Fast and Furious: Photolithography

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A short history

Photolithography, as we know it today in printmaking, has many origins. All were invented with speed of production in mind.

It all started with a missed deadline. Alois Senefelder, a trained layer with more love for the theatre than for law, was offered a substantial amount of money for a play, if he could deliver a printed version in time for the Leipzig Easter Fair. He was let down by the print workshop and the play was only delivered to the publisher two weeks after the deadline. Senefelder could just cover his cost. His hope for profit was lost and gave him the idea to open his own printing establishment. Since Senefelder did not have the financial means to set up his own letterpress, he experimented with different printing method until he came across 'chemical printing' by accident [1]:

> *'I had just ground a stone plate smooth in order to treat it with etching fluid and to pursue on it my practice in reverse writing, when my mother asked me to write a laundry list for her. The laundress was waiting, but we could find no paper. My own supply had been used up by pulling proofs. Even the writing-ink was dried up. Without bothering to look for writing materials, I wrote the list hastily on the clean stone, with my prepared stone ink of wax, soap, and lampblack, intending to copy it as soon as paper was supplied.*
> *As I was preparing afterward to wash the writing from the stone, I became curious to see what would happen with writing made thus of prepared ink, if the stone were now etched with aqua fortis.*
> *... I poured a mixture of one part aqua fortis and ten parts of water over the plate and let it stand two inches deep for about five minutes. Then I examined the result and found the writing about one tenth of a line or the thickness of a playing-card in relief. ... Eagerly I began inking in. ... The letters all took the color well…'*

Lithography (from Greek λίθος, a stone, and γράφειν, to write) had been invented.

The ease of production made this printing method attractive to art and commerce. Artists appreciated the shifts of tone that could be achieved like those produced with charcoal, see Figure 1. Commerce appreciated the speed text or musical scores could be produced .

Figure 1: Nocturne: The Thames at Battersea by James McNeill Whistler, 1878. Lithotint with scraping on a prepared half-tint ground, printed in soft gray-black ink on pale blue laid chine mounted on ivory wove plate paper, Source: https://www.metmuseum.org/art/collection/search/337702

With the introduction of colour into the printing process and an increased size of the print bed, lithography revolutionized advertising in the 1880 and 1890, see Figure 2. Almost overnight posters for all kinds of events and entertainments could be printed and distributed.

Figure 2: Title: Moulin Rouge: La Goulue by Henri de Toulouse- Lautrec, 1891, Printer: Affiches Américaines, Charles Lévy (Paris). Lithograph printed in four colors. Source: https://www.metmuseum.org/art/collection/search/333990

The potential of lithography for the distribution of photographic images was realized early. In 1855 A.L. Poitevin had invented photolithography [2] (for an example see Figure 3). He coated a lithographic stone with bichromated albumen. In contact with a negative, the layer was exposed to light. The albumen hardened where the negative was transparent (the shadows of the image) and stayed soft under the opaque areas. The whole area was wiped with a damp cloth and then inked. The ink attached to the hardened areas. After the first inking, the stone was etched and the prints were pulled from the etched stone [3]. The process sped up plate making for image reproduction. Photolithography, the printing from stone in the original sense of 'lithography,' was less successful than photometallography or photozincography, following the same principles for plate making but on the more manageable and lighter zinc plates. Originally developed for the ‘photocopying’ of maps, it became the forerunner of modern photolithography when in 1885 the first practical halftone screen production method was commercialised by Frederick Ives [4], the so called ‘second Ives process’: Two glass plates ruled with opaque lines were sandwiched together at 90 degrees and put in front of a metal plate the image was projected on.

Figure 3: Photolithography by Alphonse-Louis Poitevin. Printer: Lithographie Poitevin, source: *https://www.getty.edu/art/collection/objects/43778/alphonse-louis-poitevin-stone-discs-french-1855-1870/*

Whereas the stone in traditional lithography provides the grain in an image, the metal plate is smooth and a continuous tone photograph has to be broken up into a dot pattern of different densities to represent the tonal range of the original. In [5] Wilkinson describes the state of the art technology in 1897 of photo-zincography, photo-lithography and collotype, from the preparation of the negatives, via the preparation of the screen to the preparation of the plates. An appraisal of the collodion halftone screen, another method to generate the dot pattern, can be found in [6].

