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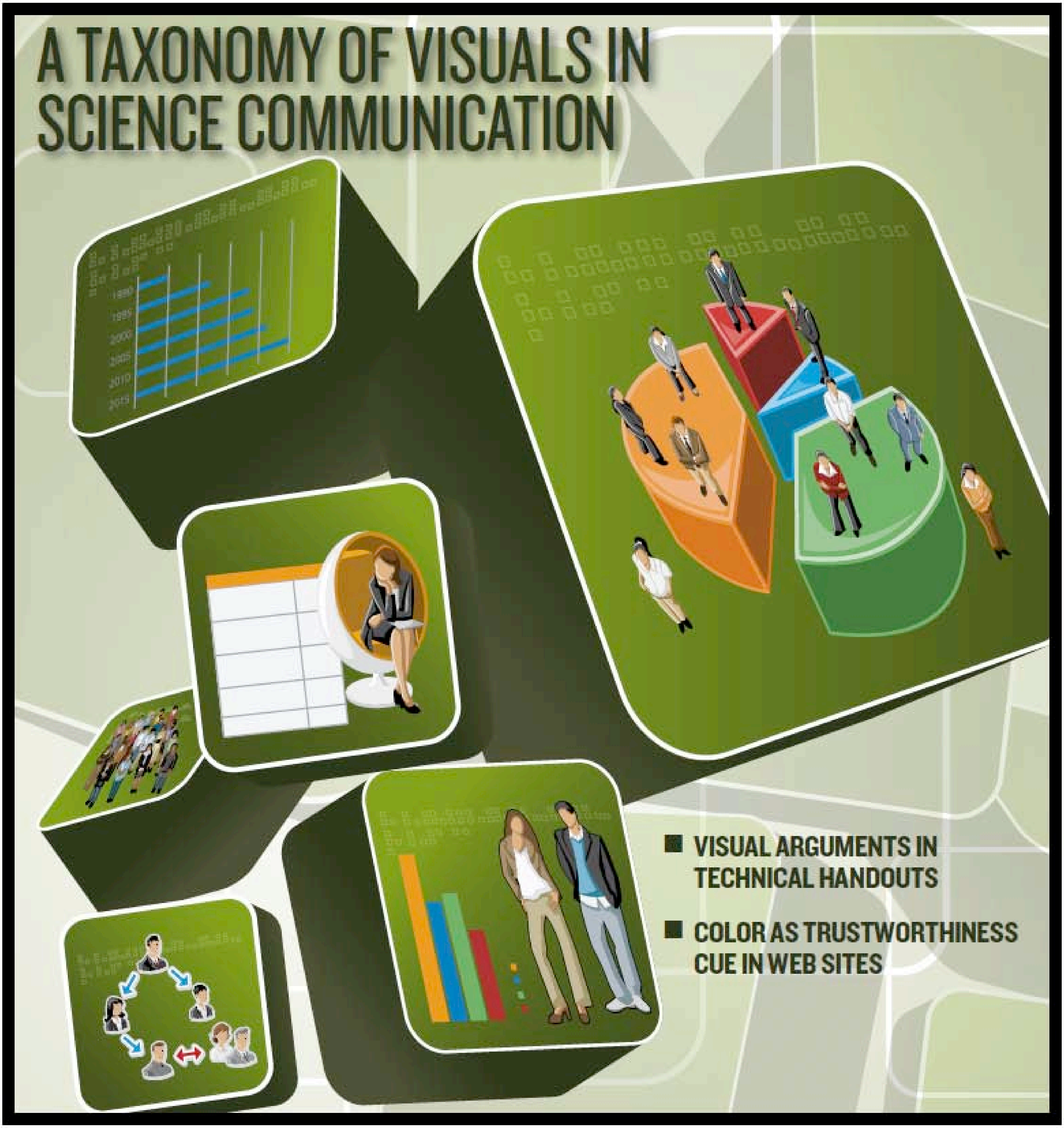

# Toward a Taxonomy of Visuals in Science Communication

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**Abstract**

**Purpose:** To develop and present a systematic, hierarchical taxonomy of visuals used in science communication, in order to facilitate analysis as well as selection and design of visuals.

**Methods:** Iterative analysis of commonly used visuals and existing typologies and selection of a classification system.

**Results:** A taxonomy is proposed based on Linnean principles, which distinguishes three classes of visuals based on their information and sign content; these are subdivided in orders and families. A systematic nomenclature is described.

**Conclusions:** Used successfully in training sessions and research, the taxonomy offers the basis for the development of comprehensive guidelines and improvements in the design and usage of visuals.

**Keywords:** visuals, taxonomy, denominations, science communication

**Practitioner's takeaway**

- Denominations of visuals used in science communication differ considerably among authors, resulting in confusion.
- The article presents a hierarchical classification and denominations based on the principles of a taxonomy developed in the natural sciences.
- Research conducted with this taxonomy shows how writers use specific types of visuals in different article genres.
- The taxonomy is currently used in training science graduates in communication.
- The taxonomy should help writers choose efficient visuals, analyze and criticize the actual use of visuals, compare results between researchers, and develop more comprehensive guidelines for the design of visuals.

## The Problems with Visuals

As part of their research activity, scientists have to report on their findings and do so using mainly two different genres of communication media: papers published in periodicals and oral presentations given at conferences. For both media, scientists systematically rely on visuals to better convey part of the information they wish to transmit. Gross, Harmon, and Reidy (2002) have shown how much the use of visuals has increased in periodicals during the 20th century: they were present in 33% of papers in a sample dating from the first quarter of the century, and in 100% in the last quarter of century. Science writers in magazines and the press are also important producers and users of visuals, and although they use a different set of visuals (Jacobi, 1985; Miller, 1998) their use of visuals has also been growing. We have no data on the evolution of the use of visuals in conference presentations, but the successive development of slide and overhead projectors and the generalization in the use of electronic projectors has no doubt led to a tremendous increase in the use of visuals for "paper" presentations.

Visuals play a slightly different role in articles and conferences. Printed visuals usually include more information and tend to be more complex than projected visuals. This is in agreement with a simple fact: Printed visuals are autonomous entities that the readers can refer to and analyze separately from the text, at their own convenience, whereas projected visuals tend to be (or should be) less dense as they have to be looked at for a restricted time while the audio-spectators are simultaneously listening to the oral presentation. Yet in both instances, as Lemke (1998) pointed out, the visuals are attempts at using spatial, topological representations to convey information hardly deliverable with the linear affordances of written or oral speech, due to their complexity. Printed and projected visuals therefore have much in common.

