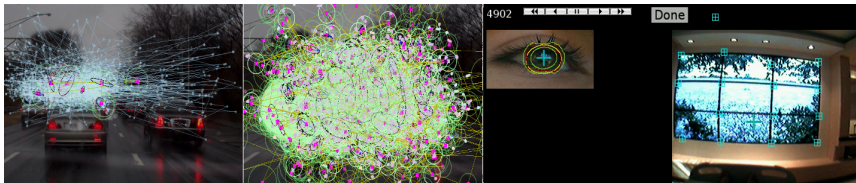


Eye Tracking Technology and its Application Toward Image Analysis & Synthesis

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School of Computing, Clemson University

27 March 2009



Abstract

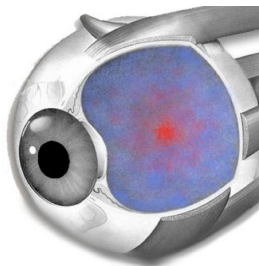
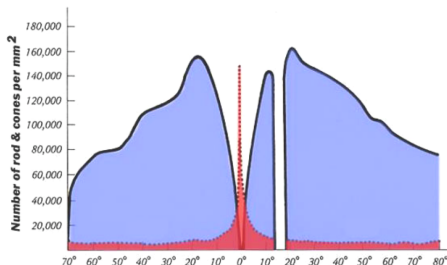
Eye movements provide a compelling record of the deployment of visual attention over imagery. Analysis and visualization of these scanpaths provides corroborative evidence of viewers' attention to direction embedded in synthesized media. Disagreement between intended foci of attention and actual fixations 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

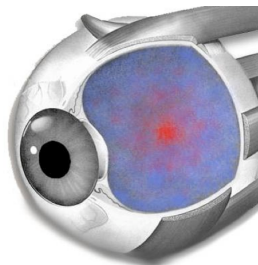
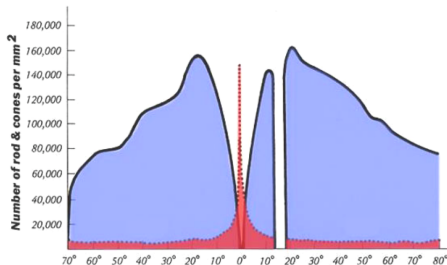


Photoreceptor distribution and fovea

(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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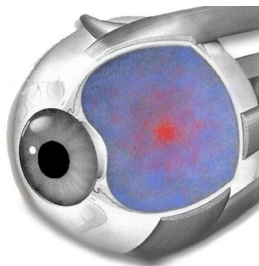
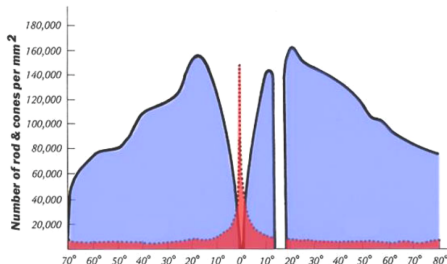


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On Wikipedia: http://en.wikipedia.org/wiki/Eye_tracking

- 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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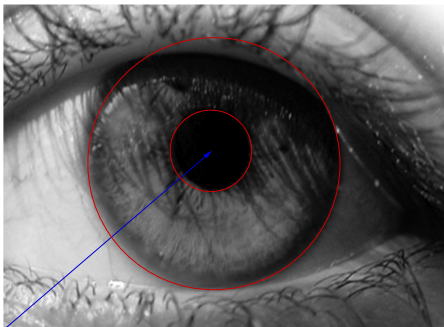
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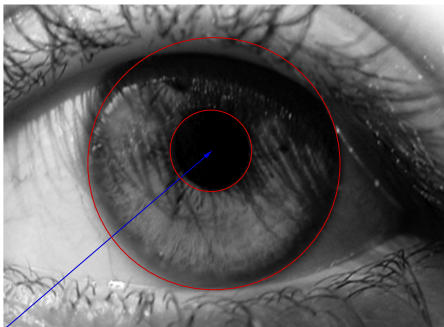
Eye Tracking Technology



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

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- Other approach is model-based (based on Gullstrand's model).

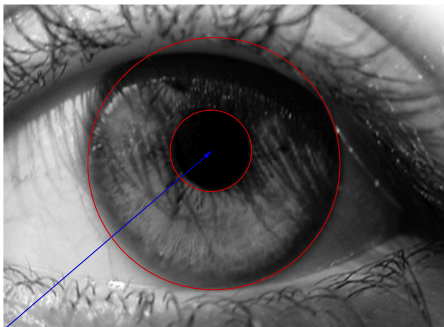
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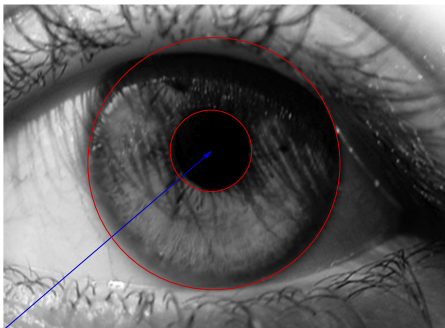
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Clemson's Eye Tracking Lab



- 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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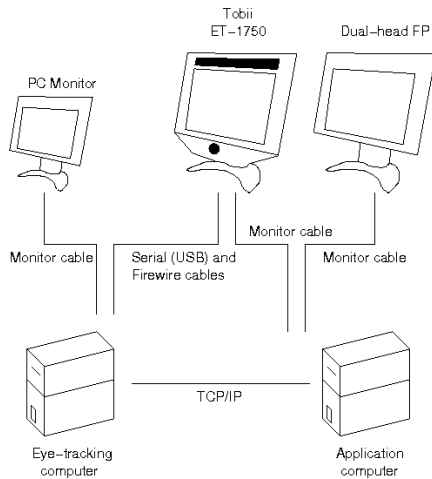
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Tobii Eye Tracking Workstation



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)
GZD	gaze data (raw data) with camera info, etc.

