

Assessing Process Attribute Visualization and Interaction Approaches Based on a Controlled Experiment

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Received 1 April 2020

Revised 3 August 2020

Accepted 6 October 2020

Published 3 December 2020

Ensuring the smooth and efficient execution of business processes requires a continuous process quality assessment and optimization. Process optimization exploits process attributes and their values, e.g. cost or duration of a process task, in order to derive, for example, control flow adaptations. The complexity of the analysis can range from a few to a plethora of attributes, e.g. machining times and sensor parameters in the manufacturing domain. Hence, it is crucial to support single and multiple users (e.g. process analysts) in visually exploring process attributes and their values. Specifically, comparing and assessing different visualization and interaction approaches with respect to their efficiency is required in order to offer the most suitable approach to users for a specific analysis task. However, such assessments are currently missing. To close this gap, this paper assesses three visualization and interaction approaches, i.e. 2D, 3D, and 3D with virtual reality (VR) support, based on a controlled experiment. We choose the process modeling standard Business Process Modeling and Notation (BPMN) as 2D approach. 3DViz is introduced as 3D approach with focus on attribute representation, and additionally augmented with VR. A statistically significant difference between the approaches can be observed with respect to their efficiency.

Keywords: Process attribute visualization; 3D representation; process model; virtual reality; controlled experiment.

1. Introduction

Business process models capture the business logic of companies and enable the implementation and execution of workflows that support users, integrate

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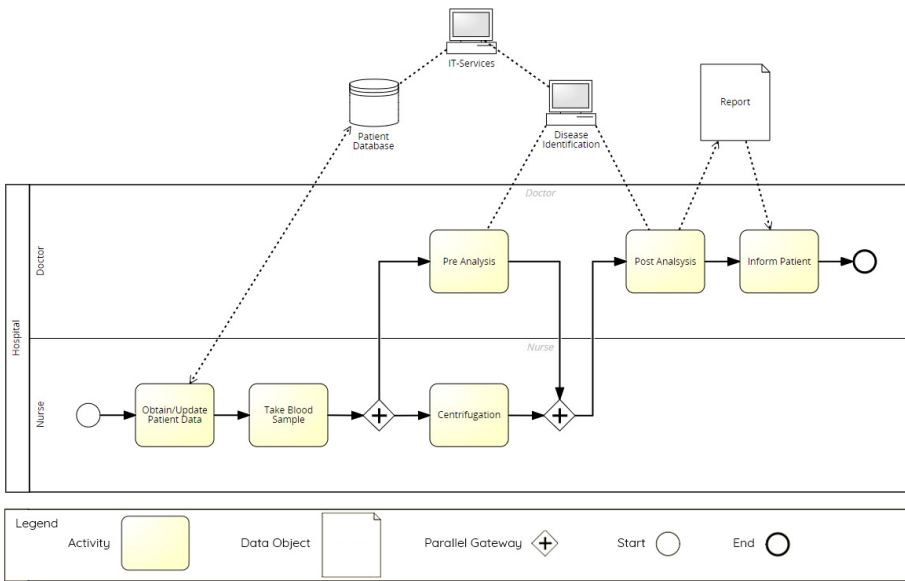


Fig. 1. Care process modeled in BPMN using *Signavio* — example.

applications and services, and log process-related information.¹ For modeling their core business processes, typically, companies use Business Process Modeling and Notation (BPMN)* as standard notation.²

Running example: Figure 1 shows a process model from the care domain. The model is provided in BPMN notation (created using Signavio[†]). The control flow is represented by 6 *Activities* (e.g., *Take Blood Sample*) that are ordered by directed edges. The process starts with a *Start* and ends with an *End* event. The control flow comprises a parallel branching denoted by *Parallel gateways*. The activities executed in parallel are *Pre Analysis* and *Centrifugation*. Data object *Report* is written by activity *Post Analysis* and read by activity *Inform Patient*.

Altogether 6 *Attributes* are assigned to the activities in the process model as summarized in Table 1, i.e., *Duration*, *Role Duration*, *Cost*, *Location*, *Role*, and *IT Services*. Table 1 also shows the attribute values that are assigned prior to the execution at the model level.

Following the BPMN meta model, attribute *Role* describing the authorization for the process activities is modeled using *Pools* and *Swimlanes*. Pool *Hospital* denotes the organizational unit in which the process takes place. The *Swimlanes* denote the role assignments to activities. Role *Nurse*, for example, is authorized to work on activities *Obtain/Update Patient Data*, *Take Blood Sample*, and *Centrifugation*. Attribute *IT Services* is modeled using BPMN *Artefact IT Service* specialized

*bpmn.org

[†]<https://www.signavio.com/>

Table 1. Attributes and their values assigned to activities in the process model (Fig. 1).

	Obtain/Update Patient Data	Take Blood Sample	Pre Analysis	Centri- fugation	Post Analysis	Inform Patient
Role	Nurse	Nurse	Doctor	Nurse	Doctor	Doctor
Duration	20 min	5 min	15 min	10 min	45 min	20 min
Role Duration	1 min	5 min	15 min	1 min	45 min	20 min
Cost	1 \$	10 \$	40 \$	1 \$	90 \$	40 \$
Location	Waiting Room	Treatment Room	Lab	Lab	Lab	Consulting Room
IT Services	Patient Database		Disease Identif.		Disease Identif.	

Table 2. Processes from different domains with absolute number of process elements and attributes.

	#activities	#sub-processes	#gateways	#events	#derived attributes
Prepayment (energy domain) ⁴	13	4	13	22	credit, credit_score deadline, waiting-time, Role_customer Role_system
Daily routine (care domain) ⁵	12	—	2	2	physical_object, worktime, Role- nurse, medica- tion hydration
Robot Interac- tion (manufac- turing domain) ⁶	9	—	3	2	data_url, end- point program, state data_state, started

in *Data Storage Patient Database* and *IT Service Disease Identification*. Attributes *Duration*, *Role Duration*, *Cost*, and *Location* can be specified with the activity.

The process model depicted in Figure 1 is rather a toy example, but already contains a set of different attributes assigned to the activities. Real-world processes are often much more complex. In the manufacturing domain, for example, they “usually comprise hundreds up to thousands of sub-processes (and sub-process dependencies)”³ with possibly assigned attributes. Table 2 provides the absolute numbers of process elements and attribute for selected process models from different domains.

1.1. Problem statement

Process models can easily become complex and contain a multitude of different information such as activities, data objects, and attributes, from various sources such as databases, services, and real-time information. For that very reason, supporting a deep understanding of the process models is a crucial task, especially for enabling process optimization. Process optimization constitutes a mandatory

step in the process (re-)engineering life cycle before implementing and executing processes and their instances. However, companies often remain overwhelmed in understanding their process models due to insufficient representation and visualization of the models.^{7,8}

In order to deal with such complex processes, representations such as views or abstractions can be of help to reduce the complexity by restricting the provided information.^{8,9} However, by restricting the information, relations between process attributes cannot be identified anymore.

3D Virtual World visualizations have been investigated with respect to understanding process models in the context of process gateways “as they are a major cause of complexity in process models”.⁷ In this line of argumentation, this paper investigates whether 3D representations are useful for visualizing and interacting with multiple process attributes and their values. Process attributes also add complexity to the process models and it is yet only partly clear how they are visualized in current notations such as BPMN.

This leads to the following research questions tackled by this work:

RQ1 How to visualize process attributes using 2D, 3D, and 3D with VR approaches?

RQ2 For easy and complex tasks does any of the three approaches (2D, 3D, and 3D with VR) outperform the other approaches with respect to efficiency?

Regarding **RQ2**, we measure and compare the efficiency of the approaches as we are primarily interested in their usability.¹⁰ Efficiency measures the time it takes the participants to complete all tasks of the experiment. In the example process, such a task could be to identify the activity with highest cost executed by the role doctor. Studies using different presentation mediums are rare in process visualization research.¹¹

1.2. Contribution

Early approaches for 3D process visualization^{12,13} could not be established due to limited resources. In the last decade, the computing power has increased and therefore rendering huge 3D models with multiple attributes is not a challenge anymore. Moreover, the so-called representation gap¹² when visualizing a 3D model on a 2D monitor is solved by using new devices called head-mounted displays (HMDs) as shown in the recent literature,¹⁴ such as virtual reality (VR) and augmented reality (AR) to explore and interact with 3D representations. The prospects of 3D visualizations combined with Virtual Worlds (VW) for process modeling have been shown in literature as well.⁷

Based on the lessons learned from early works and relevant literature, the contribution of this work is two-fold. First of all, we introduce a 3D process model visualization approach called *3DViz*. It focuses on visualizing multiple attributes within one process model, including a prototypical implementation (\Rightarrow **RQ1**). See also technical report¹⁵ and demo¹⁶ of the prototype. Second, we compare the efficiency

of 2D, 3D, and 3D with VR visualizations for process models and attributes based on an experiment.