Attempts have been made at studying the use of specific visuals in communication activities. The pioneering work in this area is probably that of Cleveland (1984), who was actually interested in detecting common errors and poor design in graphs. But Cleveland's work was also noticed because of his quantitative study on the use of different types of graphs in different disciplinary periodicals. Studies of this type have been infrequent. Also, a major obstacle encountered in analyzing and comparing the results of different authors is in the denominations used to distinguish types of visuals. All scientists and science communicators, for example, use the term "graph" and are probably confident they share a common definition of the term. Unfortunately, such is not the case. Cleveland (1984) defined graphs as figures that have scales and convey quantitative information, which included statistical maps. In his remarkable encyclopedic work, Harris (1999) defined graphs (or plots, which he considers a synonym) as one category of charts, as opposed to maps, diagrams, tables and "others" (proportional charts like pie charts, Venn diagrams, etc.); a graph is then "a chart that graphically displays quantitative relationships between two or more groups of information" (p. 164). Some authors preferred avoiding the general term "graph" and used specific denominations: the use of "bar charts" and "line charts" is reported by Busch-Lauer (1998), that of "bar graphs," "point graphs," "scatter plots," and "survival curves" by Cooper, Schrieger, and Close (2002). It may be a paradox that no author has included the graphs defined in the mathematical graph theory as a type of graph; these figures represent the links between entities and are used in the representation of all kinds of networks. Finally, it should be added that dictionaries are useless in this area, offering contradictory definitions of what is a graph, a chart, a plot, a diagram, and so on. Common denominations at times refer to more than one kind of visual, and a single type of visual frequently bears many different names, a situation defined as polysemic, and a source of confusion.

The most striking case of polysemy is probably that of the term "diagrams." For botanists, diagrams may be the schematic representations of plants; for the statistician, they may be the distribution of dots showing data in Cartesian space; for an engineer, they may be representations of the flow of matter in processes. Funkhouser (1937) defined as diagrams "all the various kinds of graphs, charts, lines and pictorial illustrations for the display and comparison of numerical data," (p. 365) which seems to exclude only maps and organigrams. In many fields, diagrams bear the name of their inventors, whatever their content: Venn's, Euler's, or Johnson's diagrams in logics, Watt's in thermodynamics, Feynman's in quantum physics, Gantt's in management, Hertzprung-Russel's in astrophysics, and the like. The denomination has also received consideration by semioticians analyzing the structure and contents of images. For example, Peirce (1978) defined as diagrams a category of icons expressing relations: he considers an algebraic formula a good example. Bertin (1973) used the term diagram to designate all types of representations, tables, or graphs that show relations between two sets of data, excluding maps, and he defined Peirce's diagrams as networks.

Denominations fare no better when considering representations of material entities: they are at times quite vague (picture, illustration), at times they refer to media (photograph, painting, line-art, etc.), or suggest the precision level of the image (sketch). Tables and bullet lists refer to specific alphanumeric visuals but the available terminology here again does not cover all types. Organigrams are either charts (e.g., flow charts) or diagrams (organizational diagrams), or trees.

This general lack of precision in the current denominations has deleterious consequences in many areas. The situation is similar in other languages and trying to translate these terms from English to French, for example, is a nightmare. Scientists and science writers looking for the right graph to produce can rely on different textbooks, but again, however excellent some may be, the terminology used by different authors varies, and the same is true for many of their recommendations. Speakers and authors are usually given guidelines for the design of visuals. Some periodicals have their own guidelines, but in most instances these are remarkably laconic as to visuals, even offering contradictory advice, as Schrieger, Arora, and Altman (2006) have shown for medical journals. Style manuals of professional groups like the often-referred-to American Psychological Association manual (2010) also present very limited guidance in graph design. Studies on the use of visuals, as discussed above, are extremely difficult to compare because authors refer to different and barely compatible classifications of visuals. A consensual glossary of visuals would facilitate the development of harmonized guidelines and therefore help students, scientists, and writers in the selection of appropriate graphs. It would be an efficient tool in the critical analysis of the actual use of visuals in publications and conferences.

A special consideration should be brought to the question of training future scientists and writers in communication, which does not attract much attention (Trumbo, 1999). Most scientists were scarcely exposed to formal training in the use of visuals and it is our experience that students resort to learning by doing and imitating what they read and see, for better or for worse. Students frequently rely on their self-acquired mastery of software like Microsoft Excel, which offers indiscriminate use of different types of awkwardly named visuals for any type of data. Studies conducted on visuals published in periodicals show a possible consequence of this: According to Cleveland (1984), 30% of visuals printed in *Science* had at least one error. The situation was described as "worse" in subsequent studies (e.g., Cooper, et al., 2002; Hartley, 1991; Krebs et al., 2001). There seems to be a definite need for more extensive and systematic training in this area.

## Historical Perspective

Despite these ambiguities and the rampant polysemy of denominations, it seems few efforts have resulted in establishing order in this chaos. In his study on the history of science graphs, Funkhouser (1937) reported that one of the first attempts in the field was produced during the 1857 International Statistical Congress in Vienna. The proposed classification was then founded on the nature of data to be presented and not on the graphical form used. Funkhouser further mentioned that in 1877, G. von Mayr presented a report proposing to separate graphical formats under two classes; diagrams and maps, where data was represented by dots, lines, areas, and three-dimensional volumes. After lengthy discussions, it was discovered that the large variety of graphical formats made it impossible to agree on a universal classification. During the final part of the 19th century, as Costigan-Eades (1984) reported, some attempts at classifications were made using descriptive approaches, and others proposed a functional basis, but no significant progress was made. And the first half of the 20th century was marked by the development of new quantitative statistical tools, which was accompanied by a decreased interest in the graphical expression of data.

In 1937, Funkhouser defined only a dozen different graphical forms. Forty years later, Macdonald-Ross (1977) was following the same path, defining around 15 formats without attempting any classification, but presenting a critical synthesis of studies on their relative efficiency. In 1981, Levin published an often-referred-to study in which he proposed a general classification of images, with eight functional groups: images were used for "decoration, remuneration, motivation, reiteration, representation, organization, interpretation or transformation" (p. 212). Five categories of this classification (decorative, representational, organizational, interpretative and transformational) (p. 759) will be the basis for a study on the nature of images used in scientific textbooks (Codone, 2005).

