White Paper: *Learning How Visitors Look: Applications of Eye Tracking Experiences by the Indianapolis Museum of Art*

1. Administrative Information

- **Institution:** Indianapolis Museum of Art
- **Project Title:** *Learning How Visitors Look: Applications of Eye Tracking Experiences by the Indianapolis Museum of Art*
- **Award Amount and Total Project Cost**: $23,781 (award amount) – $32,763.21 (cost)
- **Grant Start Date – Grant End Date:** 7/1/2011 - 6/30/2012
- **Project Director Names:** Rob Stein and Silvia Filippini-Fantoni
- **Formal Project Partner Organizations (as applicable):** N/A

2. Project Summary

Museums have many different ways to measure attendance in their galleries. From hand clickers to beam counters and even thermal cameras; however, they have made little progress towards understanding just what those visitors do when they enter the galleries. While still somewhat expensive, eye tracking technology offers the potential for museums to study at what specifically visitors are looking. Funded by an Institute for Museum and Library Services Sparks! Ignition grant, the Indianapolis Museum of Art (IMA) explored whether eye tracking technology could be useful to museums seeking to better understand how in-gallery visitors actually "see" the objects in their collections. In particular, the research project aimed to:

- Gauge the practicality of using such devices in a gallery setting.
- Determine the ability of current eye tracking technology to measure precisely how long and what people are looking at.
- Explore the potential use of this equipment in a practical setting, like a Visual Thinking Strategy (VTS) discussion, and as a way to activate content relevant to a work of art.

Through a set of three experiments carried out between November 2011 and May 2012, the IMA concluded that the range and accuracy limitations of current eye tracking technology make it difficult to use these devices as reliable and easy-to-implement tools to track where and when visitors look. While not suitable for a practical and large scale implementation in museums, eye tracking technology can be useful in a more experimental setting for in-depth analysis of specific interpretation strategies, such as Visual Thinking Strategies (VTS) discussions, and for training purposes.

3. Process

The research project was developed through a cross-departmental collaboration between the IMA Audience Engagement department, which managed the overall process and organized the three experiments, and the IMA Lab, which was in charge of equipment purchase and testing, software development, and data analysis. Additional support was provided by the IMA Publishing and Media department, whose representative was in charge of video recording the last experiment, as well as from other museum departments, which provided volunteers for the experiments.

The majority of grant funds supported the purchase of equipment and software, which was obtained at a discounted rate ($12,500 – see the "Project Results" section for more information). The remaining funds were used to underwrite half of the staff time necessary to implement and analyze the three experiments, as well as cover expenses to send an IMA representative to the Museums and the Web 2012 Conference, where initial results were presented.

While the experiments were successfully implemented on schedule, the IMA had to reconsider some of its original objectives throughout the course of the project due to limitations of the eye tracking device, which became evident during the initial experiments (see "Project Results" section for more information). In particular, it was decided to forego the testing of the device's ability to play audio content related to specific details of the work of art, depending on where participants were looking, as the tools did not provide enough accuracy to implement this in an effective manner.

While in the original proposal the IMA had planned to carry out the experiments with both staff and visitors, the nature of the eye tracking installation was not conducive to working with visitors. Its complex set up and location in the middle of one of the main galleries made it necessary to carry out the experiments on a Monday when the museum is closed to the public. Additionally, accuracy problems with the equipment required repeating the tests with the same participants for comparison, making it impossible to work with visitors.

4. Project Results

Useful findings were derived from each of the five main aspects of the project: device selection, device testing, and implementation of each of the three experiments. Such findings are briefly summarized in the sections below. For more information, please refer to the "Project-related Resources" section at the end of this report.

