

# Self-configuring Visualization Of A Production Monitoring And Control System

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## Abstract

Many changes in control systems result from a prolonged plant life. Therefore, this change process must be automated. In a prototypical framework, the control system and plant visualization engineering is performed automatically by means of standardized communication and a standardized data format. In practice, there is no uniform definition of what process visualization images have to look like. As safety-relevant aspects are important in production, such an automated system will only be accepted if the user interface is intuitive and user-friendly – briefly ‘anthropotechnically’ correct. Thus, with a layout manager, users specify partly how generated process images have to look like.

## Keywords:

Engineering, Automation, Image

## 1 INTRODUCTION

In this article, control systems are defined as complex central or decentral IT systems for capturing, aggregating/condensing and processing process signals and values in real time. They have a controlling effect on manufacturing and assembly processes - either in an automated way or through the interaction of users. In line with the definition by Polke [1], a control system is to support production personnel in operating plants and controlling and monitoring production processes. In the case of ProVis.Agent<sup>®</sup>, control system data is categorized as follows. Equipment (e. g. a conveyor belt) consists of various process variables (such as an analog process variable for the speed of the equipment). The process variables, in turn, are broken down into various process variable-specific slots. An analog process variable, for example, has an actual and a target slot.

Before a control system can be used, it has to be engineered. Engineering has three objectives: plant engineering, I/O engineering and image engineering. In image engineering, the desired process signals and plant components can either be represented by graphical objects or by I/O fields. In this context, the generation of process visualization is of major importance, as it represents the connection between the operator and the machine.

This article describes the automated generation of process images using the ProVis.Visu<sup>®</sup> visualization component of the ProVis.Agent<sup>®</sup> production control system, which was developed by Fraunhofer IITB. To this end, it was analyzed what data is required for automated visualization and whether this data could be extracted from other planning systems preceding control technology (such as hall layout). A standardized data exchange format and standardized communication mechanisms allow process images to be generated automatically from this data using a layout manager. In this context, it was examined how plants are visualized in practice. Emphasis was placed on ergonomic guidelines in this process. In addition, appropriate algorithms are to be developed to position the existing plant components and the visualized I/O signals clearly in the process image. Moreover, the

system is to allow for user interaction, enabling to adapt the process images to their personal preferences and requirements, to a certain degree.

The special field of human engineering [2] aims to adapt machinery and other technical equipment to humans to optimize their cooperation. The characteristics, potentials and requirements of human beings are taken into account, and the visualization of machinery and/or equipment is based on these conditions. For this reason, human engineering deals with both the physical/ physiological and the mental characteristics of human beings. [3]

In [4], the following seven rules are presented which form the basis of the high-quality design of the human-machine interface:

- "Mind the properties of the sense organs"
- "Depict process states in a task-dependant way"
- "Choose an attractive design which directly corresponds to the task"
- "Avoid information unnecessary for fulfilling the task (noise information)"
- "Mind the unconscious attention control of human beings"
- "Mind population-stereotypical expectations"
- "Design correlating display and operation elements in a strikingly similar way and those that do not correlate in a particularly divergent way"

Compliance with these rules is supposed to simplify the operation and use of machines (in this case the generation of process visualization) by human beings.

Interaction between men and women and machinery often requires display devices. Reference [5] recommends dividing the screen into the following sections: The topmost line should show the date and time as well as up-to-date information. Beneath, there should be an overview field showing the current state of the overall system and collective notifications that may exist. Beneath the overview field, there should be the working field, which can be used to display process images or

flow charts. Finally, at the bottom of the screen, there should be a key panel that cannot be overwritten and that serves to operate the visualization.

Currently, there is no unified standard for the generation of process images like R&I diagrams [6] in the process industry. In common systems, the majority of images is created manually. This results in process images varying significantly, depending on the preferences of the corresponding author. Since process visualization, however, represents the interface between users and machinery, this can result in severe problems, as these interfaces are meant to fulfill major ergonomic requirements. Another drawback of manual creation and engineering is that it is time-intensive and error-prone.

