Synesthesia Visualization

**New Mexico
Supercomputing Challenge
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TABLE OF CONTENTS

1.0   <u>Executive Summary</u>

We, team number one of the Academy for Technology and the Classics, have investigated synesthesia; mainly it's subset condition of seeing sounds. We hoped to create more awareness for the condition, thus our project is more an application of science than new research. Over the course out the challenge, we conducted local surveys and analyzed FMRI scans of patients. We enlisted more than one hundred test subjects from the Santa Fe County area, six tested positive for some form of synesthesia; one of our sources declares synesthesia to occur in 1 in 23 people, our results agree. Our survey results also drew a correlation between synesthesia and other conditions, so we compared the FMRI images to FMRIs of dyslexia and ADHD, but several technical failures impeded this part of our project.

Our most trying achievement was creating a real-time visualizer, the first endeavor of this sort. The program simulates some types of visual artifacts that can be seen by aural to visual synesthetes. Our visualizer works according to several anecdotes and theories on synesthesia. It gathers visual and audio data, then overlays visual artifacts influenced by certain audio attributes on the live video feed. It offers several options for modifying the final image, as synesthesia is a diverse condition. Our understanding is based upon first-person accounts across the Internet, reputable research papers, and communication with scientists themselves.

2.0   <u>Background</u>

2.1   What is Synesthesia?

Synesthesia's definition is in its Greek name: σύν (syn) αἴσθησις (aisthēsis), or unison of the senses. Any modal can be affected; a person could smell colors, or hear Hebrew glyphs; although not all subtypes have been researched by valid sources. Scientific American writes:

"*Synesthesia is an anomalous blending of the senses in which the stimulation of one modality simultaneously produces sensation in a different modality. Synesthetes hear colors, feel sounds and taste shapes. What makes synesthesia different from drug-induced hallucinations is that synesthetic sensations are highly consistent: for particular synesthetes, the note F is always a reddish shade of rust, a 3 is always pink or truck is always blue.*" (Source 1)

The neurological causes of this condition are difficult to understand. The condition gained recognition within scientist's communities in the early 1970s, but it was hampered by the belief that only hallucinogenic drugs caused such behavior. It was resurrected as a credible condition by pioneers like Dr. Richard E. Cytowic, who believed it deserved serious research and that it could even have helpful effects.

2.2   Aural to Visual Synesthesia

The main type of synesthesia we researched will be referred to in this document as aural-to-visual synesthesia (AVS). Billy Joel, also known as "The Piano Man" summarized a specific type of aural-to-visual synesthesia in an interview with Psychology Today:

"*When I think of different types of melodies which are slower or softer, I think in terms of blues or greens... When I think of certain [strongly melodic, strongly rhythmic] songs, I think of vivid reds, oranges or golds*"(Source 2)

People with AVS see visual artifacts. According to anecdotal evidence, these can be of varying size, complexity and color. Each person experiences a unique visual set; some view an entirely different plane of vision populated with audio-based structures, others see simpler effects. These are produced entirely by the subconscious in a repeatable manner. Like other types of synesthesia, the intensity of the effects vary. Some synesthete's lives are significantly affected by the visual anomalies caused by certain types of sounds. We discovered several anecdotes from musicians who experience this condition; some use the color correlations with pitch to their advantage.

Figure 1. *First concept of our goal for visual anomalies*

2.3 Purpose

We were surprised that no one had created a program to demonstrate this condition in real time. Students at Carnegie Mellon created an "Audio to Visual Synesthesia Visualization", but their program did not have real time frequency to color conversion, no audio input, and no camera input. If a person could experience a Synesthete's view of the world, the condition would gain popular understanding and perhaps inspire a new generation of neuroscientists. Synesthesia can impair a person's life or improve it

and needs more public awareness, such as well known conditions like autism or ADHD. Also, correlating color and sounds could help non-synesthetes in their daily lives; for example, by providing more accurate pitch detection for musicians.

3.0   Backgrounds and Field Work

3.1   Research

Dr. David Eagleman is a respected neuroscientist and writer at the Baylor College of Medicine, and he is a pioneer of synesthesia research. Him and one of the first researchers of the condition, Dr. Richard E. Cytowic, created the "Synesthesia Battery" found at synesthete.org. It is a public questionnaire available for use by researchers; it provides coverage of several types of synesthesia. We studied Eagleman's writings on the subject and read papers published by Carnegie Mellon, Penn State, the University College London, and other institutions. We also researched first person accounts of synesthesia by communicating with them and reading anecdotes by synesthetes. The sheer number of such accounts showed us the diversity of visual artifacts caused by AVS.

