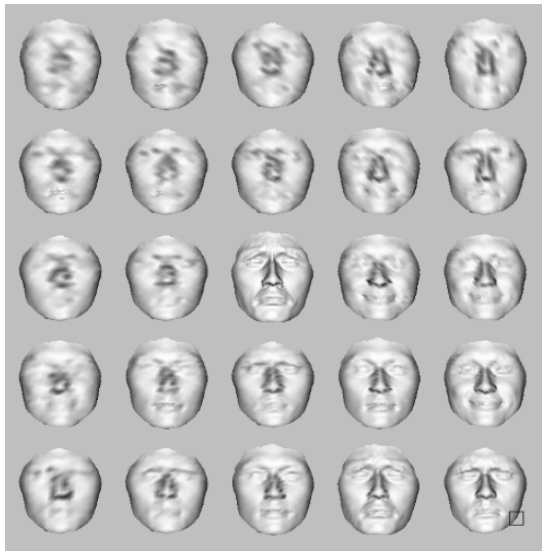

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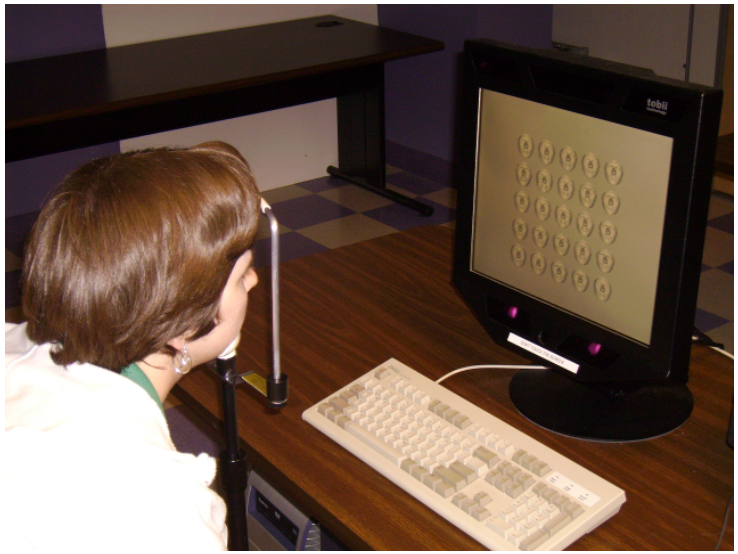
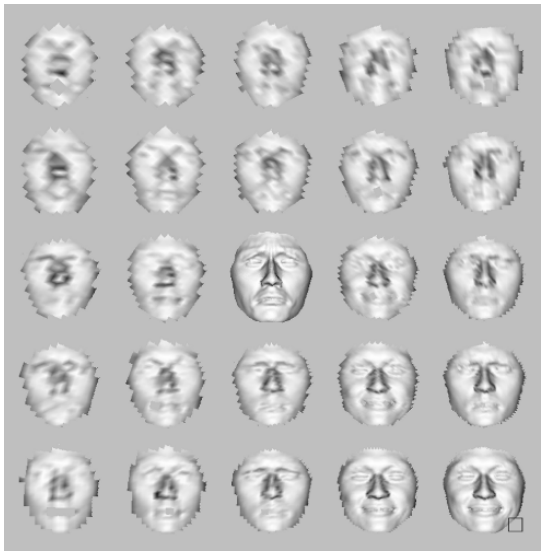
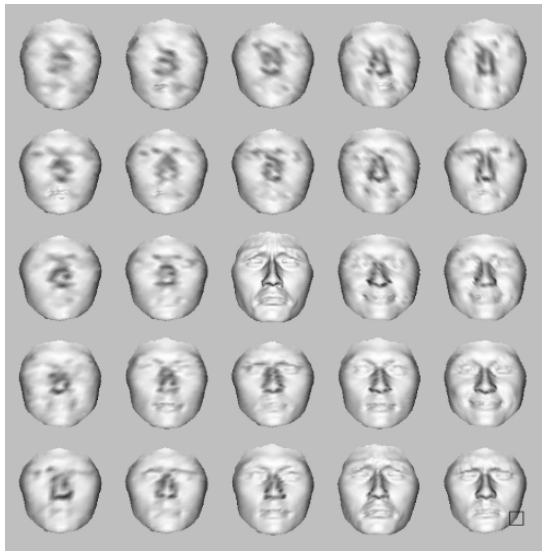

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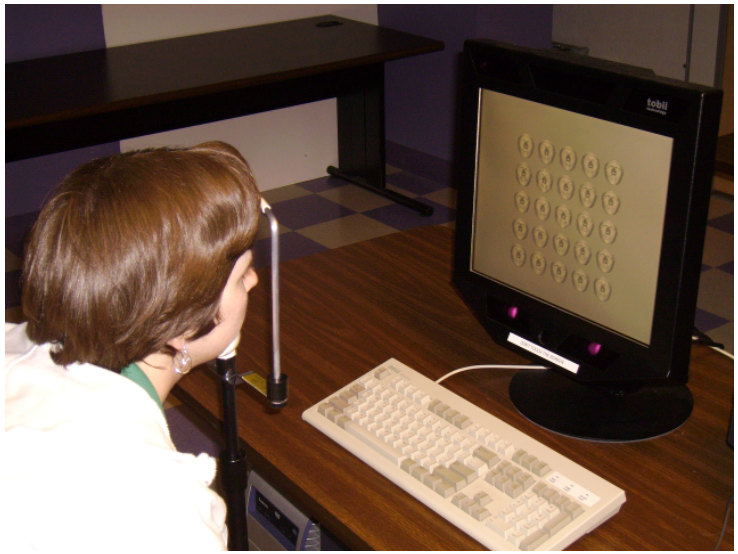
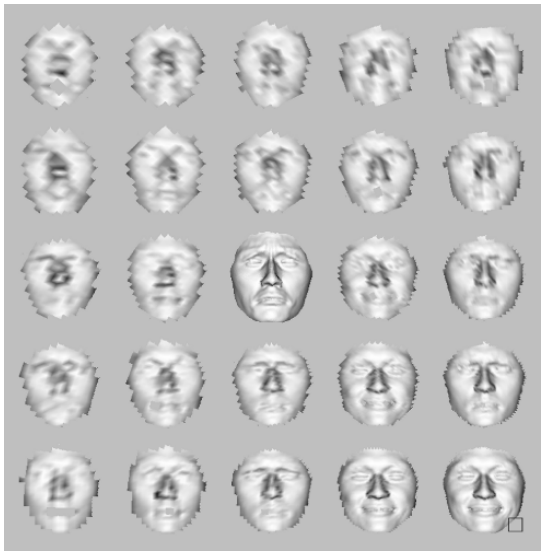
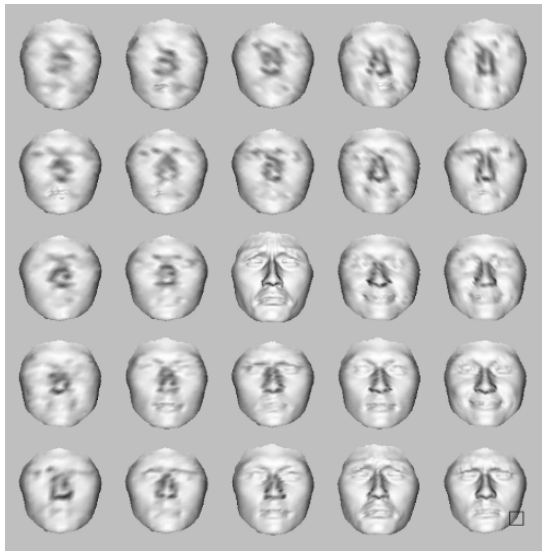

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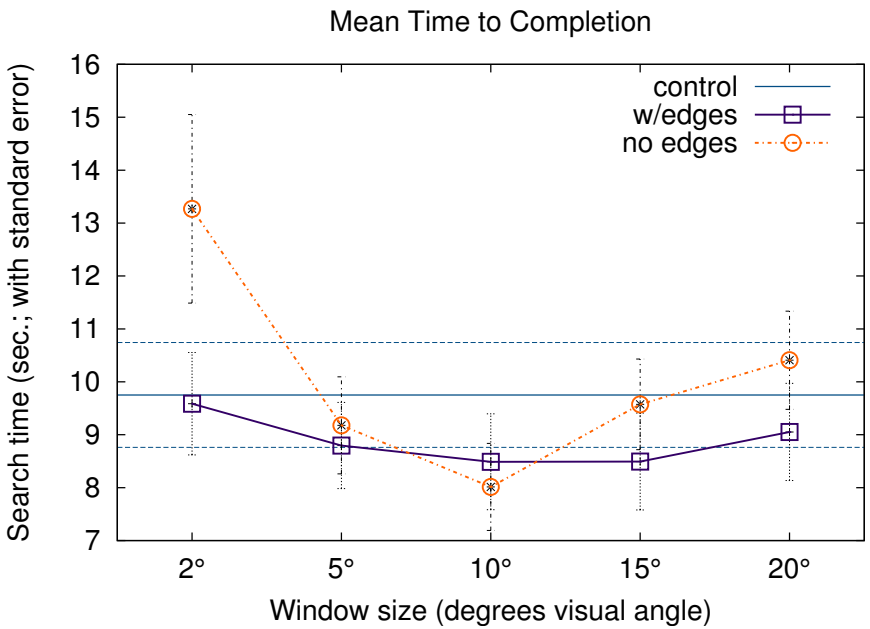

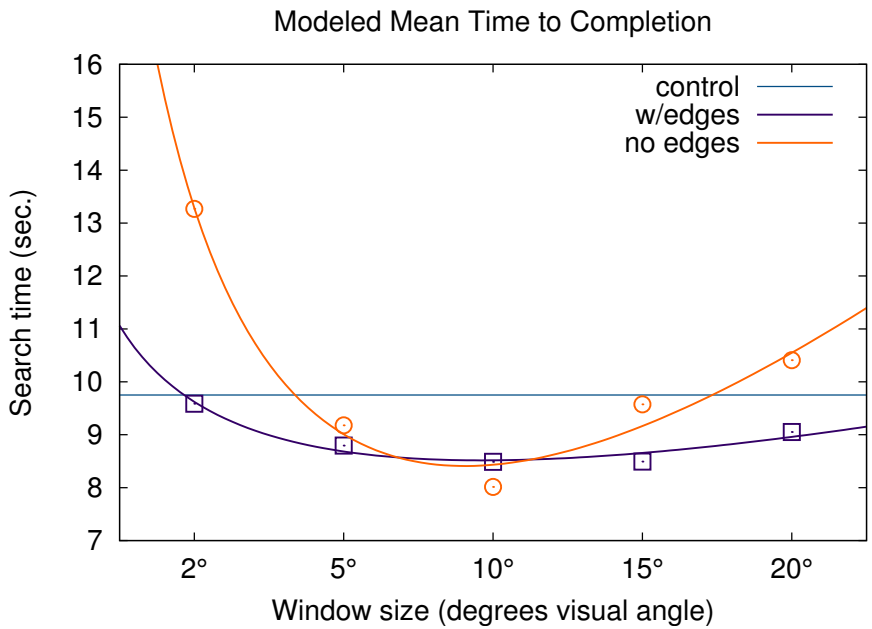

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- Repeated-measures two-way ANOVA indicated a significant main effect of window size on time to completion ($F(4,40) = 4.58$, $p < 0.01$).[1]

[1] Assuming sphericity as computed by R.

