FS51x. Changing perspectives: the science of optics in the visual arts

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Figure 1: We will extensively discuss Johannes Vermeer. Because little is known about Vermeer's life, because Vermeer's work achieved much higher levels of realism than any contemporary, and because Vermeer lived near the microscopist Leeuwenhoek, there has been much speculation about whether Vermeer knew about or used optical tools to create his paintings. Vermeer may be painting himself in his *Art of Painting*, working in the way he wants to be seen. Link to painting at Google Arts and Culture

Renaissance artists began to create stunningly realistic representations of their world. Paintings started to resemble photographs, suggesting that artists had solved technical problems that escaped their forebears. Our brains effortlessly deduce three-dimensional scenes from two-dimensional images. But faithfully transferring spatial information to a flat canvas – a sense of depth, surface and shadow, geometrical accuracy – is hard to do. We will discuss how artists from van Eyck to Vermeer to Ingres to modern artists might have used science to make art. We will ask how devices like pinhole cameras, mirrors, and lenses might help artists see more deeply and create images more faithfully. We will perform science experiments with our own hands to appreciate how optical devices might be useful to artists. We will try to use devices to create our own artwork. We will use online platforms to look closely at masterpieces around the world, using Zoom to virtually travel to distant museums and meet with their curators. We will meet artists and scientists, in person and virtually, who think about art and optics from different perspectives. Our seminar is a synthesis of art history, art making, and science. **Prerequisites:** No prior training in art or science. We will learn how to draw in our own workshop. We will learn the science of optics by trial and error, not with math or physics.

The arts and the sciences were transformed during the Renaissance and flourished in close proximity. Did science play a role in Renaissance art? The Dutch artist Jan Van Eyck reveled in optical effects like reflection and refraction, and tried hard to portray the play of light with quantitative precision. The spherical mirror depicted in his *Arnolfini Portrait* is so flawlessly painted that the room can be reconstructed from its curved reflections.

In the Renaissance, scientists and artists worked in close proximity and may have inspired one another. Photographic realism in the work of the Dutch painter Vermeer might owe something to his fellow townsman, the optical scientist Antonie von Leeuwenhoek, who developed the single lens microscope to see microorganisms [1]. Was Vermeer merely inspired? Or did Vermeer use optical tools in his studio?

Whether master artists were inspired by optics or used optical tools is still hotly debated. David Hockney, the British artist and provocateur, thinks that tools were more widely used by artists than

[1] Laura Snyder. *Eye of the Beholder*. W.W. Norton and Company, 2015. ISBN 978-0-393-07746-9

most people think. This debate is difficult to lay to rest without incontrovertible historical evidence. Either way, the interplay between science and technology with making and understanding art is an opportunity for us to explore art and science from different perspectives.

Figure 2: The Arnolfini Ducky. Is it possible to use the concave side of Van Eyck's spherical mirror to project an image that can then be painted? The image of a brightly illuminated object will be focused on a flat surface by a concave mirror at an appropriate distance and with an appropriate curvature.

Our journey through the arts and sciences will include:

- **Making Art**. Most students will not be artists. To appreciate the technical achievements of artists, we will make art ourselves. Dan Jay and Ethan Murrow, Boston-based artists and faculty members at Tufts University, will put pencils in our hands and teach us to draw.
- **Science Experiments**. Most students will not be scientists. Appreciating the interplay between optics and art requires hands-on experience. We will gain an intuitive (i.e., non-mathematical) understanding of optics, mirrors, lenses, reflection, and refraction with our own simple experiments.
- **In-person Field Trips**. We will visit local museums, the Harvard Art Museums and the Isabella Stewart Gardner Museum, to study original artworks, and evaluate their technical and aesthetic achievements. We will visit the Collection of Scientific Instruments at Harvard, and gauge the plausibility of historical optical devices being used by contemporary artists.
- **Virtual Field Trips**. Many relevant artworks and many world experts are not in the neighborhood. We will use Zoom to travel around the world to museums and visit with experts.

Figure 3: *Girl with a Pearl Earring* by Vermeer in the Mauritshuis, The Hague, The Netherlands. We will Zoom to the Mauritshuis and talk to their curators and conservationists about the Vermeer masterpieces in their gallery.

We will meet regularly in the Harvard Art Museums 0600. As needed, we will use the Art Study Center (to look at works from the Harvard collection) and the M-Lab (their maker space to perform experiments and make art). We meet Thursdays from 12:45–2:15 PM.

We will be successful if a better understanding of science and optics deepens our appreciation of art, pushes us to look more carefully at the world around us, and builds our artistic skills.

Contents

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Calendar

Class Meeting	Topic	Hands-on Projects
Week 1. Jan 27	Paintings too perfect? *Secret Knowledge* by David Hockney	Drawing with a comparator mirror Drawing with a curved mirror
Week 2. Feb 3	Ingres at the Harvard Art Museum Meet Meg Grasselli and Joachim Homann	Drawing with a camera lucida How prisms work
Week 3. Feb 10	How the brain sees art Meet Dan Jay, scientist and artist	Drawing Workshop
Week 4. Feb 17	How to draw Meet Ethan Murrow, artist	Drawing Workshop
Week 5. Feb 24	Camera obscura Meet Philip Steadman	Drawing with a camera obscura The pinhole camera
Week 6. Mar 3	Linear Perspective Field trip to Gardner Museum	Drawing with a da Vinci plane
Week 7. Mar 10	*Tim's Vermeer* Meet Tim Jenison	Using Tim's camera obscura The Varley telescope
Week 8. Mar 17	Virtual Vermeer Meet Michelle Luo of Google Arts and Culture Zoom to the Mauritshuis	The Google Pocket Gallery
Week 8. Mar 24	Perspective... and its reversal Meet Martin Kemp	
Week 10. Mar 31	Peepshows and 3D spaces Zoom to the Victoria and Albert Museum	Making a peepshow
Week 11. Apr 7	Vermeer and Leeuwenhoek Meet Arthur Wheelock, National Gallery in Washington	Use a Leeuwenhoek microscope
Week 12. Apr 14	Silhouettes Meet Penley Knipe	Making silhouettes Using Hawkin's physiognotrace
Week 13. Apr 21	Science and Art Meet Marge Livingston	

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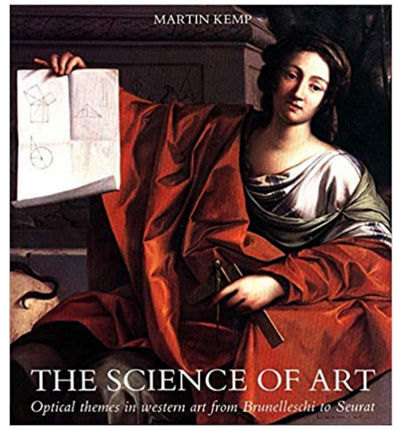
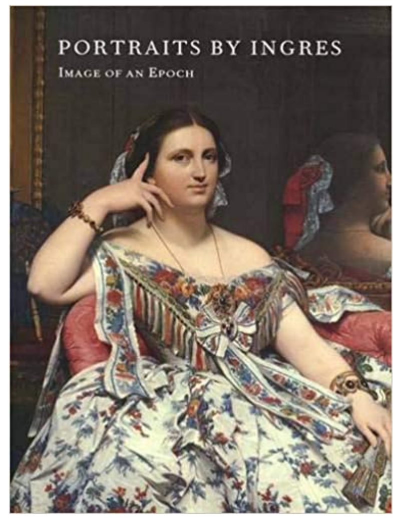
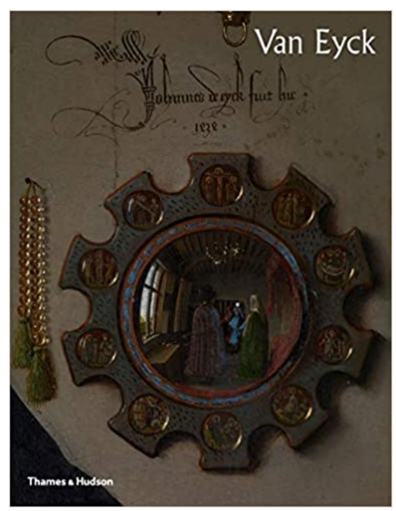
Reserve Reading

- Richard Balzer. *Peepshows: A Visual History*. Harry N. Abrams, Inc., Publishers, New York, 1998a. ISBN 0-8109-6349-3
- Ernst Gombrich. *Art and Illusion: A Study in the Psychology of Pictorial Representation*. Princeton University Press, 2000. ISBN 0691070008
- David Hockney. *Secret Knowledge*. Viking Studio, New York, 2006. ISBN 978-0-14-200512-5
- Ralph Hyde. *Paper peepshows : the Jacqueline and Jonathan Gestetner Collection*. Antique Collectors' Club, Woodbridge, Suffolk, England], 2015. ISBN 1851498001
- *Portraits by Ingres : image of an epoch*. Metropolitan Museum of Art : Distributed by Harry N. Abrams, New York, 1999. ISBN 0870998900
- Walter Isaacson. *Leonardo Da Vinci*. Simon & Schuster, New York, 2017. ISBN 1501139169
- Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6
- Martin Kemp. *Leonardo da Vinci, The Marvellous Works of Nature and Man.* Oxford University Press, 2006b
- Walter A Liedtke. *Vermeer : the complete paintings*. Harry N. Abrams, New York, 2008. ISBN 9789055447428
- Margaret Livingstone. *Vision and Art: The Biology of Seeing*. Harry N. Abrams, Inc., Publishers, New York, 2002. ISBN 0-8109-0406-3
- Abelardo Morell. *Camera obscura*. Bulfinch Press, New York, NY, 1st ed. edition, 2004. ISBN 0821277510
- Asma Naeem. *Black Out: Silhouettes Then and Now*. Princeton University Press, Princeton, New Jersey, 2018. ISBN 069118058X
- Laura Snyder. *Eye of the Beholder*. W.W. Norton and Company, 2015. ISBN 978-0-393-07746-9
- Philip Steadman. *Vermeer's Camera*. Oxford University Press, 2001. ISBN 978-0-19-280302-3
- *Van Eyck*. Thames & Hudson, London ; New York, New York, 2020. ISBN 9780500023457
- Arthur K Wheelock. *Vermeer & the art of painting*. Yale University Press, New Haven, 1995. ISBN 0300062397







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Week One - Paintings too Perfect?

Thursday, 28 January 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

David Hockney, the contemporary artist, wondered whether artists in history might have used technology to make art. He thought that artists might have used optical devices, more widely than anyone has realized, to achieve photographic realism. Lacking historical evidence, Hockney suggested that secretive artists might have guarded their methods from history. But Hockney thought he found evidence that artists used optical tools in their paintings. He thought he could explain unusual and mysterious aberrations as uncorrected optical artifacts caused by using tools. I discovered Hockney's conjecture in the *New Yorker* [2]. Hockney crystallized and elaborated his ideas in *Secret Knowledge*, a sweeping history of photographic realism in art from the Renaissance to now (Fig. 4). [3]

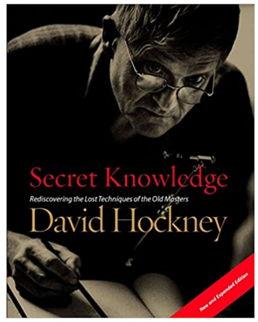

Figure 4: David Hockney using a camera lucida.

[2] Lawrence Weschler. The looking glass. *The New Yorker*, 31 Jan 2000

[3] David Hockney. *Secret Knowledge*. Viking Studio, New York, 2006. ISBN 978-0-14-200512-5

Drawing accurately is hard. Hockney is a talented draftsman. The Harvard Art Museums owns several Hockney drawings (Fig. 5). The story began in 1999 when Hockney attended an exhibit by the Metropolitan Museum of Art that focused on portraits by Jean-Auguste-Dominique Ingres, the great draftsman of the 19th century. Hockney was awed by the perfection of Ingres' drawings, their small size, the known speed of their execution, and the sureness of every line. Ingres's drawings seemed effortless and without flaw (Fig. 6). Hockney was mystified. Did Ingres have help?

At the same time that Ingres was ascending in fame and ability, the physicist William Wollaston invented the camera lucida, a prism that can be used to draw. A camera lucida gives the user a simultaneous and superposed view of the subject being drawn and the drawing itself. With a camera lucida, an artist can literally trace his subject onto paper. When Hockney tried using a camera lucida (Fig. 4), accurate drawing became easier. The technical challenge – getting the proper size and proportion in the features of the face – was done by the camera lucida. The rest of the artist's work was done by hand and eye.

Figure 5: *Drawing of Lancaster*, David Hockney. This drawing is 'eyeballed' without the use of any optical tool. Link to drawing at the Harvard Art Museums.

Figure 6: *Portrait of Madame Charles Hayard and Her Daughter Caroline* by Ingres. Link to drawing at the Harvard Art Museums. Ingres may have viewed painting as his primary calling, but was also deeply devoted to drawing, known as the leading draftsman of his day. His drawings reveal commitment to perfection in each graphite line, finely adjusted – thick, thin, hard, soft – to establish contours with greater expertise and subtler modulations than contemporaries.

Optical effects abound in Renaissance art. Hockney deeply admires the *Arnolfini Portrait* of 1434 by the Flemish painter Jan Van Eyck. The convex mirror on the rear wall of the painting has a stunning and accurately curved reflection of the scene from behind (look closely, see the artist in the mirror!). And the chandelier hanging above is painted in exquisite detail. Van Eyck is reveling in his own technical mastery.

Hockney speculated that if Van Eyck could *paint* a spherical mirror, he could *use* a spherical mirror. It is surprising and straightforward to demonstrate that a concave mirror has the same focusing properties as a convex lens. A concave mirror will project an image of a brightly lit object onto a flat surface (see Fig. 2). Hockney experimented with modern concave mirrors, and convinced himself that they can also be helpful in drawing with photographic accuracy. We will give it a shot (see Art and Science Experiments).

Figure 7: Optical effects are prominent in the work of the 15^{th} century Dutch Artist Jan Van Eyck. The spherical mirror at the back of *Arnolfini Portrait* (Link to National Gallery of London) is a near perfect portrayal of the curved reflections that should appear on the surface of a mirrored ball. Van Eyck's fascination with optical effects is undeniable, and inspired an exhibition that explored this interest across many of his paintings.Optics inspired Van Eyck, but did optics help with the execution of his paintings?

David Stork – a scientist, art enthusiast, and critic of the 'Hockney-Falco thesis' – asked what kind of concave mirror would be needed to project an image onto canvas in a way that the *Arnolfini Portrait* could be painted. The exquisite detail of Van Eyck's masterpiece allowed Stork to reconstruct the three-dimensional space of the depicted room. If a concave mirror was used, it had to be much larger than the spherical mirror depicted on the rear wall (Fig. 8). The trouble is that mirrors of sufficient size and quality did not exist in the 15^{th} century. [4]

[4] David G. Stork. Optics and realism in Renaissance art. *Scientific American*, 291 (6):76–83, 2004

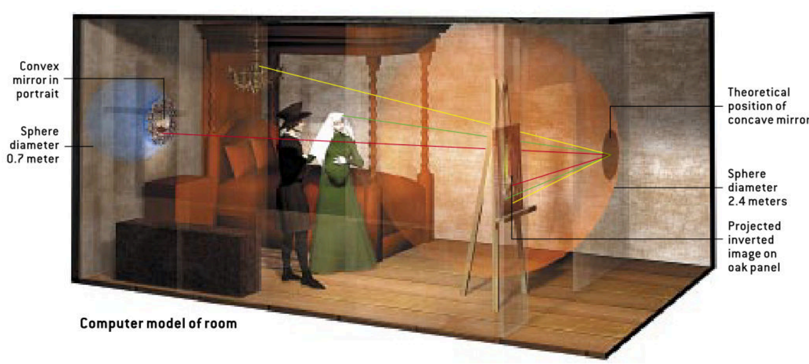

Figure 8: To test Hockney's proposal that the convex mirror in van Eyck's *Arnolfini Portrait* could have been used as a concave projection mirror, David Stork used geometrical optics and the probable sizes of real objects to estimate the three-dimensional space of the visual scene.

TIM JENISON, an inventor who works in computer graphics, wondered whether a simple tool could help him draw or paint with photographic realism. Tim discovered a technique using lenses and curved mirrors that allowed him to reliably translate scenes onto canvas, not only linear perspective but also tonality and color. These adventures are documented in the film *Tim's Vermeer*. A first step towards his invention was a tabletop *comparator mirror* system that shares its principles (Fig. 9).

