Research Experience for Undergraduates: Re-instrumenting a UI for Eye Movement Recording and Analysis (in Eight Weeks)

Andrew T. Duchowski

School of Computing, Clemson University

Queens University 2009, 6 August, Kingston, ON, Canada

Abstract

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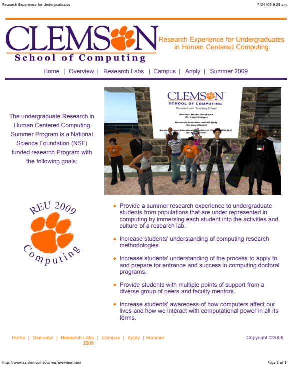
Results and lessons learned are presented from a Research Experience for Undergraduates (REU) summer program at Clemson University. The talk describes two studies conducted by the REU students during their eight week internship. The first, a collaboration with the Psychology Department, involved re-instrumentation of a web-based tractor simulator for recording of eye movements and interaction events during operation of the mock interface. The second involved empirical validation of scanpath comparison metrics featuring a Trail Making Task experimental paradigm. Results from the second experiment help validate the utility of scanpath similarity metrics in supplementing analysis of performance metrics (speed, accuracy) captured in the first experiment. Specifically, comparison of scanpaths helps explain performance differences observed between cultural groups performing the first experiment.

Research Experience for Undergraduates (REU)



Research Experience for Undergraduates 7/24/09 9:25 am

CLEMSON School of Computing

Research Experience for Undergraduates in Human Centered Computing

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REU 2009 Computing

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- Increase students' awareness of how computers affect our lives and how we interact with computational power in all its forms.

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http://www.cs.clemson.edu/reu/overview.html Page 1 of 1

Main REU web page

- The Clemson REU is a summer internship program
- Funded by the NSF
- Theme: *Human Centered Computing*
- Focus is placed on under-represented populations
- Idea is to expose undergrads to research environment
- A subgoal is to encourage graduate school enrollment

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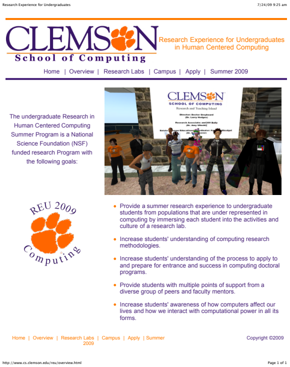
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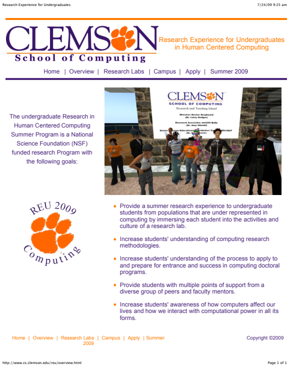
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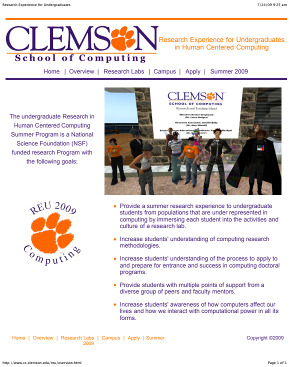
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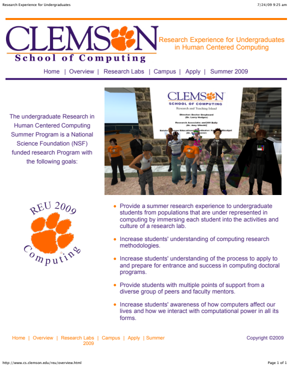

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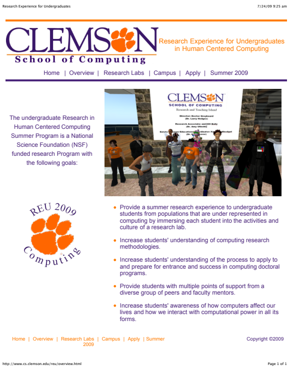
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REU students in eye tracking lab and VE lab

- Students split into two groups:
  - Eye Tracking (Prof. Andrew Duchowski)
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- My first time leading REU group
- Key questions for me:
  - how to keep five students occupied for eight weeks, and
  - how to get meaningful work accomplished
- Drawing on experience from eye tracking class at Clemson, a complete project usually takes 16+ weeks (difficult to complete in one semester)
- My strategies:
  - finish work started earlier (data collection, analysis)
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- Examine cultural differences during user interaction of Deere simulator
- Original interface was web-based (Flash)
- Lacking source code, could not re-instrument original app
- Considered off-the-shelf software (Tobii's ClearView) but web page could not be displayed
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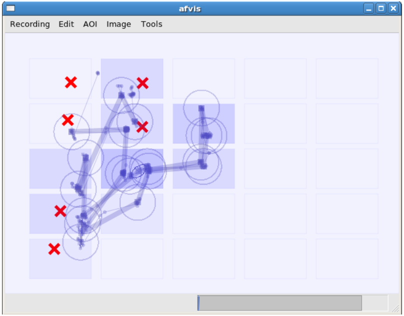