3.2   Survey

We conducted surveys across the Santa Fe area in search of first-person accounts of aural to visual synesthesia. Dr. Richard E. Cytowic, a world renowned Neurologist at George Washington Medical Center and an influential researcher in returning synesthesia to scientific credibility in the 1980s stated that "[o]ne in twenty-three people have some kind of synesthesia."(Source) Dr. Eagleman's Synesthesia Battery was used for the survey; it offers test-takers the ability to send their results to any researcher's email. This data was collected and analyzed. By January, we had collected results from fifty people and three cases of synesthesia were found; age and geographic data was stored.

The three synesthetes found all live in Santa Fe County.
- Age- 17: correlates musical instrument to color.
- Age- 19: correlates personality to color.
- Age- withheld: correlates days of the week to color.

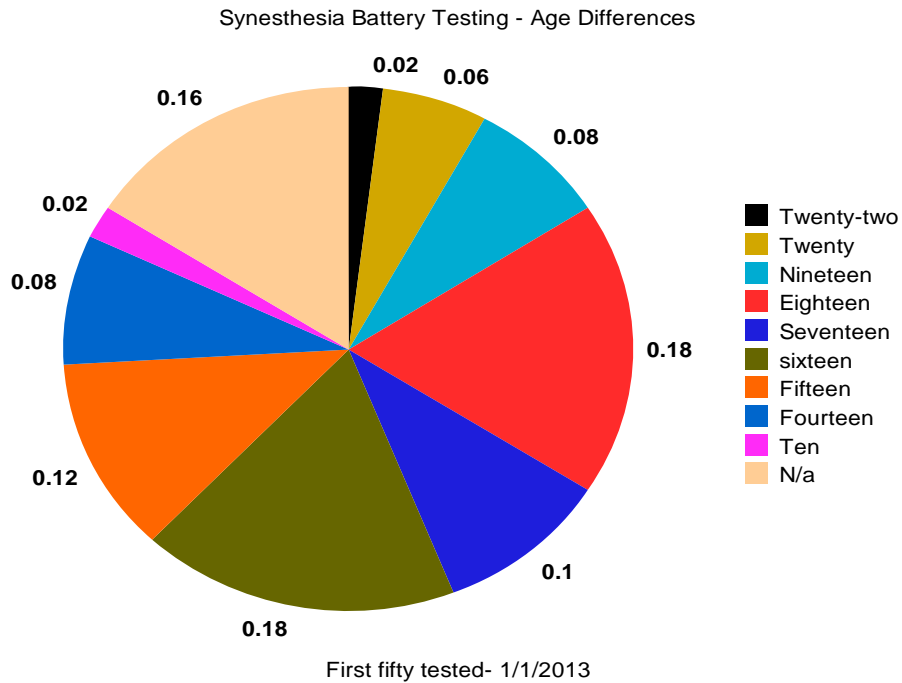Synesthesia Battery Testing - Age Differences

First fifty tested- 1/1/2013

Figure 2. *Pie chart representation demonstrating the age differences of the first 50 subjects. The ages range from ten to twenty-two with a significant portion not supplying their age.*

Dr. Cytowic's 1 in 23 statistic was proved by our results of 3 in 50. Needless to say, a bigger population would reinforce this number, as would testing people of different cultures, other backgrounds and of other age groups. Note Cytowic's later statement: "the most common kind of synesthesia is sensing days of the week as color"(Ibid)

For our second round, fifty different people from the same area submitted their results; along with age and location, the test subjects provided us with any other mental conditions. This yielded interesting results. Two of three synesthetes found in the latter test reported other mental conditions, namely dyslexia and ADHD.

The next three synesthetes detected by the battery also live in Santa Fe County.

