CHAPTER 1

HIERARCHICAL STRUCTURES: TREES

Stefanie Posavec and Greg McInerny, U.S.: "(En)tangled Word Bank," 2009.

The series of diagrams represents changes in the six editions of Charles Darwin's *On the Origin of Species*. Chapters are divided into subchapters, subchapters into paragraph "leaves," and, finally, small wedge-shaped "leaflets" stand for sentences. Each sentence is colored in blue if it survives to the next edition, and in orange if it is deleted.

In a nutshell, hierarchical systems are ordered sets where elements and/or subsets are organized in a given relationship to one another, both among themselves and within the whole. Relationships vary according to the field domain and type of system, but, in general, we can describe them by the properties of elements and the laws that govern them (e.g., how they are shared and/or related).

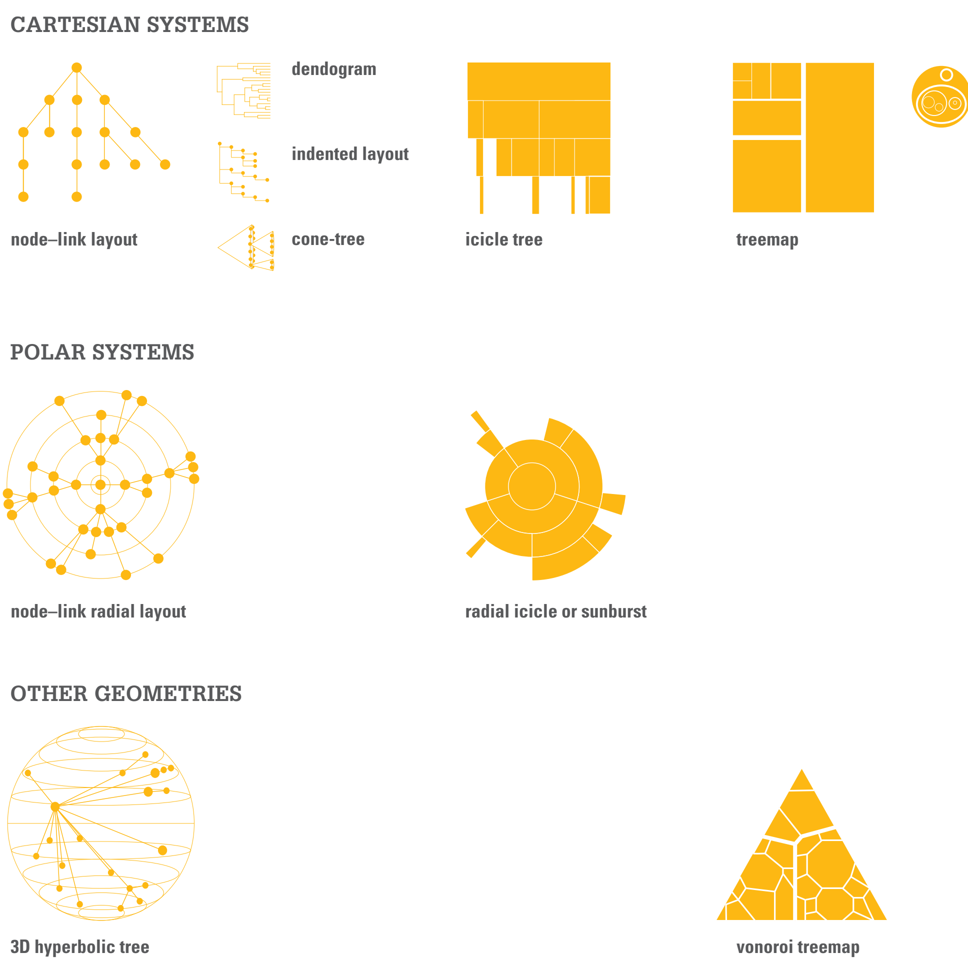
In the seminal article "The Architecture of Complexity," Herbert A. Simon contends that complexity often takes the form of hierarchy and, as such, hierarchy "is one of the central structural schemes that the architect of complexity uses."[1] Examples of hierarchical representations abound in the social and natural sciences throughout time up to today. According to Chen, "Visualizing hierarchies is one of the most mature and active branches in information visualization."[2]

REPRESENTATION

Looking at hierarchical structures over time, it becomes apparent that ordered datasets are represented visually in two basic graphical forms, which sometimes are also combined: stacked and nested schemes.

In stacked schemes, the elements are arranged in a directional relationship to one another: vertically, horizontally, or centrally (superior/inferior, center/periphery). In many instances, lines connect the elements in the set. Lines are one-dimensional visual elements described by their length and also provide directionality. Different geometries have been used to display stacked schemes, especially with recent computational models such as cone trees and hyperbolic views, for example.[3]

Elements in nested schemes are positioned within containers assembled according to their interdependency and subordination. The container, often a two-dimensional plane, provides the grouping



The table provides a summary of hierarchical structures used in diverse fields over time. With the increasing accessibility of data in the digital age, and the need to represent trees with huge amounts of leaves, methods are constantly being devised to solve readability issues of hierarchical representations in the constrained spatial computer screens. Most methods use interactivity to enhance navigating between macro and micro scales of trees with large depth and breadth. For example, degree of interest trees use "focus + context" strategies to interactively navigate large trees by allowing filtering of nodes to display or collapse, as well as semantic zooming. These and other approaches for navigating large trees with text are investigated in chapter 6, Textual Structures.

and association of elements. Known examples are Venn diagrams and treemaps.[4] The latter is examined in closer detail at the end of this chapter.

VISUAL HIERARCHIES

It might sound like a tautology, but to effectively visualize hierarchical systems we need a well-defined hierarchical visual encoding system. In the art and design fields, we refer to hierarchy of visual elements mostly in relation to emphasis and attention, for example, as a means to help the eyes follow a certain direction or purpose. It is common to find the term *contrast* rather than *hierarchy* in art and design literature. Dondis in his seminal *A Primer of Visual Literacy* considers contrast as the prime visual technique: "In the process of visual articulation, contrast is a vital force in creating a coherent whole. In all of art, contrast is a powerful tool of expression, the means for intensification of meaning and, therefore, of simplification of communication."[5]

Whatever the term—visual hierarchy or contrast—to further understand the implication of how we visually encode data, it is necessary to first briefly examine how our visual perception and cognitive systems work.

SPATIAL ENCODING

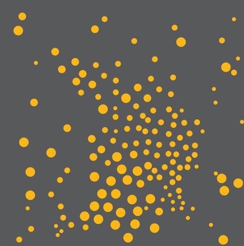
We process spatial properties (position and size) separately from object properties (such as shape, color, texture, etc).[6] Furthermore, position in space and time has a dominant role in perceptual organization, as well as in memory.

It is perhaps no coincidence that the ancient "art of memory" relied on spatial information for augmenting long-term memory.[7] Although the method called mainly for the creation of internal representations to enhance memorization and recollection, it is worth referring to its basic procedures here. The rules varied throughout its history, but, overall, the method proposes the use of an ordered sequence of *loci* as placeholders for concepts and of "active" visual images to stand for subject matters. It is quite fascinating how much these "invisible" mnemonic devices share with external data representations: an artificial and ordered system made out of visual elements, properties, and spatial relations.

Proximity

Proximity describes the tendency to group visual elements that are near one another into a perceptual unit. For example, we perceive the same six elements below as forming different groups:

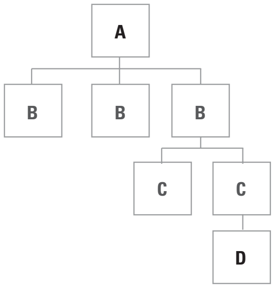
||||||	**= 1 group**	**= *word***
||| |||	**= 2 groups**	**= *two words***



Proximity relates to locational characteristics and is essential to how elements are spatially associated, whether intentionally or not. Note how easily we detect groups and how we tend to make sense of the perceived patterns in the image above with randomly generated sets of dots.

The difference between the images above is that one is rotated 90 degrees in relation to the other. Otherwise, they are identical. Note how we perceive rows in the first one and columns in the second. The space between dots makes us perceive the dots grouped as linear units in the horizontal or vertical direction.

In visual displays, it is crucial that we locate information that is conceptually related spatially close together. Spatial proximity will facilitate the detection and search for associated data.



In visual representations, the use of space is always schematic, independent of whether depictions of elements are direct or metaphorical. Spatial encoding is central to how we construct visualizations, in that the geometric properties and spatial relations in the representation—the topology—will stand for properties and relationships in the source domain. For example, in representations of physical data, graphical proximity represents proximity in physical space. The distance between A and D in the plan corresponds (in a given scale) to the physical distance between these places in real space.

In representations of abstract domains, graphical proximity corresponds to conceptual proximity, such as a shared property. For example, in an organizational diagram, distance in graphical space represents distance in the hierarchical structure of an organization. Graphical space is mapping the source domain of power and not the physical space, such that two people (A and D) might have adjacent offices in the real world, and be at opposite poles in the organizational diagram.

Most examples in this chapter visualize abstract domains, whereas spatial datasets are mostly examined in chapter 4. Because abstract domains mostly don't provide visual cues, assigning visual encoding to abstract data is a crucial step leading to robust and reliable visualizations.

Research on the cognitive operations a person executes in the process of reading a graph yields interesting results that contribute to the critical issue of finding the best spatio-visual representation to abstract data. Pinker examined these operations in relation to quantitative graphs and found that "people create schemas for specific types of graphs using a *general graph schema*, embodying their knowledge of what graphs are for and how they are interpreted in general."[8] He suggests that the theory can be extended to representations of qualitative information, where again, the reader would use schemas to mediate between perception and memory. Efficiency would be provided to the extent that the schema allows for correspondences between conceptual information and visual attributes, and insofar as the visual attributes are encoded reliably. In other words, to what extent do the visual schema and visual attributes stand for the structure and variables in the source domain? What is the likelihood of nonspatial content that is encoded spatially being readily recognizable and understood?

Guido of Arezzo, Italy: "Hand of Guido," 1274.

This was a popular medieval music theory mnemonic device created by eleventh-century musical scholar Guido of Arezzo, hence the name. The one pictured here is taken from a manuscript written in 1274. Murdoch explains, "[It] is unique in its inclusion of a human, one of whose magnified hands provides the 'diagram.' In addition to the foregoing letter notation, it represents the 20-note sequence in two other manners: first, numerically as puncti (often abbreviated as a mere 'p') with accompanying Roman numerals; second, by solmization, that is, by syllables ut-re-mi-fa-sol-la, a system invented by Guido himself, the symbols themselves being the initial syllables of a familiar hymn to St. John."[13] The solmization appears both in the hand as well as in the outer circumference.

VISUAL PERCEPTION AND COGNITION

Although information in visual displays is available to us simultaneously, our visual systems extract features separately and over stages: from early vision processes, mostly precognitive, and dominated by bottom-up processes; to higher levels of processing, in which outputs from previous stages are combined with previous knowledge and knowledge structures. Ware proposes a three-stage model of perception:[9]

Stage 1: Rapid parallel processing to extract basic features;

Stage 2: Slow serial processing for extraction of patterns and structures;

Stage 3: Sequential goal-oriented processing with information reduced to a few objects and held in working visual memory to form the basis for visual thinking.

Preattentive processing happens very fast (usually in fewer than 10 milliseconds), and simultaneously (in parallel) for the purpose of rapid extraction of basic visual features (Stage 1). Preattentive features are processed prior to conscious attention, and refer to detection of what we commonly call "at a glance." Designers can use preattentive features to enhance detection of relevant information in visualizations, because the marks will literally *pop out*.

To illustrate the relevance of preattentive features in visual tasks, I borrow and expand on Ware's example provided by the four numerical images showing the same sequence of numbers. Imagine that we have to discover the total number of occurrences of 3.[10] In the top image, we would have to scan each number sequentially until we found our "target." In the other images, preattentive features help us perform the task faster and more efficiently by rapidly identifying the target and scanning only the relevant marks.

18596746321475030608030504090
70502769843010215346748950213
06057204020503090845064201040
70204070835061305080239245798

18596746321475030608030504090
70502769843010215346748950213
06057204020503090845064201040
70204070835061305080239245798

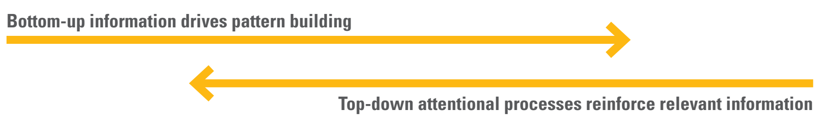
18596746321475030608030504090
70502769843010215346748950213
06057204020503090845064201040
70204070835061305080239245798

18596746**3**21475**3**06080**3**0504090
70502769843**3**010215**3**4674895021**3**
060572040205**3**090845064201040
702040708**3**5061**3**05080239245798

The examples use the same numbers but with different encoding for the number 3. In which one is it easier to detect the target "3" in the midst of the distractors?