Researchers are divided if 3D or 2D representations are better suited for presenting information.¹² In this paper, we aim at underpinning the assumption that 3D visualization is suited for the visualization of and interaction with (multiple) process attributes based on a controlled experiment (\Rightarrow **RQ1** and **RQ2**). In detail, this work compares three ways of visualizing and interacting with process models, i.e. 2D using BPMN standard notation in Signavio, 3DViz, and the 3DViz VR approach. We will investigate the perspective of a user solving tasks with each of the visualization approaches. All questions are focused on finding specific attribute-based¹⁷ activities. In particular, the experiment investigates whether there is a difference between the visualization approaches in terms of their overall *efficiency*. Efficiency is measured by the time needed to complete the tasks.

Corresponding to **RQ2** we state the following hypothesis for the experiment:

H0: For easy and complex tasks, one attribute visualization approach significantly exceeds the others regarding their efficiency.

In summary, this is an empirical work with focus on the experiment. Contributions in terms of concepts and implementations, however, are provided as well, i.e. the 3DViz approach. The experiment follows a Within-Subject-Design¹⁸ and uses VR and Desktop presentation mediums for the evaluation. Statistically significant results can be derived: overall, it can be shown that 2D visualizations are suited for simpler tasks with single attributes and 3D approaches with VR support are suited for more complex tasks with multiple attributes.

The remainder of the paper is structured as follows. In Sec. 2, the 3DViz approach is introduced. Section 3 discusses the prototype implementation. Section 4 describes the experiment and Sec. 5 provides the analysis and findings. Section 6 discusses related work and in Sec. 8, a summary is provided.

2. Attribute Visualization in 3DViz

Almost all 2D process representations focus on the control flow representation. This is also the case with 3D representations.^{12,13} The 3DViz representation provided in this paper extends the control flow view by visualizing multiple attributes within one representation. To visualize multiple attributes, we use the additional *Z*-axis. This allows to position objects in the depth. Positioning objects in the depth is the key advantage when comparing 3D and 2D visualizations. For example, activities with low costs can be displayed further forward and those with high costs further back. Such a visualization allows to immediately see for an activity how it cuts off in comparison with other activities. If an additional visual style, such as scaling, is used, the user is able to compare attributes with each other. In its current state, 3DViz is limited to static process model visualization hence, no live data processing, or replay of log files is involved.

2.1. Visual elements

In 3DViz, every process activity and control flow element is represented by one specific 3D visual element. These 3D elements are influenced by BPMN as it is the defacto standard for modeling business processes² and refined by a selection of design principles as proposed by Moody.¹⁹ In the following, we explain what has changed from standard BPMN notion towards 3DViz and how the targeted design principle is met.

- We use a distinct portion of the notion from BPMN. This contributes to the *Principle of Semiotic Clarity*¹⁹ where each symbol corresponds to one semantic construct. The *Principle of Semiotic Clarity* is satisfied in case there exists a one to one matching between a symbol and a semantic construct.
- To allow further differentiation and to reduce interpretation errors, we use the *Principle of Perceptual Discriminability*¹⁹ and *Principle of Visual Expressiveness*.¹⁹ In order to satisfy the *Principle of Perceptual Discriminability*, redundant coding^{19,20} is used. Redundant coding uses multiple visual variables for the same visual element. The *Principle of Visual Expressiveness* measures the amount of used visual variables. 3DViz uses the visual variables shape, color, and size.
- The *Principle of graphic economy*¹⁹ is defined by the number of graphical symbols within the notion. We use only a small portion of BPMN's massive vocabulary and therefore decrease the cognitive load on the user. Since we use symbols similar to BPMN, we allow advanced users to not have to re-learn the language. However, using BPMN's notion does not allow us to improve on the *Principle of Semantic Transparency*, *Dual Coding* and *Cognitive Fit*. The *Principle of Semantic Transparency* uses symbols suggesting the meaning, *Dual Coding* complements visual representations with text and *Cognitive Fit* allows for adapting the visual representation to different audiences.
- Due to the representation of certain attributes selected by the user we partially support the *Principle of Complexity Management*.¹⁹ The *Principle of Complexity Management* incorporates mechanisms to regulate the complexity of a representation.

So far, 3DViz does not include mechanisms to integrate other diagrams or systems as proposed by the *Principle of Cognitive Integration*.¹⁹ The evaluation and implementation provided in this work are concerned with a simplified version for the start which can be extended in future work.

Figure 2 depicts 2D elements as used in BPMN, specifically in Signavio, and the corresponding 3D visualization from 3DViz framework containing the following categories *Activity*, *Event* (*Start Event*, *End Event*), *Gateway* (*Exclusive Gateway*, *Parallel Gateway*), and *Directed Edge*. In order to be more distinguishable, the *Exclusive Gateway* is underlined compared to the *Parallel Gateway*. Both *Exclusive* and *Parallel Gateway* display the symbol on each side of the cube.

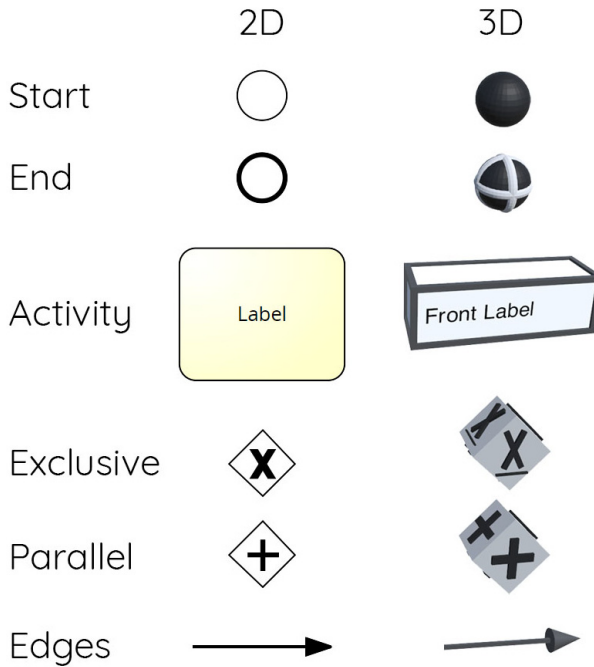


Fig. 2. 3D visual elements within the 3DViz framework in comparison with 2D elements as used in BPMN (Signavio).

2.2. Visual styles

Within the 3DViz framework three different visual styles are applied, i.e. *positioning*, *scaling*, and *labeling* of *Activities*. Other visual styles such as colors, shapes, or edge pattern are not conceivable as these styles are already used in some way representing process models. We opted for positioning, scaling, and labeling as these styles do not interfere with the notion of BPMN.

In essence, each *Activity* in the process model is represented as cube instead of a rectangle as in BPMN (Fig. 2). Hence, at first, it can be positioned on the *X*-axis, *Y*-axis, and *Z*-axis. This allows for integrating more information into the process model representation as activities are positioned based on their attribute values. Figure 3 depicts activities with high cost farther back on the *Z*-axis, e.g. activity *Post Analysis* with cost of 90\$ is positioned farthest in the back while activity *Centrifugation* has cost of 1\$ and is positioned in the front. If the user wishes to switch positions, such that activities with high cost are positioned in the front this is possible as well. Second, scaling of *Activities* can be applied on the *X*-axis, *Y*-axis and *Z*-axis, as well. Third, each side of the cube can be labeled with its own text. For example, Fig. 3 shows the *Name* of an *Activity* on the front and the *ID* on top of the cube.

Applying all combinations of the styles *scaling* and *positioning* on a process with control flow perspective allows us to integrate five attributes within one process

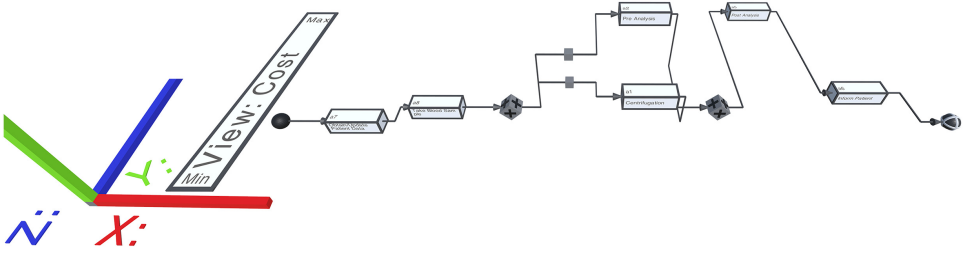


Fig. 3. Example process where attribute *Cost* is visualized on the Z-axis.

model plus additional information as a result of the cube *labels*. In case an *Activity* does not contain a certain attribute, the *Activity* style in terms of *scaling* and *positioning* will be set to a default value.

