Line thickness, a means of expression

By varying the thickness of lines and outlines as we draw, we give flat sheets of paper a meaningful third dimension

Conrad Taylor

The more I think about how drawings work, the more I believe they can give us insight into those marvellous abilities which the cognitive psychologist Donald Hoffman calls 'Visual Intelligence', in his book of the same name. ¹

Drawings can distill images of objects into a relatively small number of simple lines. In doing so, they echo the way our brains simplify and interpret the mass of raw visual data that arrives every second at our retinas. Hoffman’s book, with its dozens of visual illusions and experiments, demonstrates that an understanding of how we interpret drawings has been one of the major sources of evidence for scientists who study how human vision works.

As an illustrator and information designer, I also have a practical concern. I want to know the best way to make a drawing so that the viewer understands clearly what they are looking at. For the last 15 years, I’ve also wanted to know how to do this with computer illustration tools, as well as the brushes and pens I grew up with. That is my subject in this article.

Those important things that aren’t really there

The line is the primordial resource of the illustrator – the cartoonist, the cave painter, the technical illustrator, the child.

Lines are often used to represent the edges of objects when we draw them. But edges can be mysterious things. Consider this digital photograph of a common kitchen implement, the ‘business end’ of a hand-held blender (figure 1):

Figure 1
A photograph of a kitchen blender, and an enlargement showing a part that we interpret as an edge.
This object has a number of parts that we would interpret as ‘edges’. For example I would call the part that label A is pointing to an ‘edge’, and if I were asked to draw a picture of the blender I would make a nice firm line to represent it.

But wait a moment – wouldn’t I be drawing something that doesn’t actually exist? If I try to rotate that ‘edge’ to face the camera, only unmarked plastic comes into view; a new edge is perpetually created as a round object turns. Edges like this are optical effects, artefacts of how our line of sight intersects with the object. But though such edges may be illusions, our perception (or invention?) of them is essential in helping us to make sense of what we are looking at. They have a psychological and practical reality.

What do our eyes actually see? Look at the enlarged detail of that part of the digital photograph. This fuzzy mess of pixels is not so different from the raw input to our visual system that comes from the rod and cone cells in the retina. But those signals go off to the parts of our brain that process vision, and with a speed and sophistication that would put a supercomputer to shame we come effortlessly to conclusions about the shape of the world that surrounds us. Nor is this ability uniquely human. Visual intelligence has been around in advanced form for tens of millions of years. Ask a velociraptor.

But only people run the trick in reverse, and draw lines to represent those objects to other people.

Seven different uses for lines in drawings

1. The kind of edge we’ve just been examining – the ‘silhouette profile’ as it has been called, or ‘outline’ – is perhaps the most significant aspect of a scene that an illustrator will use a line to depict. The key fact about such an edge is, I believe, that it marks a focal discontinuity (a difference in the distance from the observer) between what is seen on either side of such a line.

2. Where two surfaces meet, and one surface is visible while the other is ‘tucked behind’, we draw a line along that edge. This can be considered an ‘internal outline’ because there a focal discontinuity is also present, even though it may be small.

3. Where two visible surfaces meet at an angle rather than in a curve, it is usual to draw a line to show where they meet.

4. If a line has been drawn or marked on the surface of the object, we would reproduce that with a line in the drawing too.

5. Adjacent areas with differing colours in the original may be separated with a borderline, if the drawing must be in pure black and white. Even in coloured drawings, colour edges are often emphasised this way.

6. Lines may be added to indicate grain or texture, to give a believable image of hair or feathers, wood or fabric.

7. Lines have also long been used as a form of tonal shading, as in hatching and cross-hatching.
Line thickness as a signifier

Illustrators routinely use different thicknesses of line to distinguish these different line ‘meanings’, and there is evidence that users find this vocabulary of line thickness helpful, as I shall explain. Let us take our blender as an example (see Fig. 2). In the version on the left, all lines are the same thickness. The version on the right is enhanced with a vocabulary of three different line weights.

