Analysing and designing visualizations – Diagrammatics (1984) revisited

Analisando e projetando visualizações – Diagramática (1984) revisitada

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diagrammatics, parts of graphical speech, DNA of visualization, visualization species, visual encoding, visuospatial resemblance, semantic correspondence

This paper reviews how the authors' current framework – the *DNA of visualization* – has evolved from the work laid out in *Diagrammatics* (Richards, 1984). The goal of this line of work was, and is, to enable the analysis and specification of an extensive range of different types of visual representations of information, such as statistical charts, maps, family trees, Venn diagrams, flow charts, texts using indenting, technical drawings and scientific illustrations. Inspired by an analogy with language, fundamental possibilities of graphic organization were identified in 1984. This work has been further developed into the current *DNA of visualization* framework. We identify the main concepts within the current framework and point to their roots to the 1984 work.

diagramática, partes do discurso gráfico, DNA de visualização, tipos de visualização, codificação visual, semelhança visoespacial, correspondência semântica

Este artigo revisa como a estrutura atual dos autores – o DNA *da visualização – evoluiu a partir do trabalho apresentado em Diagrammatics (Richards, 1984). O objetivo desta linha de trabalho foi, e é, para possibilitar a análise e especificação de uma extensa variedade de diferentes tipos de representações visuais de informações, como gráficos estatísticos, mapas, árvores genealógicas, diagramas de Venn, fluxogramas, textos usando recuo, desenhos técnicos e ilustrações científicas. Inspirado por uma analogia com a linguagem, possibilidades fundamentais de organização gráfica foram identificadas em 1984. Este trabalho foi desenvolvido dentro do framework atual do* DNA *da visualização. Identificamos os principais conceitos dentro do conjunto atual e apontamos para suas raízes no trabalho de 1984.*

1 Introduction

This paper is about the development of a framework that may support designers in the creation of charts, diagrams or other visualizations. By defining the fundamental building blocks of such visual encoding systems, and their various combinatorial possibilities, the framework can be used to explore design choices, deconstruct visualizations, and guide visualization research. This work is presented here along with the origins of this research in 1984, the relevance of which has grown with the more recent surge of interest in visualizations and their design. The goals of our current work remain close to those set out in the 1984 work:

The particular objectives of the work are to:

1. *Propose a terminology for discussing diagrams.*
2. *Provide a scheme for analysing the structure of diagrams.*
3. *Identify the fundamental modes of graphic organization found in diagrams.* (Richards, 1984, 1/4)

Quotations from Richards (1984) appear throughout this paper, referenced from here onward by the page number only (formatting: 'chapter/page' as in the original work).

2 The original diagrammatics and its offspring

> *If the nature, use, and history of diagrams as a subject of inquiry needs a name then I propose that 'diagrammatics' almost suggests itself.* (2/15)

1984 will be forever synonymous with George Orwell's grim predictions for that year of a dystopian society (Orwell, 1949)[1]. Whatever else was actually going on in 1984, for one of the authors of this paper, Clive Richards, it was a milestone year in his research. In that year he submitted his doctoral thesis to the Royal College of Art, London, following an investigation conducted there under Professors Bruce Archer and Herbert Spencer. The graphic designer, Ken Garland, and the design researcher, Linda Reynolds, were his advisers. Professor Michael Twyman of Reading University was the external examiner. Richards adopted the term 'diagrammatics', using it as the title of his thesis (*Diagrammatics*; Richards, 1984 – pdf available at: diagrammatics.com).[2]

In the late 1990s the other author, Yuri Engelhardt, while doing research at the University of Amsterdam under Professor Remko Scha[3], built on this earlier work for his own PhD thesis, *The Language of Graphics: a framework for the analysis of syntax and meaning in maps, charts and diagrams* (Engelhardt, 2002)[4] – see Figure 1. One of Engelhardt's external examiners was Clive Richards.

Both authors now continue their research jointly. This has led to the synthesis, further development and refinement of their investigations, and to the creation of the 'DNA of visualization' (Engelhardt & Richards, 2018, 2020, 2021; Richards & Engelhardt, 2020; Richards & Engelhardt, forthcoming). Most core concepts in *Diagrammatics*, and most of the associated terms, feature in the new theoretical framework. Some of the original concepts have been further refined in the development of the extended scheme, and in some cases alternative names have been adopted.

1 Many ideas and expressions from Orwell's *Nineteen Eighty-Four* are now embedded within our culture, e.g., Room 101, Big Brother is watching you, thought police. The term 'Orwellian' is popularly used to refer to deception by officialdom, mass surveillance and violations of freedom of speech in totalitarian societies.

2 The term 'diagrammatics' appeared in another context in 1932, as the title of a book (Hutchins & Adler, 1932) containing a series of philosophical riddles or linguistic puzzles by the philosopher Mortimer Adler, each accompanied by a line drawing of nude figures by the artist Maude Hutchins.

3 Remko Scha was professor of computational linguistics at the University of Amsterdam (https://en.wikipedia.org/wiki/Remko_Scha). He writes "The observable characteristics of the human capacity for language and thinking are consistent with the hypothesis that thinking happens largely diagrammatically." [translated from Dutch] (Scha, 2005).