Bélisle & Jouannade (1988) published a book on visual communication in which they distinguished seven types of visuals: photographs, drawings (including exploded views and maps), graphs ("graphical presentations of statistical results"), organigrams, sketches, tables, and texts (p. 41). This is a more complete list of visuals used in conferences, but the classification may be unsound since it is based here on technique (photograph, drawing) and there on content (maps, organigrams), while opposing drawing and sketch. Meanwhile, Cleveland (1984) had published a first systematic analysis of visuals used in periodicals. He used a simple typology, defining entities such as bar charts, histograms, point graphs, statistical maps, and miscellaneous. One might note that the author separated bar charts from histograms, which is not a universal distinction. In a statistical perspective, Cleveland also classified graphs according to the number of variables they supported, distinguishing between controlled and uncontrolled variables; a perspective rarely taken into account by others.

Kosslyn (1989) published an important paper on the design of charts and graphs. He then offered a simple classification of the visual presentation of data: graphs are images where data are represented through a scale; charts are figures where relations between entities are presented with lines; maps are a category of their own; and finally diagrams are schematic representations of objects or entities. The paper presented an analysis of certain theoretical aspects of graphic representation and a number of recommendations that will eventually be the basis for a remarkable textbook (Kosslyn, 1994; Kosslyn, 2006).

In 1990, Rankin published a detailed repertoire of "graphs," which in fact only dealt with curves and histograms and considered primarily the number of variables to be shown and the eventual periodicity of data. The result was a low efficiency classification and at times awkward denominations, such as a "Linear array of 4-D cylinder-like trend surfaces," (p.152) which has rarely been referred to in the literature. Shortly thereafter, Wileman (1993) published a much broader study. He defined three manners in which to represent objects: by pictorial symbols giving realistic representations, by graphic symbols that are more abstract, and finally with verbal symbols. This led him to put forward five categories of figures for the representation of numerical data: circle graphs, line graphs, bar graphs, pictorial graphs, maps and area graphs. Lohse, Biolsi, Walker, and Rueter (1994) used an empirical approach based on the results of attempts at classification by subjects in an experimental setup. Lohse et al. proposed a nonsystematized list of 11 categories: graphs, graphic tables, tables, network charts, structure diagrams, process diagrams, maps, cartograms, icons, time charts, and pictures. One may conclude that ambiguousness persists in denominations.

Some attempts at classification will be made for more limited fields. For example, Clément (1996) put forward a taxonomy of medical images. He first defined three categories of *graphical* images: those that are based on tables of numerical data, those representing mathematical expressions, and those that are designed to visualize scientific concepts (diagrams and schemas). A second set of images are *figurative* and result either from the iconic coding of visual signals (photographs, drawings) or from what he calls the iconic transcoding, which transforms other physical signals into visual signals.

Rowley-Jolivet (2002) published a systematic study of projections presented in scientific congresses. She defined four classes of images: scriptural, presenting textual information (titles, conclusions, etc.); numerical, showing quantitative information such as tables and equations; figurative, showing representations of material objects; and graphical, which included maps as well as graphs, sketches, and abstract diagrams. This attempt is more global than preceding efforts, but it does group together visuals that are semiotically distinct, and offers no classification of the different scientific "graphs."

The same year, Doumont (2002) proposed a pragmatic method to "choose the right graph." His list of categories is short (bar charts, dot charts, histograms, box plots, scatter plots, line plots), but he insists that the choice must be made on the basis of the database structure, of the intended use (analysis or communication), and of the operation performed with the data (comparison, distribution, correlation, temporal evolution). Here, a link is established between structure and function, but it is limited to the presentation of quantitative data.

Arsenault, Smith, and Beauchamp (2006) completed a series of studies, mostly in psychology, on graphs and tables (Smith, Best, Stubbs, Johnnston, & Archibald, 2000; Smith, Best, Stubbs, Archibald, & Roberson-Ray, 2002). They added to these two categories what they call nongraph illustrations, which include diagrams, pictures and maps as well as montages, and so-called nonvisual inscriptions, which comprise numerical tables and equations.

This short historical review demonstrates that we are confronted with a complex problem. We are faced with the existence of a huge number of different visuals, of which no complete list is available or even feasible, since any author can create new types to better illustrate certain phenomena. This diversity is probably exacerbated by the development of computer visualization techniques that offer new types of often complex visuals calling for interactive processes. We then have an abundance of denominations, a number of them being so general that they are polysemic and ambiguous. Different authors have tried, in different contexts, to produce lists or typologies of visuals used in different areas of science or of communication: none is general enough to include most types of visuals, and many are too field-specific to allow generalization. No systematic attempt has yet yielded a true taxonomy of science visuals, which could offer a comprehensive, rational classification of visuals according to generic types, and the development of a consistent nomenclature.

## Method: Developing a Taxonomy

The development of a taxonomy follows a process more akin to design than to scientific research. It is an iterative process in which trial and error contribute to the elaboration of a system that should eventually be as logical and comprehensive as possible.

The first step in the process is the assembly of an extensive catalog of current scientific visuals that should be representative of major scientific disciplines as well as communicational genres. This is a lengthy and ever unfinished process that goes on through critical attendance at conferences, consultation of periodicals of all kinds, of monographs in data analysis as well as in graphic design. There are now excellent anthologies in this field, and the work of Harris (1999), for example, is a wealth of information on science visuals.

The second step is the selection of a classification system. A *typology* of visuals would try to define and name the different types of images used in communication. A *taxonomy*, however, would go one step further in offering a logical, systematic and hierarchical classification, distinguishing related groups and subgroups.

The basis for modern taxonomy is found in the works of Carl von Linne (or Carolus Linnaeus). Throughout the 17th century, this Swedish scientist studied the diversity of living organisms to classify them in a systematic way, based on their natural characteristics. Taxonomy allows one to create categories (taxa, sing.: taxon) going from the more general to the more specific level, according to precise rules. Biological taxonomy distinguishes between phyla, which are subdivided into classes and then orders, families, genera, and species. At each level, one expects that the set of categories or taxa be collectively exhaustive and mutually exclusive. The distinction between taxa on a given level (e.g., classes) is based on a single criterion, a character that has a distinctive expression in each. Different characters will be used at different levels, and these characters may be structural or functional. One can therefore create on this basis a hierarchical classification defining groups in reference to their actual similarities and differences.

Such a taxonomy would be useless if it did not come with the attribution of a distinctive denomination for every single taxon described; this is done through nomenclature. In Von Linne's work, each phylum, class, order, family, and genus therefore received a distinctive and exclusive name. It was impossible to do the same for species because of their numbers, and Von Linne developed a binomial system to bypass the problem: species would be designated by the name of their genus plus another qualifier. Here, Von Linne systematically made up names based on Latin and Greek vocabulary, therefore creating an international system readily usable in many languages, which virtually eliminated problems in translation.One can use the same principles of taxonomy and nomenclature and apply them to any set of entities, and this is what we have tried to do for visuals used in science communication. This implies a lengthy analytical process for the selection of efficient discriminating criteria, and the actual definition of taxa at different levels. On this basis, we then had to find distinctive designations in order to avoid the confusion generated by the actual polysemic denominations.
It would prove unavoidable to create neologisms, hoping not to walk straight into abstruseness. The goal pursued would be more modest than that of biological taxonomists: it would prove impossible to try and name every visual, but a general and systematic frame of

reference would allow one to deal with the most widely used visuals in a coherent and methodical manner.

