Psychometrics 101: How to Design, Conduct, and Analyze Perceptual Studies of Computer Graphics Visualization Techniques

Tutorial Proposal for VISUALIZATION 2002

Organizer

James A. Ferwerda
Program of Computer Graphics
Cornell University

Proposed length

Half-day

Level

Beginner

Abstract

As the field of Visualization matures, there's a trend to move away from the use of ad-hoc graphics techniques and toward algorithms that are based on a formal understanding of how people perceive visual representations of information. Psychometric methods from experimental psychology can be used to quantify the relationships between the properties of images and what people perceive. The results of psychometric experiments can be used to create predictive models of visual perception that can guide the development of effective and efficient visualization algorithms and enabling graphical interfaces. This course will provide an introduction to the use of psychometric methods in computer graphics visualization, and will teach attendees how to design perceptual experiments that can be used to advance visualization research and applications.

Target audience

This course will be of interest to members of the visualization community who want to be able to interpret the results of perception psychology experiments and develop their own perceptual studies of visualization techniques.

Presenters

James A. Ferwerda
Program of Computer Graphics
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Holly Rushmeier
IBM TJ Watson Research Center

Benjamin Watson
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Prerequisites

This course assumes a basic level understanding of issues in computer graphics visualization, and digital imaging. Familiarity with freshman-level college math will be helpful. *No specific knowledge of perception psychology or statistical methods is necessary*.

Topics covered

This course will: 1) survey the experimental methods used to study human visual perception and performance; 2) explain how to interpret the results of published experiments; and 3) teach attendees how to design, run, and analyze their own psychophysical user studies, to develop perceptually-based algorithms and applications.

Syllabus

- **Welcome, Introductions, Schedule Review (Ferwerda, 10 mins)**
  - Motivation / Orientation (35 mins)
  - Psychophysical Methods (60 mins)
  - Break
  - Experimental Design (60 mins)
  - Case Studies (25 mins)
  - Panel / Group Discussion (20 mins)

- **Motivation/Orientation (Rushmeier, 35 mins)**
  - **Why psychometrics?**
    - graphics are generated to be useful to people
    - we need to be able to determine what factors contribute to visual experience
    - we need to be able to assess what methods produce an effective visual experience
  - **Why don't we just use existing psychophysical results?**
    - graphics builds on psychophysical research (e.g. colorimetry)
    - goals of psychophysical research are different than graphics research
      - determining contrast sensitivity vs. designing a rendering method that uses a model of contrast sensitivity
  - **How does this differ from usability, HCI research?**
    - focus is on visual perception and computing images , but overlap with these areas
  - **What are example problems to be addressed by psychometrics?**
    - data visualization
      - how should data values be mapped to visual attributes?
      - how effective are different visual cues for conveying information about data
      - what are the interactions between these different cues?
      - how can we make sure that the images we create are faithful representations
    - virtual environments
      - what trade-offs are acceptable to maintain real time performance?
      - what spatial representations are adequate?
      - what are the perceptual differences between screen-based and immersive displays?
    - realistic image synthesis
      - how accurate does the input need to be?
      - what input is needed?
      - how accurate does the light transfer need to be?

        - how are the results in physical units transformed to displays?
    - compression
        - what kinds of artifacts are visually acceptable in still images? In temporal sequences? In 3D geometric models?
- **What kind of results can we expect?**
    - more efficient graphics techniques -- computing only what is necessary
    - more effective graphics techniques -- choosing the right image to generate
- **How does psychometrics relate to physical measurement?**
    - human observers are responding to physical stimulus
    - depending on problem various physical measurements also needed
        - object shape/material properties; light energy from real scenes/displays
- **How do we make progress?**
    - adopt established experimental methods
    - build a literature of results relevant to graphics techniques