2.3. Attribute mapping

So far, 3DViz consists of multiple *Activities* connected by edges visualizing the control flow view. When modeling a process more information is integrated into the model. Each *Activity* can have multiple attributes for example, roles or resources. These attributes need to be processed before they can be used within the representation. We differentiate 3 processing strategies, *Direct Mapping*, *Relative Mapping* and *Discrete Mapping*.

Figure 4 depicts examples for all combinations of visual styles, mappings and attributes. To simplify the figure, only the first two *Activities Obtain/Update Patient Data* and *Take Blood Sample* from the example process are visualized. Further, the

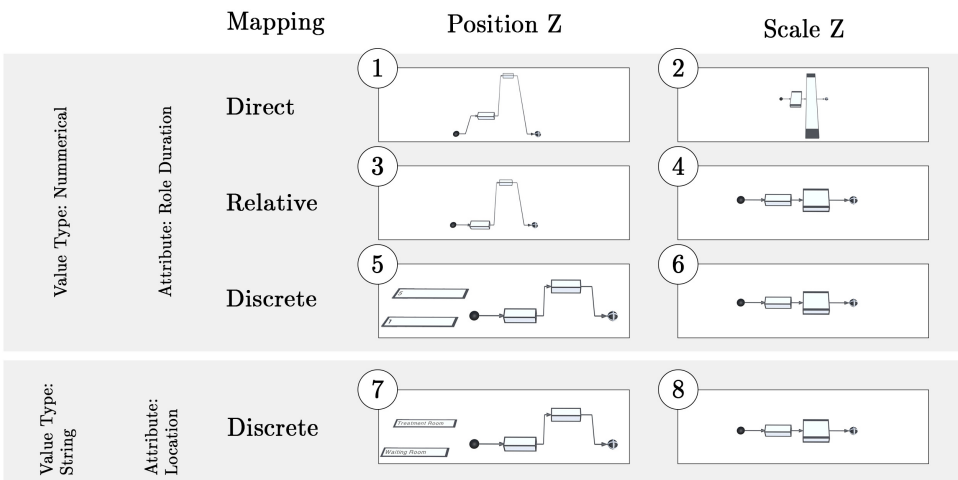


Fig. 4. Mappings applied to different attribute types with different styles.

styles *position Y-axis*, *scale X-axis* and *scale Y-axis* are not depicted as they are similar to the provided styles.

Creating a mapping for attributes imposes certain challenges such as how to handle attributes with non numerical values. Such attributes cannot be used for calculating minimum and maximum values which is necessary for the *Relative Mapping*. We allow the following mappings for attributes that consist of numerical values.

- *Direct Mapping* ①, ② uses the attribute values without further modification. For example, if a value is 5 an *Activity* gets scaled 5 times. This mapping might not be of use in many application scenarios, but it can help to detect outliers.
- *Relative Mapping* ③, ④ calculates a percentage value for each *Activity* where the minimum is 0% and maximum is 100%. For example, an *Activity* with a calculated value of 20% is scaled up by 20%. To prevent activities from getting invisible by scaling down 100% we use upscaling instead.
- *Discrete Mapping* for numerical values ⑤ uses multiple swim lanes and interpolates each attribute to fit a specific swim lane. For scaling ⑥, each discrete group is represented by its own scaling factor ranging from 0% to 100%.

When the attribute to represent is a non-numerical value like resources and roles the 3DViz framework does not allow for using *Direct Mapping* and *Relative Mapping*. Such values can only be used with the *Discrete Mapping*.

- *Discrete Mapping* for non numerical values ⑦ represents the attributes in distinct swimlanes similar to numerical swimlanes. Scaling discrete non numerical values ⑧ is done by using a scaling factor ranging from 0% to 100% per group.

It is important to know that activities for *relative* and *discrete mapping* are not able to overlay other activities when using upscaling. While activities are positioned the algorithm takes care that there is enough space between activities. However, this cannot be guaranteed for direct mapping; therefore, we suggest to use direct mapping carefully.

2.4. Representing single and multiple attributes in 3DViz

Visual styles, such as positioning and scaling, are important when one representation contains multiple attributes. These visual styles allow to express each attribute in a unique way. When integrating multiple attributes a unique representation for each attribute is important to distinguish one attribute from another.

2.4.1. Single attribute visualization

Single attribute representation extends the control flow by one attribute. Usually, in 2D representations, the attribute is connected with at least one activity. Within the

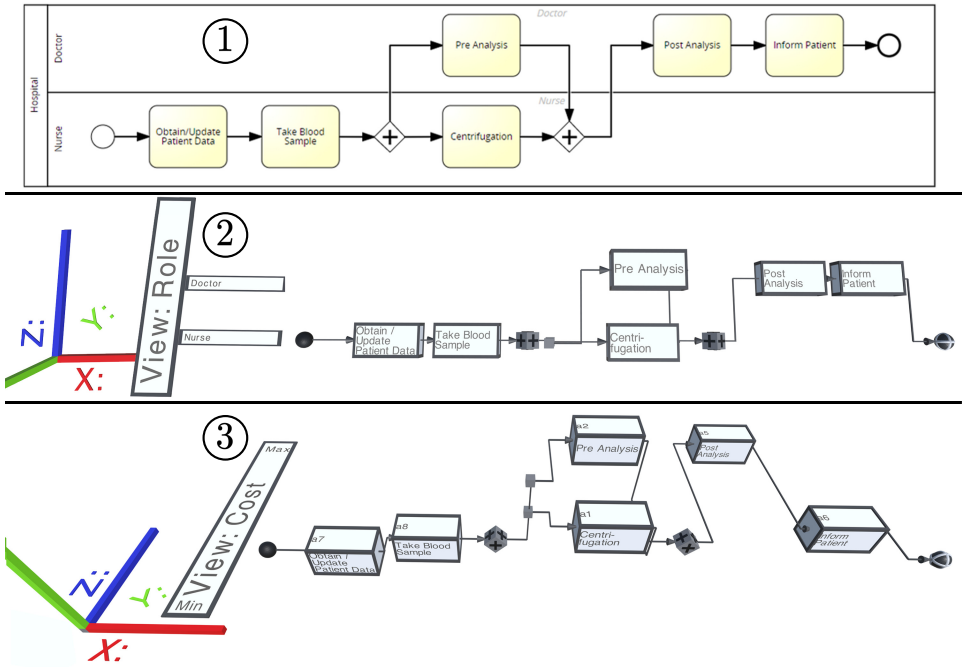


Fig. 5. ①, ② attribute *Role* with *Discrete Mapping* on the *Z*-Axis is depicted. ③ Attribute *Cost* with *Relative Mapping* on the *Z*-Axis is shown.

3DViz framework, the activities are not connected to the attributes. The attribute values are used for positioning and scaling. Omitting the edges for attributes leads to a reduction of visual clutter. This will be even more important when dealing with multiple attributes.

Figure 5 shows an example process with *Signavio Role* attribute on top ① and the 3DViz visualization with style *Position Z-axis, Discrete Mapping*, for the attribute *Role* in the middle ②. By showing one attribute the 3DViz Framework does not convey its full potential. In example ②, the angle from top was chosen to show how similar those two representations are.

Figure 5 ③ depicts single attribute *Cost* using style *Position Z-axis, Relative Mapping*. This approach differs from other approaches suggested by literature^{21,22} as the attribute values change the *Activities Z*-axis position. One can spot that the *Activities Pre Analysis* and *Post Analysis* are positioned in the back as those are the *Activities* with the highest cost. In a single attribute representation, we suggest to use *Z*-axis positioning for numerical and non-numerical values.

2.4.2. Multiple attribute visualization

Limiting one representation to a single attribute aggravates the ability to explore connections between attributes. Shifting from one attribute to another will not allow to recognize these connections either. With 3DViz we allow for combining multiple