A certain number of considerations must be mentioned before going into the details of the taxonomy. First, the "phylum" we will be considering is mainly that of communication visuals: Images developed in the field of data exploration will not be addressed specifically. In this we would follow the path offered by Bertin (1973) as well as MacEachren (2004) considering these images as analytical tools that can be quite complex, frequently interactive, and in most cases not fit for communication purposes. Second, we will be unable to tackle the domain of complex visuals or montages; taxonomies can only consider singular cases, and Von Linne himself no doubt never considered classifying floral arrangements. Third, this will also lead us to consider only static images, and not moving ones. Fourth, we cannot pretend to cover all types of visuals used in communication; as mentioned above, some types exist that are rarely used, and new ones can be developed that will have to be taken into account in due time, but this is the case with any taxonomy. Fifth, we will not attempt to name every existing visual to the species level, being satisfied with precise enough categories, denominations, and lists of qualifiers that cover most types of current visuals. Sixth, taxonomy rests on the selection of relevant criteria that must be chosen with care; in the case of visuals, it is difficult at times to choose between descriptive and functional criteria and therefore alternative criteria frequently exist, some of which will be underlined. Finally, we will renounce using general and polysemic terms such as "graph," "diagram," "chart," or "plot," to which one could not give a new definition without adding to the actual confusion; however, we will keep terms like "organigram" or "histogram," which seem unequivocal, and use the suffix "gram" to name most taxa. Following Von Linne's example, we will propose a nomenclature based on Greek and Latin terms, again to avoid confusion and facilitate communication and translation in different languages.

## A Taxonomy of Communication Visuals in Science

Over the years, the repeated observation and analysis of visuals used in conferences and periodicals has led to the conviction that Wileman's (1993) approach gave us the most efficient global categorization of science visuals in three classes. Images being defined by semioticians as assemblages of signs, it seems logical to define these classes on the basis of their information and sign content, as Wileman suggested.

A first class is composed of diverse figurations of material entities, representing for example objects under study, subjects, equipment, environments, and places. Semiotically, these visuals are essentially made of iconic signs. Since they represent entities from the infinitely small to the infinitely large, we will call them "cosmograms."

A second class, used more broadly in oral than printed communication, defines visuals that are composed of text and numbers: these visuals are essentially made up of the symbolic signs belonging to language, whether verbal or numerical. As this class is relying on the art and signs of typography, we choose to call these visuals "typograms."

A third class offers inscriptions of data that are presented through graphic symbols or signs arranged in a calibrated area, for example (but not exclusively) in Cartesian space. In this class the representation of data is always based on an analogy between a quantitative value (resulting from a counting operation, a calculation or a measure), and a dimension of space (length, angle, etc.). This has led authors to speak of an "analog scale" and this is the reason why we will call them "analograms."

Each one of these three classes is a collection of taxa that differ in their graphical design, their affordances, and the practical use we make of them. We will consider each one separately.

### Cosmograms

Scientists use various visuals to show material entities, but these all share a common feature: they are calibrated and usually show a quantitative scale, which is not the case in nonscientific contexts. Cosmograms could then be divided in two categories: photographic (analog or digital), and pictographic (drawing with different manual tools, computer assisted drawing). In the first case, we get a realistic representation of a specimen; in the second, we choose to illustrate the generic type, following iconicity levels as described by Moles (1981). A technical criterion could therefore be used to distinguish between two orders of cosmograms. However, it is generally better to refer to image content for taxonomy, as techniques can be efficient qualifiers shared by otherwise different visuals. We will therefore distinguish two orders of cosmograms: topograms and reigrams, as detailed in Table 1.

**Topograms** (from the Greek topos, place) are figurations of places and environments; in other words, a portion of space occupied by a set of objects. They can be complex visuals possibly representing a large number of entities. It is practical to subdivide topograms in two families. First come figurations of natural environments; therefore, called *ecograms (*from the Greek oikos: natural habitat). These can be aerial or satellite photographs, but more frequently they will be pictographic maps. Particularly in the case of maps, the design of ecograms is governed by rules (e.g., defining types of projections in geographical maps) that have been described by numerous authors (Bertin, 1977; MacEachren, 2004). Maps can be "silent" representations, but they can be further divided in *descriptive* maps when their purpose is to illustrate features of the environment with textual or iconic legends, or *statistical* maps when the map becomes the support of statistical information on, for example, populations or economic data. In this last case, depending on the nature of the data (nominal, ordinal, or quantitative), different graphical elements such as area coloring or hatching, vectors, or isocontour lines can be added to the map to present the data.

The second family of topograms calls for the representation of artificial constructions. These we will call *domograms* (from the Greek domos: construction). The distinction is important because, while purely

**Table 1. Cosmograms**

| Orders | Families | Qualifiers | Descriptions / examples |
|---|---|---|---|
| Topograms (environments) | Ecograms (natural environments) | Descriptive | • Topographic maps<br>• Aerial/satellite photos |
| | | Statistical | • Nominal data: zones identified by texture or color, symbols or icons<br>• Ordinal data: zones identified by gradation of tint or scale of greys<br>• Quantitative data: numbers, vectors, contour lines, histograms on specific zones |
| | Domograms (built environment) | | Photography of man-made constructions<br>Drawing in plan, elevation and profile |
| Reigrams (objects) | | Descriptive | Photography of isolated specimens<br>Pictography (anatomical, technical drawings) |
| | | Functional<br>• Cinematic<br>• Transformational | Chronophotography of movement (multiple exposures)<br>Life cycles, infectious processes |
| Both orders | | Photographic<br>Pictographic | |

descriptive domograms can be obtained by the same photographic techniques, pictographic figurations are quite different and frequently much more abstract. These are no longer maps but plans and, in the universe of architects, engineers and draftsmen, the design of such figurations obeys strict rules that differ from those governing the production of maps, implying for example the necessary representation in plan, elevation and profile. And if, as their name implies, plans are first of all tools for planning the construction of nonexistent entities, they are also used to portray existing industrial setups. The amount of information they carry can be important but, contrary to maps, plans are seldom the support of statistical information.