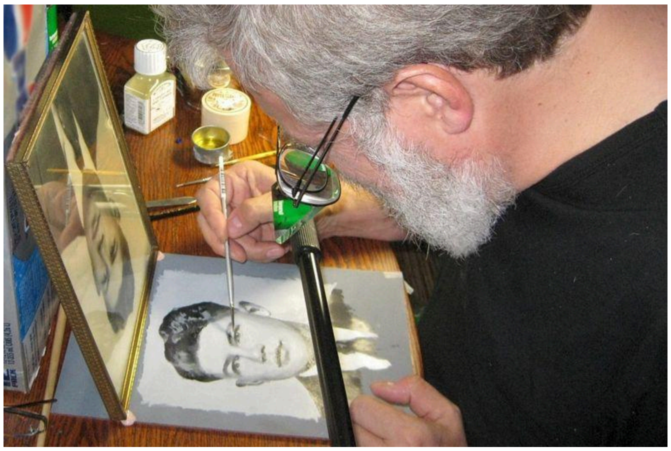
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Figure 9: Tim using a comparator mirror system to copy an image onto paper. From a blog that details the use of Jenison's tools.

Art and Science Experiments

- Like Hockney, we will use curved mirrors to project images onto canvas (Figure 2). It's tricky, but fun and instructive. Watch a video of the experiment, performed by Daniel Davis (see video). Daniel shows how a portrait of a duck and a penguin might be made by using a spherical mirror to project an image onto canvas.
- We will use Tim Jenison's comparator mirror to draw an image. It is more straightforward to use a flat mirror than using a curved mirror to project an image.

Required Reading

- Lawrence Weschler. The looking glass. *The New Yorker*, 31 Jan 2000 Download PDF
- David G. Stork. Optics and realism in Renaissance art. *Scientific American*, 291(6):76–83, 2004 Download PDF
- Chapter One, The Visual Evidence. *In:* David Hockney. *Secret Knowledge*. Viking Studio, New York, 2006. ISBN 978-0-14-200512-5

Updated: March 7, 2022

Week Two - Ingres at the Harvard Art Museum

Thursday, 4 February 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums, Art Study Center

Jean-Auguste-Dominique Ingres (1780-1867) was a giant of the French neoclassical tradition of grand history and narrative paintings. But he was also one of the best draftsmen of any era, famed for drawing portraits with near photographic accuracy [5]. The story of Hockney's interest in optical tools and art began with his admiration for Ingres' drawings. At Harvard, we can study these drawings up close – the Harvard Art Museums have the largest collection of Ingres's drawings outside France.

Meg Grasselli is a Visiting Senior Scholar for Drawings and Visiting Lecturer in History of Art and Architecture at Harvard University. She spent 40 years at the National Gallery of Art in Washington – 30 of those years as curator of Old Master drawings. She is an expert on French drawings, in particular those of the 18th century.

Joachim Homann is the Maida and George Abrams Curator of Drawings at the Harvard Art Museums. He is responsible for the European and American collection of drawings.

In his time, Ingres was highly sought to make portraits. In the 19th century, if you wanted a portrait and had the money, you might hire Ingres to draw your likeness. If not, you might have hired John Hawkins to trace your silhouette (we'll talk about Hawkins in a few weeks). Ingres might not have pleased to be asked. "Cursed portraits! They always keep me from undertaking important things." But perhaps Ingres protested too much. In his *Raphael and the Fornarina*, hanging in the Harvard Art Museums, Ingres depicts Raphael as more interested in the portrait painted by the Renaissance master than in the subject herself sitting on his knee (Fig. 10). Ingres was also not shy about showing portraits alongside 'grander' paintings in his major exhibitions, or using portraits of living subjects as models in history paintings.

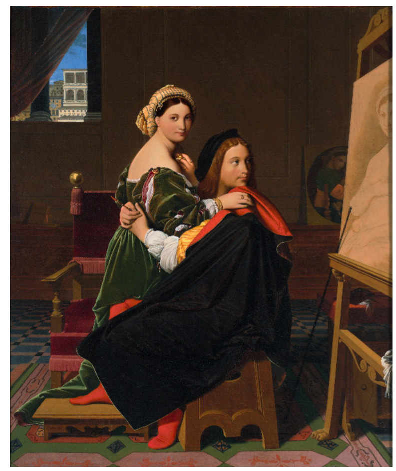


Figure 10: *Raphael and the Fornarina* by Ingres (1814), given to Harvard in 1943. Ingres revered Raphael as the pinnacle of Renaissance artistic achievement.

Hockney took a close look at numerous portraits by Ingres (Fig. 6). He noted differences in the way that different parts of the same drawing were made – loose versus precise lines, 'eyeballed' sketches vs assured and definite strokes. Hockney interpreted these differences as evidence that Ingres sometimes used a tool like a camera lucida or camera obscura [6]. Meg Grasselli and Joachim Homann will guide our own examination of original drawings by Ingres. We will judge for ourselves.

[5] *Portraits by Ingres : image of an epoch*. Metropolitan Museum of Art : Distributed by Harry N. Abrams, New York, 1999. ISBN 0870998900

[6] David Hockney. *Secret Knowledge*. Viking Studio, New York, 2006. ISBN 978-0-14-200512-5

The Harvard Art Museums have a wide range of Ingres works for us to examine. These include:

- Augustine-Modeste-Hortense Reiset
- Odalisque, Slave, and Eunuch
- Self-Portrait
- Profile Portrait of a Man
- Portrait of Count Adolphe de Colombet de Landos
- View of the Villa Medici, Rome
- Portrait of Mrs. George Vesey and Her Daughter Elizabeth Vesey, later Lady Colthurst
- Portrait of Mme Delphine Ingres
- Portrait of Etienne-Jean Delecluze
- The Martyrdom of Saint Symphorien
- Portrait of the Architect Francois-Desire Girard de Bury
- Roger Freeing Angelica

Figure 11: *Self Portrait* by Ingres (1859)

Figure 12: *Delphine Ingres* by Ingres

Does a work of art cease to be a work of art if a tool was deceptively used in its execution? This question is the crux of the animated and heated debates surrounding the Hockney-Falco thesis. Immanuel Kant had his own strong opinion.

> "But it is the indispensable requisite of the interest which we here take in beauty, that the beauty should be that of nature, and it vanishes completely as soon as we are conscious of having been deceived, and that it is only the work of art – so completely that even taste can then no longer find in it anything beautiful nor sight anything attractive. What do poets set more store on than the nightingale's bewitching and beautiful note, in a lonely thicket on a still summer evening by the soft light of the moon? And yet we have instances of how, where no such songster was to be found, a jovial host has played a trick on the guests with him on a visit to enjoy the country air, and has done so to their huge satisfaction, by biding in a thicket a rogue of a youth who (with a reed or rush in his mouth) knew how to reproduce this note so as to hit off nature to perfection. But the instant one realizes that it is all a fraud no one will long endure listening to this song that before was regarded as so attractive."
>
> Immanuel Kant, *The Critique of Judgment*

But many artists had different thoughts. John Constable, the British landscape artist, viewed his work as a branch of the natural sciences, what we call physics [7]. "Painting is a science," Constable said, "and should be pursued as an inquiry into the laws of nature. Why, then, may not landscape painting be considered as a branch of natural philosophy, of which pictures are but the experiments?"

[7] Ernst Gombrich. *Art and Illusion: A Study in the Psychology of Pictorial Representation*. Princeton University Press, 2000. ISBN 0691070008

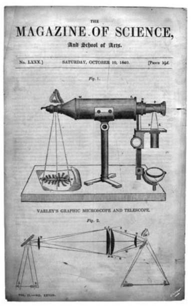


Figure 13: Illustration of the graphic telescope and its optical principles. From the Magazine of Science, and School of Arts, 1840.

The Harvard Art Museums has a drawing by Constable that we know that he been made using a transparent plane. Leonard da Vinci's sketchbooks describe the use of a transparent plane to sketch a scene: fix your viewpoint; sketch the scene before you onto an intervening transparent plane; copy your sketch onto paper. Constable's drawing is a study of perspective of architecture that appears in his *Church Porch, East Bergholt* (Figs. 14, 15).

Figure 14: *The Church Porch, East Bergholt* by John Constable Link to painting at the Tate

Figure 15: *Drawing of the Church Porch, East Bergholt* by John Constable.

The Harvard Art Museums has other drawings known to be made with optical tools. Cornelius Varley invented a patent graphic telescope, the most sophisticated drawing aid of his time, described in his *Treatise on Optical Drawing Instruments* in 1845 [8] (Fig. 13). The Graphic Telescope, a combination of a telescope and camera obscura, allows the artist to simultaneously look forward at the subject and down on the drawing surface, so that drawn image can be matched to seen image. We will compare drawings known to have been made with optical tools to drawings by Ingres whose methods we can only speculate about.

[8] Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6

Figure 16: *At Parton Hall, Staffordshire, 1820* by Cornelius Varley.

Art and Science Experiments

- The physics of a camera lucida is the physics of the prism (Fig. 17), knowing about refraction and internal reflections. We can gain an intuition for the camera lucida, invented by the physicist William Wollaston, with simple experiments using pen lasers and geometric transparent objects.
- Hockney convinced himself that Ingres used a camera lucida by using one himself (Fig. 18), finding that it was much easier to achieve photographic realism with the optical tool than without. We will try the same experiment, using our own camera lucidas to draw one another's portraits. It isn't easy!

Required Reading

- Chapter One, The Visual Evidence. *In:* David Hockney. *Secret Knowledge*. Viking Studio, New York, 2006. ISBN 978-0-14-200512-5
- Martin Kemp. Lucid Looking:David Hockney's drawings using the camera lucida. *Nature*, 400:524, 1999b Download PDF

Recommended Reading

- 'Ingres's Portraits and their Muses' by Robert Rosenblum *In*: *Portraits by Ingres : image of an epoch*. Metropolitan Museum of Art : Distributed by Harry N. Abrams, New York, 1999. ISBN 0870998900 Download PDF

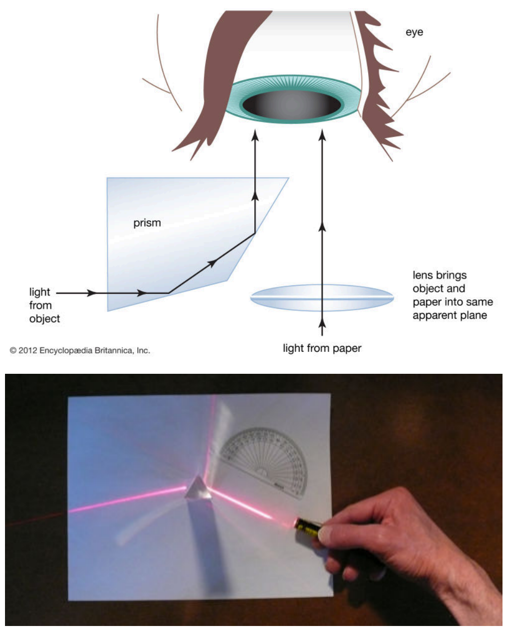


Figure 17: Upper: The physics of the camera lucida invented by William Wollaston in 1806. www.britannica.com. Lower: Refraction measured with a protractor, laser, and prism.

Figure 18: Hockney's camera lucida drawing of Martin Kemp.

Updated: March 7, 2022

Week Three - How the brain sees art

Thursday, 10 February 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 060

Art makes its impact in the mind. Dan Jay is a scientist-artist at Tufts Graduate School of Biomedical Sciences and adjunct professor at the School of the Museum of Fine Arts at Tufts. Dan has thought a lot about how art is perceived by eye and brain. Examples of his work here. Dan will give a guest lecture and guide a drawing workshop.

"Science and art are two worlds, but I feel comfortable in both, and have a wonderful sense of community in both," says Dan Jay. with his "Elements SiSSbSn".

Figure 19: Max's Hot Dogs, Long Branch NJ by Dan Jay

Dan Jay's drawing inside Max's Hot Dogs, a restaurant in New Jersey, is interpretable without effort (Fig. 19). The receding and converging lines of the ceiling tiles convey a sense of three-dimensional space. Near objects are large. Far objects are small. The busy interior makes sense to us without being photographically accurate. The straight lines that convey perspective do not precisely converge to one vanishing point. The drawing gestures to, without following, the laws of projective geometry (see Appendix I). Yet the drawing does not appear distorted or unsettling. We easily 'see' the casual restaurant, not unlike many such places we have visited.

Dan's drawing is also unlike any 'real' optical image by being a *drawing*, not a photograph. Drawings are made from the delineated edges of objects. Photographs and paintings are made from colored masses. A drawing is comprehensible because the brains of the artist and viewer can agree about an image that departs, in many ways, from any visual image of the real world. The comprehensibility of a drawing requires specific mechanisms in our visual systems and imaginations [9].

[9] Margaret Livingstone. *Vision and Art: The Biology of Seeing*. Harry N. Abrams, Inc., Publishers, New York, 2002. ISBN 0-8109-0406-3

Renaissance scientist-artist Leonardo da Vinci understood linear perspective, the principles of which had been discovered in Florence about a century earlier by Brunelleschi. *The Last Supper* is an overt portrayal of a three-dimensional space. All orthogonal lines to the picture plane precisely converge to a vanishing point at Christ's head (Fig. 20). This is not a loose sketch, but a careful creation. In the actual painting, a small nail hole at the vanishing point suggests that Leonardo might have pulled a taut string from a nail to make his perfectly radiating lines.

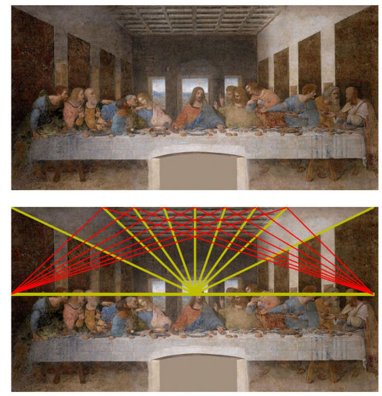


Figure 20: Analysis of the perspective of Leonardo's *The Last Supper*. The vanishing point located at Christ's head can be inferred from the coffered ceiling. The red lines indicate the focus of diagonals two coffers deep. If the coffers are rectangular, twice as wide as long, these foci convey the distance between viewer and image. Kemp (1990).

The painting appears to be a logical representation of a three-dimensional space. But look closer. Geometry and measurement reveals ambiguities. If the ceiling coffers are square (as one might expect), then the room is much deeper than wide. Whether the coffers are uniformly rectangular or square, they allow calculating the relative proportions of tapestries hanging on the side walls. If the tapestries are the same size in the real world, the laws of linear perspective predict their relative sizes in the painting. But the relative size of the tapestries violate these laws. Instead, the tapestry widths diminish in size in the ratios $1{:}\frac{1}{2}{:}\frac{1}{3}{:}\frac{1}{4}$. In whole numbers, these ratios are 12:6:3, which are musical intervals: a musical fourth interval is 3:4; a fifth interval is 4:6; an octave is 12:6. In the margins of Leonardo's notebooks for the *The Last Supper*, Martin Kemp found a doodled arithmetical progression of these tonal harmonies (Fig. 21) [10]. Perhaps Leonardo consciously traded mathematical harmony for musical harmony, making little difference to the casual viewer but making symbolic difference to him.

[10] Martin Kemp. *Leonardo da Vinci, The Marvellous Works of Nature and Man.* Oxford University Press, 2006b

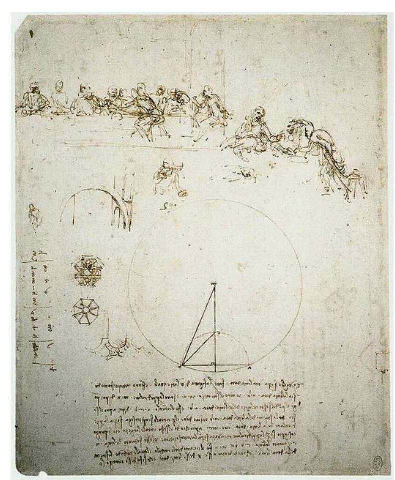


Figure 21: *Study for The Last Supper, with Method of Constructing an Octagon and Arithmetical Calculation*. Leonardo da Vinci.

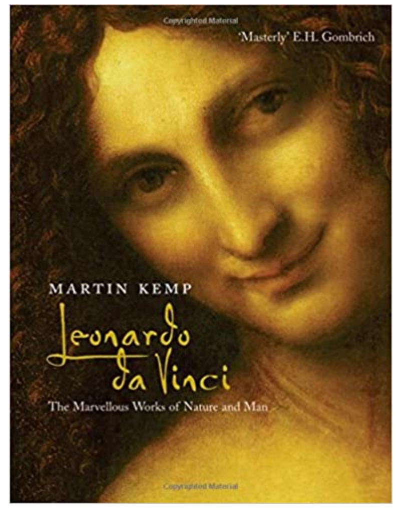
The Last Supper is an act of *fantasia*, a gesture towards the rules of perspective that make it seem like looking through a window into the hallowed space, but with carefully wrought departures to achieve narrative purposes.

