Review of visual correlation methods [1]

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Abstract

Visual correlation (VC) of objects and events (O/Es) is an important approach to support decision-making. Several complex questions should be answered to implement this approach successfully: (1) How can correlations between data with different levels of resolution be correctly visualized? (2) How can conflicting data associated with the same object/event be visualized? (3) How can the data be visualized when primarily directed for different categories of users? (4) How can an O/E symbol be made "rich enough" to portray the differences between O/E?

This paper reviews current visual correlation work. We present several examples. Each example includes a VC image, brief description of the task, VC method and the level of the method using the scale suggested in this paper. Next, we generalize these examples and other published works presenting a classification of VC methods. Finally, this review presents criteria to assess the quality of visual correlation.

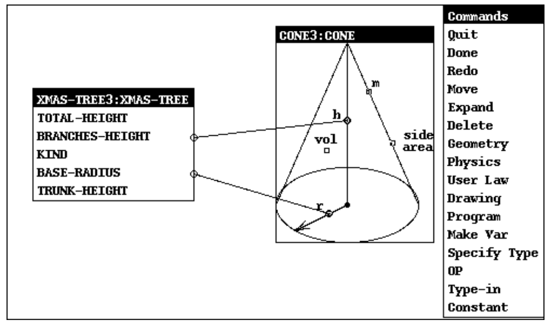
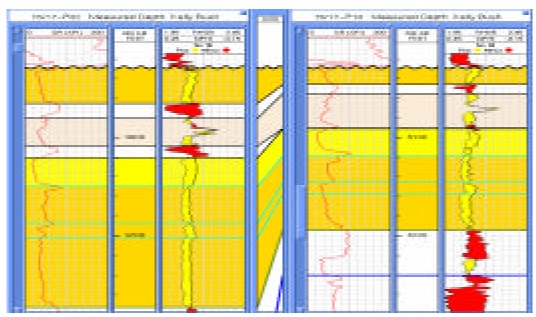
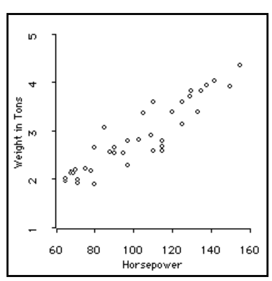
1. Review of current studies

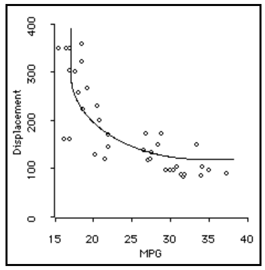
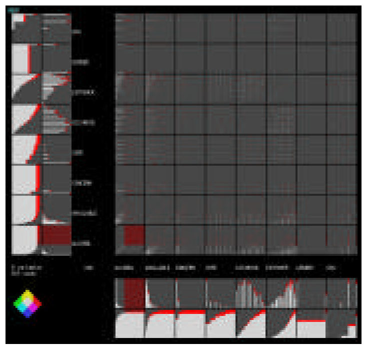
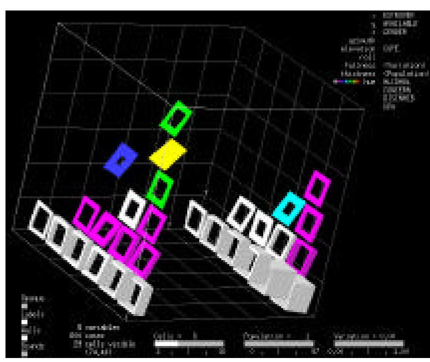
What is the visual correlation? Current studies on visual correlation range from formally defined classical linear correlation in statistics to very informally defined correlation between statements in a natural language. There are two major concepts of visual correlation:
(1) visual correlation as a **result of visualization** of O/E correlation and
(2) visual correlation as a **process of correlating** O/E visually.