- Age- 20: number to visual form synesthesia. Has Dyslexia.
- Age- 19: musical instrument to feeling. No other conditions reported.
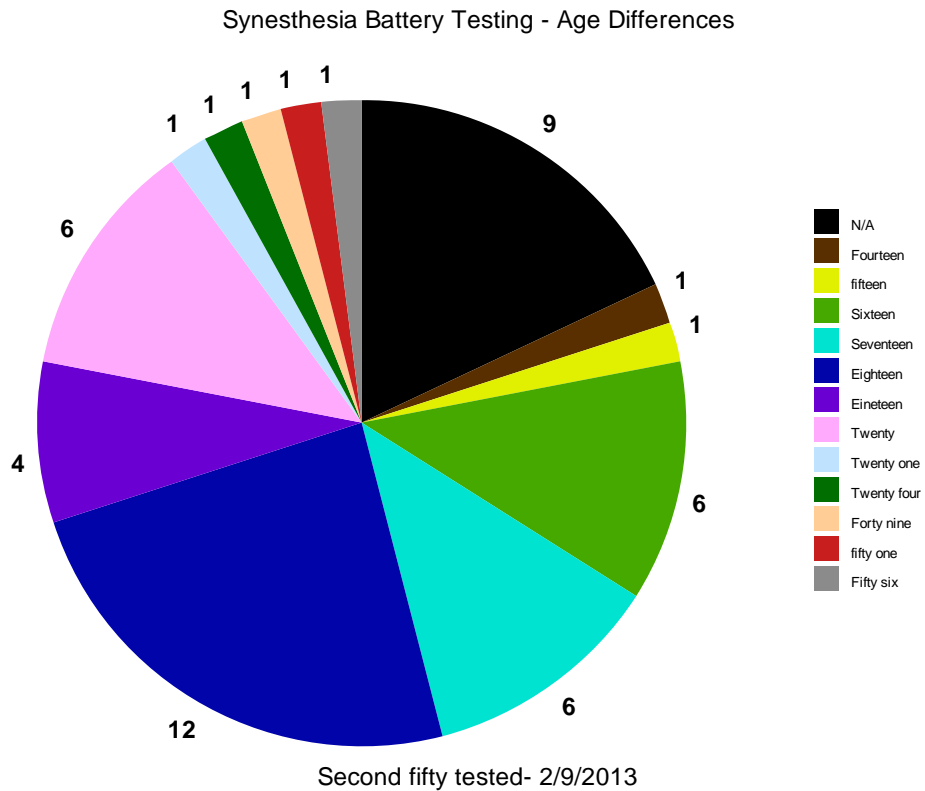- Age- 19: personification synesthesia. He has an extreme case of ADHD.

Second fifty tested- 2/9/2013

Figure 3. *A second pie chart demonstrating the age differences of the second 50 subjects, the age ranges from fourteen to fifty six with a significant portion not supplying their age.*

3.3 FMRI Imaging

Our second survey raised a new question that could fit in with our synesthesia research: are dyslexia and ADHD connected to synesthesia?

To answer this, we decided to compare FMRI scans of people suffering the diseases with those of synesthetes. We scanned various appropriate sources, such as scientific journals, for such scans. Also, Professor James Z. Wang of Pennsylvania State University provided us with synesthete's FMRIs from his earlier research.
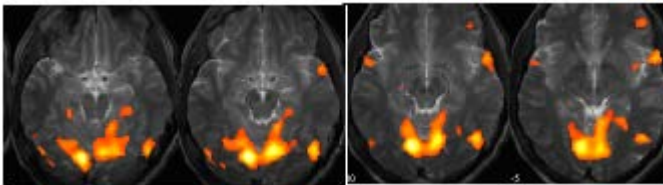

Figure 4. *The color center activation responding to visual stimulation in a 45 yo man with sound-color synesthesia (family wise error corrected, p < .05). (Source 4)*
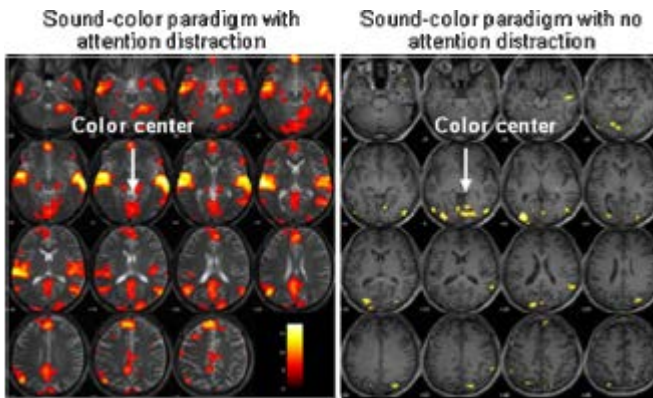

Figure 5. *Sound clips triggered color center activation in a 45 yo man with sound-color synesthesia (Left 1st run, family wise error corrected, p<.o5; right 2nd run 20 weeks later, not corrected. P<.001(Source 4)*

These images were perfect for what we needed, but we then realized that there was no way that we could plausibly find images of our other mental conditions that could be used for a clear comparison, so we decided that it would be best to attempt to render some ourselves using Rstudio and Oxfords open-source software FSL. After much troubleshooting, we were able to install FSL v5.0 within VMware workstation as a standalone OS on 12 gigs of ram, dual Nvidia Quadro FX 3700's, and two quad core Xeon E5345 processors @ 2.33 ghz. The hardware was generously lent to us for this test from Mr. Cole of Open Eye Scientific Software-Santa Fe.