**Reigrams** are the second order of cosmograms (from the Latin res, rei: thing, object). All cosmograms do not represent complex environments. Reigrams are figurations of material objects, either natural or artificial. They frequently represent objects isolated from their environment or background in order to bring out specific properties. These again can use photographic or pictographic techniques, according to the objectives of the author. *Descriptive reigrams* can show the external morphology of objects, using perspective drawing or top, frontal, and side views. They can show the internal configuration of objects with a variety of techniques (see-through views, cut-outs, exploded views, etc.). *Functional reigrams* allow one to show the spatiotemporal changes of entities using, for example, composite views. In a first case, cinematic reigrams show the different phases of a movement or displacement; this was mostly developed by Marey (1894) as chronophotography, through multiple exposures and superimposed drawings. The second case is that of transformational reigrams dealing with morphological changes; this would be the case, for example, in representing the life cycle of a parasite.

As a class, cosmograms are therefore an efficient tool in the description of the aspect and properties of the very different types of material entities considered in science communication. They are a topological, scaled transcription of entities or of their properties and that is why they include images of traces and indexes, footprints as well as traces in bubble chambers. Cosmograms play an essential role in the descriptive stages of all disciplines, yielding progressively to analograms when scientists concentrate on more analytical stages of research. The taxonomy we have put forward only defines large groups, as it can be seen that specific types of cosmograms can be well described by adding to their names one or two qualifiers specifying some properties or the function (e.g., descriptive, statistical, functional) supported by the visuals.

### Typograms

Language-based visuals are topological representations of specific aspects of discourse (Lemke, 1998). They are not the mere visual transcriptions of parts of the discourse (in which case they would not be considered as visuals), but inscriptions set in such a spatial arrangement as to complement the oral or printed presentation. Typograms can be divided into three orders, according to both their content and function, as shown in Table 2.

**Scriptograms** are the first order of typograms, and they are the closest to simple print. Scriptograms are more widely used in oral communication, where they compensate for one of the disadvantages of oral delivery, that is the disappearance of structural information about the discourse offered in printed information by layout, such as paragraphs, numbering, font choice and size, and bold characters, that have no real equivalent in oral presentation. In this context, specific screen-pages offer titles and author identification, short phrases (usually not sentences) reinforcing a statement, equations, but most of all visuals that have almost become the trademark of projections, bullet lists. These are frequently used to merely present series of items, but they seem particularly efficient when they list markers of the sequential structure of the oral text.

**Cellulograms** are the second order of typograms. They offer the possibility of presenting alphanumeric data by category, each data being filed in a cell within a metaphoric filing cabinet or pigeonhole. The archetype of this order is the numerical rectangular table, but the existence of other forms (e.g., “stem and leaf” displays, triangular tables), as well as a necessary coherence in nomenclature make us call this order cellulograms. These can be qualified according to the nature of their content, which bear either nominal, ordinal, quantitative or symbolic/iconic signs. It is worthy to note that large cellulograms are usually avoided in oral presentations: they are analytical rather than communicational tools, images that have to be “read” at length rather than “looked at” (Bertin, 1973).

**Organigrams** are the third order of typograms. Contrary to cellulograms, which simply divide entities into cells, organigrams are designed to display components of a system and their relations. Organigrams were probably first developed using the metaphor of a tree. In these *arborescent* organigrams, the components are identified by their name, each one usually enclosed in a box, and relations are indicated by lines or arrows. In many fields of science, implicit rules govern the design of these organigrams. Visuals describing processes are usually read from left to right. Hierarchical organizations are traced from top to bottom, as well as genetic transmission of characters, while evolutional anthropology will show the "ascent of man" using a bottom-up approach. Closed-loop systems or those implying feedback call for circular organigrams, while centralized organizations can be described in a radiant fashion, each subentity boxed in on a different radius. Arborescent organigrams are therefore usually easy to qualify by their graphical design as well as their content (structural, functional, conceptual). A second subgroup of *intersecting* organigrams is devoted to the illustration of logical relations between sets, as first described in the mathematical set theory; they are frequently designated as Venn or Euler "diagrams." In this case, sets are represented as circles and relations of exclusion or inclusion are illustrated by separation or overlap of circles, without resorting to lines or arrows.

**Table 2. Typograms**

| Orders | Qualifiers | Descriptions / examples / synonyms |
|---|---|---|
| Scriptograms | Phrases<br>Equations<br>Lists | Title page, statement<br><br>Bullet list, word chart, text chart |
| Cellulograms | Content (nominal, ordinal, quantitative, symbolic, iconic)<br><br>Format<br>• Quadrangular<br><br>• Triangular<br>• Linear | <br><br><br><br><br>• Tables in columns and rows<br>• Mileage table/chart<br>• Stem and leaf display/chart |
| Organigrams | Arborescent (content, structure)<br><br>Intersecting | Network diagram, organizational chart, block diagram, flow chart/diagram, trees<br>Venn, Euler diagram |

Again, typograms are efficient forms of topological translation of nominal and numerical information. They rely on some of the basic rules governing printing, with a preference for left to right and top to bottom layout, but also resorting to other layout metaphors; they afford a truly visual description of otherwise discursive information.

## Analograms

The third and final class of visuals is the most characteristic of scientific "inscriptions," as indicated by Latour (1987) and Latour and Woolgar (1988). Visuals like cellulograms or cosmograms present data mostly in their primitive form, as the result of direct observation or measure. Scientific investigation of course goes further, and for example through computational processes that yield results in forms too complex to be expressed efficiently by language, or to be shown with the visuals mentioned above. This is what led Playfair (1786) to develop new types of visuals, like histograms, and to borrow from Descartes' analytical geometry to plot mathematical relations in Cartesian space. Again, the same objective, topological transduction of information, is targeted, so that we can visualize information that would otherwise only be expressed and deciphered with difficulty. And, as we have mentioned, this transduction relies in all cases on the same analogical process, transforming numbers in a dimension of space.

Analograms use different graphical signs to represent data. These signs are those Leonardo da Vinci (Da Vinci, Kemp, & Walker, 1989) or more recently Kandinsky (1991) described as the basis of all pictorial representations, and the same that G. von Mayr recognized as the basis of graphical presentations (Funkhouser, 1937). Data can be shown by dots, by lines, by areas, by forms. And this will be the basis of the present nomenclature, distinguishing between five orders to be named punctigrams (dots), curvigrams (lines), puncti-curvigrams (both dots and lines), histograms (areas), and morphograms (shapes). Table 3 describes these orders.