THREE-STAGE MODEL OF PERCEPTUAL PROCESSING

A schematic overview of the simplified information-processing model of human visual perception proposed by Collin Ware.[14]



STAGE 1

Billions of neurons work in parallel to extract millions of **features** that are processed rapidly and simultaneously, such as color, texture, orientation, and so on.

STAGE 2

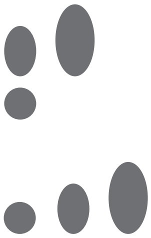
Patterns are extracted serially and slowly, such as regions of the same color, and regions of the same texture. The pattern-finding process leads to two pathways: object perception, and locomotion and action.

STAGE 3

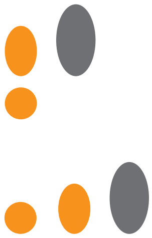
At the highest level of perception, we are able to hold between one and three **objects** at any instance in our working visual memory. Patterns that provide answers to the visual query construct the objects in conjunction with information stored in our long-term memory and that are related to the task at hand.

INTEGRAL AND SEPARABLE DIMENSIONS

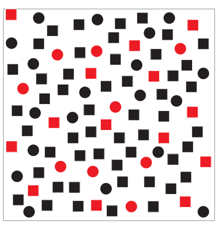
Visual dimensions can be perceived holistically (integral dimensions) or independently (separable dimensions).



The height and width of the ellipses create an integral perception of shape: the ellipses appear more similar to each other than to the circle, though it has the same diameter as the ellipse right above it.



Shape and color are separable dimensions, and the ellipse and circle with the same color are perceived as more similar than the two ellipses.[15]



CONJUNCTION SEARCHES

Elements in which features have been combined are not easily found, especially if surrounded by other elements with shared features. For example, searching for red squares in this image is not as easy as finding just red elements or only squared ones, because the surrounding elements have common features to those in our task: (black) squares and red (circles). Ware explains that these types of searches are called "conjunction searches" and are generally not preattentive and happen slowly.[16]

In this case, the visual properties of color hue (red), intensity or color value (gray/black), and line weight (bold) help us perform the task, because they are preattentively processed.

Preattentive features can increase the performance of the following tasks: target detection, boundary detection, region tracking, and counting and estimation. A series of features has been identified as preattentively processed, and they can be organized by form, color, motion, and spatial position. Sixteen preattentive features are illustrated on the table to the right, showing features for lines and planes.

There are, however, factors that might impair the detection of preattentive-designed symbols, such as the number and variety (degree of differentiation) of distractors in the representation and whether they stand for targets or nontargets (distractors).

Preattentive properties are not perceived equally. Studies in psychology have shown that our visual systems favor certain visual features over others (read more on the Similarity principle on page 51). The hierarchy depends on other features present in the visualization, such as color saturation and the degree of distinctness from surrounding marks.

Effective visualizations make intentional use of the preattentive features in the representation of graphical marks. The objective is to support perceptual inference and to enhance detection and recognition. This requires experimentation, as well as testing so as to check whether the target audience can easily perform the required tasks.

It is through discrimination (same-different dichotomy) in early vision that elements and patterns are detected and ordered (Stage 2). Patterns are central to how visual information is structured and organized. The Gestalt psychologists proposed a series of principles—known as the Gestalt laws—describing the way we detect patterns and how individual units are integrated into a coherent percept: Proximity, Similarity, Common Fate, Good Continuation, Closure, Simplicity, Familiarity, and Segregation between Figure and Ground.[11] Principles are explained in boxes throughout this book.

The Gestalt laws can be used as design principles for effective ways of enhancing pattern detection and perceptual inferences. For Wertheimer (1959), the Gestalt principles are effective not only in enhancing perceptual inferences but also in facilitating problem-solving and thinking processes.[12] He explains that the mechanisms of grouping, reorganizing, centering, etc, facilitate the understanding of the structural requirements of problems, allowing problems to be viewed as integrated and coherent wholes.

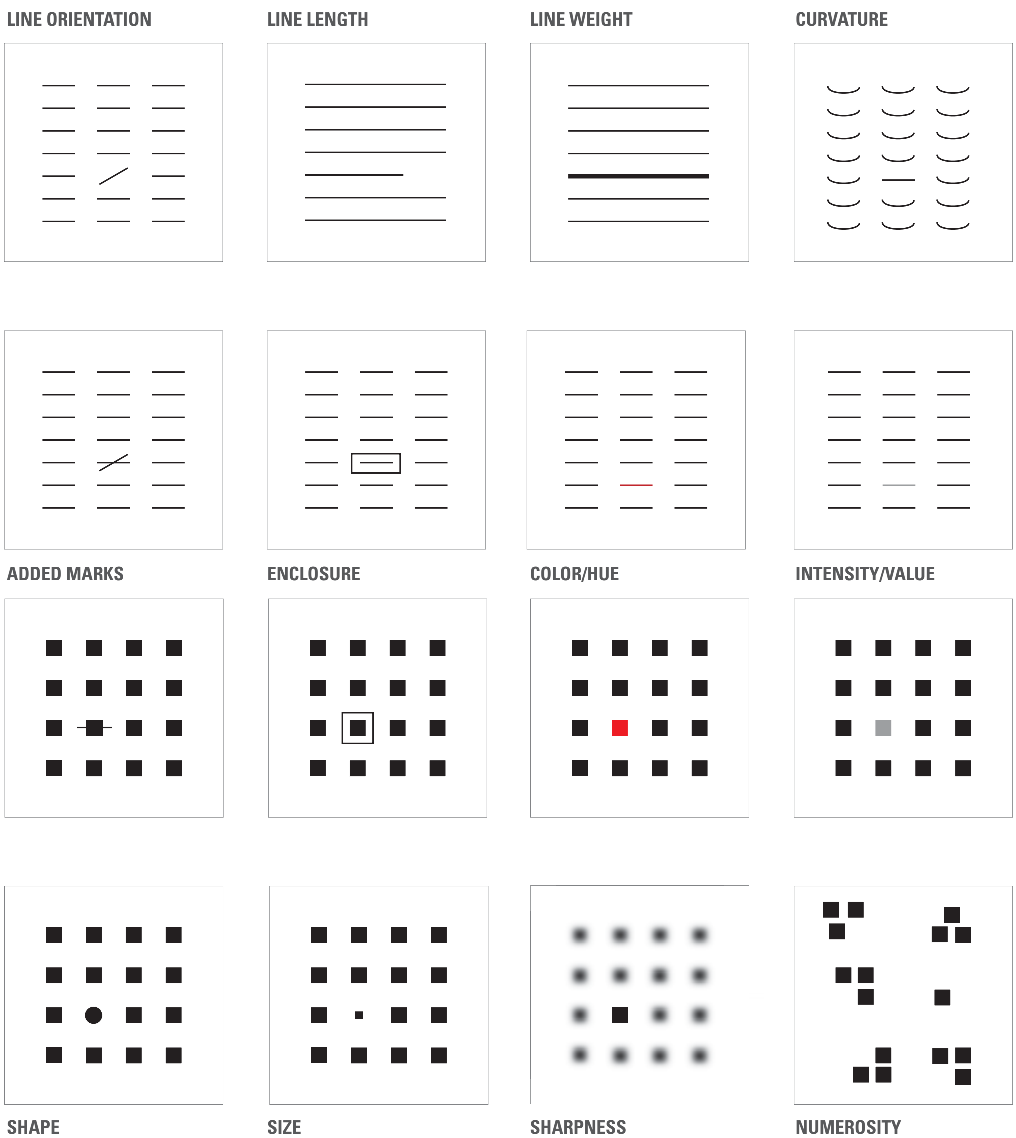
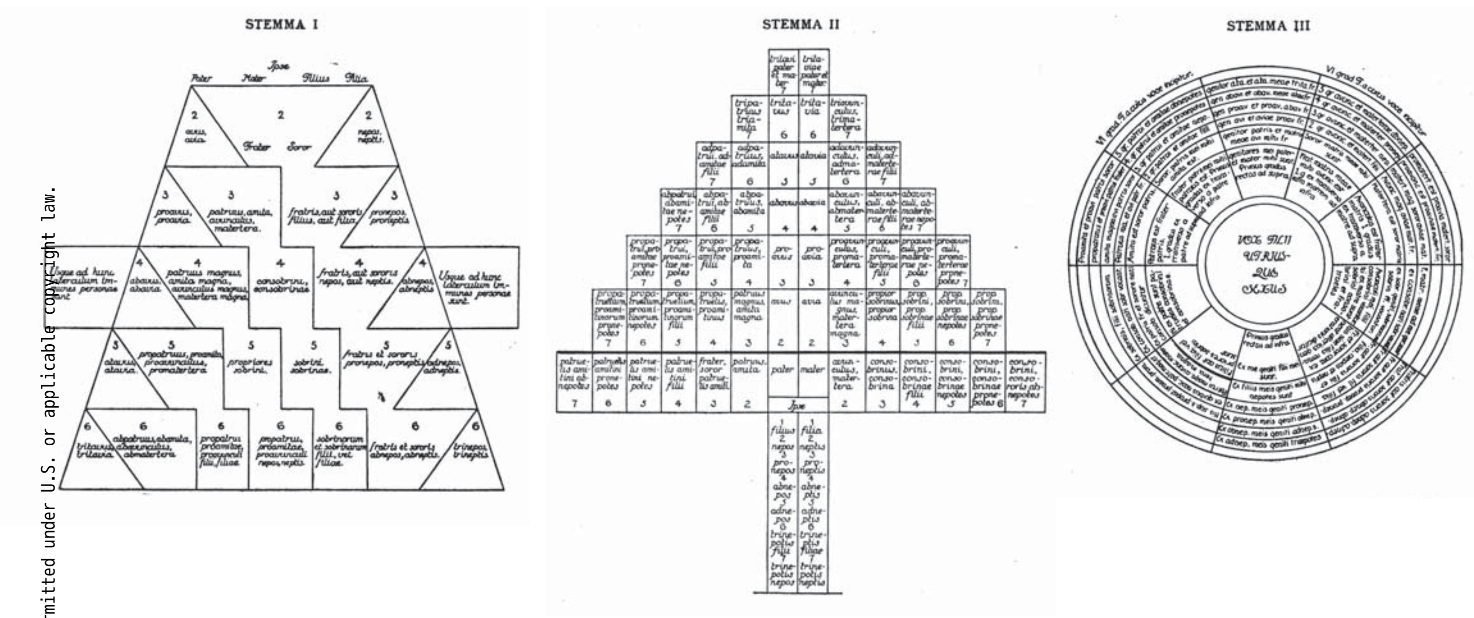
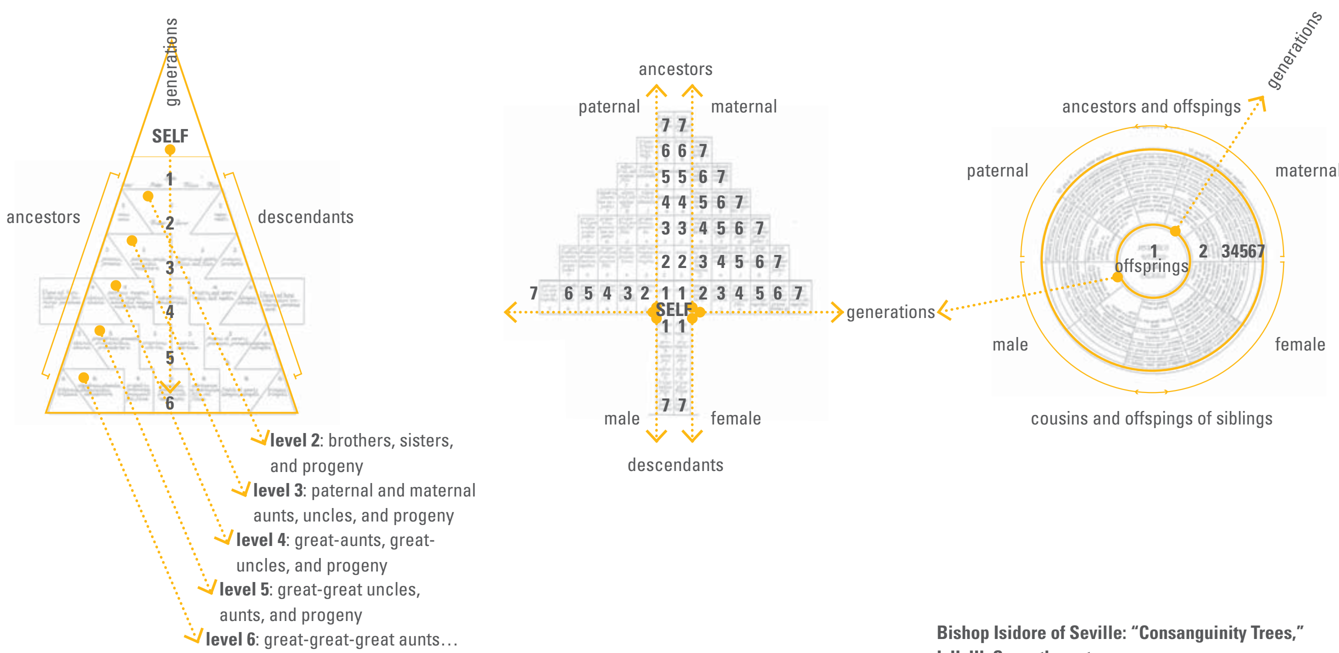


