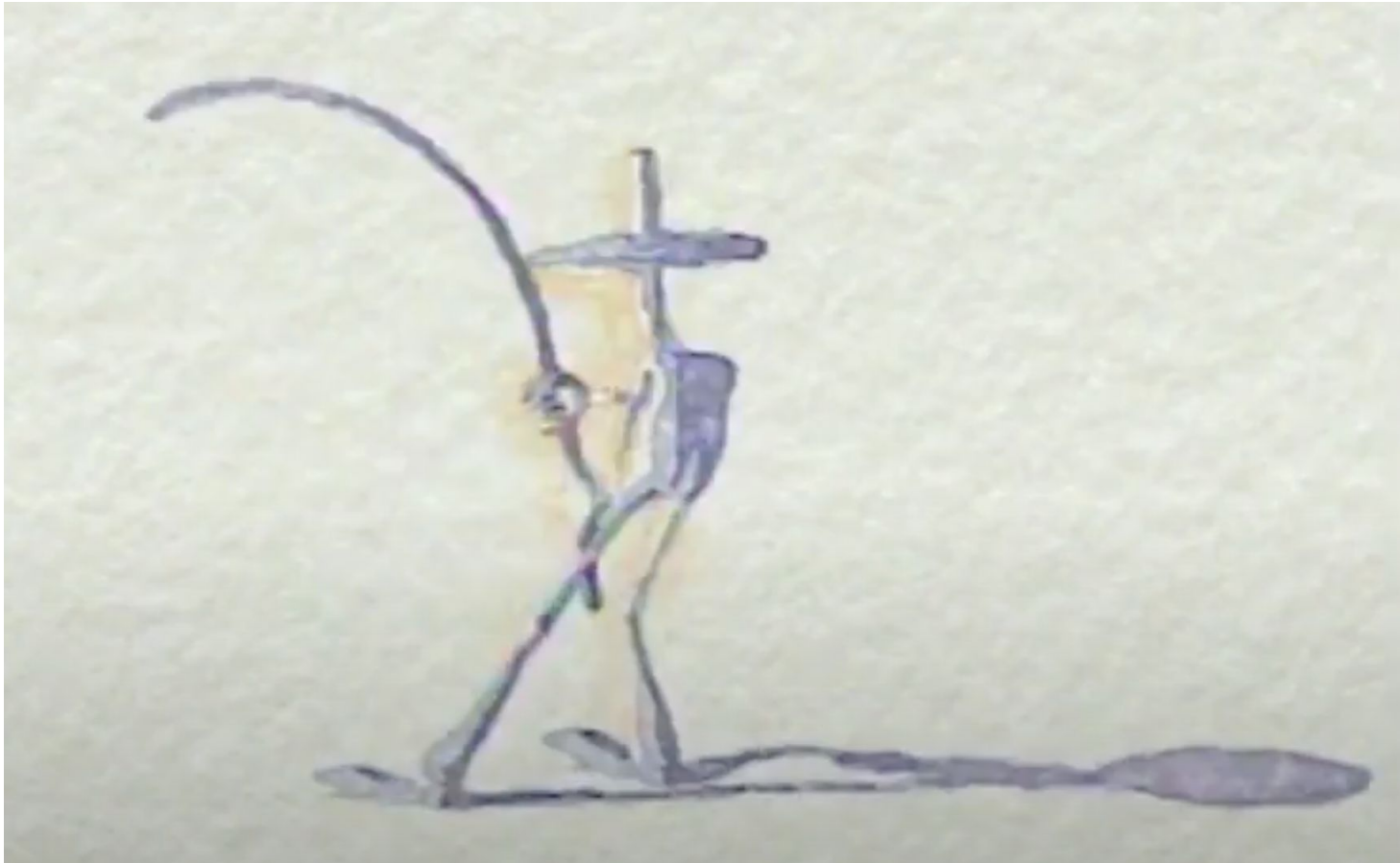


CSCI 4530/6530 Advanced Computer Graphics

<https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S25/>

Lecture 21: Non-Photorealistic Rendering

Fishing, PDI, Siggraph 1999





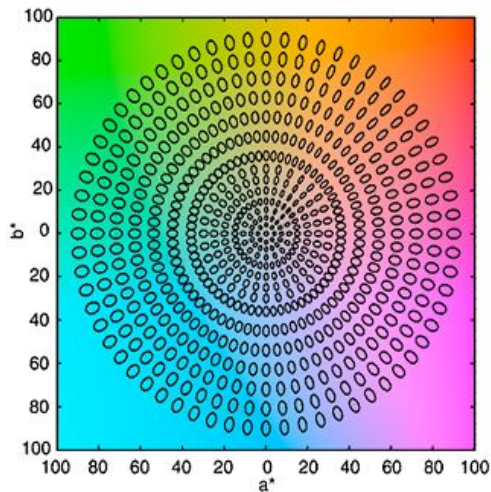
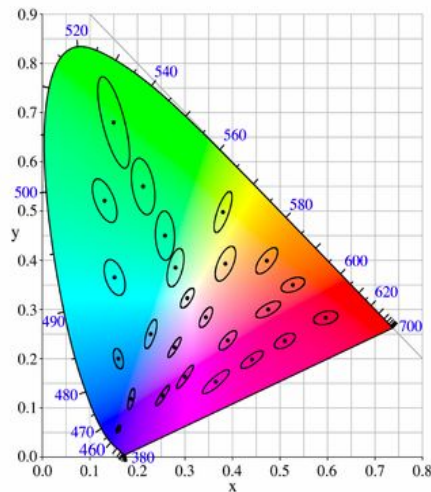
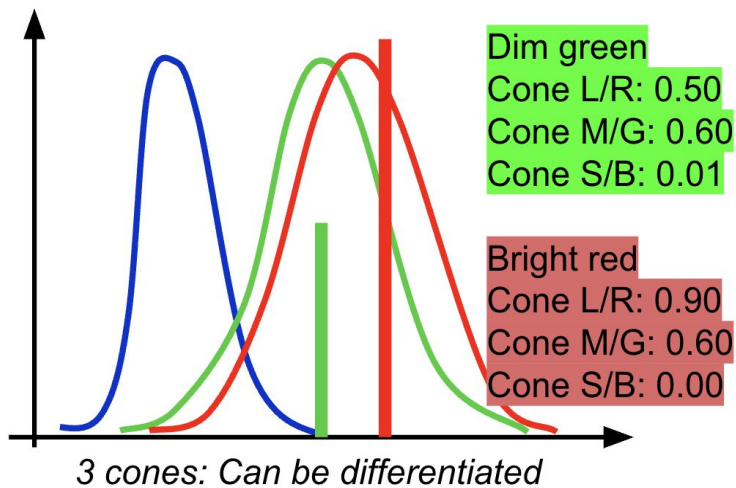
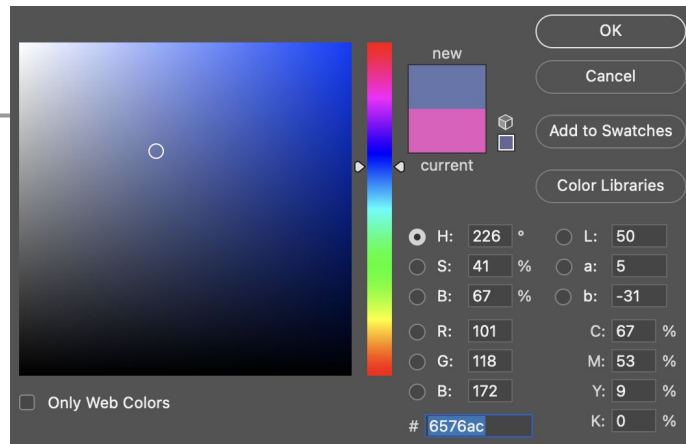
Brush, Lei Chen, Siggraph 2006





Last Time?

- Context: BRDF + Lighting
- “Normal” Human Vision
Rods + 3 cones
- Color Spaces & Human Perception

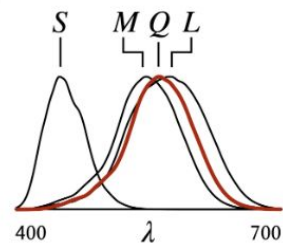


Today

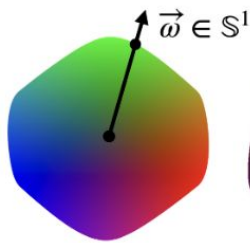
- Papers for Today
- Architectural Rendering
- Line Drawing
- Pen & Ink / Hatching
- Technical Illustration
- Artistic Styles and Painterly Rendering
- Papers for Next Time

Readings for Today

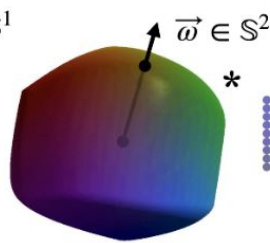
- "Theory of Human Tetrachromatic Color Experience and Printing"
Lee, Jennings, Srivastava, & Ng,, ACM TOG 2024



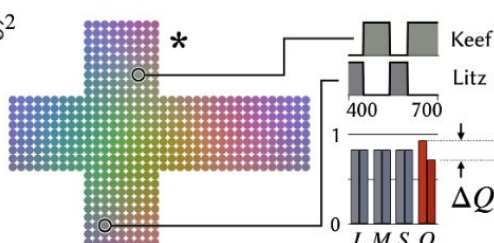
A: Human Tetrachromatic Spectral Response Functions



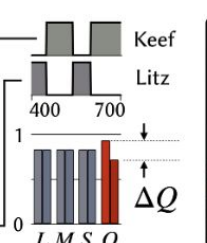
B: Regular Trichromatic Chromaticities + Hues



C: Tetrachromatic Chromaticities + Hues



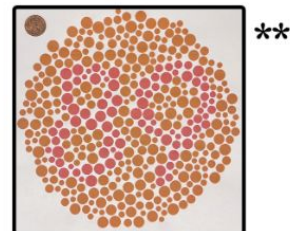
D: Tetrachromatic Hue Sphere, Flattened, and Keef/Litz Hues



E: Keef/Litz Reflectances and ΔQ



F: Prototyping Platform for Tetrachromatic Printers



G: Photo of Example Tetrachromatic Print; Color Test **

- Tetrachromat: S + [(2M & 1L) or (1L & 2M)]
- > 50% of women are genetic tetrachromats (have genes for 4 cones)
- But in practice only 1 functional tetrachromat has been identified
 - The measured difference in cone sensitivities necessary for functional tetrachromaticity (12nm) is rare (vs. more common 4-5nm)
- because we lack tetrachromat colors in our environment
 - Or are we just lacking support for printing & display technology?
- A functional tetrachromat lives in a world where:
 - the paintbox doesn't have all the colors of the rainbow
 - art / imagery that is incongruous with reality, because everything was created by 'colorblind' artists, display manufacturers, etc.
- Do you have to practice your color sensitivity or you lose it (similar to how ability to distinguish phonemes must be exercised/formed as a child)

Recommended Reading:

An Anthropologist on Mars:

Seven Paradoxical Tales

“The Case of the Colorblind Painter”

Oliver Sacks, 1995

[https://boccignone.di.unimi.it/PMP_2018_files/](https://boccignone.di.unimi.it/PMP_2018_files/Oliver%20Sacks_II%20Pittore_Cieco_ai_colori.pdf)

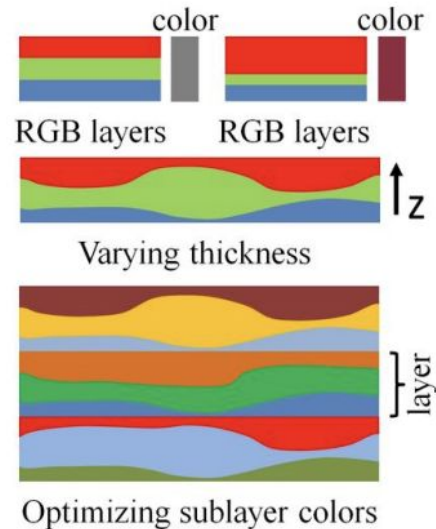
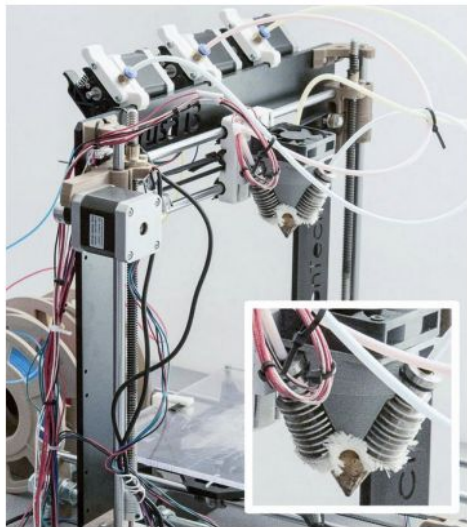
[Oliver%20Sacks_II%20Pittore_Cieco_ai_colori.pdf](https://boccignone.di.unimi.it/PMP_2018_files/Oliver%20Sacks_II%20Pittore_Cieco_ai_colori.pdf)