**Punctigrams** afford to represent individual data using dots, which will be aligned along an axis calibrating a variable. Punctigrams can be subdivided according to the number of variables they show and their configuration. In the case of a single variable, univariate distributions are shown by placing dots along a single axis, giving rise to linear punctigrams. Much more frequently, the individual dots refer to the relation between two variables, each one attributed to one axis (abscissa or ordinate) in a Cartesian space: the result is a planar punctigram. At times, data refer to three variables, and dots are arranged in a three-dimensional Cartesian space, creating a sterical punctigram. The specific affordance of all punctigrams is the descriptive presentation of all individual values without implications as to the nature or form of the relation between them, but with the intent to display the variability in data.

**Table 3. Analograms**

| Orders | Families | Qualifiers | Descriptions / examples / synonyms |
|---|---|---|---|
| Punctigrams | | Linear/ univariate<br>Planar/bivariate<br>Sterical/trivariate | One axis point graph<br>Scattergraph, scatterplot, scattergram<br>3D point graph |
| Curvigrams | | Axis system (cartesian, polar, floating…) | Globally: line graph, curve graph, line plot, line chart. Polar graph: clock, circular graph or chart. Floating: instrument graph, name derived from technical process (chromatogram, etc.) |
| | | Line configuration (straight, segmented, curved, stepped…) | |
| Puncti-curvigrams | | | Hybrid figure with both data points and curve |
| Histograms | Absolute<br>• Descriptive<br>• Comparative | Band orientation (horizontal, vertical)<br>Band arrangement (paired, opposed, stacked…) | Globally: bar/column chart or graph, vertical/horizontal bar chart or graph, frequency distribution chart. |
| | Proportional | Figure used (subdivided circle or band) | Circular: pie chart, cake chart, divided circle graph, sector chart, circle diagram, sectogram, etc.<br>Band: divided, subdivided, stacked, extended, composite bar/column chart/graph |
| Morphograms | Radial | | Star, radar, spider or radial column graph, glyph |
| | Polygonal | | |
| | Chernoff faces | | Cartoon faces |

**Curvigrams,** by contrast, afford the description of the more abstract form of the quantitative relation between two variables. They are bivariate by nature, and the curve that traces the shape of the relation is either constructed mathematically based on the principles of analytical geometry, or approximated with different techniques; it is traced in a Cartesian space. One of the graphic rules of curvigrams is that the variable whose fluctuation is studied (the dependent variable) is assigned to the ordinate or vertical axis, while the acting (independent) variable is assigned to the abscissa or horizontal axis. Rarely, attempts are made to show the relative variations of three variables; the result is then the drawing of a curved surface within an x-y-z space.

Curvigrams have been adapted to very different uses. The basic Cartesian design calls for calibrated perpendicular axes with a value of zero at the origin and a continuous progression of values along the axes. In some instances, the independent variable is treated in a different manner: values are grouped in quantitative intervals (e.g., age groups) and the resulting interval curvigram is a series of steps at times separated by vertical lines. But there are many forms of what can be called quasi-Cartesian designs, using a different axis system. The most frequent is probably the polar curvigram, whose name evokes maps viewed from the poles; here the curve is drawn within a circle whose center is the origin, with the x-axis on parallels and the y-axis on meridians. Instruments recording cyclical events frequently produce this type of recording then known as a clock chart. The floating axis is also frequent, and is used for example to represent instrument recordings such as electrocardiograms or chromatograms in which there is no real origin, and where calibrations are indicated by lines of a given length and value.

Curvigrams can also be qualified according to the type of line drawn: straight lines, broken or segmented lines, true curves, stepped lines corresponding to the nature of the data (continuous or interval) or to the type of relation depicted (linear for simple correlations, curved for higher order relations). In all these curvigrams, the distinguishing feature is the possibility to move at least one step away from the crude results and to topologically model the relation between variables.

**Puncti-curvigrams** are in a way a hybrid form between the two preceding orders. Here both the individual dots and a curve of the relation are graphed in order to show both the variability in the data and the ideal relation between them. This dual affordance makes puncti-curvigrams one of the most frequently used analograms.

**Histograms** are the fourth order of analograms. Here quantitative data belong to or describe distinct groups within a population. This is an important property of histograms: they do not represent sets of quantitative data, but quantities assigned to nonquantitative entities; therefore, they cannot be designed in a truly cartesian space, which calls for two calibrated axes. The categories used can be nominal or ordinal. They are represented by the graphical sign of a surface, or area, either rectangular or wedge shaped, with this peculiar feature that only one dimension of the figure (either length of a rectangle or angular opening of a wedge) is modulated by the value in the data.

We can distinguish two families of histograms based on the type of data they represent. The first is that of *absolute histograms*, which show data expressed as numbers resulting from counting or measuring. These are shown using series of horizontal or vertical bands or rectangles, one per category, with their length related to the appropriate value; in his first description of histograms, Playfair (1786) insisted on the metaphorical origin of the columns he used, financial data being depicted by idealized piles of coins. The rectangles in histograms are not drawn on an axis, but on an uncalibrated baseline, which is more of a plastic sign, a metaphorical representation of a post or a ground line supporting the rectangles. Printed absolute histograms are usually vertical, using "columns," while projected visuals can more frequently call upon horizontal bars, due to the greater width of screen images.

The second family of histograms, *proportional histograms*, is characterized again by the nature of the information they present. Here we deal with proportions showing the distribution of values within a given population; the values are therefore expressed in percentages. Graphically, two distinct figures can be used to represent a population and its subdivisions. In one case, a circle is used, giving birth to a visual better known as a pie chart. As is well known, the circle is the metaphor of a whole entity, 100%, which is then divided in wedges the angular openings of which are proportional to the percentage value attributed to the category they represent. The inefficiency of this graphical representation has been frequently and soundly demonstrated (Cleveland & McGill, 1985; Bertin, 1977; Tufte, 1983) and a different figure, the proportional band or rectangle, is available. In this case, the length of each rectangle is defined as 100%, and each subdivision is of a length proportional to the percentage it represents.

On a functional basis, all families of histograms can be used to simply show the distribution of a property in a population, in which case they can be qualified as descriptive histograms. But they are also used widely to establish comparisons between populations, and a certain number of graphical variants can be used to draw comparative histograms (Desnoyers, 2005). A single histogram can be drawn with multiple sets of bands that can be arranged in different fashions (e.g., paired, opposed, stacked); the texture or color of each set specifies the group it represents. Or montages can be used, juxtaposing different histograms for each set; this is the only way to show comparisons between proportional histograms.