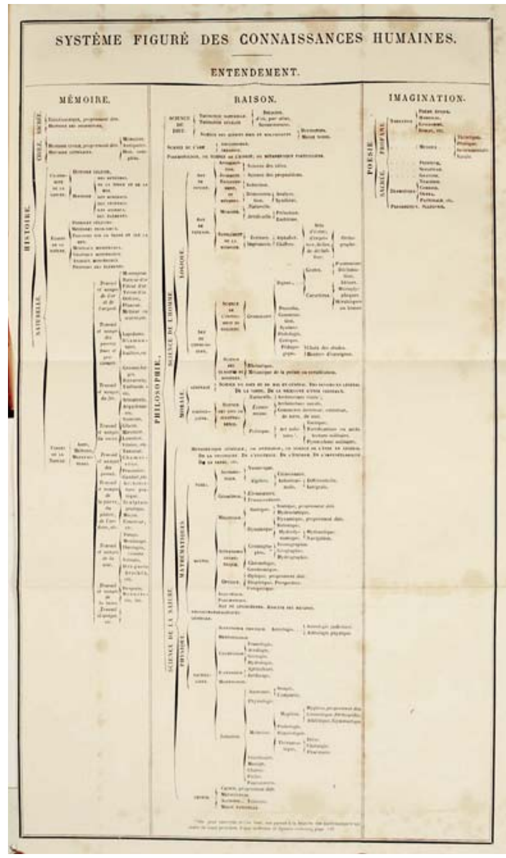
Table of preattentive features showing features for lines (top) and planes (bottom).





Bishop Isidore of Seville: "Consanguinity Trees," I, II, III, Seventh century.

Murdoch explains that one of the earliest uses of trees to illustrate a point in written text was genealogical, of which the first two diagrams are considered among the earliest instances.[17] The third option is a *rota*, a circular diagram.[18] All three consanguinity schemas appeared in the seventh-century Bishop Isidore of Seville's medieval encyclopedia *Liber Etymologiarum sieve originum*, book *XX*.



Hierarchy: *A body of persons or things ranked in grades, orders, or classes, one above another; spec. in Natural Science and Logic, a system or series of terms of successive rank (as classes, orders, genera, species, etc.), used in classification.*

Oxford English Dictionary

Ramon Llull: "Tree of Knowledge," 1515.

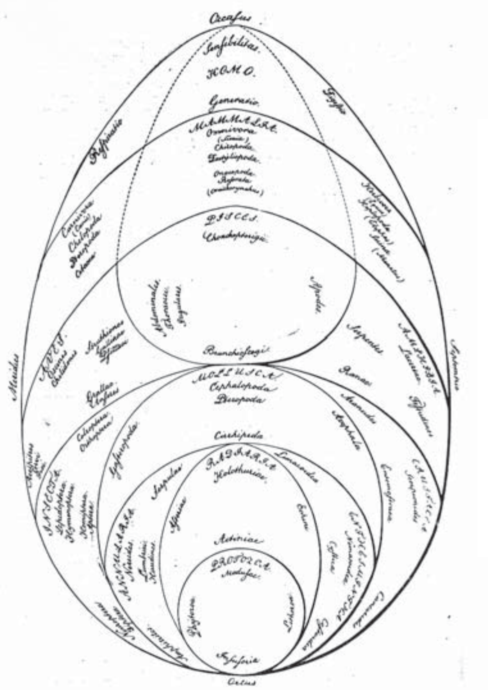
The diagram was published n the title page of *Arbor Scientiæ Venerabilis et Cælitvs.*

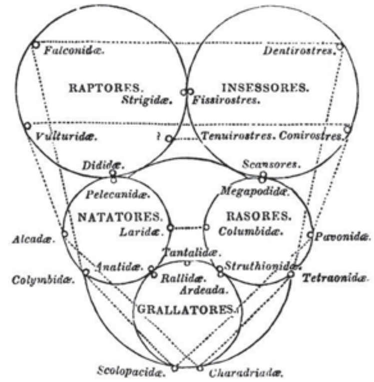
Athanasius Kircher: "Universal Horoscope of the Society of Jesus," 1646.

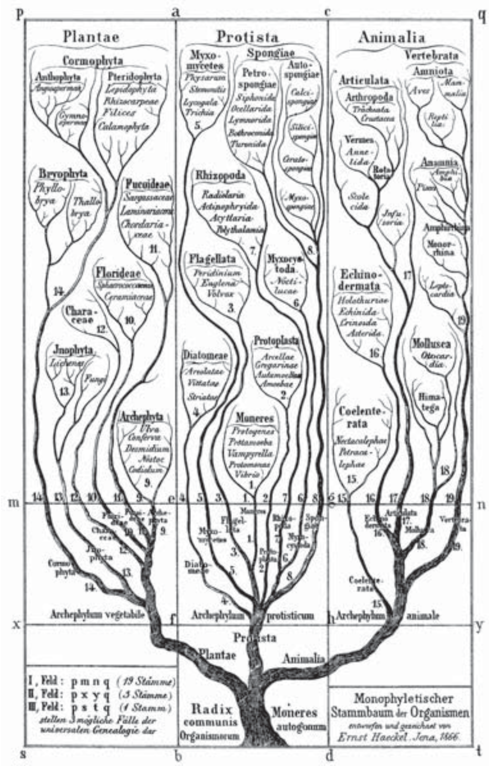
The diagram uses a composite sundial in the form of an olive tree with the base representing Rome. It appeared in *Ars Magna Lucis et Umbrae*, page 553.

Denis Diderot: Table of "Figurative System of Human Knowledge," 1751.

The system was published in *Oeuvres Complètes* (1876), tome XIII, between pages 164–165, edited by J. Assézat, Garnier, Paris.







By a hierarchic system, *or hierarchy, I mean a system that is composed of interrelated subsystems each of the latter being in turn, hierarchic in structure until we reach some lowest level of elementary subsystem. In most systems in nature it is somewhat arbitrary as to where we leave off the partitioning and what subsystems we take as elementary.*

Herbert A. Simon

Georg August Goldfuss: "System of Animals" in *Über de Entwicklungsstufen des Thieres* (*On Animal Development*), 1817.

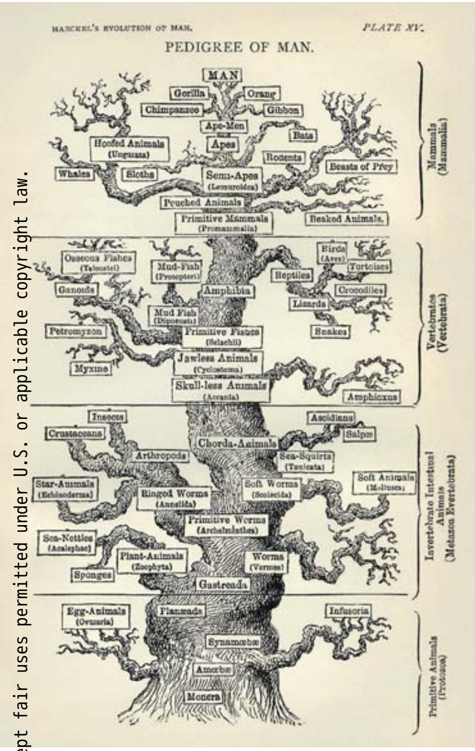
The nested diagram represents a linear progression from single-cell animals at the bottom to humans at the top. Pietsch suggests that this unique egg-shaped diagram might have been "meant to invoke an analogy between egg and the birth and progression of life."[19]

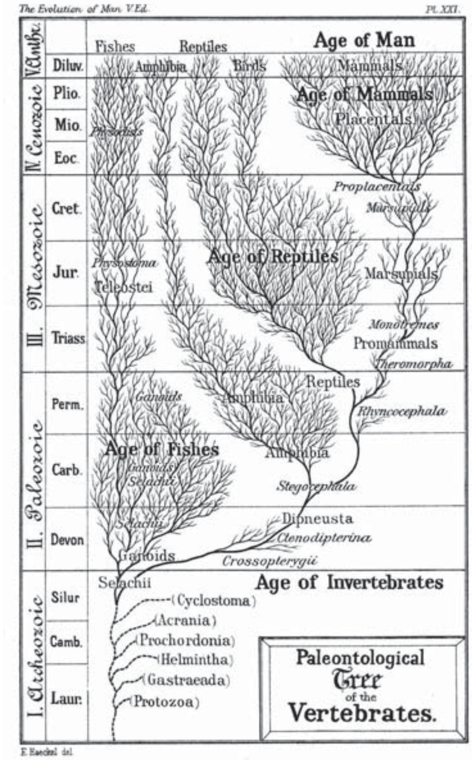
William Swainson: "Five Natural Orders of Birds" in *Natural History of Birds,* 1837.

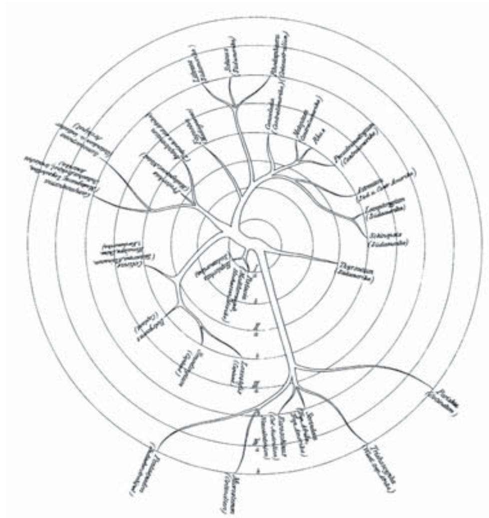
A proponent of general classification based on quinarianism, Swainson represented in the diagram the orders as circles, each containing five families. The dotted lines indicate relationships of analogy. Pietsch draws attention to the bottom part of the diagram in which the three lower orders are enclosed in a larger circle, standing for closer affinities.[20]

Ernst Haeckel: "Monophyletic Family Tree of Organisms" in the first edition of *Generelle Morphologie der Organismen* (*General Morphology of Organisms*), 1866.

This branching diagram is considered the earliest one published by Haeckel.[21] It shows the three kingdoms of life: unicellular organisms (*Protista*) and multicellular organisms—animals (*Animalia*) and plants (*Plantae*).







Ernst Haeckel: "Family Tree of Man," 1879.