- **Psychophysical Methods (Ferwerda, 60 mins)**
    - **Introduction**
        - need for objective metrics of subjective visual experience
        - fundamental psychophysical metrics: **thresholds** and **scales**
        - examples of threshold and scale metrics in computer graphics
    - **Methods for measuring <u>thresholds</u>**
        - the method of adjustment
        - the method of limits
        - the method of constant stimuli
    - **Threshold models**
        - psychometric functions
    - **Sources of error in threshold measurements**
    - **Signal detection theory**
        - SR matrices, ROC curves
        - error-free threshold measures
    - **Suprathreshold <u>scaling</u> methods**
        - Types of psychophysical scales
            - nominal, ordinal, interval, ratio
        - Ordinal and interval scaling methods
        - Thurstonian scaling
        - Ratio scaling methods
    - **Scaling models**
        - Weber's law
        - Steven's power law
    - **Multidimensional scaling (MDS)**
        - theory, demo, data analysis
    - **Practicalities of running psychophysical experiments**
        - selecting test stimuli
        - selecting observers
        - the importance of observer instructions
        - presentation/user interface issues
        - collecting data
    - **Summary/Conclusion**

    - utility and limits of psychophysical methods
    - relevance for computer graphics
  - **Resources**
    - books, papers, journals, web sites
    - software packages
    - organizations, conferences

- **Break**

- **Experimental Design (Watson, 60 mins)**
  - **Why do an experiment?**
    - real world context: an example experiment from the graphics literature
  - **Global experimental issues**
    - internal/external validity
    - feasibility
    - non-null results
  - **Design components**
    - hypothesis
    - independent/dependent/control variables
    - test or task
  - **Threats to validity, feasibility and non-null results**
    - to internal validity
      - randomness, confounds, individual differences, carryover effects, reactivity, researcher bias
    - to external validity
      - unreliability, too much control, unrepresentative population
    - to feasibility
      - population too big, design too ambitious, task too hard
    - to non-null results
      - ceiling and floor effects, type 2 errors
  - **Standard experimental designs**
    - single factor designs
      - within/between subject designs
    - multi-factor designs
      - interactions
    - mixed designs
    - repeated measures designs
  - **Analysis of results**
    - analytical tools
      - descriptive statistics
      - inferential statistics
    - ethics of analysis
      - excluding participants
      - excluding results
  - **Practical questions**
    - how many participants?
    - getting approval (human subjects committees)
    - motivating participants

    - the hunt for significance
        - pilot studies

- **Case Studies of Psychometric Methods in Visualization (Rushmeier, 25 mins)**
    - Brief description and critique of presenter's previous and current work
        - data visualization
        - realistic image synthesis
        - geometric simplification
        - image-based model acquisition
    - Survey of other work/applications in:
        - rendering, modeling, compression, virtual environments, validation

- **Panel / Group Discussion (All, 20 mins)**
    - review of day's material
    - pointers to resources
    - open questions

Tutorial notes

Course notes will consist of copies of the slides from the tutorial as well as an extensive bibliography including specific references used in the tutorial as well as a general selection of relevant survey articles, chapters, books, and web pages.

Presenter information

James A. Ferwerda
Research Associate
Program of Computer Graphics
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James A. Ferwerda is a Research Associate in the Program of Computer Graphics at Cornell University. He received a BS in psychology in 1980, an MS in computer graphics in 1987, and a Ph.D. in experimental psychology in 1998, all from Cornell University. He has served on the program committees of the SIGGRAPH Campfire on Perceptually-Adaptive Graphics, and the Eurographics Rendering Workshop. He recently co-edited a special issue of IEEE Computer Graphics and Applications on Applied Perception. In 1992, he received the Paper of the Year Award from the IEEE Computer Society. His research interests include: realistic image synthesis; computational models of visual perception; human computer interaction; and assistive technologies.

Key relevant publications:

Ferwerda, J.A.(2001) Elements of early vision for computer graphics. IEEE Computer Graphics and Applications, 21(5), 22-33.

Pellacini, F., Ferwerda, J.A., and Greenberg.D.P. (2000) Toward a psychophysically-based light reflection model for image synthesis. Proceedings SIGGRAPH '00, 55-64.

Pattanaik, S., Ferwerda, J.A., Fairchild, M.D., and Greenberg, D.P. (1998) A multiscale model of adaptation and spatial vision for realistic image display. Proceedings SIGGRAPH '98, 287-298.

