Proceedings of the 2003 Winter Simulation Conference
S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, eds.

A TAXONOMY OF VISUALIZATION TECHNIQUES FOR SIMULATION IN PRODUCTION AND LOGISTICS

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ABSTRACT

Simulation has become one of the most important techniques with regard to manufacturing and logistics systems. During modeling and experimenting simulation input and output data have to be presented to different target groups which range from simulation experts and factory planners to representatives of company management, and for different tasks and specific purposes. Different kinds of visualization techniques are used to present the simulation data, from static techniques as charts and layout plans to dynamic techniques as 2-D or 3-D animation as well as Virtual or Augmented Reality. But often, non-expressive and non-effective visualizations prevent the understanding of simulation output. This paper presents a taxonomy of visualization techniques for simulation in production and logistics and outlines how to use this taxonomy as a base for decision support to select the right visualization technique for specific target groups.

1 INTRODUCTION

In discrete-event simulation for production and logistics, visualization techniques are used to gather information and to process input data for the simulation or to present the simulation output data. The increasing number of outputs and the necessity to provide them to different target groups in a company in a usable and task-oriented form increasingly call for the targeted use of visualization techniques for the modeling and simulation of production and logistics systems. The visualization techniques which are nowadays used rather pragmatically in this field should be scrutinized with regard to their expressiveness and efficiency. 12 years ago Robertson (1991) wrote about this subject: "The choice of representation should depend on context". However, there are no suitable standards to use these techniques in the respective application fields.

The present tendencies, e. g. in the automotive industry, concerning the "Digital Factory" (Hellmann, Jessen and Wenzel 2003) still increase such requirements: "The Digital Factory is the entirety of all methods and tools for the sustainable support of a factory planning and factory operation including the respective processes (workflow) on basis of linked digital models (in connection with the product model). The definition on the one hand implies the cross-linking of necessary tools and models and on the other hand considering static characteristics and systems dynamic". This also implicates that simulation and visualization are integrated into the concepts of the "Digital Factory". It requires not only the representation of the results as 3-D animation but with the help of Virtual Reality a virtual factory walk-through should become reality.

The VDI board of experts *Simulation and Visualization* discussed this subject in 1999. The discussions lead to a classification of visualization techniques *from a graphical point of view*, published in the VDI 3633 Part 11 2003. By means of classification criteria the user is presented with a variety of possible techniques. He also gets valuable guidelines for the use of the different statistic and dynamic 2-D and 3-D visualization techniques (cf. Chapter 3).

In the scope of the sub-project *Information Management* as part of the Collaborative Research Center 559 *Modelling of Large Logistics Networks* the visualization techniques for the user of simulation in production and logistics are surveyed from *the information-related point of view* and integrated into the taxonomy (cf. Chapter 4).

The complete taxonomy is the basis for the classification of application for the relevant visualization techniques and allows the user to define his specific requirements. This meta-information form the standard for the use of visualization techniques for modeling and simulation in production and logistics.

2 APPLICATION FIELDS AND TARGET GROUPS

The usability of visualization in simulation includes visual processing in both static and dynamic form. The simulation database, the experiment process or its results are represented in a static form, e. g. as tables or diagrams. Also interaction with the simulation model and the direct manipulation of the model take place by using a graphical representation. The dynamic illustration of a process by animation makes it easier to understand complex issues.

The goals of visualization differ according to the phase of the simulation study and focus on the one hand on the cognition enhancement (e. g. during validation) and on the other hand on the knowledge mediation (e. g. in connection with training or presentation). Generally, visualization improves the understanding of the model and sets the basis for a common communication between all persons involved. Animation as a possible visualization technique demonstrates very easily the target plurality of visualization (Wenzel 1998). As a function of the different phases of a simulation study and the respective target groups visualization could be used as:

- an acquisition tool,
- a verification utility during the modeling process (Johnson and Poorte 1988),
- a validation utility (Law and Kelton 1991),
- an analysis tool for explanation among other things of deadlock-situations, system bottlenecks, strategy effects or also of stochastic influences e. g. with queues,
- a communication tool for simulation specialists and planner/customers e. g. for the explanation of process dynamics and conflict areas,
- a presentation tool (McHaney 1991) to illustrate the results for decision makers or managers as well as
- a training tool for knowledge transfer.