4 "I want to thank [...] Clive Richards for his phonebook-sized thesis titled 'Diagrammatics', which I read while trying to live in a cave on the Canary Islands. While rats were chewing holes into my inflatable mattress, Clive's book made a lasting impression on my thinking about graphic representation." (Engelhardt, 2002, p. xi)

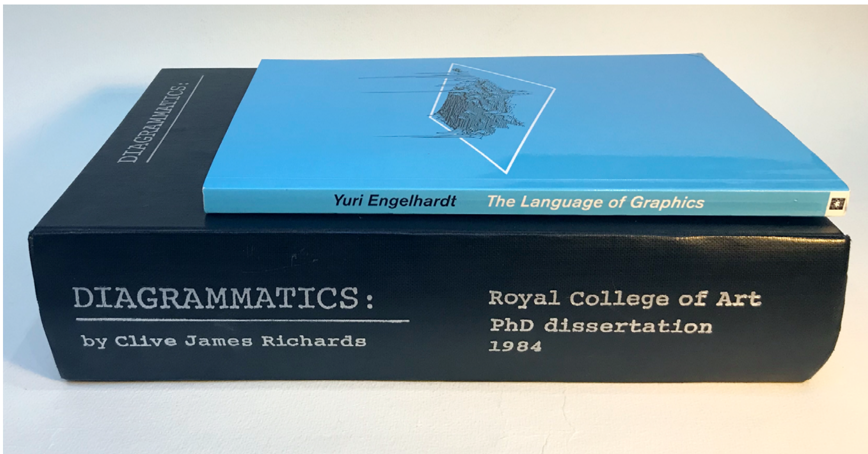

Figure 1 Yuri Engelhardt's thesis rests on that of Clive Richards.

In this paper the co-authors outline their joint work, with a backward glance to the original *Diagrammatics* from 1984 that lies at its foundation.

3 Parts of graphical speech – an analogy with language

> *The relational meaning of a diagram is taken from the arrangement of its elements, and in this respect it is akin to a sentence or text. Although we can distinguish between sentences and diagrams, in that amongst other things the former have a one-dimensional, one-directional scheme to order their elements, and the latter have the potential to utilize fully two (or even three) dimensions, both make use of a grammar to establish their meaning.* (10/2–3)

The original *Diagrammatics* thesis proposes a "grammatically-based analysis" (10/3), for example, the reader is invited to "Consider Figure [2] which may be thought of as saying, 'A is connected to B'. We might then say that 'A' is the equivalent of a grammatical subject and its connection with 'B' is the predicate; thus, the line serves a verb-like function for the nouns A and B." (3/21)[5]

5 The idea of connector lines serving a verb-like function has been explored later by Malihe Alikhani and Matthew Stone in 'Arrows are the Verbs of Diagrams' (2018).

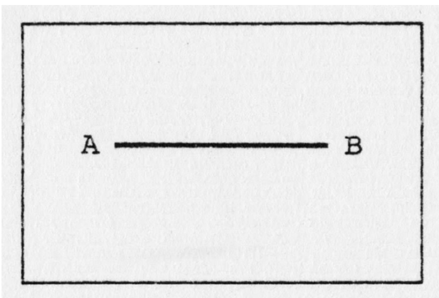

Figure 2 A line serving a verb-like function (from RICHARDS, 1984 p. 3/21).

In line with this idea, Graham Wills writes that "a visualization can be defined by a collection of 'parts of graphical speech', so a well-formed visualization will have a structure, but within that structure you are free to substitute a variety of different items for each part of speech" (Wills, 2012, p. 22). Our current work includes a 'universal grammar' that describes how 'parts of graphical speech' can be combined. We have devised a system for specifying these syntactic relationships through grammar-based, colour-coded tree diagrams for describing the compositional syntax of different visualization types (Richards & Engelhardt, forthcoming).

4 Graphic organization through visual encoding: arranging, linking, varying

> *[...] modes of organization [...] can be used to express the ideas of association, sequence, and value, and have the graphic characteristics of **grouping**, **linking**, and **variation**, respectively.* (0/9)
>
> *[...] these organizational modes may be exhibited by various graphical means [...] derived from Bertin [...] To these I have added the possibilities of enclosure, proximity, alignment, connectivity, which one might think of as being species of **grouping** and **linking**.* (8/5)
>
> *A single significant element may contain several characteristics, each capable of having different relational meanings ascribed to it. These characteristics will be termed, **relational features**.* (9/1)

The grammatical approach of the original *Diagrammatics* informed the development of the *mode of organization*, which concerns the graphical means of expressing 'relational features', categorized into *grouping*, *linking* and *variation*. In our current work we now refer to these 'relational features' as *visual encodings* which we divide in a similar way – *arranging*, *linking* and *varying*. Visual components can be *arranged* spatially, *linked* by adding *configurator components*, and *varied* regarding their visual properties:

- **Arranging** components spatially can be achieved by positional encodings such as *grouping by position*, *positioning on a coordinate axis*, *nesting*, or *coupling by adjacency*, in order to construct a meaningful configuration.
- **Linking** components can be achieved by adding *configurator components*, such as connector lines or boundaries, resulting in the visual encodings *connecting* or *grouping by boundary*.
- **Varying** components visually can be achieved by encodings regarding visual properties, such as *colour coding* or *sizing*.

In our approach, **visual encodings** include not only the use of Bertin's (1967) 'visual variables', but also Gestalt principles of perception. *Colour coding* and *shape coding* use the Gestalt principle of 'similarity'. *Connecting* is an application of the Gestalt principle of 'connection'. *Grouping by position* can be achieved either through spatial proximity – using the Gestalt principle of 'proximity', or through spatial alignment – using the Gestalt principle of 'continuity'. Our *visual encodings* also cover some of Johnson's (1987) and Lakoff's (1987) 'image schemata', concepts from Tversky's (1995) 'cognitive origins of graphic conventions' and Ware's (2008) 'graphical codings' (for a description of how our approach relates to all of these, see Engelhardt & Richards, 2018).

A visual component can be involved in *several different* visual encodings simultaneously, often representing different types of information.

An overview of visual encodings, categorized into *arranging*, *linking* and *varying*, is given in Figure 3, along with explanations and examples.

5 The DNA of visualization

In our joint work, the 1984 *mode of organization* has been extended and renamed as the *mode of visual encoding*, which includes not only the *visual encodings* themselves, but now encompasses the comprehensive catalogue of building blocks that make up the DNA *of visualization*.