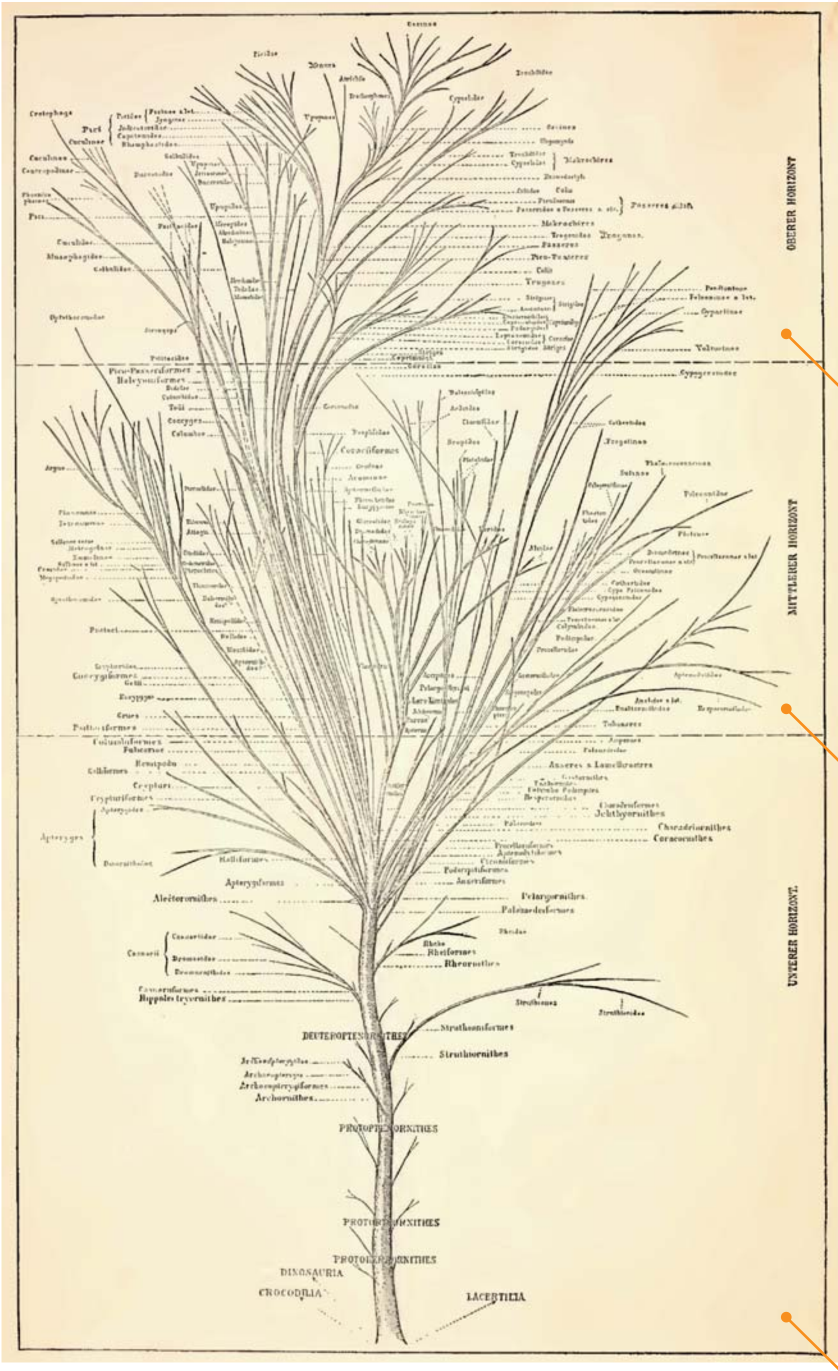
The well-known oak "Family Tree of Man" was published in the first edition of *Anthropogenie oder Entwickelungsgeschichte des Menschen* (*The Evolution of Man*).

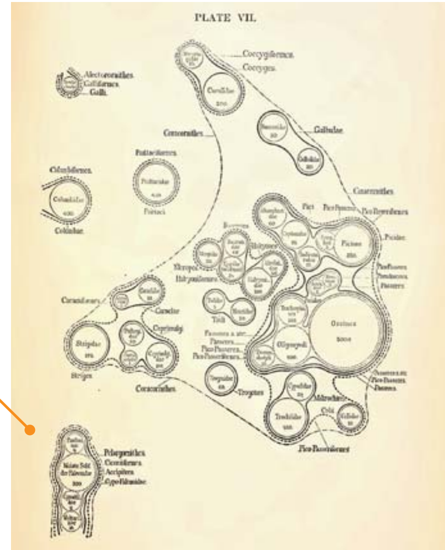
Ernst Haeckel: "Paleontological Tree of Vertebrates," c1879.

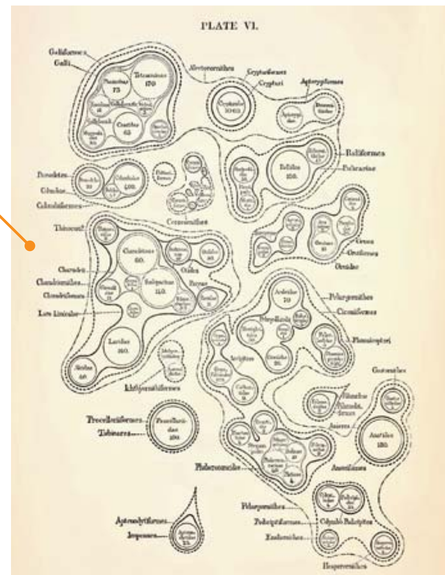
This diagram shows the evolutionary history of species.

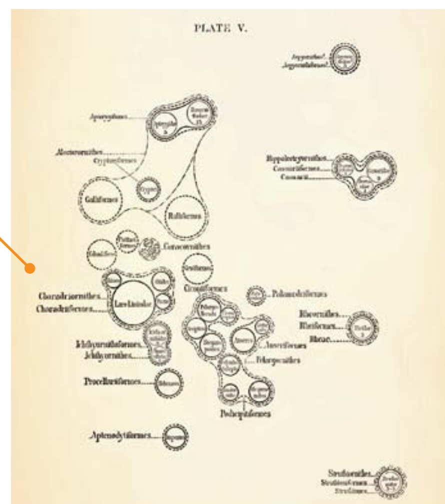
Heinrich Gustav Adolf Engler: Top-down view of "Tree of Relationships of Plants of the Cashew Family Anacardiaceae," 1881.

Pietsch explains that the "concentric circles, each corresponding to a morphological feature, provide a measure of relative divergence from a common ancestor. The idea of a tree is further demonstrated by the gradual narrowing of the branches toward their tips."[22]



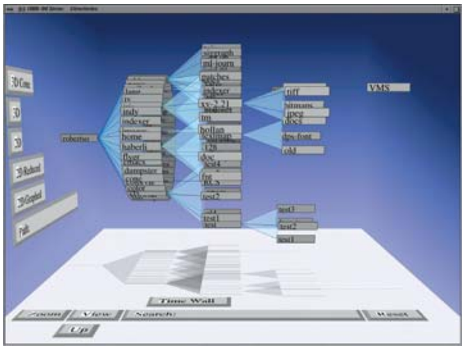


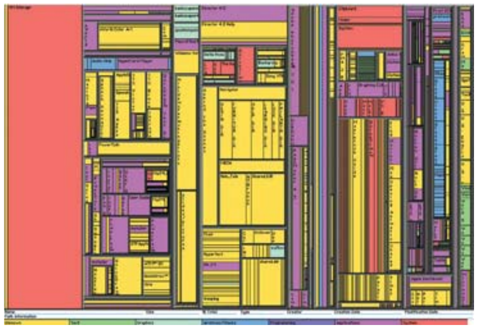


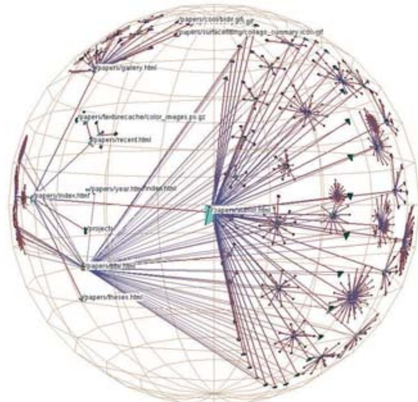


Max Fürbringer: Four diagrams representing the "Phylogenetic Tree of Birds" in *Bijdragen tot de Dierkunde*, tome XIII, vol. XV, edited by J. Assézat, Amsterdam, 1888.

The diagram on the top shows the vertical aspect of the tree, whereas Plates V–VII (to the right) show the horizontal projections for the upper, middle, and lower sections, respectively.







With increased access to large amounts of data, several new problems have arisen related to managing, accessing, and manipulating large information spaces within the constraints of computer screens. It is interesting to note that the orientation of diagrams, which mainly was vertical due to configurations of the book page, now, in the digital age, is mostly horizontal, because it better fits the aspect ratio of computer screens.

George Robertson, Jock D. Mackinlay, and Stuart Card at Xerox Palo Alto Research Center, U.S.: Snapshot of the "Cone Tree" visualization technique, 1991.

The method explored early technologies for 3-D visualization and interactive animation to structure hierarchical systems using cones: Each node is the apex of a cone, and the children are drawn around the base of the associated cone. Robertson and colleagues explain, "The hierarchy is presented in 3-D to maximize effective use of available screen space and enable visualization of the whole structure. Interactive animation is used to shift some of the user's cognitive load to the human perceptual system."[23]

Brian Johnson and Ben Shneiderman at the Human-Computer Interaction Laboratory[24] University of Maryland, U.S.: Snapshot of the "TreeViz" interface that uses a treemap to represent files in a computer, 1993.

Shneiderman originally devised the treemap technique in 1991 and he contends that "treemaps are a convenient representation that has unmatched utility for certain tasks. The capacity to see tens of thousands of nodes in a fixed space and find large areas or duplicate directories is very powerful."[25] The treemap technique is further examined in the case study that follows.

Tamara Munzner, U.S. : Snapshot of the "3-D Hyperbolic Tree," 1998.

Munzner devised and implemented the 3-D Hyperbolic Tree technique to navigate large datasets with the objective of reducing visual cluster and supporting dynamic exploration. Tamara explains that the layout in three-dimensional hyperbolic space allows for focus on a point of interest while providing enough context.[26]

TREEMAPS

SmartMoney Map of the Market

www.smartmoney.com/marketmap

The SmartMoney website describes its *Map of the Market* as "a powerful new tool for spotting investment trends and opportunities." The application represents information that is not inherently visible: stock market values. Data are structured by the value of market capitalization of public traded companies organized by sectors with updated information on capital gains and losses.

The visualization provides information on a large number of companies in a very small space: more than 530 stocks are grouped by sectors and updated every 15 minutes inside a rectangular shape of approximately 800 X 500 pixels. The display affords different levels of perceptual inferences, the most relevant being the discovery of patterns at the macro level. The application provides ways to interact with and examine data for specific periods of time in addition to other analytical tools and graphs.

Companies are organized by sectors (e.g., Financial, Technology, Communication) and arranged spatially as groups. Groups are separated by an outline that is easily detected by the line quality, which is thicker than other lines. The perceptual principle of closure facilitates the segregation between sectors in addition to the principle of simplicity affording easy detection of the groups.

Rectangular shapes representing individual companies populate each sector group. Companies are organized into two scales of order: market capitalization and price performance. The sizes of rectangles represent the market capitalization of individual companies. The color scheme encodes the stock price performances. Overall patterns in the data can be inferred easily by color detection and differentiations in the spectrum. The result is that, at a glance, we are able to spot areas showing gains and their related categorical industries.

THE BIRTH OF TREEMAPS

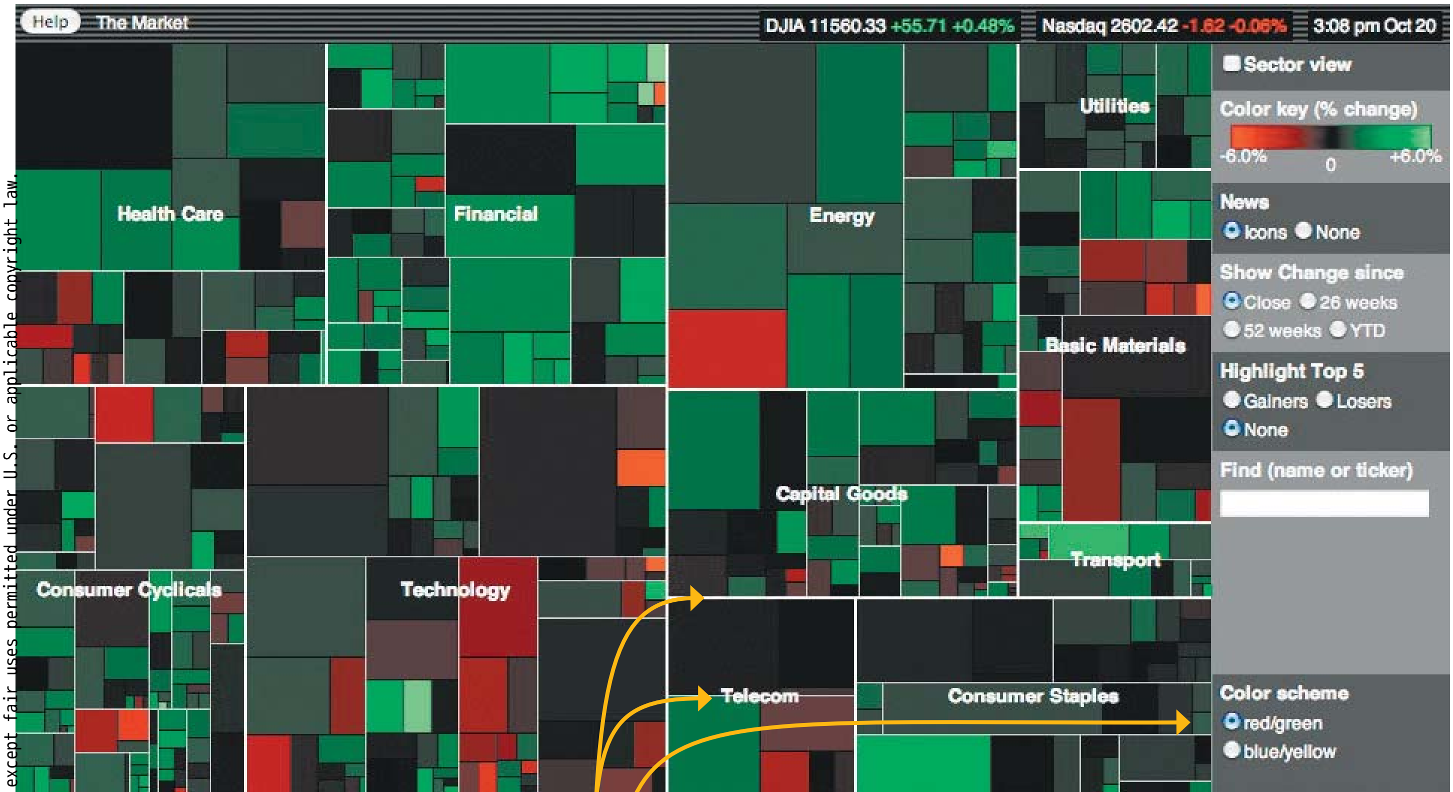
In 1990, Ben Shneiderman faced the problem of having a full hard disk and needing to find the files that were taking up most of the space. As an alternative to the analytical tools available at the time, mostly using tree structures, Shneiderman and his students at the Maryland Human-Computer Interaction Lab devised a method for visualizing the hierarchy of files using a space-filling technique called *treemap*. The name provides a good description of what the technique accomplishes: it uses all available space in a given shape to display hierarchical data.[27]

Treemap visualizations are space-efficient displays of large structured datasets: contiguous shapes are organized according to their hierarchy or categorization.