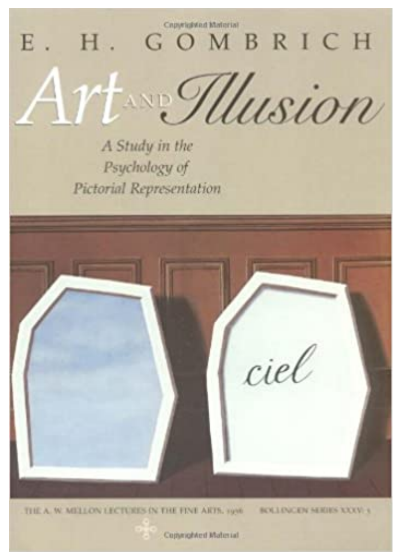
Every artwork is an act of communication between the mind of the artist, whether Dan Jay or da Vinci, and the mind of the viewer. Ernst Gombrich explored this idea in his now classic *Art and Illusion.*

> "What a painter inquires into is not the nature of the physical world but the nature of our reactions to it. He is not concerned with causes but with the mechanism of certain effects. His is a psychological problem – that of conjuring up a convincing image despite the fact that not one individual shade corresponds to what we call 'reality'."
> – Chapter One. From Light into Paint.

Recommended Reading

- Chapter One, Linear Perspective from Brunelleschi to Leonardo. *In:* Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6 Download PDF
- Chapter One, From Light into Paint. *In:* Ernst Gombrich. *Art and Illusion: A Study in the Psychology of Pictorial Representation*. Princeton University Press, 2000. ISBN 0691070008 Download PDF
- Chapter Three, The Exercise of Fantasia. *In:* Martin Kemp. *Leonardo da Vinci, The Marvellous Works of Nature and Man.* Oxford University Press, 2006b Download PDF

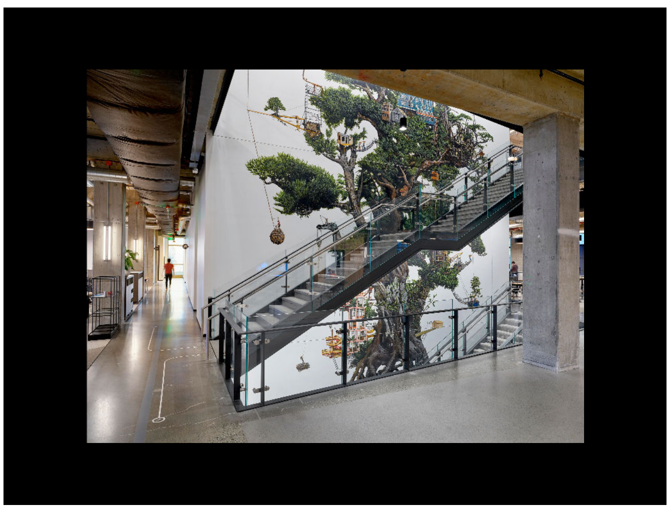


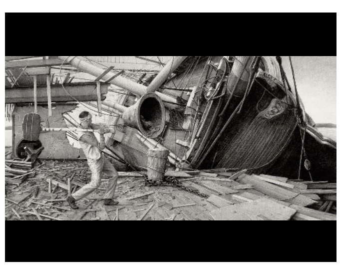


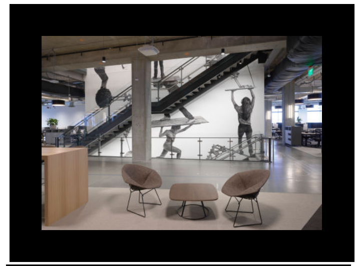
Week Four - Workshop with Ethan Murrow

Thursday, 17 February 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

Ethan Murrow, Chair of Painting and Drawing at the School of the Museum of Fine Arts at Tufts University, will join us for a drawing workshop. Ethan grew up on a sheep farm in Vermont. His creative practice focuses on historical narratives and the idealized and uncomfortable ways in which they are told, retold, and molded into powerful, absurd, and subjective tales. In addition to works on paper, he develops large scale wall drawings, murals, and installations for site specific projects and exhibitions, working closely with local communities, stakeholders, institutions, and corporations. Recent solo museum shows include the Institute of Contemporary Art Boston, The Currier Museum of Art, Museum of Contemporary Art Jacksonville, and the Clay Center in West Virginia.







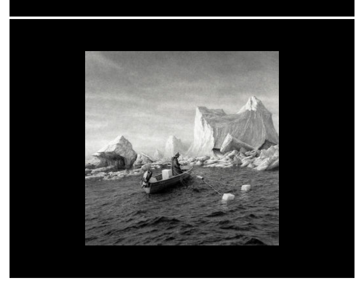


Figure 22: **Gideon Bok – drawing what we see not what we know.** Committed to painting the passage of time within a confined space, his own studio, he depicts it over and over in various states of array with objects such as draped clothes, musical instruments, and artist supplies. His intent is to make the room seem alive, showing it shortly after it has been occupied (from the Archives of askArt.)

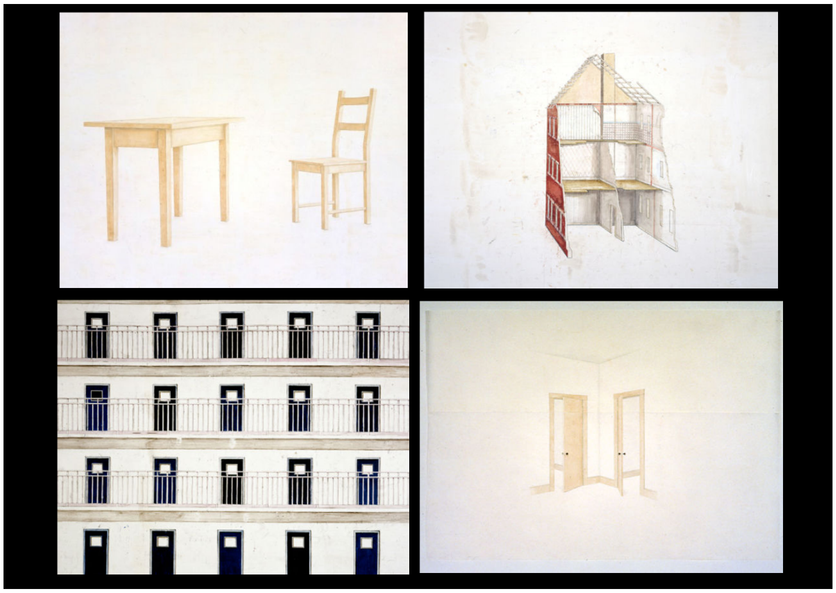


Figure 23: **Toba Khedoori – drawing how we think, as icon, symbol, or language**. Khedoori frequently depicts architectural forms from distanced perspectives, rendering commonplace objects and spaces familiar yet decontextualized. In recent years, she has transitioned from paper to canvas, producing smaller scale works that hover between representation and abstraction. Like her earlier compositions, these works are enigmatic and acutely detailed; in an art world awash with rapidly moving images and saturated colors, Khedoori remains committed to the silent, slow, and exacting process of working by hand (from www.lacma.org)

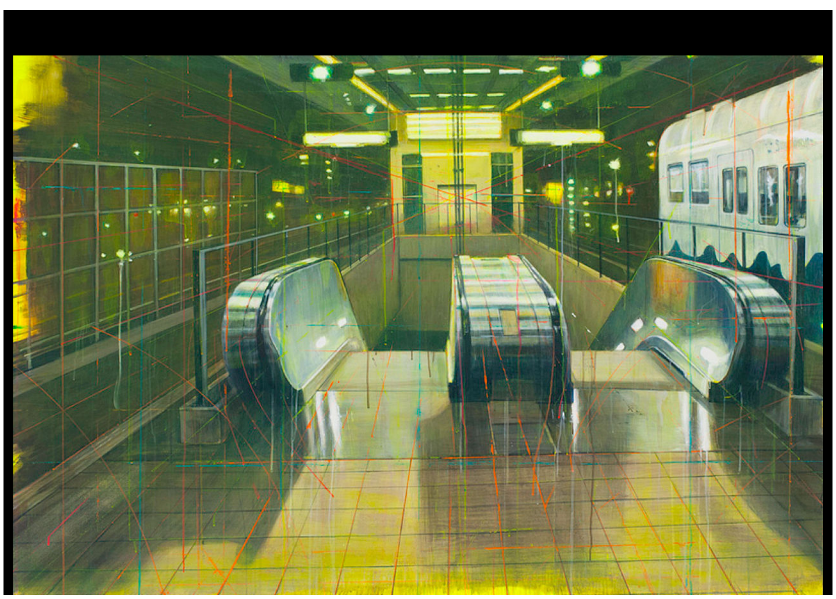


Figure 24: **Peter Waite – drawing in relation to what we understand, structure**. "For over 25 years I have made large scale paintings that document my travels – real visits to real places – to sites of the built environment that embody public sentiment or ideological concerns. Stadiums, formal gardens, bridges, museums, monuments, palaces, train stations, schools, prisons, casinos, corporate board rooms, suburban and urban housing, and ancient temples, are some of the locations that I have depicted. My interest lies in the intersection of personal and social memory. I have intentionally omitted the figure from the representation to emphasize the viewer's participation as witness to the moment of perceiving, then remembering, these architectural spaces." (from www.peterwaite.com)

Figure 25: **Gary Katchadourian – drawing in relation to experience,time, movement.** Gary Kachadourian challenges conventional means of art production with his open-source/endless supply approach to drawing. The artist brings fresh eyes to even the most mundane places or objects – a parking lot or a Pepsi machine. He encourages us to view our environment anew. He plays with the role of the artist as creator, as well as reproduction and illusionism in art by copying the world in mass quantities. Kachadourian's process entails sketching and photographing his subject, noting its dimensions, and then creating a detailed drawing. The drawing is scanned and enlarged to the dimensions of the actual object. His to-scale drawings are then reproduced in xerographic prints on paper or on vinyl in infinite supply (from ndi.arkansasartscenter.org)

The basics of representational drawing

1. Draw what you see not what you know.
2. Separate stereotype symbol memory from real time information.
3. Use all of your senses, not just your eyes
   (a) Common object. Water bottle.
   (b) Describe out loud what makes it distinctive from other chairs
   (c) Write words that would help you build this water bottle
   (d) Now draw the water bottle
   (e) What do you notice, what was difficult to draw?
   (f) Review proportion, scale, perspective angles etc.

Video Clip on Perspective Drawing

Video Clip on Measuring Angles and Proportions in a Still Life

Starting places exercise

1. We use our whole body and when able, it is best to stand
2. Remember drawing *and* artwork are subjective, seeing is fluid
3. Try to focus on creating rough summaries, don't get precious
4. Use the side of your drawing tool or a slightly wonky, wobbly approach
5. Focus on gaining a 'sense' of the form, not a perfect rendition
6. Use your eraser to blend / redact
7. Blur your eyes at the object / scene, what does it 'roughly' look like?


Ethan's Drawing Process

Measuring angles and proportion.

1. First please find two rectangular items in your space (book, box, etc)
2. Stand it up, put it a feet away from you if possible
3. Get your paper, pencils, straight edges, erasers out
4. Use your hands like a box to look carefully, assess the scene
5. Comparison is key. What is different about the way the objects look?
6. Hold up your straight edge level, what are perceived angles and intersections?


Using cross-hatch

Updated: March 7, 2022

7. Next make a quick sketch of what you see
8. Now practice measuring what the angles look like to you
9. Make some adjustments
10. Now practice measuring proportion, compare relative size
11. Make some adjustments
12. What was hard about that? What was confusing?

Other exercises to test what you see and how you can relate it to the page

1. Blind Contour Drawing
2. Draw Ethan, no looking at your page
3. Exquisite corpse drawing game
4. Go look at Contemporary Art in Boston, ICA, MIT List, DeCordova, SMFA, Harvard, MFA, etc.

Updated: March 7, 2022

Week Five - The Camera Obscura

Thursday, 24 February 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600 and the Art Study Center

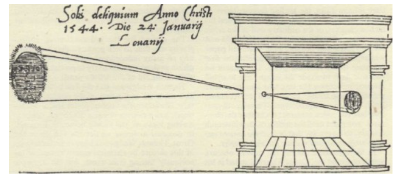


Figure 26: Camera obscura illustrated by the Dutch mathematician Gemma Frisius in 1545.

The camera obscura, or 'dark room', is a dark chamber where one wall has a small aperture to the illuminated outside world. Rays of light passing through the aperture will cross, re-emerge, and diverge. When the diverging rays are captured on a flat screen, they form a reversed and inverted image. This image is dim, because only a small fraction of photons reflected from objects in the outside world will travel through the aperture. The aperture needs to be small to produce a sharp image. The smaller the aperture, the sharper and dimmer the image. Dimness can be helpful, for example, in early astronomical observations of the sun (Fig. 26). Even now, amateur viewers of solar eclipses make 'pinhole cameras' out of cardboard boxes based on the same principles. The phenomenon of the camera obscura was known in the Middle Ages and admired by Leonardo da Vinci for shedding light on the nature of seeing and the visual world:

Figure 27: *Soldier and a Laughing Girl* by Johannes Vermeer. Link to painting at Google Arts and Culture

> "O marvellous necessity... O might process. Here the figures, here the colours, here all the images of the parts of the universe are reduced to a point... Forms already lost, can be regenerated and reconstituted." [11]

A convex lens placed at the aperture of a camera obscura will collect more light and produce a brighter image at its focal distance. A camera obscura with a lens is thus a model of the human eye. If the light is collected on photographic film or CCD chip, the camera obscura becomes a modern analog or digital camera. In the Renaissance, the camera obscura was a startling and immediate way to capture visual truth, a form of 'natural magic'. In 1622, Constantijn Huygens (father of Christiaan, the renowned Dutch physicist and optical scientist) wrote of the camera obscura:

Figure 28: *The Lacemaker* by Johannes Vermeer. Link to painting at Google Arts and Culture

> "It is impossible to express its beauty in words. The art of painting is dead, for this is life itself, or something higher, if we could find a word for it." [12]

These were provocative words in the Golden Age of the Dutch Renaissance, the era of Rembrandt and Vermeer. But the Dutch Renaissance was also a Golden Age in optical science led by physicists like Christiaan Huygens and microscopists like Antonie von Leeuwenhoek. Dutch scientists and artists knew and admired their respective and extraordinary achievements.

[11] Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6

[12] Svetlana Alpers. *The Art of Describing*. University of Chicago Press, 1983. ISBN 978-0-226-01513-2

THE LIFE OF JOHANNES VERMEER is hidden in mystery. The historical record is poor, earning Vermeer the sobriquet 'The Sphinx of Delft'. Most of the evidence about Vermeer's painting methods are the paintings themselves. These paintings attest to fascination with light and optics, refraction and reflection. Vermeer's *Soldier and a Laughing Girl* makes deliberate use of light, shadow, and perspective (Fig. 27). The soldier is painted in a silhouette against a brightly illuminated background. Vermeer pays close attention to the rules of linear perspective. The soldier is painted larger than the girl in proper geometric proportion based on his position closer to the viewer. An exquisitely detailed map hangs on the wall, a virtuoso display of 'photographic' accuracy. A partial reflection of the outside glimmers on the open window. Tim Jenison, an inventor and expert in computer graphics, noticed that this reflection resembles Nieuwe Kerk (New Church) in Delft, built in the 14^{th} century and standing today.

Figure 29: *The Girl with the Wine Glass* by Vermeer. Link to painting at Google Arts and Culture

VERMEER DELIBERATELY INCORPORATED OPTICAL EFFECTS that are characteristic of a camera obscura. In many paintings, Vermeer included 'circles of confusion', bright globules of coalesced highlights that simulate an out-of-focus effect caused by light diffraction. Circles of confusion appear on many objects in *The Lacemaker*, even on non-reflective matte surfaces that would not produce them in a camera obscura (Fig. 28). When the naked eye looks at a natural scene, every plane is in sharp focus because our lenses adapt. In a camera obscura with a glass lens, one image plane is in sharp focus, while nearer or farther image planes will have softer focus. Vermeer may have been mimicking this effect, either for aesthetics or optical realism.

Figure 30: *The Glass of Wine* by Vermeer. Link to painting at Google Arts and Culture

PHILIP STEADMAN is an architect and Emeritus Professor of Urban and Built Form Studies at University College London. When Steadman looked at Vermeer's domestic interiors, he was struck not only by their photographic realism but also by the architectural consistency of the room that appeared in painting after painting (Figs. 31, 29, 27, 30). Steadman advanced a theory that the same room was being translated from image to canvas, albeit with different decor in each tableau. He speculated that Vermeer might have used a camera obscura, not just to frame his subjects or to explore optical effects (consistent with the opinions of many art historians), but as a drawing tool to translate a scene onto canvas more accurately.

