INTERACTION PRIMITIVES IN 3D GEOVISUALIZATIONS

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Abstract: Virtual reality (VR) offers wide range of possibilities regarding not only representation of real world phenomena, but also their dynamic modification and customization. A typical representation of the geographical space is geovisualization, which is widely used in practice, namely in education and teaching, but also in such an area as scientific research for revealing human cognitive processes. Interaction with such VR products consists of many specific types of action, however currently there is no uniform taxonomy for the basic units of interaction. With the growing number of VR products we need to summarize existing taxonomies to better understand and design next generations of geovisualizations. The concept of interaction primitives can offer basic framework for understanding dynamic interaction with virtual cartographic products. In this paper, we outline an issue of interaction primitives with respect to interactive 3D geovisualizations and suggest their specific application in the VR research and development.

Key words: 3Dgeovisualization, interaction primitives, virtual reality

INTRODUCTION

Information representation takes many different forms. The development of information technologies opens wide new possibilities for the representation of information with respect to their cognitive processing and understanding by humans. Visualization in general (not solely the virtual one) is a graphical form of external representation of specific information (Ware, 2004). As such, visualization should be effective regarding its purpose and visualized data should also be presented in the most understandable way possible. The specific visualization type actively affects e.g. problem solving strategies, as demonstrated in previous studies (Bauer and Johnson-Laird, 1993). Virtual reality (VR) made huge progress in last couple of years and it is still more often used as an effective instrument for simulation of various environments. VR allows us to modify virtual content easily and it can be quickly customized for specific purposes. Furthermore, VR also offers effective ways of measuring behavioral activity of a user, who works/interacts with virtual content. The most typical representation of the space in VR is 3D geovisualization (GV). Modern technologies offer a lot of opportunities to convert geospatial data into VR in particular forms of GVs, which match users' needs as much as possible. GVs offer possibilities of e.g. *map-driven reasoning* (MacEachren and Monmonier, 1992).

Various forms of GVs differ in their features, their setting and content, but also in interactivity options. GVs can be static or dynamically interactive when displaying a specific terrain. Although two different maps can be informationally equivalent according to Larkin and Simon's concept (1987), they can differ in ways, how they can be manipulated by a user, e.g. how a user can control them (rotating or zooming), but also in the options of information display and offered choices. This feature can be labelled as *interaction equivalence.* This term represents comparability of various visualizations in their interactivity (options of interaction). Interaction non-equivalency of two different GVs (e.g. static vs interactive) results in different processing of displayed content by a reader/user due to different actions performed by the user. Regarding human psyche, the very nature of every single GV should stand in the middle of research and design focus, because misinterpretation of displayed information can bring huge safety threats in applied fields (i.e. Rierson, 2013). Specific nature of visualization should be always emphasized in design process, because as such it can strongly affect cognitive processing of displayed information (Ware, 2012). And it is the nature of the interaction with VR which can be expressed with the use of so called *interaction primitives* (*IPs*) (Roth, 2012), where IPs represent basic elements describing the interaction with interactive 3D GVs.

CARTOGRAPHIC INTERACTION

The suggestions for establishment of so called *interaction science* were based on previous knowledge in the fields of information visualization or visual analysis, nevertheless also on the contribution of GIScience as well as cartography needs. Some authors emphasize the elementary division of information visualization into two basic parts - (1) *representation* and (2) *interaction* (resp. interactivity) (Buja et al., 1996). When creating geovisualization, we can analogically observe cartographic representation on one hand and cartographic interactivity on the other.

Cartographic representation means graphic, acoustic, haptic and other parameters of the map, which represent geographical information itself (Roth, 2012). This part has been studied intensively during past years, especially with respect to human perception (how s/he sees the map), cognition (how s/he understands the map) and semiotics (what does the map visualization mean to a specific person) (MacEachren, 1995). Cartographic interactivity stands on the other side representing a specific dialog between a user and a map. Edsall (2003) sees interaction exchange as a partial sequence defined in a framework of conversation between the user and the map (sequence question → answer). The process in whole is then called an *interaction session*. Such a dialog is mediated via specific technology (or rather interface).

The user and information visualization are both interaction agents in the process of "map reading" and they affect each other. When the user looks for and reaches information leading him to his targets via interaction with the interface, he actively modifies/manipulates/changes his current preview of the visualization (primarily on the perception level). Such changes lead him to a different interpretation of the visualization, because with every change his cognitive scheme has also been modified - according to Neisser's principle (1976). If this change is desirable, the user hits his target. If not, more interaction with the visualization is needed. In this process, a computation device serves as a dialog mediator between the user and the visualization, which allows dynamic exchange of information in real time (MacEachren and Monmonier, 1992). The nature of such interaction is built on the example of a conversation metaphor, which is emphasized especially in a human-computer interaction (HCI) approach, information visualization and visual analysis (Yi et al., 2007). In general, the process of cartographic interaction can be defined by three parts: a user, a map and a computation device (Roth, 2012).