![Figure 2 — a varied repertoire of line thicknesses, and how they can distinguish between different kinds of line meaning.](image)

- **Line A** is a clear example of an outline (Type 1 line), and I have given it the heaviest line weight.
- **Line B** shows where two visible surfaces meet at an angle (Type 3), and I have given it the lightest weight.
- **Line C**, although it is within the overall shape of the object, still counts as a Type 1 outline to me because it lies on the edge of a hole through which we are able to see the background. So I have given it the heaviest line weight as well.
- **Line D** bounds another hole in the object, but the gap behind it is not so deep, so I am counting it as a Type 2 ‘internal outline’ and have given it an intermediate line weight.
- **Line E** is problematic. On the nearside of the object, it represents a Type 2 edge between a visible and an invisible surface. But if we follow the line round, on the far side it becomes an edge between visible surfaces. I have chosen to mark it with the thinnest line weight on the far side, and a thicker line weight on the near side. (But I don’t like the abrupt changeover between the two line weights. I shall return to this issue later.)
- **Line F**, if you compare it with the source photograph, shows where change in the shape of the blender’s metal blade causes differently-toned reflections. Although these lines aren’t all well-defined Type 3 angles between visible surfaces, I have drawn lines anyway. I am treating these boundaries a bit like Type 5 changes of colour.
Evidence that it’s worth using varied line weights

I recently gave a presentation about varying line weights in drawings and technical illustrations, at an informal workshop in London on ‘explanatory and instructional graphics’. Professor Clive Richards, who is Director of Research at Coventry School of Art and Design, pointed me towards some interesting experimental evidence that the illustrator’s established practice of using different line weights for different kinds of lines actually does help people make sense of complicated drawings.

At Coventry, the design school has close associations with the automotive and aerospace industries – both industries which rely on drawings for concept development and internal communication. Aircraft maintenance documentation is still overwhelmingly paper-based and line drawings are the preferred method of illustration. As a paper presented at the SIGDOC conference in Toronto in 2002, a group of Coventry researchers explained:

The documentation for the Airbus A3xx series of airliners contains 369,588 separate technical illustrations. The majority of these are line illustrations as opposed to photographs. Most of the time, photographs, even if they are available, are unacceptable as technical illustrations because they generally convey too much information. Photography cannot disregard details as it represents real-life objects and even though photographs can be post-processed to remove unwanted detail, line diagrams are usually regarded as superior. It should also be noted that often technical illustrations are made before the components they depict are manufactured; in which case, photography is not an option.

Airbus technical illustrations are usually prepared by illustrators at their publications centre in Toulouse, mostly individually and carefully by hand. But at Coventry School of Art and Design, Nicolas Bussard and others have been experimenting with software (known as the ‘shape line viewer’) which converts 3-D data from CAD databases into 2-D line drawings which are comprehensible to those who view them.

In testing how best to configure the displays produced by this software, Bussard and his colleagues tested different presentation styles on volunteer experimental subjects. They showed participants a variety of potentially ambiguous shapes using the viewer software, and asked questions to test if they understood the shapes correctly. One quite clear conclusion they found is that drawings using two line weights, according to a set of rules similar to those I’ve applied above, are clearly easier to understand than drawings with a single weight only.
Further improvements

You are probably getting quite tired of this blender by now, but I shall use it one last time to illustrate how the drawing can be made still easier to understand, and also I dare say more attractive.

Adding a simple toned or coloured background gives extra emphasis to the object outlines, and shows where there are holes through which we can see the background. The Coventry researchers found that such backgrounds are very useful in helping viewers understand drawings.

The detailed image in 3a shows a ‘broken line’ treatment given to the bends on the surface of the metal blade. This is a common trick used by illustrators. It de-emphasises the line without making it so thin as to be incapable of reproduction in print, and also hints that the line isn’t ‘structural’, more a matter of surface texture.

Line C which previously bothered me because the thick part where it indicated the boundary of a hidden surface turned abruptly into a thin line at the back where both surfaces are visible, has now been modified so that the line thicknesses continuously taper from thick at the front to thin at the back.

Similarly, the abrupt change which formerly broke the line pointed to by label B in the main diagram into a thick part and a thin part has been softened by making the line weight taper between the two thicknesses. Because this tapering happens over a short distance, I have added the detailed view 3b so you can see the tapering more clearly.