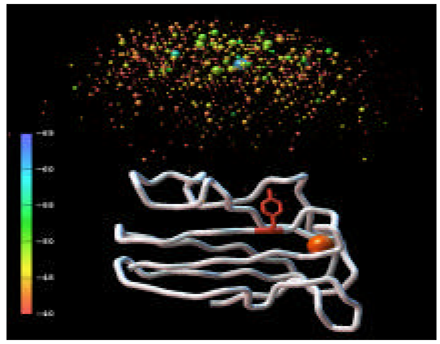
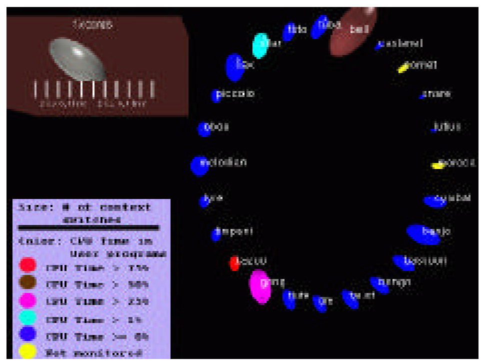
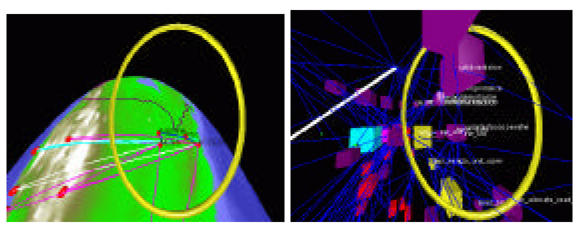
Table 1 includes examples from variety of fields, which belong to both categories . The goal of this review is to structure and classify practices and methods used in many fields. We are interested in their generalization and in finding common ground for new applications. It is important to note that examples vary in their level of exact definition and presentation of correlation to the user:

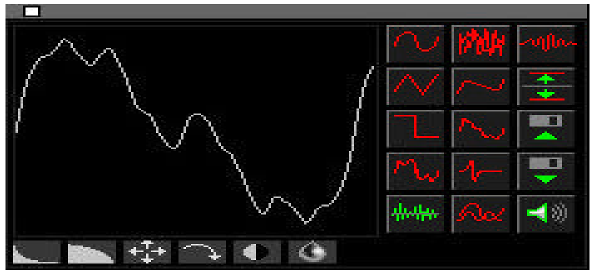
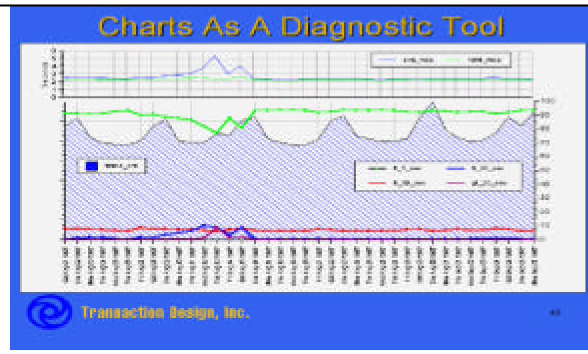
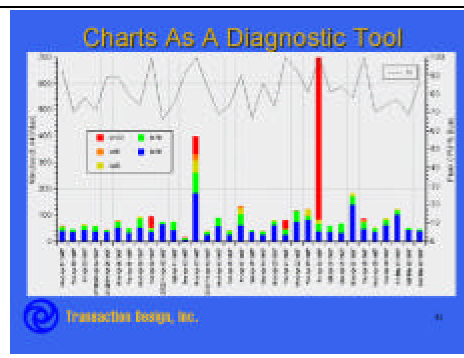
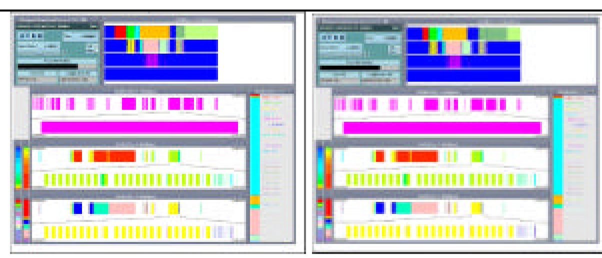
- *High level*. A system makes exact and clear correlation with the design stage.
- *Medium level*. A system does not correlate objects in advance, but provides a user with interactive tools such as a curve-matching cursor.
- *Low level*. A system mostly relies on a human perceptual mechanism, providing similar graphical or multimedia presentation of correlated entities and some pointing mechanisms.