Selecting an eye tracking device

The first step in the process of setting up the experiments was to select an eye tracking device. Of the models available on the market, the IMA opted for the EyeTech Digital Systems VT2 eye tracker (*http://www.eyetechds.com/*). This device is designed to sit on the included stand or be mounted on the bottom of a display. During operation, the eye tracker emits infrared light toward the viewer and captures a series of images (called frames) with a camera. Each frame is analyzed by the tracker to determine whether a pair of eyes is looking toward the device. When the tracker is calibrated with a reference rectangle, it is able to compute gaze coordinates relative to that area. The software library supplied can report these and other parameters during operation.

The decision to purchase EyeTech for the experiments was driven by various factors. First of all, head-mounted trackers were ruled out because one of the project goals was to determine whether an eye tracking system could be used to detect the gaze of a visitor without encumbrance or requiring calibration. While there are open-source based systems and software platform tools (OpenCV), the IMA opted for a commercial solution. This is because the main objective of the grant was to test "usefulness and practicality" of such tools. Using an open source system or software platform tool would have implied a considerable amount of additional research and development time on the part of the museum. The IMA decided to use a solution already implemented by the eye tracking industry instead.

While requiring less development time, commercially available eye tracking systems tend to be very expensive, given that they are designed for consumer product research or laboratory trials. There are only a handful of companies that sell untethered gaze tracking cameras without head-mounted gear and with some degree of tolerance for varying eye position. EyeTech is one of them. Their product not only met the IMA's requirements at an affordable price, but the company was also willing to discount the system significantly, given that they were interested in exploring a potential implementation in museums.

Device testing

Despite the fact that the EyeTech Digital Systems VT2 eye tracker was the right choice for our experiments at that point in time, the product had some limitations particularly in regards to range. These restrictions became evident during initial discussions with the representatives from EyeTech, as well as during the initial device tests that were carried out to determine the design constraints for setup in the gallery.

Due to the attenuation of intensity from the infrared emitters and the characteristics of the lens, the tracker has an ideal viewing range that was found to be approximately 25 inches from the front panel. It also is unable to detect the eyes if they are looking too far past the left or right edges of the device (the field of view is about 36 degrees at this distance), or too high above the device.

In regards to the proposed experiments, detection of the eyes of a person with arbitrary height when standing was not reliable, as adjustments to the position and/or angle of the tracker was required. Therefore, the IMA's experimentation was restricted to a scenario in which the viewer was seated, with the tracker placed in a fixed position and orientation on a desk or pedestal approximately 50cm in front of the seat and 20cm below eye level (ideally anchored in place to reduce the risk of requiring recalibration if nudged). The boundary of the artwork also needed to be well inside the 36 degree field of view that the tracker is able to operate within.

Experiment 1 (November 2011)

After considering the limitations of the device, the objective of the first experiment was refined to assess the accuracy of the eye tracker, in terms of time and location a seated person's eyes spend looking at a work of art. In a live deployment, it would be ideal to avoid disrupting a visitor's normal patterns of viewing the art by requiring calibration, so a key component of the experiment was to test whether the device performed well when not calibrated for each participant.

The painting that was chosen for the experiment was Edward Hopper's *Hotel Lobby* due to it being on display for the grant period and having noticeable representational details that could be used to focus one's attention. This last aspect made it particularly suitable for a VTS discussion or to trigger audio content based on gaze location, which were two of the aspects that we had originally set out to test as part of experiment 2 and 3.The eye tracker was set up in the gallery and calibrated once to register the position of the painting. The person for whom this calibration was performed was also a participant in the last session of the experiment.

The experiment consisted of two phases. In phase one, the seat was placed at the distance determined to be ideal based on the preliminary tests and was not moved from that position. In phase two, before beginning the session the location of the seat was adjusted for each participant to test whether results could be improved without tilting the camera. Twenty-two IMA staff participated in the experiment, representing a range of heights. Some wore glasses. Ten people participated in phase one of the experiment, and twelve people participated in phase two.