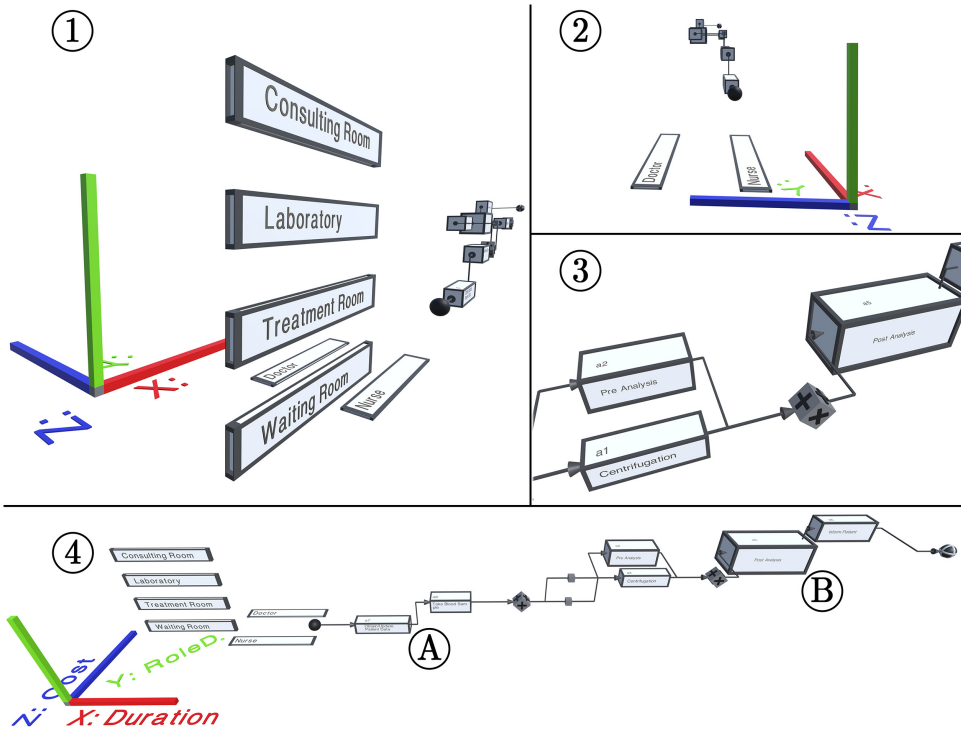


Fig. 6. Different angles on the 3D representation of the centrifuge process.

attributes into one representation. Within a 2D setting comparing attributes can be accomplished by switching between representations. In a 3D representation, the attributes can be included within one representation and compared, e.g. by the size of a cube. Further differences when comparing a 3D representation to a 2D representation is that one does not lose focus on the whole picture of the process.

When using multiple attributes we suggest to use non-numerical attributes, e.g. resources and roles with *Discrete Mapping* for the positioning on the Y-axis and or Z-axis, while numerical values should be used for scaling of activities.

Figure 6 shows the example process with the attributes and mappings from Fig. 7, *positioning* for location ①, and roles ②, *scaling* ③ for duration, role duration and cost and labels for id, name and IT-Service. On the bottom of Fig. 6 ④ gives an overview of the whole process with the scaling axis depicted on the bottom left. In order to allow for better positioning, the labels for the scaling axis are not depicted in ① and ②. Within the framework, the scaling axis is depicted every time a scaling style is active.

Based on the 3D representation depicted in Fig. 6, the following conclusions can be made and can be part of an in depth analysis for potential process improvements. Two *Activities* Pre Analysis and Centrifuge are performed in parallel at the same location by two different *Roles* ③. The duration of an *Activity* is not responsible

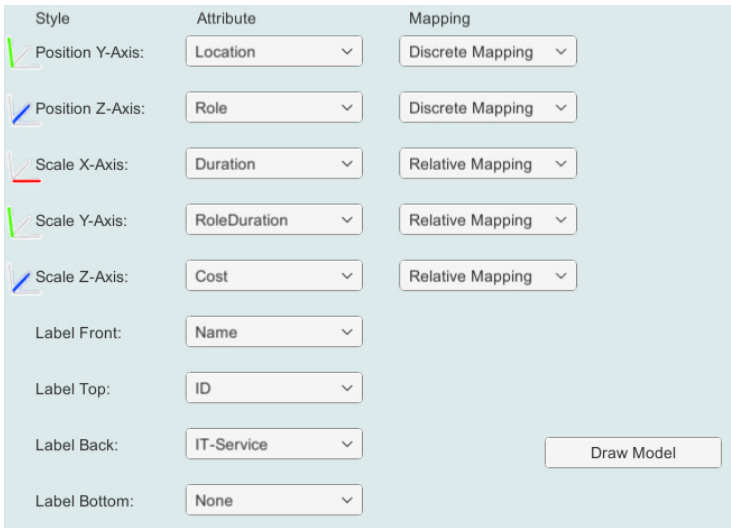


Fig. 7. User interface for 3D business process model creation.

for the attribute *Cost* ④, ①, ② whereas, the *Role duration* and *Cost* seem to be related ③ e.g. *Activity Pre Analysis* and *Post Analysis*. Under consideration of the attributes *Cost* and *Role duration*, *Doctors* are more expensive than *Nurses*.

The example combines five attributes in one representation. For inexperienced users, this can be overwhelming. However, the example demonstrates the full potential of 3DViz. The comprehension one can obtain from a 3DViz representation depends on the complexity of the process model that is visualized, the level of experience a user has with 3D representations and how good the navigation skills in such a setting are.

When dealing with multiple attributes, one has to be aware of conflicting visual styles, i.e. applying two attributes for the same visual style. For example, representing *Cost* and *Role* on the *Z*-axis. A UI (Fig. 7) was created to resolve such conflicts. The UI allows for one attribute per visual style. Reversely, attributes are not limited to be visualized by one style. The 3DViz framework allows for selecting one attribute for multiple styles for example, *Cost* could be used on *Y*-axis and *Z*-axis scaling. Figure 7 shows the UI with many filled in values. Every row can be seen as a tuple containing a visual style, the attribute and a mapping.

In conclusion, we want to emphasize that representing multiple attributes within one model is a suitable approach to detect relationships between attributes.

2.5. Visual limitations

3DViz is capable of displaying nine attributes in one visualization. Hence, for processes comprising more than nine attributes, the user can select up to nine attributes out of them for visualization in 3DViz. The remaining attributes can be inspected

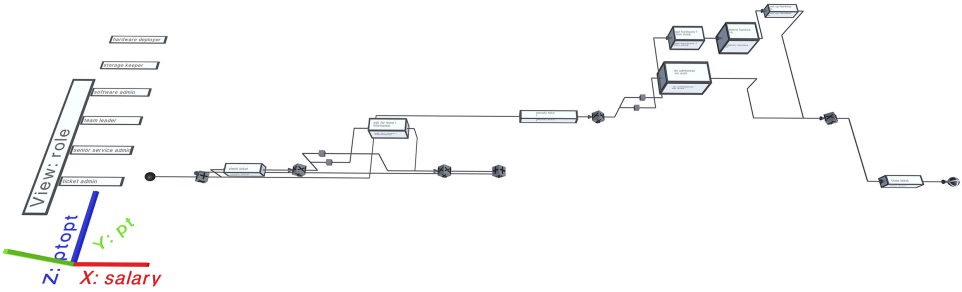


Fig. 9. Tier 1 technical support process with attribute values (3D Visualization).

Usually, 2D BPMN models²³ do not display attribute values except for task labels and swimlanes. Further attribute information is by default hidden within menus. As in 3DViz, the user has full control on how much information is displayed the 2D “behavior” of displaying only role information can be “imitated”. If more attributes are displayed with 3DViz, consequently, a user can see, but also has to understand, more information at once.

In Signavio as 2D BPMN modeling platform, it is possible to display attribute values as annotations to tasks. As an example, we modeled the real-world “Tier 1 technical support process” provided in Ref. 24 which features between 3 and 5 attributes per task, i.e. label, role, salary, pt, and pt_opt. Figure 8 shows the BPMN model using Signavio including the annotations of the attribute values with the tasks. In comparison, Fig. 9 depicts the same process using 3DViz where the roles are positioned in swimlanes and the 3 numerical attributes salary, pt, and pt_opt are visualized using relative mapping to the task sizes. The 2D and 3D approaches display attributes label and role in the same way. Contrary to 3DViz, based on Signavio’s default 2D visualization, it cannot be concluded which value belongs to which attribute.

3. Fundamentals of the Prototype

Section 2 introduces the fundamentals of the 3DViz process model and process attribute representation. In this section, the prototype implementation¹⁶ and interaction possibilities are discussed.

3.1. Engine

Previous work uses Java3D¹² and Second Life²⁵ for 3D process representation. However, when compared to how 3D Engines evolved these approaches seem to be visually outdated. In recent years, engines for creating massive 3D worlds went from closed systems accessible for a hand full of developers to broad open communities.²⁶ There are more than 600 engines currently available.²⁷ We need an engine that satisfies the following criteria. In order to visualize many instances or processes of

a certain complexity (e.g. based on the process modeling guidelines proposed by Ref. 28), the engine has to be able to draw many objects. Furthermore, the engine shall allow communication to other services, e.g. a process engine. As the proposed framework should not only visualize elements on screen, but on other devices as well, e.g. on augmented reality glasses and virtual reality glasses, an engine that supports such devices will be selected. Regarding these criteria, recent developments in the area of 3D representations exist such as rendering of large amounts of objects, AR, and VR. Therefore we are looking for an engine that constantly aligns to the use of future technology.

Big engines such as Amazon Lumberyard, Cry Engine, Godot Engine, Unity and Unreal Engine support most of the criteria. All these engines are suitable for our application. In the end, we decided to use Unity because it is established in the market and constantly adapts to new paradigms.

3.2. Creating a 3D process model

This section covers all aspects of 3DViz process representation, ranging from reading the process description files to visualizing the 3D process model.