In adding the labels to the main diagram in Figure 3, I also made sure that you wouldn’t confuse the label lines with the drawing itself by placing a white rim around each label line.
Drawings created in this style and to this standard are easy to understand and cheap to reproduce in print, so they are highly suitable for user instructions, assembly guides for equipment or furniture, maintenance documentation, training materials, technical product catalogues and dozens of other uses.

**Can you do these tricks with a mouse?**

I have been using this drawing style for decades. My early drawing tools were quite traditional. As a teenager, I had a well-cared-for set of tube-nibbed steel drawing pens (Rotring and Faber-Castell), with precisely-graded line thicknesses of 0.13mm, 0.25mm, 0.35mm, 0.5mm and 0.7mm. I also use fibre-tipped pens and sable brushes, which can create lines that vary in thickness along their length – for example, to make a tapered line.

In 1987 I discovered Adobe Illustrator, and immediately appreciated the way in which the Bézier curves produced by its Pen tool could be fitted to many of the shapes which an illustrator, especially a technical or medical illustrator, is required to draw. Having spent weeks adding adhesive-backed shading films to maps and diagrams (products like Letratone and Normatone), I also appreciated the ability to give areas a shaded fill. The convenience of being able to include illustrations in publications without scanning them was an obvious advantage, and the smooth tones and sharp edges that such illustrations produced in a PostScript publishing environment is a great source of satisfaction.

But Illustrator and similar drawing tools have their drawbacks, and using varying line thicknesses is one of them. It’s not that there’s any difficulty in varying the thickness of any line you draw in Illustrator – but each line has the same invarying thickness along its entire path. That’s a problem for which I have had to develop ‘work-arounds’.

**The duplicated-outline trick**

The most common problem I have to deal with is the need to make an external object outline thicker. An example of this is shown in Figure 4, which I drew as part of a network diagram in 1988. I have shown it twice – the larger version which lets you see the details easier may strike you as having an absurdly thick outline, but the smaller version is very close to the actual reproduced size and I think you’ll agree that the outline thickness is justified.

(Just because Illustrator and similar programs produce ‘resolution-independent’ artwork, it doesn’t mean you can use your drawings at all sizes without adjustment. The human eye requires that lines be strengthened and detail reduced for drawings printed at a small size.)

An Illustrator drawing like this is typically made up of a large stack of objects, each one having a **path** around it and a **fill** within. The path around an object has to have a uniform line thickness. Consider the shape which constitutes the left side of the monitor casing. We want it to appear to have a thicker line on the top, left and part of the bottom of that shape – but not on the other two line segments.
The solution was to select all of those objects which run out to the edge of the monitor, copy them, and paste them behind all of the objects which make up the monitor. These extra objects on the back layer can then be given a thicker outline, which shows only on the outside of the monitor because the inner parts of the thick outline are masked by the opaque objects in front (see figure 5).

The same trick, incidentally, can be used to give a satisfactory outline to type (see Figure 6).

A: Paths thickened – invasion of the interior of the letters looks ugly and destroys the integrity of the letterforms.

B: Two-layer solution – the front layer preserves the letterforms and a thick-outline version is pasted behind.
In Illustrator’s early days, these multi-layered outlining operations were hard to do; making adjustments to the widths of hidden lines afterwards was especially tricky. But once Layers were introduced as a way of organising vertical stacks of illustration components, it became much easier to handle this kind of illustration. (See Figures 7–11).

**Figure 7 (left)** – when the country shapes are placed against the light cyan shading of the sea, the low contrast between the colours means that the coastlines are under-defined.

**Figure 8 (below)** – The country shapes were duplicated to a new layer, and many surplus paths inland were deleted to reduce filesize and printing times. The coastline was defined by giving these paths a thin, dark blue stroke. Then the whole set was duplicated again to a new layer further down in the stack, and a wider, paler stroke was given to this second coastal layer.

**Figure 9 (above)** – This detail of Java better shows the two coastal lines layered on top of each other, minus the land colouring which is to lie on top of them.