The best way to demonstrate interaction of the user with specific interface is with the use of Norman's Seven Stages of Action model (Norman, 1988), see (Fig. 1). His model reflects the process of the general interaction of human with a device. In this framework we will discuss the issue of IPs.

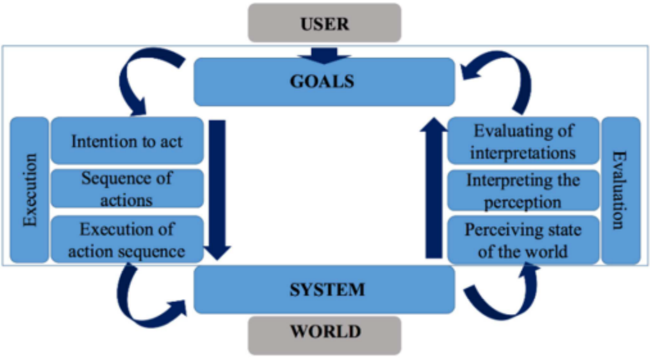

Fig. 1. Seven Stages of Action model (Norman, 1988).

Currently we can find more than one system/taxonomy describing IPs within frameworks mentioned above (MacEachren et al., 1999; Crampton, 2002; Yi et al., 2007). Their definitions partially overlap each other, still there is no unified taxonomy. As Roth suggested (2012), construction of such a unified taxonomy is considered to be a grand challenge of interaction. Roth (2012) finds useful to incorporate and interpret IPs within the Norman's model framework (Fig. 2). In this framework we will discuss the issue of IPs. In the process of interaction, the user is led by his particular goal, this goal transforms into the intention leading to the specific action. This action has effect, which can be reflected backwards by the user and further interpreted and evaluated. Evaluation and interpretation of the current state compared to the original goal leads to another action or to modification of the goals (Fig. 2).

Each stage in the Norman's model represent various ways, by which user can interact with the physical, resp. virtual objects (so called *"operands"*). The user interacts with operands via different IPs, which means that on every level of the model we speak about series of different user's actions. Roth (2012) himself divides interaction into three main categories according to their belonging to the stage within Norman's model. He speaks about three recommended approaches to parsing exchanges into IPs, calling it three O's of cartographic interaction: (1) an objective-based approach, (2) an operator-based approach and (3) an operand-based approach.

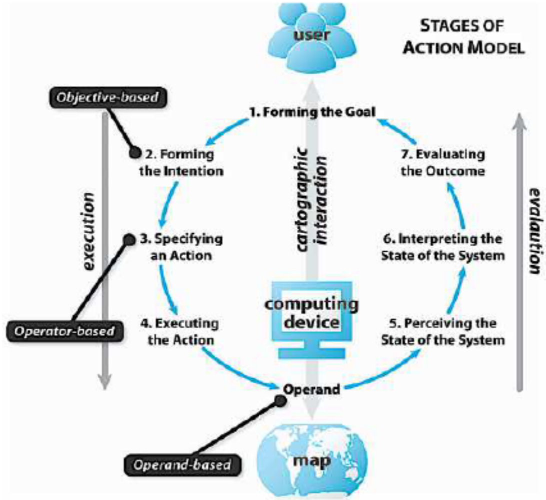

Fig. 2. The Stages of Action Model and the Three O's of Cartographic Interaction (Roth, 2012).

INTERACTION PRIMITIVES FOR CARTOGRAPHIC INTERACTION

Objective-based approach

IPs included in an *objective-based* taxonomy represent the interaction on the "forming the intention" level (see Fig. 2). These IPs define specific goals of the user interaction/working with UI (User Interface). There are many different existing lists of primitives assigned into Objective-based taxonomies according to different authors. However, in general we can understand primitives on the Objective-based level as "task purpose" or "task assignment" primitives. A couple of examples are listed below to illustrate variability in the IPs taxonomy in a better way. Roth (2012) summarizes, that in spite of considerable variability, primitives "*identify*" (also "*explore*" or "*examine*") and "*compare*", are consistently represented across different authors (see Tab. 1).

Tab. 1: Objective-based taxonomies

MacEachren et al. (1999)	Meta-operations	(1) identify, (2) compare, (3) interpret
Crampton (2002)	Interactivity Tasks	(1) examine, (2) compare, (3) (re)order/(re)sort, (4) extract/suppress, (5) cause/effect
Yi et al. (2007)	User Intents	(1) select, (2) explore, (3) reconfigure, (4) encode, (5) abstract/elaborate, (6) filter, (7) connect

Operator-based approaches

An *Operator-based* approach covers primitives engaged in to the process of a specifying action (Specifying an Action level in Fig. 2). These primitives relate to options of visualization manipulation. They can be seen as the "interaction menu" for various acts, by which the user can perform a goal-focused action, but they still do not represent the action itself. On this level in general we speak rather about a setting of UI for an upcoming real interaction. Roth (2012) finds similarities across the existing labels of these acts, especially for so called "*brushing*", which is described as "highly interactive technique for directly selecting groups of information items in a display" (Roth, 2012; Štampach et al., 2015). Further, on this level we can speak about primitives like "*focusing*" and "*linking*".

