9.S913 SYLLABUS January 2014

Understanding Visual Attention through Computation

Dept. of Brain and Cognitive Sciences
Massachusetts Institute of Technology

Title:	Special Subject: Understanding Visual Attention through Computation
Instructor:	J.K. Tsotsos (www.cse.yorku.ca/~tsotsos)
Years:	2014 only
Level:	Graduate
Prerequisites:	introductory courses in computer vision, visual perception, or visual neuroscience

Description

Interest in the phenomenon known as attention has a long history, and recently there has been an explosion of research effort, experimental, theoretical and empirical, whose goal is to develop a deeper and more complete understanding of attention, particularly visual, in humans, non-human primates and machines. The problem with all this work is that it seems to generate more confusion rather than a deeper understanding. This course explores many of the different approaches and perspectives in the current literature, within the historical context of research of the field, with the intent of developing a 'big picture' view of what this thing called visual attention might entail and how can we best further deepen our understanding. Formally, the language of computation, broadly defined, underpins the development.

The opening classes feature lectures by the instructor introducing the topic, providing basic background in the psychology and neurobiology of attention, wandering through a brief tour of highlights in attention research throughout the history of Artificial Intelligence, Cognitive Science and Computational Neuroscience, exploring the computational foundations for attentive processing, and finally detailing one theory, Selective Tuning. Then, the following classes highlight specific themes with a guest lecturer and student-led presentations. The point of these is to explore different viewpoints and theories, as contrasts to Selective Tuning, so that the class develops an appreciation of both strengths and weaknesses not only of the research but also the methodologies. The last class is led by the instructor but intended to be class discussion and debate on what has been covered with the goal of prescribing a pathway for future research on the topic. Depending on interest and progress, this last class could conclude with writing a brief technical report, authored by the whole class, detailing the routes the class feels would be most fruitful.

Required Reading:

Tsotsos, J.K., **A Computational Perspective on Visual Attention**, MIT Press, 2011.

Recommended References:

Pashler, H.E., **The Psychology of Attention**, MIT Press, 1998.
Braun, J., Koch, C., Davis, J.L., (editors), **Visual Attention and Cortical Circuits**, MIT Press, 2001.
Itti, L., Rees, G., Tsotsos, J.K., **Neurobiology of Attention**, Elsevier Press, 2005.
Posner, M.I., (editor), **Cognitive Neuroscience of Attention**, 2nd Edition, The Guilford Press, 2011.
Mangun, G.R., (editor), **The Neuroscience of Attention: Attentional Control and Selection**, Oxford University Press, 2012.

Lecture Details

February 10: Introduction to Attention

Lecturer: J.K. Tsotsos (http://www.cse.yorku.ca/~tsotsos)
Readings: Tsotsos Chapters 1 and 3
Topics: Philosophy behind the approach to attention
History of attention research
Taxonomy of elements of attention
Encyclopedic overview of theories and models

February 18: Computational Foundations of Visual Attention

Lecturer: J.K. Tsotsos
Readings: Tsotsos Chapter 2, Appendices A, B
Topics: Basic insight motivating the specific approach using computational complexity
Relevance of computational complexity for natural systems
Details on theorems and proofs
Linking the proofs to vision, attention and behavior
Implications of theorems for design of vision systems

February 24: Selective Tuning Part I

Lecturer: J.K. Tsotsos
Readings: Tsotsos Chapters 4, 5, 7, and 8
Topics: Basic ST model
Neural micro-circuitry to support ST
ST with eye movements
ST simulations
ST predictions and experimental evidence

March 3: Biased Competition

Lecturer: R. Desimone (http://mcgovern.mit.edu/principal-investigators/robert-desimone)
Readings: Desimone , R. , & Duncan , J. (1995). Neural mechanisms of selective attention, *Annual Review of Neuroscience*, 18 , 193 – 222 .
Reynolds, J. H., & Heeger, D. J. (2009). The normalization model of attention. *Neuron*, *61*(2), 168-185.
Topics: Experimental background that led to the development of the Biased Competition model
Mathematical details on the model
Model extensions
Student Presentations:

Armstrong, K. M., Fitzgerald, J. K., & Moore, T. (2006). Changes in visual receptive fields with microstimulation of frontal cortex. *Neuron*, *50*(5), 791-798.

Sundberg, K. A., Mitchell, J. F., & Reynolds, J. H. (2009). Spatial attention modulates center-surround interactions in macaque visual area v4. *Neuron*, *61*(6), 952-963.