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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 [$@ 20 \text{ ms} = 100 \text{ ms}$]).
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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*:
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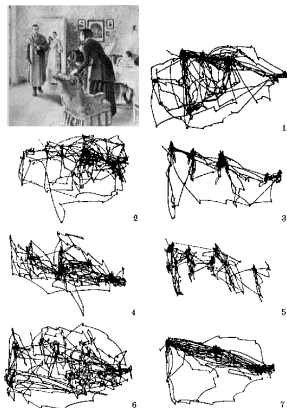
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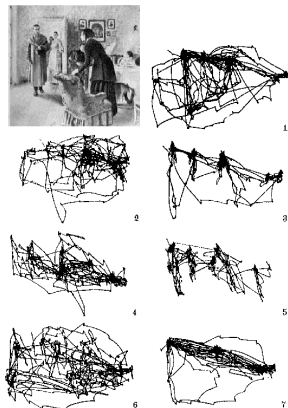
Task Dependence

- Yarbus (1967) showed importance of task dependence.
- Instructions to viewers influence scanpaths.
- Scanpaths appear to be raw data.
- Fixations would be more informative.
- Most eye tracking papers should provide scanpath visualization.
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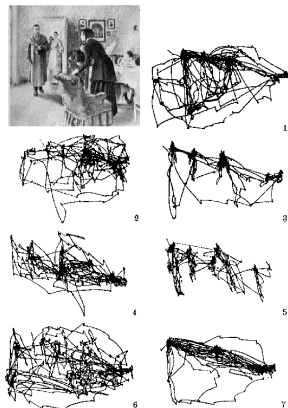
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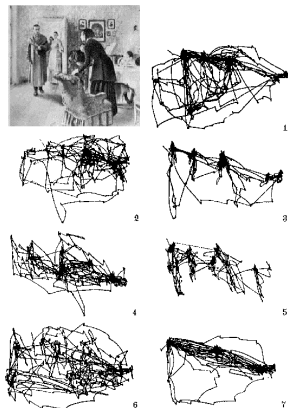
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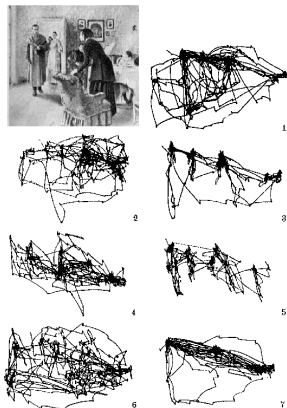
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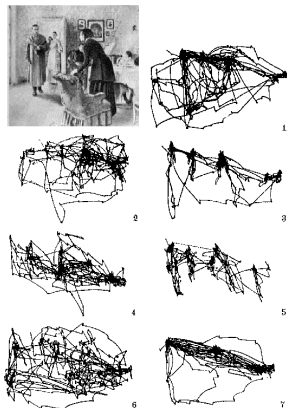
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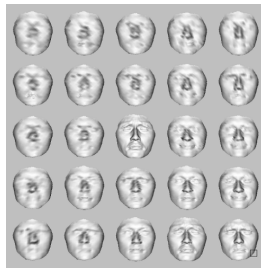
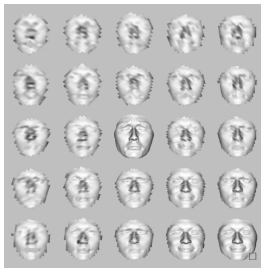


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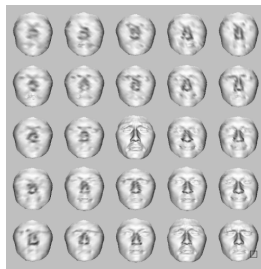
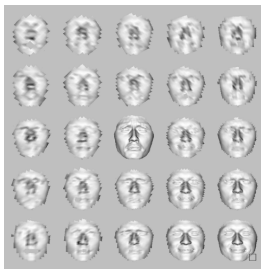


Example Study: Gaze-Contingent Window



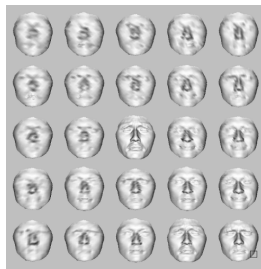
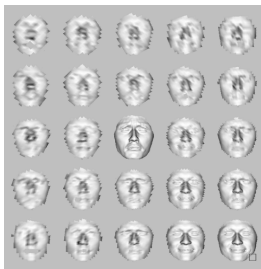
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- Search task without silhouette edges.
- Search task with silhouette edges.
- Small box at lower right indicates gaze point.