Tab. 2: Operator-based taxonomies

MacEachren et al. (1999)	Interaction Forms	(1) assignment, (2) brushing, (3) focusing, (4) colourmap manipulation, (5) viewpoint manipulation, (6) sequencing
Ward and Yang (2003)	Interaction Operators	(1) navigation, (2) selection, (3) distortion
Edsall et al. (2008)	Interaction Forms	(1) zooming, (2) panning/re-centering, (3) re-projecting, (4) accessing exact data, (5) focusing, (6) altering representation type, (7) altering symbolisation, (8) posing queries, (9) toggling visibility, (10) brushing and linking, (11) conditioning

Operand-based approach

An *Operand-based* taxonomy covers IPs laying on the borderline of Norman's *action* and *evaluation* part - namely between Executing the Action level and Perceiving the State of the System level (Fig. 2). In this case, the object of interest is a real or virtual *operand*, which can be e.g. specific type of data, structure or an object. Roth (2012) further distinguishes these primitives on *type centric and state centric.* Primitives on this level have great variability and are usually connected to the specific context.

Tab. 3: Operand-based taxonomies

Crampton (2002)	Interactivity Types	1) data, (2) representation, (3) temporal dimension, (4) contextualizing interaction
Keim (2002)	Data Types	(1) one-dimensional, (2) two-dimensional, (3) multi-dimensional, (4) text and hypertext, (5) hierarchies and graphs, (6) algorithms and software
Ward and Yang (2003)	Interaction Operands and Spaces	(1) screen, (2) data, (3) data structure, (4) attribute, (5) object, (6) visualization structure

INTERACTION PRIMITIVES FOR EMPIRICAL RESEARCH OF 3D GEOVISUALIZATION

Taking into account the mentioned approaches, we strive for a taxonomy which can be used to set a ground plane in the empirical research of interaction with interactive 3D GVs. We suggest a taxonomy of IPs usable particularly for an empirical research and optimization of interactive 3D GVs. The suggested taxonomy is in its very nature based on an elementary classification created by Laha et al. (2015) and it represents an example of an objective-based taxonomy. Examples of the tasks that we have added into the individual categories were selected from our previous studies reflecting the usability testing of interactive 3D GVs (Špriňarová et al., 2015; Herman et al., 2016; Herman et al., 2017; Juřík et al., 20017; Kubíček et al., 2017). This classification covers main categories of tasks, which can be done on the 3D GVs.

Tab. 4: Suggested taxonomy of interaction primitives for empirical research

1	**search**	
1.1	**self-localization**	**Where am I?**
1.2	**presence/absence**	**Is there a lake?**
1.3	**counting**	**How many buildings are there?**
2	**pattern recognition**	
2.1	**trend**	**Is there a global trend in the heights of buildings?**
2.2	**repetition**	**Is there any specific pattern in the terrain shape?**
3	**spatial understanding**	
3.1	**absolute comparison**	**Which hill/top is in the highest place?**
3.2	**relative comparison**	**Is the trigonometric point "A" higher than the trigonometric point "B"?**
3.3	**comparison with different type of visualization**	**Which of the terrain profiles is displayed as a 2D graph?**
4	**quantitative estimation**	
4.1	**absolute estimation**	**What is the slope of the road?**
4.2	**relative estimation (binary)**	**Do the heights of trees depend on altitude?**
4.3	**relative estimation (quantitative)**	**How many times higher is the building "A" than the building "B"?**
5	**shape description**	**How would you describe the shape of the terrain?**
6	**combined tasks**	**Find all the buildings in the terrain and determine which one is the highest one.**
7	**planning**	**Determine a specific place where it would be suitable to place a lookout to see all of the landmarks.**

DISCUSSION

The benefits of the discussed efforts to sort basic elements of interaction are undeniable. Although there is a considerable diversity in researchers' perception of IPs, many similarities can be found among them and their fundamental parts can be used for development and research purposes of many visualization products. With respect to the previously mentioned diversity in IPs taxonomies, we newly suggested a consolidating taxonomy, which can be applied as a solid starting point for the empirical research of virtual 3D GVs. This suggested taxonomy was based on a classification created by Laha et al. (2015) and completed with the use of our research findings acquired within the research of interactive 3D GVs.