March 10: Attention and Search

Lecturers: J. Wolfe (https://sleep.med.harvard.edu/people/faculty/215/Jeremy+M+Wolfe+PhD) and R. Rosenholtz (http://persci.mit.edu/people/rosenholtz

Readings: Treisman , A. , Gelade , G. (1980). A feature integration theory of attention . *Cognitive Psychology* , 12 ,97 – 136 .

Wolfe , J. (1998a). Visual search . In H. Pashler (ed.), **Attention** (pp. 13 – 74). London : University College London .

Wolfe, J. M. (2007). Guided Search 4.0: Current Progress with a model of visual search. In W. Gray (Ed.), **Integrated Models of Cognitive Systems** (pp. 99-119). New York: Oxford.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin and Review,* 1(2), 202-238.

Rosenholtz, R., Kuzmova, Y.L., Sherman, A.M., Visual search for arbitrary objects in real scenes, *Attention, Perception and Psychophysics*, 2011.

Rosenholtz, R., Huang, J., Ehinger, K. A. , Rethinking the role of top-down attention in vision: effects attributable to a lossy representation in peripheral vision, *Frontiers in Psychology* 3-13, 2012.

Topics: Feature Integration Theory
Guided Search Model family
Issues with use of psychometric data to infer mechanism
Experiments demonstrating breadth of visual search tasks and results
Attention within scene perception and set perception
An alternative account to FIT

Student Presentations:

Wolfe, J. W., Alvarez, G., Rosenholtz, R., Kuzmova, Y.L., Sherman, A.M., Visual search for arbitrary objects in real scenes, *Attention, Perception and Psychophysics*, 2011.

Treisman, A. (2006). How the deployment of attention determines what we see. *Vis. Cogn.* 14, 411–443.

March 17: Neurobiology of Attention

Lecturers: M. Fallah (http://www.yorku.ca/vpalab/) and T. Womelsdorf (http://attentionlab.ca/doku.php)

Readings: Squire, R.F., Noudoost, B., Schafer, R.J. , Moore , T., Prefrontal Contributions to Visual Selective Attention, *Annual Review of Neuroscience* Vol. 36 (2013): 451-466

Krauzlis, R.J., Lovejoy, L.P., Zénon. A., Superior Colliculus and Visual Spatial Attention, *Annual Review of Neuroscience* Vol. 36 (2013): 165-182

Petersen , S.E., Posner, M.I., The Attention System of the Human Brain: 20 Years After, *Annual Review of Neuroscience* Vol. 35 (2012): 73-89

Corbetta M, Patel G, Shulman GL., The reorienting system of the human brain: from environment to theory of mind. *Neuron* 58:306-324, 2008.

Baluch F, Itti L., Mechanisms of top-down attention. *Trends Neurosci* 34:210-224, 2011.

Fallah, M., Stoner, G., Reynolds, J., Stimulus-specific competitive selection in macaque extrastriate visual area V4 , *PNAS* 104(10):4165-9, 2007

Maunsell, J., Treue, S., Feature-based attention in visual cortex, *Trends in Neurosciences*, 29-6, 2006, p317-322

Topics: Visual areas of cortex and sub-cortical regions
Attention in visual cortex
Attention in pre-frontal cortex
Attention in sub-cortical regions
Emerging principles

Student Presentations:

Salazar RF, Dotson NM, Bressler SL, Gray CM. 2012. Content-specific fronto-parietal synchronization during visual working memory. *Science* 338:1097-1100.

Sundberg, Mitchell, Gawne & Reynolds, Attention influences single unit and local field potential response latences in visual cortex *J. Neurosci*, 2012.

March 31: Saliency Map Models

Lecturer: N.D.B. Bruce (http://www.cs.umanitoba.ca/~bruce/)

Readings: Bruce , N. D. B. , & Tsotsos , J. K. (2009). Saliency, attention, and visual search: An information theoretic approach . *Journal of Vision*, 9 (3), 1 – 24 .

Borji, A., Itti, L., State-of-the-art in Visual Attention Modeling, *IEEE Transactions on Pattern Analysis and Machine Intelligence,* 2012.

Topics: Details of the Itti, Koch and Niebur model and issues arising
Attention via Information Maximization (AIM)
Evolution of saliency maps during the past decade
Evaluation and performance
Relationship to human vision
Future Directions

Student Presentations:

N. Riche, m. Duvinage, m. Mancas, b. Gosselin, t. Dutoit, 2013, "saliency and human fixations: state-of-the-art and study of comparison metrics", Proceedings of the 14th International Conference on Computer Vision (ICCV 2013), Sydney, Australia, December 1-8.