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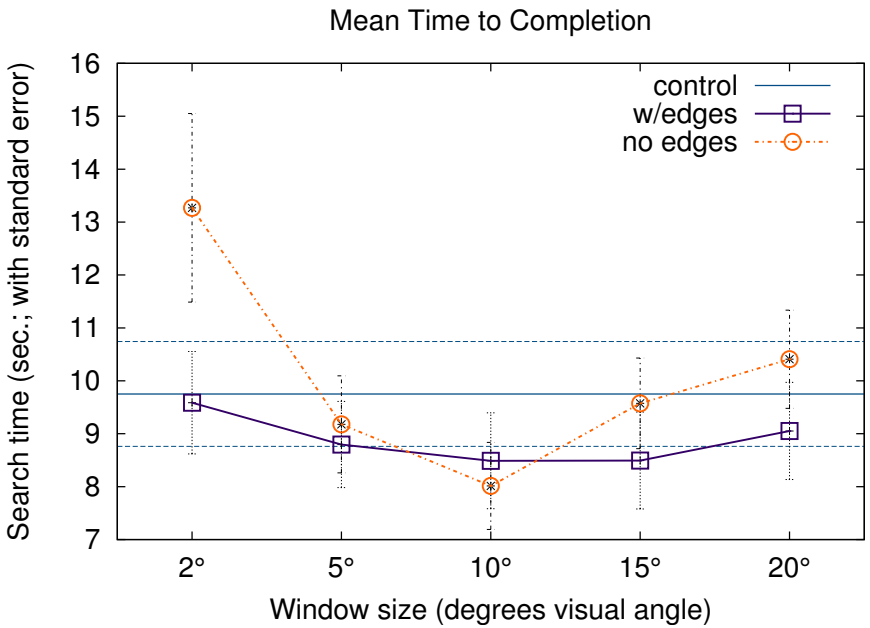

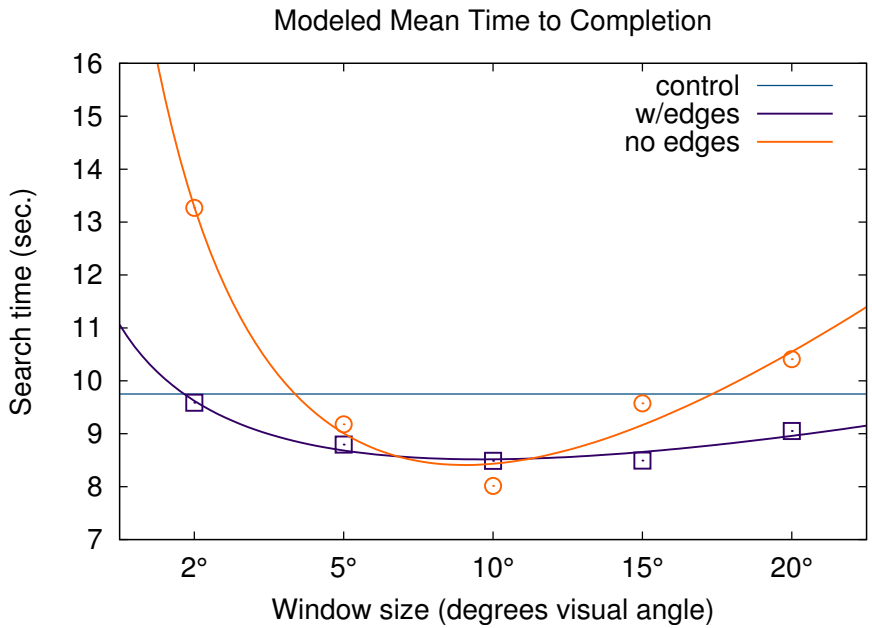

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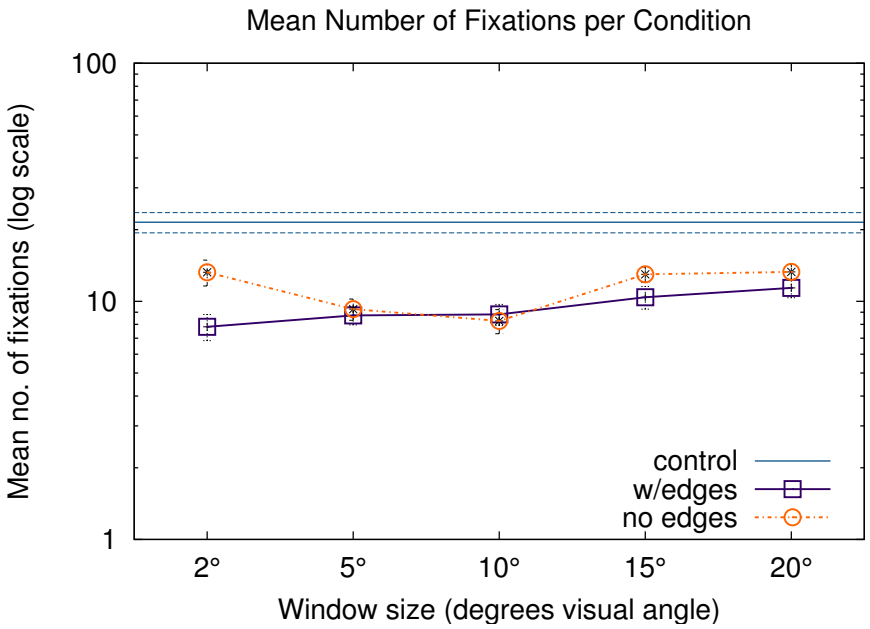

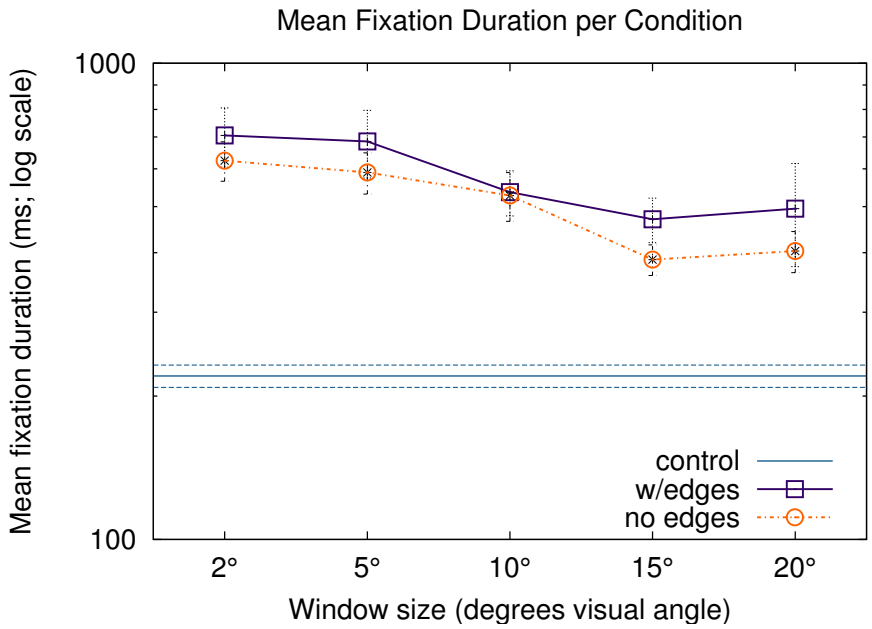

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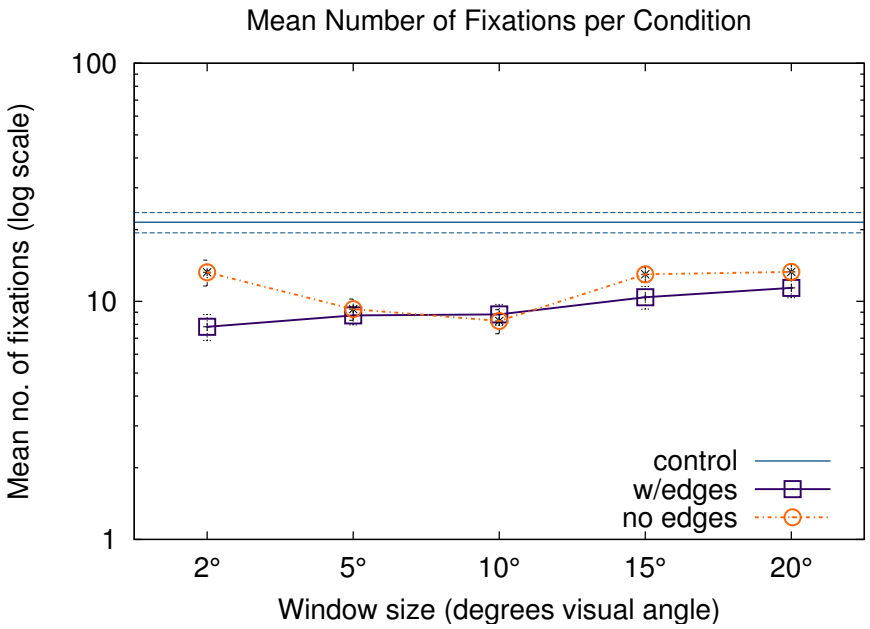

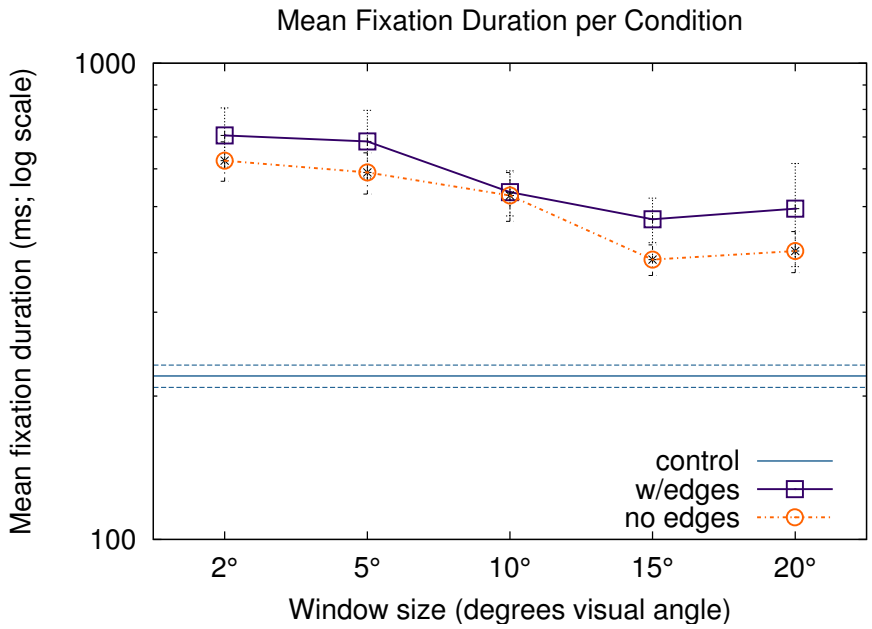

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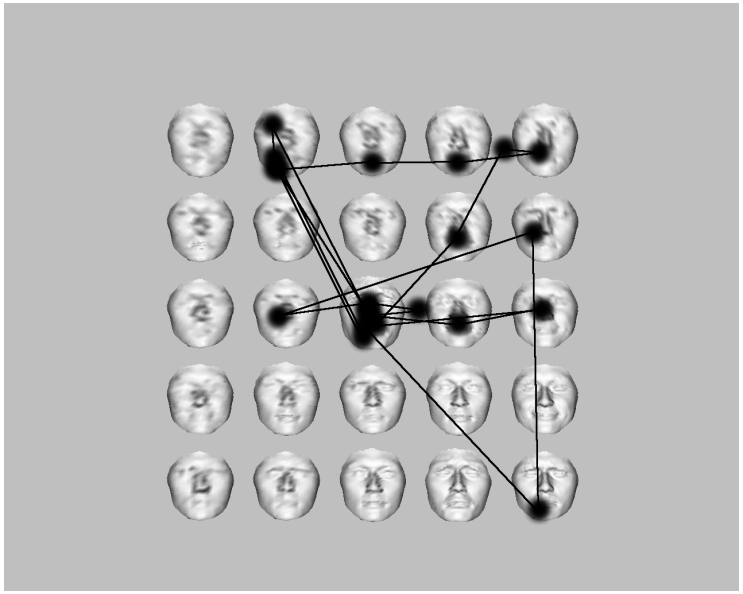