Purpose of the taxonomy was verified also with respect to its empirical grounding, where e.g. Roth (2013) strongly highlights applicability for practical tasks. In HCI and human factors research, interactive GVs represent a valuable asset for looking for answers in case of human behaviour and human possible failures in real environment (e.g. human error). Elsewhere Roth (2012) summarizes, that IPs taxonomy represents a complex lexicon for education and practice and as such - besides the applied field - the IPs taxonomy fulfils didactic purposes. However in general, the suggested taxonomy creates essential theoretical background for design and development of virtual cartographical products with interactive parameters. We can compare our suggested taxonomy with other existing examples, which are commonly used for classification of IPs. Both of them (Kjellin et al., 2010; Rautenbach et al., 2014) are used in researches dealing with empirical testing of 3D GVs. Compared to both taxonomies mentioned above, our taxonomy is the most robust one, especially because it takes into account advanced types of tasks (see tab. 5. - categories 6 and 7). We also consider its hierarchical form (composed from two levels) to be advantageous for finding similarities or differences when classifying user tasks.

Tab. 5: Examples of other existing taxonomies of IPs

		User operations – Koua et al. (2006) in Kjellin et al. (2010)	**Map reading tasks** – Morrison (1978) in Rautenbach et al. (2014)
1	**search**	locate	search, locate, identify, count
2	**pattern recognition**	distribution, cluster	delimit
3	**spatial understanding**	locate, rank, compare	compare or contrast, verify
4	**quantitative estimation**	identify, distinguish, categorize, correlate, associate	measurement, direct estimation, indirect estimation
5	**shape description**		identity
6	**combined tasks**		
7	**planning**		

Comparison of various UI settings became a crucial issue in the field of human factors, where different options of interaction can have a huge impact on safety. In consonance with this, in upcoming research there should be more emphasized testing of interaction equivalence within interfaces design and development, because interaction became an immanent part of visualization in its very nature. Every type of user's action performed within the UI (including control actions) may hugely influence the process of user's perception, evaluation, interpretation, and decision-making in the problems being solved. Such aspects should be subjected to a deep analysis and discussion.

CONCLUSIONS AND FUTURE WORK

In this paper we discussed the existence of various approaches in the issue of IPs – i.e. basic building blocks of interaction with GVs. The exact setting of IPs taxonomy seems to be necessary especially from didactical point of view, because such taxonomy is considered to be starting point for description and further development of virtual interactive maps, for their classification and evaluation of their functionality. Also, the necessity of better evaluation and specifying user issues is grounded in legislative demands (Řezník, 2013).

We find Objective-based approaches and Operator-based approaches consolidating IPs useful primarily for the design and optimization of the interactive GVs (not only three-dimensional ones). With respect to many existing approaches in the issue of IPs, we summarized the types of interaction used in practice and suggested a new conclusive taxonomy of IPs, which can serve as a solid ground plane for design, development and research of interactive 3D GVs. The suggested taxonomy offers a comprehensive typology of ecologically relevant tasks for comparison of the different types of UIs, e.g. 3D GVs with various types of control devices (e.g. Špriňarová et al., 2015). It can also be used for the assessment of cognitive skills/competences when dealing with information content in specific a GV. Last but not least, the suggested taxonomy can represent a methodological alphabet for interaction equivalence testing in the issue of various UI settings.

To conclude, suggested taxonomy offers instruments for evaluation and comparison of different interfaces. Currently we have the methodology, which can decide whether two different visualizations are information equivalent or not, however the interaction aspect of visualizations still remains quite an unexplored issue. This suggested taxonomy will be used as a starting point in our upcoming research projects in the field of cognitive cartography.

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Shrnutí

Virtuální realita představuje přirozený posun ve vývoji a výzkumu interaktivních geografických produktů, především map. V tomto článku shrnujeme problematiku interakčních primitiv, tedy elementárních prvků interakce, s jejichž pomocí lze přesně popsat proces práce člověka s virtuálními geografickými vizualizacemi, konkrétně s interaktivními 3D geovizualizacemi. V současnosti neexistuje jednotná taxonomie interakčních primitiv, nicméně na základě předchozích výzkumů lze tyto základní jednotky interakce dělit dle různých autorů do konkrétních podkategorií – objective/operator/operand-based primitives (Roth, 2012). V rámci tohoto článku jsme konsolidovali různá dělení interakčních primitiv (např. jejich dělení v rámci Normanova modelu) a na tomto základě jsme vytvořili vlastní komplexní taxonomii pro pochopení, výzkum a rozvoj interaktivních geovizualizací s ohledem na člověka – uživatele. Navržená taxonomie je vhodná pro posouzení tzv. interakční ekvivalence u různých typů geovizualizací s různým nastavením uživatelského rozhraní a má sloužit jako výchozí bod při dalším testování funkčnosti a optimalizaci interaktivních 3D geovizualizací.