- Custom app built on image viewing program with menus
- Development carried out in `C++`, `Qt`, and `OpenGL`
- Besides eye movements, program enhanced to track mouse clicks and AOIs
- Interaction simulated by toggling button texture maps

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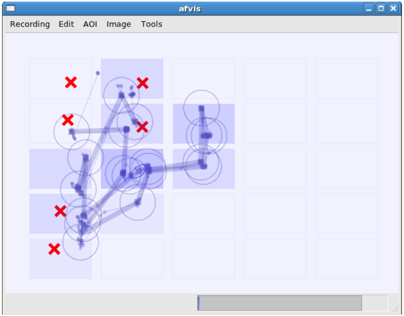

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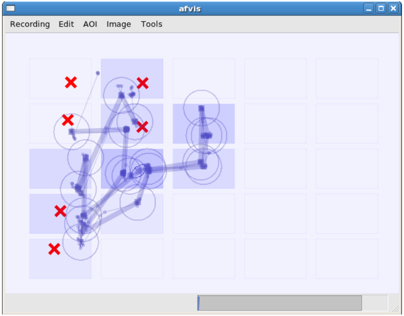

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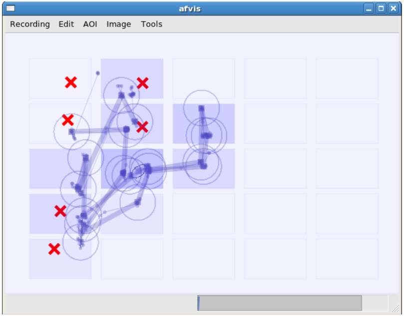

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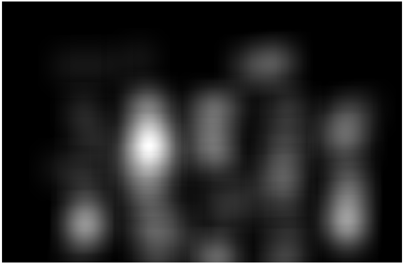

- Heatmap visualization (Wooding, 2002) uses a Gaussian kernel to deposit intensity at fixation coordinates (x, y)

$$H(x, y) = \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right), \quad x, y \in [-2\sigma, 2\sigma]$$

- The kernel is truncated beyond 2σ (Paris & Durand, 2006), limiting pixel processing to $(2\sigma)^2$ instead of n^2 where n is the image size (currently $\sigma = 25$)

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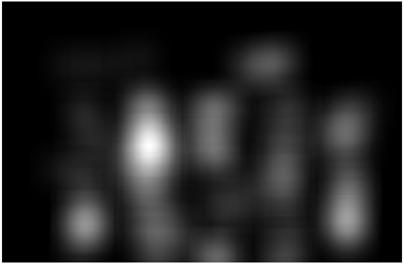

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Experiment 1: Experimental Design

- Subjects: 20 college students (13 M, 7 F; ages 22-28, median age 24)
  - Group split evenly among Easterners and Westerners
  - All Easterners were of East Indian descent
- Stimulus: partial simulator, shown at 1280 $\times$ 1024 resolution
- Procedure: 5-point calibration sequence, followed by four trials, two involving search of menu items, two involving search of icons (order counterbalanced via Latin Square)
- Apparatus: Tobii ET-1750 video-based corneal reflection (binocular) eye tracker

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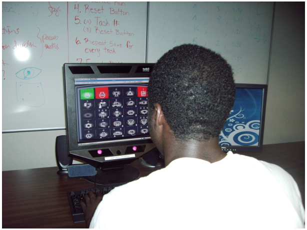
Experiment 1: Pilot Testing



- Pilot testing exposed various programming problems, i.e., need for proper labeling of files, study, and subject numbers in file headers
- Various other programming as well as procedure problems were also resolved, e.g., should users press the *Start Engine* button every trial?
- Decision was made not to record eye movement data when menus active (scanpaths would show inflated activity over top-left icons)

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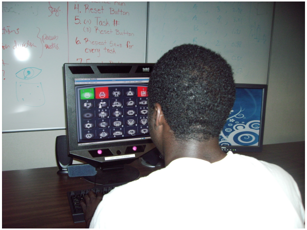

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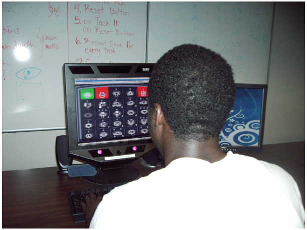

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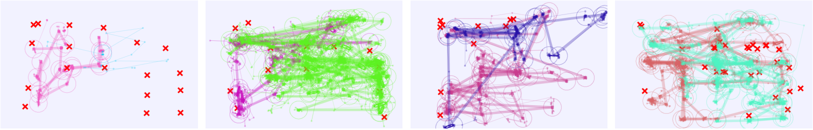
Experiment 1: How to Process Scanpaths?



- Pilot testing produced numerous scanpaths and dilemma of what to do with them
- Scanpath inherently encodes time to completion (*performance*)
- Mouse clicks provide accuracy information
- What about *process* measures?
- It would be nice to quantitatively compare scanpaths between cultures—*how* did they perform tasks?