Koehler, K., Guo, F., Zhang, S., & Eckstein, M. P. (2014). What do saliency models predict? *Journal of Vision*, 14(3):14, 1– 27, http://www.journalofvision.org/content/14/3/14, doi:10.1167/14.3.14.

April 7: Selective Tuning Part II

Lecturer: J.K. Tsotsos

Readings: Chapters 6, 9

Topics: ST and recognition
ST and binding
ST and executive control
Cognitive programs

April 14: Dynamical Systems Models

Lecturer: S. Ardid (http://sardid.cognitive-neurobiol.org/)

Readings: Mante V, Sussillo D, Shenoy KV and Newsome WT. Context-dependent computation by recurrent dynamics in prefrontal cortex. *Nature* 503, 78-85, 2013

Buia CI and Tiesinga PH. Role of interneuron diversity in the cortical microcircuit for attention, *Journal of Neurophysiology*, 99(5), 2158–2182, 2008

Ardid S, Wang X-J and Compte A. An integrated microcircuit model of attentional processing in the neocortex. *Journal of Neuroscience*, 27(32), 8486–8495, 2007

Topics: Historical development of approach
Mathematical foundations
Overview of models
Evaluation and performance
Future Directions

Student Presentations:

Ardid, Wang, Gomez-Cabrero, Compte. Reconciling Coherent Oscillation with Modulation of Irregular Spiking Activity in Selective Attention: Gamma-Range Synchronization between Sensory and Executive Cortical Areas. *J Neurosci,* 2010.

Börgers, Epstein and Kopell. Gamma oscillations mediate stimulus competition and attentional selection in a cortical network model. *PNAS*, 2008

April 28: The Roles of Gist, Context and Task

Lecturer: A. Torralba (http://web.mit.edu/torralba/www/)

Readings: Torralba, A., Oliva, A., Castelhano, M. S., & Henderson, J. M. (2006). Contextual guidance of eye movements and attention in real-world scenes: the role of global features in object search. *Psychological review*, *113*(4), 766.

Oliva, A., & Torralba, A. (2006). Building the gist of a scene: The role of global image features in recognition. *Progress in brain research*, *155*, 23-36.

Torralba, A. (2003). Modeling global scene factors in attention. *JOSA A*, *20*(7), 1407-1418.

Topics: Evidence suggesting the use of gist, context and task in attention
- Overview of approaches
- Evaluation and performance
- Future Directions

Student Presentations:

Isola, P., Xiao, J., Torralba, A., & Oliva, A. (2011, June). What makes an image memorable?. In Computer Vision and Pattern Recognition (CVPR), 2011 IEEE Conference on (pp. 145-152). IEEE.

Oliva, A., Torralba, A., Castelhano, M. S., & Henderson, J. M. (2003, September). Top-down control of visual attention in object detection. In Image Processing, 2003. ICIP 2003. Proceedings. 2003 International Conference on (Vol. 1, pp. I-253). IEEE.

May 5: Bayesian Methods for Attention

Lecturer: T. Serre (http://serre-lab.clps.brown.edu/)

Readings: Chikkerur, S., Serre, T., Tan, C., & Poggio, T. (2010). What and where: A Bayesian inference theory of attention. *Vision research*, *50*(22), 2233-2247.

Angela, J. Y., & Dayan, P. (2004). Inference, attention, and decision in a Bayesian neural architecture. In *Advances in neural information processing systems* (pp. 1577-1584).

Lee, T. S., & Mumford, D. (2003). Hierarchical Bayesian inference in the visual cortex. *JOSA A*, *20*(7), 1434-1448.

Topics: Historical development of approach
- Mathematical foundations
- Overview of models
- Evaluation and performance
- Future Directions

Student Presentations:

Dayan, P. (2009). Load and attentional bayes. In *Advances in neural information processing systems* (pp. 369-376).

Dayan, P., & Yu, A. J. (2003). Uncertainty and learning. *IETE Journal of Research*, *49*(2/3), 171-182.

May 12: Final Integrative Discussion

Lecturer: J.K. Tsotsos

Topics: (this activity will require one student to act as note-taker)
- Triage of class questions
- Distillation of questions around major issues
- Debate and evaluation of major issues
- Selection and ranking of key topics
- Outline of summary report and assignment of sections