*The sunset scene of which Mr. I. could see
virtually nothing (—an effect simulated by a
black-and-white photocopy of it.)*



Readings for Today

- "Colored Fused Filament Fabrication",
Song, Martinez, Bedell, Vennin, & Lefebvre, ACM TOG 2019



- Low cost 3D printing using fused (mixed in nozzle) filament colors
- Control of changing color is challenging (timing is slow and inconsistent)
- instead vary thickness of (translucent) layers
- ‘Prime shield’ (waste printing) used between color changes
- Future work: what ratio of available filaments color produce a specific perceived color when mixed?
- “Runtime” - means computational runtime? Or print runtime?
(print time can take hours, computational time might not be relevant)

Readings for Today

- "Flash Photography Enhancement via Intrinsic Relighting",
Eisemann & Durand, SIGGRAPH 2004



no flash
*warm ambiance,
noisy*



flash
flat lighting



combined result
*original lighting,
denoised*

- Great idea, algorithm/technique clearly & intuitively described
 - Can be implemented on modern smartphone. Has it been?
- Image quality is subjective.
 - Ambiance in sample images seems off. Too bright? Unnatural?
 - Some readers preferred the flash images. Would it be more convincing if the viewer had experienced scene in person?
 - Examples with reduction of artifacts were good / most convincing.
- Technology (filters & smoothing) covered in Computational Vision course
- Technique seems to have a lot of arbitrary constants

Today

- Papers for Today
- **Architectural Rendering**
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ARCHITECT



what my parents think I do



what my friends think i do



what society thinks i do



what i think i do



what my kids think i do



what i actually do

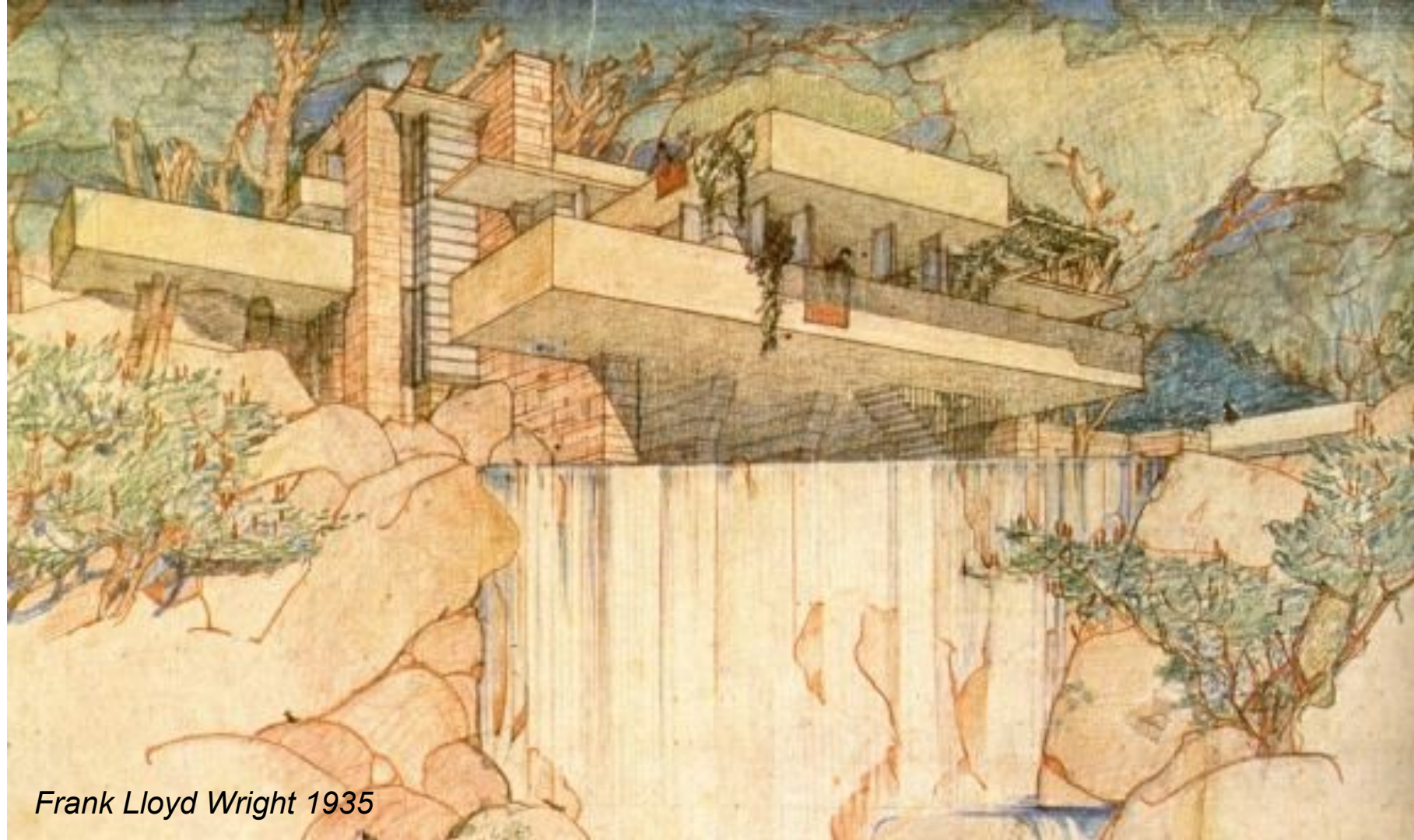




<http://www.thetimesnewroman.com/2011/07/luxe-living-fallingwater.html>



<http://www.thetimesnewroman.com/2011/07/luxe-living-fallingwater.html>



Frank Lloyd Wright 1935

Fallingwater - Frank Lloyd Wright

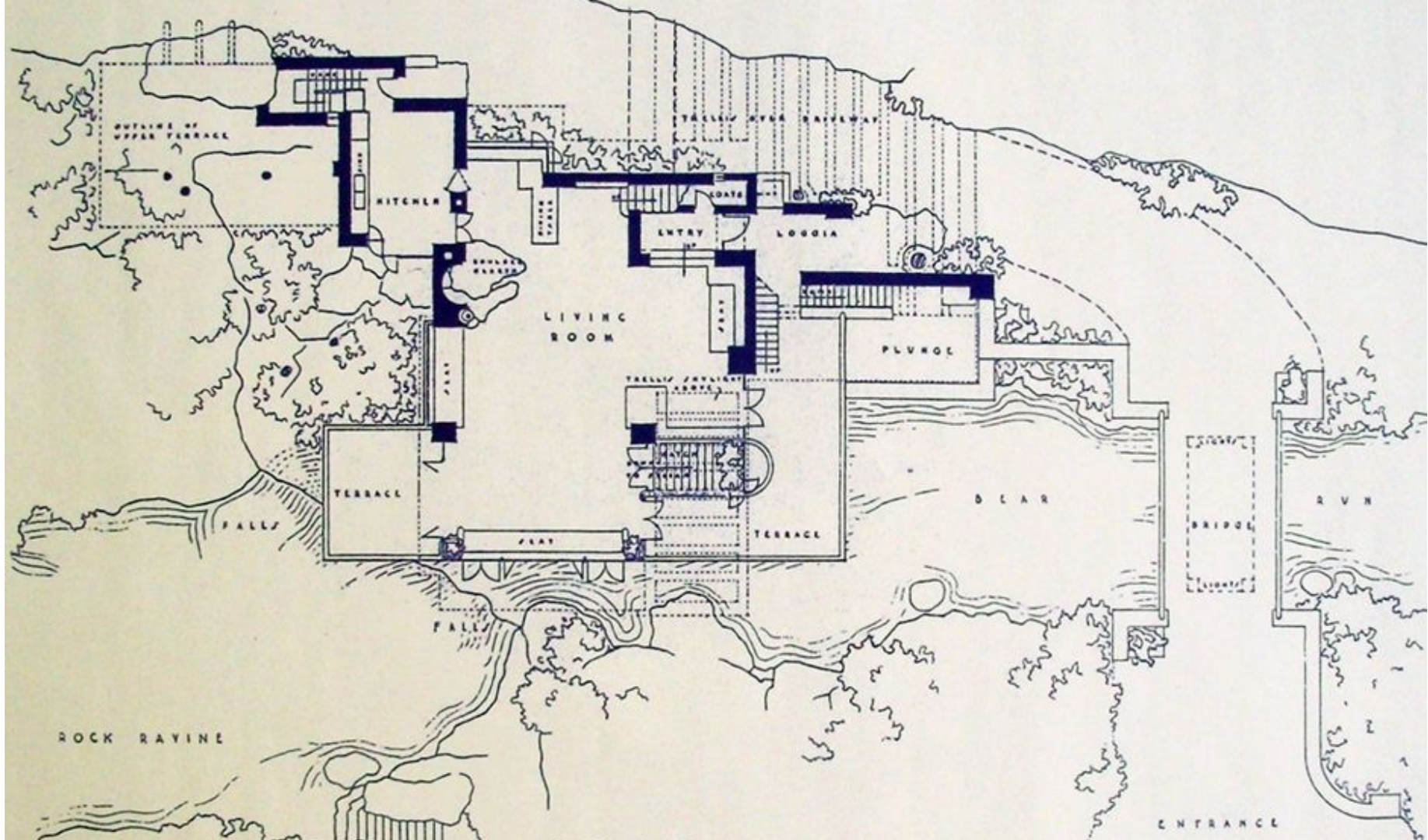
- Designed for Kauffman family
- Rural Pennsylvania
- Designed 1935
- Main house completed 1937
- Construction cost: \$155,000
~\$3 million in 2025
- 4 times the original budget!

Frank Lloyd Wright 1935





https://si.wsj.net/public/resources/images/OD-AG561_FALLIN_G_20110506021738.jpg



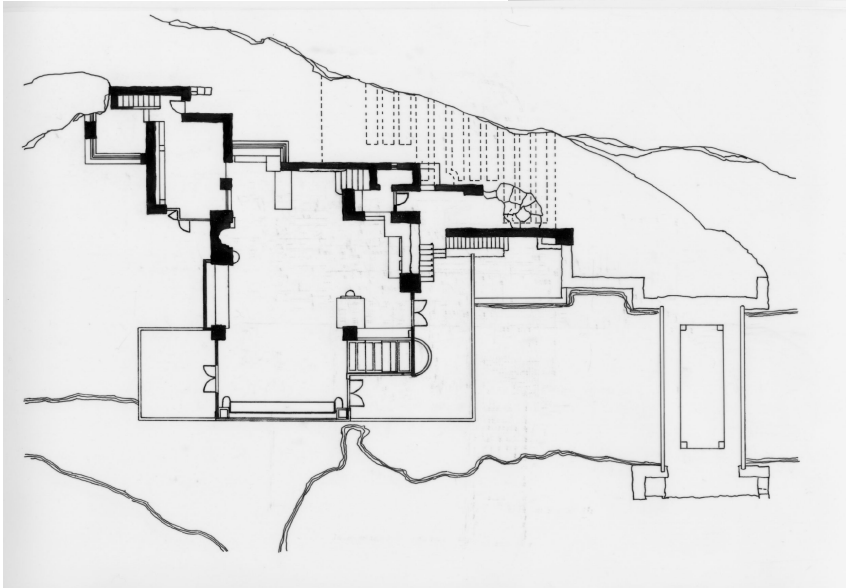
Fallingwater Design

- Family asked for a house with a window to view the small waterfall.
- Wright suggested instead that the house overhang the waterfall.
- The living room fireplace hearth is placed around original rocks where the family would picnic and relax.
- A staircase from the living room leads down to a swimming platform hovering above a small pool at the top of the falls.