Subjects' standing and seated heights were measured, as well as the distance from the floor to mid-eye level when seated. Over a period of sixty seconds, participants were asked to look in the field of the painting including the frame (referred to here as "in bounds"), then outside, and then directed back inside. Simultaneously, two research assistants observed the participants and used stopwatches to manually track time of gaze in bounds. These recorded times were then averaged and compared to the time tracked by the device to gauge accuracy. Research assistants also noted any movement by the participants.

In phase two, the procedure was as detailed above, but if the device did not pick up participants' gazes when first getting into position, participants were asked to move the seat until they could see their eyes reflected back in the device and the system reported that it could detect the eyes fairly consistently. The distance from the device to the new position of the seat was recorded, and the data recording session for the participant began.

Some participants from phase two were also asked to take part in a secondary experiment in which the ability of the device to accurately track gaze location when not calibrated for each viewer was assessed. Participants were instructed to look at six different areas within the painting (i.e., the blond woman's hair, the man behind the desk, the old man's face, the old woman's shoes, the old woman's hat, and the painting on the wall) for 10 seconds each. Tracker data was logged in the same manner as the other sessions.

The results of this first experiment, which are described in detail in Bactha et al., *Evaluating the Practical Applications of Eye Tracking in Museum,* presented at the Museums and the Web 2012 Conference (see "Project-related Resources" section), indicated that the eye tracker was unable to continuously capture data for the duration of each session and, as a result, to identify precisely the time spent by participants looking in and outside the painting. Allowing the viewer to adjust the position of the seat improved the accuracy, but not to the degree that the computed duration was a reliable measurement. When having participants sit, there was still enough variation in height that the eyes may not be in a good position for tracking, and it is likely that the frames of glasses interfere with the ability of the tracker to detect the eyes.

In an attempt to improve this performance, an algorithm was implemented to account for missing data within a certain threshold of time if the participant was looking in bounds before and after the gap. This algorithm was applied to the recorded data with thresholds of 100 milliseconds, 500 milliseconds, and 1 second. The algorithm appeared to improve the accuracy when a threshold between 100 and 500 milliseconds was used.

When it comes to the precision of the gaze location, the tracker was unable to report accurate coordinates in a gallery setting for un-calibrated viewers. The system, in fact, was only fairly accurate in tracking the horizontal component of gaze location and not accurate in tracking the vertical component.

Experiment 2 (February 2012)
Based on the accuracy issues that emerged in Experiment 1,it was decided to repeat the same sequence of steps for experiment 2, but in these sessions the device was calibrated for each participant to see if the results would be more accurate both in terms of time and location of the gaze within the painting.

Twelve IMA staff participated in this second experiment. These were selected amongst the 22 that had participated in the first experiment. Unlike the first experiment which took place in the gallery, this experiment took place in one of the IMA Adult Lecture rooms, where the exact size of the painting was reproduced on a white board. Specific points were drawn on the board and accuracy was judged at these points. The use of the board as opposed to a painting reduced the chance of distraction during this test of accuracy, and more exact reference points allowed for higher precision in evaluation.

The results of this second experiment, which are also detailed in the Museums and the Web presentation (see Project-related Resources sectionindicated that the tracker was able to log a larger quantity of valid data during each session. Gaze duration results were better than in the un-calibrated study, but still not 100% accurate.
Just like with experiment 1, time accuracy increased when we attempted to algorithmically compensate for missing data between valid frames. A 500ms gap handling proved to be more precise when applied.

Gaze location results were also better than in the un-calibrated study, but not as accurate as expected. The average error in gaze location when looking at a fixed point across all participants was 1.64 degrees. From the perspective of eye tracking research, it is debatable whether a difference in the range of 1-2 degrees should be considered an intentional change in gaze location. The best session had an average error of 0.144 degrees, and 6.22 degrees was the worst. It is clear that in some of the sessions it would not have been possible to distinguish between error and an intentional change in gaze location.