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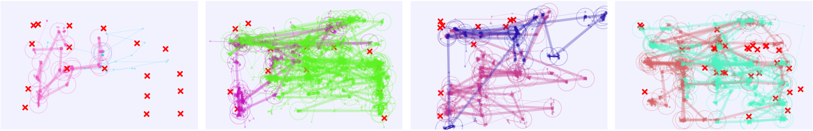

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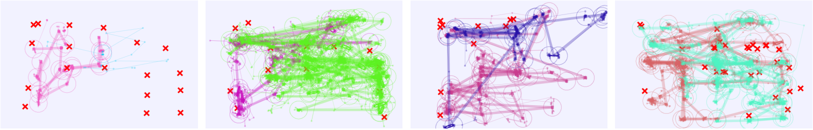

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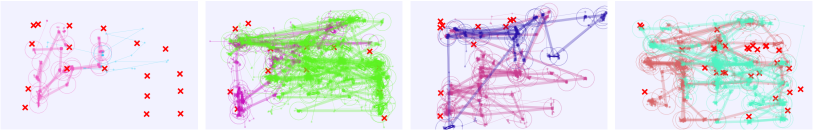

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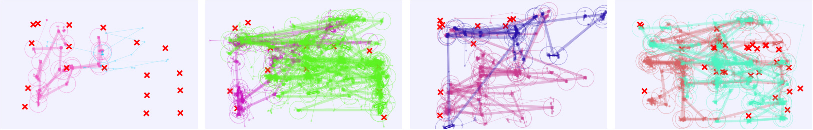

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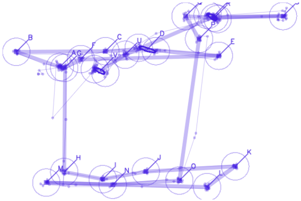

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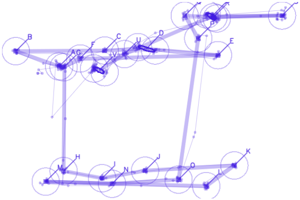

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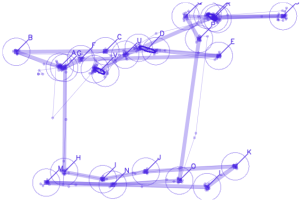

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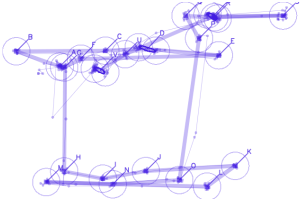

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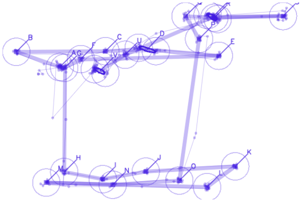

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- Given two strings $s_1 = abcfeffgdc$ and $s_2 = afbffdcdf$, construct 10×9 array
- Assign cost of character *deletion*, *insertion*, or *substitution*
- Use genetic programming to arrive at transformation cost
- Normalize total cost to the length of the longer string, in this case 9, yielding $S_s = (1 - 6/9) = 0.33$

	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
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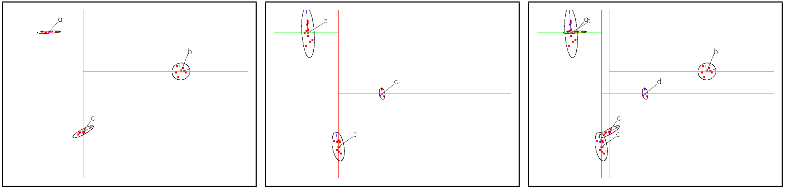

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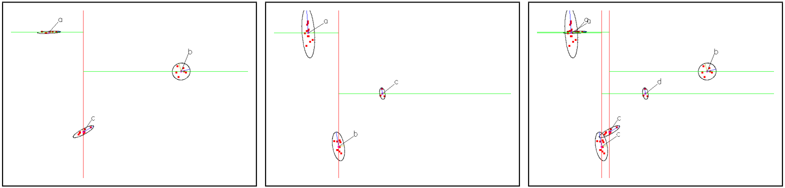

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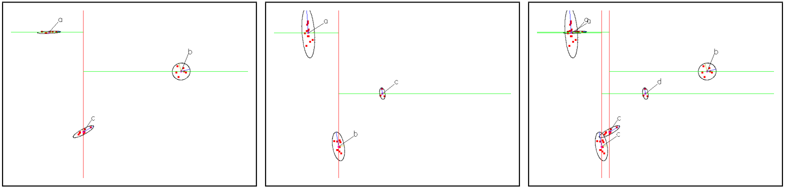

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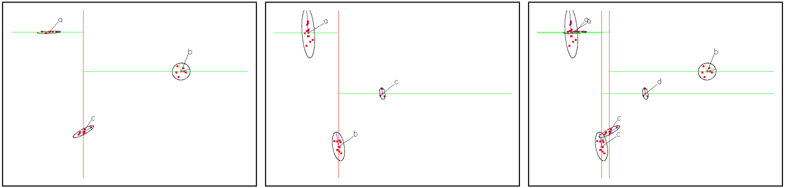