Part 11 of the VDI-guideline 3633 (VDI 3633 Part 11 2003) describes target plurality by concretizing the application fields and target groups and their relations regarding the necessity for the use of visualization procedures to each other. The weighted correlations between the application fields and the different target groups are illustrated in figure 1.

target groups / application fields	simulation department	planning department	management	technical purchasing	facility maintenance	production and logistics	distribution and marketing	customer	public
system analysis	●	●		●					
modeling	●	❍							
validation	●	●						❍	
experimentation	●	●						❍	
representation and interpretation of results	●	●	●	●	●	●	●	●	
training						●	❍	●	
operation parallel		●	❍			●		❍	
sales promotion and public relation			●				●	●	●
interdisciplinary communication	●	●	●	●	●	●	●	●	

● full applicable ❍ partly applicable

Figure 1: Relevance of Visualization Referring to Application Fields and Target Groups (VDI 3633 Part 11 2003)

By experience, a variety of different visualization techniques are used to simulate material flow and production processes. Each technique has its own expressiveness and covers only certain aspects of a presentation. A 3-D-animation, for example, offers no information about a characteristic number such as throughput while a presentation of statistical values gives only a limited insight into the dynamic behavior of the process.

The criterion for the establishment of the so-called classification schemes is the complete range characteristic features of a procedure, e. g. the criteria dimension of the representation in 1-D, 2-D, $2^1/_2$-D and 3-D. The scheme, presented as a morphologic box, offers the possibility to characterize each visualization technique by means of its specific parameter values. Thus, it is easy to find a suitable technique by comparing the parameter values requested for the visualization with those of the classified procedure (cf. Chapter 5).

The classification by criteria is described below from the graphical point of view (see also figure 2). Chapter 4 presents a classification scheme from the basic information-related point of view (see also figure 3).

3 TAXONOMY OF VISUALIZATION TECHNIQUES FROM THE GRAPHICAL POINT OF VIEW

To choose a suitable visualization technique for a certain purpose and a selected target group it is necessary to have a detailed scheme by which the different visualization techniques can be classified exactly.

3.1 Dimension

This criterion describes the number and importance of the dimensions used in the visualization:

- 1-D: Presentation which determine only one dimension (e. g. bar height of a chart).

Criteria	Specifications						
Dimension	1-D	2-D	2 ½-D	3-D			
Representation	symbolic/ character	symbolic/ abstract	iconic/ stylized	iconic/ close-to-reality	photo-realistic		
Display Format	font	table/ spreadsheet	chart	drawing/ diagram	picture	virtual world	augmented reality
Scale	none	linear	logarithmic	exponential	categorizing		
Planar Geometrical Projection	none	orthogonal	oblique	perspective			
Temporal Dimension of the Graphical Model	none	discrete	continuous				
Time Mode within the Presentation	fixed-image	non-proportional full video	proportional full video – slow motion	proportional full video – real time	proportional full video – fast motion		
Interaction	none	navigation within the presentation	interaction with graphical model	interaction with simulation model	immersion		

Figure 2: Taxonomy of Visualization Techniques from the Graphical Point of View

Criteria		Specifications							
Primary Function: Intention		Identification	Localization	Correlation	Association	Comparison	Structures and Patterns	Grouping	Classification
Type of Information to be Represented		qualitative	quantitative	qualitative and quantitative					
Information Relationship		independent	relational	circular	hierarchical	network			
Information Encoding	Level of Measurement	none	nominal discrete	ordinal discrete	ordinal continuous	interval discrete	interval continuous	ratio discrete	ratio continuous
	Dimension of Dependent Variables	none	1-D	2-D	3-D	n-D			

Figure 3: Taxonomy of Visualization Techniques from the Information-Related Point of View

- 2-D: Presentation of 2-dimensional charts and model layouts.
- 2½-D: A 3-D presentation developed from a 2-D presentation.
- 3-D: Spatial presentation with a free choice of perspective.