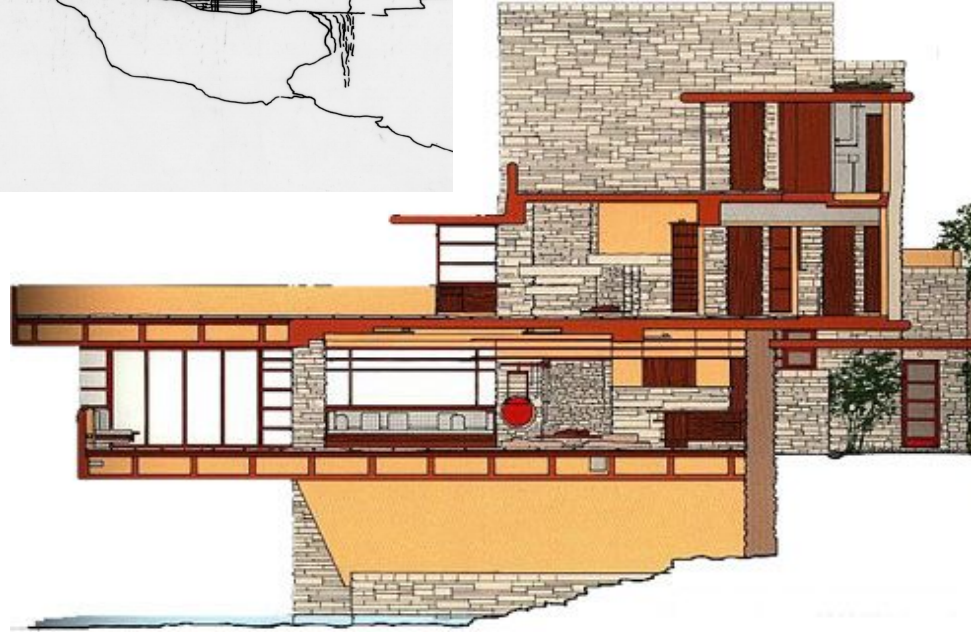
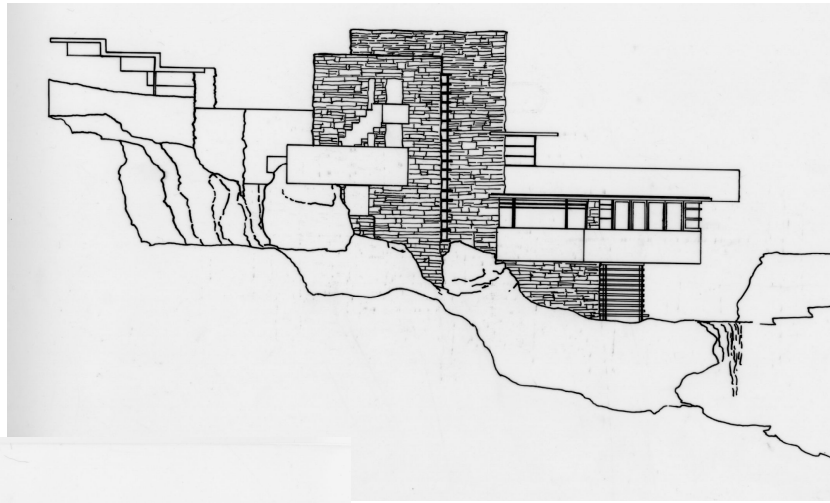


Traditional Architectural Drawing Types

**drawing type:
“site/floor plan”**



**drawing type:
“elevation”**



**drawing type:
“section”(cut-through)**

[http://www.architecturelist.com/wp-content/
uploads/2007/10/fallingwater_4.jpg](http://www.architecturelist.com/wp-content/uploads/2007/10/fallingwater_4.jpg)



Digital Models

Would the Kaufmans have agreed to spend 4X their original budget if these were the presented design documents?









<https://www.youtube.com/watch?v=MbCL4WJmcgg>



<https://3dwarehouse.sketchup.com/model/5b9851979897e7e3a03c22556407e748/Falling-Water>



© 2007 Google™

© 2007 Europa Technologies
Image © 2007 TerraMetrics
© 2007 Sanborn

Falling Water House by [MillieModels](#) **\$75.00** [Add to Cart](#)



Product File Downloads

3ds Max 7 (.max) 119 KB

[Live Chat Now 24/7](#)

[Quality Guarantee](#)

[File format conversions](#)



Product License

Standard Royalty Free [View License](#) | [FAQ](#)

3D Model Specifications

Product ID:	266247
Published:	Jun 6, 2005
Geometry:	Polygonal
Polygons:	17,864
Vertices:	9,653
Textures:	Yes
Materials:	Yes
Rigged:	No
Animated:	No
UV Mapped:	Unknown
Unwrapped UVs:	Unknown

Product Rating

Unrated



*Anyone can buy
digital models of
Fallingwater
and many other
famous buildings
and objects!*

*[http://www.turbosquid.com/
3d-models/
water-house-3d-x/266247](http://www.turbosquid.com/3d-models/water-house-3d-x/266247)*





<http://lvlworld.com/t.php/Frank+Lloyd+Wright's+-+Falling+Water>



*From
Half Life 2*

Photorealism

Now that we have “solved” photorealistic rendering: Is it always the right choice for Architectural Design Presentations?



<https://vimeo.com/802540>

FEATURING THE FRANK LLOYD WRIGHT MASTERPIECE • WWW.ETEREAESTUDIOS.COM © CRISTÓBAL VILA, 2007



*A spatially-augmented
reality art installation!*

*<http://luftwerk.net/projects/fallingwater/>
<https://www.youtube.com/watch?v=6RJbnA7ESKk>*

How important is context to the design?



<https://www.6sqft.com/a-kooky-1970s-fallingwater-lookalike-in-greenwich-is-asking-3-5m/>

Photorealistic Miniatures

Great for understanding the 3D spatial relationships and communicating with clients

*Wiley White
Architectural Models*



[http://www.architectural-models.com/
galfallwat.html](http://www.architectural-models.com/galfallwat.html)

Non-Photorealistic Miniatures



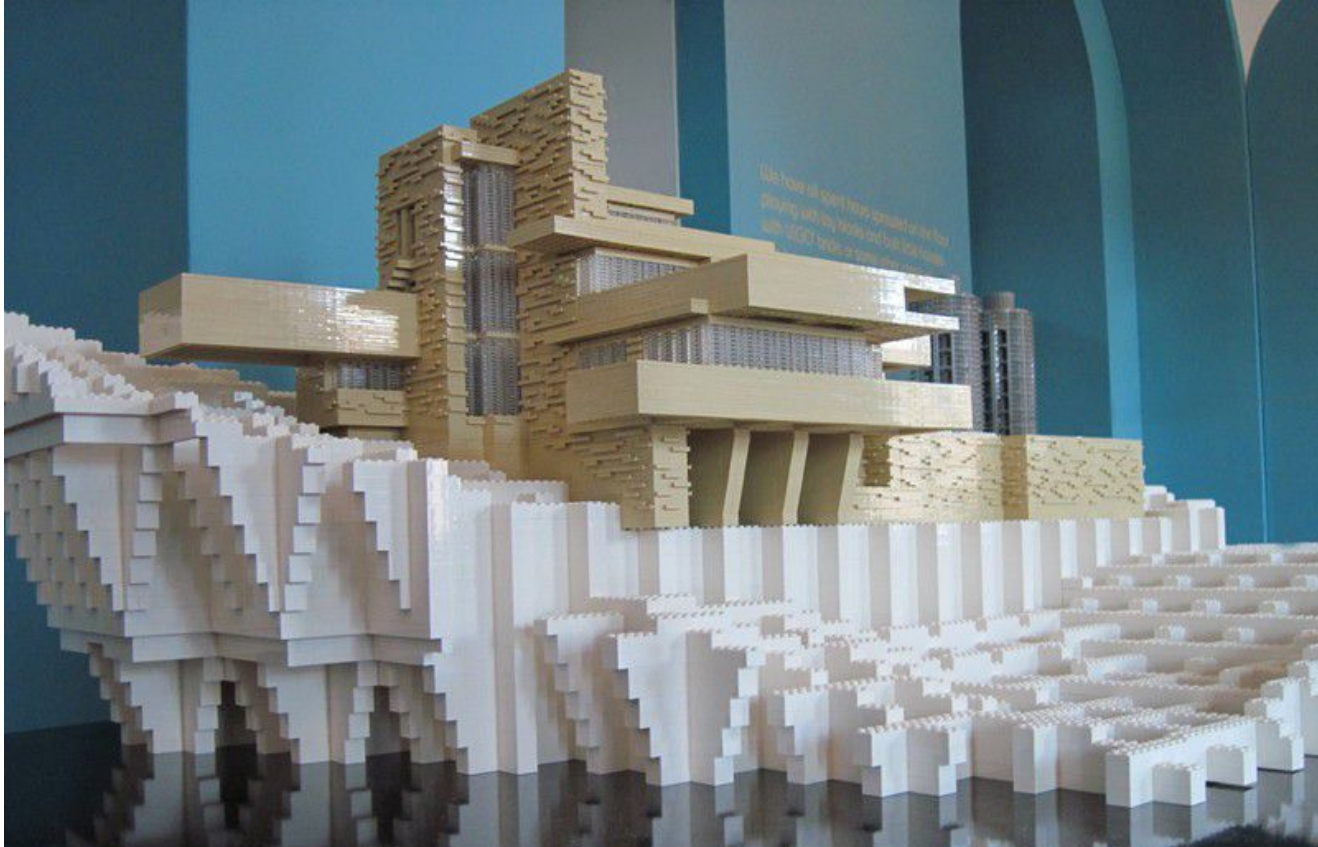
<http://shop.lego.com/ByTheme/Product.aspx?p=21005&cn=52>
<http://www.urbanbydesignonline.com/urbanbydesign/tag/fallingwater>

Non-Photorealistic Miniatures



<http://www.flickr.com/photos/matijagrguric/sets/72157623778661188/>

Non-Photorealistic Miniatures



Adam Reed Tucker <http://www.mocpages.com/moc.php/220533>

Non-Photorealistic Miniatures



<http://gardenmelodies.blogspot.com/2010/11/falling-water-gingerbread-house.html>



http://twls.libsyn.com/index.php?post_id=35584



HGA Architects & Planners - Cantilevers: Inspired by Falling Water
http://www.flickr.com/photos/j_bussmann/4549613488/

