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The Effectiveness of Propagating Viewsheds' Geovisualization from Topographically Prominent Viewroutes

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Abstract

The problem of visibility is studied in a context where geospatial digital data handling and analysis result in perceivable dynamic cartographic outputs by utilizing a GISystem, an image processing software and a statistical analysis software. Since only 'moving vistas' can approximate the actual, active visual perception, a concern regarding the selection of observation routes (*viewroutes*) arises. Although the exploration 'doctrine' dictates that one should proceed in an entirely data-driven approach, some linear features (e.g. ridgelines) are 'topographically endowed'. Therefore, our attention is focused on rendering the evolution of 'what is visible' for some defined topographically prominent routes (e.g. ridge-routes) by cartographically exploring viewsheds. However, the dynamic rendering of vistas along each route implies the visualization of both observer's (viewpoint's) movement and visibility spatial patterns' (viewsheds') propagation. Under this perspective, insight can be gained from pre-ordered animated sequences of such patterns which also include the viewpoint corresponding to each viewshed. These sequences could be rated as facilitating visualization schemes – recalling the case of '3-d fly-overs' – dedicated to visual exploration and self-evaluation. Yet, viewpoint election along such routes raises the issue of discretization: propagating visibility patterns could be influenced in a dissimilar manner along different types of routes under the effect of viewpoint discretization, and this may consequently call for non-uniform viewpoint spacing intervals. Therefore, the main strategy lies in creating 'equivalent' visualscape sequences by employing different viewpoint arrays both for the same viewroute and for different types of viewroutes, and making comparisons. The adequacy of the approximation and apprehension of each viewroute sequence set is not only visually evaluated, but also further assessed by employing novel statistical indices (*DCVI*) which quantify the viewsheds' coherence from successive viewpoints by harnessing their (viewsheds') spatial intersection.

Keywords: Dynamic viewshed geovisualization; prominent topographic viewroutes; visualscape exploration; animated maps; dynamic coherence visibility index (DCVI).

Introduction

Active visual perception in the natural landscape is and has always been an essential component for gaining information and knowledge from our surroundings. The delineation of the regions of these surroundings and the identification of the observer(s) that are mutually visible on 2-d cartographic products can be attained via GISs' terrain analytical functions (suitable algorithms) conducted on Digital Terrain/ Elevation Models (DTMs/ DEMs). Visibility or viewshed maps are such cartographic products depicting which regions of an area are visible/ invisible from one or more observation points, irrespective of viewing direction or field of view (i.e. 360-degree field of view).

Literature teems with research papers and reviews dealing with terrain visibility concepts and computation in relation to different algorithms and elevation data structures. However, this paper focuses on visualizing viewshed changes with respect to observers who move along routes with prominent topographic attributes. Proper scaling and sampling aspects in topographic and visualization terms reveal some essential dimensions to describe a visual landscape (visualscape) without prior knowledge of its visual properties or structure (e.g. Pfalz 1976; Lee 1994; Lee and Stucky 1998; O'Sullivan and Turner 2001; Kim et al. 2004; Lu et al. 2008). Yet, for static visualscape representations to acquire the potential to facilitate dynamic visualizations, they require 'special management'. When the *desideratum* is *locomotive observation*, this management can emerge by the consideration of conceptual and implementation folds pertaining to viewshed computation and digital terrain modeling, – within the overarching framework of cartographic visualization (geovisualization).

Granting that locomotive observation fits to the actual visual experience, and as Gibson (1986: 75) asserts: "[only] when the moving point of observation is understood as the general case, the stationary point of observation is more intelligible", the gist is that the locomotive observation is the generic case for visual perception and cognition – albeit it is hard for it to be conceptualized, represented, manipulated and visualized in a modeled simulation. Yet, since one is able to compute viewsheds from each single viewpoint – "the limiting case of a point of observation in motion" (Gibson 1986: 72) – in a straightforward manner in a GIS, it appears rational to seek strategies to reconstruct the more generic case. Observation in locomotion shifts the concern from 'viewpoints' to 'viewroutes', and towards this direction this paper further elaborates.