3.2 Representation

The representation is the visual description of information by the following means:

- symbolic: The meaning of a symbol is determined by a code. It is differentiated between a *character* and the general *abstract symbol*. A character is an element which represents information out of an

agreed finite quantity (e. g. alpha-numerical / numerical characters). The abstract symbol is a simple 2-D, $2^1/_2$-D or 3-D picture with a specific meaning within a certain application (e. g. symbol of a building block within a graphical representation of a simulation model).
- iconic: An *icon* directly represents its meaning without a code convention. Iconic forms of representation are *stylized* and *close-to-reality image* which, owing to their typical visual features, are more or less realistic (e. g. stylized representations of sports).
- photo-realistic: The photo-realistic representation (realistic illustration) faithfully shows a real situation.

3.3 Display Format

The display format of a visualization technique comprises the total representation of a fact by using different representations:
- font: a finite series of characters.
- table/spreadsheet: a structured visual arrangement of characters.
- chart: the structured graphical arrangement of characters, symbols and icons.
- drawing/diagram: a special, earmarked abstraction of the original (2-D, $2^1/_2$-D or 3-D representation with a topological structure similar to that of the original).
- picture: representation which highly resembles the original.
- virtual world: a 3-D environment which can be experienced by the viewer.
- augmented reality: a reality enhanced by virtual objects/scenes.

3.4 Scale

The criterion scale (Harris 1999) considers the measure which has been chosen for the geometrical reference system like Cartesian, polar, cylindrical or spherical coordinate systems:
- none: no geometrical reference system available.
- linear: equidistant partition of the axis.
- logarithmic: logarithmic partition of the axis.
- exponential: exponential partition of the axis.
- categorizing: partition of the axis not to scale but to categories.

3.5 Planar Geometrical Projection

A projection is the transformation of objects in a n-dimensional space into a space with less dimensions. (Foley, van Dam, Feiner, Hughes and Phillips 1994). The planar geometrical projection is performed with projection rays which start at a projection center and while crossing each point of the object cut the projection plane. The most important geometrical projection types are:
- none: no planar geometrical projection needed.
- orthogonal: a projection with an infinite projection center.
- oblique: similar to the orthogonal projection but the projection rays hit the picture level transversely.
- perspective: the center of the projection is in a finite distance to the projection plane; here, all projection rays meet.

In addition to these projections often there are used free or mixed projections.

3.6 Temporal Dimension of the Graphical Model

The temporal dimension of the graphical model basically determines if and how visualization is defined referring to a time axis:
- none: static model with no changes.
- discrete: dynamic model which changes at discrete points of time.
- continuous: dynamic model which changes continuously.

3.7 Time Mode within the Presentation

The time mode within the presentation determines, how a single image or an image sequence of the graphical model is presented to the viewer referring to a time axis:
- fixed-image: presentation of the (static or dynamic) model as a single picture.
- non-proportional full-video: presentation of discrete views of the (static or dynamic) model as a stream of chronologically arranged images.
- proportional full-video: presentation of the (static or dynamic) model as a stream of images which are arranged chronologically and proportional to a time axis (slow motion, real time, fast motion).

3.8 Interaction

Interaction defines how a user can perceive the visualized simulation input and output and how he can manipulate the presentation. A system is called interactive when the system response time does not influence the users working process:
- none: only watching a presentation.
- navigation within the presentation: controlling the presentation, e. g. by Start-Stop buttons.

- interaction with the model: depending on the model level the user can change the view (graphical level, e. g. zoom, details-on-demand, filter as Shneiderman (1996) described) or the behavior (data or simulation level) of the model.
- immersion: the user is part of the model and interacts within a virtual world.

4 TAXONOMY OF VISUALIZATION TECHNIQUES FROM THE INFORMATION-RELATED POINT OF VIEW

In addition to the criteria which are studied in Chapter 3 from the graphical point of view the taxonomy for visualization techniques is completed by a survey of the criteria from the information-related point of view. These are on the one hand the primary functions of the visualization technique in terms of its potential use and on the other hand the description of the information which can be represented and imparted by the chosen visualization technique.

In this context a clear distinction is made between data and information to develop the taxonomy:

- Data consist of analogous or digital signals or characters (syntax) and are used to represent and illustrate information which are to be processed (cf. in dependence on DIN 44300 1995).
- Information comprises statements on and descriptions of the characteristics and structures of certain objects or facts (semantic); it is sent and received referring to the specific purpose of the relation between sender and recipient. Information is encoded with data. Information is described as communicated and formalized knowledge and used to augment knowledge (in dependence on DIN 44300 1995 and Nonaka and Takeuchi 1997).