## 2 OVERALL APPROACH TO AUTOMATED ENGINEERING

For automated engineering, the IITB's Control Systems business unit uses the supplier-independent XML-based CAEX format (Computer Aided Engineering Exchange, [7]) as a standardized data format. References [8] and [9] describe the structure and elements of CAEX in more detail. Although CAEX was developed for process engineering, [10] and [11] have shown how the CAEX model is suited for the exchange of static data in a production control system such as Provis.Agent® and in what way it was adjusted and applied for that purpose.

The CAEX model consists of three different structures organized in libraries - the 'InterfaceClassLibrary', the 'RoleClassLibrary' and the 'SystemUnitClassLibrary'. In addition, there is the 'SystemHierarchy', where specific pieces of equipment are described. The CAEX model only describes the structure of the CAEX data, but it does not deal with the semantics. In the application presented below, this description of the semantics was achieved, among other things, by breaking down each of the three libraries and the 'SystemHierarchy' into products, processes and resources. This allows the individual classes and their inter-dependencies to be mapped. CAEX is the framework format for this application. The starting point of the engineering process is a definition which comprises all interacting components in the form of CAEX classes or templates. Each system has such a describing class, which contains all possible data including their structuring and semantics.

If control system data or data of another component is stored in CAEX, this process is based on the aforementioned class description. By comparing the CAEX classes of two data sources, a mapping can be created manually, which can later be applied to the CAEX data of a specific plant in an automated way.

The communication standard that was found to be appropriate and that is being used is OPC's successor, the OPC Unified Architecture (OPC UA, [12]).

If this kind of CAEX-based plant description is available from a tool (such as an e-planning tool, see Figure 1), it is transmitted to the change management of the control system by means of OPC UA, which then fulfills the task of engineering. Since OPC UA is a new communication standard which is not very wide-spread yet, there is also the option of a web service-based data transmission.

First of all, the provided CAEX data is checked with respect to structural correctness using the standard CAEX-XML schema. If the validation is successful, the CAEX data can be processed further on the basis of the structure and semantics. For this purpose, the mapping developed before is used to transform the data into a ProVis-specific CAEX format. If the validation is successful, the CAEX data can be processed further on the basis of

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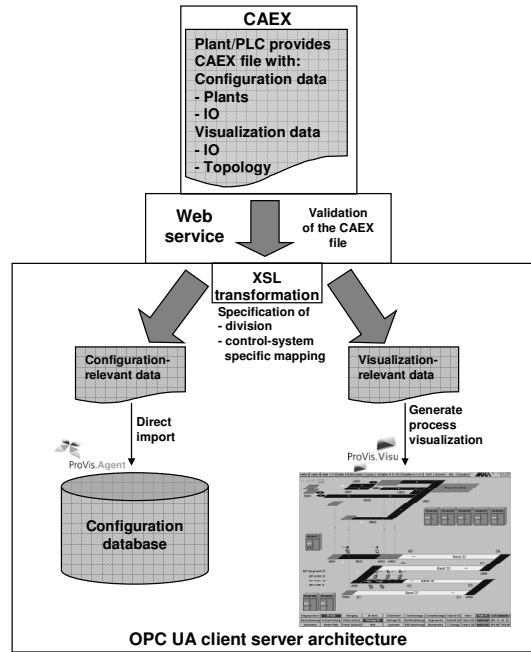


Figure 1: Automated engineering of control systems.

If the validation is successful, the CAEX data can be processed further on the basis of the structure and semantics. For this purpose, the mapping developed before is used to transform the data into a ProVis-specific CAEX format. To allow aggregates to be supported, the existing CAEX data had to be modified. The classes of the 'SystemUnitClassLibrary' can be used as modules for complex plants. For this reason, a new 'SystemUnitClass' called 'Aggregation' was created, which allows to manage the information required for aggregates. This class owns the two attributes 'Ist\_Aggregat' ('is an aggregate') and 'Gehort\_zu\_Aggregat' ('forms part of an aggregate'). They allow to specify whether each piece of equipment forms an aggregate itself or whether it is possibly part of an aggregate.

## 3 PROVIS.VISU®

Common SCADA or process visualization systems usually include a graphical editor and a runtime component for displaying the process images (online tool). It is possible to integrate various graphical objects and texts. In addition, the import of existing or frequently used diagrams is supported, at least in the bitmap format.