**Figure 10 (left)** – The completed stack of country shapes & shorelines gives a satisfactory definition of the coasts. Because the shoreline-thickening happens only on the ‘sea’ side, the definition of the coastline edges is not blurred or rounded off.
Outlines inside – what to do when objects have holes in them

Working in a program like Illustrator, how do you effectively draw objects – and give them thick reinforcing outlines – when they have one or more holes through them? The answer is another piece of PostScript trickery called compound paths.

Compound paths were developed early in the history of the PostScript page description language to solve a problem in how some letterforms are rendered in a PostScript imaging system. Consider, for example, the word ‘London’ in Figure 6. The letter o could be thought of as a black elliptical shape with a white elliptical shape inside it. But what a disaster that would be if you wanted to set it against a tinted or a coloured background! (Figure 12):

Figure 11 – The screen dump from Illustrator shows how the file is organised into six layers – a light blue for the sea, two layers of shoreline, then the country shapes, then borders and capital cities.

All the elements that make up a single nation are grouped (here, it is Indonesia that is selected). This makes it easy to change country colours e.g. for statistical presentations. Where country borders touch, one has been made by duplicating the path of the other so that the ‘jigsaw’ fits together precisely!

Figure 12 — If the internal shapes of letters o and d were rendered opaquely, they might look like this on a coloured background.
And so the idea of compound paths was invented. A compound path may include *sub-paths* that lie inside the external path. In Illustrator, you can select two or more paths that are arranged this way, and convert them (via the Object menu) into a compound path. You should then see a hole punched through the compound object where the inner path was drawn. Sometimes it doesn’t quite work like you expected, and that’s when you need to trouble-shoot the illustration by adjusting the path directions.

Not many people know that PostScript paths have a direction. Most of the time it doesn’t matter. But Illustrator relies on what PostScript programmers call the ‘non-zero winding order rule’ to make masks and compound paths hide the bits we want them to. Essentially, for our purposes, the rule means that the sub-path on the inside must have the opposite ‘winding direction’ from that on the outside. Illustrator provides an Attributes palette to adjust this direction (see figure 13).

![Figure 13](image13.png) — How the path directions affect the rendered appearance of a compound path. (Arrows have been added to show the direction of the paths.)

(Though every PostScript path has a direction, Illustrator doesn’t bother to make the direction buttons in this palette active unless you have selected one of the sub-paths within a compound path.)

The three back layers of the completed blender illustration in Figure 3 use this trick, and are shown ‘deconstructed’ in Figure 14: (a) a white shape defined as a compound path, so we can look through the holes in it; (b) a copy of that white shape, placed behind it and given a thick outline (and here shown with a darker fill so its compound-path nature is evident); and (c) a background tint.

![Figure 14](image14.png) — the three back layers of Figure 3 deconstructed to show the use of compound paths.
A brush with the cartoon experience

Although I am pleased to have discovered construction tricks that help me (and hopefully you) to make better drawings and diagrams and maps in Adobe Illustrator, the process still feels very ‘wooden’ and unexpressive compared with what I can achieve with a nice springy sable brush and a pot of ink. The winter tail-hairs of the Siberian weasel, *Mustela sibirica*, are used for the best ‘Kolinsky’ sable brushes. By varying the pressure on the brush, one can draw a line that varies in thickness along its length, as shown in my two example drawings in Figure 15.

Many cartoonists rely on outlines of varying thickness to suggest the curvature and depth of what lies within those outlines. This is very important for cartoonists who have had to work in black and white, or whose fill colours have been laid in as flat tint panels, such as Mort Walker (‘Beetle Bailey’), Charles M Schultz (‘Peanuts’), Georges Remi a.k.a. Hergé (‘Tintin’) or Albert Uderzo (‘Asterix the Gaul’).

In a future article for *Kunskapsbrevet*, I shall describe different ways of taking hand-drawn line illustrations of this sort, scanning them, and adding colour and shading to them in the computer. Meanwhile, I shall put down the tail-hairs of the weasel and grab the mouse again, to see if we can bring this sort of variable-width expression to our Illustrator drawings and diagrams.

When is a line not a line?