We have kept the name histogram for this class since its etymology seems appropriate: histo referring in ancient Greek to mast as well as tissue, which is compatible with rectangular or wedge-shaped areas. Some authors distinguish histograms from bar graphs or pie charts, reserving the first denomination only for sets of adjacent rectangles presenting classes based on quantitative intervals; there is no sound reason to use full rectangles in this case, and it is our opinion that such figures are better described and represented as interval and stepped curvigrams. We have not considered here the case of iconic histograms, which are a tool of science popularization rather than of communication among scientists. Neurath (1980) one of the most important protagonists of their use, has well demonstrated the usefulness but also the limits in the efficiency of these figures (i.e., Tufte, 1983).

**Morphograms** are the fifth and final order of analograms. This order specifically affords the comparison of statistical populations described with multivariate data. Each population is represented by a figure of the same type, and each variable is attributed to one calibrated graphical element of this figure. The result is, for each population, a particular shape of this figure, and the visual comparison of shapes allows one to detect global similarities and differences between populations. The figures used here are best described as "object-oriented figures" and have received considerable attention in fields concerned with display design (Carswell & Wickens, 1987). Morphograms are not frequently used by scientists, despite their efficiency (Desnoyers, 2011).

A first family of morphograms is often referred to as "star," "radar," or "spider" graphs but is better described as *radial morphograms*. In this case, the figure is made by drawing from a central point equidistant and calibrated virtual spokes, each one assigned to a specific variable. A line of appropriate length is then drawn on each spoke, giving rise to a starlike figure of a distinct shape. *Polygon morphograms* use the same principle, but in this case the ends of all radiuses are joined by a line, giving rise to a solid figure. The third case is that of *Chernoff's faces* (Chernoff, 1973) where the figure is a stylized human face with each variable assigned to a given trait, the size or shape of which varies with the value of the variable. The human brain being quite efficient in recognizing shapes in general and particularly faces, morphograms can be an efficient tool for global multivariate comparisons.

Globally, analograms are the class of visuals that call for the more radical form of topologization. The transfer of nonspatial, quantitative data to spatial representation is done according to a set of rules rarely defined in explicit terms. Basically, these rely on the concept of calibrated Cartesian space, while frequently referring to metaphors or object-oriented images for graphic expression. They are the visuals that are the most characteristic of scientific discourse, up to the point where they are often used in nonscientific contexts to offer a veneer of science and credibility.

## Comments

We briefly mentioned the study by Cleveland (1984) and others on errors made in visuals accompanying papers in periodicals. It seems paradoxical that, despite the professionalism of authors as well as editors and referees, so many faulty visuals would be printed. The causes of such a failure could be manifold, from a lack of consideration for graphical expression to inadequate visual literacy (Felten, 2008). In all areas of knowledge, literacy implies the mastery of both a lexicon and the rules or the grammar that govern its use in expression. It is certainly difficult to master a language when the basic vocabulary is loaded with ambiguity and clouded by polysemy, as it is impossible to learn playing chess without knowing the names of the pieces. Training students, helping professionals, and conducting research on the use of visuals are problematic in the absence of a consensual lexicon of visuals.

It is these reasons that led us to develop the taxonomy summarized in Figure 1. We have followed the rules developed by von Linne to organize taxa and to develop a systematic nomenclature. This ensures a certain coherence in the proposed taxonomy but certainly offers no warranty as to its adequacy, its usefulness, or its acceptance. We know the proposed taxonomy is incomplete, considering the remarkable number and diversity of existing visuals, as well as the creativity of scientists and authors in graphic design. It will have to be added to, analyzed, discussed, and put to the test in order to verify its relevance.

## Implications: Guidelines Development

As mentioned above, the development of a consensual taxonomy would provide a harmonized lexicon, but visual literacy also implies a grammar whose rules would be the basis of guidelines in the choice as well as design of efficient visuals. Some of the existing texts on guidelines are productive tools, but many are incomplete since they either cover only part of the visuals used in science or overlook some of the guiding principles in the design of efficient visuals, not to mention their differences in denominations. There is need for a thorough integration of theoretical and empirical knowledge from areas as diverse as perception psychology, science methodology, and particularly statistics, graphic arts, communication sciences, etc. A systematic taxonomy is but a first step in this direction.