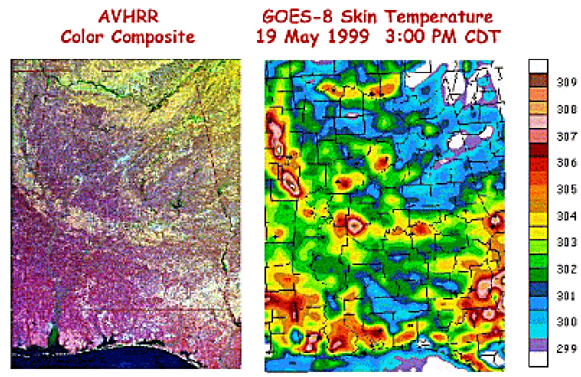
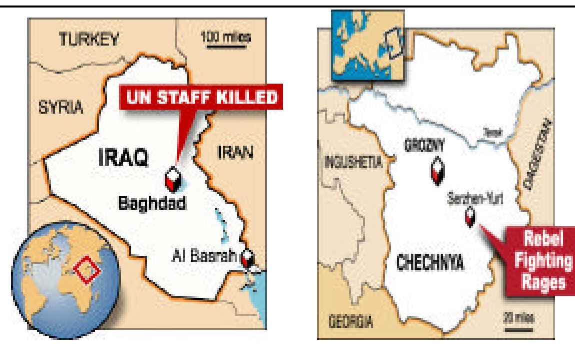
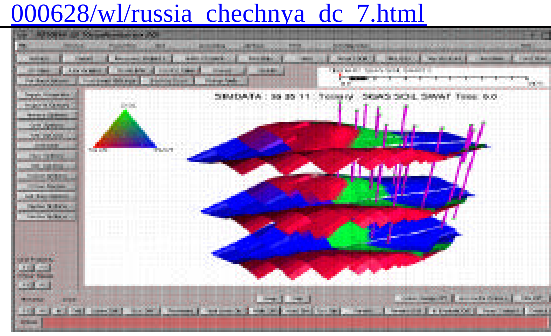
Table 1. Summary of visual correlation methods for multi-source data

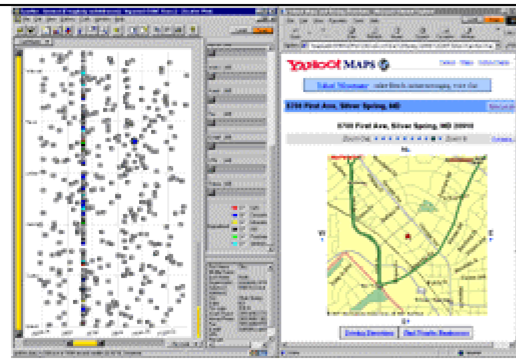
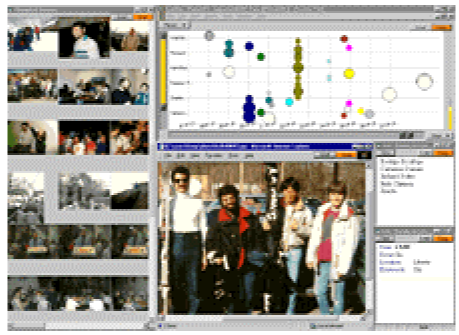
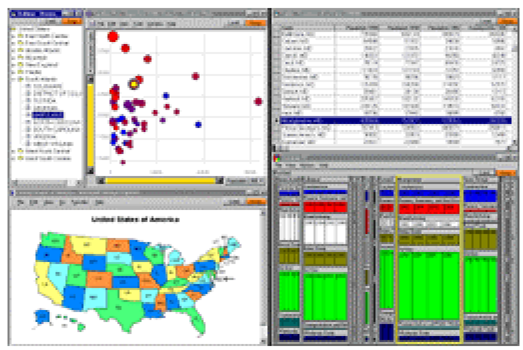
Level of exact definition of correlation	Task and method of visual correlation	Example
High (direct matching by a system designer)	Task: Concept visualization Method: **Static Pointers.** The system designer links three heterogeneous panels in advance: 1. Image, 2. Text descriptors, and 3. Commands. The user applies the system.	 Teaching physics Http://www.cs.utexas.edu/users/novak/diagrams.html
Medium (interactive matching by a user armed with a curve-matching cursor)	Task: Visual correlation of two homogeneous numeric datasets. Method: **Dynamic Interactive Pointers.** The system designer provides software for displaying and interactive linking two side-by-side panels. The user correlates these panels by the curve-matching cursor.	 Spatial interwell correlation http://www.oilfield-systems.com/
High	Task: Visual linear correlation of two homogeneous numeric variables. Method: **Linear Correlation Plot** The system designer provides software computing Pearson correlation and visualizing it in a single VC panel. The user selects variables and evaluates VC.	 Characteristics of automobiles, Pearson correlation for linear relationship. http://forrest.psych.unc.edu/research/vista-frames/help/lecturenotes/lecture11/overview.html