As part of its ProVis.Agent® production control system, Fraunhofer IITB has developed the ProVis.Visu® visualization system [13]. In addition to being real-time-compliant, it can also easily be installed on any client. ProVis.Visu® consists of the 'Operation and Monitoring' visualization component, a 'Process/Diagram Editor', a 'Start Center' and a configuration tool for managing users and authorizations'. The Process/Diagram Editor can be used to generate, modify and administer the process visualization. In this context, image generation does not only include the drawing of the process visualization. Rather, the process link of the graphical elements to the data points from the engineering database or the signals of a running production process is supported, too. Process images can be linked to both the data from the production process provided and pre-processed by the control system (using OPC, i.e. OLE for

Process Control) and to any other OPC server providing data. The 'Operation and Monitoring' visualization system is used to display and operate process images created with the Process/Diagram Editor during operation.

#### 4 REQUIREMENTS

The precondition for the automated generation of process visualization is to specify the requirements that had to be met by the process images. In this context, the experience made with both existing process visualization and common systems were included.

The following five basic requirements could be identified:

- to take account of the unconscious attention control of human beings,
- to create a topological overview of the entire plant,
- to visualize partial components,
- to display process variables and their current values,
- to allow for the operability of the plant,
- to allow users to define interactively what plants and process variables they want to monitor and operate.

#### 5 CONCEPT OF THE AUTOMATED GENERATION OF VISUALIZATION

In line with these requirements, both a topological and a structural overview of the available machinery and equipment should be provided and, in addition, it should be possible to operate individual pieces of equipment. For this reason, three different views were designed, namely the topological, the structural and the operational view.

The topological view has the purpose to visualize the topology of the monitored plant. In this process, it should be possible to zoom into the plant. To this end, a model of hierarchical levels was created which allows to combine several pieces of equipment to form an equipment aggregate. This idea is shown in Figure 2.

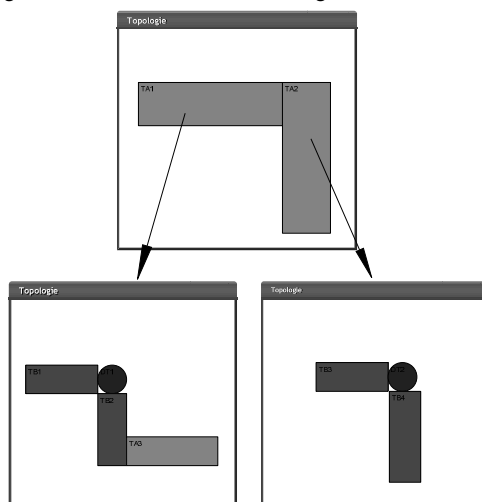


Figure 2: Concept of the topological view.

The topmost hierarchical level only allows visualizing the aggregated equipment, whereas the lower levels enable the individual pieces of equipment to be visualized. In this process, any level of abstraction is possible, allowing entire production halls to be depicted clearly in just one image. Nevertheless, the most important information such as faulty states in the aggregates can be shown.

The second view to be generated is the structural view. This view is designed to provide an overview of the sig-

nals of the existing pieces of equipment to users. Every line stands for a piece of equipment contained in the overall plant. The other elements represent the linked process variables, their slots and their current values. Similar to the topological view, the structural view provides an overview of the plant, yet referring to its structure rather than to its topology. Therefore, both views have an equal status.

The operational view is the third view that has to be created. It is designed to allow the users to operate the plant they monitor. The operational view is rather similar to the structural view, as it also enables users to monitor the linked process variables, their slots and their current values. However, the operational view only displays the process variables of one piece of equipment rather than those of the entire equipment, as is the case in the structural view. This means that an operational view has to be generated for every piece of equipment deployed in the plant and can be interpreted as the lowest hierarchical level of the topological view.

The design of all views aims to meet ergonomic requirements. For this reason, all views only display necessary information.