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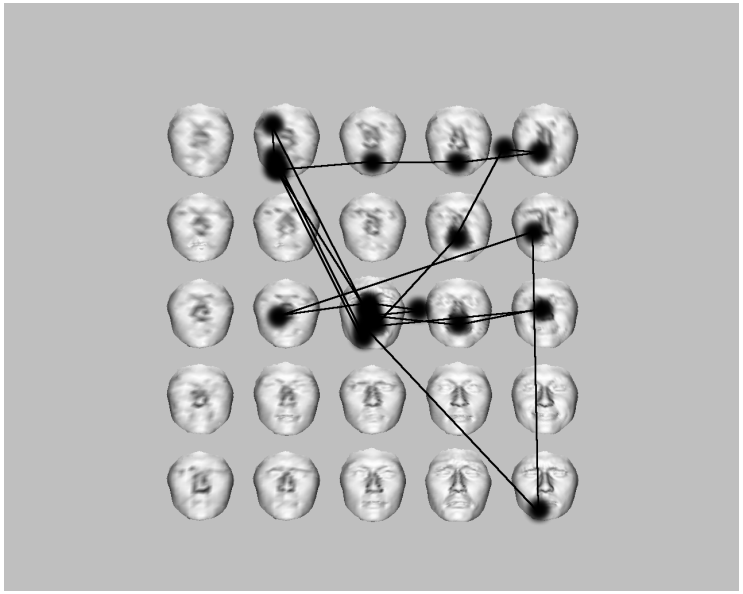

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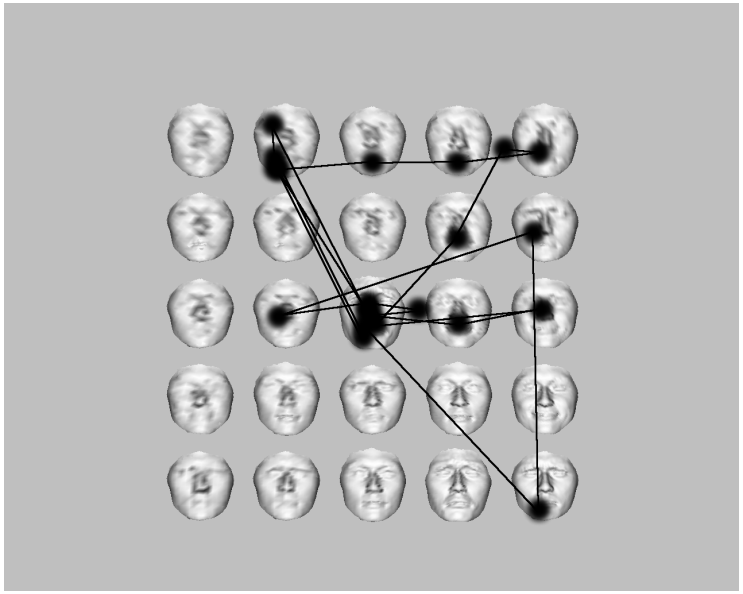

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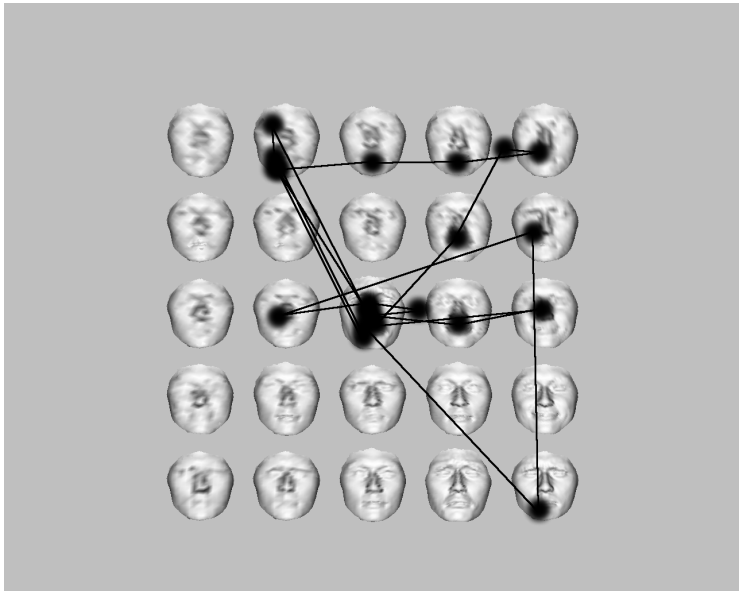

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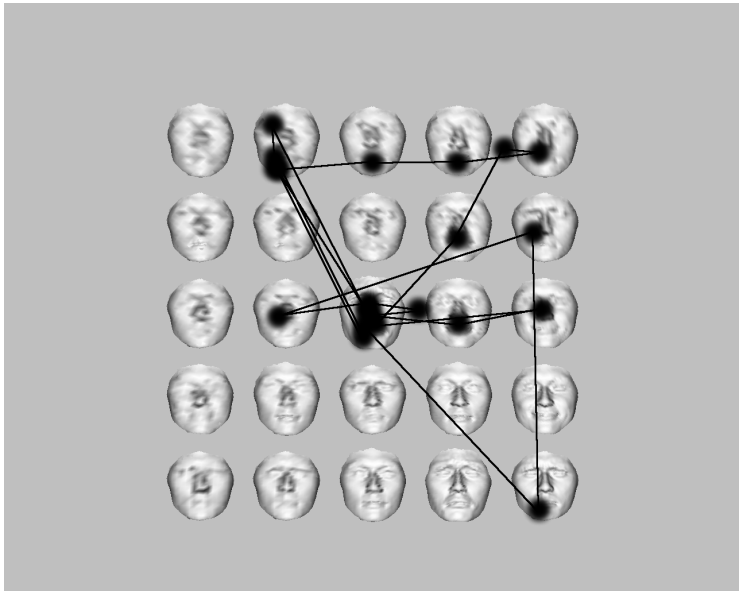

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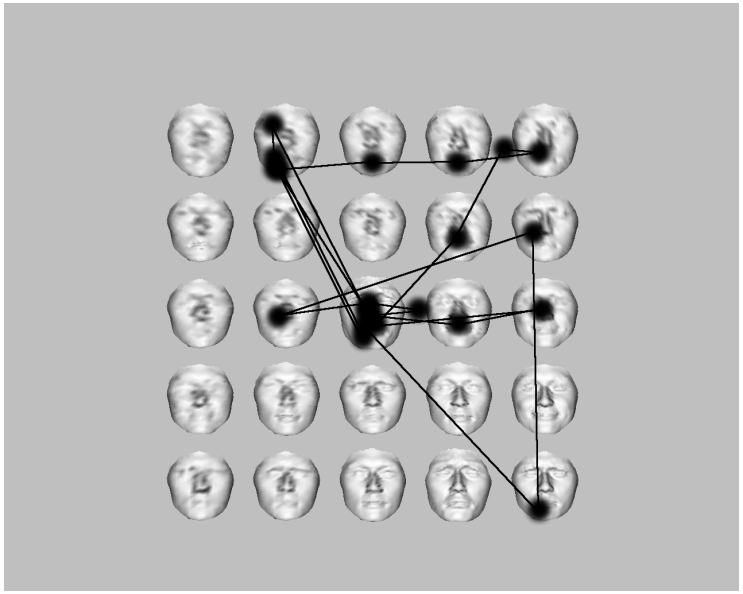

Typical search strategy

Eye Tracking Web Usability

Jakob Nielsen and Kara Pernice Coyne
Nielsen Norman Group

Test Session Chronology

- Welcome/set-up
- Consent form
- Interest questionnaire
- Calibration of eye tracker
- Tasks
- Web experience observed score
- Post-task questionnaires: users rated their satisfaction, frustration, and confidence after each task
- Retrospective (in some cases)

NN/g

Data Collected

- 1.2 million fixations (or “looks”) from users
- 265 GB of data
- 255 study participants
- 50 test tasks

Reading

F-Pattern Dominates Reading Behavior

- People start off fresh and eager
- Users spend more time and fixations:
  - at the beginning (left side) of lines of text
  - at the beginning of a page
- They quickly resort to scanning – reading fewer words
- They frequently do not finish the line completely

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Images

Images as Obstacle Course

- Web User Defense Mechanism: users treat pages with superfluous images like obstacle courses
  - Useless images are barriers to overcome and to be avoided
- Things that appear unneeded, at least peripherally, can be erroneously tuned out

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NN/g

Task: Is DVR for you? <http://www.adelphia.com>

NN/g

Men

Men

Women

Homepage

Websites and Tasks

- Open-ended tasks where users could choose any sites they wanted
- Closed tasks where users were asked to use a specific site
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NN/g

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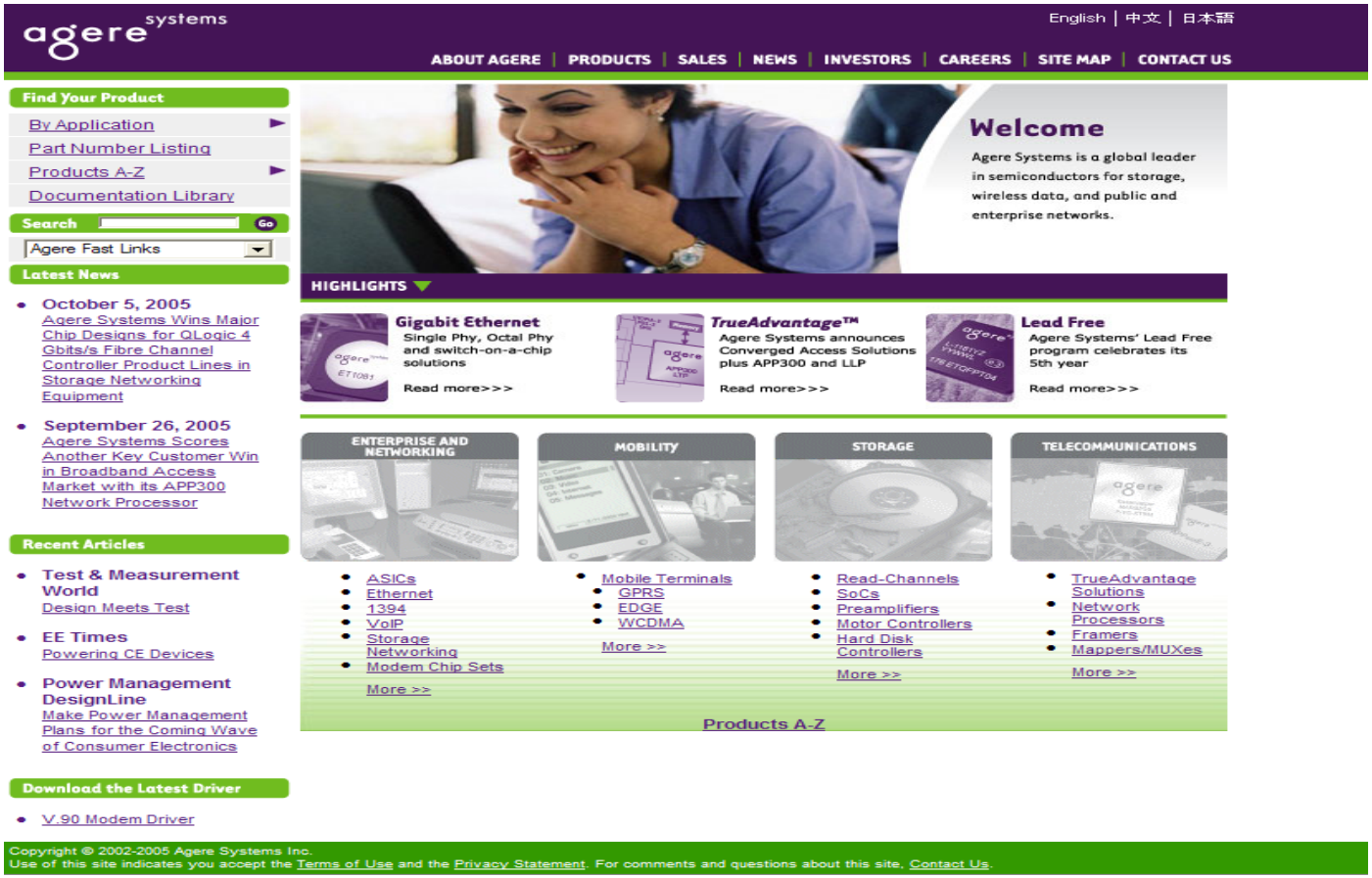