ALGORITHM

Novel algorithms have extended the treemap technique by proposing different layout methods for the partition of hierarchical data. The algorithm devised by Wattenberg generates a layout where the partitions have reasonable aspect ratios and are optimized by neighbor similarity. In other words, partitions are as close to squares as possible. This facilitates comparison of areas by positioning companies with similar price histories near each other.[28]

The popularity of the *SmartMoney Map of the Market*, which became one of the most trafficked sections of the site according to Wattenberg, gave rise to a broad use of the treemap technique in different domains. Treemaps are now considered to be one of the most often used techniques for visualizing large sets of hierarchical or categorical data. Furthermore, the technique has become a standard tool for visualizing financial data.



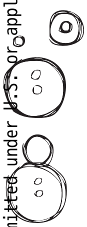
AUTHOR	Martin Wattenberg
COMPANY	SmartMoney.com
COUNTRY	United States
DATE	1998
MEDIUM	Online, real-time interactive application
DOMAIN	Finance
TASK	To provide an overview of stock market performance with detection of trends at given periods of time
STRUCTURE	The visualization uses the treemap technique. The algorithm devised by Wattenberg renders the internal divisions closer to squared shapes, resulting in a more legible and easier to interact with interface.

DATA TYPE AND VISUAL ENCODING

Categorical:	Sectors
Encoding:	Spatial positioning (grouping) and line weight
Temporal:	Invariant period of time
Encoding:	Text (enabled by selection)
Quantitative:	Market capitalization
Encoding:	Area size
Quantitative:	Price performance as percentages
Encoding:	Color scheme

CONCEPTUAL MODEL
Lakoff's theories on metaphor and categorization describe how basic-level and image-schematic concepts structure our experience of space and are used metaphorically to structure other concepts.[29]

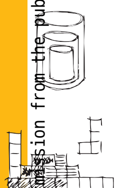
The *container* and the *part–whole* image schemas play a central role in the *SmartMoney Map of the Market* tool. These two image schemas are meaningful because they structure our direct experience, and in particular, our bodily experience. We experience ourselves as entities, as containers with a bounded surface and an in-out orientation. Lakoff explains that we tend to project this view onto other physical objects, events, and actions and to conceptualize them as entities and most often as containers.[30] The result is an act of quantification, in that we are defining territories—bounded areas—that can be quantified in terms of the amount they contain. We also experience our bodies as wholes with parts.



The structural elements of a container schema are interior, boundary, and exterior. Containers are the most appropriate schemas to structure categories.[31]

The structural elements of a part–whole schema are a whole, parts, and a configuration. The configuration is a crucial structuring factor in the part–whole schema. Considering that the parts can exist without constituting a whole, it is the configuration that makes it an image schema.

In the *SmartMoney Map of the Market*, enclosed rectangular shapes hierarchically represent quantitative data: sectors (containers) are each populated by subdivisions (sub-containers), which are divided into companies (sub-sub-containers). In all levels, we find part-whole schemas.

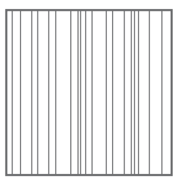


ARTIFACTS
Two artifacts that use similar fitting mechanisms as the treemap technique come to mind: nesting dolls and Tetris, the ubiquitous computer game from the 1980s. Coincidentally, both have Russian origins.

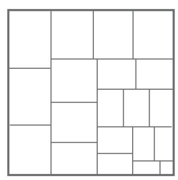
LEVEL 1:
Sectors

LEVEL 2:
Subdivisions of sectors

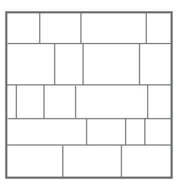
LEVEL 3:
Companies



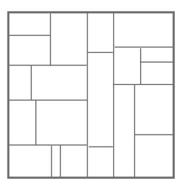
slice-and-dice



squarified



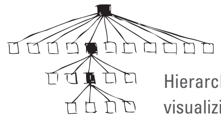
strip treemap

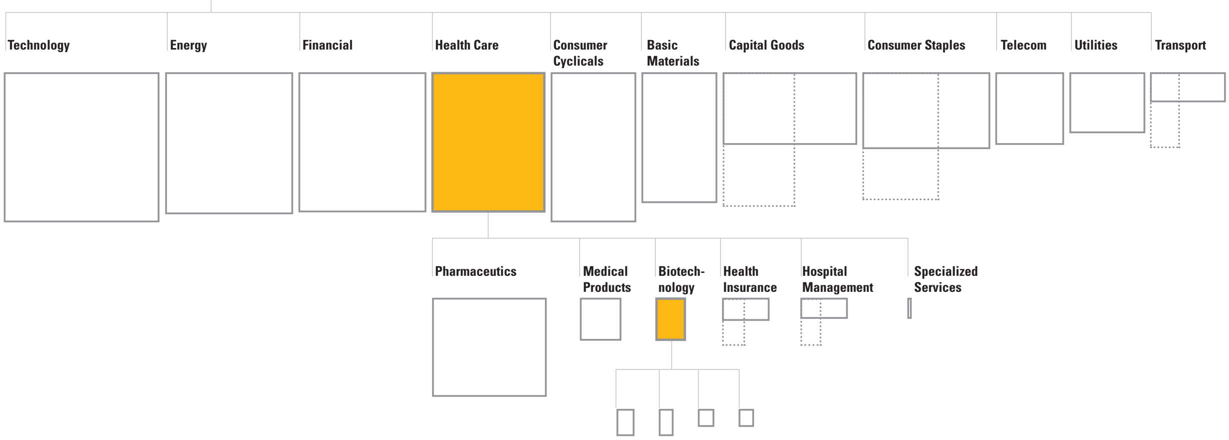


pivot by split size

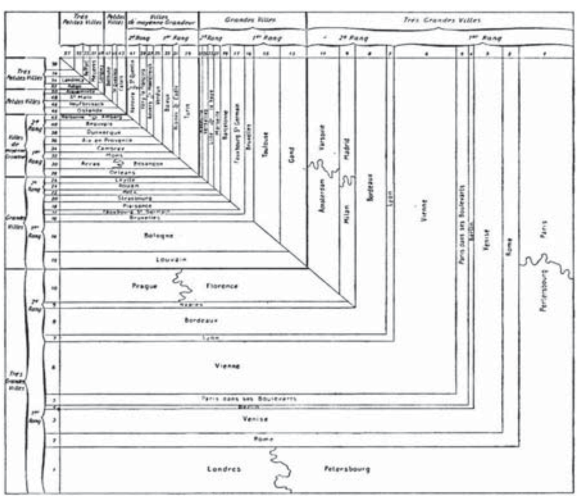
Martin Wattenberg and Ben Bederson, from the Human-Computer Interaction Lab at the University of Maryland, designed an applet titled Dynamic Treemap Layout Comparison. As the title suggests, the tool allows comparison between the four most common layout methods for the partition of treemaps. The diagrams to the left were redrawn after their tool.[38]

www.cs.umd.edu/hcil/treemap-history/java_algorithms/LayoutApplet.html





Hierarchical node–link diagrams are not effective for visualizing large datasets, as the tree structure for the data highlighted in the screenshots on the left attempt to show. In the diagram, sectors are organized by market capitalization, from larger to smaller areas. Rectangles that were rotated to facilitate area comparison have their original orientation displayed with dotted outlines. In comparison, the treemap technique as seen in the *SmartMoney Map of the Market* presents hierarchical data in a very condensed and effective way.



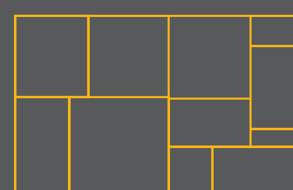
Charles de Fourcroy, France: "*Tableau Poléometrique*," 1782.

Jacques Bertin considers this one of the earliest representations of proportional data.[39] The method uses variation in area sizes to compare quantities by superimposing squares. Each city is represented by a square with the size proportional to its land area. Cities are organized by size, and the smallest cities are represented by a half square. This can be noted on the top left, where we see a diagonal line.

Closure

The closure principle of perception describes our tendency to see bounded visual elements as wholes and to unite contours. Even when bounded elements overlap, there is a tendency—influenced by the principle of good continuation—to separate units and apply closure to defining units. It is as if the mind "fills" the missing parts and "closes" the visual element. For example, we tend to perceive the four lines below as a square.

When we perceive data representations such as Venn diagrams, for example, we make use of the closure principle to extract information. The closure principle plays a significant role in distinguishing the sectors and the levels of hierarchy in the *SmartMoney Map of the Market*. Each sector, or container, has a clear boundary represented by thicker and lighter lines.



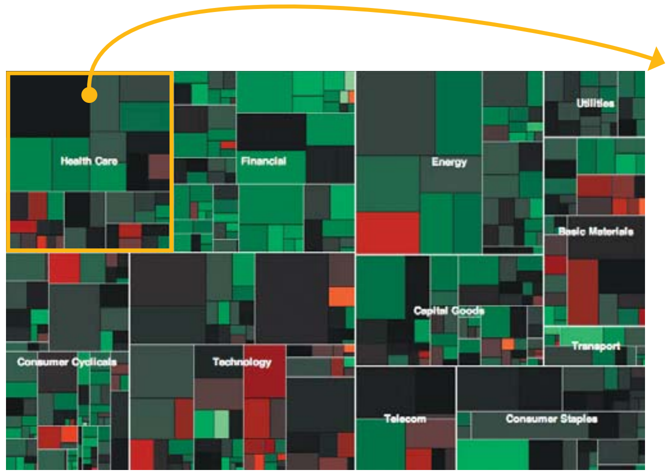
AREA SIZES
The area sizes of rectangles encode the market capitalization of companies within the hierarchical wholes. Because we are not good at making comparisons between area sizes due to constraints in our perception processes, our impressions of sizes are impaired. In most cases, we can say that a shape is larger or smaller than another, but hardly ever with any precision. It gets harder when comparing rectangles of different aspect ratios, or orientations. For example, which is the largest: Basic Materials or Capital Goods? And it is often a struggle when comparing shapes with different colors, because colors affect how we perceive area sizes. Visual perception studies indicate that we tend to perceive lighter areas as larger than darker ones (see box on page 145).[32] Our perception of color is also not absolute, such that surrounding colors often influence our impressions.

We can still get an overall sense of proportions in the *SmartMoney Map of the Market*, despite the fact that comparisons of absolute quantities are compromised. Precise amounts are provided on demand and displayed on an extra window positioned adjacent to the selected company when we mouse over its shape. Recall that the main goal of the visualization is to provide patterns to help inform investment decisions. Thus, the stock performance is the main variable to be watched, which is encoded by color.

PROPORTIONS
The external (and larger) container of the *SmartMoney Map of the Market* has a fixed size, around 500 X 800 pixels, and represents the topmost level selected. When we initiate the application, the container represents the entire map of the market with more than 530 companies. In this view, the subcontainers provide information about sectors, and their sizes are relative to the aggregated market capitalization of their innermost divisions, the companies. When we select to view a sector—say, Health Care—the external container now represents the total value for that sector, and the subsectors and related companies have their sizes changed according to the proportions to this new whole. Once again, if we select a subsector, Pharmaceuticals, inner partitions change accordingly.