Experiment 3 (May 2012)
Given that the level of precision of the eye tracking device even when calibrated for each user was still not 100% accurate, it was decided for the third and final experiment to test whether the device was able to gauge where people were focusing their attention during a VTS session rather than as a way for people to access audio content related to specific details of the painting. The latter would have required more accuracy to be implemented in an effective manner.

Using the VTS method, educators regularly engage groups in interactive discussions seeking to draw out visitor thoughts regarding a work of art. While such discussions often provide unique insight into an individual’s thoughts about a work of art, direct measurements of the connection between viewing and thinking are often difficult and subjective.

In order to be able to assess whether eye tracking was a useful tool to examine the connection between gaze and response, as part of experiment 3, video recordings of five VTS sessions were made and synchronized with the data stream from the eye tracking hardware (to see the videos go to: http://ima.tc/eyetrackingsessions username: guest, password: optics).

During each five-minute VTS session, five people participated in the group discussion led by a facilitator. However, the gaze was tracked and recorded only for the participant who was sitting in front of the eye tracker and for whom the device was initially calibrated. Given the nature of the eye tracker, it would have been impossible to simultaneously track the gaze of all participants in a discussion with only one device. Participants were once again selected from IMA staff. In particular, those whose gaze was tracked were chosen amongst the ones with higher levels of accuracy during experiment 2.

During the five sessions the eye tracker was able to capture between 77% and 93% of the session depending on the participant. The percentage of time that the device was not able to track was either due to the limitations of the device highlighted above or to the fact that participants were looking outside of the trackable area. The actual width of trackable area depends on the seat position, but was about 12 inches, and might have only occasionally included the facilitator, who was constantly moving during the session.

In order to determine whether the video recordings could be useful in the field of VTS research and practice to study the ways in which visitors approach artworks in museum collections, we contacted a number of professionals who specialize in VTS. These specialists were asked to view the videos and communicate whether they would find any practical applications of this technology to their work, despite the limitations of the device.
In general, the VTS specialists who responded (five in total) found the recorded videos very useful, mainly as a tool for assessing the detailed effects of VTS as a discussion-based learning tool:

> " [by] following the eyes of people during a VTS discussion, you begin to get a sense of how individuals respond to the opportunity to look at images, to see what they look at as they speak, how they follow (mostly) what other people say, when they follow the pointing/paraphrasing aspects of VTS, ……….when they glance over at the facilitator." [Philip Yenawine, CoFounding Director of VTS/VUE].

Another important way in which these videos can be used according to Linda Duke, Director of the Marianna Kistler Beach Museum of Art, is as training tools for facilitators "to see changes in facilitation ability over time, or how the use of additional VTS questions, such as place, character, time, etc. could be explored as well."

While assessing the overall effects of VTS discussion on looking and facilitators' training are the two most obvious applications of eye tracking in VTS, the consulted specialists also provided other possible research opportunities offered by this technology, including:

- Tracking eye movements during a discussion where significantly different interpretations developed;
- Tracking eventual differences among students in first, second, or third years of the VTS curriculum;
- Tracking eventual difference when using VTS in the classroom versus an art museum environment, or compare the facilitation in both environments over time;
- Tracking a wider range of eye movement beyond the picture frame, possibly a range that captures nearby objects;
- Examining potential differences in group dynamics and audience types.

All VTS specialists also agreed that even though the device does not record the entire session, partial recordings would still be useful, “unless one wanted to examine flagging attention when a session lasts too long or loss of interest if an art image were poorly chosen” (Linda Duke). The device’s inability to record more than one session participant at a time, was also not considered a major limitation by the consulted specialists.

All in all, the feedback received from VTS specialists was positive, confirming that, despite the current limitations of the device, recording of visitors gaze through this type of eye tracker can be useful for the progress of VTS research and practice.