3.2.1. File handling

We use XML files from the CPEE²⁹ process modeling and execution engine as input. As most of the existing formats these files are not tailored towards a 3D representation. Nonetheless, we aim at being able to process real-world process input files and to show that they can be used in a 3D representation. While reading a file each element, e.g. activity, and exclusive gateway is internally stored as an object. In the following, we call these objects *Nodes* and store them within a list. A *Node* consists of the following attributes:

- *Types* express the behavior of elements such as exclusive gateway and parallel gateway.
- *Labels* are used for activities.
- *Ids* serve as unique identifier that allow for *Node* identification.
- *Attributes* comprise all the additional values stored within the XML file and are designed to be a flexible structure as not all files contain all kinds of attributes. Examples for attributes are the time needed to execute an *Activity*, the role executing an *Activity*, costs when executing an *Activity*, services used when the *Activity* is executed and many more.

3.2.2. Drawing the control flow

Creating the control flow is achieved by iterating over a list of *Nodes* and drawing the appropriate visual element determined by the *Type* attribute. There are *Types* leading to a more complex behavior when drawing the process model, e.g. exclusive

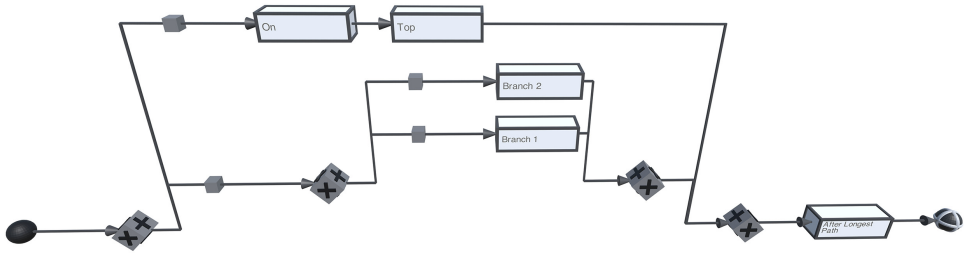


Fig. 10. Example showing that depending on the height of the lower branch the next branch is visualized.

gateway. When handling these special *Types* we have to be aware that they can influence the positioning of other *Nodes*. For example, a parallel branch could consist of an XOR gateway with multiple branches. In this case, the height positioning of the next parallel branch has to be calculated based on the height of the last branch.

Figure 10 depicts an example, where the height positioning of the second parallel branch is calculated based on the height of the branch below. This is achieved by drawing the first branch. Then the height of the branch is calculated and the second branch is drawn.

3.3. Virtual and augmented reality

As literature suggests, viewing a 3D model on a monitor might not be the appropriate way to transport the visual fidelity introduced with a 3D model.¹² Therefore, we opted for extending the 3DViz representation beyond desktop monitors towards viewing a process model with various devices. So far, we have implemented the viewing on a monitor and an HTC Vive VR device.[‡]

3.4. Interaction with the model

Every representation should support certain actions when interacting with a model, i.e., *zooming*, *panning*, *rotating* and *click* actions.¹² Based on the device used for viewing a process model, we implemented different interaction possibilities as described in the following.

3.4.1. Monitor

When a monitor is used a mouse interacts with the process model. We allow for *zooming* by using the scroll wheel, *panning* by holding the left mouse button and moving the mouse, *rotating* by holding the right mouse button and moving the mouse, and *click* actions by left clicking on a *Node*. Click actions are used to get more details on a specific *Node*, e.g. by visualizing id, responsible roles and other attributes.

[‡]3DViz tool and screencast <https://bit.ly/2WFMHcm>

3.4.2. VR device

A VR device allows for the same interactions as the monitor/mouse combination. However, these interactions are implemented in a different way. *Zooming*, *panning*, and *rotating* are direct results of the head movement observed by the VR device. For example, when a certain *Node* is interesting, leaning towards the *Node* will *zoom* in. The *click* action is realized by using VR controllers. When a controller is near a *Node*, a *click* selects the *Node* and shows the same information as a mouse click will show.

3.5. Using a 3D scene

The 3DViz framework and prototype enable to display process models within 3D scenes. As an example for such a 3D scene, we digitalized one of our conference rooms. Figure 11 visualizes the real-world conference room on the left and the virtual conference room with a process model on the right. To be as accurate as possible, the real-world size of every object was measured. Afterwards, all the objects were created with a 3D modeling tool. This approach supports a 1:1 scale between real and virtual world. From a pure visual point of view, the created scene can be seen as a digital twin of our conference room. The focus of the scene is on top of two tables in the middle of the conference room. On top of these tables, the 3D process models are visualized.

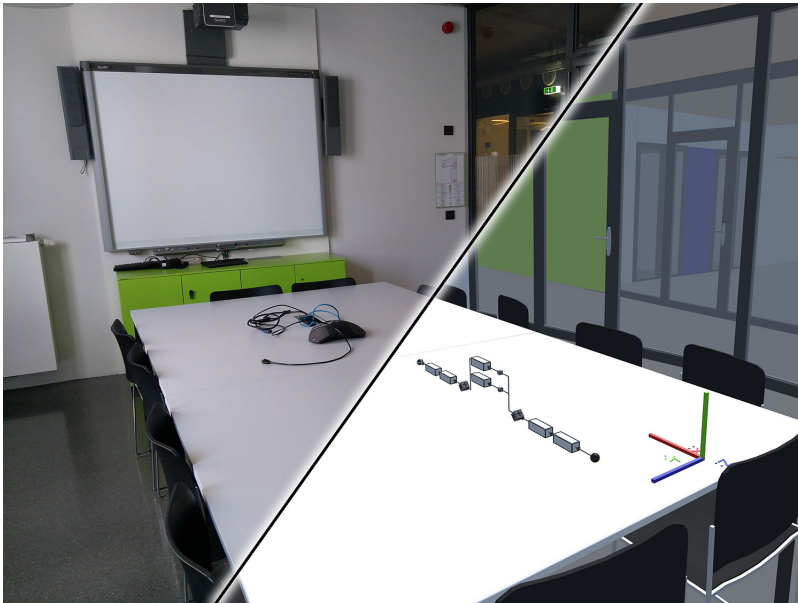


Fig. 11. The left side depicts a picture of a real world room, the right side a virtual conference room.

During prototype development, we found that using a 3D scene aids the navigation and orientation in a virtual environment. For example, when losing focus of the model by moving the head or rotating with the mouse, one still knows where to find the model as there are points for orientation within the scene. Such a scene can be compared to grid or ledger lines within a 2D representation.

We suggest to use scenes for all 3D representations. Scenes can be used in single user settings such as business process analysis and runtime evaluation. In a multi-user setting such as for collaborative process modeling, scenes can help to improve communication. We want to point out that a scene around the process only makes sense when wearing a VR device or using a monitor. For screenshots, the scene might be a bit irritating.

This section shows that the 3DViz prototype is able to draw a 3D process model based on a CPEE XML input file. We want to emphasize that the data in the file was not captured specifically for this purpose or enhanced to allow for 3D representation. We also showed how the created 3D process model can be explored with different interactions and devices.

4. Experiment

The experiment compares three process model visualization and interaction approaches, namely, Signavio, 3DViz, and a VR approach. They represent the independent variables for the experiment. During the experiment, the participants solve tasks with each of the approaches following a Within-Subject Design.¹⁸ The time it takes to complete the tasks (*efficiency*) is the dependent variable.

4.1. Experiment planning

Every experiment session was planned as face to face session allowing for one participant per session. In order to avoid fatigue, the experiment was designed to require approximately 15 min per participant. The 15 min time frame was chosen based on literature³⁰ denoting a students attention span with at least 10–15 min.

There might be a different experience level among the participants, e.g. in using Signavio or navigating with mouse and keyboard. Therefore, we created a survey to be answered before the experiment. The survey consists of 8 questions and is available here.[§] It contains one demographic question for gender and four questions to be answered on a scale from none to expert. These four questions ask for experience with Signavio, experience with PC games, experience with 3D modelling tools, and experience with VR devices. Additionally, there are three questions on the survey to be answered after the experiment. These three questions ask for the fastest type to solve simple tasks, the fastest type to solve complex task, and the most pleasant experience.

[§]<https://bit.ly/2WFMHcm>

In order to fit the 15 min attention span, each of the experiments was designed to take approximately 5 min. Within 5 min we are able to show a tutorial and allow for answering 7 questions. They range from questions referring to *single attributes* to questions referring to *multiple attributes*. To allow for comparable results across the experiments, the questions are the same for each of the experiments.