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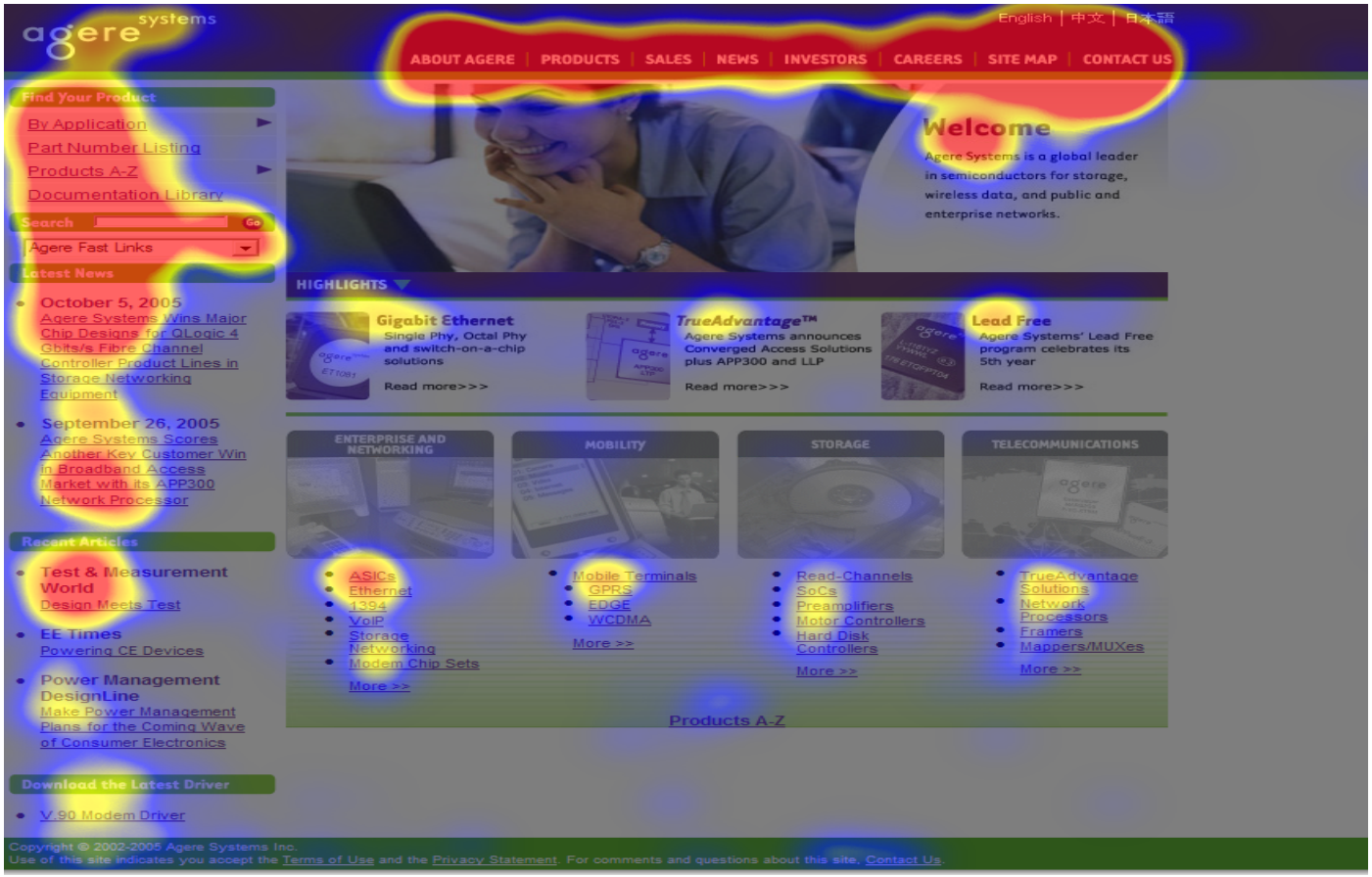

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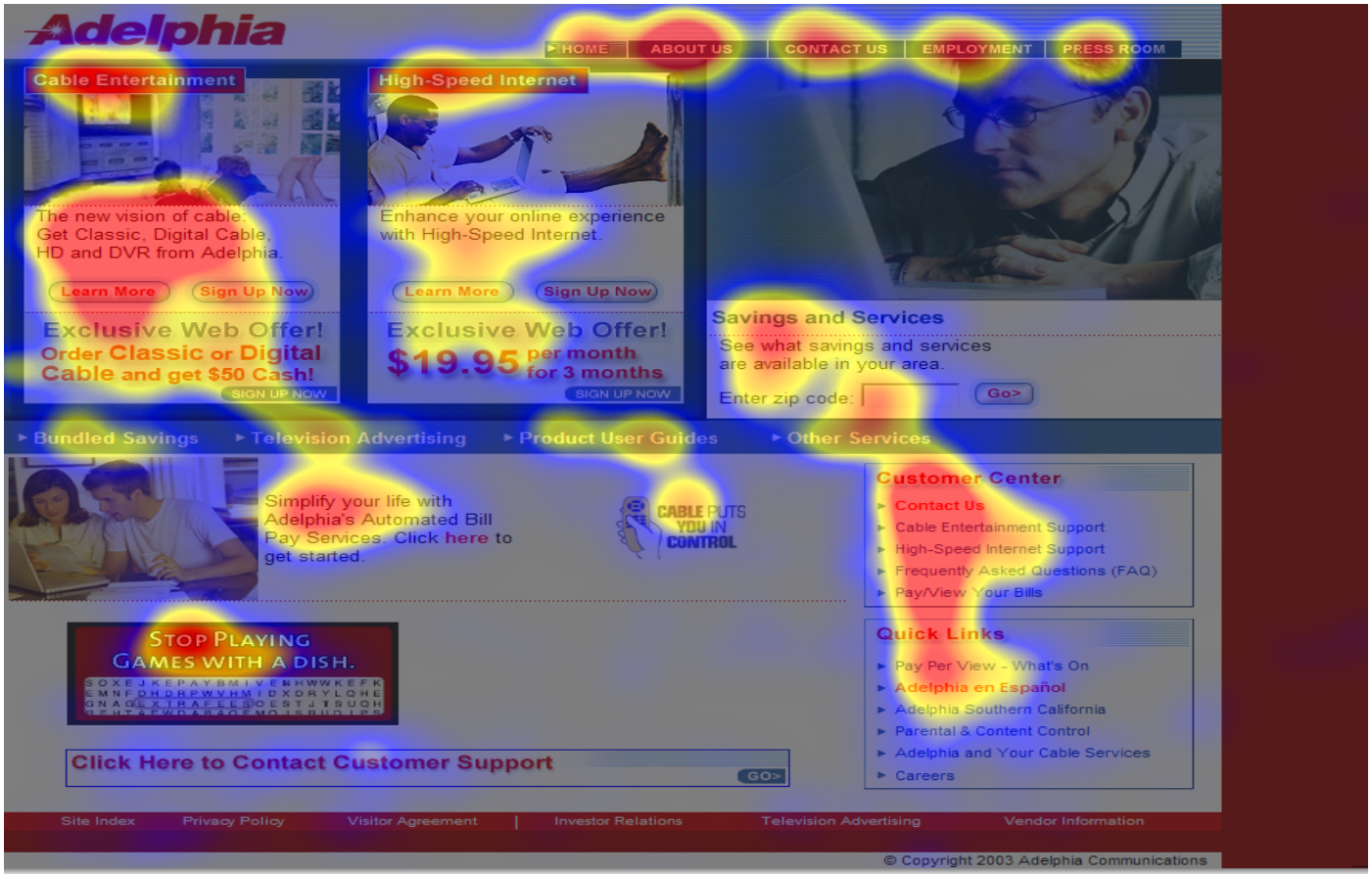

NN/g

Task: Learn about Mikhail Baryshnikov

<http://www.danceworksonline.co.uk>

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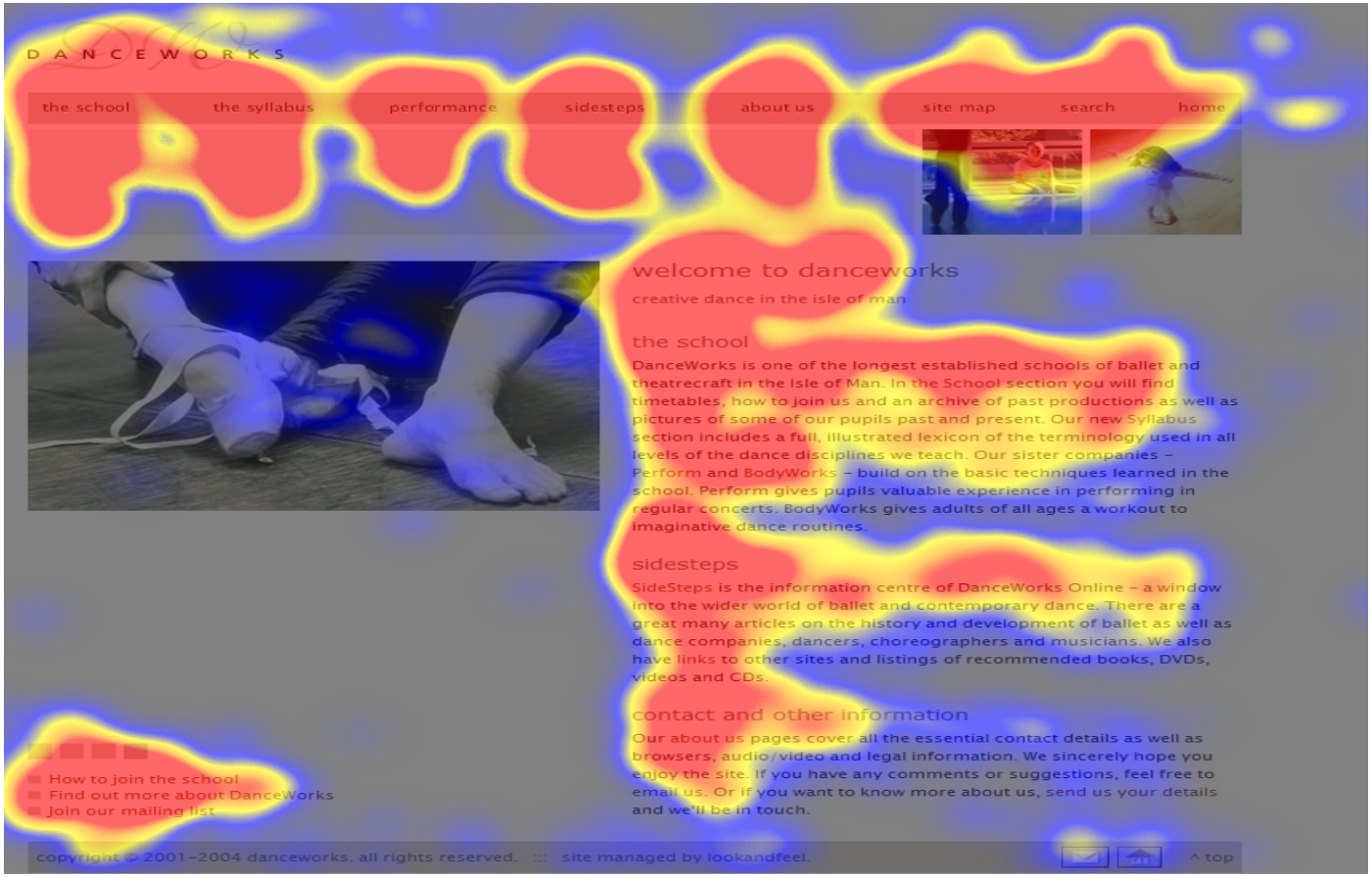