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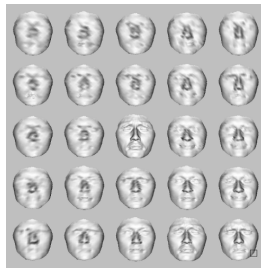
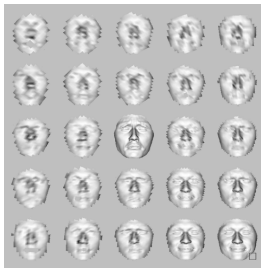
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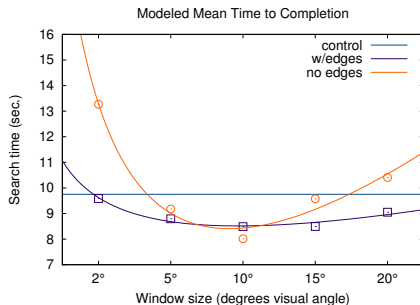
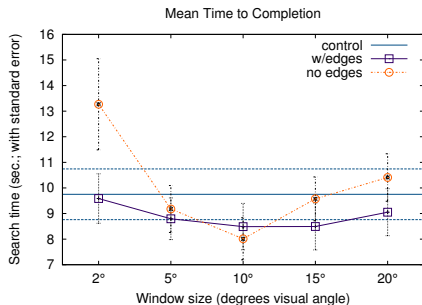
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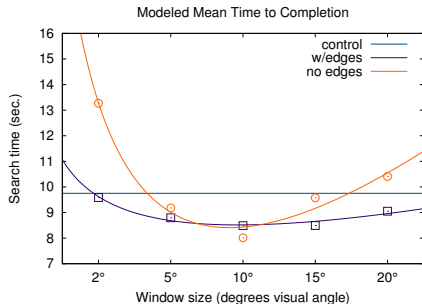
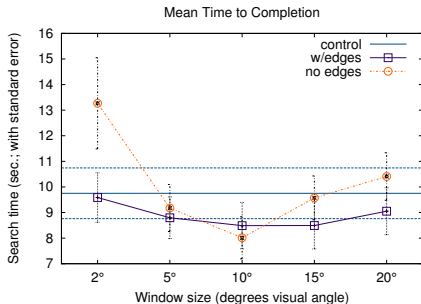
Example Statistics: Time to Completion



- Example analysis of time to completion during visual search using a gaze-contingent display (Murphy et al., 2009).
- 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.

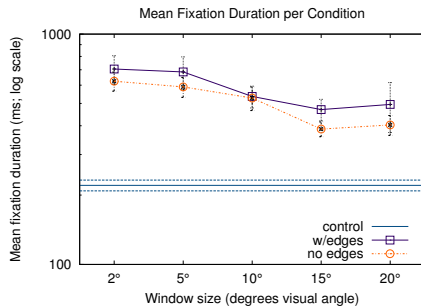
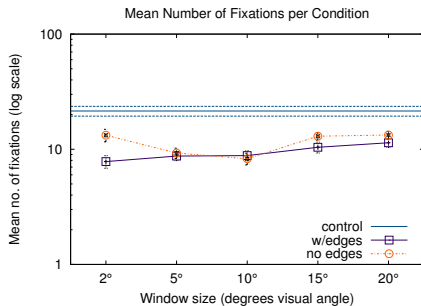
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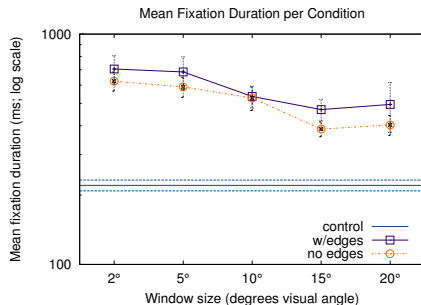
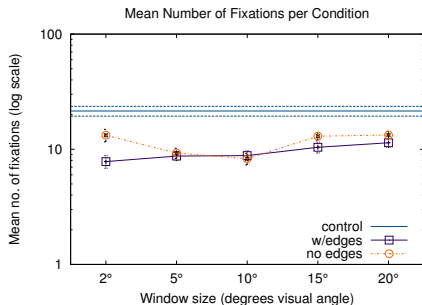
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Example Statistics: No. of Fixations, Durations



- Repeated-measures two-way ANOVA indicated a significant main effect of window size on number of fixations ($F(4,40) = 5.80, p < 0.01$).
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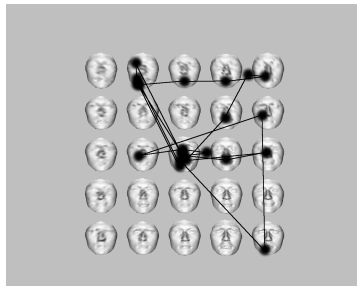
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Example Conclusions Drawn

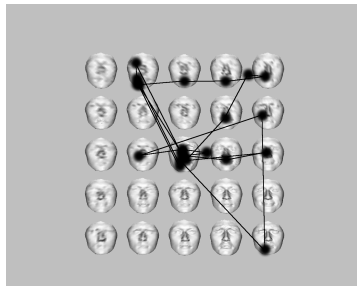
- Some results consistent with Geisler et al.'s (2006) results.
- Smaller windows \longrightarrow fewer, longer fixations.
- Larger windows \longrightarrow more shorter fixations.
- Longer fixation durations \implies task difficulty?
- Performance benefit with 10° window.
- Point of diminishing returns with 15° window.