5.1 'DNA' and 'species' – a metaphor for visualization

In their 'Tour through the Visualization Zoo', Jeffrey Heer et al. (2010, p. 60) say that "all visualizations share a common 'DNA' – a set of mappings between data properties and visual attributes such as position, size, shape, and color – and that customized species of visualization might always be constructed by varying these encodings." We use this metaphorical idea of the "DNA" and "species of visualization" in a similar vein, taking it to the extent of identifying a comprehensive set of DNA building blocks that specify different 'visualization species', and the rules for combining these building blocks. This allows for the construction of a broad range of different types of visualization – Heer's "customized species of visualization". The DNA building blocks of 'visualization species' in this biological metaphor correspond to the 'parts of graphical speech' in the linguistic analogy discussed above. We will refer to these building blocks as 'VisDNA'.

	visual encoding		**description** which *type of information* is shown, and how	**example usage**
arranging	Picturing	PIC	shows *configuration and visual appearance* of entities or scenes in the physical world (existing or imagined), using methods such as perspective projection.	pictorial/technical illustration
	Mapping	MAP	shows *locations* within the two-dimensional layout (typically horizontal) of physical configurations (existing or imagined), using methods such as cartographic projection.	world map, street map, floor plan
	Positioning along a coordinate axis	AXI	shows *quantities* or *points in time* by arrangement along an axis with a measurement scale.	scatter plot, timeline, clock face
	Proportional space-filling	PSF	shows *proportions* of a total by *sizing* and *arranging partitions* (or *repeating* and arranging *blocks*) into a contiguous total surface area.	pie chart, treemap, stacked bar, waffle chart
	Ordering	ORG	shows *order* by arrangement into a sequential spatial order, or into spatially ordered levels of indenting.	comic strip, bump chart, ordered list, indented hierarchy
	Grouping by position	GRP	shows *category* membership by spatial proximity or alignment.	rows and columns in a table
	Coupling by adjacency	ADJ	shows the *presence of a given relationship between two entities* by placing one visual component next to another visual component (from the same set[1]). In the case of a linear non-branching sequence of components, we speak of *ordering* rather than *coupling by adjacency*.	icicle diagram, sunburst diagram, Nassi-Shneiderman diagram
	Nesting	NES	shows the *presence of a given* hierarchical (or sequential) *relationship between two entities* by spatial containment (of one visual component within another (from the same set[1]). Usually, nesting comes with *grouping by boundary* and it is the *boundaries* (around components) that are nested (creating levels of containment).	treemap, circle packing
linking	Connecting	CON	shows the *presence of a given relationship between two entities* through the use of a *configurator component* that establishes a pathway between two visual components (from the same set[1]), e.g. two symbols connected by a line or arrow.	flow chart, family tree, network graph
	Grouping by boundary	BOU	shows *category* membership (or the *presence of a given relationship between two entities*) by grouping visual components using a *configurator component* such as a demarcating line, enclosure or shared background.[2]	Venn diagram
varying	Sizing	SIZ	shows *quantities* or *order* by varying the surface area of visual components.	bar chart, word cloud, size-ranked symbols on a map
	Repeating	REP	shows *quantities* or *order* by the use of multiples of visual components.	Isotype, dot plot, dot matrix chart, waffle chart
	Gradient coding	GRA	shows *order* by the use of gradated differences in brightness or saturation, transparency, fuzziness, etc.	heatmap table, brightness gradient on a map
	Colour coding	COL	shows *category* membership by the use of colour.	coloured lines on a subway map
	Shape coding	SHA	shows *category* membership by the use of shape.	the outline shapes of signs in a traffic sign system

[1] In this context, 'components from the same set' means components fullfilling the same general function in a visualization.
[2] When the exact locations are meaningful for all the points on a demarcating line, enclosure or shared background, we do *not* regard those as *grouping by boundary*, but as *line locators* or *surface locators* (e.g. country borders or areas on a map).

Figure 3 Visual encodings, categorized into *arranging* (red), *linking* (pink), and *varying* (blue). *Picturing* involves *arranging* into a configuration as well as *varying* visual appearance, hence the combination of red and blue colouring.

5.2 The main groups of VisDNA building blocks

The VisDNA building blocks fall into several main groups – these main groups and their relationships are shown in Figure 4. We have given each group a colour code. These groups are: *types of information* to be represented (grey DNA), *visual encodings* to represent them (red/blue/pink DNA), *visual components* that make up the visualization (green DNA), and any *directions* or *layout principles* that may be involved (black-on-white DNA). In addition to colour coding, every VisDNA building block has a three-letter code, as shown in Figures 3 and 6. These codes have been devised for the convenience of auditing visualizations, a process introduced in section 10.