VIEW OF PART OF BOLTON ABBEY.

[Made with a Levy Screen upon an ordinary Gem Dry Plate, developed with Pyro Soda.]

Figure 4: Example from [5].. The Levy Screen was the first high quality halftone screen produced and sold by Max Levy & Co.[7], based on Ives's ruled glass screens.

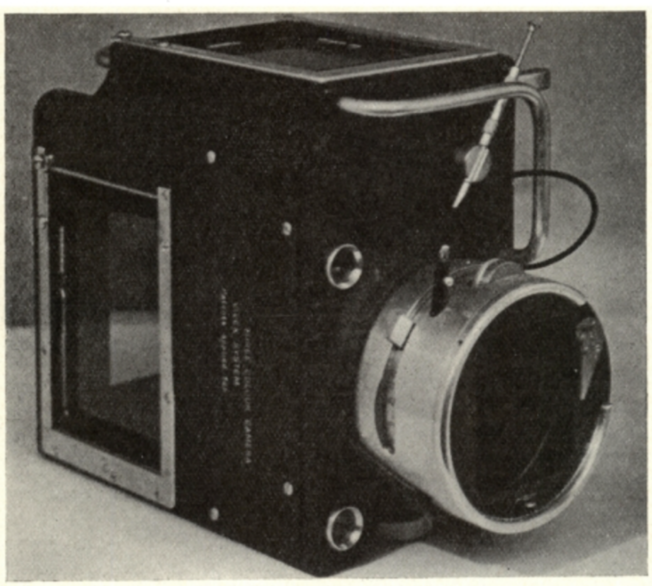
The next increase in printing speed was the invention of the offset press where the image is transferred from the plate to a blanket and then to the substrate. First used in 1875 for printing on metal, it was adapted to print on paper by Ira Rubel, a paper manufacturer in New Jersey in about 1905 [8]. The advent of the today's pre-sensitized plates, developed by 3M in 1951 [9] and further developed by Fuji for example [10], make photolithography one of the fastest and most cost-effective printing processes for archivable images. Because of that, it is widely used in commercial printing, and, at the same time, it gives the practitioner the freedom to experiment. The way in which halftone is generated, the dot size and its shape can be used to create a variety of effects in the printed image influencing the tonal range and colour reproduction.

Our practice

Analogue black and white negatives taken through red, green and blue filters are the basis of our printmaking practice. With this approach we return to James Clerk Maxwell's trichromatic colour theory and its application to the then newly invented photography (that it did not happen how it is now widely reported is the topic of another paper). In [11] Maxwell describes his work as:

> *'Let a plate of red glass be placed before the camera, and an impression taken. The positive of this will be transparent wherever the red light has been abundant in the landscape, and opaque where it has been wanting. Let it now be put in a magic lantern, along with the red glass, and a red picture will be thrown on the screen.*
> *Let this operation be repeated with a green and a violet glass, and, by means of three magic lanterns, let the three images be superimposed on the screen. The colour of any point on the screen will then depend on that of the corresponding point of the landscape; and, by property adjusting the intensities of the lights, etc., a complete copy of the landscape, as far as visible colour is concerned, will be thrown on the screen.'*

The method is very slow. We do not own any of the old fashioned three colour cameras, like the ones built for the Vivex process [12], see Figure 5, where the three images were recorded in one shot, but use an analogue camera with panchromatic film and red, green and blue Lee filters. Colour is recorded as greyscale. The recording on black on white silver halide film and the knowledge of the spectra of the filters makes the colour completely archivable. It gives the practioner the freedom to change the colour in unusual ways or to reproduce just one of the images as a black and white image. The reproduction method of our choice is photolithography. Maybe, but only maybe, the range of grey levels is inferior to photogravure, but the speed of plate making and printing compensates for it.



A *typical one-shot camera (Vivex) making all three negatives at one exposure.*

Figure 5: Vivex camera from [14]

The influence of halftone on contrast and colour

According to The New Shorter Oxford English Dictionary halftone is defined as '*an image, produced by photographic or electronic means, in which an effect of continuous tone is simulated by dots of various sizes or lines of various thicknesses*'.