The underlying presupposition is that a spatiotemporal process of the real world needs equally dynamic counterparts if it is to be effectively approximated and apprehended. Traditionally, the cartographers' composure against an ever-changing world, and their deliberate evasion of addressing time by mapping relatively static phenomena with static maps had transferred the burdensome task of temporality to the map users (Muehrcke 1978). However, the paradigm of Geovisualization encompassed non-static phenomena and space-time processes; geovisualizations (i.e. interactive and animated maps) harnessing dynamic variables are able not only to present, but also to synthesize, analyze and explore phenomena and processes (DiBiase et al. 1992; MacEachren 1994).

This shift has, in turn, given rise to new questions. As Peterson (1995) explicates, cartography refers to the process of externalizing internal representations similar to maps that emerge from memory (mental maps) in the form of generalized, helpful visual depictions of the environment. But he also adds that "the human mind can visualize not only static mental maps but also dynamic mental map animations" (Peterson 1995: 43). Studies conducted by cognitive psychologists (see Tversky et al. 2002) have stressed the necessity for further elaboration when it comes to animations. It may seem rational for people to form mental representations of dynamic processes in the shape of animations to attain the natural cognitive correspondence between "the structure and content of the external representation" and "the desired structure and content of the internal representation" – that is to effectuate the Congruence Principle (Tversky et al. 2002: 249). Yet, this not the only case. The externalized representation "should be readily and accurately perceived and comprehended" as well – it should comply with the Apprehension Principle (Tversky et al. 2002: 256). In other words, even if "animations are believed to be useful for the representation of spatial dynamics because they can mimic real-world dynamics and show processes", it is questionable "whether they are also effective" (Blok 2005b: 71).

Since the viewshed spatiotemporal propagation is visualized and investigated herein from a gibsonian perspective, the exploration of the viewshed patterns along a route and the manner in which these patterns develop as the viewpoint moves for different types of viewroutes are approximated through animated sequences. Nonetheless, these sequences should not be created without further elaboration. Contrariwise, the keystone is to furnish a strategy for experimentally investigating the effect of viewpoint sampling by comparing equivalent viewshed animations exploiting the potency of cartographic abstraction (dynamic variables), and regulating the cognitive load (see DiBiase et al. 1992; Harrower 2007; Battersby and Goldsberry 2010).

Thence, this paper deals principally with the potentiality and appropriateness of harnessing an animated viewshed as a 2-d fly-over (fly-by) facilitator to explore the visualscape of different viewroutes by addressing the discreteness effect originating from the digitization of terrain and by inquiring the importance of abstraction in such a cartographic exploration. The accomplishment of this generic goal is connected with our two basic research hypotheses which steer this research:

- Hypothesis 1: Animated viewshed sequences have the potential of substituting 3-d oblique fly-overs in landscape exploration.
- Hypothesis 2: Denser viewpoint locations signify better approximation of the dynamic (animated) viewshed geovisualization and optimal insight gaining about the underlying process through cartographic exploration for every single viewroute.

Materials and Methods

The initial task was to select a region including a variety of distinguishable topographic features – ridges, valleys and passes – without at the same time demonstrating extravagant roughness. In addition, the availability of reliable, dense, and accurate elevation data determined the election of the study area. A mountainous landscape with those traits and with available and proper digital elevation data was found in Wyoming, USA: the study area is a 25-km^2 rectangular one, situated at the Jackson Ranger District, approximately 15 km SSW off the town of Jackson (Wyoming) (Fig. 1). Elevation data collected by LiDAR technology capturing a point-cloud at up to 1-m planimetric resolution was downloaded freely from the NSF Open Topography portal (Open Topography 2013) in the shape of a 4-m rectangular DEM, representing only the underlying topographic relief (Fig. 2). The 4-m cell size was deemed to be appropriate partly due to the relatively moderate computation load its manipulation is entailed and partly because the most refined available resolution is not by all means the one approximating in most realistic terms the actual visible region(s) (see Riggs and Dean 2007).

Figure 1: Satellite image depicting/ locating the area of interest (Source: GoogleEarth).