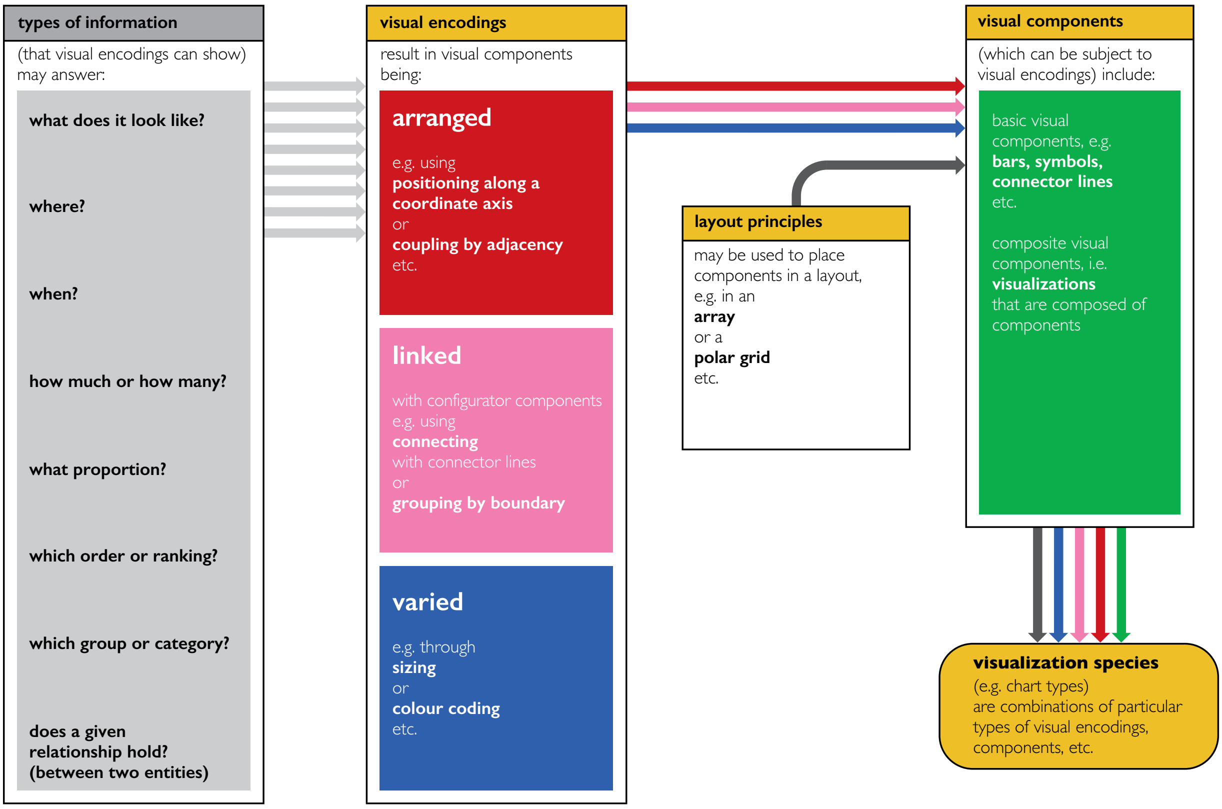

Figure 4 This basic overview diagram shows the main groups of VisDNA building blocks and how they relate to each other: *types of information* in terms of the questions they answer, possible *visual encodings* (listed separately in Figure 3), *visual components* (listed separately in Figure 6), and *layout principles* that may be used in a *visualization species*.

5.3 Visualization species

We refer to a 'well-formed' combination of building blocks, i.e., one that follows the VisDNA grammar rules (Richards & Engelhardt, forthcoming), as a **visualization species**. Tamara Munzner (2014) uses the term 'vis idiom' in a similar sense. Many common *visualization* *species* have been given a name (e.g., 'pie chart') and are generally referred to as 'chart types', while novel or rare visualization species often do not have a name (yet). As Heer et al. (2010, p. 67) write, "many more species of visualization exist in the wild, and others await discovery." There is, however, no standard for classifying visualization species (chart types). For example, does using vertical bars versus horizontal bars constitute a different type of chart? Does a chronological ordering of bars versus an ordering by value constitute the same type of chart? There are many ways to 'draw the lines' between species, subspecies or variants of species, and most of the differences between these can be identified by differences in their VisDNA. We have analyzed a large number of *visualization species* using the VisDNA system, including most of the corpus at datavizproject.com plus many other examples. Example analyses can be found on our accompanying website: VisDNA.com

An aspect of visualization that largely falls outside the VisDNA framework is the prescription of 'rules for good design'. Like academic work in linguistics, the framework is primarily descriptive rather than prescriptive, in the sense that it enables the understanding and modelling of (graphic) language.

6 Visual components

> *A significant element is the primary unit of analysis in the scheme to be proposed here. [...] I take the view that there seems to be little profit in using such items as an individual dot or line as a unit of analysis. If we are going to use linguistics as a model, then what is needed for present purposes is not the pictorial equivalent of a phoneme or morpheme but something closer to a noun phrase [...] A significant element is, then, literally any single graphic element in a diagram which signifies something or which at least is capable of having some meaning.* (3/13)

What were referred to in 1984 as 'significant elements' that make up visualizations, we now define as **visual components**. A visualization consists of one or more sets of visual components, of which at least one set is involved in one or more visual encodings. See Figure 5 for an example of a chart disaggregated into its visual components. The chart shows the development of products manufactured by a machine tool company. The small drawings of machines are visual components that are involved in three types of visual encodings – *picturing*, *colour coding*, and *connecting* with directed connector lines. A list of the different types of visual components (green DNA) can be found in Figure 6.