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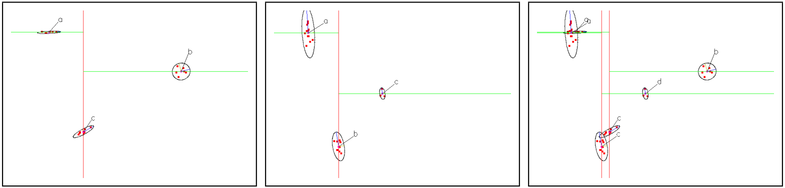

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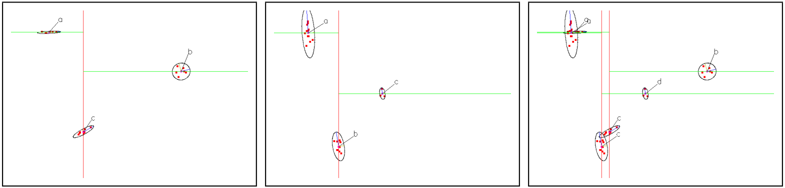

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	Pict 1	Pict 2	Pict 1	Pict 2
S1P1	**R**	**I**	**L**	**G**
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S2P1			**R**	**I**
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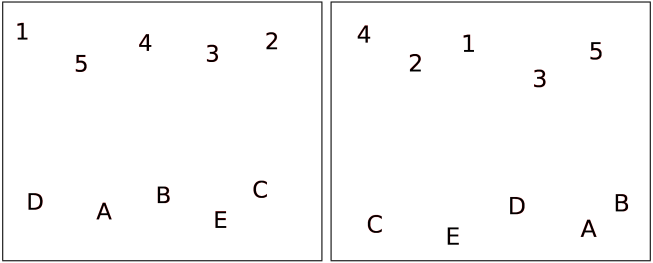

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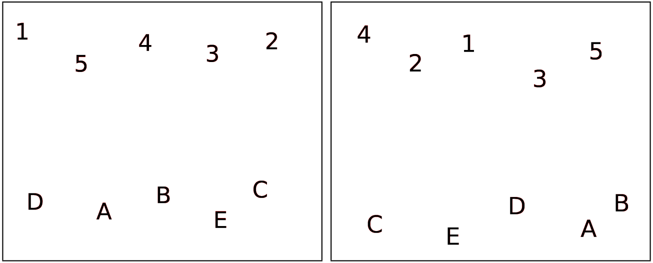

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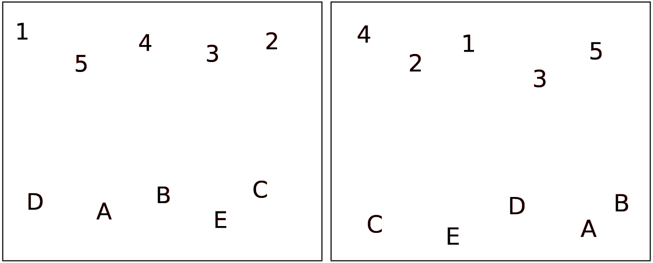

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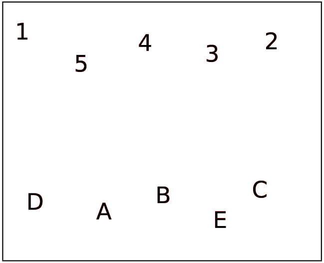

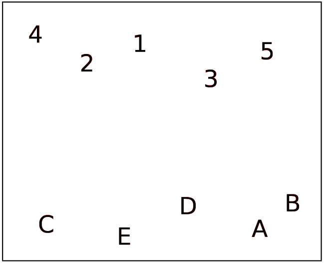

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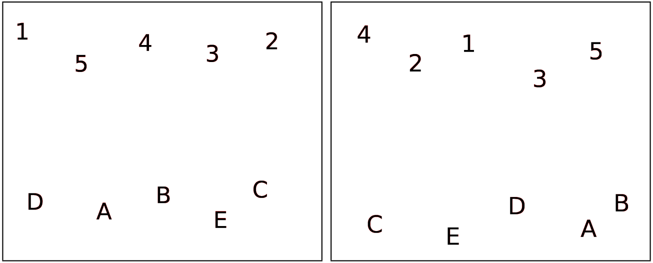

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Experiment 2: Experimental Design

- Subjects: six college students (4 M, 2 F; ages 18-27, median age 21)
  - results from the TMT should be stratified by age and education (Tombaugh, 2004); our sample represents one such strata
- Stimulus: two 1280 $\times$ 1024 images
- Procedure: 5-point calibration sequence, followed by TMT-A, and TMT-B, each image viewed twice (order not counterbalanced)
  - participants were asked to view the sequences as quickly as possible but dwelling over each number or letter for a fraction of a second (they were aware of the underlying fixation algorithm)
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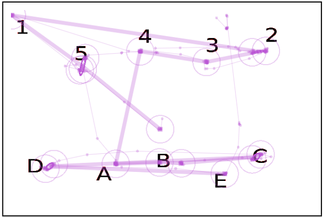