At the back of our eyes is a layer of detectors, separate cells for black and white and colour on which the image we see is projected through the lens system of our eyes. The different signals are then merged in the brain to form a colour image. The detail we can see is a function of the quality of the lens system in our eye and the cell size of the detectors. The angular resolution of the human eye is about 1 arcminute [13] which means that the human observer can see the difference between two lines separated by 30 cm at a distance of 1 km, equivalent to 0.09 lines per inch (lpi), or 0.12 mm at a viewing distance of 40 cm, equivalent to about 210 lpi. Anything closer together will be seen as one. This is exploited by halftoning.

The viewing distance is coupled to the size of the image. As an example, we base the following calculations on the central visual field which is about 30º [14]. Within the central visual field, the whole image can be seen clearly without eye movement. Of course, image content outside of the central field of view is easily explored by head and eye movement. The two limiting cases for comfortable observation are when the observer is either so far away from the image that the detail in the image is blurred because it is outside of the resolution of the eye, or the observer is so close that parts of the image are spatially distorted. A classic example for the second case is a seat at the edge of the front row in a cinema. To place an image with the dimensions of 10 cm by 10 cm into the central visual field it should be about 19 cm from the eyes. An image of 100 cm by 100 cm should be at 3.7 m from the observer. In the first case, the image should be printed with at least 427 lpi, whereas in the second case 47 lpi are sufficient to generate the illusion of a continuous grayscale and display detail which can be resolved by the human eye. 47 lpi are not really a problem, but 427 lpi are. For hand printed photolithography anything more than 150 lpi causes problems:

1.) Plates with more than 150 lpi are easily over-inked. Constant quality is difficult to achieve, and grayscale is lost when ink builds up on the plate.
2.) Even though finer detail can be captured by a higher lpi, it is not necessarily visible since finer halftone dots hold less ink. The lighter areas have a tendency to lose tonal definition and appear simply white because the small and spaced dots do not hold the ink since the water film on top of them does not rip. The darker areas lose tonal definition because the dense population of hydrophobic dots makes the water film between them rip and disappear. A kind of bleeding occurs.


Figure 6: Golden gate, lithograph

Figure 6 is an example where grayscale in the shadows is lost. As pre-press lithographic film we used Arista Ortho Litho 3.0, a high-contrast film, characterized by a very steep gradation and gradation tone, along with a wide density range with high Dmax and low Dmin values for enhanced UV transmission. We developed in diluted black and white developer to soften the contrast as recommended for continuous tone. As screen we used technical nylon cheesecloth which produced a screen of 300 lpi. The cloth generates a random pattern since it is soft. The print is 15 cm x 15 cm. The resolution of the detail is excellent, the nylon cheesecloth gives the print a soft quality, but the plate is easily over-inked.