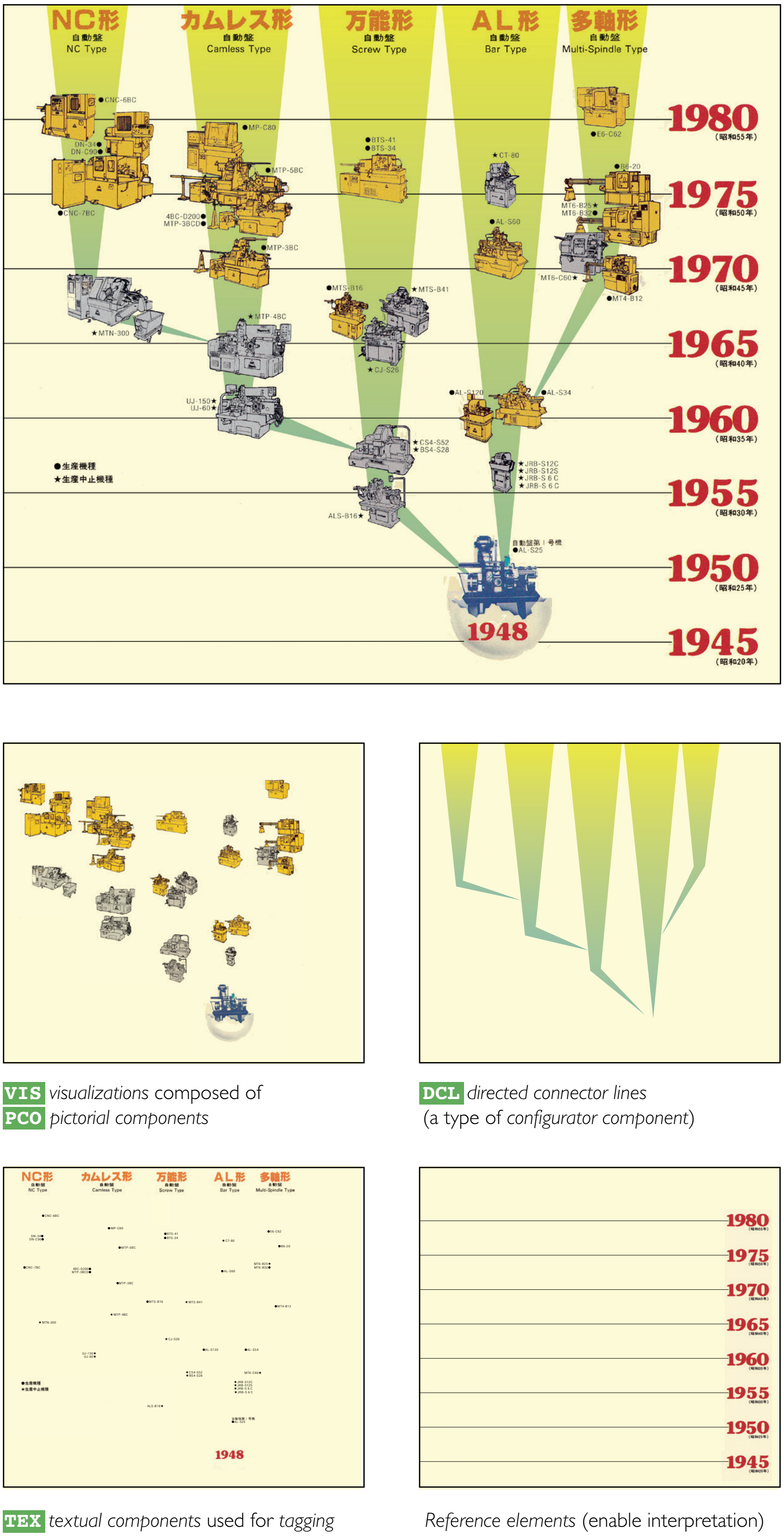

Figure 5 A chart showing the evolution of Miyano machine tools is disaggregated here into its various visual components. (Image courtesy of Citizen Machinery Miyano Co Ltd.)

component	description	example usage
pictorial components PCO	*Pictorial components* show entities or scenes in the physical world (existing or imagined), using representational methods such as perspective.	technical illustration, Isotype chart
textual components TEX	*Textual components* are the constituents of natural and formal languages, including numbers and mathematical notation.	word cloud
connector lines CLI	A visual component that connects two other visual components is a *connector line*, unless the description for *bands* applies (see below). Variation: CLI* *bundled connector line* ('edge bundling').	network graph, family tree
directed connector lines DCL	If a *connector line* comes with an indication of directionality then it is a *directed connector line* (e.g. arrows, lines with color gradients). Variation: DCL* *bundled directed connector line*.	flow chart
bands BAN	A *band* shows changing quantities through differences in width along its length, achieved either by width variation along a single band or by splitting or converging with regard to a cumulative width. Variation: BAN* *directed bands*, with indication of directionality.	stacked area chart, Minard's map of Napoleon's march
boundaries BND	A *boundary* is a demarcating line, enclosure or shared background that serves to achieve *grouping by boundary*. When the exact locations are meaningful for all the points on a demarcating line, enclosure or shared background, we regard it as a *line locator* or a *surface locator* rather than a *boundary*.	Venn diagram
line locators LIL	A *line locator* is a visual component that defines a line, where the exact locations are meaningful for all the points on the line.	rivers on a map, lines on an electrocardiogram
surface locators SUL	A *surface locator* is a visual component that defines an area within a visualization space, where the exact locations are meaningful for all the points within the defined area.	a blue area representing a lake on a map
disks DIS	A *disk* is bounded by a circular edge. It uses *sizing* and/or it is composed using *proportional space-filling*. Variation: DIS* *ring-shaped disk* (as in a donut chart).	bubble chart, pie chart, donut chart
blocks BLO	A *block* may or may not be part of a grid structure, but it always has the shape of a grid cell in either a *regular grid* or – in case of a *curved block* – in a *polar grid*. If the description for *bars* applies (see below), it is not a block. Variation: BLO* *curved block*.	cells in a heat map, outer bounding box of a tree map
bars BAR	*Bars* use *sizing* of *length*, away from a fixed 'foot' and/or shared baseline (usually representing 'zero'), and all bars in a set do this in the same *direction* (*ver*, *hor*, *rad*, *ang*). Variation: BAR* *100% bars*, which are always equally sized and composed using *proportional space-filling*.	bar chart, population pyramid
range markers RAM	Unlike *bars*, *range markers* do *not* have a fixed 'foot', but they always span two points *positioned along a coordinate axis*, representing an interval between two values.	Gantt chart, dumbbell chart
partitions PAR	Proportionally sized *partitions* are arranged to fill a given contiguous surface area, using *proportional space-filling*, in order to show percentages of a total.	slices of a pie chart
glyphs GLY	A *glyph* has a number of visual features each of which varies independently to represent different pieces of information.	Chernoff faces
spatial positions POS	*Spatial positions* are 'empty' locations (points or areas) within a visualization that can be *tagged* and/or *linked* to each other using either *connecting* or *grouping by boundary*.	the areas within a Venn diagram, the connected locations in Minard's map
symbols SYM	All basic visual components to which none of the above descriptions apply, are referred to as *symbols*.	dots in a scatter plot
visualizations VIS	*Visualizations* are composite visual components, composed of any of the visual components in this list.	any *visualization species* (e.g. any type of chart)

Figure 6 *Visual components*, listed with descriptions and examples.