High	Task: Visual curvilinear correlation of two homogeneous numeric variables. Method: **Curveinear Correlation Plot.** The system designer provides software, which computes a curvelinear relationship and visualizes it in a single VC panel. The user selects variables and evaluates VC.	 Characteristics of automobiles, measuring curvilinear relationship. http://forrest.psych.unc.edu/research/vista-frames/help/lecturenotes/lecture11/overview.html
High	Task: Visual correlation of eight homogeneous numeric variables. Method: **Grid of correlation and distribution plots** The system *designer* provides software, which computes curvelinear relationships for each pair of variables and visualizes 8*8=64 correlations explicitly in a single VC panel. The *user selects* variables for VC and *evaluates* VC.	 Alcohol use (600 persons) http://oldweb.oac.ucla.edu/compsvc/sciviz/matthew1.html
Low. The user visually correlates objects. Such correlation can be unstable, because it depends on scaling of numeric variables. Scaling may relocate and change boxes used to discover patterns.	Task: Visual correlation of eight homogeneous numeric variables. Method: **3-D Glyph correlation.** The system *designer* provides software, which *visualizes data* in a single panel using a set of 3-D *boxes* of different colors, sizes, orientations, and shapes. The *user* selects variables for VC and visually *correlates* objects (boxes) using his/her natural perception mechanism.	Alcohol use (about 450 persons) http://oldweb.oac.ucla.edu/compsvc/sciviz/matthew1.html.

Low	Task: Visual correlation of hundreds of objects. Method: **3-D Glyph correlation.** The system designer provides software, which **visualizes data** in a single panel using a set of *bolls* of different sizes, colors, orientations, supported by adjustable lighting source and viewpoints. The **user** selects variables and visually **correlates** objects (bolls) using his/her natural perception.	 Molecules, energy (color) and orientation (size) http://www.supercomp.org/sc95/proceedings/636_LTEN/IMAGES/FIG4HI.HTM
Low	Task: Visual correlation of three homogeneous variables for 20-30 objects. Method: **3-D Glyph correlation.** The system *designer* provides software, which visualizes data in a single panel using a set of ellipses of different sizes, colors and orientations. The *user* selects variables and *visually correlates* objects (ellipses) using his/her natural perception.	 CPU analysis http://www-pablo.cs.uiuc.edu/People/Staff/Schaeffer/HTML/RealTime.html
High. The system sets multilevel links/relations explicitly.	Task: Visual correlation of objects of different levels of resolution. Method: Magic Lens The *user* selects an area for magnification and the system reveals magnified objects with different display metaphors and layouts using query and text modes. The *system* supports nested graphs for hierarchical views of geographic computations.	 Computer network, magic lens tool http://www-pablo.cs.uiuc.edu/People/Staff/Schaeffer/HTML/MagicLens.html and Shaffer E., Reed D., Whitmore S., Shaffer B., Virtue: Performance visualization of parallel and distributed applications, Computer, v. 12, 1999,pp. 44-51.

Low	Task: Visual correlation of image and sound. Method: **Image-sound correlation.** The system designer provides software, which **visualizes waves and** produce **sounds** in a single panel. The *user* selects a wave image and *correlates image and sound* produced by the wave using his/her natural perception.	 VC between wave shape and timbre by playing a selected wave shape. Http://www.uisoftware.com/PAGES/MS_WaveTable.html
Low	Task: Visual correlation of several datasets with time. Method: **Multiple Datasets - Single Correlation Plot** The system designer provides software, which visualizes curvelinear relationships in a single VC panel using charts of identical or similar types. The user selects variables and evaluates VC.	 Transactions data http://www.transactiondesign.com/perspective/sld044.htm
Low	Task: Visual correlation of several datasets with time. Method: **Multiple Datasets - Single Correlation Plot** The system designer provides software, which visualizes curvelinear relationships in a single VC panel using charts of using charts of different types. The user selects variables and evaluates VC.	 Transactions data http://www.transactiondesign.com/perspective/sld044.htm
Low Correlations are left for user's perception and recognition.	Task: Visual correlation of program behavior at different situations. Method: **Two Visualizations Side-by-Side.** The user visually correlates contents of subpanels in two panels.	 Program visualization IBM research http://www.research.ibm.com/pvres/vis94abs.html