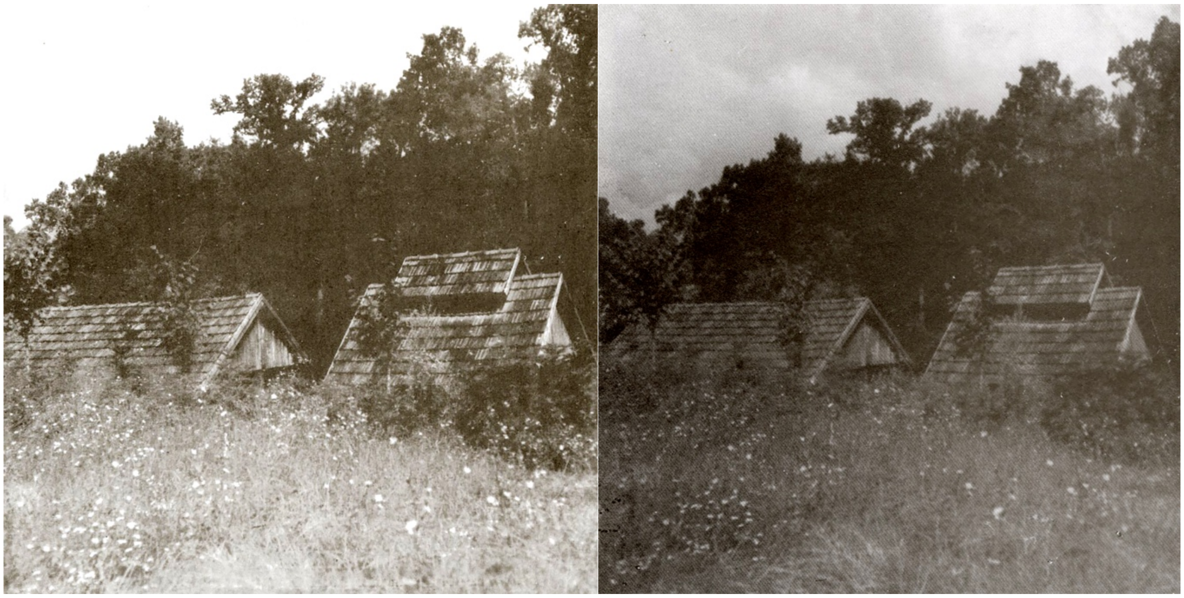


Figure 7: On the left side, the film for the litho plate was prepared with nylon cheesecloth, on the right side with a Kodak contact screen of 150 lpi. Fishing hut, 9cm x 9cm

Figure 7 is an example how the contrast is changed when the lpi is changed from 300 lpi to 150 lpi. The print is with 9cm x 9cm relatively small. The halftone dots are fused in the eye when the screen has at least 427 lpi. We have printed with 300 lpi. The dot pattern is not detectable. The contrast is hard, and detail is lost most noticeable in the sky. 150 lpi generate a much softer contrast. The cloud structure in the sky becomes visible and there is more detail in the trees as well. The dot pattern is visible and give the image a newspaper look. Printing smaller formats with smaller lpi recovers the grayscale but blurs the picture.
Even photographic film is not necessarily continuous tone. High speed films, for example Ilford Delta 3200, become very grainy at low lighting conditions and the image can be transferred directly, without further halftoning, to the printing plate which has the advantage that all detail recorded is transferred to the plate.

Figure 8: Heimat 1, full colour lithograph, no screen

Figure 8 is an example of a full colour lithograph without screen. The halftone is the result of the grain of the film. The image was recorded in winter on Ilford Delta 3200, recorded though red, green and blue filters. The exposure was measured with a Gossen Profisix light meter through the filters. The film was developed with Rodinal 1+25. Because of the low lighting levels, the developed film became very grainy, grainy enough to make lithographic plates without any additional screen. The negatives were simply enlarged onto Arista Ortho Litho 3.0, brought into contact with the litho plate and exposed to UV light. The positive recorded through the blue filter was printed as the first with Van Son PrimeBio Process Yellow ink. The second layer was the positive recorded through the green filter and printed with Van Son PrimBio Process Magenta ink, and the third layer was the image recorded through the red filter, printed with Van Son PrimeBio Process Cyan. We do not print a black layer, since we match the spectra of the filters to the printing inks. Black is generated by the overprinting of yellow, magenta and cyan.
When the sun is shining, the results look different.

Figure 9:: Dragon Tree in Icod de los vinos, left side lithograph without screen, right side lithograph with 133 lpi screen.Both prints 20 cm x 20 cm.

On the left-hand side of Figure 9 the film used was Kodak Tri-X 400, on the right Arista EDU Ultra 100. Both films were developed with Rodinal 1+25. The Kodak Tri-X 400 was grainy enough to make the plate without a screen. The grain was much finer than in Figure 8 which has the same result as in Figure 7: the contrast was hardened. Even though the rgb negatives have the same density, the high colour temperature of the light at the time of recording, leads to more detail on the negative recorded through the blue filter and therefore to a yellow shift in the print. On the right-hand side of Figure 9 the negatives were recorded on a fine grained 100 ASA Fomapan film and we used a 133 lpi Kodak contact screen. The result is a much more realistic colour reproduction. Since we are not after a truthful colour reproduction, we can achieve that or come close to it with the digital cameras in our mobile phones, halftone is a welcome tool to change colour and contrast in the prints and achieve surprising results.

Figure 10: St Pauls carnival dancer, Photoshop separations.

I will get a better scan of this image asap

Figure 10 is of a full-colour lithograph created using an image taken on colour negative film. The image was taken on Fujifilm Superia X-Tra - 35mm Film and developed using Cinestil Cs41 chemicals. For this image we used the same separation theory used by Maxwell, however, we used Photoshop to separate the colour channels retrospectively instead of manually using the Lee RGB filters.