Typical search strategy

Example Conclusions Drawn

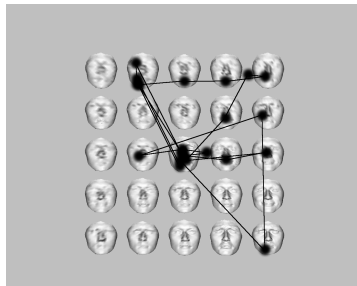
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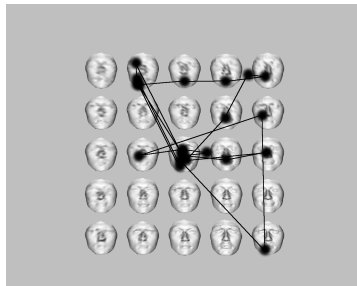
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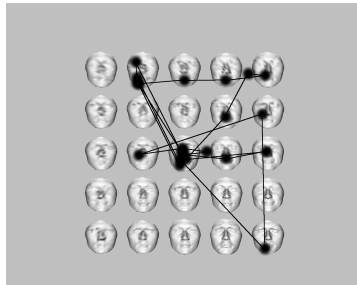
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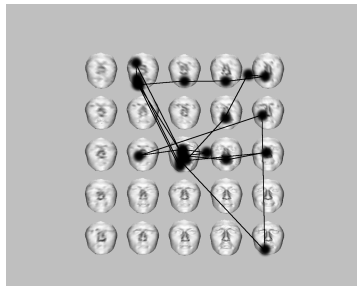
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Typical search strategy

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)



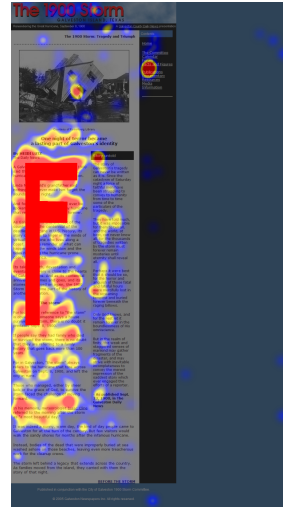
Data Collected

- 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



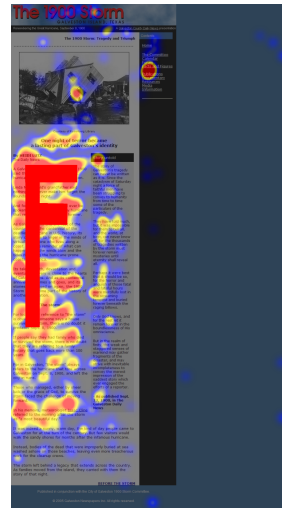
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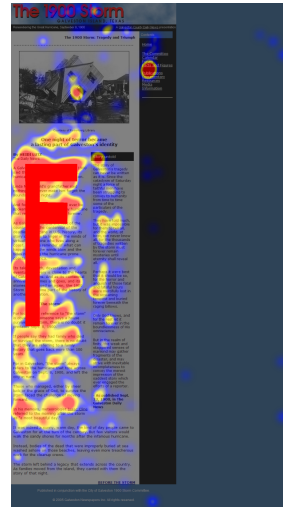
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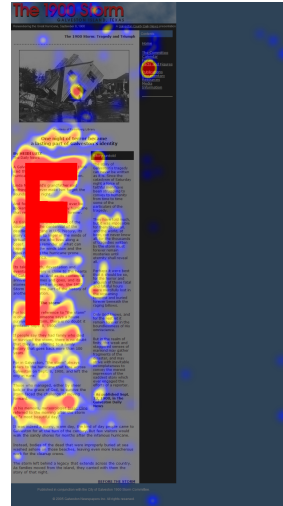
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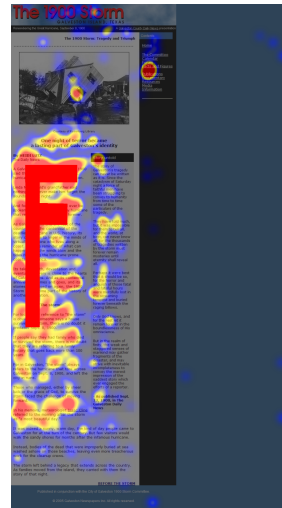
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Images

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

Images as Obstacle Course

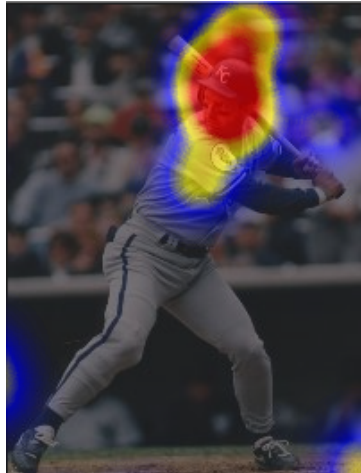
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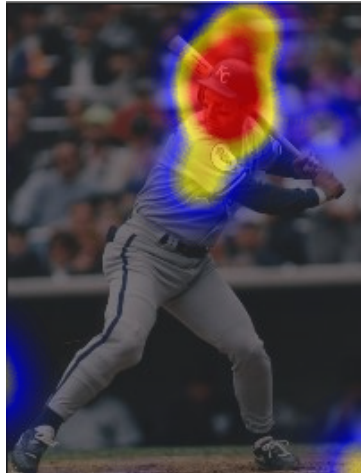
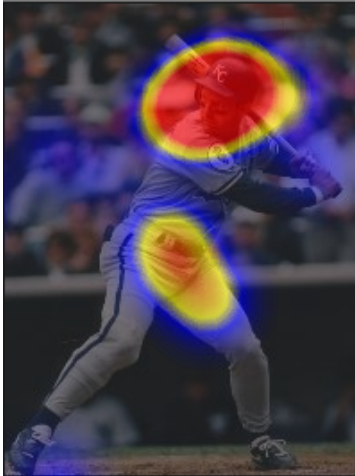
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Task: Is DVR for you? <http://www.adelphia.com>