The information-related criteria of the taxonomy refer to this definition of data and information.

4.1 Primary Function: Intention

The primary function of a visualization technique is characteristic for the problem which should be solved with this technique. It also includes the requirements which have to be achieved by the visualization technique. Among the characteristics of this criterion are the problem categories which have been developed in dependence on Schumann and Müller (2000) and Frick (1998):

- Identification: determination of characteristic values
- Localization: determination of location and place (relative or absolute).
- Correlation: to point out direct relationships.
- Association: to point out indirect relationships.
- Comparison: to point out similarities or differences.
- Structures and Patterns: to point out typical characteristics and patterns (e. g. hierarchies, outliers or trends).
- Grouping: to point out different characteristics and corresponding bundling.
- Classification: division according to known characteristics.

The above-mentioned characteristics of the primary functions of a visualization technique are based on the primary functions of visualization in scientific visualization and software design, but there is a more abstracting view on the data content to be represented.

4.2 Type of Information to be Represented

Because of its nature information is divided into qualitative and quantitative information. Qualitative information rather reflects ideas and correlations which can not be described and illustrated mathematically and in figures. Quantitative information can be described by quantities (“how many”).

4.3 Information Relationship

Information relationship is the recognizable formal pattern of the correlations between the single information. The information relationship shows, for example, no formal/logical pattern of correlations but it can be linked to an extremely high degree, e. g. in the form of a network (in dependence on the data relationship specified by Schumann and Müller 2000 and Pfitzner, Hobbs and Powers 2002).

4.4 Information Encoding

Information can be differently encoded by the visualization technique. The information encoding comprises on the one hand the level of measurement and on the other hand the dimension of the dependent variable.

The level of measurement indicates the exactness of the illustration and especially the deducible conclusions. While nominal values show only similarities of or differences between the characteristics, ordinal values establish a hierarchy or mathematical links. Ordinal values themselves can be discrete and continuous ones.

The dimension of the dependent variable is defined by the number of values which can be coded visually for each observation point (Keller and Keller 1993).

5 UTILIZATION OF THE TAXONOMY

The taxonomy was developed to match the requirements of a user with the specific characteristics of a visualization

technique. The precondition is the complete classification of all visualization techniques which are relevant for simulation in production and logistics according to the criteria mentioned in chapter 3 and 4. The user specifies his/her requirements with regard to the task and purpose of the presentation and other requirements, e. g. working field conventions, by means of the same taxonomy. However, this does not require a complete specification. By comparing his/her requirements with the entirety of visualization techniques the user is led to a category of possible visualization techniques or, ideally, to just one technique. This comparison can be realized by a appropriate software program. The final selection is done manually by the user himself on the basis of extended criteria such as preparation effort and interpretation effort of the target group.

5.1 Classification of Visualization Techniques Using the Taxonomy

To show the classification of visualization techniques in the taxonomy exemplary some common techniques used in simulation of production and logistics systems are classified below.

The simple column graph is characterized by a 2-D representation, a symbolic representation and a generally linear, categorized or logarithmic scale without projection; it either includes none or a discrete form of time representation and is a fixed-image without interactions. It allows for the representation of mainly quantitative information but in combination with a value cluster – e. g. in the form of a histogram - also of qualitative information for identification, comparison and representation of characteristics and patterns of relational information. The information are coded on a discrete level of measurement and with one-dimensional dependent variables.

Unlike the simple column graph the simple line graph uses no categorizing but an exponential scale. If the independent variable represents time a continuous temporal dimension of the graphical mode is possible.

The criteria of the simple scatter graph are exactly like those of the simple column graph. According to the present taxonomy they are of the same category.

The proportional flow map is an abstract symbolic drawing/diagram without scale. It is used to identify, localize and show the correlations and associations of relational and network information on the basis of multi-dimensional dependent variables.