The negative was scanned using an Epson Perfection v600 at 1200 DPI. It was then imported into Photoshop where the image was resized to 17x 27cm, and the colour mode set to RGB. We then made three new blank documents, one saved as R, G and B, using the same dimensions, mode and DPI. Using the channels function we copied and pasted the R, G and B channel information separately over to their respective blank documents. When doing this it's vital to not mix up which channel is which, doing so would result in a large colour shift with the tone and contrast of the image being incorrect.

Once the separations are made we must create the halftone, this was also done digitally using Photoshop's Bitmap function. For this image, the DPI was 1200 and the LPI was 80 with the dot shape being an Ellipse. To print photolithography, the screen angle of the halftone dot for each colour separation must be at least 30 degrees from one another to ensure there is no Moire. The optimal degree of seperation is 45. When the correct screen angles are used the three colours create a rosette pattern that is easy for the eye to understand. For this image, we used B =15 degrees, G=75 degrees, R=45 degrees. The image mode was then changed into greyscale and the DPI reduced to 300. If the DPI is reduced whilst still in Bitmap mode the halftone is compressed and distorted. If the DPI isn't reduced from 1200 the printer will not be able to print it without compression and banding. The files must then be saved in TIFF format so no information is lost. We then printed each layer onto inkjet transparency film using black inject ink. These are then used to expose the aluminium plates with the UV lightbox. This image was printed using the Vansom process colours with B=Y, G=M and R=C. Printing in this order ensures our contrast and colour balance are correct.

Figure 11, Amber, Merck Spectraval Red, Green and Blue, Black Plike 100 LPI, 15,60,105 degrees, ellipse. Image taken on Iphone 12 pro

Will get better scan instead this is just a place holder.

The cornerstone of lithography is the chemical reaction between the oleophilic image area of the plate and the oleophobic gummed non-image area. For this reason, the inks we print with must be oil-based. However, we are not limited to only printing using industry-standard CMYK inks. This process easily allows us to use a large variety of inks many of which we mix up ourselves using pigments and linseed oil.

Figure 11 shows a photolithograph that was printed using Merck's Spectraval pearl effect pigment in red, green and blue. The image was taken digitally, then separated and halftoned on photoshop. To achieve contrast, we first print the red, then green then blue. Merck Spectraval pigments are a key area of interest to us as these mica pigments have been optimised for the RGB print processes. These pigments broaden the illustratable colour space by using additive RGB colour as opposed to subtractive CMY colour. Spectraval pigments lend themselves well to both offset and direct lithographic hand printing. To achieve satisfactory prints we have found that they must be printed at extremely high pressure and then overprinted due to their narrow viewing angle. It is also essential they are printed onto dark, highly calendared paper stock. For Figure 11 we used Plike by GF. Smith, this matt paper has a plastic-like smooth feel which lends itself perfectly to printing these unique pigments. Thanks to the small molecule size of the Spectraval pigments we are able us to print fine halftones. Figure 11 was printed at 100 LPI, we could print a finer LPI, however as when hand printing with standard inks, the plate would easily over ink and our grayscale would be compromised. Merck struggle to print their Spectraval pigments on industrial offset presses, however, thanks to our handprint techniques we are able to produce highly detailed, multicoloured prints without problem using both direct and offset lithography.

Accurate registration is of course essential to create correct photolithographs. Once we have created the transparencies, we must ensure the separations are correctly lined up. We then register them on the UV box before exposing them onto the plate. Once the images are in the correct place on the plate, we must keep the plate and paper in the same place on the press to keep our registration true. Unlike with other print processes such as screen-print we cannot move the plate around once it is inked up as the plate is stuck down to the press. With commercial offset printing they use the same technique of registering the image to the plate, however, industrial presses use a lay system to move the plates from side to side once they are loaded in. This ensures each sheet enters the machine in the same position hence each sheet is in register. As we hand print our lithographs, we don't have this luxury, therefore must use a pin or jig system to ensure each plate and piece of paper is put down in the same position.
Any misregistration is obvious with photolithographs, this is particularly true for images of people, facial features such as eyes make even the slightest misregistration incredibly prominent. Another reason it is essential to keep the registration accurate is to keep the halftones for each colour separation at in the correct position. Wrongly placed the screen angle may change which could cause Moiré.

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