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
 - The eye tracking system opened the website to be tested (or another site) for the user

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Task: HQ location <http://www.agere.com>

agere

systems

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Gigabit Ethernet
 Single Phy, Octal Phy and switch-on-a-chip solutions
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A. T. Duchowski (Clemson University)

Eye Tracking Technology

Univ. Autònoma de Barcelona

33 / 65

NN/g

Task: HQ location <http://www.agere.com>

The screenshot shows the Agere Systems homepage. The navigation menu at the top includes links for ABOUT AGERE, PRODUCTS, SALES, NEWS, INVESTORS, CAREERS, SITE MAP, and CONTACT US. The left sidebar contains a 'Find Your Product' section with links for By Application, Part Number Listing, Products A-Z, and Documentation Library. Below this is a search bar and a list of 'Agere Fast Links'. The main content area features a 'Welcome' message, a 'Highlights' section with three featured articles (Gigabit Ethernet, TrueAdvantage, and Lead Free), and a 'Products A-Z' section with four categories: ENTERPRISE AND NETWORKING, MOBILITY, STORAGE, and TELECOMMUNICATIONS. Each category has a list of products and a 'More >>' link. The footer contains copyright information and a link to the Terms of Use and Privacy Statement.

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

Adelphia

HOME ABOUT US CONTACT US EMPLOYMENT PRESS ROOM

Cable Entertainment

The new vision of cable. Get Classic, Digital Cable, HD and DVR from Adelphia.

[Learn More](#) [Sign Up Now](#)

Exclusive Web Offer!
Order Classic or Digital Cable and get \$50 Cash!

[SIGN UP NOW](#)

High-Speed Internet

Enhance your online experience with High-Speed Internet.

[Learn More](#) [Sign Up Now](#)

Exclusive Web Offer!
\$19.95 per month for 3 months

[SIGN UP NOW](#)

Savings and Services

See what savings and services are available in your area.

Enter zip code: [Go>](#)

Bundled Savings Television Advertising Product User Guides Other Services

Customer Center

- Contact Us
- Cable Entertainment Support
- High-Speed Internet Support
- Frequently Asked Questions (FAQ)
- Pay/View Your Bills

Quick Links

- Pay Per View - What's On
- Adelphia en Español
- Adelphia Southern California
- Parental & Content Control
- Adelphia and Your Cable Services
- Careers

STOP PLAYING GAMES WITH A DISH.

[Click Here to Contact Customer Support](#) [GO>](#)

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

Adelphia

HOME ABOUT US CONTACT US EMPLOYMENT PRESS ROOM

Cable Entertainment

The new vision of cable. Get Classic, Digital Cable, HD and DVR from Adelphia.

Learn More Sign Up Now

Exclusive Web Offer!
Order Classic or Digital Cable and get \$50 Cash!

High-Speed Internet

Enhance your online experience with High-Speed Internet.

Learn More Sign Up Now

Exclusive Web Offer!
\$19.95 per month for 3 months

Savings and Services

See what savings and services are available in your area.

Enter zip code: Go>

Bundled Savings Television Advertising Product User Guides Other Services

Simplify your life with Adelphia's Automated Bill Pay Services. Click [here](#) to get started.

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Task: Learn about Mikhail Baryshnikov

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



welcome to danceworks

creative dance in the isle of man

the school

DanceWorks is one of the longest established schools of ballet and theatre/craft in the Isle of Man. In the School section you will find timetables, how to join us and an archive of past productions as well as pictures of some of our pupils past and present. Our new Syllabus section includes a full, illustrated lexicon of the terminology used in all levels of the dance disciplines we teach. Our sister companies - Perform and BodyWorks - build on the basic techniques learned in the school. Perform gives pupils valuable experience in performing in regular concerts. BodyWorks gives adults of all ages a workout to imaginative dance routines.

sidesteps

SideSteps is the information centre of DanceWorks Online - a window into the wider world of ballet and contemporary dance. There are a great many articles on the history and development of ballet as well as dance companies, dancers, choreographers and musicians. We also have links to other sites and listings of recommended books, DVDs, videos and CDs.

contact and other information

Our about us pages cover all the essential contact details as well as browsers, audio/video and legal information. We sincerely hope you enjoy the site. If you have any comments or suggestions, feel free to email us. Or if you want to know more about us, send us your details and we'll be in touch.



- How to join the school
- Find out more about DanceWorks
- Join our mailing list

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Task: Learn about Mikhail Baryshnikov

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



Poor Calibration Examples

Lean back →



Lean back →



← Lean left



Lean back →



← Lean left



Lean forward →



Lean on chin →



Lean on chin →



Hand on chin →



Hands up →



Hands up →



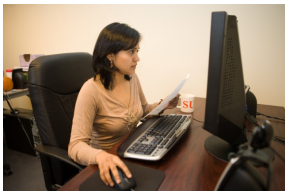
← Task sheet up



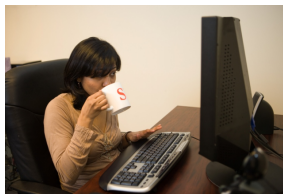
Hands up →



← Task sheet up



Cup up →



Glasses low →



Glasses low →



Hat low →



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

How to Amend Poor Calibration Situations

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

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 - Be gentle

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 - Be gentle
 - Always warn during set-up that you may change (correct) a situation

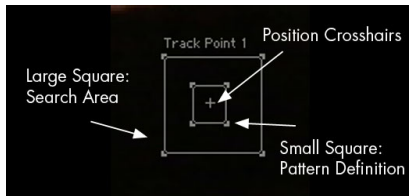
Advanced Considerations

- High-level metrics:

- transition matrices,
- scanpath comparison.