We classify the questions as follows:

- Questions 1, 2, 4 are easy as they concern one attribute within process models ranging from 4–10 activities, e.g.: “*Select the activity with the longest duration.*”
- Questions 3 and 5 are of medium difficulty as they concern two attributes where at least one of them is visualized by swim-lanes, e.g.: “*Select the activity with the shortest duration, if multiple activities have the same shortest duration, select the activity executed by role student.*”
- Questions 6 and 7 can be considered complex as they concern at least two numeric attributes, e.g.: “*Select the activity with the lowest cost, if multiple activities share the lowest cost select the activity with shortest duration, if multiple activities share the shortest duration, select the activity executed by role lecturer.*”

The question design is inspired by Ref. 31 and describes how activities are executed. All questions are focused on attribute-based tasks,¹⁷ i.e. find an activity with a specific attribute. For each of the 7 questions, three artificial process models were created. Artificial process models reduce the learning effect between experiments and eliminate imbalance between the participants prior knowledge.³² Per question the three models have the same complexity, i.e., identical amount of activities, control flow elements, and attributes. Table 3 illustrates all the components the process models are constructed of. The process model from the tutorial was the same for each of the experiments. Table 3 summarizes the attribute labels and the data types used for each of the attributes.

The experiments were planned such that advancing to the next question is only possible if the answer to the current question is correctly answered. This avoids guessing and quick run-throughs.

There is one variable measured during the experiment: *efficiency* measures the time it took to answer the questions. As previously explained, advancing to the

Table 3. Description of the process models used during the experiment.

Model	#Activities	#Control Flow Elements	String Role	String Location	Num. Cost	Num. Duration	Num. Data Usage
Tutorial	7	3	X		X	X	X
Q1	4	0	X				
Q2	5	1				X	
Q3	8	1	X	X			
Q4	7	1				X	
Q5	15	1	X		X		
Q6	11	1			X	X	
Q7	14	1			X	X	X

next question is only possible when a question is answered correctly. Hence, the variable for efficiency to some extent includes a punishment for wrong answers.

4.2. Hardware

For Signavio and 3DViz, we use the same hardware setup consisting of a low-end computer with no dedicated graphics card, a dual core CPU with 2.6 GHz, and a dual monitor system. As input devices keyboard and mouse are used. The VR experiment uses a high-end computer with a quad core CPU with 3.6 GHz, a GTX 1060, and an HTC Vive VR head mounted display. Interactions during the experiment are achieved by using the Vive controller. The 3DViz setup demonstrates that 3D applications run on low-end hardware. The VR approach requires a much higher frame rate and resolution and hence a mid to high-end computer.

4.3. Participant selection

In terms of visually interpreting business processes, students can be seen as equal compared to professionals.³³ Therefore, we invited PhD and Master students from the Faculty of Computer Science at the University of Vienna to the experiment. According to the curriculum of the Faculty of Computer Science, Master students have gained experience in modeling business processes through at least three courses. Motivating factors to take part in the experiment for all participants were sweets offered after the experiment. Students of the courses Business Intelligence and Workflow Technologies were rewarded with participation points.

In total, 44 participants took part in the experiment, 33 (75%) men, 10 (22.7%) women and 1 (2.3%) did not answer the question for gender. Figure 12 depicts four box plots one for each question from the questionnaire (Sec. 4.1). The participants

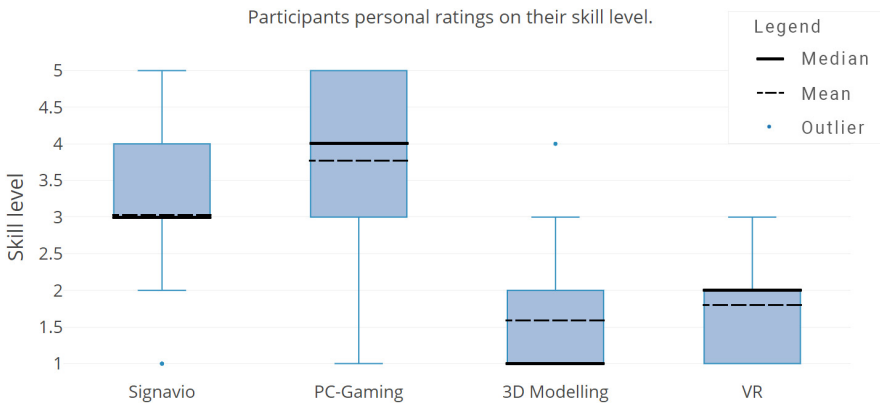


Fig. 12. Boxplots depicting the participants' personal skill rating.

rated themselves on a skill level ranging from none (1) to expert (5). Signavio (med 3, mean 3.02) and PC-Gaming (med 4, mean 3.77) are more known among the participants compared to 3D modelling (med 1, mean 1.60) and VR (med 2, mean 1.80).

4.4. Pre-test

We conducted a 2-stage pre test. The first stage was conducted with two Post-doc and two PhD staff members of the research group Workflow Systems and Technologies at the University of Vienna. The second stage was conducted with 3 Post-doc and 1 PhD staff member of the same group.

After the first pre-test, we implemented several modifications. The first set of modifications is reflected by all 3 experiments. The wording of Question 6 was modified to be more precise. In order to have an additional complex example, Question 7 was added to the experiments. The addition of a question does not exceed our time limit of 15 min as the total time for the experiment during the pre-test was on average 13 min.

For the Signavio part, we printed a description of the attribute symbols and labels and stuck them on the monitor. When activating an attribute visualization, its attributes values at first became visible when hovering over an activity. We modified the visualization such that the attributes are visible on top of an activity (without hovering) allowing for faster comparison of attribute values. Figure 13 depicts an example how the attributes *Role*, *Cost* and *Time* were displayed during the experiment within Signavio. The 3DViz approach was enhanced by using arrow keys for camera movement. The numpad keys 1, 2, and 3 can be used for switching between camera positions. Within the VR approach, the font size was decreased and bad kerning was fixed.

After the second pre-test, we added a grid to the 3DViz and VR approach.

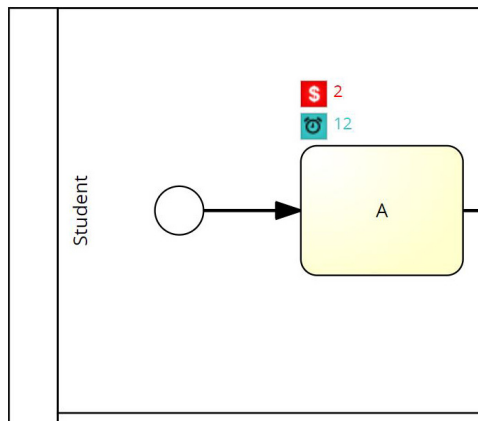


Fig. 13. Signavio: attribute visualization, roles in swimlanes additional attributes on top.

Table 4. Random list for up to 50 participants to determine the order of experiments and their process models.

Nr.	Group 1 Experiment Order			Group 2 Used Process Models		
	Signavio	3DViz	VR	Signavio	3DViz	VR
1	3	1	2	3	2	1
2	1	2	3	2	1	3
3	2	1	3	1	2	3
4	3	1	2	3	1	2
5	3	1	2	1	2	3
...
50	2	3	1	2	1	3

4.5. Experiment execution

Each participant started the experiment by choosing a number between 1 and 50 that has not been chosen before. Every number corresponds to an entry in a balanced latin square. The first group determines the order in which the experiments are conducted. The second group determines which of the three process model groups shall be used for the experiment. Table 4 provides a short excerpt of the balanced latin square. All entries can be found on our Website.[¶]

For example, if a participant decides to use number 5, the first experiment is 3DViz with process model group 2, the second experiment is VR with model group 3 and the last experiment is Signavio with model group 1. The list was designed for up to 50 participants and helps us to conquer learning effects during the experiment by evenly distributing the first, second, and third experiment.

After choosing a number, the survey discussed in Sec. 4.1 was handed to the participants. They were told to answer all questions except the last three. Then the experiments followed in the order determined by the random list. Every experiment started with a short oral tutorial. These tutorials were adapted to the order of the experiments as some concepts are known from previous experiments.

- Signavio’s introduction showed how roles and attributes are visualized. On the left screen, a process model with Signavio was loaded, on the right screen, the questions and a dropdown menu for selecting the answer were provided.
- For 3DViz, the controls for movement were explained. If 3DViz was executed before VR, the positioning and scaling of nodes and their attributes was explained. Similarly to Signavio’s approach, the 3DViz approach displays the model on the left screen and the question on the right screen. Selecting the answer for the question was achieved by clicking on the activity within the 3D model.
- For the VR approach, the headset was adjusted to the participants’ needs. If VR was executed before 3DViz the positioning and scaling of nodes and their

[¶]<https://bit.ly/2WFMHcm>



Fig. 14. Experiment setup, on the left VR, on the right Signavio and 3DViz.

attributes was explained. Questions were displayed within the VR scene and answers could be selected by grabbing activities with the Vive controller.

Figure 14 illustrates the experiment setup. On the left the participants solve the tasks using the VR device. The left monitor is optional it allows others to see what the participant wearing the VR device is currently seeing. On the right, the participants solve the 3DViz and Signavio tasks.