Low Correlations are left for user's perception and recognition	Task: Visual correlation of locations with temperature map. Method: **Two Maps Side-by-Side.** The user visually correlates contents of maps in two panels.	 Temperature, http://wwwghcc.msfc.nasa.gov/irgrp/lst_goes.html
High. The designer creates, locates and links all panels. The user recognizes links using a **matching symbols** (rectangular and pointer)	Task: Visual correlation of two objects with some identical attributes. Method: **2-D glyph, shape matching.** Visual correlation of wells using the same shape -- circle -- for their symbols.	 Well - not water Well - water Geospatial Symbology for Digital Display (GeoSym) http://164.214.2.59/publications/specs/printed/89045/89045.pdf, MIL-PRF-89045.
High. The designer creates, locates and links all panels. The user recognizes links using **matching symbols** such as a rectangular on the world map and an arrow from the event to the city.	Task: Visual correlation of multilevel objects/events Method: **Linked panels.** Panels of different levels are linked by an inserted rectangular (region i n the world) or a pointer (event).	 Events in Iraq and Chechnay http://dailynews.yahoo.com/h/nm/20000628/wl/iraq_shooting_dc_7.html http://dailynews.yahoo.com/h/nm/20000628/wl/russia_chechnya_dc_7.htmlhttp://dailynews.yahoo.com/h/nm/20000628/wl/russia_chechnya_dc_7.html
Low-Medium Some correlations are left for user's perception, recognition, and discovery. Some relations are pointed explicitly.	Task: Visual correlation of locations with attributes. Method: **Three Visualizations in the Single Panel.** The user visually correlates contents of three visualizations and uses links.	 Reservoir simulation datasets http://www.geovisual.com/rvframed.htm

Low-Medium-High Some correlations are left for user's perception, recognition, and discovery. Some relations are pointed explicitly.	Task: Visual correlation of locations with attributes. Method: **Side-by-side panels** The user visually correlates contents of several panels. "Information visualizations with **multiple coordinated views** enable users to rapidly explore complex data and **discover relationships**. However, it is usually difficult for users to find or create the coordinated visualizations they need. Snap-Together Visualization allows users to coordinate visualizations to create multiple-view interfaces that are customized to their needs. Users query their relational database and load results into desired visualizations. Then they **specify coordinations between visualizations** for selecting, navigating, or re-querying. Developers can make independent visualization tools 'snap-able' by including a few simple hooks". http://www.cs.umd.edu/hcil/snap/	   http://www.cs.umd.edu/hcil/snap/

2. Classification of visual correlation methods

Table 2 codifies a variety of visual correlation methods.

Table 2. Visual correlation methods

Single panel	Single dataset -single correlation plot	Linear correlation plot
		Curvilinear correlation plot
	Multiple Datasets - Single Correlation Plot	*n* visualized entities in the single panel.
	Glyphs	2-D Glyphs correlation
		3-D Glyph correlation
Line of panels side-by-side	Static pointers	Linked panels
	Dynamic interactive pointers	User sets up links interactively
	n panels side-by-side	*n* abstract visualizations side-by-side.
		n X-ray films side-by-side
		N real-world pictures side-by-side
Tree of panels	Vertical tree of panels	
	Horizontal tree of panels	
	Centered tree of panels (root in the center)	
Grid of panels	Table of *n* x *n* panels.	Grid of correlation and distribution plots
Network of panels	Static pointers	
	Dynamic interactive pointers	
	Side-by-side panels	
Nested panels	Nested panels for hierarchical views	Nested geographic maps and events
Panels in 3-D	Mountain panel	
	Fish eye	
	Room	
	Gallery	
	Cone or disk tree	
Zooming and popping up panels	Standard zooming	Geographic map zooming (2D or 3D)
	Zooming with changing metaphors and layouts	Magic Lens (2D or 3D)
Panels spread over several monitors	Combination of all above listed methods	

3**. Visual correlation software**

Table 3 presents examples of visual correlation software.

Table 3 Visual correlation software: generic and field-specific.