To begin, a duplicate of figure 3 was rendered; having the original image made this a trivial task. Next we took the we took pre-designed points for ADHD FMRIs and entered them into Rstudio to see if there was a way to graph which turned out to be more haste than worth, so next we entered those points into FSL and gave the matching approximately 13 hours to render. When we checked back on the computer, the rendering had crashed with no apparent error. We thought that maybe FSL was having an error utilizing all of the cuda cores, so we reinstalled FSL via VMware player within Windows xp 64 bit on the same machine (VMware does not allow for individual core tweaking, and the drivers for the cards permitted overclocking/tweaking.). The second rendering secession also crashed, leaving us to believe that our points were somehow possibly too hard to render, or possibly incomplete.
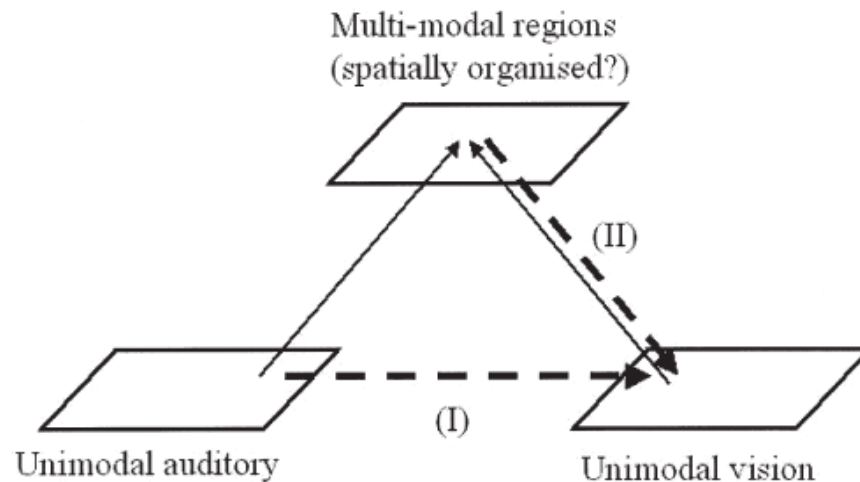
Figure 6. Sound-color synesthesia could plausibly arise from (I) direct connections between unimodal auditory and visual centers that are not normally found in other people, or from (II) feedback from multi-modal to unimodal regions that resembles normal cross modal perception. (Source 10)

Figure six, above, shows us a theory developed by the University College of London that was further confirmed by our FMRI study. We are currently in contact with Pennsylvania State about helping us achieve our goal of comparing synesthete's FMRIs; however, the vast size of our enterprise will impede any further progress for some time. Nonetheless, we have learned about synesthesia's relationship with other mental conditions and found another path for future research.

4.0 CODE DEVELOPMENT

4.1 Overview and Workflow

Figure 7. *Abid Rahman's logo for OpenCV and Python.*

Our team built a simple visualizer called Synesthesia:aur-vis. It shows visual artifacts drawn on a live camera feed or video file, according to several factors of an audio stream, likewise, from a live microphone feed or audio file. As Synesthesia has diverse variations, this program offers several GUI based modifications.

We considered implementing the program in Processing, a language similar to Java, or even Netlogo, but their manipulation functions were underdeveloped. We settled on using Python, a reliable, powerful, and fast interpreted language; along with the Python bindings for four libraries, tkinter for the GUI (graphical user interface) used to change the settings, OpenCV an expansive computer vision library, PyAudio for sound input, and Numpy(Numeric Python) for storing and processing visual and aural data.

This program was typed mainly on Linux using the minimal yet productive Scribes text editor, with testing done on Windows.

Dropbox was heavily utilized as our synchronization service. The total timeframe for typing these approximately 720 lines(23KB) of code was approximately four months.