Ferwerda, J.A., Pattanaik, S., Shirley, P., and Greenberg, D.P. (1997) A model of visual masking for computer graphics. Proceedings SIGGRAPH '97, 143-152.

Ferwerda, J.A., Pattanaik, S., Shirley, P., and Greenberg, D.P. (1996) A model of visual adaptation for realistic image synthesis. Proceedings SIGGRAPH '96, 249-258.

Holly Rushmeier
Research Scientist
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Holly Rushmeier received the BS, MS and PhD degrees in mechanical engineering from Cornell University in 1977, 1986 and 1988 respectively. She is a research staff member at the IBM T.J. Watson Research Center. Since receiving the PhD, she has held positions at the Georgia Institute of Technology and the National Institute of Standards and Technology. In 1990, she was selected as a US National Science Foundation Presidential Young Investigator. In 1996 she served as the papers chair for the ACM SIGGRAPH conference, in 1998 as the papers co-chair for the IEEE Visualization conference and in 2000 as the co-chair for the the Eurographics Rendering Workshop. From 1997 to 1999 she was Editor-in-Chief of ACM Transactions on Graphics. Her research interests include data visualization, rendering algorithms, and acquisition of input data for computer graphics image synthesis.

<u>Key relevant publications:</u>

Botts, M., Uselton, S., Walton, j., Watkins, H., Watson, D., and Rushmeier, H. (1995) Metrics and benchmarks for visualization. Proceedings Visualization ’95. 422-426.

Rushmeier, H., Barrett, H., Rheingans, P., Uselton, S., and Watson, A. (1997) Perceptual measures for effective visualizations. Proceedings Visualization ’97, 515-517.

Meyer, Gary W., Holly E. Rushmeier, Michael F. Cohen, Donald P. Greenberg and Kenneth E. Torrance. “An Experimental Evaluation of Computer Graphics Imagery.” ACM Transactions on Graphics 5(1) (January 1986) 30-50.

Rushmeier,Holly E., Gregory Ward, Christine Piatko, Phil Sanders, and Bert Rust, “Comparing Real and Synthetic Images: Some Ideas About Metrics”, Proceedings of the Sixth Eurographics Rendering Workshop, revised version in Hanrahan and Purgathofer (Eds.) Rendering Techniques ‘95, Springer-Verlag 1995.

H.E. Rushmeier, B.E. Rogowitz, C. Piatko, "Perceptual issues in substituing texture for geometry" Proceedings of SPIE Vol. 3959 Human Vision and Electronic Imaging V, 372-383, (2000)

Benjamin Watson
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Dr. Benjamin Watson earned his B.S. in Computer Science at UC Irvine in 1983 and his M.S. and Ph.D. in Computer Science at Georgia Tech's GVU Center in 1989 and 1997, respectively. After graduating, he worked for three years as Assistant Professor of Computing Science at the University of Alberta before moving in 2000 to Northwestern University's Computer Science department, where he is currently an Assistant Professor. Dr. Watson recently co-chaired the Graphics Interface 2001 conference. His research interests include measurement and prediction of visual fidelity, perceptually based alternative rendering techniques, model simplification, three dimensional interaction, visualization, psychological applications, and computer games.

Key relevant publications:

B.A. Watson, N. Walker, L.F. Hodges & A. Worden (1997). Managing level of detail through peripheral degradation: effects on search performance with a head-mounted display. *ACM Trans. on Computer-Human Interaction*, *4,* 4, 323-346.

B.A. Watson, N. Walker, W.R. Ribarsky V. Spaulding (1998). The effects of variation in system responsiveness on user performance in virtual environments. *Human Factors,* Special Section on Virtual Environments, *40,* 3 (Sept), 403-414.

B.A. Watson, A. Friedman, A. McGaffey (2000). Using naming time to evaluate quality predictors for model simplification. Proc. ACM Computer-Human Interaction (The Hague, April), 113-120.

B.A. Watson, A. Friedman, A. McGaffey (2001). Measuring and predicting visual fidelity. Proc. SIGGRAPH 2001 (Los Angeles, August). In *Computer Graphics* Proceedings, Annual Conference Series, ACM SIGGRAPH, 213-220.

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