6.1 Composite visual components

Complex visualizations may be structured at different levels, with lower-level structures being embedded in higher-level structures (e.g., a time series of maps, drawings of animals embedded in an evolutionary tree, small pie charts on a map, etc.). Thus, *visual components* may be either *basic* visual components (most of which are commonly referred to as 'marks' in the data visualization community) or they may be composite visual components (last item at the bottom of Figure 6). We refer to a *composite* visual component as a *visualization*. Components at any level can be subject to *visual encodings*. This approach accommodates the analysis of complex embedded structures.

7 Mode of visuospatial resemblance and mode of semantic correspondence

In addition to the *mode of visual encoding*, two other representational modes have been more or less retained for the VisDNA framework from the original *Diagrammatics* – the *mode of visuospatial resemblance* and the *mode of semantic correspondence*.

7.1 Mode of visuospatial resemblance

> *[...] the term* **schematization** *is used to denote the process of image reduction which leads to what may be thought of as a synopsis [...]* (7/10)

The **mode of visuospatial resemblance** applies to pictures and maps, covering *projection methods*, *detail-revealing techniques* and level of *schematization*. **Projection methods** include linear perspective, orthographic views, and cartographic projections. **Detail-revealing techniques** for showing otherwise occluded or difficult-to-see parts include cut-away views, exploded views, ghosted views and insets showing enlarged details (some of these are discussed in Richards, 2017).

Schematization, also referred to as 'mode of depiction' in the original diagrammatics, is "concerned with the degree of fidelity with which the image is rendered, that is, the extent to which it is barren of detail" (10/7). The degree of schematization ranges along a continuum from the **mimetic** to the **schematic**, from being visually or spatially realistic and detailed to being visually or spatially edited and synoptic – see Figures 7 and 8. Regarding *picturing*, the idea of a continuum from the *mimetic* to the *schematic* is illustrated by Scott McCloud (1993, p. 45) with a sequence of images running from a 'realistic' picture of a face to a very simplified one. In the case of *mapping*, a detailed relief map of a mountain range is an example of a relatively *mimetic* map, while a subway map is an example of *schematic* map.

		picturing	*mapping*
Schematization (mode of visuospatial resemblance)	*mimetic*	**visually** realistic and detailed	**spatially** realistic and detailed
	schematic	**visually** edited and synoptic	**spatially** edited and synoptic

Figure 7 *Schematization* – *mimetic* versus *schematic* in *picturing* and *mapping*.

7.2 Mode of semantic correspondence

> *[...] it is proposed that the mode of correspondence may range from the* ***literal****, to the* ***non-literal*** (3/32–33)

Picturing can be characterized by its **mode of semantic correspondence**, which deals with the type of relationship between 'what is pictured' and 'what is meant'. The *mode of semantic correspondence* may be *literal* or *non-literal*.

- In **literal** picturing, 'what is pictured' – the physical entity (or scene), existing or imagined – is 'what is meant'.
- In **non-literal** picturing, 'what is pictured' is *not* 'what is meant', but rather represents it through *metaphor*, *metonymy* or *convention*, for example.

This concept of *semantic correspondence* being *literal* or *non-literal* constitutes a further analogy between visualization and language (see section 3).

Figure 8 shows that *mode of semantic correspondence* and *mode of visuospatial resemblance* can vary independently from each other. It shows *literal* and *non-literal* examples of both *mimetic* and *schematic* picturing.

8 Visual treatment

> *[...] rhetoric and associated modes of speech can in some cases have a visual counterpart [...] what is represented can be subject to mediation by a process we might well describe as diagrammatic rhetoric.* (6/36)

> *[...] style can have a great effect on the mood of an illustration, without necessarily influencing the internal relational content.* (7/4)

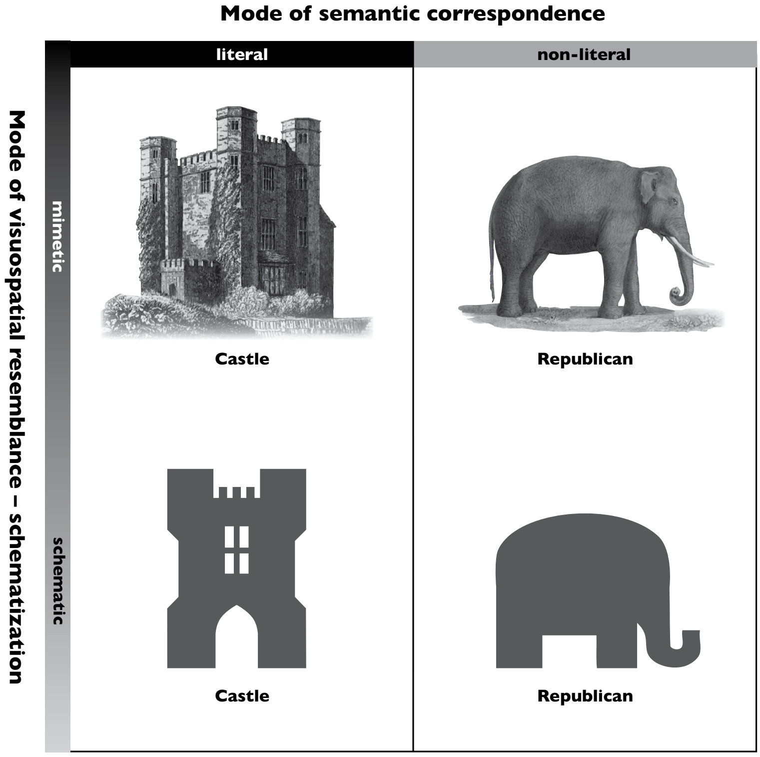

Figure 8 *Mode of semantic correspondence* and *mode of visuospatial resemblance* can vary independently from each other.

Through **visual treatment** the visual components and the visual configurations in a visualization may be manipulated to suggest additional nuances of meaning, or connotations, beyond what is conveyed by the *visual encodings*. The graphic designer Nigel Holmes has made statistical charts take on the appearance of something related to the topic, adding a further level of meaning. For example, a spiky graph of 'Monstrous Costs' is pictured as the teeth of a dragon (Holmes, 1984, p. 45). We may term this a case of 'graphical *rhetoric*'.