In the topological view, the associated process variables were left aside deliberately as they would distract users from the actual purpose of this view, namely to show the topological structure of the plant. This complies with the fourth basic rule of reference [4], which states that information unnecessary for fulfilling the task has to be avoided. In addition, the way in which the plants are displayed is in line with these qualitative basic rules as an attractive design which directly corresponds to the task (third basic rule) was chosen. Human beings can observe only a low number of elements at a time. For this reason, the design of the topological view focused on ensuring the aggregation of several plant components to form one aggregate plant, thereby reducing the number of elements to be visualized. In the topological view, plant elements are visualized by graphical elements in a defined color. However, if an error occurs in the plant, the color changes (to the signal color red), taking account of the fifth basic rule cited in reference [4].

The structural view complies with the seventh basic rule of reference [4] by grouping each plant with the process variables that are linked to it and the slots in the same line.

The operational view also took account of the recommendation to group correlating elements (process variables, the slots linked to them and current values), which reflects the seventh basic rule according to reference [4]. Besides, the identical division of the screen as proposed in [5], all three views meet the ergonomic requirements process visualization is faced with.

#### 6 LAYOUT MANAGER

To allow users to adapt the generated process images to their own needs to a certain degree, a user setting form was included which allows users to tailor the process visualization to their own wishes. In this process, the basic structure of the process images remains the same. This avoids the problem that the images diverge considerably depending on the persons who drafted them, as was the case with the manual creation of process visualization.

Fraunhofer IITB specified that in the topological view (see Figure 3-left) users can define the equipment that represents the highest hierarchical level. This enables users to visualize only that part of the existing plants that is relevant to them.

Figure 3-right shows the user interface for the settings of the structural and operational views. This form shows a treeview of all process variables currently available in ProVis.Agent® as well as the slots that can be linked to them. Here, users can choose which process variables they want to have visualized in the structural and operational views and which they don't. In this process, the selection is not restricted to the process variables. Instead, the relevant slots can be selected individually, too. For instance, it is possible to display the actual values of the distance process variables in the views. The selection of the process variables and/or slots results in the fact that the structural view displays only those pieces of equipment to which at least one of the selected process variables or one selected slot is linked. If, for example, the distance process variable is the only one selected for the visualization, the structural view will not include any pieces of equipment that do not contain any such process variable.

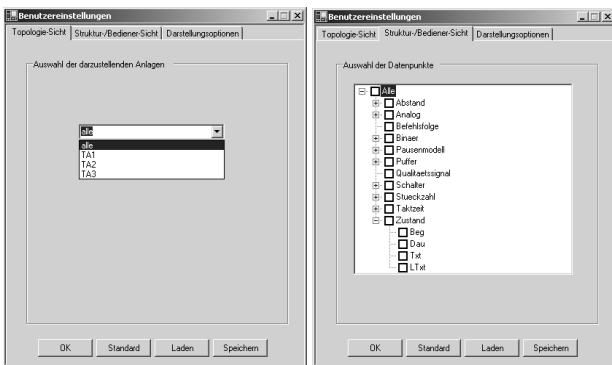


Figure 3: User interaction in the topological view (left) and in the structural/operational view (right).

The CAEX files used here include 'SystemUnits', which may contain describing information about the representation objects of the various pieces of equipment. Currently, there are two kinds of 'SystemUnits', namely rectangles and circles. Each piece of equipment in the 'SystemHierarchy' instantiates such a 'SystemUnit', i. e. there is a value mapping to the pre-defined attributes. To this purpose, the values are to be extracted from external descriptions such as the hall layout. However, it may happen that some values such as the coloring of the pieces of equipment are not available or that the users wish a different coloring for the representation. For this reason, the form shown in Figure 4 may be used to specify the color or a bitmap graphic that should be used.

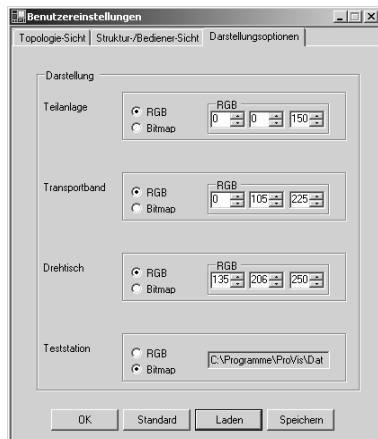


Figure 4: User interaction for visualization options.

