Cooper Union RS201A Optics for Artists, Fall 2005
Research Project Topics

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As described in class, there will be no final exam for this course. Instead, each student will submit a final project which can be either (1) an independent investigation of questions pertaining to the subject matter discussed in class (10+ pages) or (2) a studio project and a 2-3 page paper. The projects (or papers) may be presented to the class during the last session. By **17 October 2005**, you should be ready to submit a one or two paragraph description of your proposed project.

Depending on the topic, a research project may entail analytical calculation, computer simulation, library research or simple experimentation. In the accompanying paper, you must discuss why you became interested in the artist or idea or technique and how your paper is a response to that interest. I expect you to use a proper term paper format (footnotes, bibliography, etc.) and you will be graded for content, i.e. have you presented a well developed and researched argument, and writing style.

Here is a list of more than 20 potential research topics. Whenever possible, I have listed references to help you get started but, more often than not, `Google` is a good place to begin. Feel free to get in touch with me if you need advice, supervision, equipment, etc...

Physics, chemistry & technology:

1. Sonoluminescence is the emission of light by bubbles in a liquid excited by sound. Measurements of the spectrum indicate that the temperature inside the bubbles reaches at least 10,000 Kelvin (more than hot enough to melt steel) and may be as high as 1 million or 1 billion Kelvin (hotter than the center of the Sun). Although originally discovered in 1934, the mystery of how a relatively low energy sound wave can be transformed into high energy light is still unsolved. Investigate this phenomenon. What are the leading theories being pursued? If interested, one might be able to make a small-scale prototype of such a sonoluminescent system. Best place to get started is the *Scientific American* article by Seth Puttermann (Feb 1995). The phenomenon has been used in an artistic project by Evelina Domnitch & Dmitry Gelfand (*Leonardo* (2004), **5**, pp. 391-396).

2. Holography & holographic storage. Holography is a form of photography that allows a three-dimensional image to be recorded on film. The technique can also be used to optically store and retrieve information. Investigate the theory behind holography. How are the various types of holograms created? Why is it (usually) necessary to use laser light to record the holograms? How does holographic data storage work? What are the physical/technological limitations to the storage capability? In class, we will produce simple reflection holograms using photographic film, however, holograms can also be recorded with digital cameras and the corresponding three-dimensional image reconstructed with computer software. You might want to construct such a system.

3. Thin films & interference colors. What do soap bubbles, oil slicks, butterfly wings and flecks of mica have in common? The colors displayed by all of these objects are manifestations of wave interference. Investigate how these colors arise. What colors are possible? What materials can produce these phenomena? Are there applications of this phenomenon for wavelengths outside of the range visible to the human eye? Some scientists are interested in creating "physical" pigments based on this interference phenomenon. Such pigments would in principle never fade. Investigate how such materials are manufactured. What are appropriate media for applying these pigments? (You can purchase some of these pigments and experiment with them.)

4. Stealth & invisibility. Engineers designing stealth systems are looking for solutions which minimize an object's cross-section to light (i.e. scatter or reflect as little light as possible). Systems which are (nearly) invisible to radio waves (radar) have been successfully manufactured for military purposes. However, making objects ”invisible” at visual wavelengths is a much more difficult problem. Investigate the theory behind these stealth systems. Are the military systems (planes, ships) invisible under all conditions? If not, when do they fail? Why are different approaches required at different wavelengths? What are the approaches currently being pursued for visible wavelength objects (so-called optical camouflage)? Check *Wired* August 2003.

5. David Hockney's theory of optical devices and Renaissance art. Did Vermeer use a lens to help him capture the intricate patterns in the folds of a tablecloth? Or van Eyck, to re-create the pattern of light falling on a brass chandelier? In his book *Secret Knowledge*, David Hockney posits that, as far back as the mid 15^{th} century, painters used optical devices (lenses, concave mirrors and camera lucida) to enhance the realistic details of their pictures. The theory is highly controversial and has generated much commentary. Although Hockney and his collaborator Chris Falco (Physicist, University of Arizona) have presented some compelling analysis, most art critics and historians are skeptical. Investigate the theory and criticism. Reproduce some of Hockney's simple demonstrations.