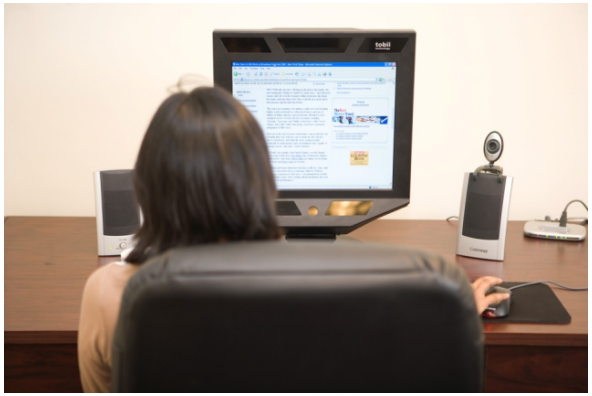
NN/g

Poor Calibration Examples

Lean back →

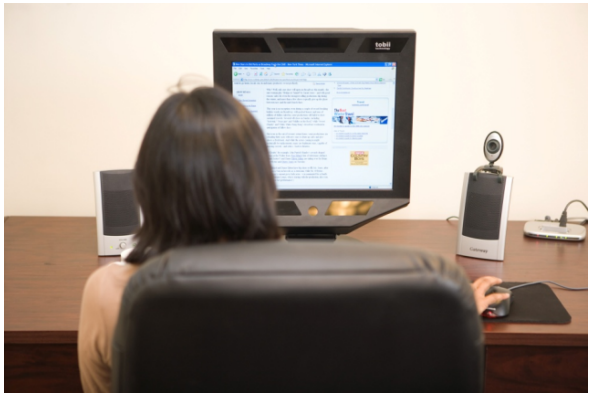
NN/g

Lean back →



← Lean left

Lean back →



← Lean left

Lean forward →

NN/g

Lean on chin →

NN/g

Lean on chin →

Hand on chin →

NN/g

Hands up →

NN/g

Hands up →

← Task sheet up

Hands up →

← Task sheet up

Cup up →

NN/g

Glasses low →

Glasses low →

Hat low →

NN/g

How to Amend Poor Calibration Situations

- Screen during recruiting

How to Amend Poor Calibration Situations

- Screen during recruiting
- Prepare, test, and correct during test set-up

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- Screen during recruiting
- Prepare, test, and correct during test set-up
- Correct issue during test session (qualitative sessions)

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- Interrupt user to fix issues

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  - Be gentle

NN/g

How to Amend Poor Calibration Situations

- Screen during recruiting
- Prepare, test, and correct during test set-up
- Correct issue during test session (qualitative sessions)
- Interrupt user to fix issues
  - Be gentle
  - Always warn during set-up that you may change (correct) a situation

NN/g

Advanced Considerations

- High-level metrics:
  - transition matrices,
  - scanpath comparison.
- Dynamic AOIs:
  - often the best approach: re-instrument the app;
  - source code is required of course;
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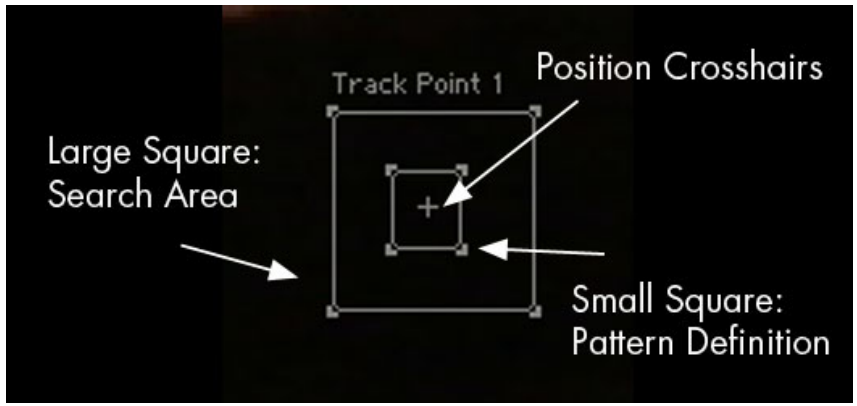

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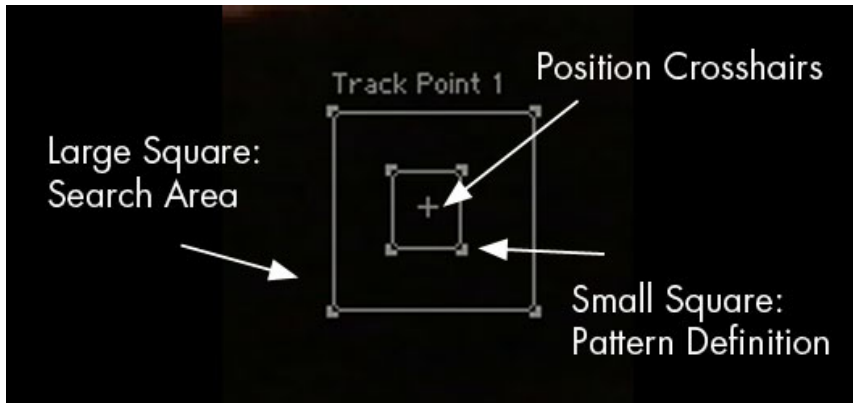

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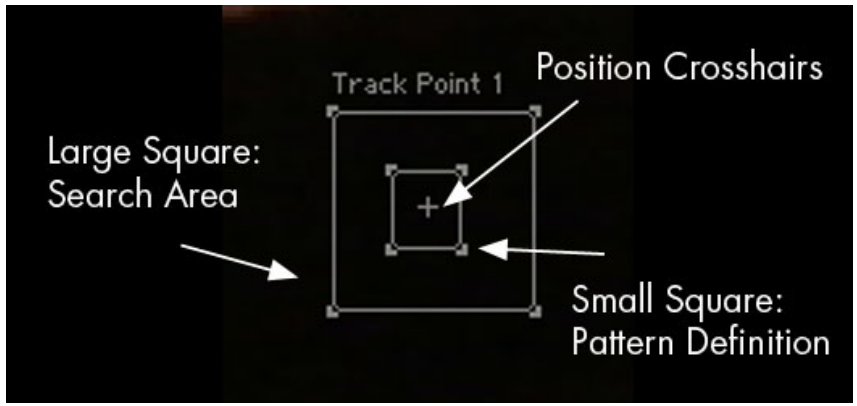

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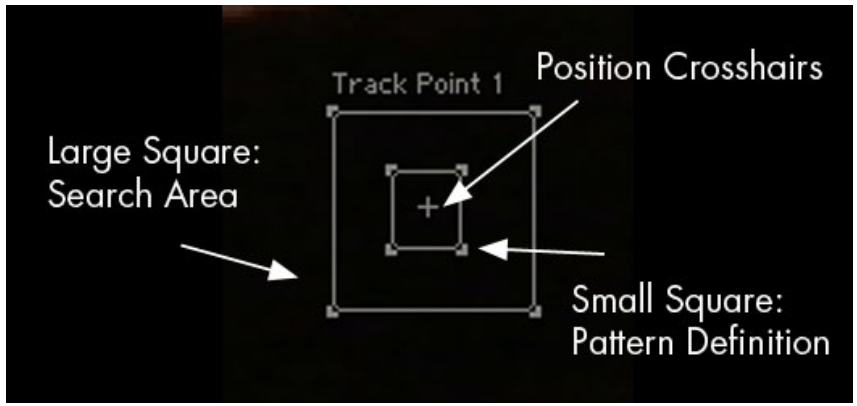

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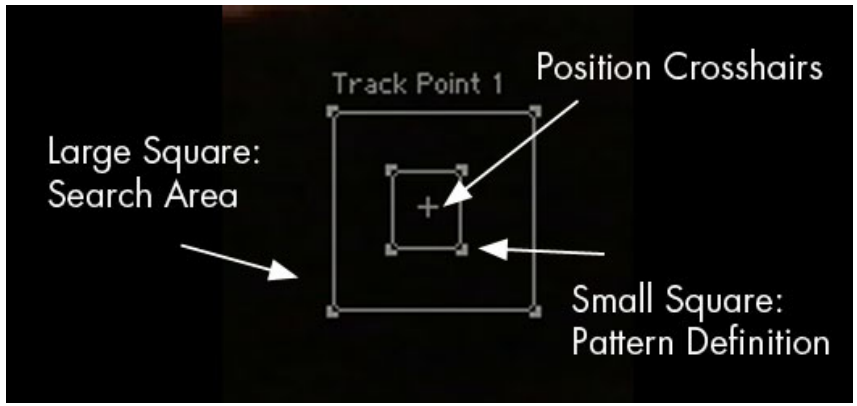

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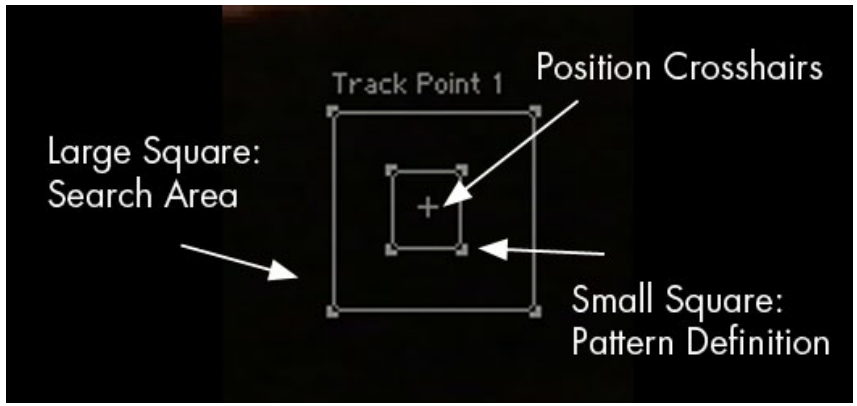

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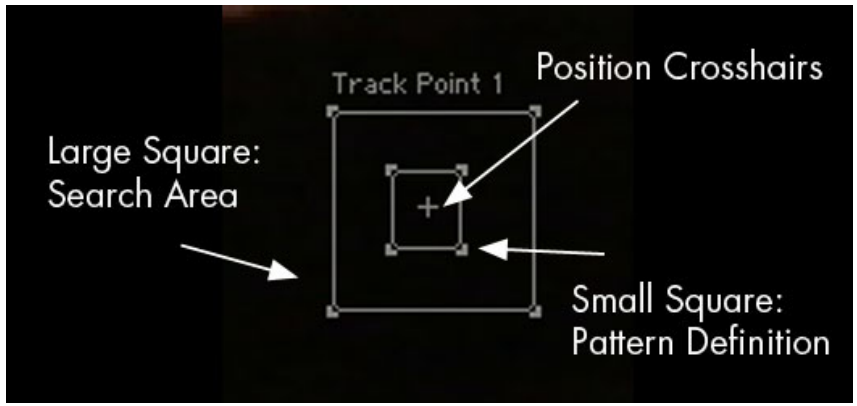

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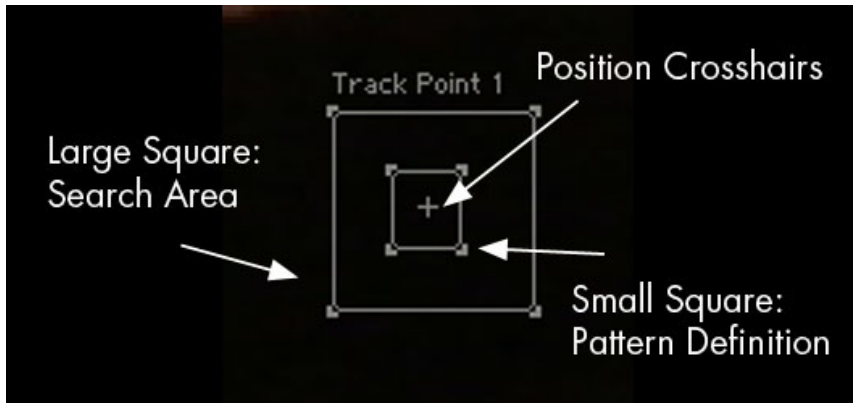

One Approach to Scanpath Comparison

- String editing was developed by Privitera and Stark (2000) to compare human fixations with those predicted by automatic means (e.g., Itti et al.'s (1998) saliency model).