Name/source	*Capabilities*
Generic statistical software (SAS, SPSS and so on)	Full range of single panel linear and curvilinear visual correlations of numeric datasets
Generic Data Mining software	Variety of visualizations of multidimensional data and discovered patterns
Correlation Builder for wells http://www.oilfield-systems.com/	Rapid curve correlation using the curve-matching cursor. Displays curves and saves curves and correlation information Supports use of predefined correlation templates for different users. Support mixture of templates in the same panel. Supports interactive set up of curve correlation parameters (width, gap)
Software application performance visualization Shaffer E., Reed D., Whitmore S., Shaffer B., Virtue: Performance visualization of parallel and distributed applications, Computer, v. 12, 1999,pp. 44-51	The user selects an area for magnification and the system reveals magnified objects and their text descriptions using query and text modes. The system supports nested graphs for hierarchical views of geographic computations. The user selects a site and "drills down" to the next level and may see a different display metaphor and layout. The user can expand multiple elements of graph hierarchy at separate sites.
Software architecture visualization Loe Feijs, Roel de Jong, 3D visualization of software architectures, Communications of ACM, vol. 41, N. 12, pp. 73-78., 2000.	Uses VRML. Supports LEGO type 3-D glyph metaphor for software elements; General data types -- brick with foundation; Special data types -- brown brick with four cylinders above; Data collector -- violet brick with foundation; Table -- cylinder.
Information Visualization (for the Management of Arid Lands Vegetation) http://ialcworld.org/Projects/95info.html	The visual correlation of various geo-spatial and temporal data. Supports VC for satellite imagery, photographs, GIS layers, databases, spreadsheets, custom displays, etc. A visual interface to data through hyper-text and hyper-area links. Supports access to a database from a map with "hotspot" which links to data related to that location. Supports the mouse to click on the "hotspot" for displaying the data related to that position.

4. Criteria for visual correlation efficiency

Visual correlation shares many efficiency criteria with visualization in general. Table 4 contains a list of criteria for visual correlation efficiency. The problem of measuring information density (IDS) for visual information is highly nontrivial. For textual information, this problem has been well known for a long time. C. Shannon offered a measure of information -- information entropy -- applicable for transmission of information using communication channels. In visual correlation, we have a specific communication channel transmitting information from a computer to a human.

Table 4. Criteria

Criterion	*Description*	*Comment*
TT -- Text time	Time for catching correlation of objects and events presented as a text.	
TS -- Text speed	Speed for catching correlation of objects and events presented as a text.	
VCT-- Visual correlation time	Time for catching up correlation visually.	If VC time is relatively small then VC can be used in time-critical and/or information overloaded applications.
IDS -- Information density	Amount of information presented visually. IDS is measured for a separate panel, screen and as a sum of them (integral measure). Amount of information can be measured in bits, bytes, Kb, Mb, and Gb.	If IDS is relatively small then VC can be used in time-critical and/or information overloaded applications. If IDS is relatively large then VC can handle large applications. Visualization and visual correlation can be viewed as a specific type of data compression
VCS -- Speed of VC	IDS/VCT -- amount of information consumed per time unit.	If VCS is relatively high then VC can be used in time-critical and information overloaded applications
RVCT--Relative VC time	Time of visual correlation (VC1) relative to another visual correlation (VC2) or a text (TT1): VCT1/VCT2; VCT1/TT1.	If RVCT is relatively low then VC can be used in time-critical and information overloaded applications. Relative time can be measured in experiments without explicitly measuring information density of the VC.
RVCS -- Relative VC speed	Speed of visual correlation (VC1) relative to another visual correlation (VC2) or text TT1 VCS1/VCS2; VCS1/TS1	If RVCS is relatively high then VC can be used in time-critical and information overloaded applications. Relative time can be measured in experiments without explicitly measuring information density of the VC.
PIP -- parallel information processed	Amount of information processed in parallel as a result of visual correlation in contrast with textual or other VC.	Image processing is a parallel process in contrast with sequential textual and audio information.
PIPS -- speed of parallel information processed	Speed of parallel information processing as a result of visual correlation in contrast with textual or other VC.	

5. Conclusion

Visual correlation of objects and events is not yet shaped as a separate area of the general decision-making process in general. A variety of methods have been developed independently in different fields with little or no communication and without common terminology. A significant amount generalization work should be done. This paper has provided a preliminary structure and classification for visual correlation methods based on the presented examples. This review also presents criteria to assess the quality of visual correlation.