After completing all three experiments, the participants got their survey back to answer the last questions regarding their experience. During the experiment, some of the participants gave feedback or had minor issues. We did not ask for feedback during the experiment, however, to be as rigorous as possible everything was noted and is available on our website.^{||}

4.6. Threats to validity

We addressed threats to validity by using a randomized list for experiment ordering, clear scope on a specific task during the experiments, restricting the duration to the participants attention span, and inviting sufficient participants.

5. Analysis and Findings

This section reports on the data created by the experiment and the analytical findings based on the data.

^{||}<https://bit.ly/2WFMHcm>

5.1. Data set

The collected data set contains the following entries as a comma separated list^{||}:

- *UserID* is a unique identifier that is assigned to each participant.
- *Question Number* stores a numeric value indicating which question was answered. This value starts at zero and goes up to 7.
- *Process Model Group* is the question group (Sec. 4.5) used within an experiment.
- *Answer* states if an answer was correct or wrong.
- *Time* is the time difference between starting the experiment and creating the current data entry.
- *Date and Time* is the current date and time.
- *Mode* stores which of the experiments, e.g. Signavio, 3DViz, or VR, is currently observed.

During the experiment, the order in which the experiments were performed was stored by appending the values to the list. However, for future analysis, it could be important to know the order of the experiments directly without further investigation. Therefore, we created an additional column where the order of the experiments is stored. We were able to retrieve the order by the *Time* attribute. Additionally we crosschecked the order with the randomized list.

After completing the experiment, the data set is cleaned from the following flawed entries:

- Participant with ID 30 accidentally skipped the tutorial for Signavio, therefore the first entry for id 30 was removed and the experiment started again, this time with an introduction.
- ID 99 is the test user used to test if everything works as intended. These entries were removed from the data set. Usually, tests were performed every morning before the experiments started.
- We recorded the date and time when a new entry is added to the data set, however due to data privacy issues this entries had to be removed as participants could find the answers and results an other specific participant has given as they know the time slots and who was participating in the experiment.
- User with ID 28 accidentally performed a double click when answering question 6 during the Signavio experiment resulting in a wrong answer. The wrong entry was removed from the data list. The time difference between the two entries was 0.13 seconds this also indicates that this was a corrupt entry.
- For every question, Signavio needed some loading time. During the experiment, we were not able to detect if Signavio finished loading. Therefore the time needed to load Signavio is included in the experiment time. After the experiments we measured the loading times of Signavio with 10 iterations. These can be found on our Website.** We subtracted the mean loading times from the recorded data entries for Signavio.

**<https://bit.ly/2WFMHcm>

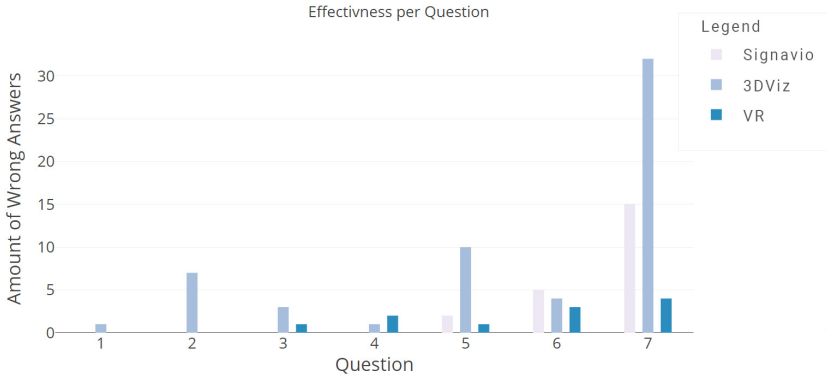


Fig. 15. Bar chart depicting the amount of wrong answers per Question for each visualization approach.

5.2. Descriptive statistics

During the experiment, every wrong answer was recorded. Figure 15 visualizes the total amount of wrong answers per question and visualization approach. In total, VR (11) had the lowest amount of wrong answers followed by Signavio (22) and 3DViz (58).

Figure 16 displays box plots for the measured time for completing the experiments without tutorial time for the three approaches. These plots provide a first indicator on the participants performance regarding their efficiency. With a median of 109.65 VR scores best, followed by Signavio 171.44 and 3DViz 176.72.

After the experiments, the participants had to select their preferred visualization for completing simple tasks, complex tasks and the most pleasant experience. Figure 17 depicts the questionnaire results with a tendency towards Signavio (72.72%) for simple tasks, and towards VR for complex tasks (79.55%) and most pleasant experience (65.91%).

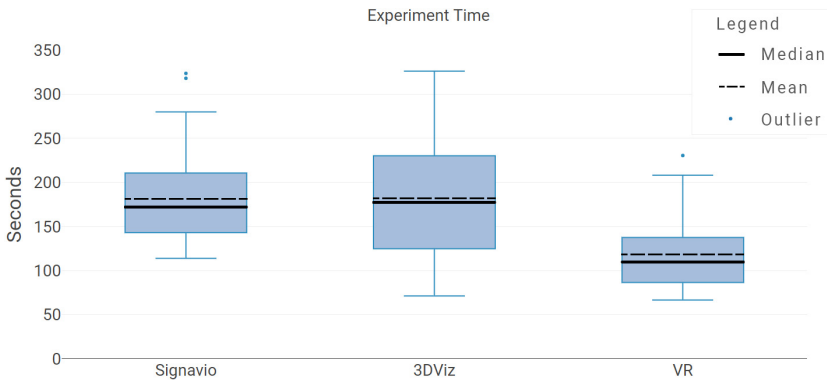


Fig. 16. Measured time used for completing the experiments without the tutorial time.

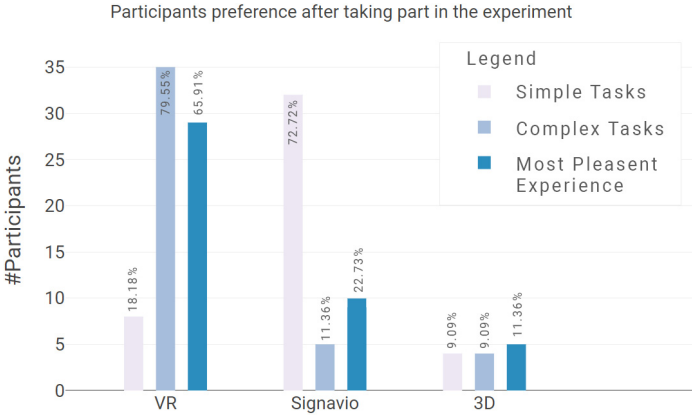


Fig. 17. Bar chart on personal preference after completing the experiment.

5.3. Hypothesis testing

For testing our hypothesis (Sec. 1.2), we use the dependent variable efficiency. Efficiency is the time measured to answer the questions correctly. If answered wrong, a participant had to answer the question again. For each of the three approaches, we compare the time it took the participants to answer all 7 questions. First we explore if there is a significant difference in efficiency between the visualization approaches. If such a difference is explored, we examine the data in more detail to see which approach is the best regarding efficiency.

With a Shapiro-Wilk test, we examine if the data is normally distributed. Based on their p-values, Signavio (0.00152), 3DViz (0.12162), and VR (0.00124) we can say that except for 3DViz the efficiency is not normally distributed. Figure 18 depicts that the three data sets are skewed to the left. As not all assumptions for an ANOVA are met and the data sets are all skewed to the left we opt for a Kruskal-Wallis *H*-test.

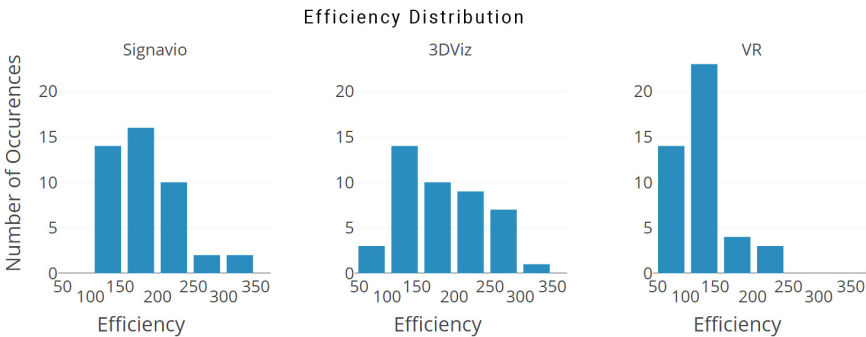


Fig. 18. Efficiency distribution for the three visualizations.

Table 5. *P*-values for Conover and Dunn test comparing the visualization approaches.

	Conover		Dunn	
	3DViz	Signavio	3DViz	Signavio
Signavio	4.3e-01		5.1e-01	
VR	1.2e-08	2.3e-10	3.2e-07	7.5e-09

The Kruskal–Wallis *H*-test showed that there is a statistically significant difference in efficiency between the visualization approaches, $\chi^2(2) = 40.006, p < 0.00001$, with a mean efficiency score (low is better) of 84.03 for Signavio, 78.59 for 3DViz, and 36.89 for VR.