4.2 Code

We used several techniques from object-oriented programming such as classes, separate code files, and data encapsulation; and we implemented error catching, input checking, and error logging. "Make things as simple as possible, but no simpler." Reviews typically included a scan for any code that could be shortened or reused in another section (such code would become a function to minimize code).
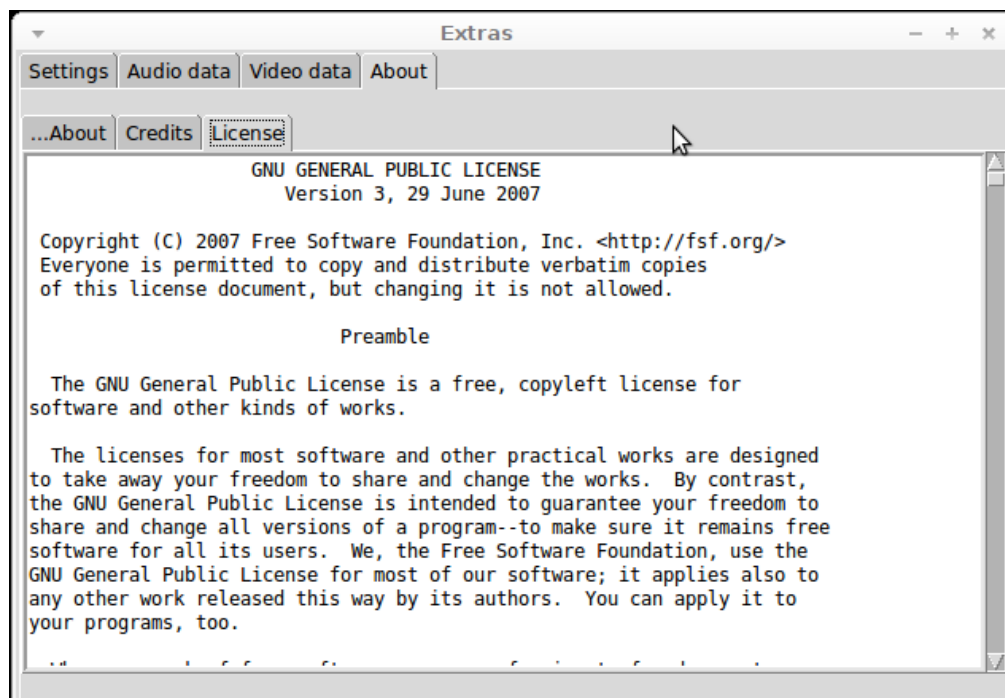
Figure 8. *Tkinter window, runs alongside camera output; shows settings and other information*

- *Synesthesia.py* Initializes program. Create a thread for audio management and start a video processor. Initialize main loop, which receives audio and video, and draws an overlay on the video according to audio frequencies and user settings. Overlays include colored and filled contours, contour lines, and a transparent color over the entire video; audio data is processed to find the loudest frequencies, and strongest frequencies in a particular band of audio, such as high-pitched sounds. It also scans for any escape sequences, such as Alt+F4 and the Escape key.

- *vid_processor.py* Communicates with OpenCV to acquire video data from a camera or video file of the users choice. Optimizes motion tracking history count—if it is set to 10, then the current frame is compared to the average of the previous ten frames to detect motion— by reading the video stream's FPS (frames per second) and image reduction is calculated by reading the resolution. If it is a high-resolution video, it can be shrunk before finding the contours for speed, otherwise leave it unprocessed. Contours are calculated by using the Teh-Chin89 algorithm. Uses this same algorithm

to track motion. Manages images and contours using numpy
arrays.

- *aud_processor.py* Queues requests to the computer's
  microphone or reads from an audio file. The Fast Fourier
  Transform—commonly used for this application—was used
  to calculate the strength of each frequency, for example
  90Hz at 30 units. The frequency data is returned in a numpy
  array.

- *gui34.py* Creates and manages a window separate from the
  OpenCV window. Runs in a separate thread. Offers several
  options and some information through tabs. Colors and
  frequency management can be set using sliders and
  selectors.

- *packaging* Packaging was our final action. We provided a
  fully featured Windows distribution; every required library
  is included. Linux and Windows versions are included.

Figure 9.