The 3-D animation is characterized by a 3-D representation, an iconic/stylized, iconic/close-to-reality or photo-realistic representation, a linear scale and mostly a perspective but also an orthogonal projection. It may include a discrete or a continuous form of time representation and interact with the graphical and/or the simulation model. It allows representation of qualitative information and for the localization, comparison, correlation and association of any information relationships. Information is encoded on a discrete and/or continuous level of measurement and with multi-dimensional dependent variables (geometries, time, states).

Unlike the 3-D animation the 2-D animation is a pure 2-D representation with a mainly iconic but also symbolic representation. Generally, it has no scale and allows only for a limited localization on the basis of two- and multi-dimensional dependent variables.

5.2 Example of User Requirements

A typical simulation result during the model-aided analysis of an order-picking device is the behavior of a order-picking warehouse. One central characteristic number, for example, is the warehouse inventory which may result in the following different requirements on the visualization:

- The visualization of the *stock flow in time intervals* requires the representation of one-dimensional dependent variable *stock* with a discrete level of measurement to point out typical characteristics and patterns and to identify the absolute stock averages in the given interval.
- The visualization of the *stock flow at any time of stock change* requires the representation of the one-dimensional dependent variable *stock* with a discrete level of measurement to show typical characteristics and patterns and to identify the absolute occupancy at any time of stock change.
- The visualization of the *stock distribution* in terms of a classification of measured values dependent on the stock categories to be built requires the representation of the one-dimensional dependent variable *number of measured values* with a discrete level of measurement to identify the absolute number of measured values for an stock category. Additional information are typical characteristics and patterns like minimum, average value, maximum, and standard deviations.
- The visualization of *in- and outbound amount* requires the representation of multi-dimensional dependent variables with a discrete level of measurement. It visualizes a network information relationship to identify and point out the correlations and associations of the absolute number of objects which flow through the warehouse per unit of time.
- The visualization of *model-inherent interdependencies* requires the representation of multi-dimensional dependent variables to identify, compare, localize and point out the correlations and associations of the system behavior focusing on the order-picking warehouse.

5.3 Criteria Comparison and Selection of Visualization Technique

The criteria comparison results from the user requirements and the visualization techniques categorized in chapter 5.1. The final selection depends on the target group and the expected preparation effort (see figure 4).

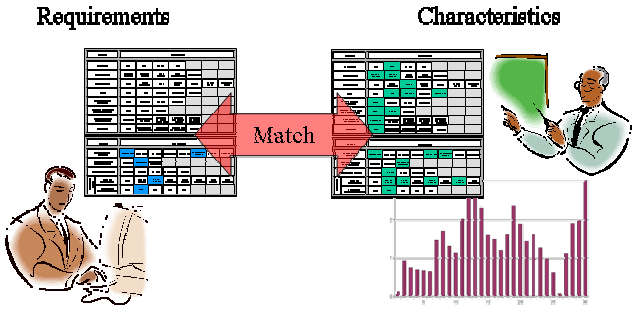

Figure 4: Selection Process

The *stock flow in intervals* can be visualized either by a simple column graph or by a simple scatter graph. Owing to common software the preparation effort is low and the type of diagram is chosen depending on the conventions of the target group.

In contrast, the *stock flow at any time of stock change* can only efficiently be visualized by a simple line graph because this allows for the continuous representation of the dependent variables (interpolation degree 0).

The *stock distribution*, on the other hand, can be visualized by a simple column graph or a simple scatter graph. Due to the assumed rectangular distribution within an stock category the simple column graph is the most suitable and widely used visualization technique to represent the facts.

The *in- and outbound amount* is mostly visualized as a proportional map. This allows for the static representation of quantitative object flow per time interval with the illustration of the network-like information relationships.

The dynamical visualization of mainly qualitative *model-inherent interdependencies* can be visualized by a 2-D animation as well as a 3-D animation. For the selection the target group and the preparation effort have to be considered. For example the preparation effort is much higher for 3-D animation than for 2-D animation. Furthermore a realistic 3-D animation represents information much more efficiently to a target group with no consolidated knowledge about the simulated system (VDI 3633 Part 11 2003).

6 SUMMARY

The presented taxonomy of visualization techniques to be used in simulation of production and logistics systems is the result of various research and industrial projects. The taxonomy of visualization techniques from the graphical point of view was mainly developed together with users during the joint preparation of the guideline VDI 3633 Part 11. Its applicability has been validated by typical visualization examples.