Related to the idea of graphical rhetoric are inflections in meaning created by the illustrative *style* used to produce a visualization – giving it a 'mood' or 'tone of voice', e.g., 'whispering' versus 'shouting' its message. Within style we may also include the use of *decoration* and *backgrounds*. Clive Ashwin (1979) discusses style in illustration, offering a framework for its analysis.

9 Supporting visualization design with the VisDNA framework

> *I rejected the notion of working with a taxonomy of diagram types, which could be potentially restricting [...]* (10/19)
>
> *Whilst such classifications may be useful for other purposes, I am uncertain of the value of these schemes to designers of diagrams.*

> *In working with a taxonomy of diagram types there may be a tendency to design within common families and to overlook the possibilities of hybrid forms.* (10/9)
>
> *It is further proposed that [...] this investigation can be used by designers as a basis for generating alternative diagrammatic structures.* (0/9)
>
> *[...] one means of generating a series of alternative [...] diagram[s] could be to use the modes [...] as a check list of what may be regarded as conceptual building bricks.* (10/19)

All of the above, from 1984, still holds for our current VisDNA framework. The framework provides a tool for the analysis and specification of a comprehensive range of different types of visualizations in terms of specific combinations of VisDNA building blocks.

Figure 9 details *which* visual encodings may be used to represent *which* types of information. For opening up further visual encoding options, information of one type may be transformed into another type – Figure 10 lists possible transformations. When creating a visualization, one may follow the process laid out in Figure 11. Through this process the VisDNA framework offers a means of exploring a wide range of available options for visual encoding and composition. It may even support the generation of entirely novel *visualization species*.

information type	question	visual encodings
configuration and visual appearance	What does it look like?	**arranging:** picturing
spatial location	Where?	**arranging:** mapping
point in time	When?	**arranging:** positioning along a coordinate axis
quantity	How much or how many?	**arranging:** positioning along a coordinate axis
		varying: sizing, repeating
proportion	What proportion?	**arranging:** proportional space-filling
order	Which order or ranking?	**arranging:** ordering
		varying: sizing, repeating, gradient coding
category	Which group or category?	**arranging:** grouping by position
		linking: grouping by boundary
		varying: colour coding, shape coding
presence of a given relationship (between two entities)	Does a given relationship hold? (between two entities)	**arranging:** coupling by adjacency, nesting
		linking: connecting, grouping by boundary

Figure 9 *Types of information* with the *visual encodings* that may be used to represent them.

question	can be transformed into	examples
Where? *spatial location*	How much or how many?	distances
	Which order or ranking?	nearest, furthest
	Which group or category?	location names
When? *point in time*	How much or how many?	durations
	Which order or ranking?	chronological order
	Which group or category?	daytime, nighttime
How much or how many? *quantity*	Which order or ranking?	low, medium, high
	Which group or category?	normal, exceptional
	What proportion?	percentages
What proportion? *proportion*	How much or how many?	absolute numbers
Which order or ranking? *order*	Which group or category?	group A, group B
	Does a given relationship hold (between 2 entities)?	Is this next in order or rank?
Which group or category? *category*	What does it look like?	 or 
	Does a given relationship hold (between 2 entities?)	Is this in the same category?
Does a given relationship hold? (between two entities) *presence of a given relationship (between two entities)*	Which order or ranking?	Which rank in terms of steps from a given starting point?

Figure 10 Transforming information from one type to another opens up further visual encoding options.

Because of its flexible structure, further VisDNA building blocks may be added to the framework to accommodate any additional visualization species that one may want to describe and that cannot be fully specified using the current scheme. Examples may be the addition of VisDNA building blocks for animation or interactivity in visualizations.

10 Auditing visualizations

> *A process of* ***auditing*** *diagrams is proposed which is aimed at isolating the fundamental modes of graphic organization available for certain classes of diagram.* (0/8)

The *Diagrammatics* of 1984 introduced a method of analyzing diagrams, a process referred to as 'auditing'. We have taken this concept forward and devised a new method of analyzing visualizations using VisDNA. This approach uses 'specification trees' – an example is shown in Figure 12, which describes the diagram shown in Figure 5 (this diagram was analyzed in the original *Diagrammatics*, 9/13–9/19). VisDNA specification trees are constructed using rigorous rules of composition, and aligned with every specification tree is an equivalent description in an English language sentence – which may help when discussing visualization options.

	Steps	description	VisDNA
1	*Types of information*	Identify the *types of information* to be visualized, listed in figure 9.	• • •
2	*Possible information transformations*	Consider transformations from one type of information into another type of information. For example, pairs of locations (*spatial location*) can be transformed into distances (*quantity*). See figure 10.	• • • ▶ • • •
3	*Visual encodings*	Identify *visual encodings* that can be used to represent these types of information. See figure 9 and figure 3.	• • • ▶ • • • • • • • • •
4	*Visual components*	Identify *visual components* that can be used to express these visual encodings. See figure 6.	• • •
5	*Directions and layout principles*	Identify *directions* and *layout principles* that may be applied to these visual encodings and visual components. See VisDNA.com	• • •
6	*Creating visualization species*	Having chosen all the VisDNA building blocks in steps 1 to 5 above, combine these into possible *visualization species* (i.e. types of visualizations). This can be an iterative process, sketched out by hand or otherwise created.	
7	*Visualization species selection*	Select some of the most promising species, bearing in mind the intended audience, purpose and context of use.	
8	*Prototyping*	Implement these with the information to be represented, while considering choices regarding *mode of visuospatial resemblance*, *mode of semantic correspondence*, *reference elements* (e.g. axis labels, grid marks, legends) and *visual treatment* (e.g. graphic style).	
9	*Evaluation*	Evaluate these implementations, ideally including testing with a group of target users, identify aspects that may deserve further attention, and go back to previous steps accordingly, reconsidering choices made there.	
10	*Production*	Select the preferred implementation and produce the final visualization(s).	