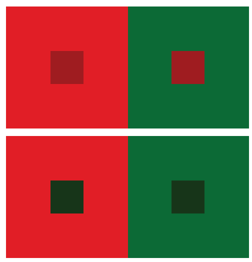
Given that we interact with the partitions in the *SmartMoney Map of the Market*, it is relatively easy to understand changes in meaning for what the shapes stand for: At every level, the larger container represents the whole. In other words, the external container always stands for 100 percent of its parts.

However, attention should be paid when comparing treemap visualizations in static media, because most often they will represent different total amounts. Although such displays may do a good job communicating differences in their compositions, the comparisons of the amounts are hindered.

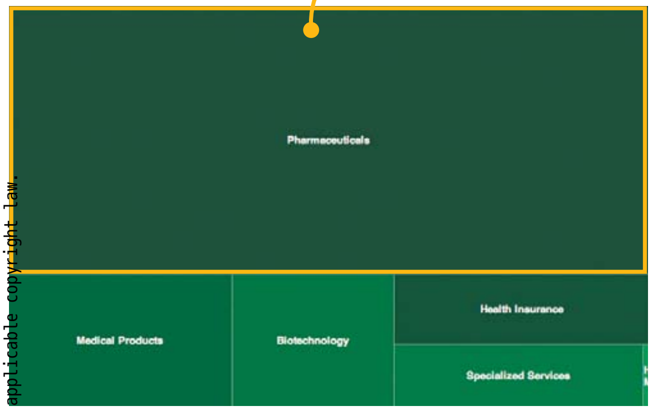


All sectors = 100%

The external container of treemaps stands for the total amount of the top-most level selected, independent of their absolute numbers.



The surrounding colors affect our perception of area sizes as well as our impression of the colors themselves. The inner squares are identical but perceived differently due to background colors



Health Care sector = 100%

Pharmaceuticals subsector = 100%

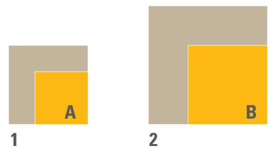
COMPARISON OF GRAPHICAL REPRESENTATIONS OF QUANTITIES:

Diagram and descriptions are based and expand on the original explanation by Otto Neurath, *Isotype* (1933).

Squares (or Other Area Comparison)

We can say that: 2 is larger than 1
B is greater than A

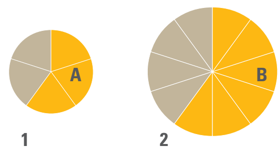
But we cannot say by how much. Representing quantities only by area size provides an impression of magnitude, which might suffice for macro-scale views.



Pie Charts

We can say that: 2 is larger than 1 in area
A is 3/5 of 1
B is 6/10 of 2

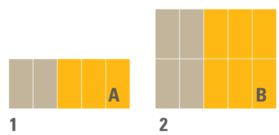
But we cannot say by how much. Pie charts are good at providing relative quantities to a whole insofar as there are not many partitions. Comparison between edges is problematic, as explained on page 36.



Groups of Geometric Units

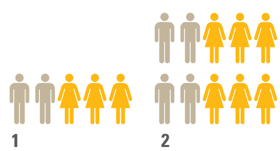
We can say that: 2 is twice as large as 1
A is 3/5 of 1
B is 6/10 of 1
A is 1/2 of B

This format provides measurable comparisons between units and groups. It is recommended that units be grouped into meaningful amounts to facilitate counting. Decimal groups are the most commonly used.



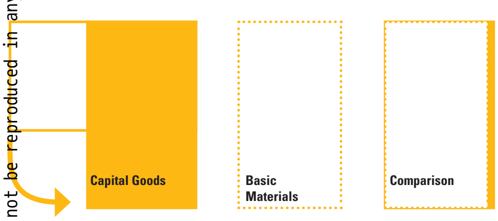
Groups of Signs

We can say that: 2 is twice as large as 1
the number of women is 3/5 of 1
the number of men is 4/10 of 2
the number of women in 1 is 1/2 the number of women in 2



Scale of Signs

We should not represent quantitative information using the area of icons, nor should we use the height of signs to represent quantities. In other words, when using signs to represent quantitative information, assign each a numeric unit and a semantic meaning.



It is hard to compute areas with different aspect ratios and orientations. By flipping the rectangle for Capital Goods and comparing it to the one for Basic Materials, we see that the first is slightly larger.

PIE CHARTS

Our visual system tends to distort the dimensions of area sizes. This factor affects the efficiency of displays representing proportions to a whole and that use area size to encode quantitative data.[33]

A familiar example is the pie chart, which is considered one the most used displays of quantitative data currently, especially in mass media and business publications. Pie charts convey general information about proportions of a whole, but we cannot infer absolute amounts from the perception of the wedges. Kosslyn explains that "about one-fourth of graph readers apparently focus on relative areas of wedges when they read such [pie] graphs—which means that they will systematically underestimate the sizes of larger wedges."[34] Furthermore, when it comes to presenting proportions among many entities, pie charts are inefficient, because it becomes almost impossible to compare and judge segments. It is often recommended that pie charts have not more than five or six wedges.[35]

The pie chart as a graphical invention is attributed to William Playfair, who devised and published a series of statistical graphs in the late eighteenth and beginning of the nineteenth century. The first known version of a pie chart was published in his notable *Statistical Breviary*.

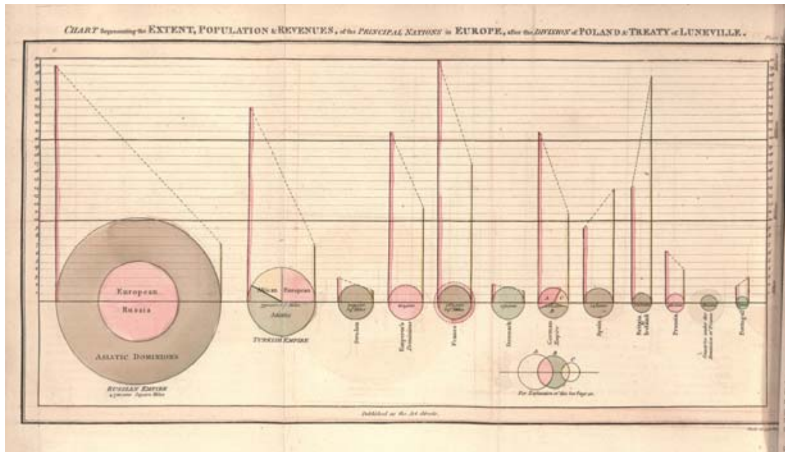
COLOR SCHEMES

The variable of color encodes the price performance. There are two color schemes available: red-green and yellow-blue, which coincide with two of three of an individual's color channels, with the third one being black-white (or luminance).

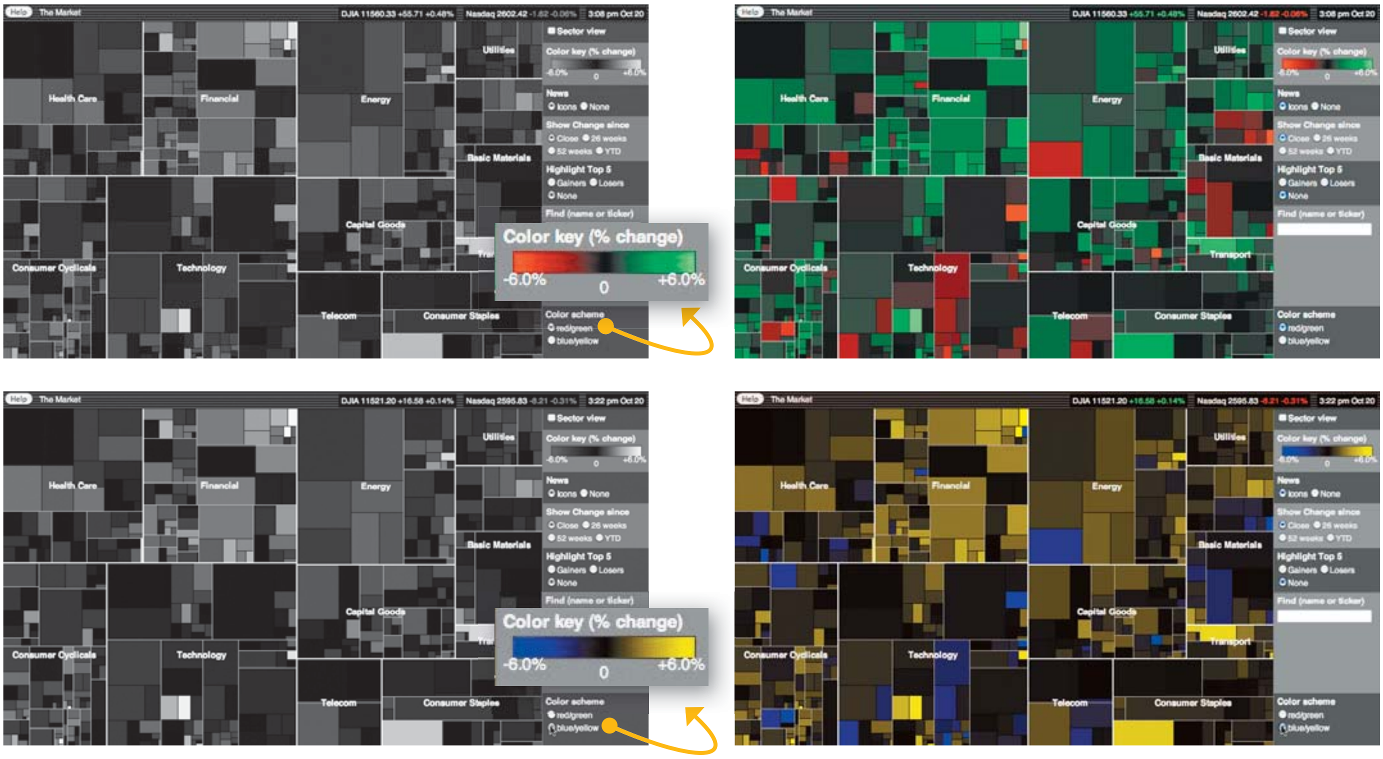
The default color scheme ranges from bright green—showing that stock price is up—to bright red—representing the opposite, that price is down. The midpoint on the scale is black, representing no loss or gain (zero value). The shades of green and red represent the gradations in price performance since the previous market close.

The red-green scheme uses the metaphor of green "to go" and red "to stop, danger," accepted universally as a color convention. Take for example traffic lights, which are well understood all over the world. Convention apart, the two colors are very distinct from each other and afford easy discrimination.

The second color scheme is not an aesthetic device; rather, it offers an option for people with color-perception deficiencies and represents the information on a blue to yellow scale. Ten percent of the male population and 1 percent of the female population suffer from some form of color-perception deficiency. The most common form of color blindness relates to the inability to distinguish red from green, while almost everyone can distinguish colors in black to white as well as yellow to blue dimensions. Ware explains that color-blind people can still detect these sequences, including green to blue and red to blue.[36]



Spence and Wainer attribute William Playfair as the first person to use pie and circle diagrams to represent statistical data: "Playfair was a capable and inventive adapter of ideas from other domains, and his adaptation of logic diagrams to portray and compare empirical data was ingenious."[40] The graphic compares the extent, population, and revenues in European countries in 1801. The area of circles stands for the land area, the length of the left line (for each country) represents the population, and the length of the right line represents the revenues. Both lines share the same scale of millions, the latter in pounds sterling. Playfair used two methods to show subdivisions in the countries: inner circle (as in the Russian Empire) and sectors (as in the Turkish and German Empires). The latter is considered to be the first use of pie charts to display empirical proportions as well as to distinguish fractions by the use of colors. Playfair is also know to have invented the line graph and the bar graph, both having appeared in the *Commercial and Political Atlas* of 1786 (see page 93), in addition to the circle graph and pie diagram published in his 1801 *Statistical Breviary*.



Comparison of the two color schemes available in the *Smart Money Map of the Market* against their grayscale representations.

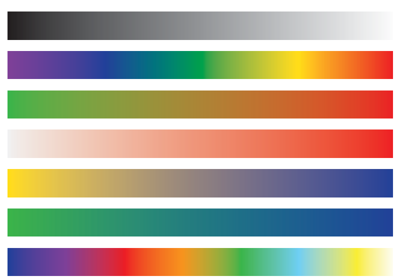
The luminance channel is better at conveying detail, shape, and motion information than the chromatic channels are. We are unable to perceive differences that are purely chromatic. As such, the luminance channel plays a crucial role when designing for conveying information.[37]

Considering the dominance of tonal values in our perception, it would be beneficial to check color schemes against their grayscale representations. For example, it is possible to check that both color schemes for the *SmartMoney Map of the Market* when viewed in grayscale keep the distinction between the shades. This is not to say that information should be encoded on grayscale; rather, close attention should be paid to luminance illusions as described previously (see box on page 145).