Since the users often would like to relate the visualization techniques with the actual tasks and targets the information which may be represented becomes more important. In the scope of the Collaborative Research Center "Modelling of Large Logistics Networks" this situation lead to an additional differentiation of the visualization techniques from the information-related point of view. At this time, this part is also validated together with users regarding its usability.

Based on their experience the authors refer to the current discussions about a differentiation or consolidation of the scientific and the information visualization. From the users point of view they prefer the consolidation.

7 ADDITIONAL INFORMATION

Additional information can be found in the Guideline 3633, Part 11 Simulation and Visualization and under <http://www.sfb559.uni-dortmund.de>.

ACKNOWLEDGMENTS

This research was supported by the Deutsche Forschungsgemeinschaft as part of the Collaborative Research Center "Modelling of Large Logistics Networks" (559). The document was prepared based on the prior guideline work of the Technical Committee for Simulation and Visualization, a section of Department A5 Modeling and Simulation of the Association of Engineers Society for Materials Handling, Materials Flow and Logistics Engineering (VDI-FML).

REFERENCES

DIN 44300 1995: Deutsches Institut für Normung e.V. *Informationsverarbeitung – Teil 1*. Berlin: Beuth Verlag.

Foley, J. D., A. van Dam, S. K. Feiner, J. F. Hughes and R. L. Phillips 1994: *Grundlagen der Computergraphik - Einführung, Konzepte, Methoden.* Bonn, Paris: Addison-Wesley.

Frick, A. 1998: *Visualisierung von Programmabläufen*, Fortschritt-Berichte VDI, Reihe 10, No. 561.

Harris, R. L. 1999: *Information Graphics. A Comprehensive Illustrated Reference. Visual Tools for Analyzing, Managing, and Communicating.* Oxford University Press.

Hellmann, A., U. Jessen and S. Wenzel 2003: e-Services – a part of the "Digital Factory". In *Proceedings of the 36th CIRP International Seminar on Manufacturing*

Systems 2003, ed. H. Bley, 199–203. Saarbrücken, Germany.

Johnson, M. E. and J. P. Poorte 1988: A Hierarchical Approach To Computer Animation in Simulation Modeling. *Simulation*, 50 (1988) 1, pp. 30-36.

Keller, P. and M. Keller 1993: *Visual Cues. Practical data visualization.* IEEE Computer Society Press.

Law, A. M. and W. D. Kelton 1991: *Simulation Modeling and Analysis.* Second Edition. New York: McGraw-Hill.

McHaney, R. 1991: *Computer Simulation. A Practical Perspective.* San Diego, California: Academic Press.

Nonaka, I. and H. Takeuchi 1997: *Die Organisation des Wissens.* Frankfurt, New York: Campus Verlag.

Pfitzner, D., V. Hobbs and D. Powers 2002: A unified taxonomic framework for information visualization. In *Proceedings of the Australian Symposium on Information Visualization*, Adelaide, Australia, pp. 57-66.

Robertson, P. K. 1991: A methodology for choosing data representations. *IEEE Computer Graphics & Applications* 11 (1991) 3, pp. 56-67.

Schumann, H. and W. Müller 2000: *Visualisierung.* Berlin: Springer.

Shneiderman, B. 1996: The eyes have it: A task by data type taxonomy of information visualizations, In *Proceedings of the IEEE Symposium on Visual Languages '96*, Boulder, Colorado, pp. 336-343.

VDI 3633 Part 11 2003: Verein Deutscher Ingenieure, Düsseldorf: *VDI-Richtlinie 3633, Blatt 11, Simulation und Visualisierung.* VDI-Handbuch Materialfluss und Fördertechnik, Volume 8, Berlin: Beuth Verlag, more information available online via <www.vdi.de> [accessed June 18, 2003].

Wenzel, S. 1998: *Verbesserung der Informationsgestaltung in der Simulationstechnik unter Nutzung autonomer Visualisierungswerkzeuge.* Dissertation. Series Unternehmenslogistik, ed. A. Kuhn, Dortmund: Verlag Praxiswissen.

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