*Consecutive images
processed by Python
script*

4.3 Next Steps

Several improvements can be made. A better image
manipulation library would help create better simulation of visual
artifacts. A more powerful, yet easy to use GUI would allow more
diverse customization; a Synesthete could show the world their unique
vision. Second, more research into the human eye and ear would be
needed. Implementing a retina model could be a possible step; such a
model simulates human vision by increasing middle colors and
increasing contrast (example of human retina simulator). For audio,
position could be an improvement; sounds emanating from the left
would cause a different reaction than those from the right.

Figure 10. *Example of a retina model(included in OpenCV 4.3.3), right picture shows
output*

We explored various alternative hardware options. The Raspberry Pie would provide a portable platform for this live program; the software is supported, but our code would require optimization. Alternatively, and more interactively, a user could use a set of ESPON lcd goggles to view and fully experience the live simulation. Also thanks to ELEMENT14, we were graciously donated a Texas instruments C2000 LaunchPad Evaluation KIT, which is unusable as it cannot run Python.

4.4 Software Credits and License

As we made extensive use of Open Source software and their liberties, we hope releasing our code under a similar license will inspire and assist as well. Being allowed to view our foundation's source code saved many hours of frustration, distribution was also eased by the minimal license restrictions.

If manual troubleshooting failed when problems were encountered, we referred to the documentation for each library, along with blog posts and other Internet resources. Finally, gratitude is in order for the creators and maintainers of Python, OpenCV, PyAudio, Tkinter, Linux, and all open source software used.

5.0   <u>ACKNOWLEDGMENTS</u>

We would like to thank Stephen Guerin, who assisted us with image compositing; and Abid Rahman, a popular OpenCV blogger whom we emailed regarding technicalities as well.

Also, we would like to thank Mr. Cole of OpenEye Scientific Software of Santa Fe for generously allowing us to use their workstations for our FMRI testing, and lending us a Raspberry PI for optimizing our program for the system.

It was an honor to receive interest from ELEMENT14 and have them donate hardware to further the development of our program, and we are highly gracious of this fact.

Gratitude is in order for the creators and maintainers of Python, OpenCV, PyAudio, Tkinter, Linux, and all open source software used.

Finally, we would like to acknowledge and thank all synesthetes of any specific condition, for without their bravery in speaking up about their condition, no research could have been conducted, and we can only hope to advocate for more scientific research and a more complete understanding of this anomaly.

6.0 <u>SOURCES</u>

1.) http://www.scientificamerican.com/article.cfm?id=what-is-synesthesia possibly the most simplistic definition of synesthesia online.

2.)   http://www.psychologytoday.com/blog/tasting-the-universe/201205/hes-got-way-about-him Billy's Joel's interview about his "Audio to Visual Synesthesia" to Phycology Today.

3.) http://www.loc.gov/search/?q=How+Synesthesia+Speaks+to+Creativity %E2%80%9D   Dr, Richard Cytowic's Library video entitled "How Synesthesia Speaks to Creativity"

4.) http://pennstatehershey.org/c/document_library/get_file?folderId=245 7192&name=DLFE-27908.pdf   Dr. James Wang's paper that he shared with us that showed us his work on audio to visual synesthesia FMRI scans.

5.) http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSL   FSL software source.

6.) http://www.rstudio.com/ide/   Rstudio

7.) http://ark.intel.com/products/28032/Intel-Xeon-Processor-E5345-8M-Cache-2_33-GHz-1333-MHz-FSB Specifics on our Xeon Processors

8.) http://www.sciencedirect.com/science/article/pii/S0890856709616130 FMRI scans of a patient with ADHD

9.) http://woldorfflab.ccn.duke.edu/files/pdfs/Liotti_cortex_2005.pdf   A paper from Duke university that explains much to an ADHD's Mind

10.) http://www.ncbi.nlm.nih.gov/pubmed/16683501 Sound-Colour Synaesthesia: To What Extent Are Cross-Modal Mechanisms Common To Us All?

11.) Jamie Ward, Brett Huckstep and Elias Tsakanikos(Department of Psychology, University College London, London, UK)

12.) http://www.huck.psu.edu/research/neurosciences/events/retreats/a bstracts-2009   A novel data processing method for olfactory fmri examinations- from penn state

13.) http://www.python.org/getit/releases/2.7.3/ Python 2.7.3 release page.

14.) http://opencv.willowgarage.com/wiki/ Opencv library release page

15.) http://www.eyesopen.com/ OpenEye Scientific Software

16.) http://www.element14.com/community/index.jspa   Element 14

17.) http://www.contrib.andrew.cmu.edu/~jingxiao/hw4/intro.html Carnegie Mellon's audio to visual visualization