6. Solid-state lighting (LEDs, lasers & quantum dots). Solid-state physicists, making use of the quantum mechanical and quantum electrodynamical properties of materials (namely semiconductors), have created a wide range of highly efficient and precise light sources (e.g. light emitting diodes (LED), lasers, quantum dots, etc...) Economies of scale in manufacturing have now driven the price of these devices so low that they are rapidly becoming viable alternatives to the inefficient lightning systems that we've lived with for the past century. Investigate the theory and design of these devices. What makes them so efficient? What are the current (technological) limits to their use? How small can we make them? Good place to start is with articles in the January 1993 (quantum dots), July 1996 (laser diodes) and February 2001 (LED) issues of *Scientific American* .

7. Wireless communications. Electromagnetic radiation of any kind is subject to the rules of optics that we are covering in this course. This includes communication devices such as radios, cell phones and wireless internet. Investigate how these systems work. How/why is it possible to transmit these signals through walls and around buildings? How can multiple devices, in some situations (e.g. cell phones) transmit information simultaneously using the same wavelength without interference?

8. Quantum teleportation and/or quantum encryption. In the quantum mechanical world, it is possible to create pairs of objects whose properties are correlated. One of the consequences of this is that, if one of these so-called ”entangled” particles is disturbed, its partner is also instantaneously affected no matter how far apart they are physically. This interaction can occur in less time than it would take for light to travel between the two particles which is in seeming contradiction with Einstein's theory of special relativity[1]. Nevertheless, the phenomenon is real and has implications and applications in quantum computing, quantum cryptography, and quantum teleportation. Investigate these entangled states and their consequences. Describe how these various applications of entangled states work in principle. Can you imagine any other applications for these bizarre quantum mechanical states? Start with some *Scientific American* articles published in August 1993 and April 2000 (updated in 2003).

9. Electronic paper. We are living in an world in which information (e.g. audio, video, text, etc...) is increasingly available in a convenient and compact digital format. Technological innovation has led to a plethora of easy portable devices for playback of audio and video data but the same cannot be said for text[2]. For centuries, paper has served as the ideal medium and form factor

[1]Einstein greatly disliked the notion of entangled quantum states and derisively referred to the phenomenon as ”spooky action at a distance”.

[2]We can argue about the utility of PDAs and Blackberries but they have numerous limitations and drawbacks.

for presenting text and one of the holy grails of the consumer electronics industry is to create a suitable electronic replacement. Investigate the leading technologies. What are some of the major difficulties encountered by scientists and engineers? Can you think of other formats that are as convenient as paper? (Have a look at `http://eink.com/`).

10. Optical gyroscope. A gyroscope is an instrument that helps maintain orientation in space. Historically, these have been mechanical devices consisting of a rapidly spinning mass which, due to the conservation of angular momentum (think of a spinning ice skater), precesses when tilted away from its spin axis. Gyroscopes are essential parts of the guidance systems found in ships, commercial airliners, rockets and satellites. Recently, these mechanical gyroscopes are being replaced with optical ones which have few or no moving parts. Investigate how these devices work (you'll want to start by looking up a phenomenon known as the Sagnac effect).

11. Pigments & dyes. Most of the pigments and dyes that you, as artists, use on a daily basis have been made possible because of innovations in chemical synthesis. In fact, the need for bright, color-fast textile dyes in the mid to late 19^{th} century, was a driving factor behind the explosive growth in industrial chemistry (companies such as BASF and Bayer trace their origins back to this time). Investigate the history of dyes & pigments. Some questions: How are modern pigments created? What ”accidental” discoveries have led to breakthroughs? Some good places to start are *Bright Earth*, by Philip Ball; and *Colors: The Story of Dyes and Pigments*, by Ber Francois.

12. Diffraction patterns & personal security. See me for information on this topic.

13. Bioluminescence is simply light produced by a chemical reaction which originates in an organism. It is primarily a marine phenomenon and is the predominant source of light in the deep ocean . On land it is most commonly seen as glowing fungus on wood (called foxfire), or in the few families of luminous insects (fireflies & glow worms). Investigate this phenomenon. What evolutionary pressure caused it to develop? How is it used in various species? Are there cases of symbiosis with non-bioluminescent organisms? Start with `http://www.lifesci.ucsb.edu/ biolum/`

14. Machine vision. In the 1960's, hubris lead scientists to declare that the neurobiology of vision would be understood within a decade and we could move on to building machines which mimics that behavior. Nearly four decades later, we still don't understand the brain and machines are still very far behind. Investigate the current state of the field. What are the major challenges for machine vision systems? Are there viable solutions on the horizon? Are we limited by lack of computational resources or by lack of biological understanding?