$s_1 = abcfeffgdc$ $s_2 = afbffdcdf$	start	cost 0
$s_1 = abcfeffgdc$ $s_2 = afeffdcdf$	after substitution of first *b* by *e*	cost 1
$s_1 = abcfeffgdc$ $s_2 = abcfeffdcdf$	after insertion of *bc* after first *a*	cost 2
$s_1 = abcfeffgdc$ $s_2 = abcfeffdc$	after deletion of last *df*	cost 2
$s_1 = abcfeffgdc$ $s_2 = abcfeffgdc$	after insertion of *g*	cost 1

String editing framework

- Comparison relies on cost of three character operations: *deletion*, *insertion*, and *substitution*.
- Character transformation costs are based on Levenshtein distance, as illustrated below for strings $s_1 = abcfeffgdc$ and $s_2 = afbffdcdf$.

		a	f	b	f	f	d	c	d	f
	a	0	1	2	3	4	5	6	7	8
	b	1	1	1	2	3	4	5	6	7
	c	2	2	2	2	3	4	4	5	6
	f	3	2	3	2	2	3	4	5	5
	e	4	3	3	3	3	3	4	5	6
	f	5	4	4	3	3	4	4	5	5
	f	6	5	5	4	3	4	5	5	5
	g	7	6	6	5	4	4	5	6	6
	d	8	7	7	6	5	4	5	5	6
	c	9	8	8	7	6	5	4	5	6

Example of Levenshtein distance calculation.

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	f	3	2	3	2	2	3	4	5	5
	e	4	3	3	3	3	3	4	5	6
	f	5	4	4	3	3	4	4	5	5
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Example of Levenshtein distance calculation.

Y-matrix structure

S_p	Subj. 1		Subj. 2	
	Pict1	Pict2	Pict 1	Pict 2
S1P1	**R**	**I**	**L**	**G**
S1P2		**R**	**G**	**L**
S2P1			**R**	**I**
S2P2				**R**

S_s	Subj. 1		Subj. 2	
	Pict1	Pict2	Pict 1	Pict 2
S1P1	**R**	**I**	**L**	**G**
S1P2		**R**	**G**	**L**
S2P1			**R**	**I**
S2P2				**R**

Structure of *Y*-matrices (Privitera & Stark, 2000).

- Since complete *Y*-matrices are too large for display, *parsing diagrams* are used to condense the data.

Parsing diagrams

- Parsing diagrams contain averages of similarity coefficients collected from Y-matrices and consist of four main entries:
  1. **R**epetitive: same viewer looking at same scene at different times;
  2. **L**ocal: different viewers looking at the same scene;
  3. **I**diosyncratic: same viewer looking at different scenes; and
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- A *Ra*ndom entry is included for significance testing.

Same Subj.	Diff. Subj.
Repetitive	**L**ocal
Idiosyncratic	**G**lobal
S_p	*Ra*ndom

← Same Image →
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Related Work

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  - evaluation of web page design and television news layout (Josephson and Holmes, 2002; 2006),
  - amalgamation of numerous scanpaths into a single, representative (e.g., “expert”) scanpath (Hembrooke et al., 2006),
  - augmentation of string editing with Needleman-Wunsch weighting (West et al., 2006) (often used in bioinformatics); resultant *eyePatterns* is (not yet) available at: `<http://www.juliamae.com/eyepatterns/>`
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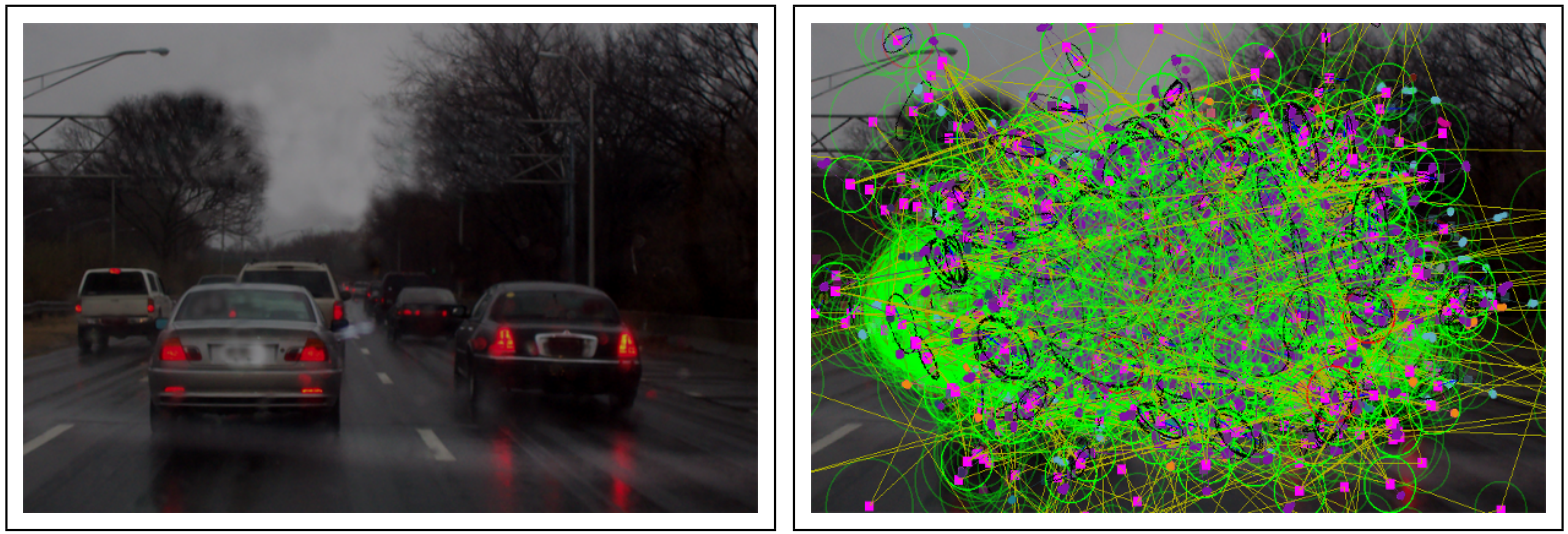

Human and random scanpaths with overlapping clusters.

- Number of scanpaths: 42 (21 subjects, each seeing two images).
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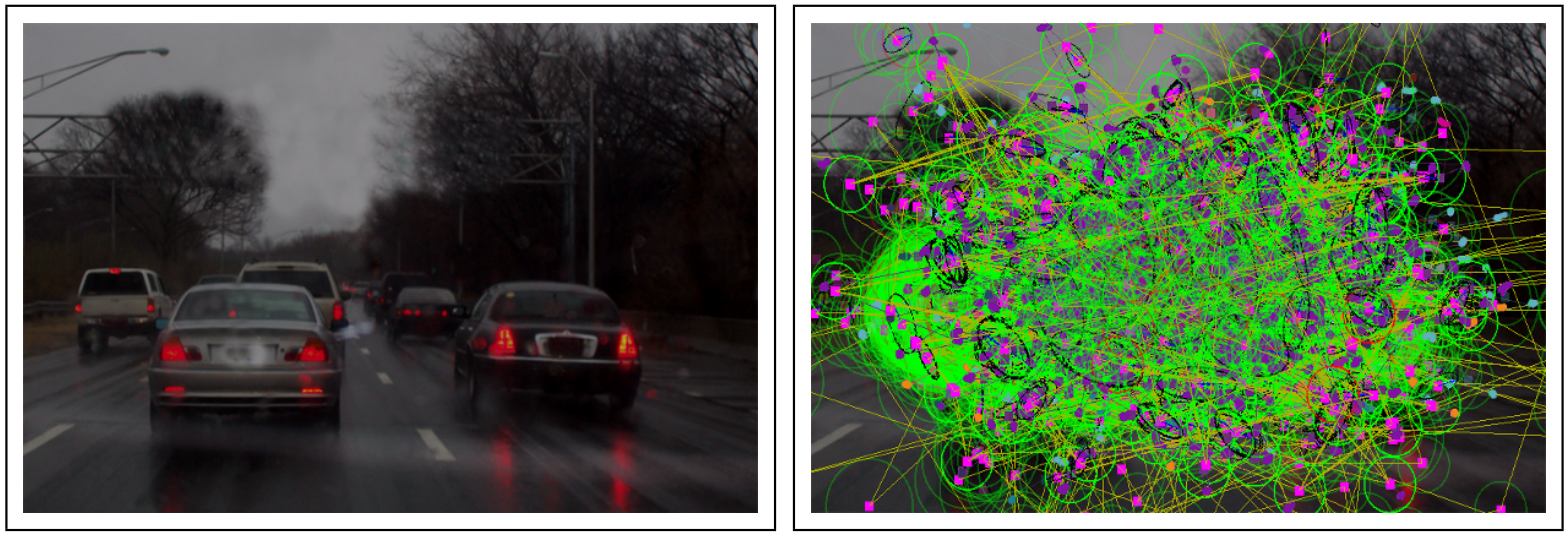

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0.71	0.72	← Diff. Image →	0.27	0.20
S_p	0.13		S_s	0.13

Parsing diagrams for brakelight study.

- Analysis shows spatial correlation (S_p) $>$ sequential (S_s).
- What does it mean?
- People tend to look at similar things but in different order.
- Especially over time—each scanpath was about 10 minutes long.
- Good rule of thumb: limit stimulus exposure.
- One gaze point every 20 ms means a lot of data.
- Analysis may be more meaningful for shorter scanpaths and for distinct groups of viewers, e.g., experts vs. novices.

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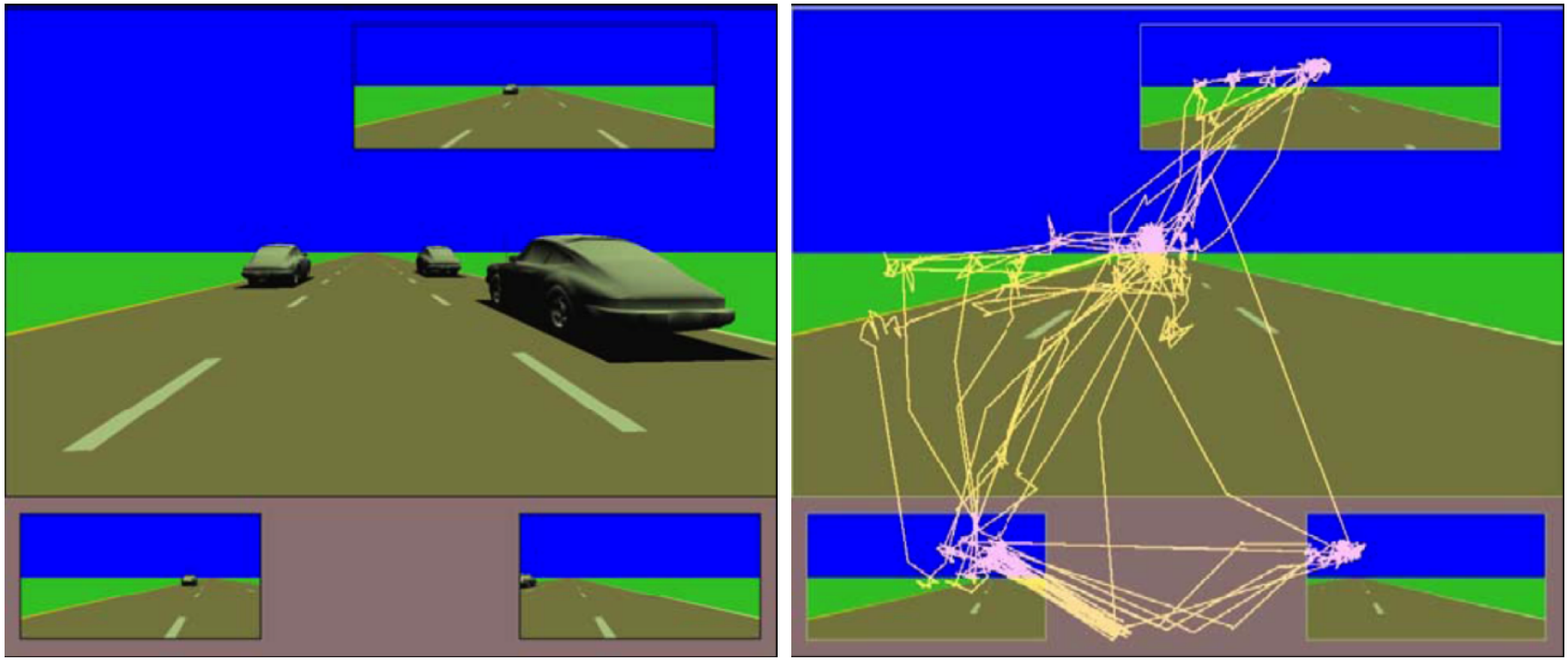