On a side note, it is interesting how intuitively we perceive monochromatic representations, such as when we see black-and-white photos and films. The lack of colors (or hues) doesn't affect our understanding of images; rather, quite often we fill the images with colors from our imagination and memories. For more on the perception of colors, see pages 146–147.

SEVEN COLOR SEQUENCES AFTER COLIN WARE[41]:

Sequences in bold will be perceived by people suffering from color blindness.



Grayscale

Spectrum approximation

Red-green

Saturation

Yellow-blue

Green-blue

Sequence in which each color is lighter than the previous one

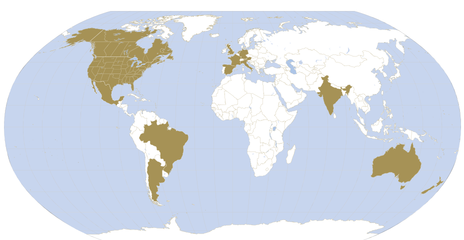
Countries

AUTHOR	Marcos Weskamp (concept, design, frontend and backend coding) and Dan Albritton (backend coding)
COUNTRY	United States
DATE	2004
MEDIUM	Online, real-time interactive application
URL	http://newsmap.jp
DOMAIN	News coverage aggregated by Google News API
TASK	To provide an overview of online news stories and reveal underlying patterns in news reporting around the world
STRUCTURE	The visualization uses the treemap technique. The algorithm renders the inner-division shapes closer to rectangles, facilitating readability of text.
DATA TYPE AND VISUAL ENCODING	
Categorical:	News segments
Encoding:	Color hues and spatial grouping
Categorical:	Countries
Encoding:	Label and enabled by selection
Temporal:	News age: how old the news is
Encoding:	Color value
Quantitative:	Number of related stories
Encoding:	Area size
Nominal:	Title of news story
Encoding:	Type size relative to the quantitative data

AMERICAS

EUROPE

ASIA



Canada
United States
Mexico
Brazil
Argentina

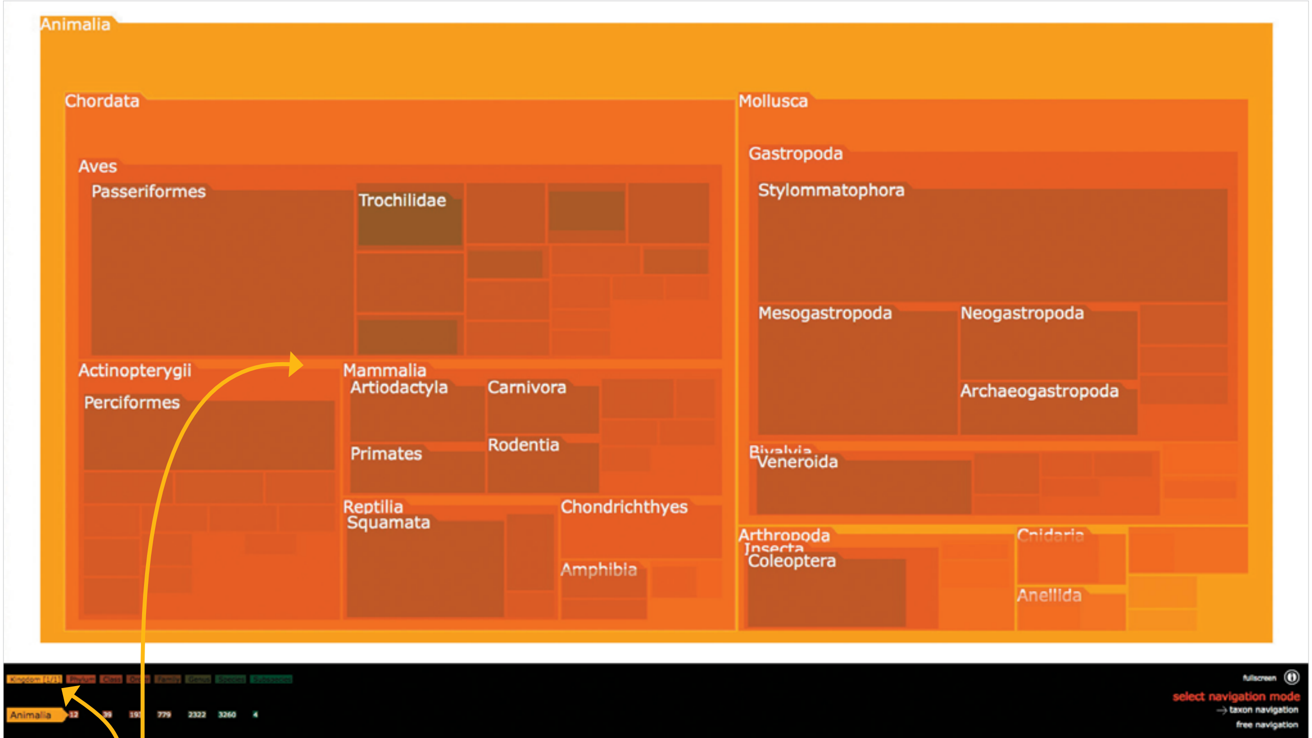
United Kingdom
Netherlands
France
Spain

Germany
Austria
Italy

India
Australia
New Zealand

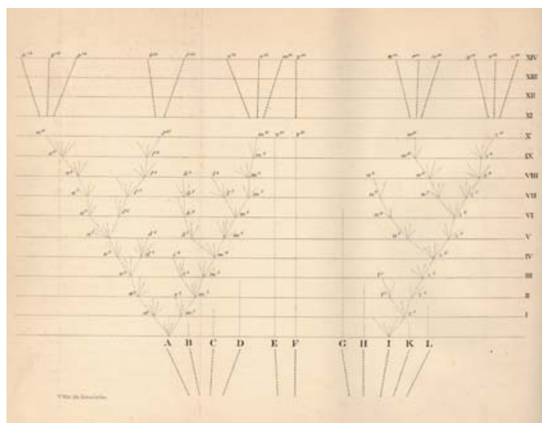
The interactive application *Newsmap* displays news stories aggregated by Google News API using a treemap algorithm. Marcos Weskamp designed *Newsmap* with the objective to "demonstrate visually the relationships between data and the unseen patterns in news media."[42] The application shows stories for fifteen countries in their original languages. Stories are categorized into seven segments: World, National, Business, Technology, Sports, Entertainment, and Health, and are easily detected by different color hues. Color hues are effective for encoding categorical data.

This page shows screenshots taken within seconds of each other for all fifteen countries offered in the tool. The images were captured on February 28, 2012, a day after the Oscar ceremonies in the United States. It is revealing how countries cover the news in diverse ways, both in relation to proportions dedicated to specific news segments, as well as to individual stories. For example, all countries have covered both the Oscars and the GOP race in the United States, but not equally: Canada seems to have attended more to the political issues of its neighbor than did the United States, which dedicated more attention to the Oscars. Overall, it is contrasting the coverage of world news between the two countries. The tool allows many interesting comparisons and readings of how we differ culturally around the globe. For example, we can see that sports plays a larger role in Italy, whereas in Brazil we see the predominance of the national news.



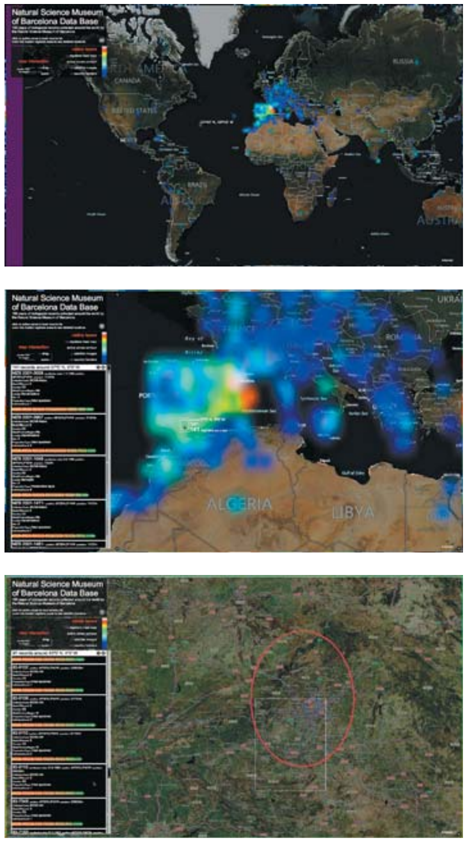
AUTHOR Bestiario
COUNTRY Spain/Portugal
DATE 2010
MEDIUM Online interactive application
URL http://arbre.bioexplora.cat
DOMAIN Biological records
TASK To provide access to 150 years of biological records collected around the world by the Natural Science Museum of Barcelona
STRUCTURE The project uses a treemap structure to display hierarchical biological data.

DATA TYPE AND VISUAL ENCODING
Categorical: Taxonomy (classification of organisms)
Encoding: Spatial positioning (grouping)
Quantitative: Amount of species within each *phyla* (taxonomic category)
Encoding: Area size
Qualitative: Divisions of the classification
Encoding: Colors of rectangles. A different color is used for each of the eight divisions of the Animalia kingdom



William West: The single illustration in Charles Darwin's first edition of *On the Origin of Species*, 1859.

This diagram demonstrates "how the degree of similarities between a number of varieties and species is explained by descent from common ancestors."[43]



The heat map visualization allows access to the collection of the Natural Science Museum of Barcelona both by selecting geographical areas in order to learn about species with provenance in those locations and by selecting species from the list of records.

http://mapa.bioexplora.cat

Regardless of whether one chooses to navigate data in space or using the taxonomy system, the output includes both types of information. The bottom image is an inset that shows the map with location of the related active record, similarly to the screenshots of the map interface, where the taxonomy information is included for each record on the list.

In 2010, Bestiario designed two visualizations that are used as interfaces to explore the collection of the Natural Science Museum of Barcelona. One is a treemap interface with data organized by taxonomy (on the left). The other provides geographical access to the same data, which can be viewed on the right.

The database contains more than 50,000 records and is continuously updated as new data are entered into the collection. The records belong to places all over the world, with higher density on the Iberian Peninsula and western Mediterranean Sea. This is particularly visible when one navigates geographically.

In both interfaces, data are structured following the Darwin Core standard, developed by the Global Biodiversity Information Facility (GBIF), for which the museum is one of the information providers.

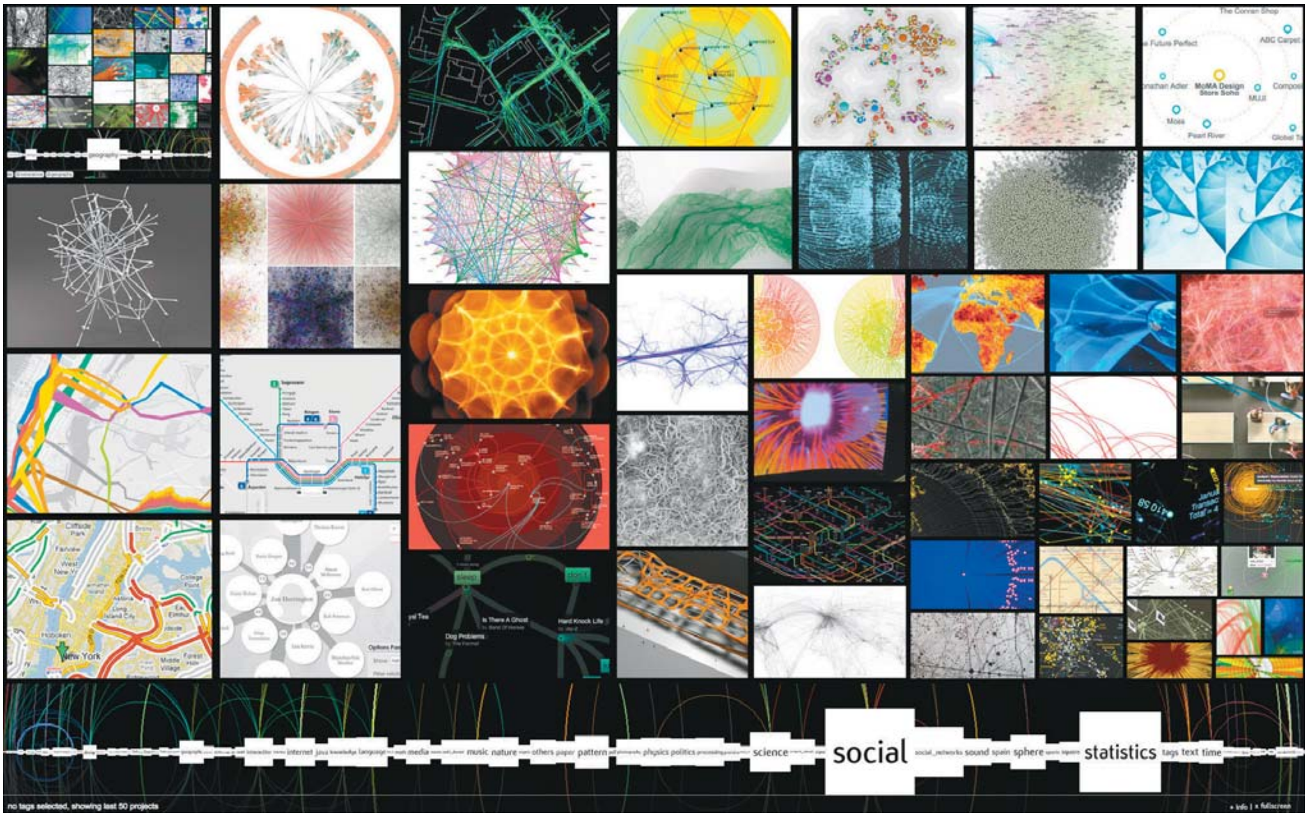
The use of a zoomable treemap structure is easily used by the museum's general audience, especially considering that the "tree of life" metaphor is strongly associated with evolutionary theories, even though it predates them.