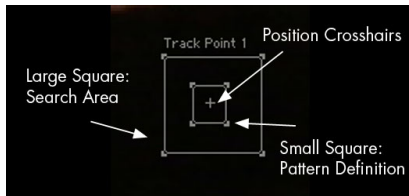
- Dynamic AOIs:

- often the best approach: re-instrument the app;
- source code is required of course;
- alternative approach: integrate motion tracking software;
- Apple's Shake, for example, tracks AOIs, exports coords.



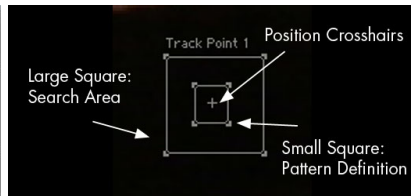
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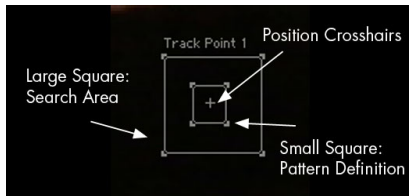
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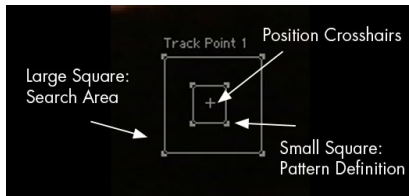
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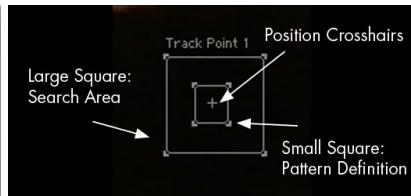
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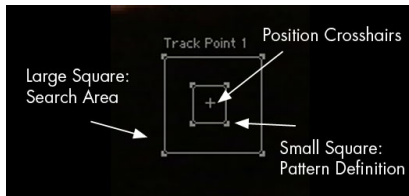
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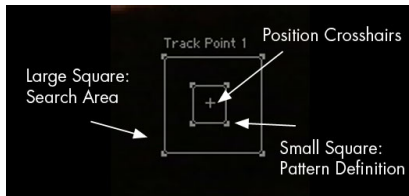
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One Approach to Scanpath Comparison

- 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).

$s_1 = \text{abcfeffgdc}$ $s_2 = \text{afbffdcd}$	start	cost 0
$s_1 = \text{abcfeffgdc}$ $s_2 = \text{afeffdcdf}$	after substitution of first b by e	cost 1
$s_1 = \text{abcfeffgdc}$ $s_2 = \text{abcfeffdcdf}$	after insertion of bc after first a	cost 2
$s_1 = \text{abcfeffgdc}$ $s_2 = \text{abcfeffdc}$	after deletion of last df	cost 2
$s_1 = \text{abcfeffgdc}$ $s_2 = \text{abcfeffgdc}$	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 $s_2 = afbffdcd$.

	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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e	4	3	3	3	3	3	4	5	6
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Y-matrix structure

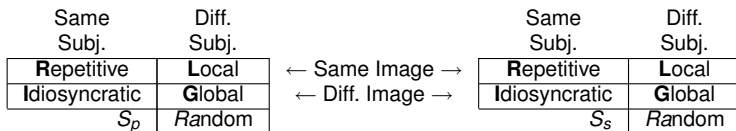
S_p	Subj. 1		Subj. 2		S_s	Subj. 1		Subj. 2	
	Pict1	Pict2	Pict 1	Pict 2		Pict1	Pict2	Pict 1	Pict 2
S1P1	R	I	L	G	S1P1	R	I	L	G
S1P2		R	G	L	S1P2		R	G	L
S2P1			R	I	S2P1			R	I
S2P2				R	S2P2				R

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

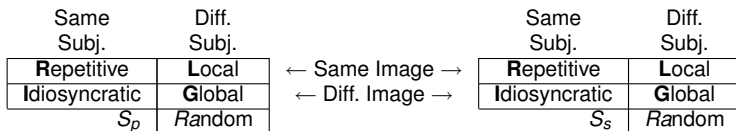
- Parsing diagrams contain averages of similarity coefficients collected from Y-matrices and consist of four main entries:
 1. **Repetitive**: same viewer looking at same scene at different times;
 2. **Local**: different viewers looking at the same scene;
 3. **Idiosyncratic**: same viewer looking at different scenes; and
 4. **Global**: different viewers looking at different scenes.
- A *Random* entry is included for significance testing.