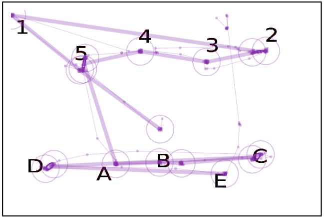

- Mean shift clustering of fixations $\mathbf{x}_i = (x_i, y_i, t_i)$ depends on the use of a kernel function (Santella & DeCarlo, 2004)

$$K([\mathbf{x}_i, t_i]) = \exp\left(\frac{x_i^2 + y_i^2}{\sigma_s^2} + \frac{t_i^2}{\sigma_t^2}\right)$$

  where σ_s and σ_t determine local support of the kernel in both spatial (dispersion) and temporal extent
- Pilot testing revealed the importance of both spatial and temporal support

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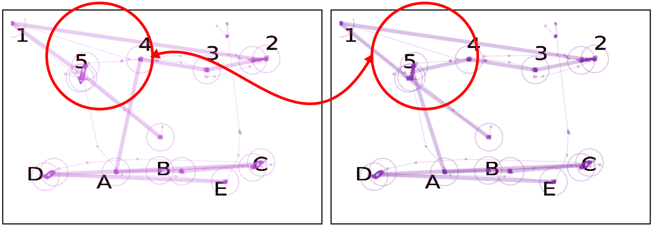

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Experiment 2: Aggregate Results

	SS	DS
SI →	**R**epetitive 0.65 F(1,22) = 98.2, $p < 0.01$	**L**ocal 0.47 F(1,238) = 848.2, $p < 0.01$
DI →	**I**diosyncratic 0.44 F(1,46) = 165.4, $p < 0.01$	**G**lobal 0.44 F(1,238) = 884.0, $p < 0.01$
	S_p	Random 0.06

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- Statistical significance derived from random scanpath comparisons
- Position indices > sequence indices
- Repetitive indices show highest correlations
- Repetitive position index is comparable to previous work (0.65 vs. 0.64)
- Key difference here is task (TMT vs. free viewing)
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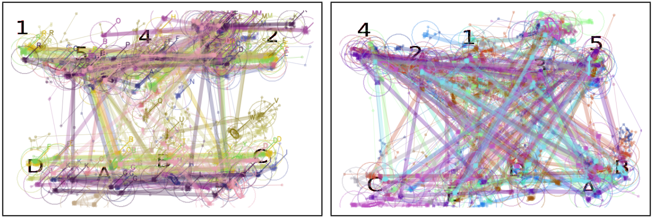
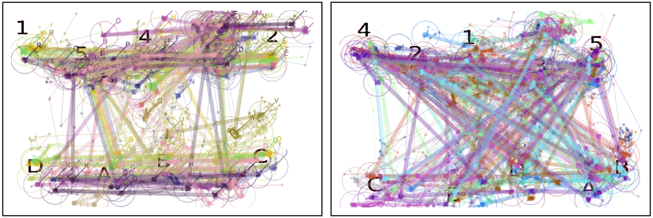
Experiment 2: Segregate Results: TMT-A vs. TMT-B



- Aggregate statistics tend to obscure processes related to individual behaviors or stimuli
- Analysis over just TMT-A and TMT-B shows that repetitive (and local) scores are higher for TMT-A
- TMT-A relies mainly on visual search and should therefore be easier to execute (fewer errant saccades)

Experiment 2: Segregate Results: TMT-A vs. TMT-B



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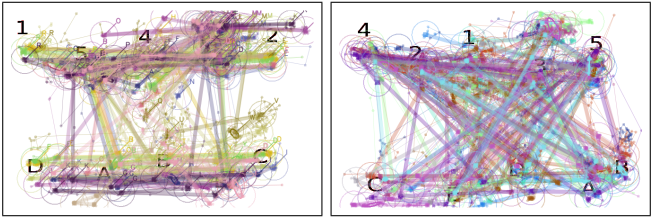

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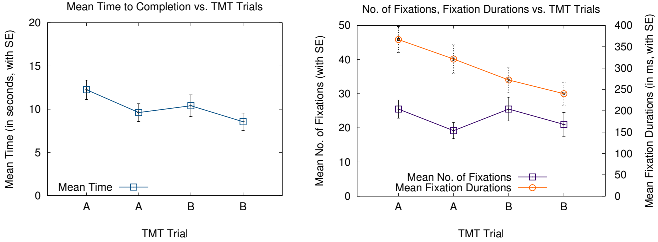

- TMT-B's lower S_p, S_s suggest increased cognitive difficulty
- However, repeated measures ANOVA only shows a marginally significant main effect of trial on speed, and ...
- ... time to completion decreases, suggesting decreased cognitive difficulty (opposite of what was expected)
- Process measures suggest **learning effect** as fixation durations decrease significantly across trials but the number of fixations do not

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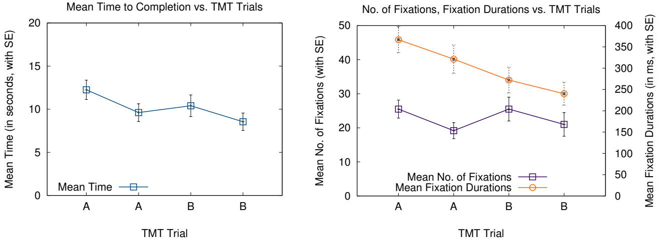