Recommendations and future plans
In conclusion, the three experiments conducted have pointed out that the device limitations in terms of range and accuracy make it difficult to use this type of eye tracker as a reliable and easy-to-implement tool to track where and when visitorslook. While not suitable as a practical implementation for measuring attention in museum galleries, this type of tool, however, can still be useful in a more experimental setting for in-depth analysis of specific interpretation strategies and for training purposes, as feedback from VTS specialists seems to indicate. The same technology, in fact, could be applied to different teaching strategies, such as gallery talks or lectures, as well as to different contexts (school vs. museum) and/or age groups.

The IMA’s objective for the upcoming months is to focus on the dissemination of the results of research within the wider museum community though conferences and papers. Following this year’s presentation of the initial findings at the Museums and the Web 2012 Conference, the IMA is currently co-writing a paper for Museums and the Web Conference 2013 with researchers from the Knowledge Media Center in Germany and the Oregon State University, which have also carried out similar eye tracking experiments in museums. The IMA is also interested in working with the VTS community for a more in-depth analysis of the videos that have been created as a result of experiment 3. While at the moment the IMA does not have any concrete plans to carry out more studies on eye tracking, it is hoped that this technology can be utilized in the future to support interpretative installations at the museum or for further research on interpretative strategies.

Project-related Resources

- Museums and the Web 2012 article: Bachta et al., Evaluating the Practical Applications of Eye Tracking in Museums, in *Museums and the Web 2012 Proceedings*. http://www.museumsandtheweb.com/mw2012/papers/evaluating_the_practical_applications_of_eye_t

- Museums and the Web 2012 powerpoint presentation: http://www.slideshare.net/SilviaFantoni/mw2012-eyetracking
- Experiment 3 videos: http://ima.tc/eyetrackingsessions (username: guest, password: optics).

References

Falk, J.H. (2009). *Identity and the Museum Visitor Experience*. Walnut Creek, California, USA: Left Coast Press.

Hein, G.E. (1998). *Learning in the Museum*. London: Routledge, 138.

Hoffman, J.E. (1998). “Visual attention and eye movements”. In H. Pashler (ed.), *Attention*. Hove, UK: Psychology Press, 119–154.

Housen, A. (1999). “Eye of the Beholder: Research, Theory, and Practice.” Presented at the conference of *Aesthetic and Art Education: a Transdisciplinary Approach*. September 27–29, 1999, Lisbon, Portugal. Consulted January 20, 2012. Available at: *http://www.vtshome.org/system/resources/0000/0006/Eye_of_the_Beholder.pdf*

Milekic, S. (2010). “Gaze-Tracking and Museums: Current Research and Implications.” In J. Trant & D. Bearman (eds.), *Museums and the Web 2010: Proceedings*. Toronto: Archives & Museum Informatics. Consulted September 28, 2011. Available at: *http://www.archimuse.com/mw2010/papers/milekic/milekic.html*

Rayner, K. (1978). “Eye movements in reading and information processing.” *Psychological Bulletin. 85(3).*

Rayner, K. (1998). “Eye movements in reading and information processing: 20 years of research.” *Psychological Bulletin*. *124(3).*

Rolfs, M. (2009). “Microsaccades: Small steps on a long way”. *Vision Research, 49.* Elsevier Ltd., 2415–2441. Consulted January 29, 2012. Available at: *http://www.martinrolfs.de/Rolfs_MicrosaccadeReview.pdf*

Smith, J.K., & L. F. [hc1] (2001[EB2]). “Spending Time on Art”. In *Empirical Studies of the Arts*, 19(2).

Wooding, D. (2002). “Fixation maps: quantifying eye-movement traces.” In *Proceedings of the 2002 symposium on Eye tracking research & applications (ETRA '02).* New York, NY, USA: ACM, 31–36.

Yenawine, P. (1997). “Thoughts on Visual Literacy.” In J. Flood, S.B. Heath, & D. Lapp (eds.), *Handbook of Research and Teaching Literacy through the Communicative and Visual Arts*. Consulted January 20, 2012. Available at: *http://www.vtshome.org/system/resources/0000/0005/Thoughts_Visual_Literacy.pdf*