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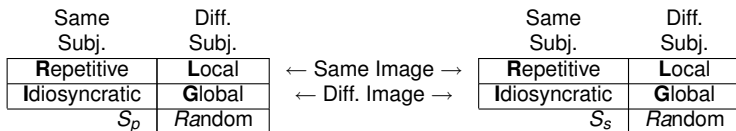
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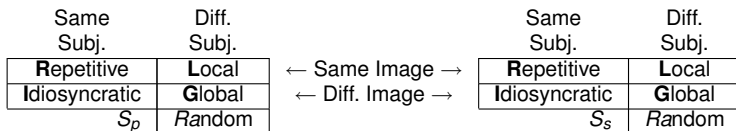
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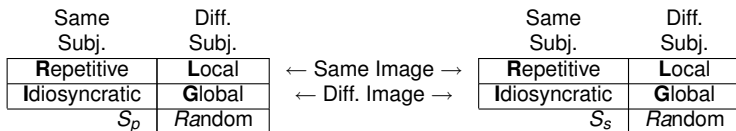
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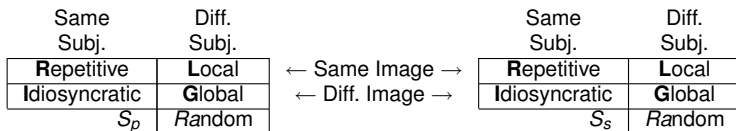
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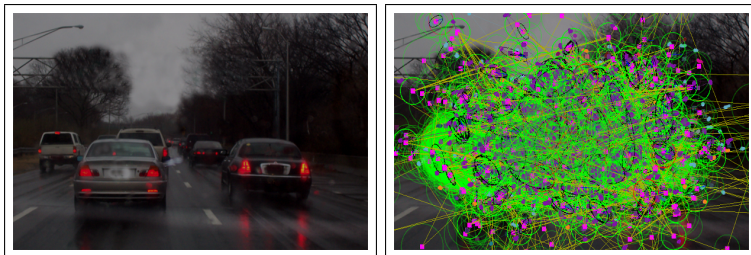
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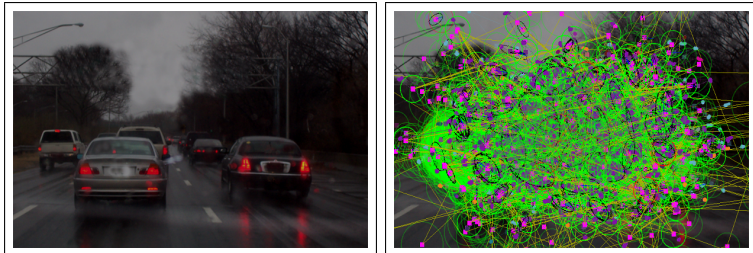
Preliminary Results: Brakelight Study



Human and random scanpaths with overlapping clusters.

- Number of scanpaths: 42 (21 subjects, each seeing two images).
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Same Subj.	Diff. Subj.		Same Subj.	Diff. Subj.
–	0.73	← Same Image →	–	0.20
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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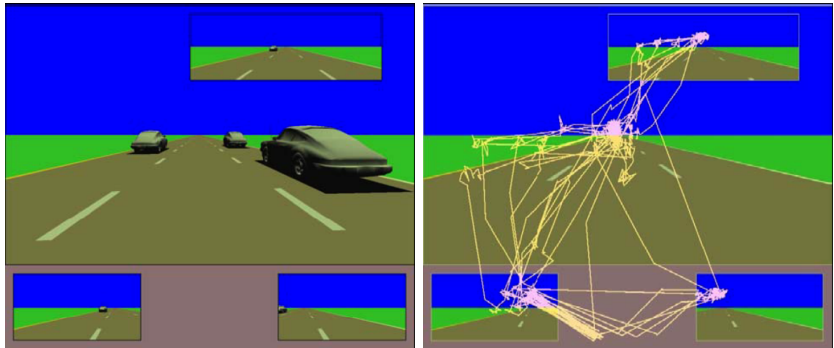
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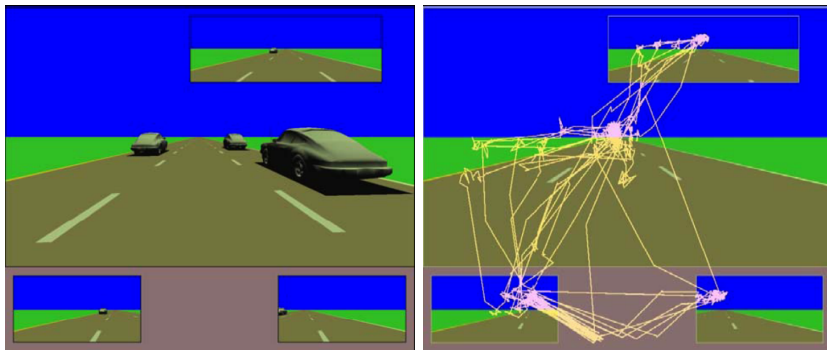
Dynamic AOsIs: Simulators

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- Key component was registration of fixations over moving vehicles.