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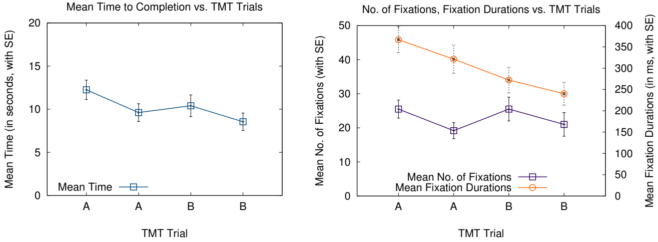

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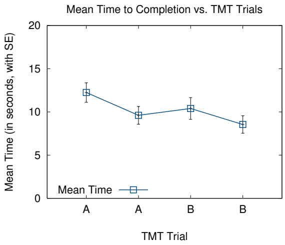

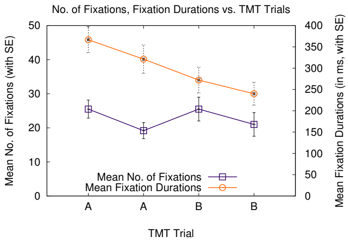

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- Construction of a *k*d-tree facilitates efficient lookup ($O(\log n)$ average time per search)
- The combination of these algorithms removes prior reliance on preevaluation and human intervention
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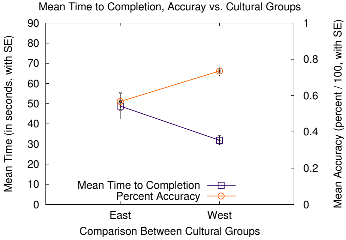
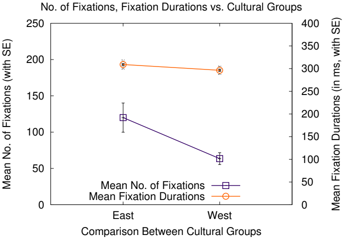
Back to Experiment 1 . . .

- Armed with scanpath comparison, examine data generated by Experiment 1

Experiment 1: Analysis Between Cultures





- Significant difference in time to completion
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  - Westerners more accurate
- Significant difference in no. of fixations
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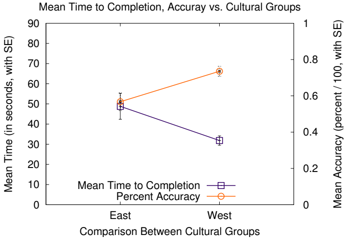

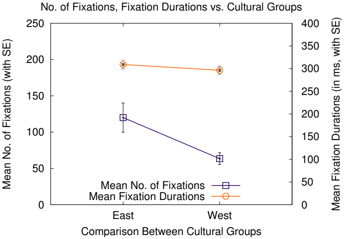

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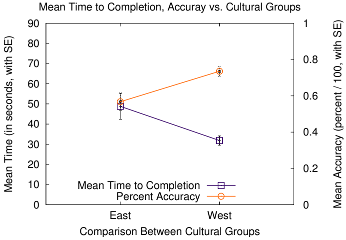

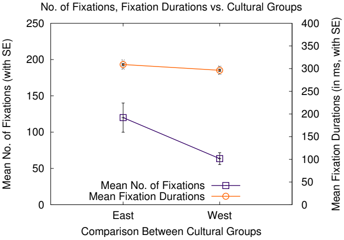

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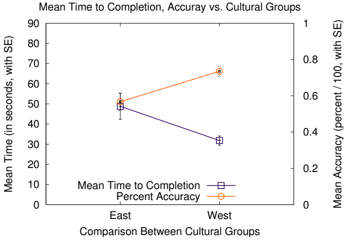

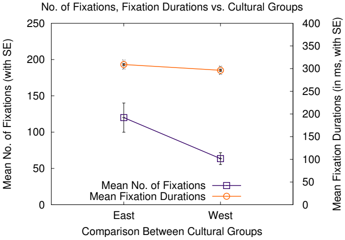

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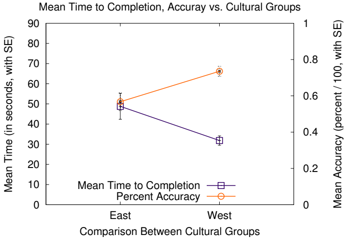

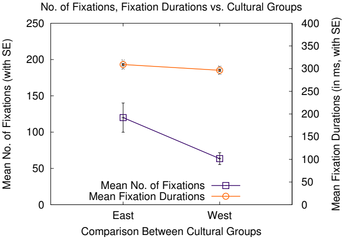

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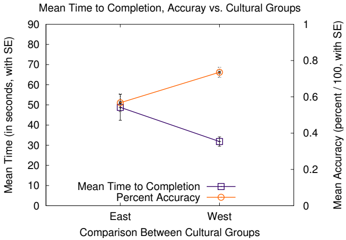