Steadman reconstructed the rooms from several of Vermeer's domestic interiors and worked out their viewing positions. He worked

Figure 31: *Lady Standing at a Virginal* by Vermeer. Link to painting at Google Arts and Culture

out where the images of these brightly lit interiors would occur if they were projected by a camera obscura in the back of the room. These reconstructions revealed a remarkable consistency from painting to painting. Steadman proposed that Vermeer could have used a camera obscura, positioned in the same place at the back of the same room, to frame or compose several paintings of domestic scenes. Steadman envisions Vermeer's camera as a room, sectioned off and darkened, at one end of his studio. An aperture and lens would cast an image of the scene at the other end of the studio onto a surface. This image, re-inverted and re-reversed, could then be transferred to canvas (Fig. 32).

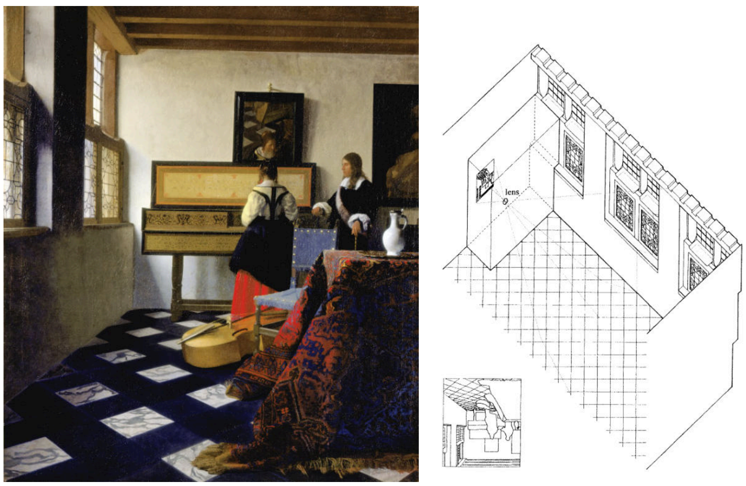


Figure 32: Did Vermeer use a camera to compose or create domestic scenes? *Left*: Lady at the Virginal with a Gentleman in *The Music Lesson* by Vermeer c.1662 - 1665. *Right:* Possible arrangement for Vermeer's *camera obscura* in the form of an enclosed booth, with the lens in the front wall projecting an image onto the back wall.

ART HISTORIANS have different takes about Vermeer and optics. As Walter Liedtke, Vermeer scholar and former curator of Dutch Art at the Metropolitan Museum of Art, put it:

> "In general, the debate divides between optical and artistic camps and on both sides proponents will argue in favour of one hypothesis or another but are ill-prepared to comprehend the reservations expressed by their critics." [13]

[13] Walter A Liedtke. *Vermeer : the complete paintings*. Harry N. Abrams, New York, 2008. ISBN 9789055447428

Vermeer owed as much to contemporary artists as he may have to contemporary scientists. Whether Vermeer needed or chose to use optical devices to achieve his unsurpassed qualities of realism, light, and shadow is impossible to directly prove. The historical record is too poor. Liedtke has shown that, while Vermeer is unique in many ways, he also borrowed ideas and aesthetics from contemporaries that have not been accused of 'cheating' with optical tools. Arthur Wheelock, former Curator of Baroque Paintings at the National Gallery of Art in Washington, observes that Vermeer, while often achieving optical realism, also often overruled realism in his own aesthetic judgment. [14]

[14] Arthur K Wheelock. *Vermeer & the art of painting*. Yale University Press, New Haven, 1995. ISBN 0300062397

Optical devices are not only a way of assisting artists who work in different mediums, but can be the artistic medium itself. The principle of the camera obscura is the same as pinhole photography, capturing an entire scene by carrying all of its visual information through a tiny hole into a darkened room onto film or photographic paper. Abe Morrell, a Boston-based artist, takes photographs of this photographic process itself, creating images of the inside of the camera obscura as it captures the outside world. [15]. The Harvard Art Museum has several works by Abe Morrell in our collection to see, study, and enjoy.

[15] Abelardo Morell. *Camera obscura*. Bulfinch Press, New York, NY, 1st ed. edition, 2004. ISBN 0821277510

Figure 33: *Camera Obscura* Image. View of Philadelphia from Loews Hotel room 3013 with upside down bed by Abelardo Morrell. From the Harvard Art Museums.

Art and Science Experiments

- To better understand the camera obscura we will build our own pinhole camera (Figure 34). A small hole in one wall of a dark room will project an inverted image of an exterior scene onto a flat surface. In this video, Chris Stokes projected his backyard onto a screen in his darkened garage. With a pinhole, cardboard tube, and translucent screen, make your own portable pinhole camera. Replace the pinhole with a lens and the image brightens! The basic steps are shown in this video.
- A box camera obscura can be used to draw scenes. We will try using one to arrange and draw a scene (Figure 35).

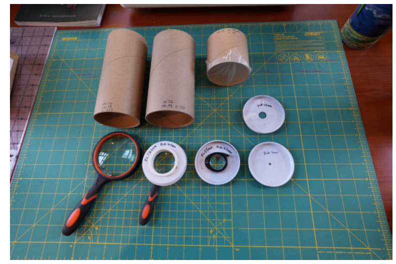


Figure 34: Elements of a pinhole camera kit

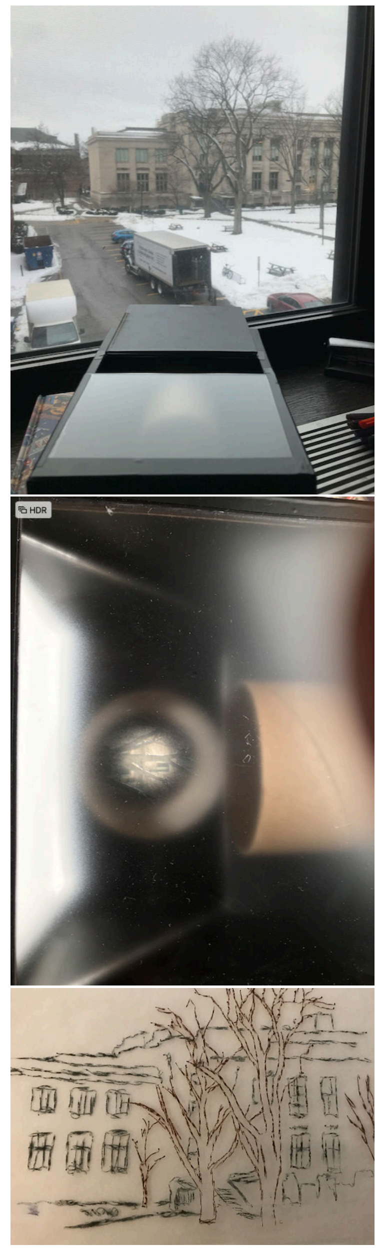


Figure 35: *Top:* Aravi's camera obscura aimed outside his office. *Middle:* Photograph of the frosted plate showing a focused image. *Bottom:* Aravi's tracing of the camera obscura image onto a sheet of plastic transparency paper.

Required Reading

- Martin Kemp. Vermeer's vision. *Nature*, 392:27, 1998 Download PDF
- Appendix A. Vermeer and the Camera Obscura. Walter A Liedtke. *Vermeer : the complete paintings*. Harry N. Abrams, New York, 2008. ISBN 9789055447428. Download PDF
- Introduction by Luc Sante. Abelardo Morell. *Camera obscura*. Bulfinch Press, New York, NY, 1st ed. edition, 2004. ISBN 0821277510

Recommended Reading

- Philip Steadman. *Vermeer's Camera*. Oxford University Press, 2001. ISBN 978-0-19-280302-3.
  - Download Chapter 4: A room in Vermeer's House?.
  - Download Chapter 5: Reconstructing the space in Vermeer's painting
  - Download Chapter 6: The riddle of the sphinx of Delft
- Arthur K Wheelock. *Vermeer & the art of painting*. Yale University Press, New Haven, 1995. ISBN 0300062397 Download PDF

Updated: March 7, 2022

Week Six - Linear Perspective

Thursday, 3 March 2022, 12:45 - 2:15 PM EST.
Field Trip to Isabella Stewart Gardner Museum

We think we see in three dimensions. But before we see the world in depth, visual information is flattened onto our retinas. Retinal information is un-flattened by the brain for us to see three dimensions. Our brains process images in many different ways when we see. The laws of projective geometry and linear perspective were hard to discover *because* the brain does not solely rely on geometry to infer depth. We integrate many different visual cues – perspective, shading, motion, stereopsis – to create our internal sense of our three-dimensional surroundings. This leads to to interesting illusions (Fig. 36).

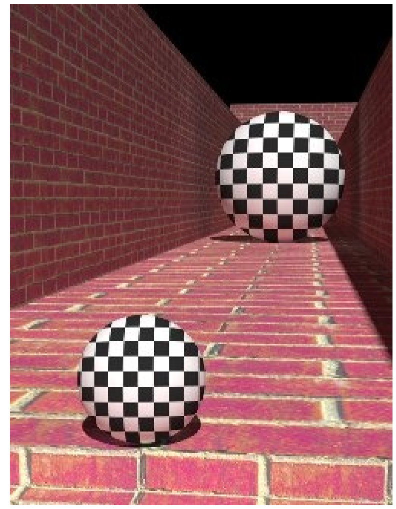


Figure 36: The two balls are exactly the same size, yet the upper ball appears larger. The brain uses additional cues from the scene to infer the relative sizes of the ball. 123opticalillusions.com

The geometry of linear perspective, the relationships that turn scenes with depth into flat images (see Appendix I), had to be discovered before they appeared in Renaissance art. This discovery is credited to Filippo Brunelleschi (1377-1446), a Florentine architect [16]. Brunelleschi discovered that parallel lines that are orthogonal to the viewing plane in the real world (lines that never meet in space) converge to one central point in the flat visual image. Every other set of parallel lines in space will converge to a unique lateral point in the flat image. Brunelleschi incorporated these discoveries in demonstration panels, now lost but reported to be stunningly accurate, of the Baptistery of the Florence Cathedral, an octagonal building with many sets of parallel lines to contemplate (Fig. 37).

[16] Martin Kemp. Journey into space. *Nature*, 400:823, 1999a

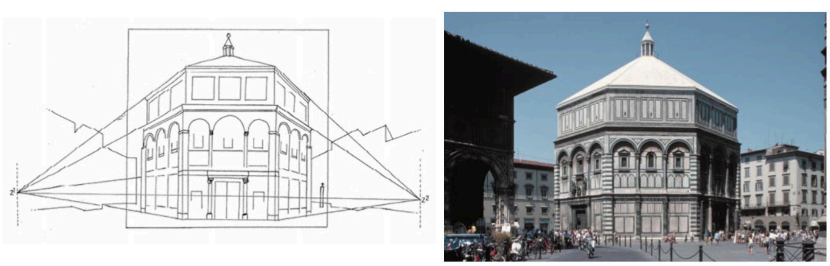


Figure 37: Brunelleschi's first demonstration of linear perspective using the Baptistery of Florence Cathedral.

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Once discovered, Renaissance artists seized upon the importance of perspective in faithfully representing Nature.

> "Perspective must... be preferred to all the human discourses and disciplines. In this field of study, the radiant lines are enumerated by means of demonstrations in which are found not only the glories of mathematics but also of physics, each being adorned with the blossoms of the other." -Leonardo da Vinci

Updated: March 7, 2022

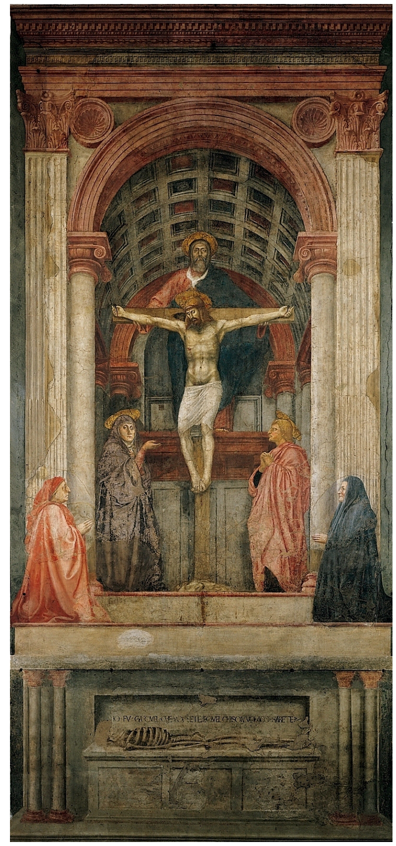


Figure 38: *The Holy Trinity* by Masaccio. Link to artist at Google Arts and Culture.

THE EARLIEST RENAISSANCE PAINTING that incorporates Brunelleschi's perspective is *The Holy Trinity* by Masaccio. This painting, a fresco in the Santa Maria Novella in Florence, is the first where all orthogonals seem to converge to a single point. Here, the artist did not transcribe a real visual scene, like what Brunelleschi did with the Baptistery. He predicted the two-dimensional visual image that would be produced by a three-dimensional space that existed only in his mind. Brunelleschi, an older friend, may have been an important consultant in Masaccio's pioneering work.

In *Secret Knowledge*, David Hockney tried using a concave mirror to project an image of the Florentine Baptistery onto paper, to see whether it helped to render linear perspective. Philip Steadman performed an experiment by directly painting the image of the Florentine Baptistery onto its image on a flat mirror. Martin Kemp favors the hypothesis that Brunelleschi used surveying tools – tools that would be familiar to a practicing architect – by measuring and transcribing lines of sight onto his demonstration panels [17].

Figure 39: *Scenes from the Story of the Western Wing* by an unknown Japanese artist.

[17] Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6

PUTTING ASIDE THE TECHNICAL CHALLENGES AND QUESTIONS, for a moment, in how Brunelleschi might have captured linear perspective, Hockney makes a perhaps deeper point related to aesthetics and psychology. Brunelleschian perspective is not strictly needed to produce a careful and convincing flat image of volume and space in the real world. Our brains use many different cues to build our internal representations, mechanisms that a skilled artist can tap into. There is nothing primitive about architectural images in Eastern Art that, in many ways, are closer to our lived experiences (Fig. 39). Lines that are parallel in the real world are drawn as parallel, appealing directly to our tactile and intuitive senses at the cost of photographic accuracy. I find it interesting that, when arguing how Vermeer might have used a camera obscura to capture linear perspective in the Brunelleschi style, Philip Steadman creates architectural diagrams where parallel lines are drawn as parallel, just as you might find them in representations of architecture in Eastern art (Fig. 32).

THE USE OF PERSPECTIVE SPREAD WIDELY IN RENAISSANCE ART after Brunelleschi's discoveries. Perspective became a primary means of creating the illusion of a three-dimensional space behind the surface of a painting, as if the painting were a window, producing a sharp difference in representations of architecture before Brunelleschi (Fig. 40 and after Brunelleschi (Fig. 41).

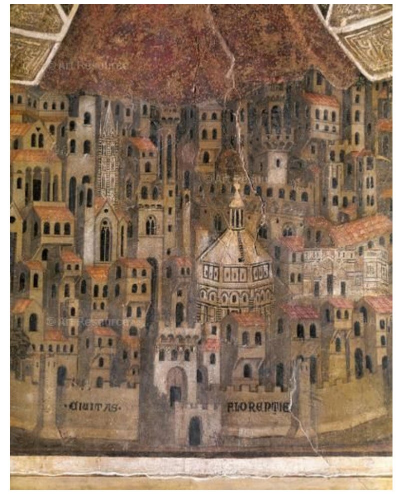


Figure 40: View of Florence in 1352 by an unknown artist

Figure 41: *Annunciation*, the central panel from the St. Lucy Altarpiece in Florence (1442-1448) by Domenico Veneziano Link to painting at Fitzwilliam Museum

THE OBJECTIVITY AND ACCURACY that result from following the laws of projective geometry allow, by computational reversal of the same laws, the 'un-flattening' of information contained in a picture into a three-dimensional model. Martin Kemp, working with computer scientists at Microsoft, performed 'un-flattening' experiments on several Renaissance paintings including Masaccio's *Holy Trinity* (Fig. 42) [18]. They found that few paintings were slaves to mathematical laws. Deviations were common. Upon close examination, logical inconsistencies could even be found in Masaccio's *Holy Trinity*. When these deviations were found, they could often be ascribed to a higher aesthetic purposes. When choosing between photographic realism and aesthetic judgment, aesthetics won.

[18] Antonio Criminisi, Martin Kemp, and Andrew Zisserman. Bringing pictorial space to life: Computer techniques for the analysis of paintings. pages 77–99, 2002

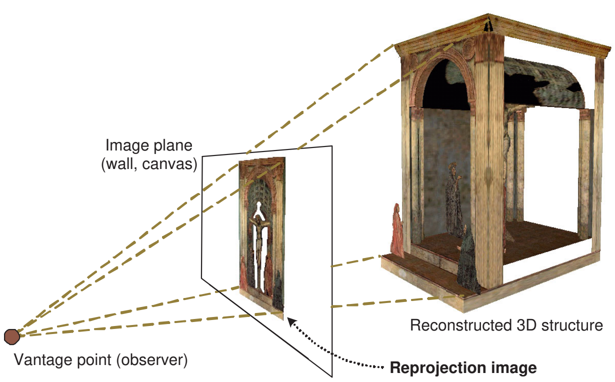


Figure 42: The reprojection image is defined as the image created by projecting the computed three-dimensional reconstruction onto the plane of the painting. The three-dimensional model will differ, depending on different assumptions about the geometry of the space. If the ground plan is assumed to be square, the ceiling coffers will be rectangular. If the ceiling coffers are assumed to be square, the ground plan will be rectangular. Different geometrically consistent models will project onto the same flat image.