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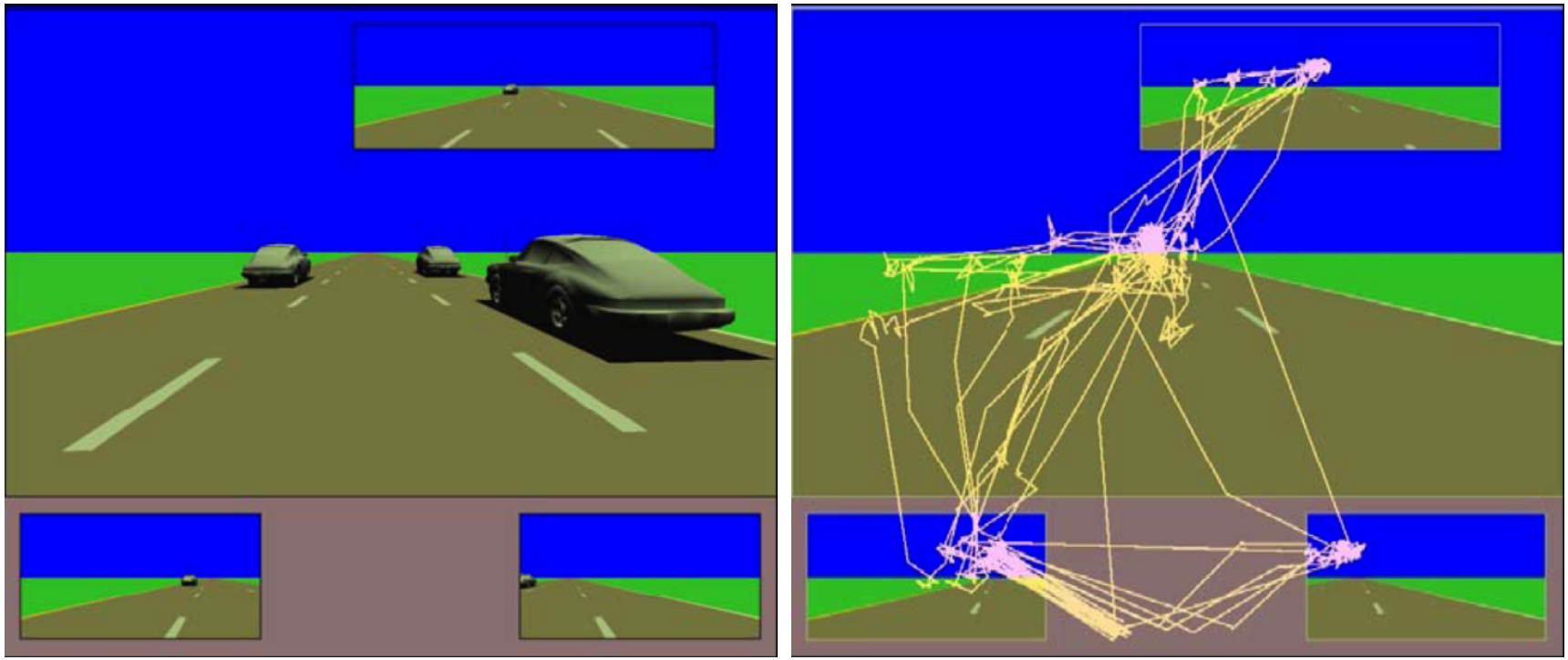
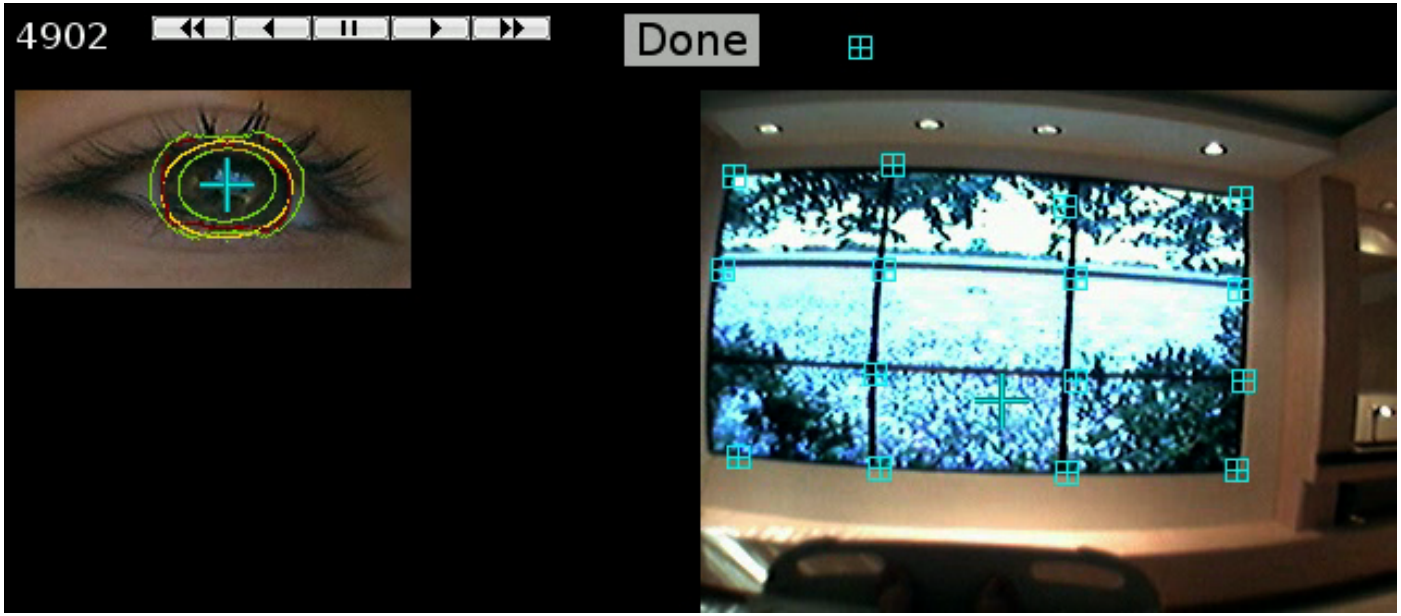


Dynamic AOIs: Dynamic Media



- For dynamic media, need to track AOIs.
- Some manual intervention may be necessary (keyframing).
- VCR controls are most helpful.

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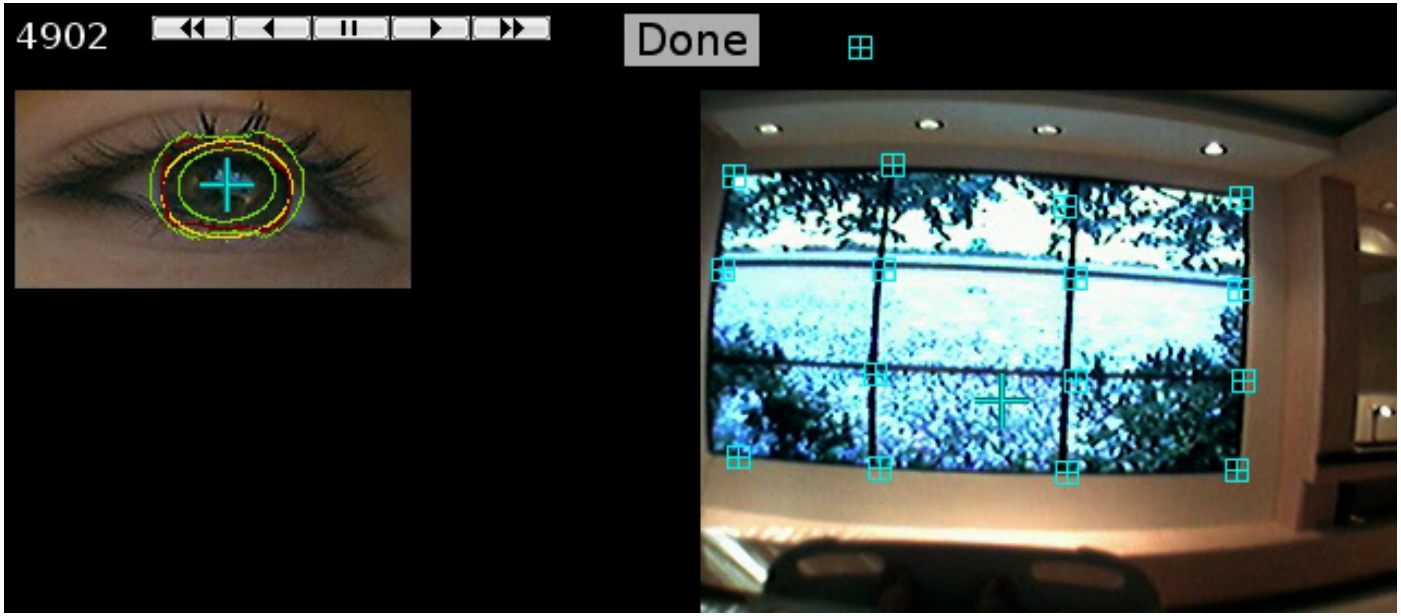

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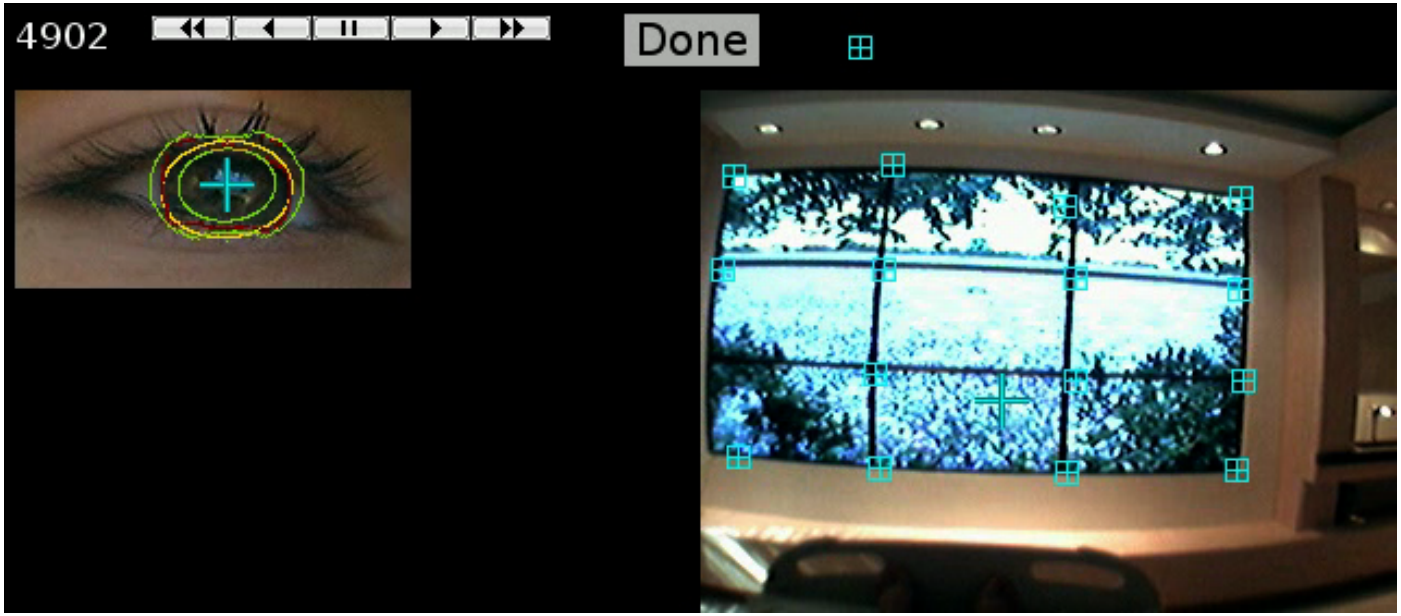