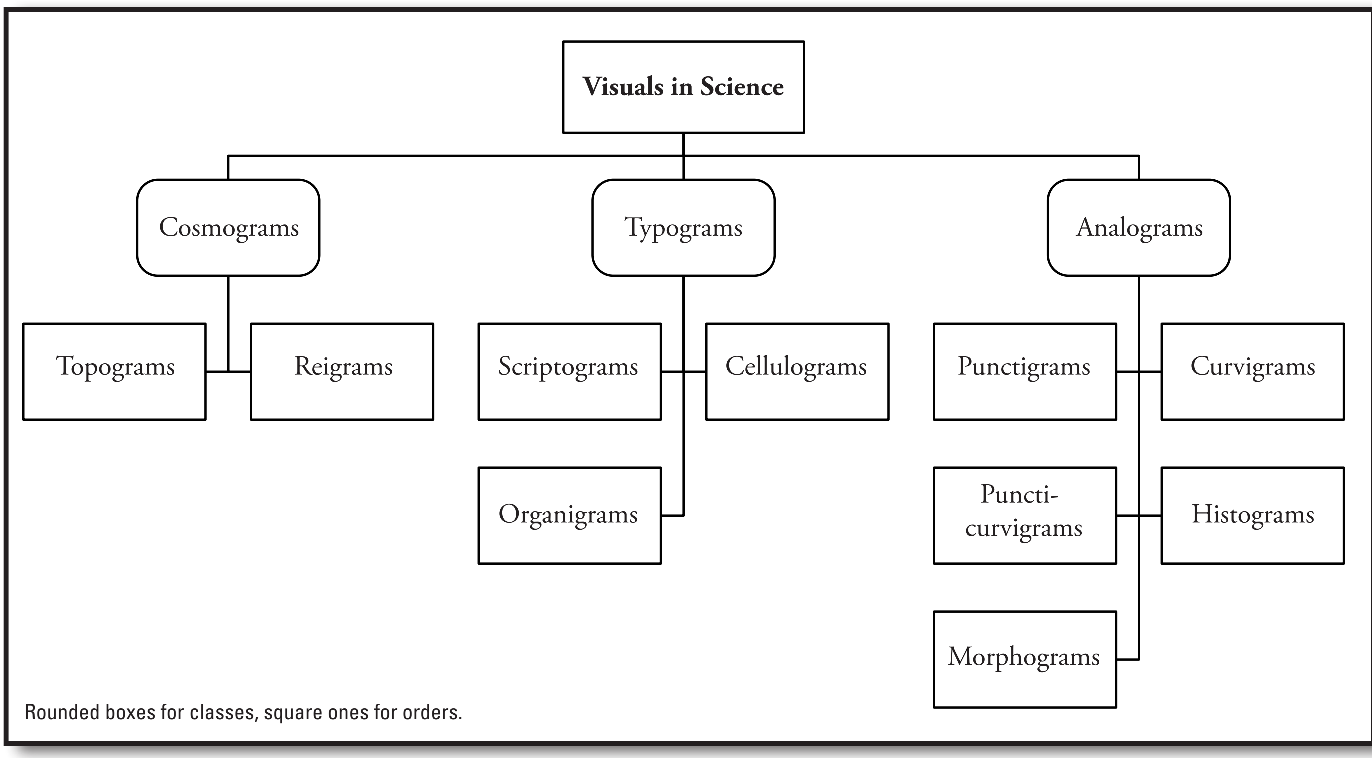


**Figure 1. Organigram of the taxonomy and nomenclature of the main taxa of scientific visuals**

### Implications: Student Training

In the long term, an improvement in the use and design of visuals in science implies a major move in training, particularly with graduate students in science. The generalized use of presentation software like PowerPoint has wrongly convinced students that paper presentation is impossible without projections and that almost anything is better than a blank screen. There is a need for coordinated efforts in training, while little information is available on isolated attempts throughout the world. In our continued practice, mostly at Université du Québec à Montréal, the proposed taxonomy is systematically used as a basis to expose the specific affordances of currently used visuals (Desnoyers, 2007). The guidance provided is put to the test when students are invited to evaluate visuals presented to them as well as react to the presentations by colleagues during rehearsals within the class group. Although this type of course has not been submitted to scientific evaluation, the simple fact that it is still offered after 30 years indicates a certain efficiency. It is our opinion that this area deserves more attention than what it gets, and that the extension of such training to groups like science communication classes should be considered.

### Implications: Professional Practice

Science communicators and scientists are avid readers of papers and monographs in their field of interest and have been trained or have developed abilities in the critical reading of scientific prose. Visuals are some of the most important arguments in these writings (Latour & Woolgar, 1988). But the fact that so many still contain mistakes after a strict reviewing process is a challenge for readers, who in our opinion could be better trained in error detection (Bryan, 1995). A harmonized taxonomy and more stringent guidelines would alleviate our task in appraising scientific visuals as well as other forms of presentation. We could likewise all become more rigorous in our own production of visuals.

### Implications: Research

As noted above, little research has been produced on the actual use of visuals in science communication. Again, the lack of a harmonized classification and lexicon is an impediment in such activity and in the comparison of published results. Using the proposed taxonomy, we have been able to analyze the use of different categories of visuals in different scientific paper genres published in ergonomics periodicals (Desnoyers, 2009; forthcoming). The preliminary results show that review papers make a very limited use of visuals, except for organigrams, while papers dealing with theorization and modeling used the largest number, particularly equations, organigrams, and pictographic cosmograms. Experimentations make a massive use of analograms, mostly histograms, and photographic cosmograms. Reports of inquiries use a maximum number of quantitative cellulograms. Such findings call for in-depth analysis and comparisons with different disciplines and communicational genres, and they should be useful in training.

## Conclusion

Communication in science and technology relies heavily on visuals of an extraordinary diversity, developed and still developing in separate and even isolated fields of science as well as in different contexts. That this diversity has led to such variety in the denominations of visuals and to the prevailing polysemy is probably not surprising, but surprising is the fact that not much has been done to bring some order in this chaos.

From the author's ergonomics perspective, taxonomy can be considered as a tool. There is no such thing as a universal and definitive tool, and for example the simple hammer has been adapted in shape, mass, and material to the specific needs of mechanics as well as sculptors, carpenters, and the like, and no doubt more adaptations will follow. Frequent adjustments or additions have been made to this taxonomy since it was first considered in the 1980s. It is expected that adaptation would go on to make room for new entities, and to consider additional criteria for classification.

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## About the Author

**Luc Desnoyers** is an Associate (retired) Professor in the Biological Sciences Department at the Université du Québec à Montréal. After earning a PhD in visual system neurophysiology (1969), he turned to ergonomics and made a specialty of visual ergonomics. He has been involved in the training of graduate students from different fields in science communication for more than 30 years and has conducted research in this area. He is an Honorary Fellow of the Société d'Ergonomie de Langue Française and the Canadian Association of Ergonomists, having served as president of both Societies. Correspondence concerning this article should be addressed to Luc Desnoyers, Département des Sciences biologiques, Université du Québec à Montréal, CP 8888 Succ Centre-ville, Montréal QC, Canada H3C 3P8. E-mail: desnoyers.luc@uqam.ca

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Society for Technical Communication

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# International Society Honors Quebec Professor

The Society for Technical Communication honored Université du Québec à Montréal professor Luc Desnoyers in a ceremony at its annual conference in Rosemont, IL on 22 May.

Desnoyers received a Distinguished Article honor in the Frank R. Smith Award for his article "Toward a Taxonomy of Visuals in Science Communication" in the May 2011 issue of *Technical Communication*. The Frank R. Smith award recognizes the authors of exceptional articles that appeared in *Technical Communication* during the preceding calendar year. Since 1966, STC has paid tribute to the authors whose contributions have made *Technical Communication* one of the most highly respected journals devoted to the arts and sciences of technical communication.

The judges wrote of Desnoyers's article: *The Desnoyers article is ground-breaking work that addresses a key issue in visual communication that has not received much attention: classifying the wide array of disparate graphical forms used in many different scientific and technical disciplines. The article is well written, provides a broad scholarly perspective on the subject, and proposes an ingenious and comprehensive taxonomy that will enhance our understanding of visuals.*

Luc Desnoyers is an Associate (retired) Professor of Ergonomics at Université du Québec à Montréal (UQAM), Canada. His specialty is visual information gathering and, although retired, he is pursuing research on the use of visuals in communications by scientists. His research has led him to develop a taxonomy of the visuals used by scientists in articles as well as in congress presentations. This taxonomy has been helpful in analysing the differential use of visuals in communications as well as in training graduate students for congress presentations, a task Professor Desnoyers has been involved in for the past thirty years, at UQAM as well as in different institutions in France.

Luc Desnoyers is the author of a monograph on this subject ("La communication en congrès – Repères ergonomiques", PUQ 2005). His work in this field, over the last ten years, has also led to the publication of ten papers in periodicals dealing with science and technical communication as well as visual semiotics.

Professor Desnoyers is a Fellow of the International Ergonomics Association; he is also an Honorary Member of the Société d'Ergonomie de Langue Française and the Canadian Association of Ergonomists, having served as President of both Societies.

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