FLORENCE IS TOO FAR TO TRAVEL to see 15th examples of Brunelleschi's influence on Renaissance art. Instead, we will travel to the Isabella Stewart Gardner Museum in Boston that has two contemporary examples in their collection. Piermatteo da Amelia's *Annunciation* ca. 1475 is a classic example of Renaissance perspective with its tiled floor and architecture converging to a central point of focus in a distant garden. Botticelli's *The Story of Lucretia* tells a more gruesome story from Ancient Rome, where all orthogonals also converge to a central point. Both Botticelli and d'Amelia studied with Fra Filippo Lippi, a contemporary of Masaccio and Brunelleschi.

Figure 43: *The Annunciation* by Piermatteo da Amelia. Link to artist at Google Arts and Culture.

Figure 44: *The Story of Lucretia* by Sandro Botticelli, about 1500. Link to Gardner Museum.

Art and Science Experiments

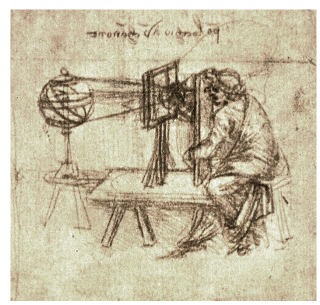


Figure 45: Leonardo's *Draughtsman using a Transparent Plane to Draw an Armillary Sphere*

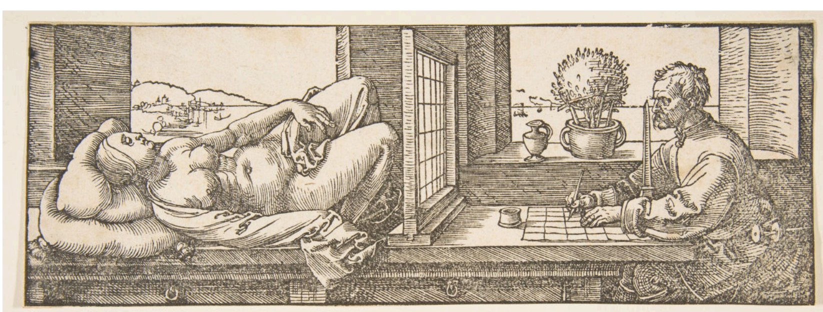


Figure 46: Albrecht Dürer. *Artist Drawing a Nude with Perspective Device.*

- We will use a transparent plane like one illustrated by Leonardo da Vinci to draw in linear perspective (Figure 45, see online tutorial). Albrecht Dürer illustrated a similar perspective device (Figure 46).
- Convince yourself of some of the fundamentals of linear perspective described in Appendix I.

Updated: March 7, 2022

Required Reading

- Martin Kemp. Journey into space. *Nature*, 400:823, 1999a Link to PDF
- Martin Kemp. Piero's perspective. *Nature*, 390:128, 1997 Link to PDF
- Chapter 7. From 3D to 2D. Perspective. Margaret Livingstone. *Vision and Art: The Biology of Seeing*. Harry N. Abrams, Inc., Publishers, New York, 2002. ISBN 0-8109-0406-3

Recommended Reading

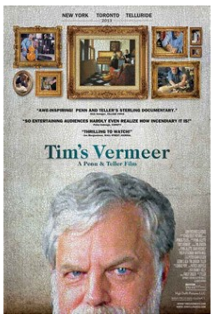
- Chapter One. Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6 Link to PDF
- Antonio Criminisi, Martin Kemp, and Andrew Zisserman. Bringing pictorial space to life: Computer techniques for the analysis of paintings. pages 77–99, 2002 Link to PDF

Week Seven - *Tim's Vermeer*

Thursday, 3 March 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600 and the Art Study Center

Figure 47: *The Astronomer* by Vermeer Link to painting at Google Arts and Culture, and copy by L.P.F. Garreau (18^{th}-19^{th} centuries) Link to drawing at Harvard Art Museums

Tim Jenison is an inventor and founder of NewTek, a company working in computer graphics. Reading *Vermeer's Camera* by Philip Steadman got Tim thinking about plausible improvements to the camera obscura to capture more than linear perspective. His approach was empirical. Tim asked whether *he* could achieve a painting that resembled a Vermeer tableau using simple optics. This adventure is chronicled in the film *Tim's Vermeer*.



The heart of Jenison's device is a mirror comparator system. Looking at the mirror from above, you see a reflection of the scene to be drawn. Near the edge of the mirror, you see the drawing you are trying to make. Rock back and forth, alternately looking at and comparing the desired and made images. Add details until you match the two images. Our visual systems are sensitive to any type of contrast, and so the mirror comparator system allows you to match shape, luminosity, and color with high precision. You just have to spend enough time making corrections.

Artists have long copied earlier masterpieces as a means of study or practicing technique (Fig. 47). The mirror comparator system can help. Without artistic training, I used it to draw a photograph of my son playing the violin. Because the comparator mirror reflects the image, I first had to use Photoshop to create a reflected image, which was restored to its original configuration by the mirror comparator.

Figure 48: Eliot Samuel.

Strikingly, some, but not all, of the copies of Vermeer paintings made in the 18^{th} and 19^{th} centuries in the Harvard Art Museums are also mirror reflected. Something got reflected somehow in their making.

- Copy of Portrait of a Young Woman in a Red Hat
- Copy of The Pearl Necklace
- Copy of The Soldier and Young Girl Laughing
- Copy of Lady at a Virginal
- Copy of Lady Reading

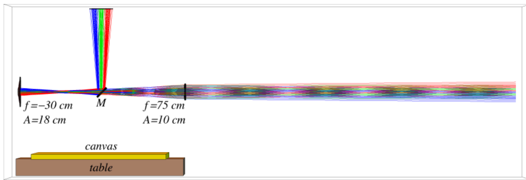


Figure 49: Ray-tracing diagram of Jenison's optical telescope and mirror comparator used for copying/transcribing studio reconstruction of Vermeer tableaus. The studio is off to the right and light passes from it through a converging lens, then to a concave mirror, back to a small plane 'secondary mirror,' M , then up to the artist's eye. From Stork et al. 2021.

The comparator mirror works at short range. To use it at a distance, you need more optics. Jenison added a lens and curved mirror to focus images onto the comparator mirror (Fig. 49). This setup has advantages over the camera obscura. The artist is not confined to a dark room. By comparing the image at the mirror's edge with the painted image, the projection is not overlaid on the painted image, and thus not confounding its appearance. A downside is a small field of view. The artist has to systematically scan the scene.

In *Tim's Vermeer*, Jenison painted *The Music Lesson*. The portability of the setup allowed using it in broad daylight. Jenison recently painted a version of Vermeer's *View of Delft* (Fig. 50). Did Vermeer use something like Jenison's device when painting these masterpieces? Jenison notes an extraordinary accuracy in Vermeer's paintings in capturing the effects of light and shadow, reaching a quantitative precision that exceeds his contemporaries. The genius that Vermeer achieved in his unparalleled naturalism is difficult to fathom. Was it technical genius, of the type practiced by optical scientists of his day, or painterly genius, an extraordinary eye and hand that led to new levels of achievement?

Figure 50: *View of Delft* by Vermeer (above) Link to painting and by Jenison (below).

Whether Vermeer used a tool like Jenison's is controversial. Optical setups with two focusing elements were new in Vermeer's era. Galileo and Kepler had just begun to use telescopes with two lenses. Leeuwenhoek used single lens microscopes to discover microorganisms. There is substantial documentary evidence of lenses being used by astronomers and microscopists, but there is none for Vermeer. These and other counterarguments were reviewed by David Stork, a scientist who thinks about optics and art [19].

[19] David G Stork, Christopher W Tyler, and Sara J Schechner. Did Tim paint a Vermeer? *Journal of Imaging Science and Technology*, 64:60403–1–60403–12, 2020

Vermeer created magic with the naturalism and beauty of his paintings. Tim created magic using an optical device to create his own paintings. Teller, the magician and co-producer of *Tim's Vermeer* aptly captured how any magic is made, whether by artistic skill or scientific ingenuity.

Figure 51: *View of Delft* by Carel Fabritius, 1652

Figure 52: View of Delft after the Gunpowder explosion of 12 October 1654, Egbert Poel Link to painting at Google Arts and Culture

A fascinating View of Delft was made by Carel Fabritius, Rembrandt's most gifted student, just before Vermeer (Fig. 51). Fabritius died at age 32 in a gunpowder explosion that destroyed many of his works and much of Delft (Fig. 52), but was already famed, known to push perspective towards art and illusion. [20]

The strangeness of Fabritius's *View*, with curvatures and warps that defy linear perspective, deserves serious explanation. Viewed frontally, it looks like the wide-angle view that we take with iPhones in panorama mode. Wide-angle, close-up views are problematic in Brunelleschi's linear perspective. At wide angles, the viewer looks obliquely at the surface of the painting; to compensate, the portions of a painting seen at wide angles have to be stretched to appear normal, a process called *anamorphosis*. Here, Fabritius may be searching for a solution to this problem well known problem.

One possibility is that the *View of Delft* is an act of imagination; the artist predicts, in his mind's eye, what your iPhone might later do [21]. Liedtke thinks that the painting is not meant to be viewed frontally and flat, but inside a curved box [22]. Drawing machines that mapped scenes onto the curved insides of boxes did exist (Fig. 53). When Liedtke looked at the *View* in a perspective box from one peephole, the strangeness resolved itself into natural appearance (Fig. 54). Wheelock thinks that Fabritius painted what he saw through a convex lens. Wheelock did the experiment. He took a wide-angle camera to Delft and reproduced the scene with similar optical distortions [23] (Fig. 56).

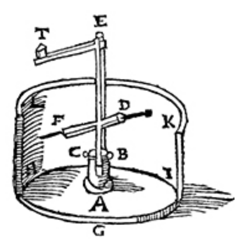


Figure 53: Baldassare Lanci device to project a view on the inside of a cylinder (Kemp, 1990)

Art historians largely agree that Vermeer did not use tools to create his paintings, but are divided on what optical or mechanical tool that Fabritius might have used to create his strange *View*.

Updated: March 7, 2022

[20] "Carel Fabritius is a very fine and outstanding painter, who in matters of perspective and natural coloring or the placement of his color was so skillful and powerful, that (according to the judgment of many connoisseurs) has never had his equal..."
– Dirck van Bleyswijck, 1667

[21] Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6

[22] Walter Liedtke. The 'View of Delft' by Carel Fabritius. *The Burlington Magazine*, 118:61 – 73, 1976

[23] Arthur Wheelock. Carel Fabritius: Perspective and Optics in Delft. *Netherlands Yearbook for History of Art*, 24:63 – 83, 1973

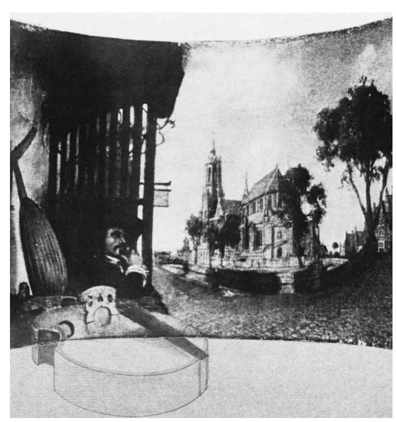


Figure 54: Photograph of Fabritius's *View* mounted on a hemicylindrival surface within a perspective box, with an added sketch reconstructing the *viola de gamba* as it would appear on the floor of the box from the peephole.

Art and Science Experiments

- Tim Jenison kindly sent us the parts needed to reconstruct a similar device to the one he used in *Tim's Vermeer*. We will build the device, and see how it works.
- Varley's Graphic Telescope was the most optically sophisticated drawing aid in the 19th century (Fig. 55). Light enters a telescope, passes through four lenses, and arrives at an eyepiece where it is reflected upwards to the viewer's eye. The viewer thus looks simultaneously downward and forward, and can draw and trace in the same way as using a camera lucida. Chris Stokes built his own 'Varley Graphic Telescope' which we will try to use.

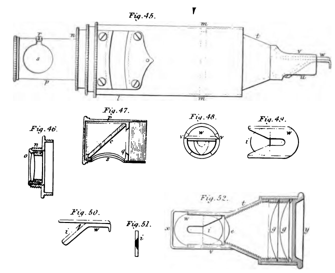


Figure 55: Varley Graphic Telescope from *Optical Drawing Instruments*.

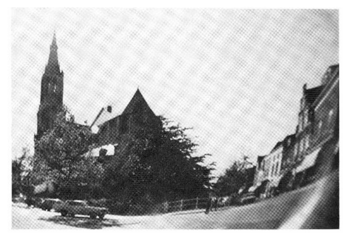


Figure 56: View of the church painted by Fabritius, but photographer through a double convex lens. From Wheelock (1973).

Required Viewing

- Watch *Tim's Vermeer* Link to Harvard's video database. The movie is free with Harvard login

Recommended Reading

- Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6
  Download Chapter IV. Machines and Marvels
- Walter Liedtke. The 'View of Delft' by Carel Fabritius. *The Burlington Magazine*, 118:61 – 73, 1976
  Download PDF
- Arthur Wheelock. Carel Fabritius: Perspective and Optics in Delft. *Netherlands Yearbook for History of Art*, 24:63 – 83, 1973
  Download PDF

Updated: March 7, 2022

Week Eight - Virtual Vermeer

Thursday, 10 March 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

Figure 57: *The Girl with a Pearl Earring*. In the Mauritshuis Museum, Netherlands. Link to painting at Mauritshuis

Vermeer's complete works have been united in a virtual museum by the Google Arts and Culture Program. All 36 paintings from 18 museums across 7 different countries can now be viewed in ultra-high resolution in a gallery that only exists online. The Mauritshuis in the Netherlands has taken a different approach to the virtual museum, digitizing full and seamless panoramic views of their brick-and-mortar galleries with gigapixel resolution. The Mauritshuis is home to several Vermeer masterpieces including *The Girl with a Pearl Earring* (Figure 57) and *The View of Delft* (Figure 50). These achievements required collaboration between computer scientists and curators to solve technical and aesthetic issues, creating the illusion of viewing two-dimensional paintings while exploring virtual three-dimensional galleries.

We will visit the Vermeer room of the Mauritshuis Museum and take a close look at the paintings in their collection. The gigapixel resolution of their online exhibits allows one to see the brushstrokes of Vermeer masterpieces. At ultrahigh resolution afforded by a gigapixel camera, details emerge that convey mastery beyond accuracy in geometry, tone, and color. The pearl in his most famous portrait is only made with a few brushstrokes, one stroke to create a reflection under another thick dab. Technology reveals magic that technology did not create.

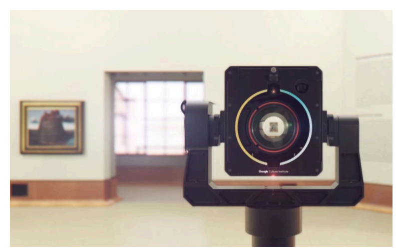


Figure 58: Google's Art Camera is deployed around the world to capture gigapixel images of masterpieces. artsandculture.google.com

Updated: March 7, 2022

The Girl With a Pearl Earring is probably not a portrait. The painting is a *tronie*, a study of interesting expressions, postures, and faces that are based on live models, but are not necessarily a photographic record of an individual subject. Vermeer painted several *tronies* including *The Study of a Young Woman* (Figure 59) and the *Girl with a Red Hat*(Figure 60). The *tronies* demonstrate a mastery that is distinct from Vermeer's ability to represent perspective, spatial geometry, and light and shadow in a room or city. But the *tronies* are consistent with Vermeer's obsession with the effects of light.

Consider *The Girl with a Pearl Earring*. The pearl is not painted as a distinct object. The pearl emerges entirely as a reflectance of incident light. Throughout the painting, Vermeer is obsessed by subtle reflectance. Highlights on the girl's lips and eyes reveal points of light reflecting off wet surfaces. Shadow is also used to evoke objects that are not distinctly drawn. Look closely. The bridge of the girl's nose is not delineated. You 'see' her nose by seeing its shadow and surface highlight.