Non-Photorealistic Rendering



<http://www.fallingwater.org/>

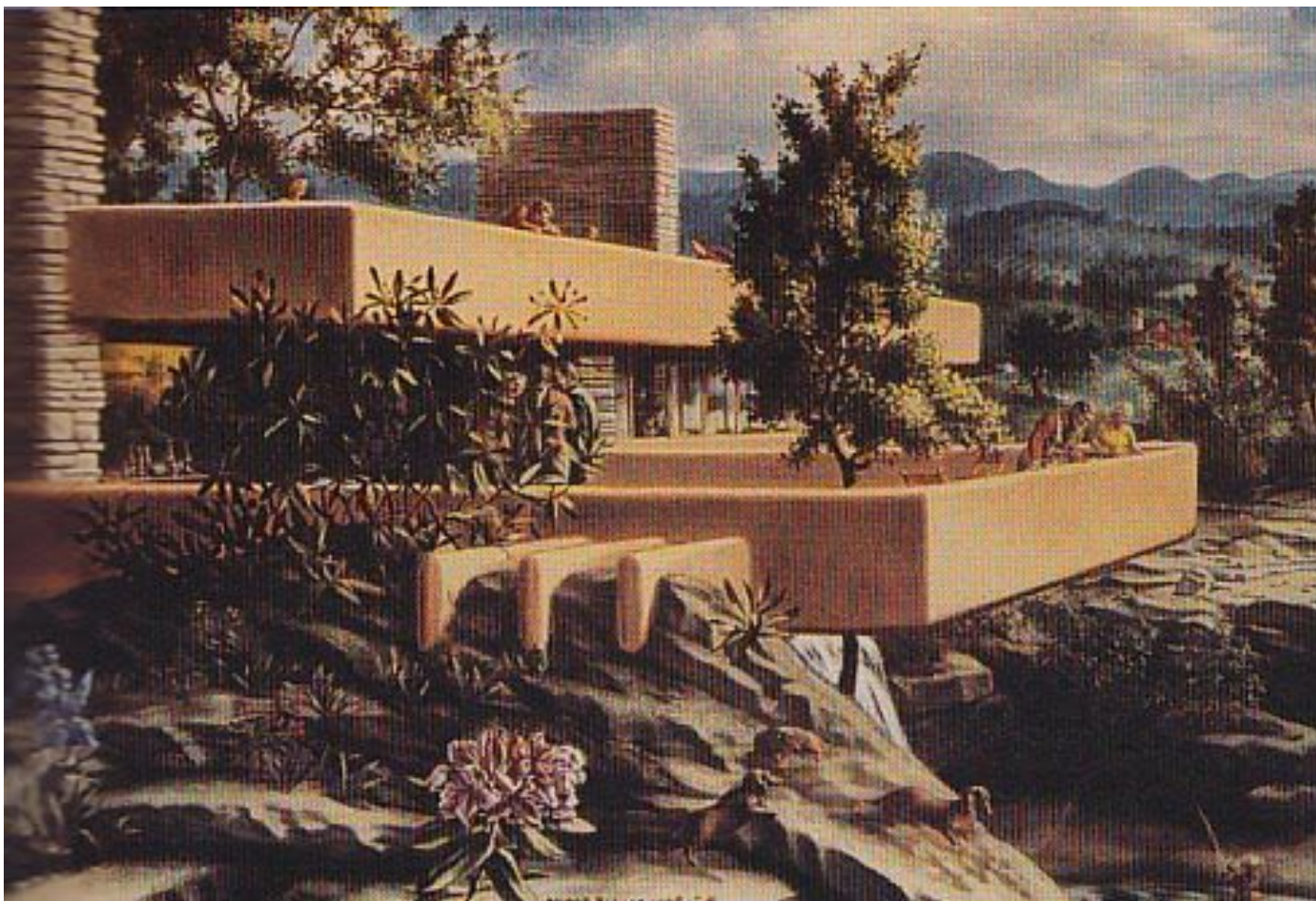
Non-Photorealistic Rendering



<http://www.studio360.org/2009/may/29/fallingwater/>



<http://www.funnyfishdesign.com/casestudies/craft-lights/?ckattempt=1>



*"House At Falling Water", Peter Blume, 1938-1968.
First painting of Fallingwater. Commissioned by the owners.*



<http://fineartamerica.com/featured/falling-water-jamie-frier.html/>



<http://disney.go.com/create/art/2gs11k6UcUbS000010040000-g-bce863>



<http://www.ivonneimagines.com/487/falling-water/>



<http://kempersmith.com/fallingwater.html>



<http://www.historichollywood.biz/drawings-pennsylvania/fallingwater.htm>

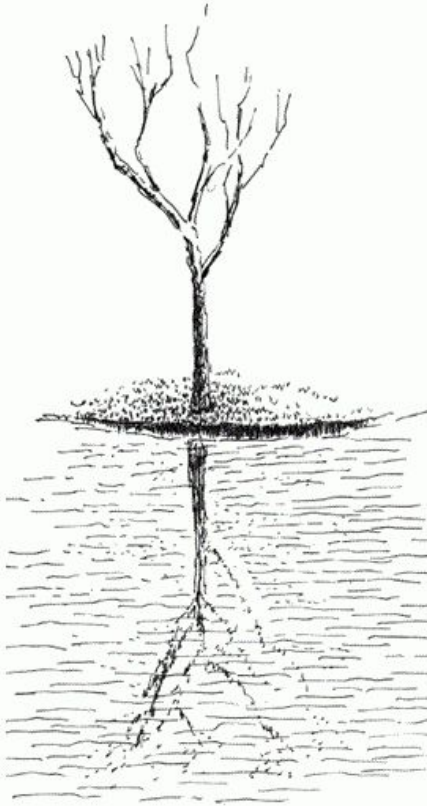


Brian Bent http://www.dirtgalleryla.com/bb_falling.html



[http://www.anopensketchbook.com/
2009/02/monticello-fallingwater.html](http://www.anopensketchbook.com/2009/02/monticello-fallingwater.html)

How to Draw Water with Pen and Ink



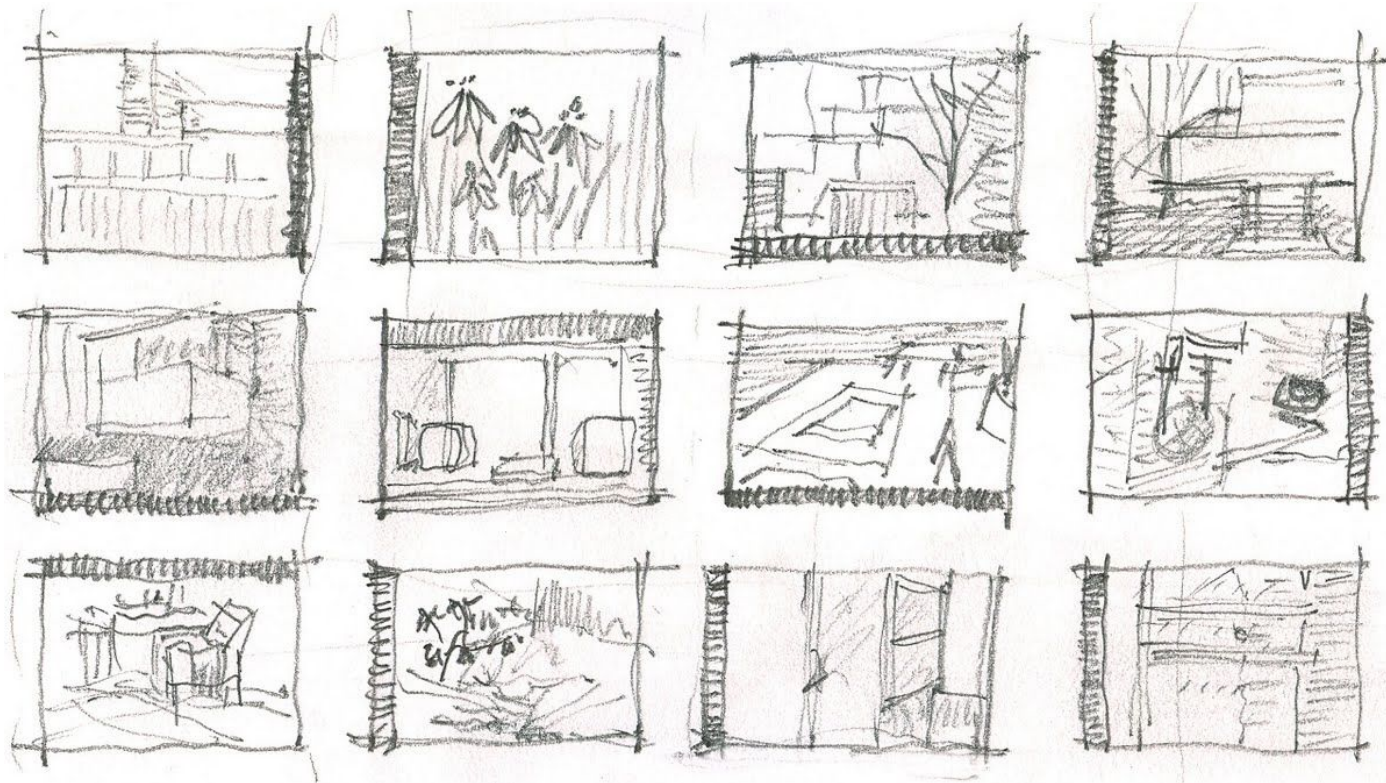
Rahul Jain <https://pendrawings.me/2016/01/04/draw-water/>



[http://www.gibson-design.com/images/
Slides/fallingwater-entry-100dpi.jpg](http://www.gibson-design.com/images/Slides/fallingwater-entry-100dpi.jpg)

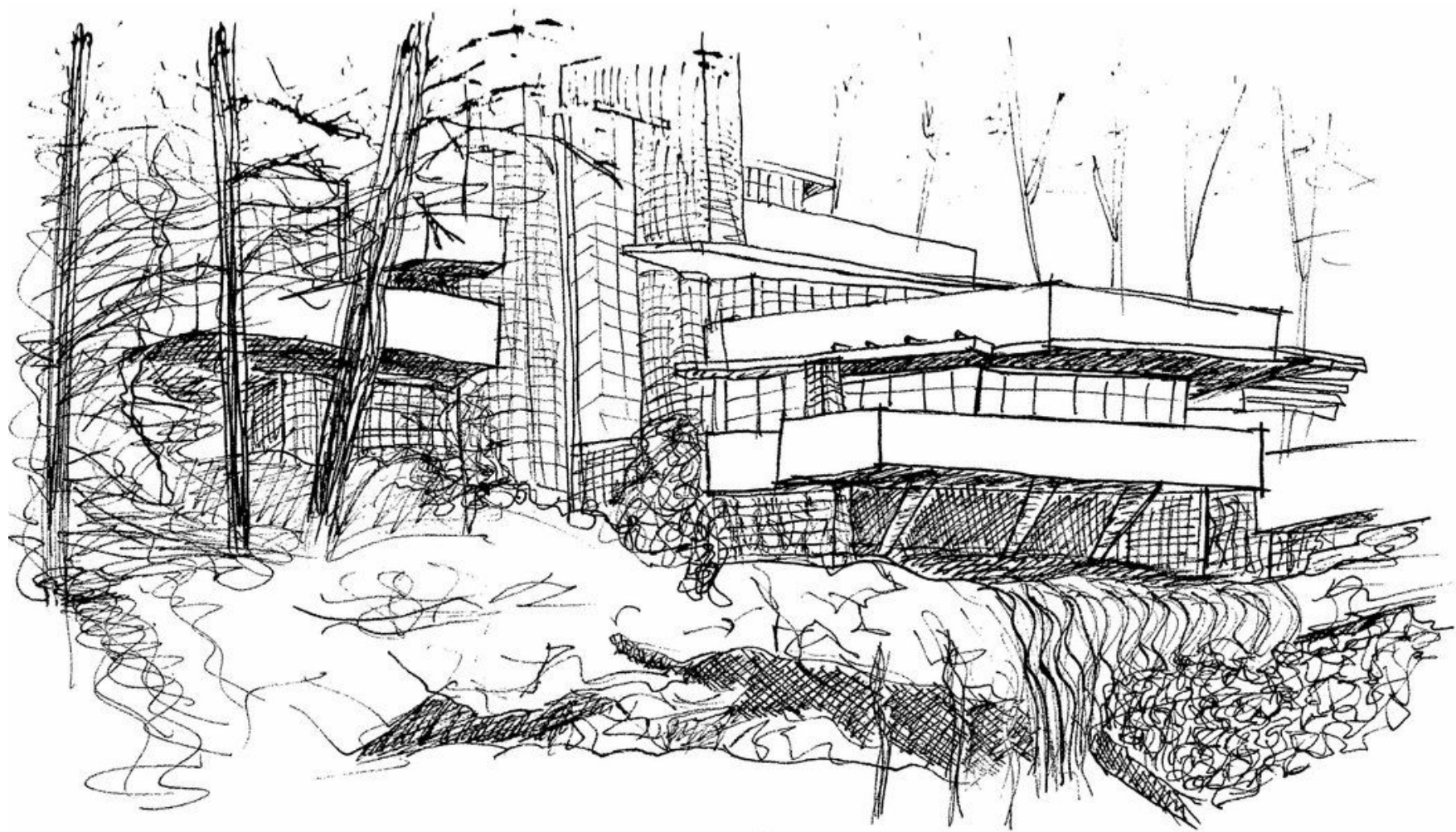
Freud 8.20.89

Artistic/Architectural Sketchbooks are great for capturing impressions, new perspectives, and design ideas.