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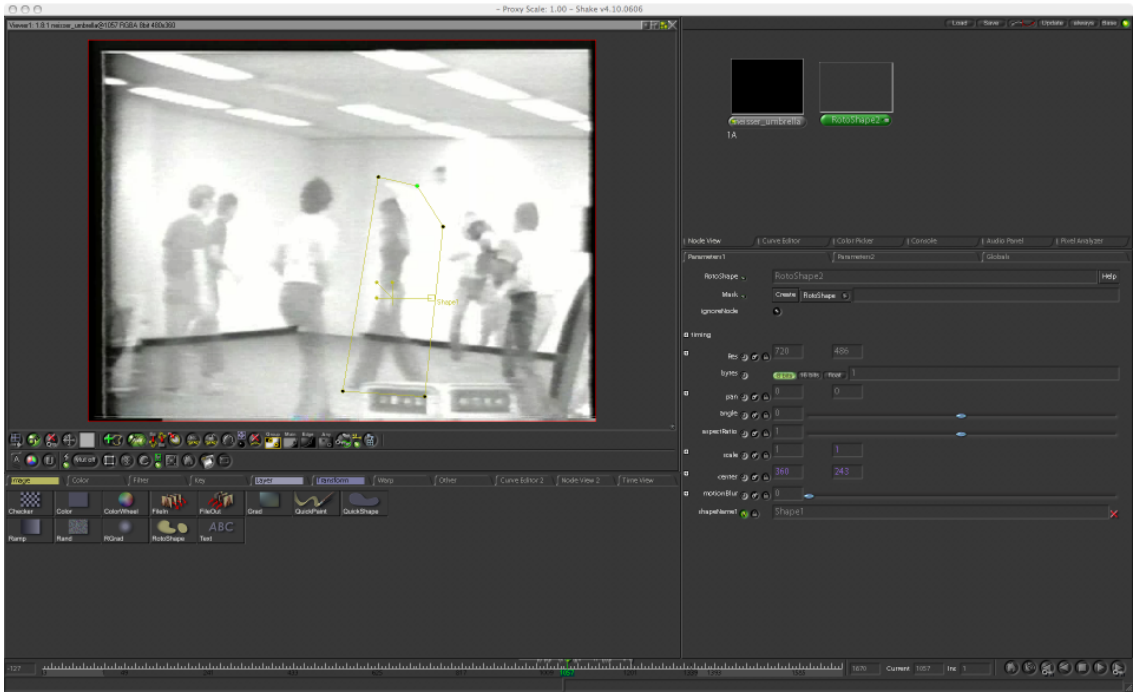
Dynamic AOIs: `Shake` Rotoshape

```
shake_shape_data 4.0
motion_blur 0.000000
shutter_timing 0.500000
shutter_offset 0.000000
num_shapes 1
shape_name Shape1
parent_name
closed 1
visible 1
locked 0
tangents 1
edge_shape 1
num_vertices 5
num_key_times 170
key_time 952.000000
center_x 531.190002
center_y 104.557999
color_r 1.000000
color_g 1.000000
color_b 1.000000
color_a 1.000000
vertex_data 517.852905 219.235275 517.852905 219.235275 517.852905 ...

 ...
```



Couple of examples: image analysis

Example: Video

- Dixon et al. (2006) demonstrate basic rotoshape approach:
  - eye movement (fixation) data compared with ‘target maps’ (rotoshapes essentially),
  - keyframing operation performed manually with automatic inbetweening via interpolation,
  - rotoshape serves as a ground truth used to evaluate human tracking performance.

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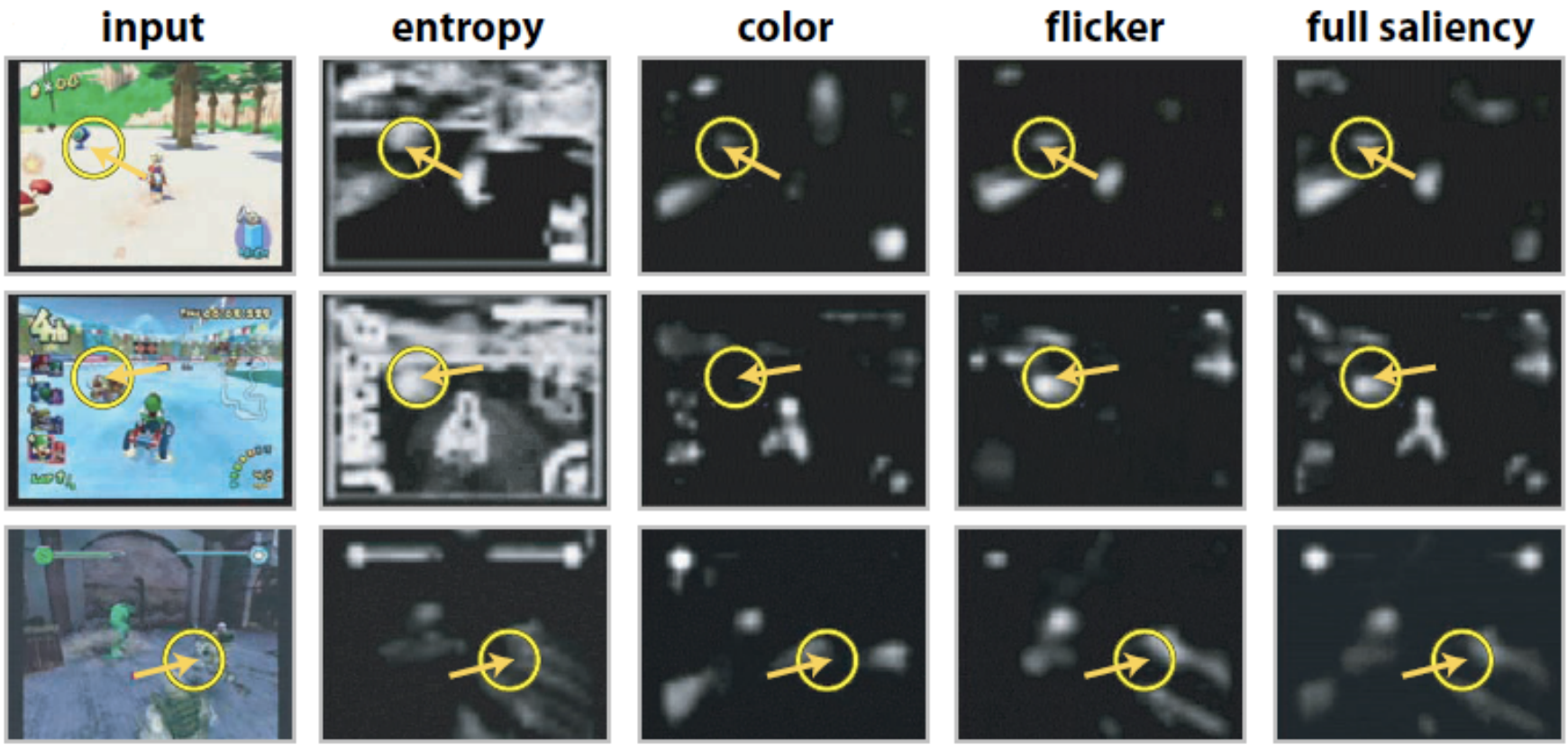
Example: Virtual Environments



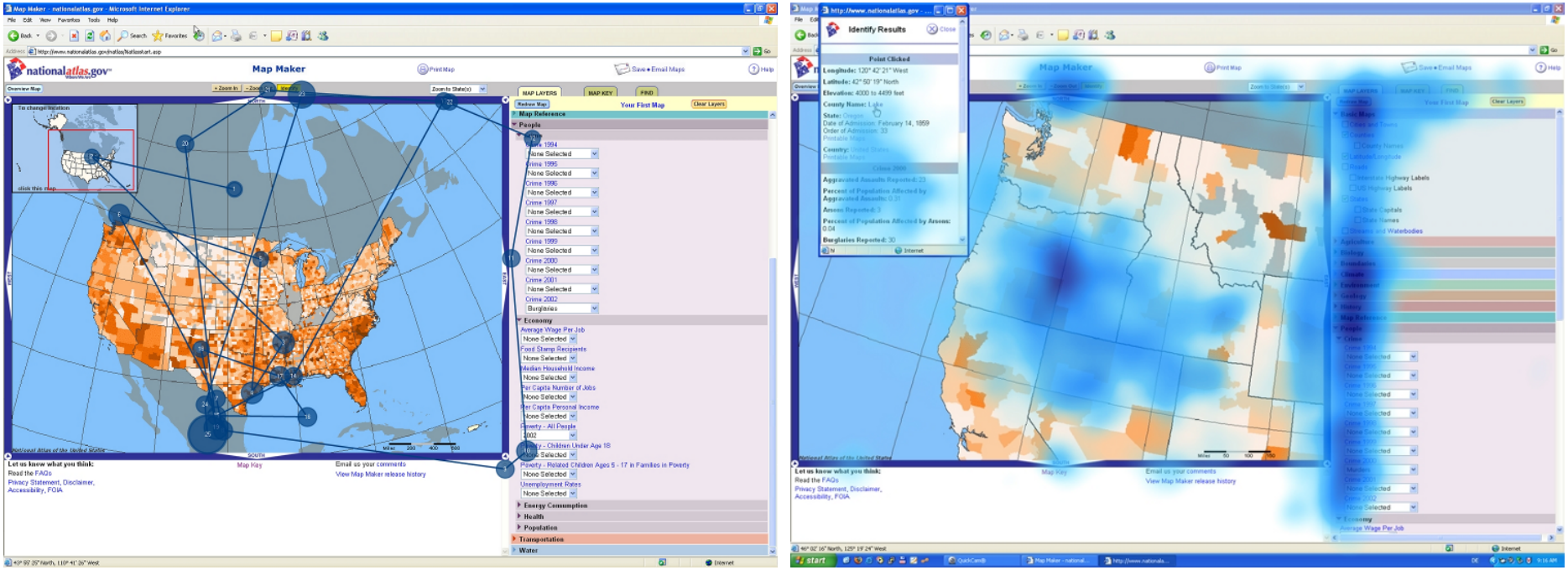
- Peters and Itti (2006) compare automatic saliency classification with gaze data.

Couple of examples: image synthesis

Example: Non-Photorealistic Rendering

- DeCarlo and Santella (2002) used gaze data to synthesize stylized images.

Example: Stylized Cartography



- Çöltekin et al. (2009) are evaluating gaze data for cartography display (e.g., using foveation).

To summarize...

- Eye movements are useful for *diagnostic* evaluation.
- Commercial eye trackers fairly easy to use these days.
- Eye movement analysis is important.
- As is experimental design.
- Methodology applicable to image analysis:
  - Did human gaze agree with prediction made by analysis?
- Methodology applicable to image synthesis:
  - Did human gaze follow direction implied in design?
- Dynamic media: challenging hot topic.

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Questions

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For Further Reading I

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