There are two ways of making a variable-thickness line in Illustrator, and they both involve ‘cheating’. The first method I’ll describe was suggested to me recently by Brian Parkinson, a graphic designer at Sheffield Teaching Hospital Trust.
Brian suggests exploiting the fact that recent versions of Illustrator allow us to take a line, give it a width, and then convert the shape represented by that line into a closed path with a fill in the middle, as shown step-by-step in Figure 16. Once the line is in fact no longer a line but a shape, you can adjust the position of the edges to look like a line of variable width.

The other method, which I’ve used for many years now, is to layer a smaller shape on top of a larger one in such a way that the gap between the edges appears like a line. As an example of this, see Figure 17 – a detail from an image created for a training manual on telematics. The image is partially deconstructed to show how this ‘trick’ is done.

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**Figure 16** — Using the **Outline Path** tool in Illustrator, step by step. (The line to pay attention to is the blue one. I’ve artificially marked the path positions with black lines, and the position of the anchor points with small squares.)

1. A typical two-segment Bézier curve path is created.
2. The path is given a width.
3. The Outline Path command is applied. The path is replaced by a closed-path shape that occupies the same location.
4. The position of the anchor points can now be adjusted and the curves re-shaped to produce what looks like a line with varying widths along its length.

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**Figure 17** – Deconstruction of part of an image created for a training manual (see inset for whole image).

The strong lines which mark the edges of the young woman’s face and clothes vary continuously in thickness, as if they had been drawn with a sable brush. In fact they are an illusion caused by the way one closed-path shape has been layered over another.

The outlines of the more mechanical components of the illustration had their outlines strengthened by the copy-and-paste-behind method.
Is it time to dump the brushes and pens?

Creating diagrams and illustrations with precision drawing software like Illustrator has many clear advantages in today’s publishing world.

- In the example we’ve just analysed, the modular construction of the computer equipment – as a hierarchy of grouped objects – means that elements of the illustration can be re-used easily.

- The geometric construction using Bézier curves and shape-fill attributes means that the image is resolution-independent, giving excellent reproduction quality in litho print, plus ‘zoomability’ in PDF-distributed documents.

- The file sizes of geometrical drawings are usually much smaller than scanned images of comparable quality.

- If colour fills and tints are used, they are laid in with great accuracy and can be in a colour model (CMYK, or Pantone spot colour) already suitable for the printing process.

However, one must also consider the subject of the illustration. If the subject is purely mechanical, such as the technical drawings for the Airbus airliner, they can be made with software of this sort to a standard which the viewer will find highly acceptable.

But if you want to depict complex natural forms, such as people, you will find that drawing ‘with geometry’ is hard to do, forces you to resort to much cheating and cunning workarounds like the ones I’ve introduced you to in this article, and can gobble up huge amounts of time. You will also find that such drawing tools lack spontaneity and expression, and cannot easily simulate natural textures.

This has implications for how we create some kinds of explanatory graphics. If you want your readers to learn how to use a blood glucose meter, dress a wound, sharpen a chisel, re-pot a plant or prune a fruit tree, it can be very helpful for them to see a person’s hands performing those operations. On my shelves I have two manuals of woodworking and an excellent health encyclopaedia, and I think it is significant that they have been illustrated with line drawings created by hand with pen, brush and ink. Coloured tints were then added to enhance the basic black-and-white drawings.

Perhaps when you consider the clumsy business of making lively-looking drawings by computer, you will decide to work with hand-drawn illustrations instead. Even so, the computer is still a useful tool in preparing them for use in publications. In my next article for *Kunskapsbrevet*, _Line drawings, hand-drawn by computer_, I shall explain various ways of ‘processing’ a line illustration to make it ready for use in different kinds of print, for multimedia and for the Web.
Notes


2. *Explanatory & Instructional Graphics and Visual Information Literacy* brought together twenty designers, illustrators, academics and information scientists to discuss how we communicate with pictures and diagrams. See www.ideography.co.uk/infodesign/eigvil/

3. *Integrating Interactive 3-D Diagrams into Hypermedia Documentation* by N Bussard, RM Newman and CJ Richards, presented at SIGDOC ’02 in Toronto, 20–23 October 2002. SIGDOC is organised by the Association for Computing Machinery.