The VisDNA framework can be used to create possible visualization species for implementation – steps 1 to 6.
Steps 7 to 10, shown in grey, can be regarded as part of a standard design process.
At any step the designer may return to any previous step for reconsideration, including to step 1.

Figure 11 A design process that can be followed to create visualizations.

The complete set of VisDNA grammar rules for creating specification trees is given in Richards and Engelhardt (forthcoming) – together with descriptions of *layout principles* and *directions* (only touched on here). Also see the VisDNA.com website.

The VisDNA building blocks and the way in which they can be combined, as exemplified by the specification trees, may offer the basis for a process of formalization and the potential for machine readable specifications. This may serve as a basis for a software system that provides computer generated visualization advice, which could be linked to a rendering engine in order to produce actual visualizations and variants of them.

11 Conclusions

Much of the original theoretical basis of *Diagrammatics*, propounded in 1984, with its "grammatically-based analysis" (10/3) still holds good today, and has provided much of the foundation on which our newer

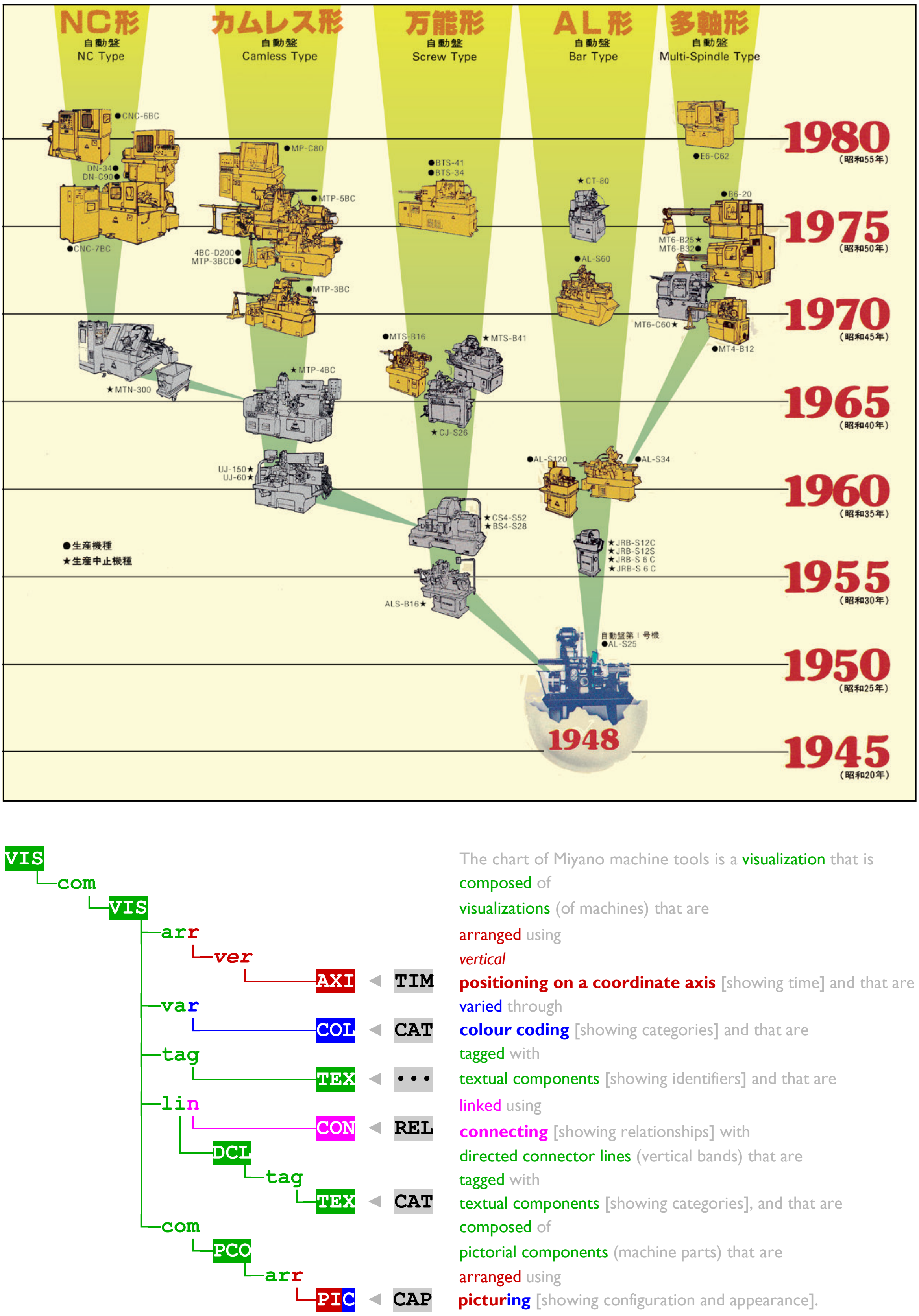

Figure 12 The VisDNA specification tree for the chart of Miyano machine tools (also shown in disaggregated form in figure 5). More example specification trees can be found in Richards and Engelhardt (forthcoming) and at VisDNA.com.

VisDNA framework has been constructed. That earlier work has been extended by adding to its grammatical analogy the biological metaphor of DNA. This has introduced the scheme of colour-coded building blocks with three-letter codes, and the rules for their combination in representing various *visualization species*.

One of the goals of *Diagrammatics* was "to provide a more precise scheme of terminology than is customarily used by designers and design teachers [... and] those engaged in research into various issues related to communication through diagrams" (1/7). This has been addressed through the VisDNA vocabulary.

The work introduced here offers the designer a means to explore visualization options, as opposed to "working with a taxonomy of diagram types, which could be potentially restricting" (10/19). The *DNA of visualization* (VisDNA) goes beyond the 1984 work. With its precisely defined building blocks and rigorous grammatical combinations rules, the VisDNA framework provides a system for undertaking a range of analytical activities, both in visualization design practice and in related visualization research.

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