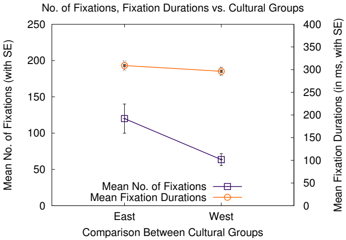

- Significant difference in time to completion
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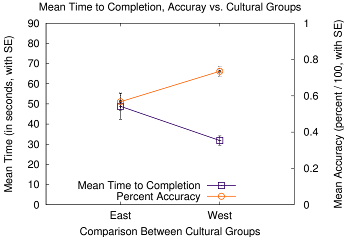

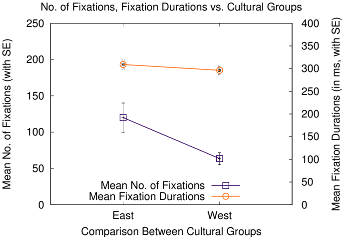

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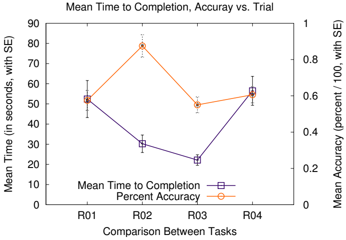

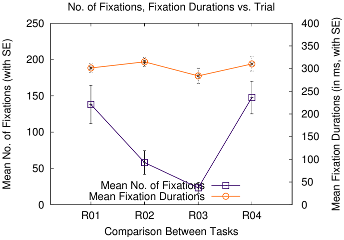

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  - menu search more accurate, but only in one instance (R02)
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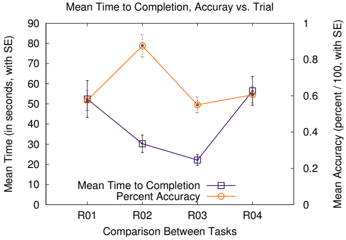

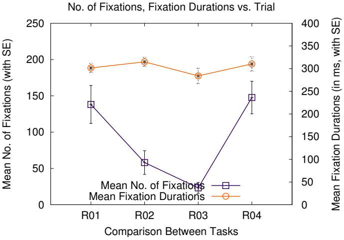

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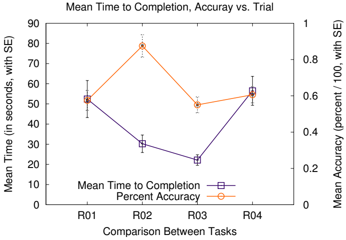

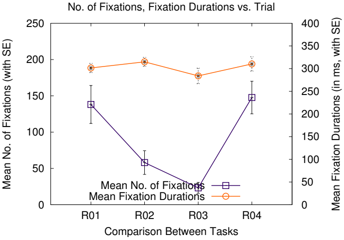

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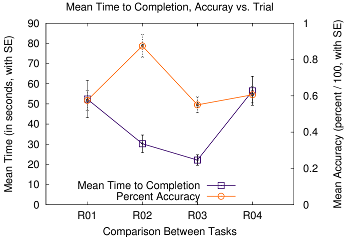

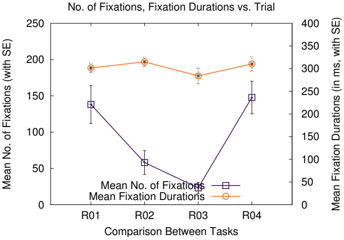

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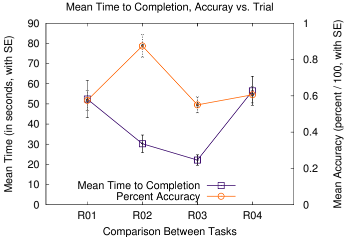

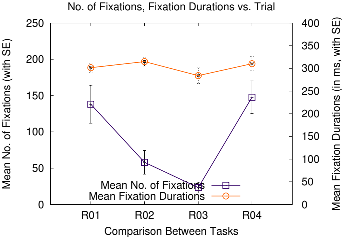

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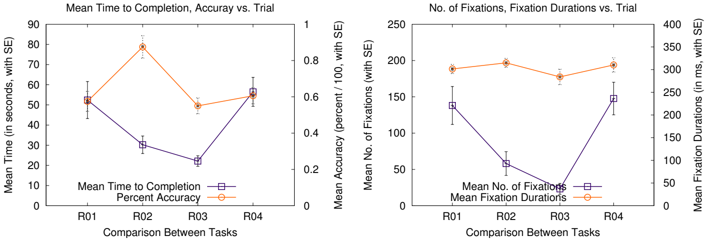

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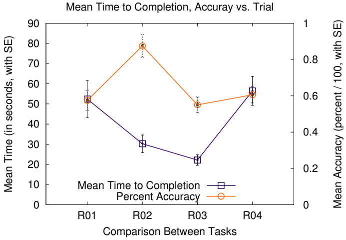

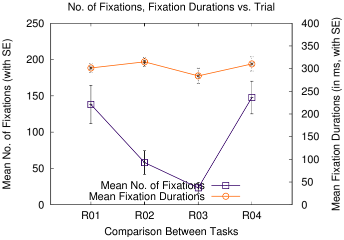

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Experiment 1: Aggregate Scanpath Comparison