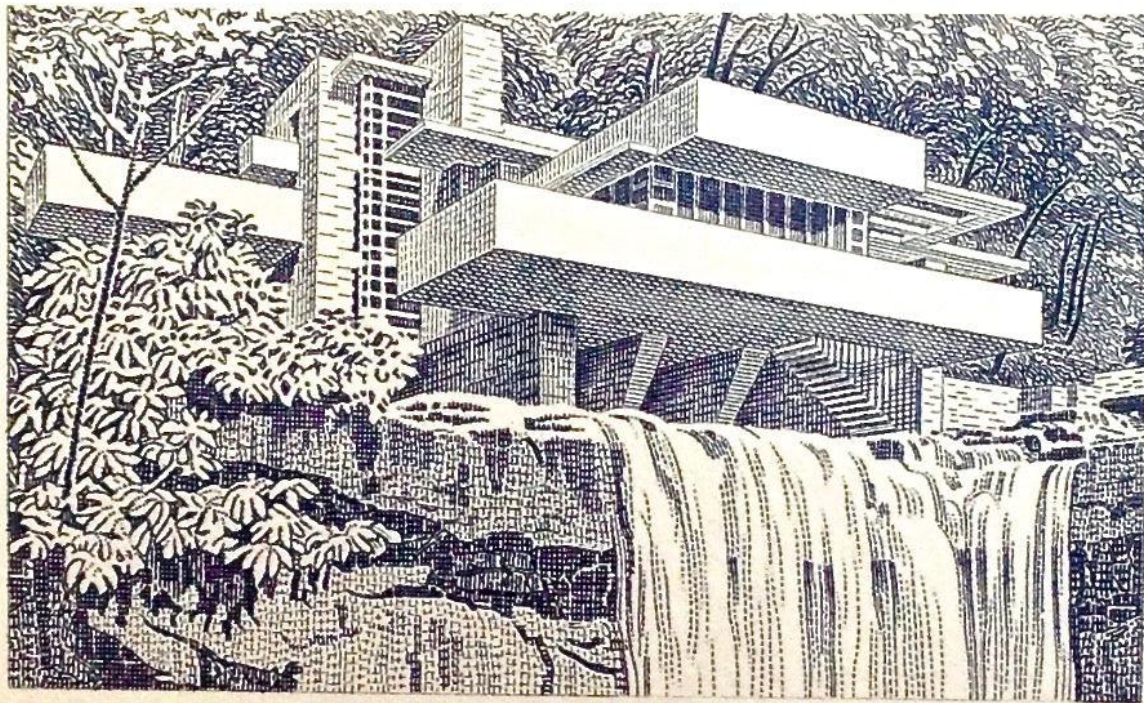


F A L L I N G W A T E R O N E

<https://architectureassociate.blogspot.com/2012/12/fallingwater.html>



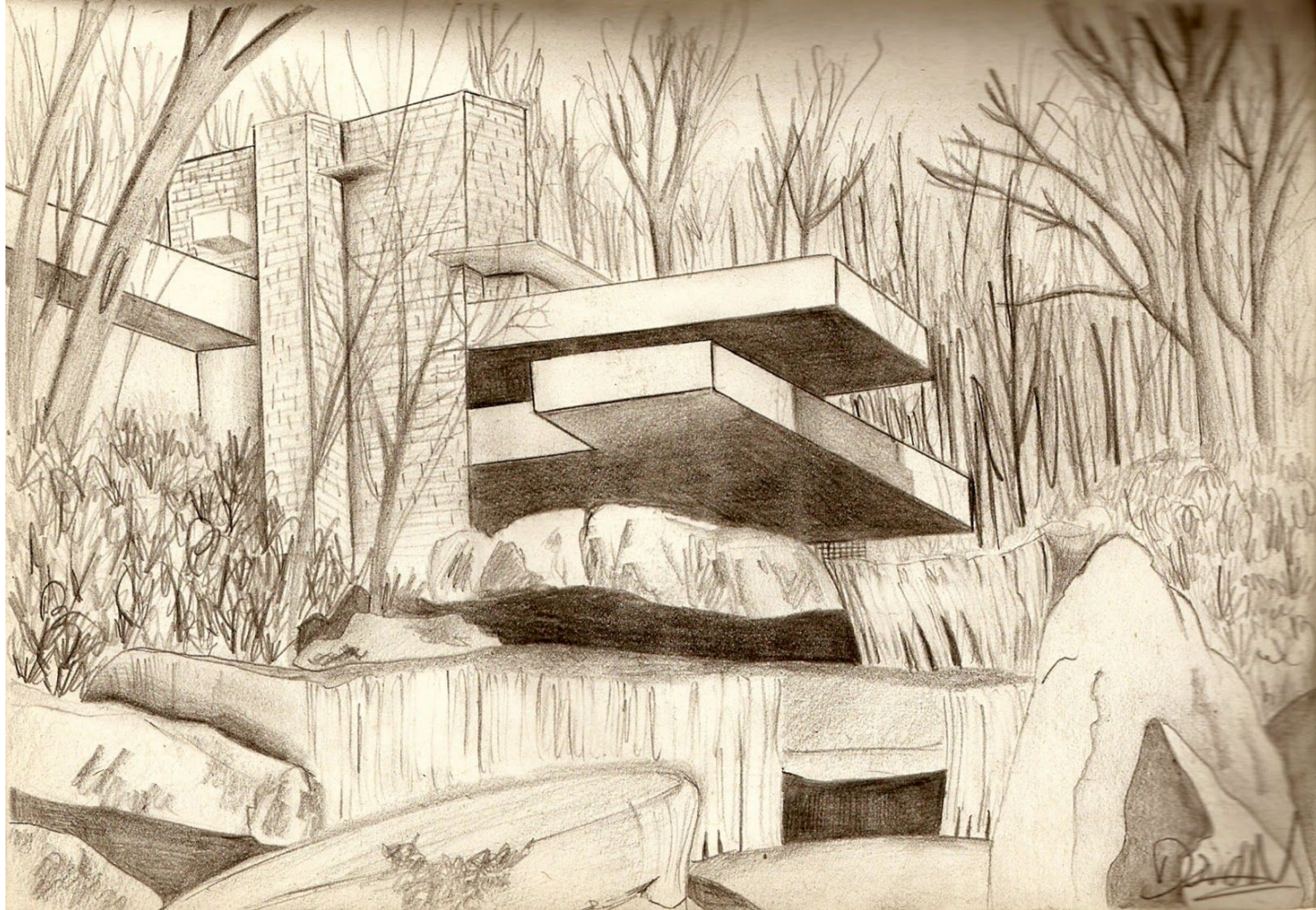
<http://burningapolloiv.deviantart.com/art/Falling-Water-202864974>



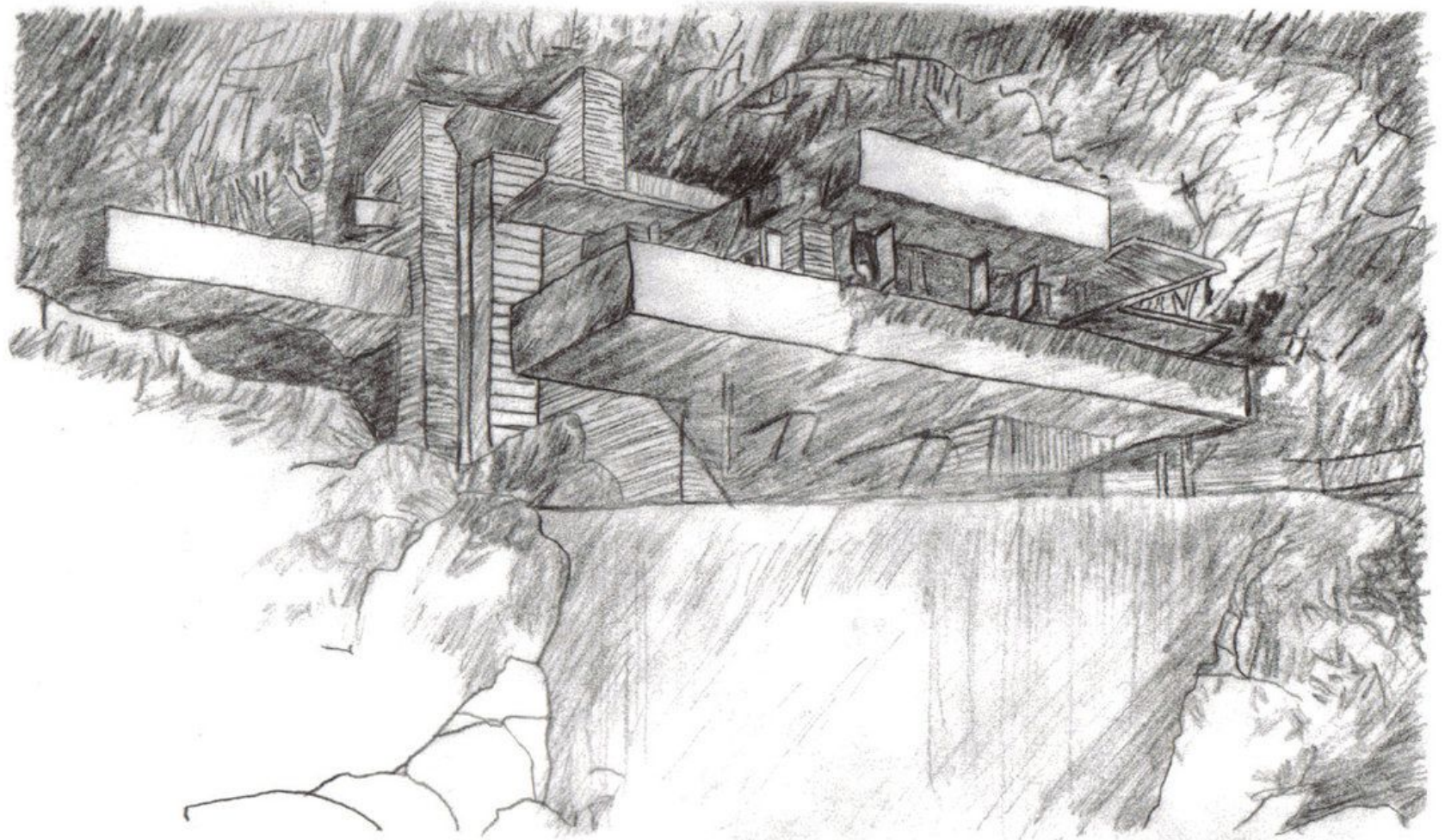
Frank Lloyd Wright 1867-1959 Fallingwater Mill Run PA
Architecture USA 20c



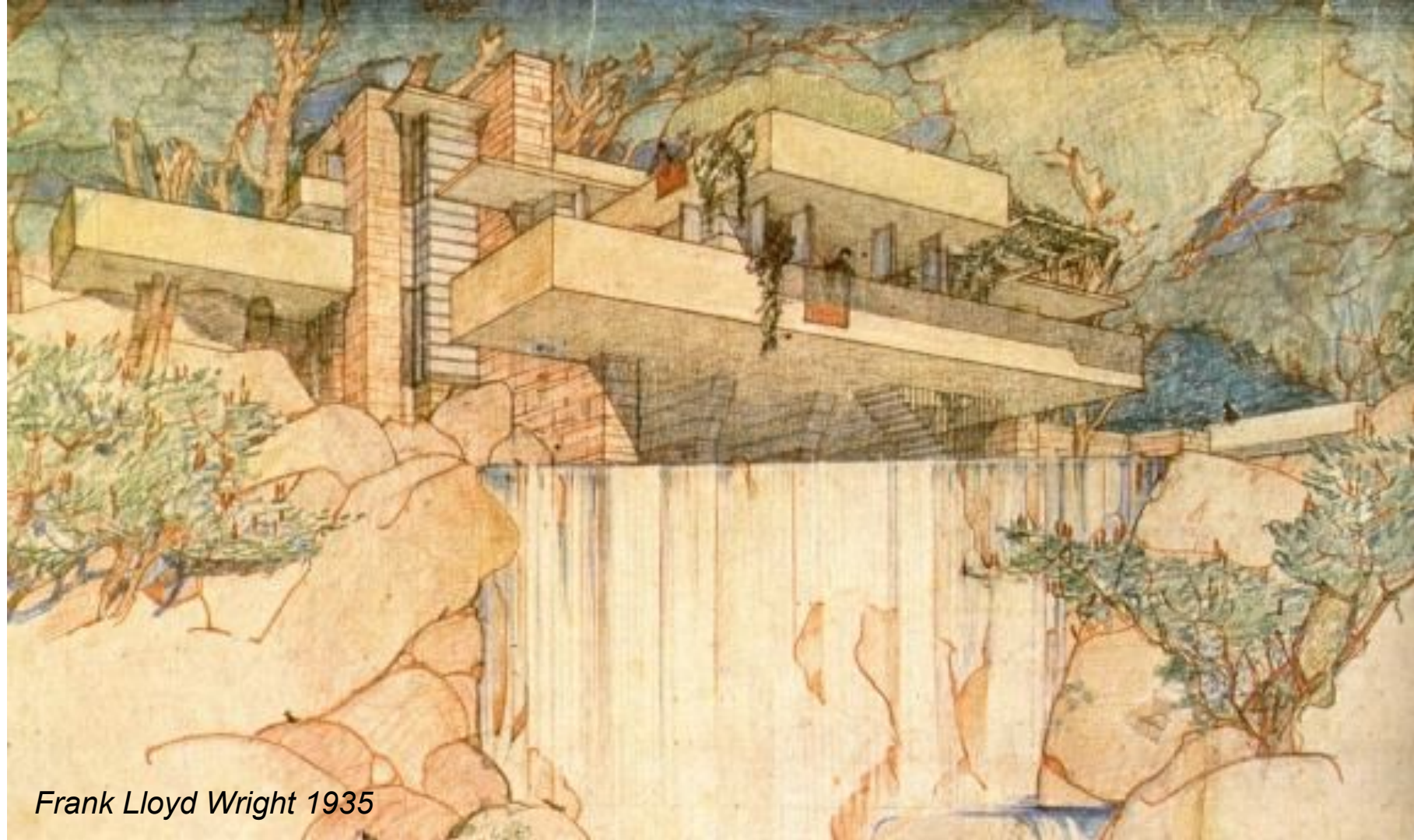
<http://jjh1392.deviantart.com/art/Fallingwater-151791274?q=sort%3Atime+gallery%3Ajjh1392&qo=1>