Figure 59: *Study of a Young Woman* by Vermeer. Like *Girl with a Pearl Earring*, this painting was most likely not a commissioned portrait, but rather a so-called *tronie*, a portrayal of an intriguing individual, often in fanciful costume. From the Metropolitan Museum of Art. Link to painting

We will meet Abbie Vandivere at the Mauritshuis who led a team of conservators and scientists in their detailed examination of *The Girl with a Pearl Earring* with the latest tools in non-invasive imaging [24]. Her investigations revealed new clues about Vermeer's methods. Vermeer used underlayers that varied in tone to create subtle optical effects. He let these underlayers dry before applying surface paint, using thinner or thicker upper layers in different regions of the painting, thereby controlling how underlayers contribute to the appearance of light and shadow. High-resolution imaging reveals other preparatory steps such as fine black outlines. Analysis has also revealed *pentimenti*, subtle corrections and changes to the painting including relocations of the iris and ear. *The Girl With a Pearl Earring* was carefully planned and perfected at many levels.

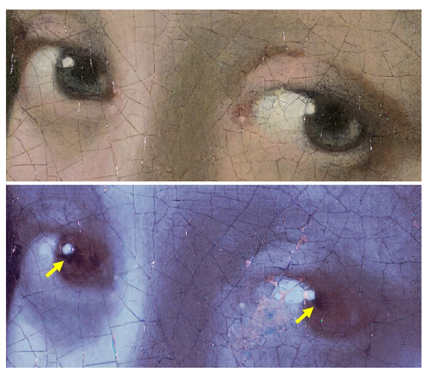


Figure 61: Evidence for pentimenti in the Girl's eyes. a Visible light photograph. b MS-IRR false colour detail. Dark marks indicate possible earlier iris locations (yellow arrows)

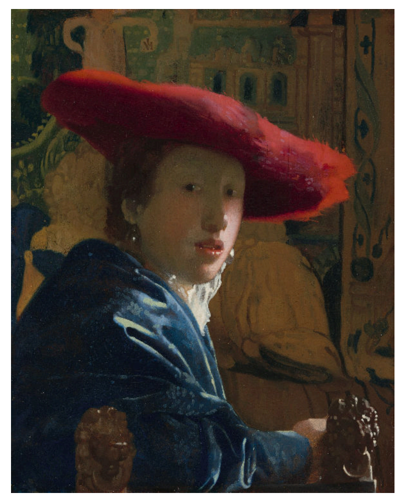


Figure 60: *The Girl with a Red Hat* is one of Vermeer's smallest works that is painted on a panel, not a canvas. From the National Gallery. Link to painting

[24] Abbie Vandivere, Annelies van Loon, Kathryn A. Dooley, Ralph Haswell, Robert G. Erdmann, Emilien Leonhardt, and John K. Delaney. Revealing the painterly technique beneath the surface of Vermeer's Girl with a Pearl Earring using macro- and microscale imaging. *Heritage Science*, 7:64, 2019a

Art and Science

The best way to experience Vermeer is to travel to the original artworks. This is not usually possible. We will meet Michelle Luo of Google Arts and Culture who will describe their efforts to create 'Pocket Galleries' that, to the limits that technology allows, mimics the experience of visiting a brick and mortar museum using a desktop computer or handheld device. The idea of experiencing artwork via the screen is interesting in itself. We did this with movies before the internet. *The Girl with a Pearl Earring* has itself been the subject of a novel and movie by the same name.

We will talk about the Pocket Galleries exhibitions with Michelle Luo, where you can visit a virtual Vermeer gallery.

Required Reading

- *Girl with a Pearl Earring* Walter A Liedtke. *Vermeer : the complete paintings*. Harry N. Abrams, New York, 2008. ISBN 9789055447428 Download PDF
- *Girl with a Pearl Earring* Arthur Wheelock and Ben Broos. *Johannes Vermeer*. Yale University Press, New Haven, 1995. ISBN 9040097941 Download PDF
- Abbie Vandivere, Jorgen Wadum, Klaas Jan van den Berg, Annelies van Loon, and The Girl in the Spotlight research team. From 'Vermeer Illuminated' to 'The Girl in the Spotlight': approaches and methodologies for the scientific (re-)examination of Vermeer's Girl with a Pearl Earring. *Heritage Science*, 7:66, 2019b Download PDF
- Alexandra Schwartz. Alone in the virtual museum. *The New Yorker*, 5 Sep 2014 Link to Article

Recommended Reading

- Abbie Vandivere, Annelies van Loon, Kathryn A. Dooley, Ralph Haswell, Robert G. Erdmann, Emilien Leonhardt, and John K. Delaney. Revealing the painterly technique beneath the surface of Vermeer's Girl with a Pearl Earring using macro- and microscale imaging. *Heritage Science*, 7:64, 2019a Download PDF
- Watch *A Girl With a Pearl Earring* available on Canvas.

Updated: March 7, 2022

Week Nine - Perspective... and its Reversal

Thursday, 17 March 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

Linear perspective is one system of mapping points in 3D space onto a 2D plane between the viewer and subject. The use of linear perspective, once discovered by Brunelleschi and codified by Alberti in the 15th century, spread through Europe. The geometric consistency of linear perspective corresponds to the physics of the camera obscura, an argument in its favor with its evocation of natural law. But the strict use of linear perspective exacts a cost of freedoms that previous and later artists might have fully appreciated but were unwilling to pay. A painting made using linear perspective only strictly corresponds with reality when the viewer fixes his eye in the same location as the artist. Before the rules of linear perspective were 'discovered' in 15th century Florence, artists may have appreciated its limitations and not bothered with it.

Figure 62: *Enthroned Madonna and Child*. Byzantine, 13th century. Link to painting at Google Arts and Culture

A common view of the Renaissance is as a resurgence, regaining heights in science and art that Europe lost with the Fall of Rome. This Eurocentric view diminishes the accomplishments of a millennium of medieval civilization and is blind to the achievements of the nearby Eastern Roman Empire – a vast area spanning Egypt, Syria, and Asia Minor. Byzantium thrived for centuries after the fall of Rome. The achievements of Byzantine art were not crude failures to achieve the accomplishments of 15th century Florentines. Byzantine artists thought hard about rendering three-dimensional space onto two-dimensional surfaces, persuasively argued by Pavel Florensky, the Russian art historian [25].

Figure 63: Icon with St. John the Baptist, c.1300, Constantinople. Link to British Museum

Byzantine perspective or 'reverse perspective' is a carefully considered means of depiction that tries to capture *more* than is possible with linear perspective. The lines of perspective in the *Enthroned Madonna and Child* on the throne and footstool converge towards the viewer, not towards a central vanishing point as in linear perspective (Fig. 62). The result is an intentional and simultaneous view of all planes of the object. The perspective is called 'reversed' because the depicted objects are between the projective point and the viewing plane, not behind the viewing plane as in linear perspective (Fig. 64). In an Icon of St. John the Baptist painted in Constantinople in 1300, the multiple planes of the face, nose, neck appear to be turned forward. Here, many viewing surfaces are combined in one painterly view (Fig. 63). The effects are intentional, not illiterate.

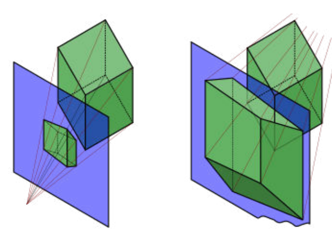


Figure 64: Linear perspective of a cube (left) and reverse perspective (right). The viewing plane is shown in blue, with the projection point where the red lines meet. Link to Wikipedia

[25] Pavel Florensky. *Beyond Vision: Essays on the Perception of Art*. Reaktion Books Ltd, 2002. ISBN 9781861896391

Updated: March 7, 2022

Linear perspective is a choice, not an inexorable step in the evolution of art. We will discuss linear and reverse perspective with Martin Kemp, an art historian at Oxford University who has long thought about the intersection of science and art.[26] While 15th century Florentines were discovering and painting their own illusions of three-dimensional space, sophisticated artists that were deeply grounded in their own traditions of science, technology, and mathematics were advancing on their own in different directions (Fig. 65). *The Story of Haftvad and the Worm* tells a story of Haftvad eating an apple in the shade of a tree, and who spares the life of the maggot in the fruit. The story of the entire town is told in the different areas of the painting, a sophisticated rendering of three-dimensional space without attention to the laws of linear perspective. Persian mathematics and geometry were extremely sophisticated when Dust Muhammad painted this scene. But the artist was not beholden to Alberti's rules.

Figure 65: *Story of Haftvad and the Worm*, c.1540, by Dust Muhammad in Safavid Iran. Link to Painting

[26] Martin Kemp. *Seen/unseen : art, science, and intuition from Leonardo to the Hubble telescope*. Oxford University Press, Oxford ; New York, 2006a. ISBN 0199295727

Figure 67: *Jacqueline with Glossy Hair*, by Pablo Picasso.

Art changed after the invention of photography. Cameras were perfect at capturing one-point linear perspective. To be different, artists had to do more than what their cameras could do. Multi-point perspective is closer to the reality of conscious perception than single-point perspective. We have two eyes that see objects from different angles. As our eyes move, our perspectives shift, and the totality of our perception is a synthesis of these viewpoints.[27] Like Byzantine artists in the prior millennium, Cezanne and Picasso explicitly rejected linear perspective when rendering scenes and faces. In his *Still Life with Commode*, Cezanne either consciously or unconsciously includes views of the jugs, fruit, and table from multiple perspectives. There is no attempt to achieve the correctness of linear perspective, and the result is more lively and persuasive. Cubism is another radical way of incorporating multiple perspectives into single paintings. Picasso performed these experiments in portraits and still lifes (Fig. 67.)

Figure 66: *Still Life with Commode*, (1887-1888) by Paul Cezanne. Link to painting in the Harvard Art Museums

[27] Bevil R Conway and Margaret S Livingstone. Perspectives on science and art. *Current opinion in neurobiology*, 17(4):476–482, 2007. ISSN 0959-4388

David Hockney learned of Pavel Florensky and his work on Byzantine perspective from Martin Kemp. Fra Angelico was a contemporary of Brunelleschi and Masaccio in 15th Florence, and his fresco of *The Annunciation* is one of the most well known. Fra Angelico's *Annunciation* is one of the earliest uses of light and a central vanishing point to achieve spatial awareness (Fig. 68)

Hockney turned the same scene inside-out by painting it in reverse perspective (Fig. 69)!

Figure 68: *The Annunciation* by Fra Angelico. Link to Google Arts and Culture

Figure 69: *The Annunciation* in reverse perspective by David Hockney Link to upcoming Hockney retrospective at the Fitzwilliam Museum

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Art and Science

David Hockney did many experiments on multi-point perspective using photography. David Hockney's photocollage of a chair combines views from many different perspectives into one image, but retains the recognizable shape of the chair and its sense of depth (Figure 70). We can try similar experiments with a camera and Adobe Photoshop.

Figure 70: *Chair Jardin de Luxembourg* (1985) by David Hockney

Required Reading

- Pavel Florensky. *Beyond Vision: Essays on the Perception of Art*. Reaktion Books Ltd, 2002. ISBN 9781861896391 Download PDF
- Bevil R Conway and Margaret S Livingstone. Perspectives on science and art. *Current opinion in neurobiology*, 17(4):476–482, 2007. ISSN 0959-4388 Download PDF

Week Ten - Peepshows and 3D space

Thursday, 24 March 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

When a three-dimensional scene is drawn in linear perspective, the artist selects a vantage point. The scene only makes original geometric sense when the beholder has the same vantage. From any other angle, the scene will be distorted relative to reality. The three-dimensional illusion requires fixing the beholders perspective. To do this, the peepshow was invented in Renaissance Europe. These confined spaces create three-dimensional illusions with carefully considered perspective from a fixed point.

Samuel van Hoogstraten was an artist and scholar, who worked in the workshop of Rembrandt and wrote a treatise on painting, *Introduction to the Academy of Painting, or the Visible World*. Hoogstraten's book can be taken as a description of the state-of-the-art in Dutch artistic technique in the 17th century, but it settles no debates about the extent to which his contemporary, Vermeer, did or did not use a camera obscura. Hoogstraten's interest in the theory and practice of perspective led to his experiments with peepshows, the finest being the *Dutch Box* in the National Gallery of London (Fig. 71).[28]

Figure 71: *The Dutch Box* by van Hoogstraten, 1655-1660

[28] Christopher Brown, David Bomford, Joyce Plesters, and John Mills. Samuel van hoogstraten: Perspective and painting. *National Gallery technical bulletin*, 11(1):60–85, 1987. ISSN 0140-7430

The Dutch Box in London has two high lateral eye holes in its end walls that control views into the interior. The interior walls and ceiling are painted with an awareness of anamorphosis, and compromises made for the two separate views. Conspicuous shifts in anamorphosis occur at the junctions between the orthogonal panels because of the abrupt changes in viewing angle. *Pentimenti* suggest that Hoogstraten worked out many of the perspectival problems by trial and error, looking through the peephole and making adjustments as needed.[29] To top off his box, Hoogstraten added a racy anamorphic view of a reclining Venus that only makes sense in an oblique view. [30]

[29] Martin Kemp. *The Science of Art*. Yale University Press, New Haven, Connecticut, 1990. ISBN 0-300-04337-6

[30] Jun P. Nakamura. Seeing Outside the Box: Reexamining the Top of Samuel van Hoogstraten's London Perspective Box. *Journal of Historians of Netherlandish Art*, 12(2), 2020. ISSN 1949-9833

Updated: March 7, 2022

The peepshows of the Dutch Golden Age, rare works of art made by leading talents, evolved into an industry of peepshows that were popular entertainment throughout Europe, Asia, and the United States, a way of transporting viewers on journeys in space and time by looking into a box and exploring their hidden worlds.[31] Traveling peepshows were the precursors of the cinema. They also evolved into 'paper art' that many could make and own in their own homes.

The Victoria and Albert Museum in London has an amazing collection of these paper peepshows – The Jacqueline and Jonathan Gestetner Collection – that we will explore with Catriona Gourlay. Paper peepshows had their heyday in the 19th century, when optical devices were rising in popularity. They could be produced cheaply, and could be sold as souvenirs or as an early form of virtual reality.

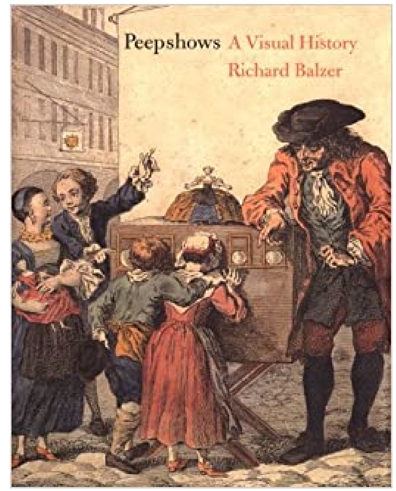
Clare Bryan, an artist who works in paper, has thought about how to evoke 3D space from the flatness of her medium. We will follow her instructions to construct our own paper peepshows (Fig. 73).

Required Reading

- Richard Balzer. *Peepshows : a visual history*. Abrams, a New York, 1998b. ISBN 0810963493 Link to PDF
- Christopher Brown, David Bomford, Joyce Plesters, and John Mills. Samuel van hoogstraten: Perspective and painting. *National Gallery technical bulletin*, 11(1):60–85, 1987. ISSN 0140-7430 Link to PDF
- Jun P. Nakamura. Seeing Outside the Box: Reexamining the Top of Samuel van Hoogstraten's London Perspective Box. *Journal of Historians of Netherlandish Art*, 12(2), 2020. ISSN 1949-9833 Link to online article

Recommended Reading

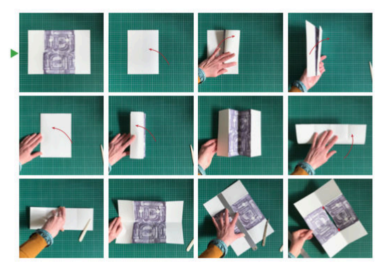
- Ralph Hyde. *Paper peepshows : the Jacqueline and Jonathan Gestetner Collection*. Antique Collectors' Club, Woodbridge, Suffolk, England], 2015. ISBN 1851498001,



[31] Richard Balzer. *Peepshows : a visual history*. Abrams, a New York, 1998b. ISBN 0810963493

Figure 72: Peering through *The Thames Tunnel at London*. The Victoria and Albert Museum. Photography: Dennis Crompton

- Virtual Tour of Tabletop Tableaux
- Virtual Tour of Thames Tunnel
- Virtual Tour of Great Exhibition



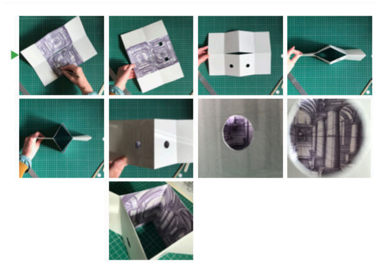


Figure 73: Instructions for Clare Bryan's fold-able peepshows. Download PDF

Updated: March 7, 2022

Week Eleven - Vermeer and Leeuwenhoek

Thursday, 7 April 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

Vermeer has been called the Sphinx of Delft because we have so little evidence about his life. What we know about Vermeer is inferred from the paintings or extrapolated from the history and lives of his contemporaries. Arthur Wheelock – former curator of Northern European Art at the National Gallery of Art in Washington, DC – has thought about Vermeer and his connections to his time, his city, and the people around him. Arthur will visit with us by Zoom to discuss his most recent paper.[32]

Vermeer's works are both uniquely his and entwined with his surroundings. Dutch painters knew and influenced each another. This is demonstrated in three paintings by Gerard ter Borch, Frans van Mieris, and Johannes Vermeer (Fig. 74). Each depicts a similar scene of a young lady getting dressed, but the Vermeer stands out. Vermeer's painting, like all of his paintings, is deeply serene, restrained, thereby achieving a universality that makes him timeless.