This benefits from the fact that the CAEX files used in this article are complete, which means that each piece of equipment included in the 'SystemHierarchy' has been

assigned a role description. The role description ensures that all pieces of equipment executing that role are represented by the same object. Thus, users can specify what color the conveyor belts deployed in the plant should have. To this end, they only have to enter the desired color in the form in the RGB (red-green-blue) format. In addition, there is the option to specify a bitmap graphic representing the corresponding pieces of equipment. In addition, it is possible to store the settings in a XML configuration file or to load them from such a file.

### 6.1 Example of use

To be able to test the findings, an example of use was created (see Figure 5) which served as a benchmark application. The sample plant consists of three hierarchical levels in total. The top hierarchical level consists of two equipment aggregates called TA1 and TA2. They are aggregates of several pieces of equipment.

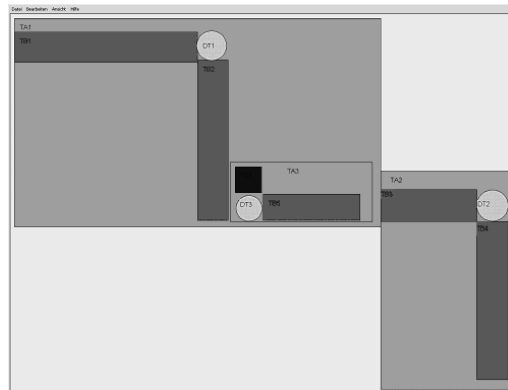


Figure 5: Example of use.

In the second hierarchical level, the equipment TA1 consists of two conveyor belts TB1 and TB2, a turntable DT1 and another equipment aggregate TA3. The equipment aggregate TA2 includes two conveyor belts (TB3 and TB4) and a turntable (DT2).

The third and thus lowest hierarchical level is represented by the TA3 equipment aggregate. This, in turn, consists of a turntable DT3, a test station TS1 and a conveyor belt TB5. Thus, the sample application is made up of twelve pieces of equipment, three of which are aggregates (the equipment aggregates TA1 to TA3) and nine 'genuine' pieces of equipment.

### 6.2 Generation of the operational view

An operational view (see Figure 6) is called either by clicking a piece of equipment that does not represent an aggregation in the topological view or by clicking any element in the line of the appropriate piece of equipment in the structural view.

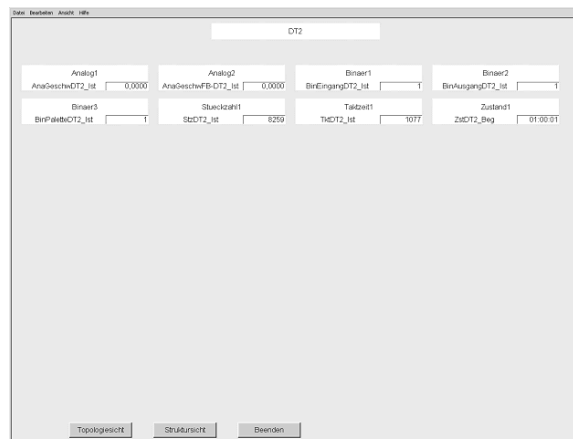


Figure 6: Operational view.

As Figure 6 shows, the first thing to be displayed is the name of the relevant piece of equipment. It is followed by the linked process variables selected for visualization and their slots. The depiction of the process variables is divided into four columns, which makes the process visualization clearer. The individual process variables were summarized in blocks. The topmost line of these blocks indicates the name of the corresponding process variable (e.g. 'Binaer1'). The lines below show the names of the linked slots (e.g. 'BinAusgangDT2\_Ist', i.e. BinOutputDT2\_Actual) and their current values.

At the bottom margin of the process image, there are three buttons which allow the users to navigate within the visualization. The 'Topologie' button enables users to shift from the operational view to the topmost hierarchical level of the topological view directly, whereas the structural view can be displayed by clicking the 'Struktursicht' button. By clicking 'Beenden' (Cancel), the visualization (or the 'Operation and Monitoring component of ProVis.Visu®) is terminated.