<http://obrasdearteacarvao.blogspot.com/>



<http://rocket-204.deviantart.com/art/Falling-Water-Sketch-61337019>



Frank Lloyd Wright 1935

Goals and Tools of Non-Photorealistic Rendering



Goals and Tools of Non-Photorealistic Rendering

- Draw attention to specific elements of the scene
- Shift viewer's focus by exaggeration or de-emphasis of elements
- Indicate uncertainty or unimportance about:
 - Material, geometry, lighting, texture, contrast, perspective, etc.
- May use limited palette of colors, or precision/resolution
- Intentional and controlled variation in level of detail
- May contain more detail than a single photorealistic image:
 - Through use of cross section, transparency, exploded view, multi-viewpoint rendering, etc.

Today

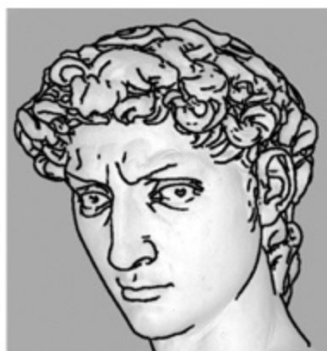
- Papers for Today
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- Papers for Next Time



silhouette



contours



**contours and
suggestive contours**

main view

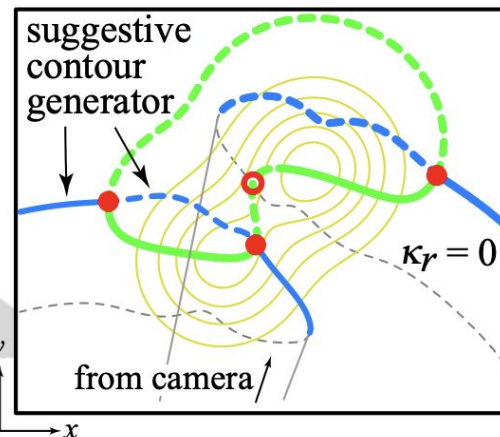
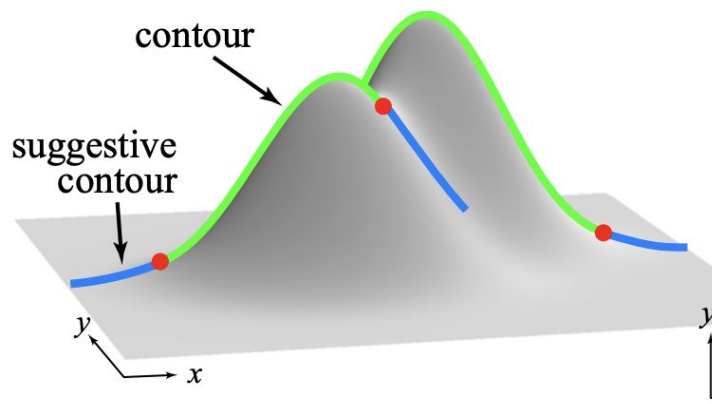
$c \triangleleft$

nearby
view

$c' \triangleleft$

p

$q' q$



Suggestive Contours for Conveying Shape

DeCarlo, Finkelstein, Rusinkiewicz, Santella, SIGGRAPH 2003

Types of Edges in Line Drawings

- Silhouettes/Contours: normal is perpendicular to the view direction
- Suggestive Contour: inflection points of the surface normal
- Ridges & Valleys: extremum of curvature
- Apparent Ridges:
based on *view dependent* curvature

anticipation



contours in
original view c

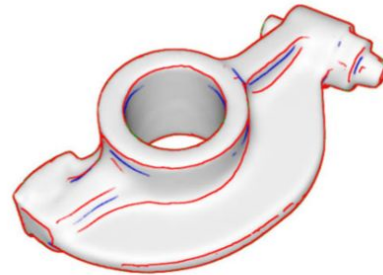
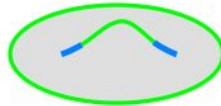


contours in
nearby view c'

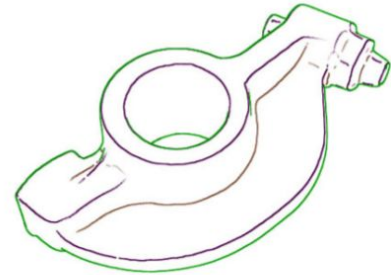


suggestive contours
and contours in c

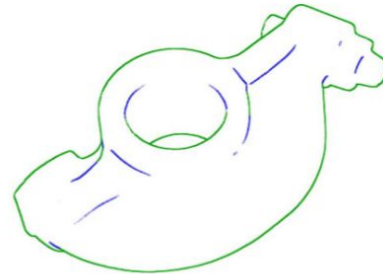
extension



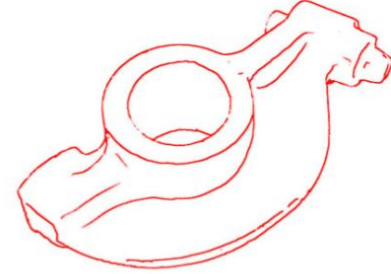
Shaded View



Ridges & Valleys



Suggestive Contours



Apparent Ridges



Shaded View



Contours



Suggestive Contours



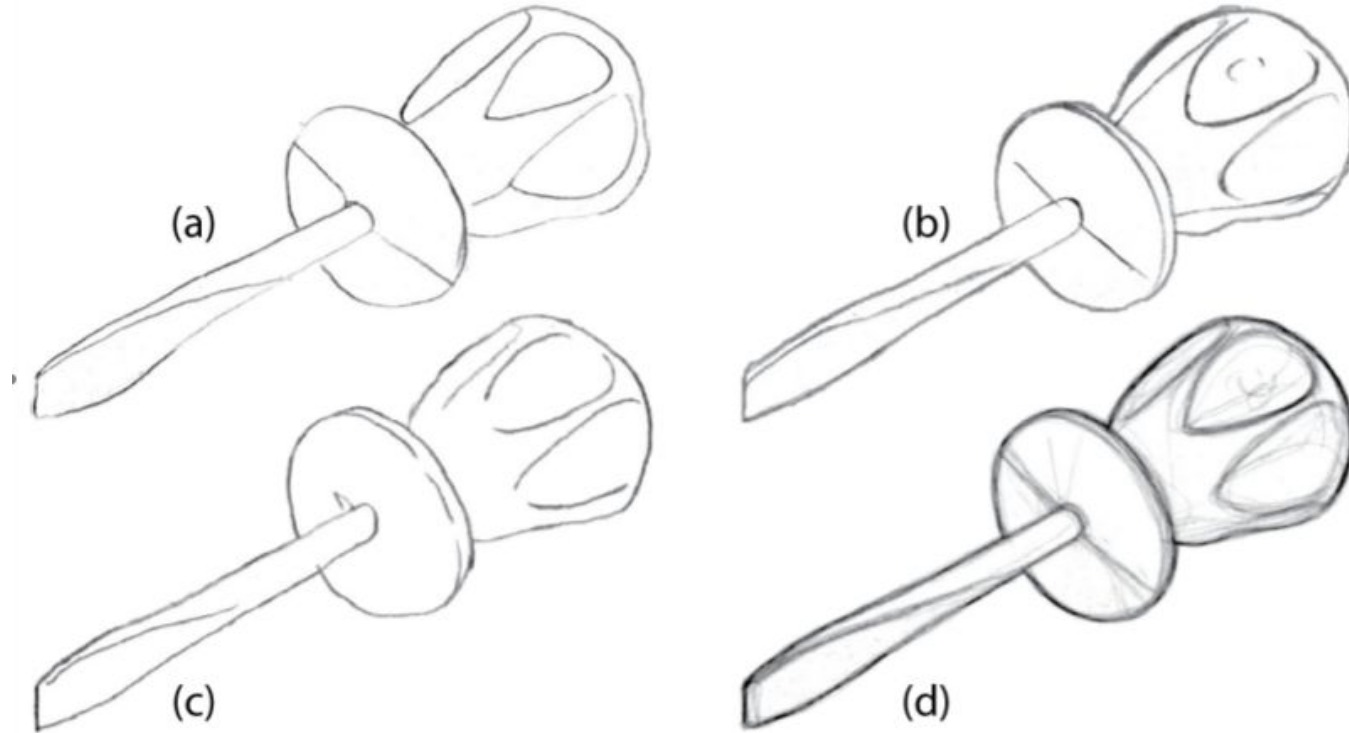
Ridges & Valleys



Apparent Ridges

Apparent Ridges for Line Drawings
Judd, Durand & Adelson, SIGGRAPH 2007

Where Do People Draw Lines?

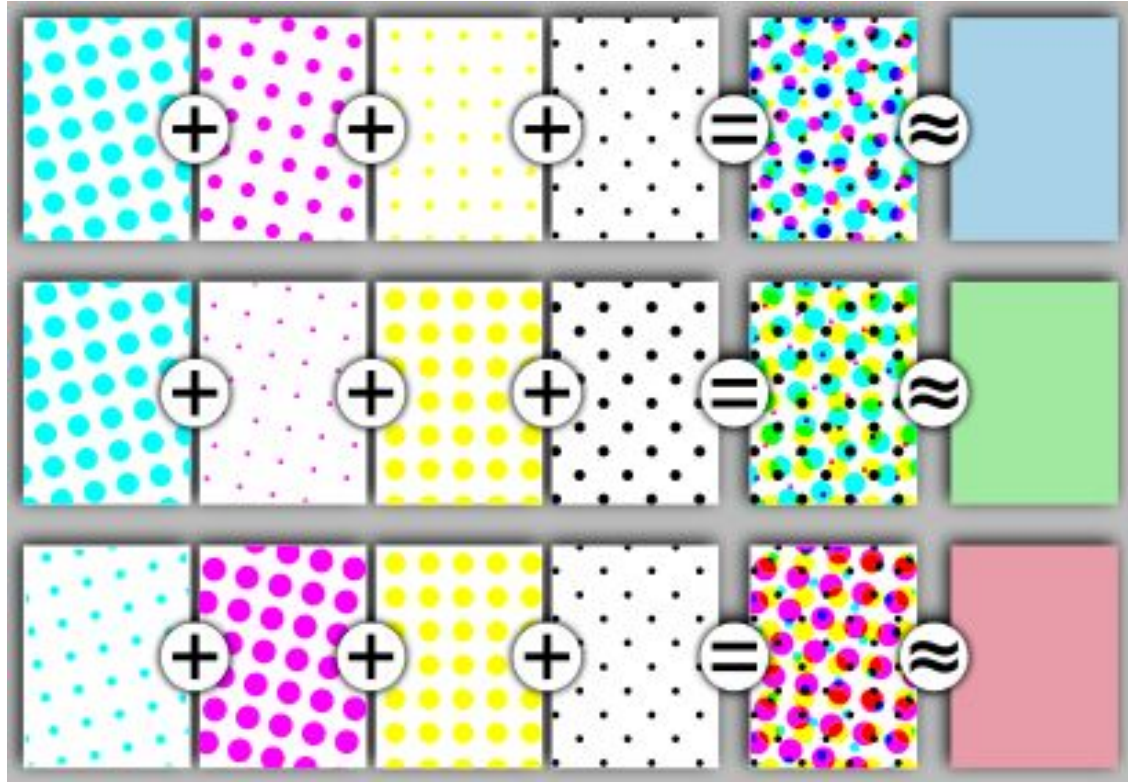
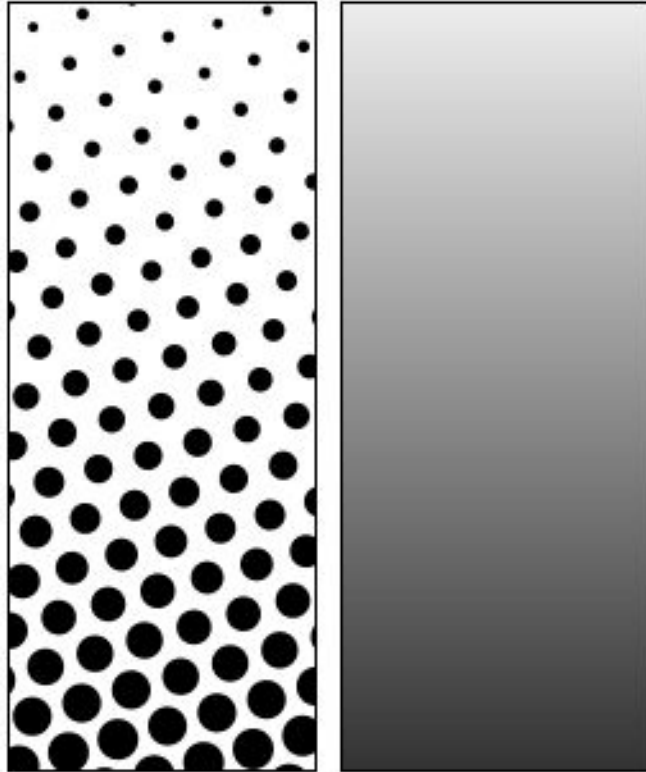