Lawrence Weschler points out that the quietude in Vermeer was not a transcription of his world.[33] Europe in the 17th century and the so-called Dutch Golden Age was violent and cruel. Sieges, famine, and massacres were common. The British and Dutch were in the midst of frequent wars. In 1654, Delft itself saw calamity when 80,000 pounds of gunpowder exploded, killing hundreds including Carel Fabritius, Rembrandt's finest student who may have mentored Vermeer. Conflict devastated the Dutch economy, shriveling the market for high-end art, leading to Vermeer's bankruptcy, and perhaps speeding his early death at 42. And yet Vermeer turns away from the chaos and fills painting after painting with peace and light.

Vermeer endowed his luminous paintings with a realism bordering on scientific accuracy, integrating a rigorous understanding of linear perspective and the behavior of light and shadow. Vermeer was fascinated, like Fabritius, in optics and light as a natural phenomenon. He is likely to have looked through the camera obscura that was well known in the Netherlands in the 17th century. Many Vermeer paintings capture the effects of the camera obscura such as specular highlights and soft focus in different planes. Vermeer took careful pains to capture the effects of complex shadows, reflections, and gradations in detail, outdoing his peers in capturing their physical accuracy.

Vermeer's personal relationships with contemporary scientists

Figure 74: Top: *Young Woman with a Pearl Necklace* by Vermeer, 1662. Middle: *Young Woman at Her Toilet with a Maid* by Gerard ter Borch, 1650-1651. Bottom: *Woman Before a Mirror* by Frans van Mieris 1662

[32] Arthur Wheelock. Vermeer Becoming Vermeer. 2022

[33] Lawrence Weschler. *Vermeer in Bosnia : a reader*. Pantheon Books, New York, 1st ed. edition, 2004. ISBN 0679442707

may have made the difference in his own achievements in rendering light and perspective. Vermeer probably knew Jacob Spoors who used telescopes to see the heavens and Antony van Leeuwenhoek who used microscopes to discover bacteria. All were deeply religious. The scientists used optics to better see God's Creation. For Vermeer, properly capturing light, optics, and geometry in painting was his way of seeing Creation.

Vermeer was firstly a painter with aesthetic taste and insight. He dispensed photographic accuracy when his art demanded. In his *Young Woman Standing at a Virginal*, the painting on the instrument is depicted at an angle but not with anamorphosis like the skull in Holbein's *Ambassadors* (Fig. 75). Anamorphosis would be distracting. Vermeer chose to paint the landscape more subtly with a more straightforward perspective.

Vermeer may have painted with religious sentiment but without religiously transcribing. He often painted the same room with the same props. Look at the painting of the Cupid on the back wall of the *Young Woman Standing at a Virginal*. This prop now appears in the newly restored *Girl Reading at an Open Window*. For over a century, the rear wall in *Girl Reading at an Open Window* was blank (Fig. 76). Recent analysis revealed that the Cupid was painted over by someone else in the 19th century! But compare the two Cupids. The prop is the same in both paintings, but Vermeer reproduced it in two different sizes.

Figure 75: Top: *Young Woman Standing at a Virginal* by Vermeer. Bottom: Girl Reading at an Open Window by Vermeer.

VERMEER'S INTEREST IN NATURAL SCIENCE is made emphatic in two unusual paintings, *The Geographer* and *The Astronomer* (Fig. 78). Vermeer's interest in the tools and aspirations of natural scientists is made explicit. The young man shown in these paintings may be Anthony van Leeuwenhoek, who perfected the single-lens microscope to first discover swimming microorganisms (Fig. 77. The great artist and scientist were born in the same year of 1632 in the small town of Delft with population 24,000. Vermeer died young and Leeuwenhoek was the executor of his will. There is no other written documentation that they knew each other. But these leading figures in art and science shared a deep fascination with optics and seeing. Their parallel lives are captured in the joint biography, *Eye of the Beholder*, by Laura Snyder [34].

Figure 76: *Girl Reading at an Open Window* prior to restoration

Figure 77: Portrait of Anthony van Leeuwehhoek by Jan Verkolje

[34] Laura Snyder. *Eye of the Beholder*. W.W. Norton and Company, 2015. ISBN 978-0-393-07746-9

THE LEEUWENHOEK MICROSCOPE is a delightful instrument that we can use to appreciate the state of optical science in Vermeer's time (Figure 79). We will look at replicas of the original Leeuwenhoek microscope. We will use small spherical lenses – the heart of the microscope – to learn about image formation and appreciate the challenges and advantages of using optical tools. Coupling the single-lens microscope to a smartphones, we have a way of creating art photography on the microscopic scale.

Figure 78: *The Astronomer* by Vermeer. The Geographer by Vermeer.

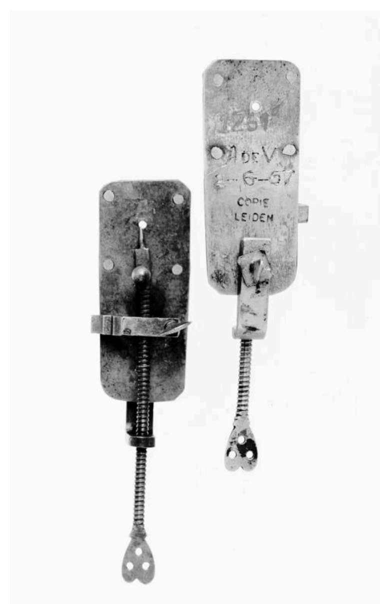


Figure 79: Leeuwenhoek's microscope. Brass plates secure a glass-bead lens. The specimen pin is on a threaded shaft. The focus is another screw that shifts the specimen closer or farther from the lens.

- Think about the Leeuwenhoek microscope as a *very* strong magnifying glass made with a ball lens. Explore a virtual model of a real Leeuwenhoek microscope.
- Use a replica Leeuwenhoek microscope to make pictures and movies. See some online examples and images taken by Aravi using one of our microscopes (Fig. 80).

REQUIRED READING

- Arthur Wheelock. Vermeer Becoming Vermeer. 2022 Link to PDF
- Lawrence Weschler. *Vermeer in Bosnia : a reader*. Pantheon Books, New York, 1st ed. edition, 2004. ISBN 0679442707 Link to PDF

RECOMMENDED READING

- Laura Snyder. *Eye of the Beholder*. W.W. Norton and Company, 2015. ISBN 978-0-393-07746-9

Figure 80: Eukaryotic cells taken with Leeuwenhoek microscope and iPhone

Updated: March 7, 2022

Week Twelve - Silhouettes

Thursday, 14 April 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

Tools can be useful in capturing optical effects like linear perspective, light, and shadow. But in the 19^{th} century, before the invention of photography, creating a convincing human likeness still required substantial mastery and time. Another way to create likenesses that leveraged the power of tools was the silhouette, a popular form of portraiture before photography. The flattening of an image in black and white abolishes photographic realism and linear perspective, while preserving another form of naturalness and likeness, capturing our familiar shadows. Silhouettes were not curiosities, but a different means of expression that is tightly connected with the history of tools in art.

Figure 81: Augustin Amant Constant Fidèle Edouart, French, *Album of Silhouettes*. Harvard Art Museums.

[35] Asma Naeem. *Black Out: Silhouettes Then and Now*. Princeton University Press, Princeton, New Jersey, 2018. ISBN 069118058X

Figure 82: A Sure and Convenient Machine for Drawing Silhouettes by Thomas Holloway ca. 1788.

Silhouettes in history and modernity were the subject of a recent exhibition at the National Portrait Gallery and accompanying book. [35] Penley Knipe of the Harvard Art Museum authored a chapter focusing on silhouettes in American portraiture, and is the local expert on Harvard's substantial silhouette collection. Silhouetted portraits played a powerful role in American portraiture. A silhouette can be created with a simple pair of scissors and skilled hands. Surging interest in silhouettes led to technological inventiveness to speed production and accuracy. The invention of photography was the end of the heyday of the silhouette in American history.

Modern artists have reinterpreted the silhouette as an art form. Kumi Yamashita has played with the dimensionality of the silhouette by creating three-dimensional paper objects that create flat silhouettes as shadows when properly illuminated (Fig. 83) In essence, Yamashita's works are anamophoric images made with shadow. Kara Walker manipulates the history of the silhouette in her disturbing and striking social commentaries (Fig. 86).

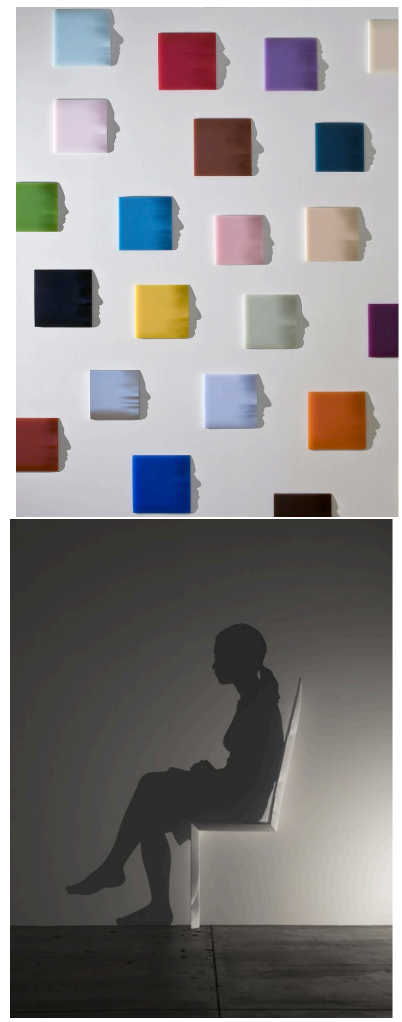


Figure 83: Works by Kumi Yamashita. *Fragments(detail)*, 2009. Cast resin, single light source, shadow. Permanent Collection New Mexico History Museum, Santa Fe, USA. *Chair*, 2014. Carved wood, single light source, shadow. Private collection.

Updated: March 7, 2022

Art and Science Experiments

- The easiest way to make a silhouette is to trace a shadow or projection, using tracing paper, a flashlight, and the transparent plane in your kit, transfer to the silhouette paper, and carefully use your scissors.
- We made a version of the pantograph (a simpler version of John Hawkin's physiognotrace device) (Figure 84).

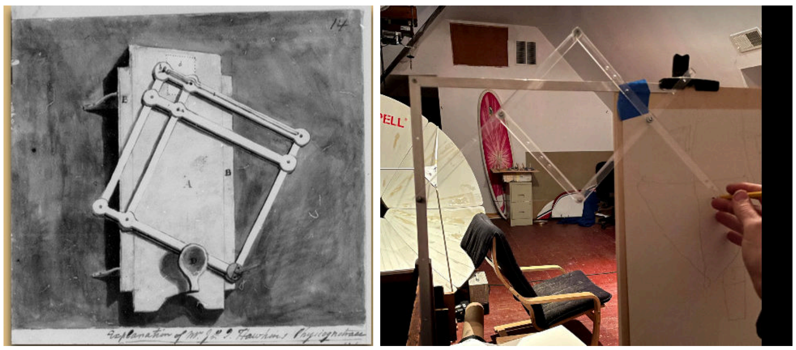


Figure 84: Left: Drawing of John Hawkin's physiognotrace device from *Black Out:Silhouettes Then and Now*. Right: Pantograph from your kit.

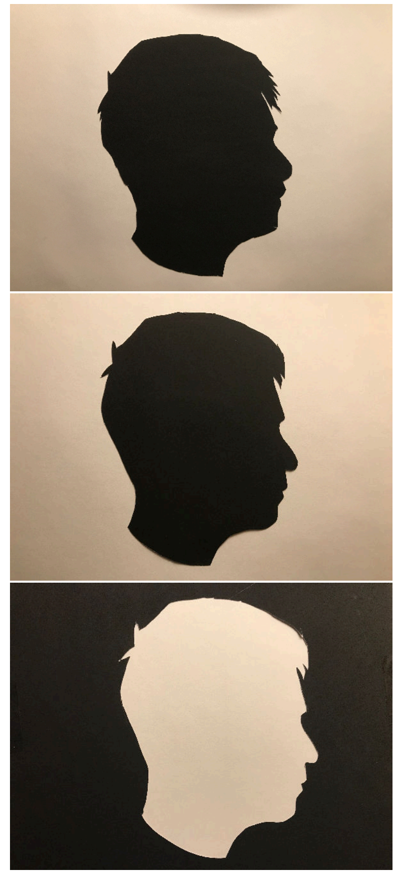


Figure 85: Aravi captured his own profile using an iPhone, using an Apple Pen and iPad to convert the full color image into black and white silhouettes. He printed the image, and transferred to silhouette paper. Cut using silhouette scissors. First, Aravi cut the printout using the scissors, traced the boundary on silhouette paper with a pencil, then cut the silhouette paper with scissors. Aravi used the comparator mirror and graphite pencil to transfer the image of the printout to silhouette paper, which was cut using an Exacto knife. Cutout (negative) of the image on the right.

Required Reading

- "Shades of Black and White" by Penley Knipe. From Asma Naeem. *Black Out: Silhouettes Then and Now*. Princeton University Press, Princeton, New Jersey, 2018. ISBN 069118058X
- Look at Harvard Art Museums collection of silhouettes including Augustin Amant Constant Fidèle Edouart's *Album of Silhouettes*.

Figure 86: *Auntie Walkers Wall Sampler for Savages* by Kara Walker. Kara Walker, a contemporary artist, uses mural-scale silhouettes to enact the cruelty of antebellum plantation life. In contrast to polite portraiture, what the silhouette largely was in the 19^{th} century, Walker evokes exploitation and dark fantasy in 19^{th} century life with her modern use of the art form of their era.

Updated: March 7, 2022

Week Thirteen - Science and Art

Thursday, 21 April 2022, 12:45 - 2:15 PM EST.
Harvard Art Museums 0600

The artist's brain is both hindrance and help when recreating natural scenes. Our visual systems process many different cues to form internal representations of external images. This is why it was hard to 'discover' the rules of linear perspective in the Renaissance. Our brains easily build self-consistent and reasonable three-dimensional scenes in our mind's eye from faulty or incomplete retinal information. Consciously or unconsciously, artists must battle and use the science of visual perception when creating their images.

Marge Livingstone is a Professor of Neurobiology at Harvard Medical School who has long worked on the visual system.[36] She has long thought about the interplay between the visual arts and our visual systems. Looking at the self-portraits of Rembrandt, Livingstone and Bevil Conway noticed a divergence in his left and right eyes, a strabismus. This strabismus is consistent throughout his drawings, paintings, and etchings. A strabismus is a problem for stereoscopic vision. Rembrandt might have seen the world as flat. But an inability to see the world in three-dimensions using information from both eyes may be an advantage when drawing or painting, where the artist is faced with the challenge of creating three-dimensional scenes on a flat surface.