ProVis.Visu® offers a variety of template elements to visualize the individual objects in the process images. The automated generation of process visualization was able to use these elements. For the generation of the operational view, text fields, I/O fields and buttons were used. For each object that has to be visualized (e.g. the name of the piece of equipment or the value of a binary variable), a 'createElement()' method is invoked including the required parameters. This method, in turn, uses an existing ProVis.Visu® method (e.g. 'CreateButton()'). In addition, the interactive approach was applied by defining the consequences of certain mouse clicks (such as an image shift, the display of detailed information or the invocation of the process operation). This means that a mouse click on a certain button, for instance, triggers an image shift to the topological view. To do so, the new image that is to be displayed has to be known. Furthermore, interactions were applied to be able to operate the plant if necessary.

### 6.3 Generation of the structural view

The structural view (see Figure 7) can be called by clicking the 'Struktursicht' button in one of the operational or topological views.

Equipment	Variable	Value
TB6	Analog1	1.5000
	BinAer1	1
	BinAer2	1
	BinAer3	1
DT3	Analog1	0.0000
	Analog2	0.0000
	BinAer1	1
	BinAer2	1
TS1	Analog1	0.0000
	BinAer1	1
	BinAer2	1
	BinAer3	1
TB1	Analog1	0.0000
	BinAer1	1
	BinAer2	1
	BinAer3	1
TB2	Analog1	0.0000
	BinAer1	1
	BinAer2	1
	BinAer3	1
DT1	Analog1	0.0000
	Analog2	0.0000
	BinAer1	1
	BinAer2	1
TB3	Analog1	0.0000
	BinAer1	1
	BinAer2	1
	BinAer3	1
TB4	Analog1	0.0000
	BinAer1	1
	BinAer2	1
	BinAer3	1
DT2	Analog1	0.0000
	Analog2	0.0000
	BinAer1	1
	BinAer2	1

Figure 7: Structural view.

As was described in the previous section, the operational views must be in place before the structural view can be generated. This is due to the fact that the structural view should allow for a direct shift to one of the operational views. Since this is implemented by an image shift, as was the case with the buttons, the relevant names or numbers of the operational views have to be known.

These, in turn are not defined until those views are generated.

The structural view takes the form of a table. Each line in the structural view stands for a piece of equipment in the visualized plant. The beginning of the line indicates the name of the relevant piece of equipment. The name is followed by the linked process variables that need to be displayed. Process variables are represented by three different kinds of information, namely the name of the process variable (e.g. 'Analog1'), the name of the slot (e.g. 'Ist', i.e. actual) and the current value. At the bottom of the structural view, there are the buttons for navigating within the visualization, as was the case before.

Owing to the limited space available in the structural view, it is only possible to visualize a maximum of eleven pieces of equipment. If the plant to be monitored consists of more than eleven pieces of equipment, several structural views must be generated. In that case, the structure of the views is always identical. If several views exist, there is an additional button which allows to shift to the following view.

A mouse click on an element of a piece of equipment (e.g. the equipment name) results in an image shift to the operational view of the corresponding piece of equipment. To this end, the numbers of the operational view are used; they were stored when the operational view was generated. Consequently, they had to be in place before the structural view could be created.

### 6.4 Projection of coordinates and placement

As was mentioned before, the information about the position and the size of pieces of equipment stored in the CAEX file are to be extracted from the layout of the hall, for instance. In this article, it was assumed that all position data was greater than or equal to zero, i.e. the equipment is located in the first quadrant of the Cartesian coordinate system. Basically, it does not matter whether the data is expressed in pixels or in metric units (feet, inches, etc.) because what counts for the visualization is the relation of the sizes of the individual pieces of equipment.

To enable the equipment to be visualized in the topological view, all pieces of equipment forming part of the relevant aggregate have to be identified first. Once this is done, the calculation of the positions and extensions of the individual pieces of equipment can start. This is necessary because the data from the CAEX file may reflect the real-world sizes, which cannot be represented graphically in that form, of course. Finally, a transformation of the coordinates into the coordination system of the corresponding visualization (in this case ProVis.Visu®) may be required.

The following steps are necessary to adjust the coordinates and the size data:

- specification of overall extension of the plant to be visualized,
- specification of scaling factors for the graphical representation in ProVis.Visu®,
- calculation of new coordinates, heights and widths,
- specification of appropriate reference point and adjustment of the coordinates.