Cole, Golovinskiy, Limpaecher, Stoddart Barros, Finkelstein,
Funkhouser, & Rusinkiewicz, SIGGRAPH 2008

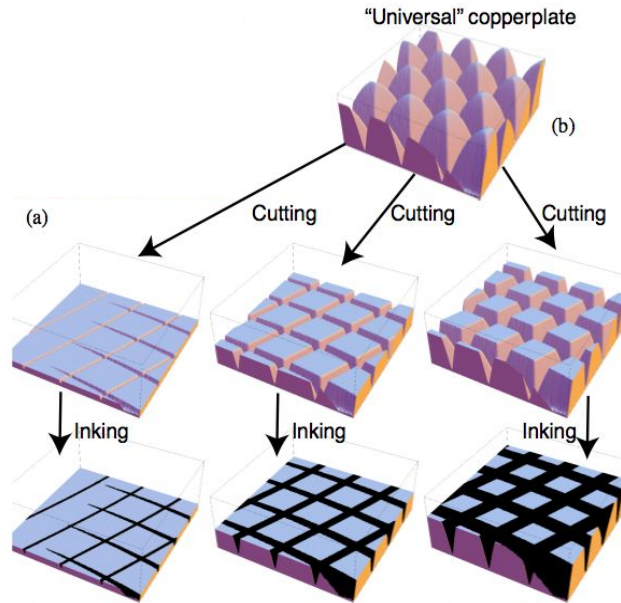
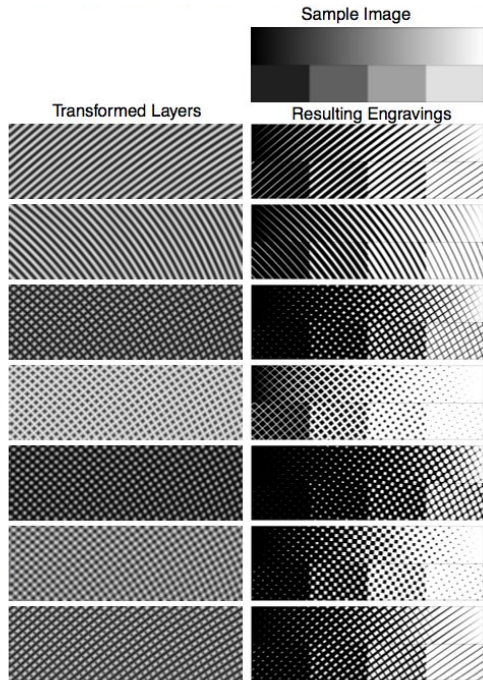
Today

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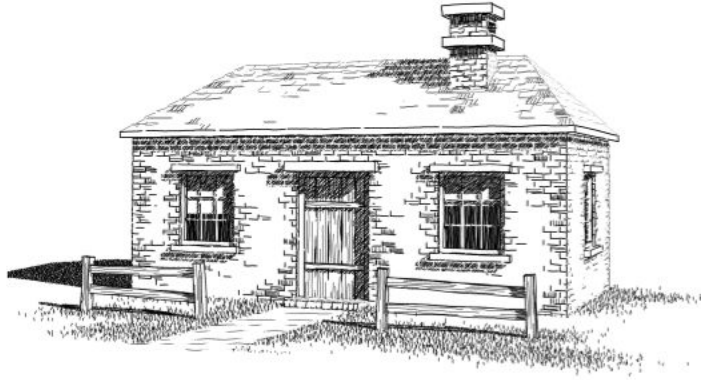
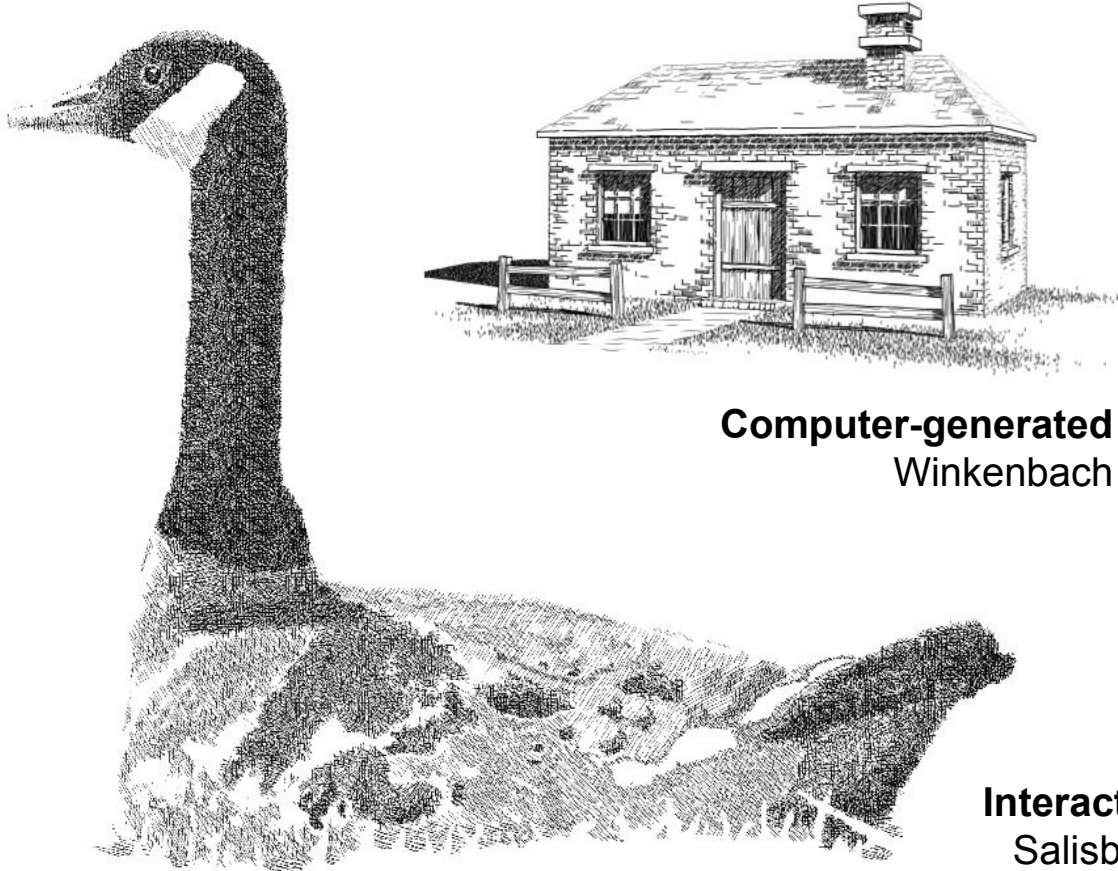
Halftoning



“Digital Facial Engraving”, Ostromoukhov, SIGGRAPH 1999



Pen & Ink Illustration



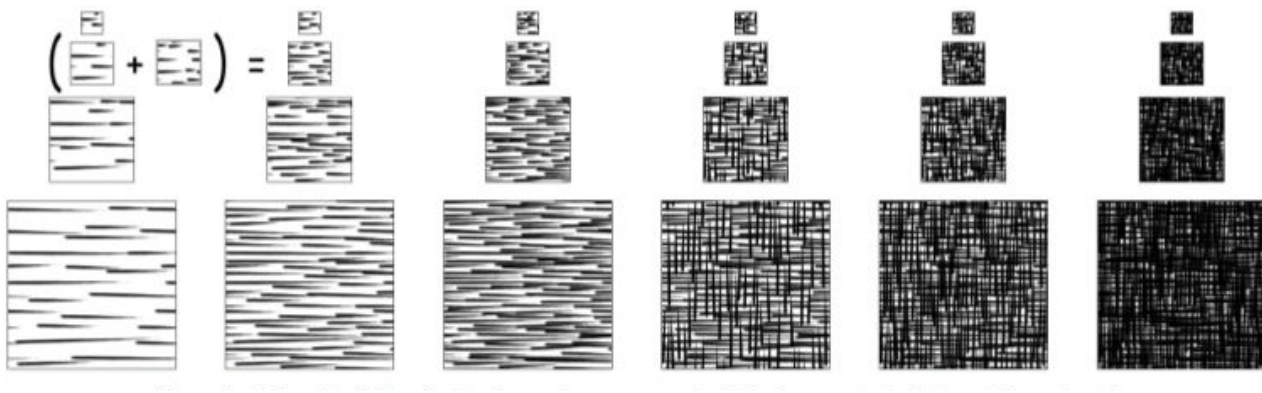
Computer-generated pen-and-ink illustration
Winkenbach & Salesin 1996



Interactive Pen-and-Ink Illustration
Salisbury et al., SIGGRAPH 1994

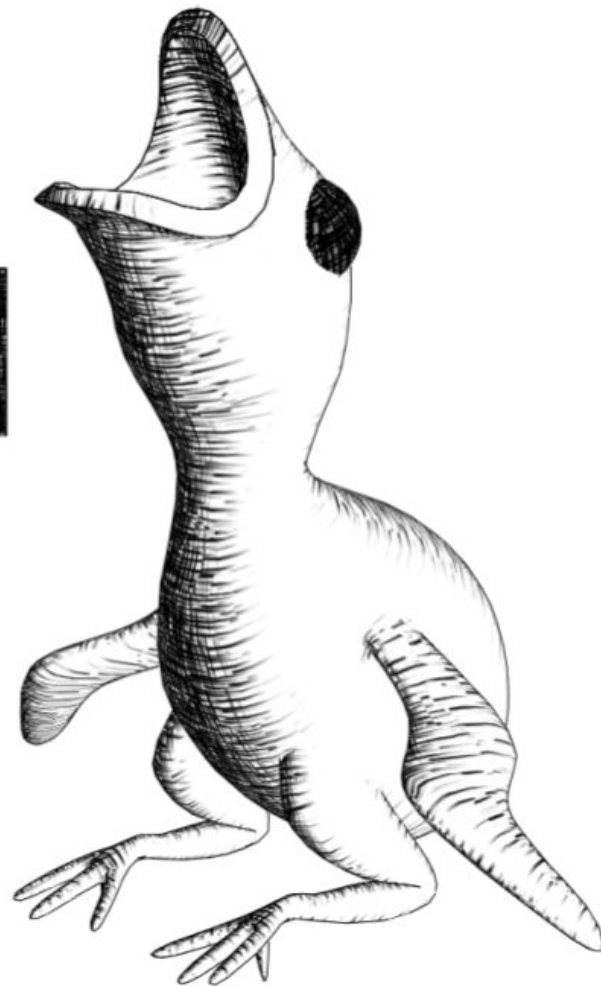
Real-time NPR

- *Before programmable pixel shaders were available:*
 - Create 1D texture map of shading tones
 - Local lighting (normal, view, & light directions) turned into texture coordinate
 - Texture lookup is final color
- Concerns about spatial & temporal coherence
 - Popping: visual elements appear or disappear frame to frame
 - “Shower door” effect: texture slides over the surface of objects rather than sticks to follows translation/zoom of the scene & objects