For Post-Hoc analysis, we use the liberal Conover method and the more conservative Dunn method. Table 5 clearly shows that there is no significant difference between Signavio and 3DViz. VR shows significant differences to both, Signavio and 3DViz.

In order to answer our hypothesis, easy and complex tasks have to be investigated. Table 6 shows the mean efficiency values the participants needed to answer the questions. See Table 7 for further analysis with Kruskal–Wallis *H*, and Conover *p*-values that show no evidence that there are relations within the groups.

5.4. Interpretation

H0 has to be rejected as there is no clear evidence that there exists an visualization approach that is statistically significant better in terms of efficiency compared to the other approaches.

For easy tasks VR shows signs to be the best option, however the results are not clear on this and need further investigation. The Conover and Dunn test for complex tasks shows that VR is statistically significant different from the other

Table 6. Mean efficiency for easy and complex tasks.

Group Question	Easy			Complex	
	1	2	4	6	7
Signavio	10.14	14.42	14.63	33.77	66.32
3DViz	13.04	15.83	11.00	28.60	44.78
VR	11.49	12.48	10.60	21.18	28.89

Table 7. Deeper analysis of easy and complex questions show no relationships between the visualization approaches.

Group	$\chi^2(2)$	<i>p</i>		3DViz	Sign.
Easy	129.47	0.00001	Sign.	5.1e-24	
			VR	4.9e-02	2.3e-31
Complex	103.84	0.00001	Sign.	5.3e-16	
			VR	7.0e-05	6.9e-29

two approaches. By comparing the means it is clear that VR is statistically more efficient compared to the other approaches.

When asked for their preferences 72.72% of the participants would use Signavio for simple tasks. Our analysis showed that in terms of efficiency Signavio (39.19s), 3DViz (39.87s) and VR (34.57s) are closely related. Even though the data suggests that the VR approach is slightly faster we can relate that the participants favored Signavio for simple tasks as most of the participants are familiar with 2D approaches and already know Signavio. For complex tasks, the preference shifted towards VR (79.55%). Within the data we can see that there is evidence that complex tasks can be accomplished in a more efficient way with VR (50.07s) compared to 3DViz (73.38s) and Signavio (100.1). The data underlines the discussion given in Section 2.4 where the strength of the presented approach are when multiple attributes are visualized.

We think the main difference between VR and 3DViz is the type of interaction with the model. Using the headset seemed more intuitive to the users compared to navigating with mouse and keyboard as discussed in Sec. 3.3. This is underlined by the fact that the presented models are rendered exactly the same way in both situations.

6. Related Work

Visually searching for information is a common problem among multiple domains.³⁴ Human-computer interaction works range from using 2D interfaces³⁵ to 3D interfaces.³⁶ These works consider visually searching databases,³⁷ web^{38,39} and many others.⁴⁰ In our study, we extend this by using visual search to compare different process model visualizations.

Several approaches in the business process analysis domain encode relevant information in process modeling techniques.⁴¹ These approaches range from performance validation and verification to algorithmic performance evaluation and observational analysis. Observational analysis utilizes process model visualizations such as BPMN, UML and YAWL.

A detailed process analysis incorporates the analysis of several so-called process perspectives, most prominently, control flow, resource, data and time.⁴² The existing process notions, such as BPMN, enable the visualization of certain perspectives. As a baseline, the control flow perspective is used and enriched with information from other perspectives. Other attributes, for example, time or costs are typically not visualized within the process model. This work takes a different analysis approach and incorporates information of multiple perspectives into one visualization.

In order to tame the possible complexity of business process models, (e.g. including different perspectives) several approaches provide techniques to create process views or abstractions.^{8,9,43} Views and abstractions can also tailor the visualization of process information along stakeholders' needs, for example, only showing process

activities of a selected role. Usually, views and abstractions are limited to represent a single process attribute.^{21,22} Hence, they cannot be applied to visualize multiple attributes and particularly the relations between these attributes. This work takes a different approach by allowing to incorporate multiple attributes to satisfy a stakeholder's needs. Moreover, the presented approach enables users to identify relationships between views.

All of the referenced approaches are in 2D. However, there are some 3D approaches for process model visualization.^{13,25,44} When compared to 2D representations such 3D representations allow for incorporating more information into one representation.¹² However, the existing 3D approaches do not consider representing multiple attributes.

Additionally, these approaches use monitors to visualize 3D representations which is not suitable.¹² Other domains, by contrast, use HMDs to visualize 3D representations.^{14,45} With our research we want to visualize multiple attributes within one 3D representation that can be explored through a HMD.

Several papers and studies report on the support of processes by Virtual Reality (VR), Augmented Reality (AR), and Virtual Worlds (VW) in different application domains, including therapeutic processes⁴⁶ as well as maintenance⁴⁷ and simulation⁴⁸ processes in the manufacturing domain. The practical value of VR, AR, and VW particularly for, e.g. training purposes seems undoubted.

The study provided by Ref. 7 investigates how 3D process modeling in combination with VW can support companies in employee training and the acquisition of process knowledge. The results show significant improvement in understanding complex process models with different gateways. One of the conclusions of the study is that “VWs can provide a comprehensive training solution for organizations”⁷ and are particularly useful in diverse settings with a large number of process participants.

7. Vision

3DViz is a first step towards our vision of a multi-user collaboration tool. This tool should allow to view, discuss, create, modify and analyze process models in a mixed reality setting. The tool should not be limited to people who are physically present in the room, but should also allow remote participation. With this paper we present a model that is suitable for the visualization and analysis of process models in a mixed reality setting. 3DViz could support processes analysts working in domains ranging from logistics, through robotics, to health care.

8. Conclusion and Transferability

We discussed three approaches for process model attribute visualization, i.e., Signavio, 3DViz, and the 3DViz VR approach (\Rightarrow **RQ1**). In a controlled experiment the efficiency of these approaches was measured by completing multiple tasks.

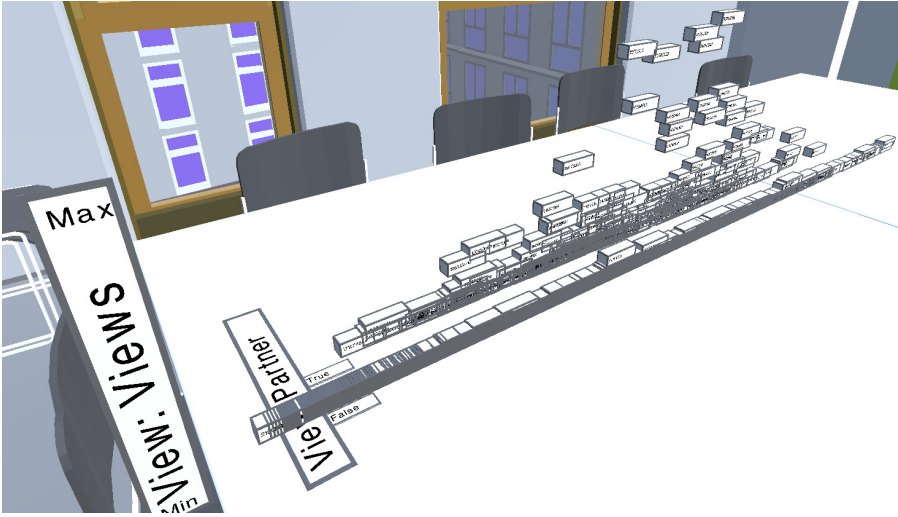


Fig. 19. Twitch social network visualized with 3DViz.

For simple tasks no clear evidence was found that one approach is more efficient when compared to the others. For complex tasks the results provide evidence that there is a statistically significant difference between the investigated visualization approaches. In detail, we found that the 3DViz VR approach is the most efficient way to visualize complex process models with attributes (\Rightarrow **RQ2**). Due to these promising results, in future work we will investigate how collaborative process modeling and analysis can be facilitated using 3D and VR approaches.

Viewing the visualization approach from a more general perspective reveals potential transferability beyond the process model domain. Figure 19 demonstrates that 3DViz can be also used to visualize social network data from twitch.⁴⁹ One observation from the 3DViz-based visualization of the social network in Figure 19 is that long time (X -Axis) partners (Z -Axis) have a higher view count (Y -Axis). Currently the 3DViz tool is not optimized for large data sets as for the twitch data set. Due to its size of ≈ 10 k nodes the tool runs with approximately 20 FPS.

In future work, hence, we will dig deeper into performance optimization and transferability of 3DViz for social network and other data. The goal is to investigate the generalizability of the approach.

Acknowledgments

This work has been partially supported and funded by the Austrian Research Promotion Agency (FFG) via the “*Austrian Competence Center for Digital Production*” (CDP) under the contract number 854187.

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