### 6.5 Generation of the topological view

Before the topological view is generated, all pieces of equipment intended to be displayed at the highest hierarchical level of the topological view have to be identified. Subsequently, all pieces of equipment are identified that form part of this equipment aggregate. When all pieces of equipment that are supposed to be visualized at this hierarchical level are found, the data on coordinates and

sizes have to be adapted for the graphical representation.

Currently, three different elements are used to visualize the equipment. On the one hand, there are the geometric elements 'circle' and 'rectangle', on the other hand there is the option of visualizing equipment on the basis of bitmap graphics. The assignment of the elements is based on the role of each piece of equipment. Users can specify the coloring and a bitmap graphic. On the basis of these specifications, the equipment is then visualized in the topological view by drawing the appropriate object, taking into account the calculated data on position and size.

Figure 8 shows a topological view that was created automatically. The visualization of the equipment covers the major part of the available space. At the bottom margin, there are the aforementioned buttons.

In the topological view, too, interactions are used. As was the case in the operational and structural views, the buttons allow for an image shift by a click of the mouse. In addition, an image shift was created for each of the elements of the pieces of equipment, too. In that case, it has to be distinguished whether the equipment is an aggregate or a 'genuine' piece of equipment. If it is a genuine piece of equipment, a mouse click on the corresponding visualization element results in an image shift to the operational view of the equipment. If the equipment is an aggregate, the image shifts to the topological view, where the pieces of equipment that belong to that aggregate are visualized. The generation of any further topological view follows the same pattern as the topmost topological view.

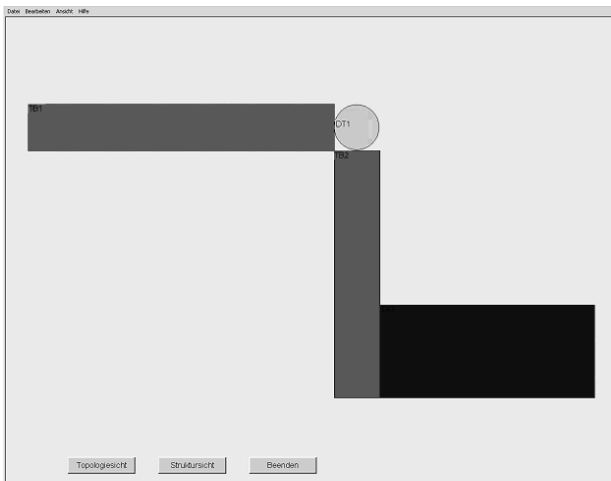


Figure 8: Topological view.

In addition to the image shifts, another kind of interaction is used in the topological view, namely the change of color presented above. To this end, the 'sum state' of the associated state process variables is linked to the pieces of equipment additionally. The value of the 'sum state' changes depending on the state of the equipment. If a fault occurs in the piece of equipment, the 'sum state' takes on a certain value, and this change triggers a change of color (in this case to the color red). The element of the corresponding piece of equipment is displayed in that color and thus alarms the user that the equipment is not working properly at that moment. For 'genuine' pieces of equipment, the link is implemented through the corresponding 'sum state' of their state process variables. Since aggregates do not own any process variables, it is possible to combine the 'sum states' of the individual pieces of equipment and to link the result of this combination.

## 7 SUMMARY AND OUTLOOK

IITB's efforts aimed at an automated generation of process images in ProVis.Visu<sup>®</sup> on the basis of CAEX descriptions. Considering the requirements the visualization of plants is faced with, the graphical representation was defined in multiple views. This allowed for a topological and a structural overview of the entire plant as well as a zoom into the equipment. In addition, the equipment can be operated (provided that the system allows doing so). To ensure that users can adapt the visualization to their own needs, the visualization allows for some interaction which enables users to make various specifications such as the process variables and equipment intended to be represented. These specifications can be stored and reloaded, so repeating settings are available quickly. To test the automated generation, an example of use was designed. Subsequently, this example was integrated in the existing CAEX format. On this basis, the visualization varieties resulting from the option of user interaction could be tested.

In a further step, the efforts are aimed at the integration with a common layout tool, ensuring that data that is actually relevant in practice can be used, too.

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