Real-Time Hatching

Praun, Hoppe, Webb & Finkelstein
SIGGRAPH 2001



Dynamic Solid Textures for Real-Time Coherent Stylization

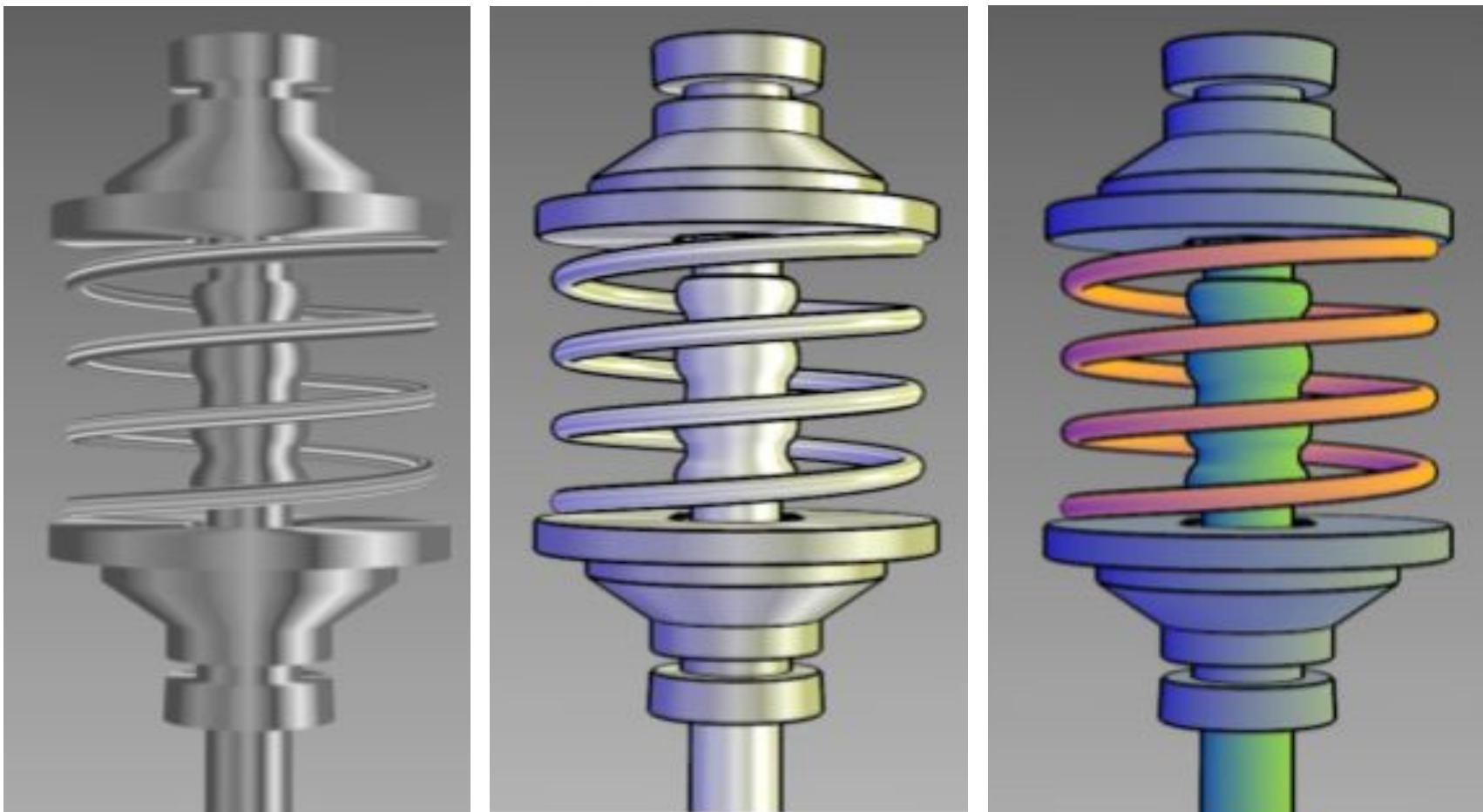
Bénard, Bousseau, and Thollot, I3D 2009



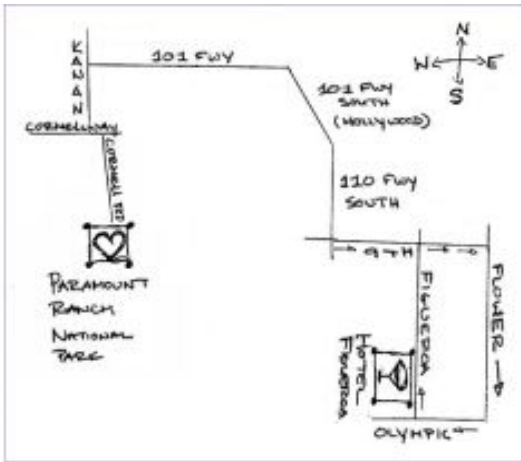
<http://artis.imag.fr/Publications/2009/BBT09/DynSolidTextures.mov>

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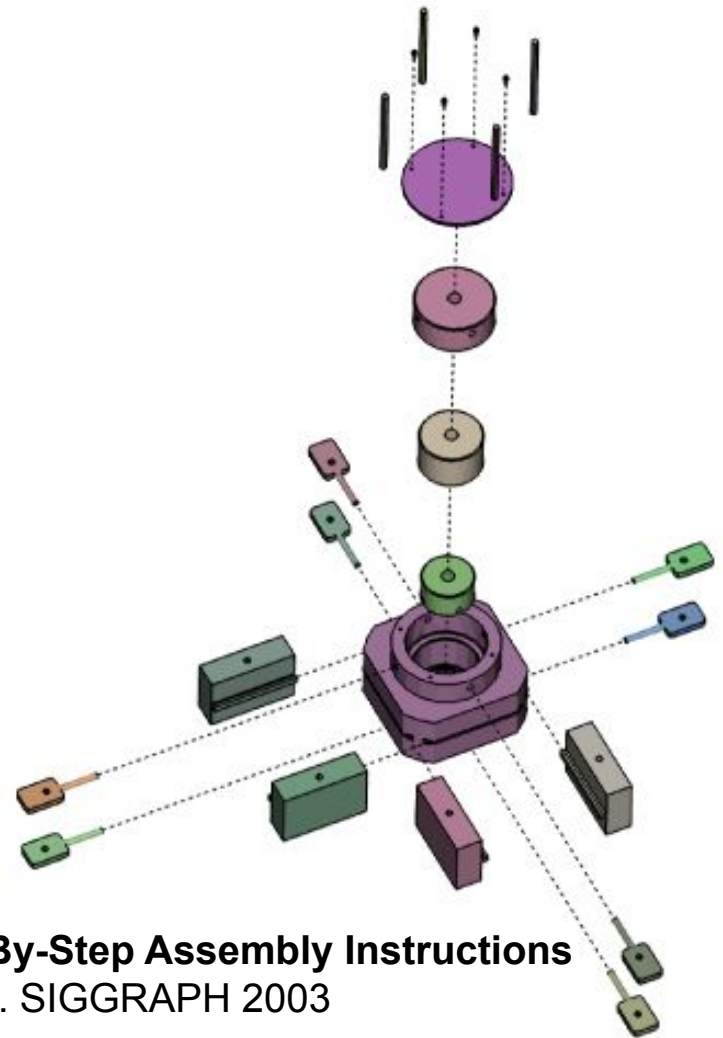


A non-photorealistic lighting model for automatic technical illustration
Gooch, Gooch, Shirley, & Cohen SIGGRAPH 1998



Rendering Effective Route Maps: Improving Usability Through Generalization

Agrawala & Stolte,
SIGGRAPH 2001



Today

- Papers for Today
- Architectural Rendering
- Line Drawing
- Pen & Ink / Hatching
- Technical Illustration
- **Artistic Styles and Painterly Rendering**
- Papers for Next Time



Towards Artistic Minimal Rendering

Rosin & Lai,
NPAR 2010



Artistic Thresholding

Xu & Kaplan,
NPAR 2008



WYSIWYG NPR: Drawing Strokes Directly on 3D Models

Kalnins, Markosian, Meier, Kowalski, Lee, Davidson, Webb, Hughes, & Finkelstein, SIGGRAPH 2002



Painterly rendering with curved brush strokes of multiple sizes
Hertzmann SIGGRAPH 1998

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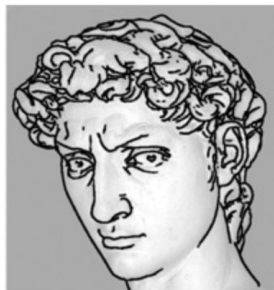
Reading for Next Time: (*pick one*)



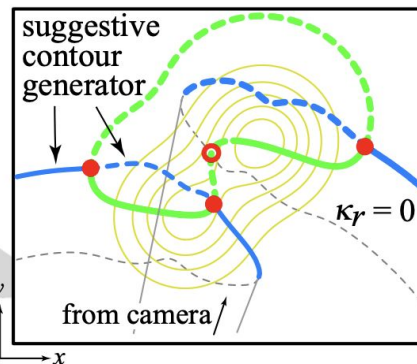
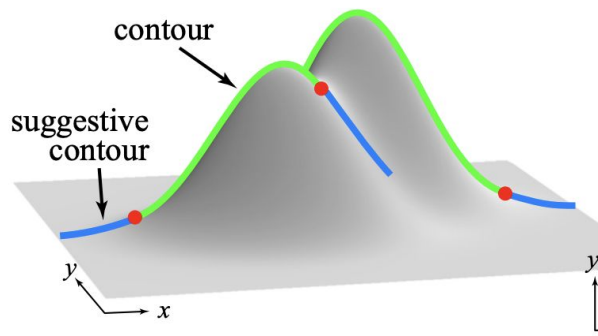
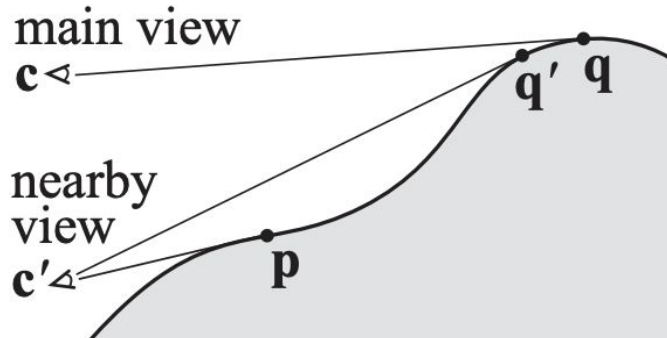
silhouette



contours



**contours and
suggestive contours**



Suggestive Contours for Conveying Shape

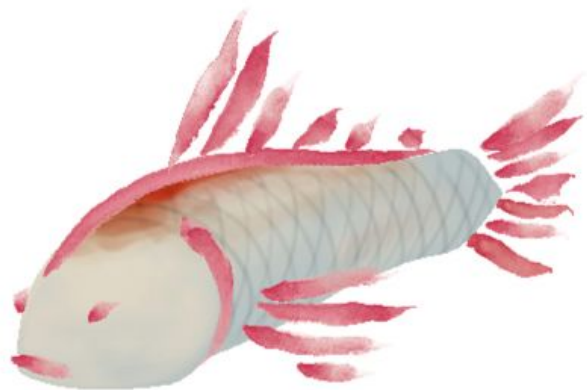
DeCarlo, Finkelstein, Rusinkiewicz, Santella, SIGGRAPH 2003

Reading for Next Time: (*pick one*)



Painterly rendering with curved brush strokes of multiple sizes
Hertzmann SIGGRAPH 1998

Reading for Next Time: *(pick one)*



Example-Based Brushes for Coherent Stylized Renderings

Zheng, Milliez, Gross, and Sumner, NPAR 2017