Figure 87: *Self-Portrait, Leaning on a Stone Wall*, Rembrandt, 1639

Figure 88: *Self-Portrait*, Rembrandt, 1659

[36] Margaret Livingstone. *Vision and Art: The Biology of Seeing*. Harry N. Abrams, Inc., Publishers, New York, 2002. ISBN 0-8109-0406-3

Required Reading

- Margaret S Livingstone and Bevil R Conway. Was Rembrandt Stereoblind? *The New England Journal of Medicine*, 351(12):1264–1265, 2004. ISSN 0028-4793 Download PDF
- MF Marmor and S Shaikh. Was Rembrandt Stereoblind? *The New England Journal of Medicine*, 352(6): 631–632, 2005. ISSN 0028-4793 Download PDF

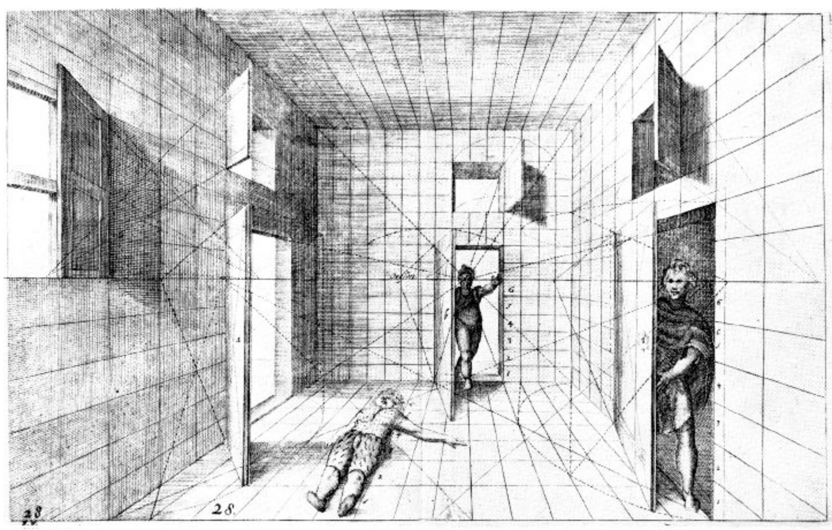
Recommended Reading

- Margaret Livingstone. *Vision and Art: The Biology of Seeing*. Harry N. Abrams, Inc., Publishers, New York, 2002. ISBN 0-8109-0406-3

Updated: March 7, 2022

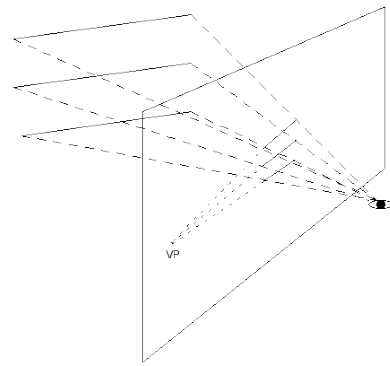
Appendix I - The Rules of Perspective by Chris W. Taylor

Linear perspective has a history going back at least to Aristarchus, a scene painter for Aeschylus in the 4th century BC who astonished his audience, including Plato, with his realistic depiction of depth by size reduction in the spatial layout of buildings. This Greek expertise was transmitted to the Roman Empire in the accurate central vanishing points in evidence in the wall-paintings of Pompeii, for example. The development of Renaissance one-point perspective may be traced over the 14th and 15th centuries. The elaboration of two-point perspective took another two centuries. Three-point perspective did not come into widespread use until well after the invention of photography, when the flexible availability of tilted camera angles revealed its visual effectiveness.



Jan Vredeman de Vries, *Perspective* (Leiden, 1604–5), plate 28. Courtesy, the Bancroft Library, Berkeley, California.

The following is an attempt to distill the rules of perspective into an elementary form that may be easily applied in practice. They are first stated in brief form, then elaborated to convey the rationale and significance of each of the rules.



THE RULES OF PERSPECTIVE are first stated in their most direct form, then elaborated.

1. There is only one geometry of perspective projection onto a fixed picture plane.
2. All straight lines in space project to straight lines (or points, if end on) in the picture plane.
3. The projections of all lines that are parallel in space either remain parallel in the picture plane or intersect at a single vanishing point.
4. All sets of parallel lines lying within a specified plane in space have vanishing points that fall along the horizon line defined by the orientation of that plane.
5. For two sets of parallel lines at some angle in the scene, the two vanishing points form that same angle at the viewer's eye, regardless of the orientation of the angle in space. In particular, the vanishing points for any 90° angle in space form a 90° angle at the viewer's eye.
6. Any planar figure in space is foreshortened in the direction of its slant from the observer (up to a 45° viewing angle).
7. Circles in the scene, if foreshortened, project to ellipses in the picture plane.
8. For correct projection of its perspective, a picture should be viewed from its center of projection in space.
9. When the eye is at the center of projection, the perspective geometry in the picture plane is independent of where in the plane the eye is looking.

Implications of the Rules of Perspective

1. There is only one geometry of perspective projection onto a fixed picture plane. Perspective is the geometry of projection from a scene through a plane to a point (or center of projection) corresponding to the pupil of the viewing eye. The plane is the picture plane on which the painter wishes to depict the scene. If the perspective is correct, the depiction on the plane will generate the same projective structure at the eye as did the scene behind it. The different forms of perspective construction concern the rules that apply to specific structures, allowing simplified forms of the projective geometry to be codified. But all are subcases of the same optical transform.
2. All straight lines in space project to straight lines (or points, if end on) in the picture plane. This fact is a simple consequence of the geometry of projection through a point in space (corresponding to the pupil of one eye). If a line is parallel to the picture plane, it must project to a straight line on that plane by virtue of similar triangles. Obviously, tilting the line within the plane of projection will not introduce any curvature, just a change in its extent within the line of projection. In the limit, the projected line may contract to a point in the picture plane when the line is viewed head on. Lines of any orientation can be described by this construction. Thus, all such point projections are to straight lines or points.
   (a) Introducing lens optics, as in the human eye, introduces the potential for curvature in the projection. Such curvature may consequently be a property of human perception at the extrema of the field, but the laws of perspective will be considered to be those of the point projection of pinhole optics, which permit no curvature.
   (b) Humans actually view scenes with two eyes, but the straight-line projections in each eye are both straight lines. The average, or binocularly-fused, projections is therefore also a straight line. No curvature is introduced by the geometry of binocular combination.
3. The projections of all lines that are parallel in space either remain parallel in the picture plane or intersect at a single vanishing point. This common intersection is valid for each entire set of parallels regardless of where in the visual field the lines arise. Each set of parallel lines intersects at a different vanishing point, of course. Thus, the first job in perspective projection is to identify all the lines in the scene that are parallel to a given line, then make sure that they are drawn so as to project to a common vanishing point.
   (a) Parallel lines in space that are also parallel to the picture plane remain parallel to each other in the projection. This leads to the particular case of central perspective, in which all the lines on the scene are either parallel with the line of sight or at right angles to it, parallel with the picture plane. The first set will be horizontal and receding from a viewer looking straight ahead. The vanishing point for this first set is directly in front of the viewer, making a central point of convergence for these horizontal receding lines. The second set consists of any lines at right angles to the first set, thus at any angle within the picture plane. These lines, such as the verticals of the sides of buildings, will all remain parallel within the picture plane if they were parallel in space. Note that what makes central perspective central is simply the choice of lines present in the scene. Perspective itself is universal, an optical projection of the light rays.
   (b) The corollary of the central perspective construction is that it is implicitly incorrect to set the "central" vanishing point is away from the viewing center of the picture. This modification was employed in the mid Renaissance, where the "central" vanishing point may have been moved even to a point beyond the edge of the picture. The "frontal" sides of all the squares nevertheless remained parallel

in such constructions (usually horizontal and vertical), so that the perspective is incorrect unless the picture is expected to be viewed from the unlikely position of directly front of the shifted vanishing point.

4. All sets of parallel lines lying within a specified plane in space have vanishing points that fall along the horizon line defined by the orientation of that plane. The particular case is the ground plane. All sets of parallel lines in the ground plane have vanishing points in the horizon line. (The fact that the earth is not flat means that it does not strictly conform to a ground plane, defined geometrically. The deviation is generally too small to be of consequence in art.)
   (a) Rules 3 and 4 may be combined to consider the vanishing points not just for lines within a single plane but within a sheaf or stack of parallel planes. All lines on all parallel planes still have vanishing points falling along the same line. For example, all lines on or parallel with the ceiling or floor have vanishing points in the line of the horizon, as do all horizontal edges of doors and casement windows. But all the lines at angles on the sides of a Ferris wheel, for example, would have vanishing points in a vertical line.
5. For two sets of parallel lines at some angle in the scene, the two vanishing points form that same angle at the viewer's eye, regardless of the orientation of the angle in space. In particular, the vanishing points for any 90° angle in space form a 90° angle at the viewer's eye. In particular, the vanishing points for any right angle in space form a 90° angle at the observer's eye. This result may be seen by considering the member of their respective parallel bundles, coming directly toward the viewer's eye. These lines form the same angle as any other pair from the two bundles. Their angle at the eye, and hence the viewing angle between the vanishing points, therefore match the angle of the lines in space.
   (a) A classic case of this rule is the diagonals of any square, which are always at 90° to each other. The vanishing points (or "distance points", Leonardo, 1492) for these diagonals should therefore form a 90° angle at the center of projection, regardless of their orientation in space. Twist the angle in any direction whatever in three-dimensional space (even to the point of complete foreshortening) and the vanishing points will nonetheless hold to a strict 90° angle at the viewer's eye. In terms of pictorial distance, this angle between the vanishing points corresponds to the same distance in the picture plane except for the tan transform for projection of the equal angles at the eye onto the plane.
   (b) The corollary of this principle is that, if the vanishing point in central perspective is displaced from the center of view, the simplicity of the central perspective construction has been violated and a second vanishing point arises at 90° from this displaced vanishing point (for lines in the same plane). In fact, an entire crescent of vanishing points is required to accommodate lines of all orientations, aligned diametrically opposite the direction of the displacement.
6. Any planar figure in space is foreshortened in the direction of its slant from the observer (up to a 45° viewing angle). In particular, any square in space must be foreshortened in the direction of its slant, even for the projection outside the frame up to the range defined by the vanishing points. Beyond that, the foreshortening becomes lengthening, but this will occur outside the range of almost any picture (unless its edges extend beyond a 45° angle from the line of sight).
   (a) The degree of foreshortening of a square of central perspective is defined by its diagonals, which should project to vanishing points at a 90° angle to the viewer. Thus, the vanishing point for the corners of horizontal squares in central perspective should be at 45° to (and at the same height as) the central vanishing point. The intersection of the diagonals with the cardinal grid defines the degree

of progressive foreshortening of the receding squares. This geometry of a second vanishing point to set the spacing of the horizontals corresponds to one version of the costruzione legittima, or distance point method, of Leonardo (1492).

(b) In general, foreshortening follows the construction of the multiple implicit vanishing points even in central perspective, which is conceptualized as having only a single vanishing point. As long as there are intersecting lines in the scene, as there will be in any piazza grid, the vanishing points for the construction lines through the intersections must obey rules 2, 3 and 5, lying in the same line at the horizon of the plane and at same angle to the viewer as the intersections of the lines themselves in space.

(c) The progressive foreshortening as equal divisions recede in space gives a sense of curvature to the perspective transform of a regular array. All the lines are straight, but the array elements change shape as they recede, violating one's expectation of self-similarity. On top of this gradient of shape, the line thickness in virtually all perspective diagrams does not vary as it should in true perspective. Thus, the lines form an increasing proportion of the element area and perhaps induce a sense of distortion in an otherwise correct transform.

7. Circles in the scene, if foreshortened, project to ellipses in the picture plane. Although perspective distorts rectangles to asymmetric trapezoids in general, the properties of circles are such that they always project to an ellipse of some orientation. If the circle is parallel to the picture plane, it projects to a circle, which is the limiting case of an ellipse with no bias.

   (a) The projection for a circle may be derived by inscribing it in a square, for which the previous rules define the perspective distortion. The requisite ellipse is then obtained by inscribing it within the trapezoid obtained from the projection of this square. In practice, this ellipse may be selected from a set of ellipse templates as the one that just touches all four sides of the trapezoid without crossing them at any point. These constraints uniquely define the correct ellipse, since an ellipse is defined by four points in the plane (as a circle is defined by three points). The four 'touches' define four points and the avoidance of crossing anywhere provides the fifth constraint.

   (b) The center of the requisite ellipse does not correspond with the center of the circle being projected, but it displaced away from the vanishing point and toward the observer. The projected center of the circle may be determined by drawing the diagonals for the trapezoid, which intersect at the center of the projected circle. The degree of displacement may be determined by drawing the major an minor axes of the ellipse. The intersection of these axes defines its geometric center, which will be displaced from the projected center of the circle.

   (c) Spheres in space also project to ellipses in the picture plane, although generally with much less distortion than circles because the roundness of the spheres means that they are never foreshortened. Spheres always project to circles when at the center of projection. The elongation arises only because of marginal distortion, the stretching of the image as the picture plane itself recedes from the viewer at increasing angles of view. The requisite ellipse may be obtained by first projecting the sphere to a circle in a plane at right angles to the line of sight through its center, then projecting this circle to the picture plane. The major axis of the resulting ellipse is thus aligned with the axis of rotation of this projection and its ellipticity from the cosine of the (dihedral) angle between the intermediate and final projection planes.

8. For correct projection of its perspective, a picture should be viewed from its center of projection in space. In terms of distance, Rule 5 implies that the vanishing points for lines at right angles should

be viewed so as to be orthogonal, forming 90° angle at the viewing position. Any parallel pair of right angles in the picture thus defines its correct viewing distance, by defining two orthogonal vanishing points. In terms of angle, the plane of the picture should be viewed at the angle of slant for which the perspective was designed. Other viewing angles, away from the center of projection in any direction, will result in perspective distortion.

(a) For the particular case of central perspective based on a square grid aligned with the line of sight, the 45° angle between the diagonals and the line of sight means that the distance points should have a 45° to the main vanishing point at the viewer's eye. The geometry between the eye, the central vanishing point and a distance point is therefore a 45° triangle, which means that the picture is correctly viewed at the distance that matches the span to each distance point. The physical distance between the vanishing points depends on the intended viewing distance, but a good rule of thumb is that it should correspond to a distance of at least twice the width of the picture. Leonardo recommended at least 20 times the height of the largest objects depicted.

(b) Telephoto distortion and its limiting case, orthographic projection, conversely, represent a strong magnification of the image in true perspective. If a tiny piece of the scene is magnified, the distance of its vanishing points is correspondingly magnified. The effect may be so extreme that the rear of the object looks as though it curls up toward the front of that object. The perceived distortion is so strong that it has been termed "reverse perspective", as though the lines which should be converging were in fact diverging. The effect is particularly strong in orthographic projection, where parallel lines in spaces are drawn as parallel in the picture, as though it were viewed from an infinite distance. Nevertheless, the perceived "reversal" is an illusion obtained simply from abnormally distant projection. Despite the distorted appearance, telephoto distortion is a valid perspective projection if viewed at the correct distance (although the scene may in practice be invisible at that distance).

9. Telephoto distortion and its limiting case, orthographic projection, conversely, represent a strong magnification of the image in true perspective. If a tiny piece of the scene is magnified, the distance of its vanishing points is correspondingly magnified. The effect may be so extreme that the rear of the object looks as though it curls up toward the front of that object. The perceived distortion is so strong that it has been termed "reverse perspective", as though the lines which should be converging were in fact diverging. The effect is particularly strong in orthographic projection, where parallel lines in spaces are drawn as parallel in the picture, as though it were viewed from an infinite distance. Nevertheless, the perceived "reversal" is an illusion obtained simply from abnormally distant projection. Despite the distorted appearance, telephoto distortion is a valid perspective projection if viewed at the correct distance (although the scene may in practice be invisible at that distance).

(a) The center of view in the picture should not be confused with the line of sight of the viewer. The center of view is the point in the picture plane closest to the viewer. The line of sight is the direction in which the viewer's eye is pointing, which may be anywhere within (or outside) the picture. Where the viewer samples the optic array does not affect the correctness of the perspective. The perspective is correct when the viewer's eye is placed at the center of projection in space for which the perspective was generated (regardless of the direction of the line of sight).

(b) This point is contentious because most authors agree that the perspective projection changes with viewing angle. Presumably this misconception arises because lines that are parallel in central projection of a scene appear to converge as the viewer looks to the side. This observation, however, implicitly assumes that the relevant picture plane is rotated with the rotation of the line of sight. Rule 9 refers instead to an observer viewing a fixed picture, projecting an optic array to the viewer's eye. In this case, if the observer's eye looks away from the center of view, the picture plane itself will project to the eye with a perspective transform. It is the perspective distortion of this picture plane that provides the convergence of the parallel lines in oblique view, just as in the physical scene itself. Thus the correct geometry for perspective in the picture plane is indeed independent of the direction in which the viewer is looking at this plane (assuming the eye stays at the center of projection).

(c) As long as the viewer is directly in front of the central vanishing point (and the picture plane is frontoparallel), the verticals project to parallel lines in the picture plane (Rule 3A). Once the main vanishing point is moved up or down from the viewer's eye position, the verticals are required to converge so as to make an angle of 90° to the direction of this vanishing point (Rule 5).

Appendix II - Guidelines for Art Study Center

1) Faculty and students should swipe their Harvard ID on the badge card reader located outside of the Broadway Entrance to check in for the class session.

2) Before entering the seminar room, all personal items, including coats, handbags, backpacks, and umbrellas, should be placed in the lockers provided in the reception area.

3) Hands should be washed at the hand washing station on Level 4 prior to entering the seminar room.

4) Paper and pencils are allowed in the seminar room. Laptop computers may be used, but museum staff reserve the right to request the removal of the laptop from the display table to ensure the safety of the artwork being viewed.

5) Please note that a museum staff member will attend each class session. The museum staff member is available to move the artwork as necessary.

6) Please be mindful to not point at the artwork with objects such as pencils.

7) No leaning or sitting on the tables or ledges.

8) Pens or other inks, beverages, chewing gum and food are **prohibited** in the seminar room.

9) No flash photography is allowed in the seminar rooms. Photographs taken in the seminar rooms may be used exclusively for research and other non-profit educational or personal purposes.

Updated: March 7, 2022