15. Lightning. (taken from M. Silverman, *Waves & Grains*) Investigate the subject of natural lightning. What is lightning? How is it generated? What accounts for the zigzag shape of lightning bolts? What is ball lightning? How does a lightning rod work?

16. World's largest optical mirrors. For nearly five decades (starting in 1948), the 5-meter (200-inch) Hale Telescope was the world's largest optical telescope. However, since 1993, 14 telescopes ranging in size from 6.5 to 10 meters have become operational and there are now at least three groups planning to construct mirrors with diameters of 35 to 100 meters![3] Investigate the technological improvements that have made this possible. Have new materials been developed? Have there been new manufacturing methods invented? Is there a limit to how large these telescopes can be?

Neuroscience, perception & psychology:

17. Synaesthesia (or synesthesia) is the neurological mixing of the senses. Subjects report to be able to taste colors, to hear textures and to see sounds. Investigate the neural basis of this disorder.

[3] To give you a sense of scale, this ranges from the size of a basketball court to greater than the size of a soccer or football field!

Do we make allude to or make use of these perceptions in creating artistic and linguistic metaphors? A good place to start might be *A Brief Tour of Human Consciousness*, by V.S. Ramachandran.

18. Eye evolution. One of the most remarkable consequences of light on earth has been the evolution of eyes that has made vision possible. Nearly all animal phyla have eyes of one sort or another, but the variations in design are immense. Darwin, the great English naturalist who first brought the systematic explanatory power of evolution to bear on the bewildering biological complexity of our planet, felt that eyes offered a special challenge to evolutionary thinking. Investigate the current state of knowledge on eye evolution. What are the major scientific questions? In what ways are these questions being studied (e.g. paleobiology, comparative zoology, genetics)?

19. Persistence of vision. The eye possesses a finite integration (exposure) time. This means that anything which moves during this time is smeared across the eye into a 2D pattern. Property is exploited to give us movies, after-images, and laser shows. Design (and build) a piece which generates a floating image.

20. Edwin Land's retinex theory of color. Color constancy is an example of subjective constancy and a feature of the human color-perception system which ensures that the perceived color of objects remains relatively constant under varying illumination conditions. An apple for instance looks green to us at midday, when the main illumination is white sunlight, and also at sunset, when the main illumination is red. The precise algorithm used for this process is not known. The effect was described in 1971 by Edwin Land (Polaroid), who formulated retinex theory to explain it. Investigate Land's theory. We will see some examples of Land's provocative demos in class but you should attempt to construct your own.

21. Neural prosthesis. Signals in the brain propagate electrically and chemically. Disease and trauma can cause disruptions in this signalling system which leads to paralysis, hearing loss, blindness and other conditions. Recently, scientists have been able to develop electrical devices which interface with the brain and either mimic the function of lost neurons or bypass the affected regions entirely. Investigate the current state of neural prosthesis research. Although we don't entirely understand the language/code of the brain, we can still engineer these devices. How is this accomplished?

22. Blindsight. Following certain kinds of brain lesions, patients report an inability to see objects, but if pressed to guess at their location they display a capacity to point at them with reasonable accuracy. The phenomenon, called "blindsight", is one of the more dramatic of a number of lines of evidence suggesting that being aware of doing something is distinguishable from doing something, that areas of the brain underlying the experience of doing at least some things are distinct from those needed to actually do those things. Investigate this phenomenon. What do the symptoms teach us about the underlying architecture of the brain? How would one go about alleviating the symptoms?

23. Eye tracking. See me for more details.

24. Face recognition. Humans are social animals and primarily recognize each other by their faces and voices. Hundreds or thousands of times a day, your brain analyzes a visual scene, detects the presence of faces and recognizes some of those faces. It also does it quickly and effortlessly. How? Explore the current research and discuss the outstanding questions.

25. Stereopsis / 3D vision. Our eyes comprise a pair of detectors which record 2-D information about the world and our brain somehow uses this to create a 3-D perception. Investigate this phenomenon. How does the brain deal with incomplete information?