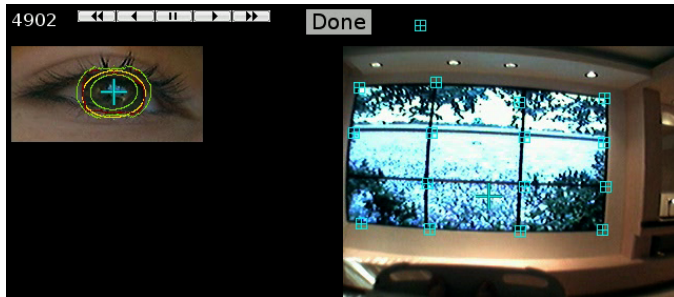


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Dynamic AOIs: Dynamic Media



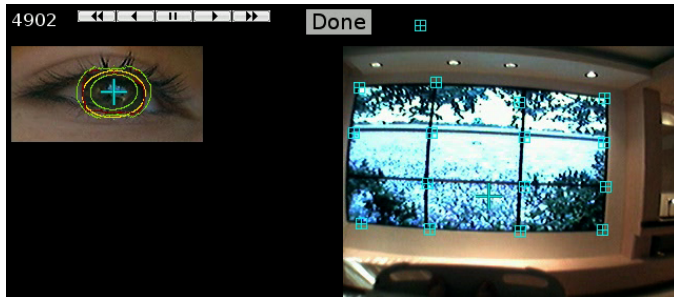
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Dynamic AOIs: Shake Rotoshape

```

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 ...

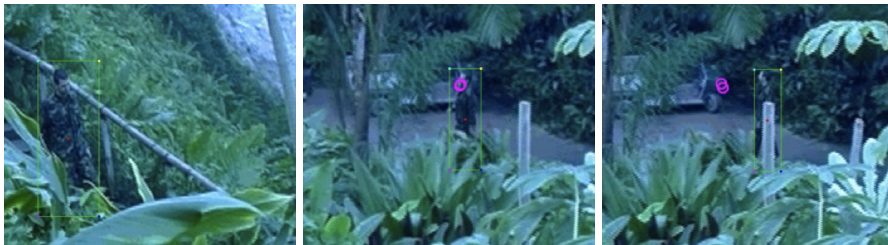
```

...



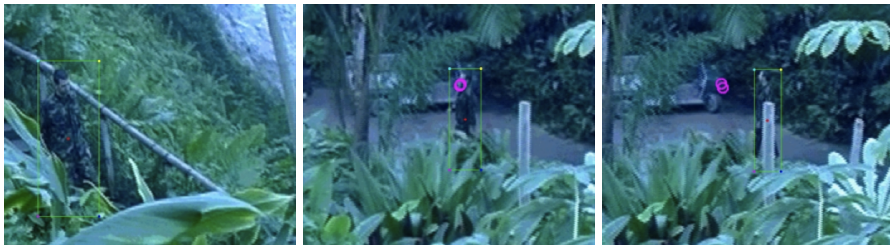
Couple of examples: image analysis

Example: Video



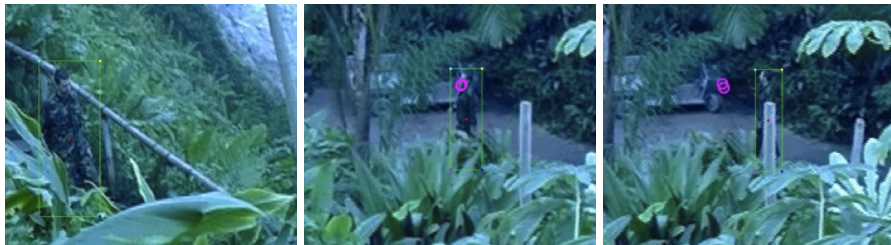
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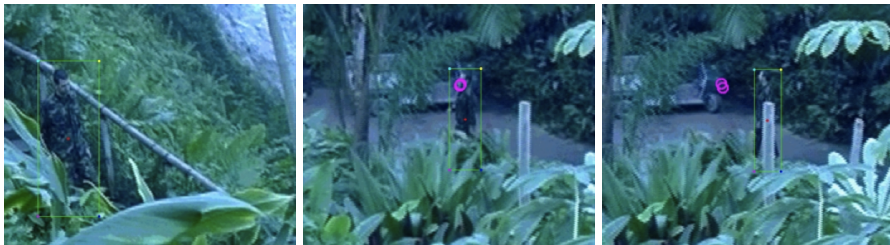
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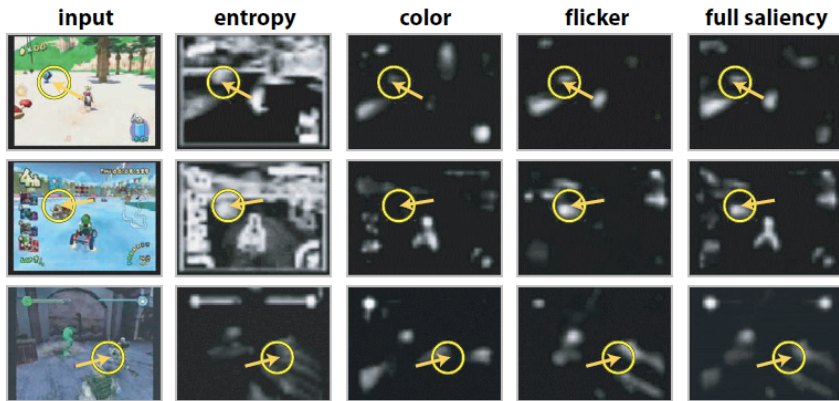
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Example: Virtual Environments



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

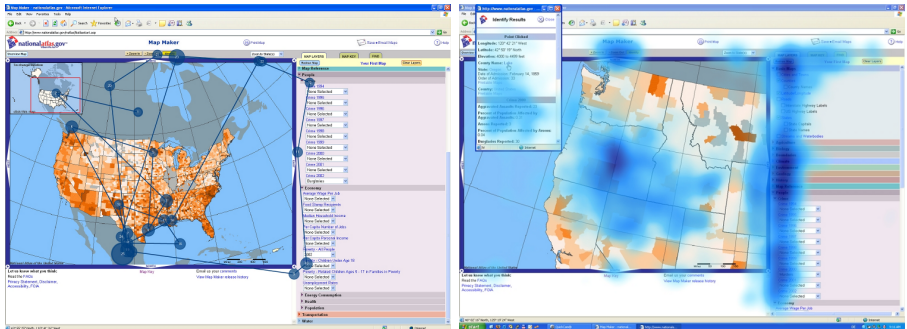
Couple of examples: image synthesis

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?
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- 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

- Thank you.
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