AUTHOR	Bestiario
COUNTRY	Spain/Portugal
DATE	2010
MEDIUM	Online interactive application
URL	http://bestiario.org/research/tessera/changingnewyork
DOMAIN	Data visualization
TASK	To provide a means to explore large image collections
STRUCTURE	The project uses a squarified algorithm for the display of images, and a tag structure for the navigation of categories.

DATA TYPE AND VISUAL ENCODING

Categorical:	Semantic tags
Encoding:	Label inside white rectangle, organized alphabetically
Quantitative:	Amount of images within category
Encoding:	Area size of white rectangles at the bottom navigation
Quantitative:	Amount of semantic connections between tags
Encoding:	Colored rectangles on bottom right corner of images indicating exact number of shared tags within given selection. Also encoded by the image size, which is relative to the quantitative data. The thickness of colored arcs (at the bottom navigation) indicates the number of connections.

When *Tessera* is first opened, fifty images are shown with approximate sizes. When a project has been selected, it is positioned on the top right corner, with the most related images organized according to the quantity of shared tags, which can be checked by the small colored rectangles with numbers.



Tessera is based on a 2009 project titled "ReMap," which displays projects from the website VisualComplexity.com, a collection of visualizations curated by designer Manuel Lima.

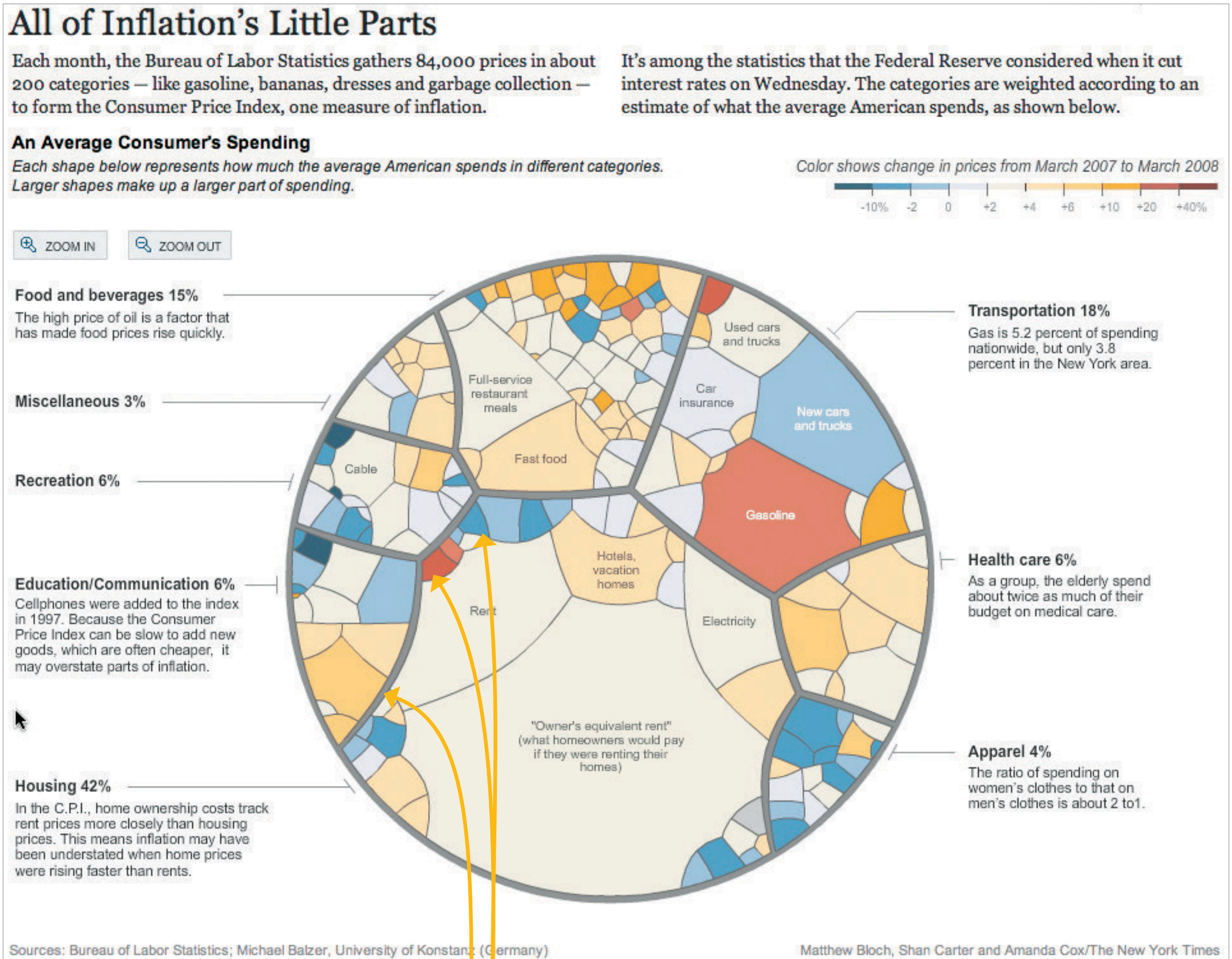
http://bestiario.org/research/remap

Tessera is a prototype designed by Bestiario for the display and exploration of large image collections using a quadrification visualization method. The version of *Tessera* reproduced here displays the New York Public Library's Flickr photo stream "Changing New York, 1935–1938, Berenice Abbott."

Users can navigate the photographic collection using *Tessera* in two ways:

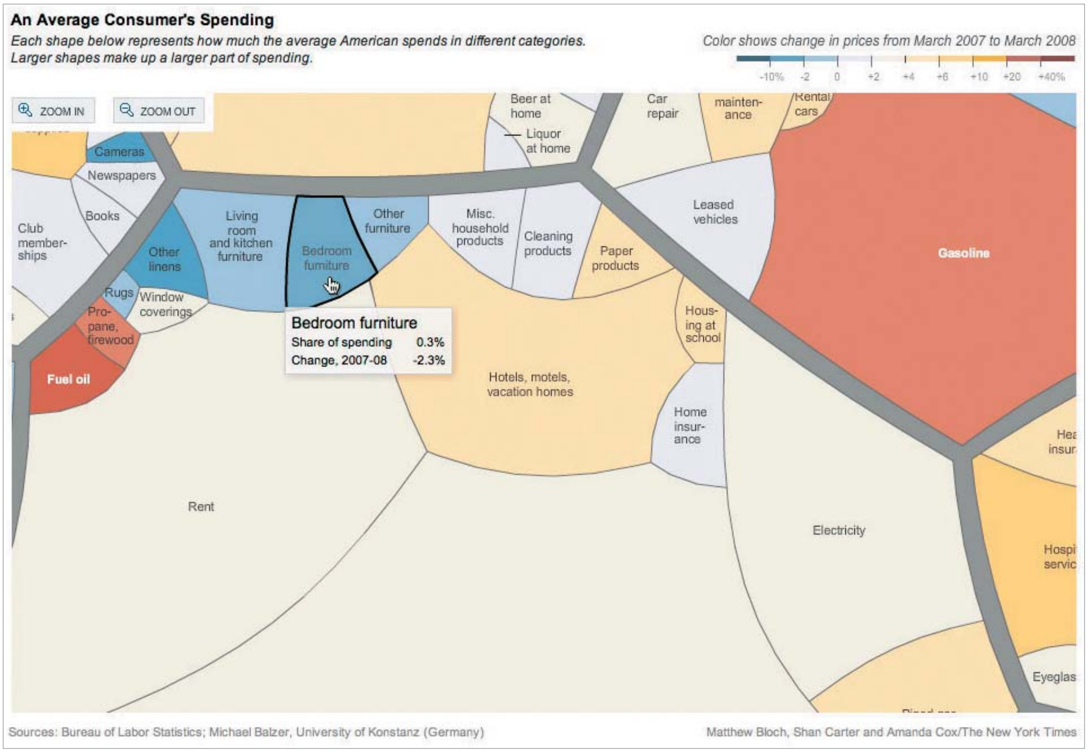
1. By category: Clicking on a category tag at the bottom navigation reconfigures the image structure to represent projects within the category (or combined categories) selected. Category tags are assigned using a semantic engine by Bestiario.
2. By project: Directly clicking on the project's thumbnail reconfigures the structure to display related visualizations.

Access to large amounts of data, including visual data such as photos and videos, has increased exponentially in recent years. The need for applications that will enable both archiving and accessing datasets in a meaningful way is unprecedented. *Tessera* is an attempt to solve the problem of image collections. It proposes a structure based on semantic navigation while visualizing the hidden metadata connections.



AUTHOR Matthew Bloch, Shan Carter, and Amanda Cox (*New York Times*)
COUNTRY U.S.
DATE 2008
MEDIUM Online interactive application
URL www.nytimes.com/interactive/2008/05/03/business/20080403_SPENDING_GRAPHIC.html
DOMAIN Finance (consumer spending)
TASK To provide an overview of the average American consumption in relation to price performance over a year
STRUCTURE The visualization uses a Voronoi treemap algorithm to render consumption items.

DATA TYPE AND VISUAL ENCODING
Categorical: Expenditure groupings
Encoding: Spatial positioning (grouping) and line weight
Quantitative: National spending shares as percentages
Encoding: Area size
Quantitative: Price performance within the one-year period (as percentages)
Encoding: Color sequence: from blue (< 0%), to white (neutral), to yellow (> 7%) to brown (> 20%)



Michael Balzer and Oliver Deussen developed the algorithm for Voronoi treemaps in 2005 with the purpose of eliminating the aspect-ratio problems imposed by rectangle-based shapes in traditional treemaps.[44] Voronoi treemaps use arbitrary polygons instead of rectangular subdivisions. The layouts are computed by the iterative relaxation of Voronoi tessellations, which allows arbitrary shapes to be used as the outer container, such as circles and triangles. However, the comparison of area sizes, which was one of the problems raised earlier about rectangle-based treemaps, gets amplified in the Voronoi version, where partitions have very different shapes, with almost no base for comparisons.

On May 3, 2008, the *New York Times* published an interactive visualization titled "All of Inflation's Little Parts" that uses the Voronoi treemap algorithm to structure expenditure data. The visualization maps an average consumer's spending between March 2007 and March 2008. The data source is the Bureau of Labor Statistics, which collects prices on about 200 categories, in order to generate the Consumer Price Index. In the visualization, data are grouped into eight categories, each subdivided into common spending items. For example, within the category Transportation, the two largest spending items are Gasoline, with 5.2% of national shared spending, and New Cars and Trucks, with 4.6%.

Voronoi diagrams (such as Delaunay triangulations and convex hulls) are often used to record information about distances and regions of influence. The mathematical method has been used over time, and in various domains, such as anthropologic research examining cultural regions of influence, economic studies of market models, and computational problems looking for the nearest neighbor. An early use of a similar method that is particularly relevant to this book was made by the British physician Dr. John Snow, who is known in the visualization field for mapping the 1854 London cholera epidemic as a way to prove to the health authorities that the disease was spread by infected water and not an airborne disease, as was believed then (see page 135).