	SS	DS
SI →	**R**epetitive 0.65 F(1,38) = 69.3, $p < 0.01$	**L**ocal 0.61 F(1,1518) = 810.2, $p < 0.01$
DI →	**I**diosyncratic –	**G**lobal –
S_p		Random 0.33

	SS	DS
SI →	**R**epetitive 0.15 F(1,38) = 13.8, $p < 0.01$	**L**ocal 0.12 F(1,1518) = 18.5, $p < 0.01$
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S_s		Random 0.11

- Position indices > sequence indices
- Repetitive indices show highest correlations
- Repetitive position index is comparable to previous work (0.65 vs. 0.64)

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Experiment 1: Westerners' Scanpath Comparison

	SS	DS
SI →	**R**epetitive 0.67 F(1,18) = 59.0, $p < 0.01$	**L**ocal 0.69 F(1,358) = 1224.4, $p < 0.01$
DI →	**I**diosyncratic –	**G**lobal –
	S_p	Random 0.32

	SS	DS
SI →	**R**epetitive 0.17 F(1,18) = 20.0, $p < 0.01$	**L**ocal 0.15 F(1,358) = 117.1, $p < 0.01$
DI →	**I**diosyncratic –	**G**lobal –
	S_s	Random 0.11

- Position similarity, with **L**ocal > **R**epetitive indices, suggests that Westerners tend to look at the same image regions (**L**), but they may vary their strategy when inspecting the same image (**R**)—an adaptive strategy?

Experiment 1: Easterners' Scanpath Comparison

	SS	DS
SI →	**R**epetitive 0.66 F(1,18) = 25.5, $p < 0.01$	**L**ocal 0.55 F(1,358) = 211.8, $p < 0.01$
DI →	**I**diosyncratic –	**G**lobal –
	S_p	Random 0.25

	SS	DS
SI →	**R**epetitive 0.14 F(1,18) = 3.8, $p = 0.06$, n.s.	**L**ocal 0.11 F(1,358) = 16.2, $p < 0.01$
DI →	**I**diosyncratic –	**G**lobal –
	S_s	Random 0.09

- Easterners may be doing the reverse: with position similarity **R** $>$ **L**, they may be repeating the same strategy (**R**), one that visits a larger number of different regions (**L**)
- Note the lack of significant difference in repetitive sequence similarity

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Westerners' and Easterners' heatmaps

- Scanpath comparison shows how the two groups examined the interface
  - Westerners appeared to be more focused, visually covering less of the interface
  - Easterners appeared to be more systematic in search for icons, using a strategy apparently no different from random
  - heatmaps support this qualitatively

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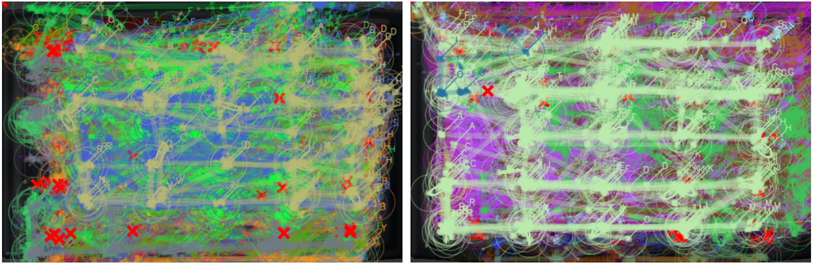

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- Westerners outperformed Easterners in both speed and accuracy
- Reason for disparity may be different scanning patterns (perhaps due to familiarity with vehicular symbols)

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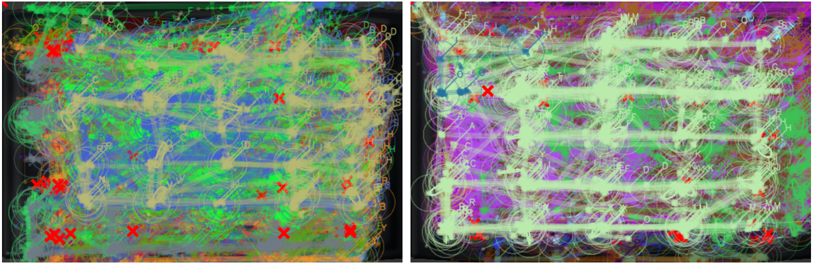

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- Important to remember that eye movement recording was turned off during menu search
  - skews between-task comparison of no. of fixations . . .
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General Discussion

- Scanpath comparison adds another dimension to traditional speed/performance analysis
- Quantification of position and order similarity appears to provide useful information (e.g., pointing out similarity to random order)
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Conclusion & Future Work

- REU program allowed completion of earlier and newly developed work
- Success of undergraduate research experience may be rooted in sufficient preparation, i.e., what's already in place, e.g., tools
  - `C++`
  - `Qt`
  - `OpenGL`
  - `subversion`
  - `R`
  - `gnuplot`
  - LaTeX

  and works-in-progress, such as scanpath comparison code and/or idea(s) for empirical study

Questions

- Thank you
- Comments, Questions?

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