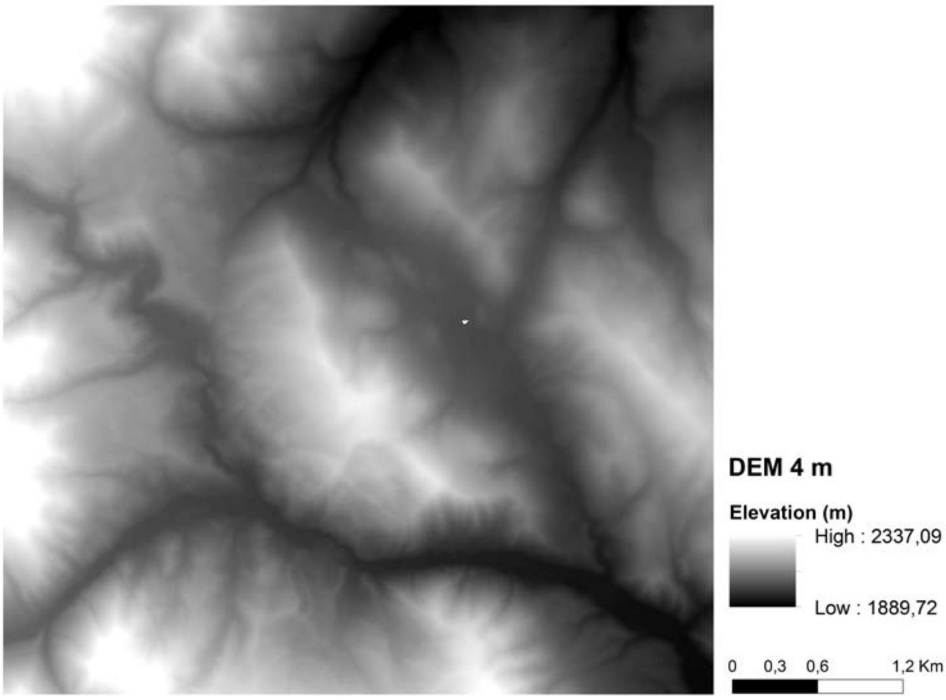


Figure 2: The 4-m resolution DEM – elevation is visualized with a stretched (unclassified) grayscale color ramp.

Resorting to the fundamental notion of the sampling theorem about topographic cross-sections (see Li et al. 2005; Hengl 2006), the gist was to engrave three routes along the three linear topographic features and digitize them under three different spacing intervals of 40, 20 and 10 m (Fig. 3; Fig. 4). This spatial sampling procedure entailed the potential for visualizing dynamic terrain visibility with more/ less dense sets of viewpoints-viewshed pairs when animating their spatio-temporal evolution. So, for key-frames sampled under varying intervals, it was examined in what manner does the fidelity of the visualization is affected within the same type and across different types of viewroutes.

Before answering this question, there was an exigency for minimizing the manual intervention when creating the alternative visualizations. So, after having imported the DEM and georeferenced it (12th NAD Zone) in a GIS software (ArcGIS), a semi-automated polyline feature digitization procedure was conducted. Harnessing the 'streaming digitization mode' and the capabilities of the ArcGIS ModelBuilder, we plotted the aforementioned nine polyline features semi-automatically and derived the viewpoints from the polyline vertices (Fig. 5).

ModelBuilder was also utilized to automatically compute in both geospatial and arithmetic terms: i) the viewsheds from each viewpoint and ii) the spatial intersection of the viewsheds of each three successive viewpoints. Whereas the geospatial outputs from (i) constituted the frames for the viewshed animation, the numerical outputs were required to quantify: the visibility magnitude of each key-frame (i) and the coherence among successive key-frames of the sequence (ii). For (i), a very simple index was used: the ratio of visible cells to the total number of cells – the Dynamic Visibility Index (DVI). As for (ii), the pertinent index was developed as follows: initially, the number of the intersecting visible cells for every three consecutive viewpoints was utilized, and the ratio of this number to the total number of cells was expressed as a percentage (Intersection_Index); subsequently, by calculating the average of the visibility index for every three consecutive viewpoints – (Moving_Average_Index) –, an index that integrates these two figures resulted from the ratio of the first to the second one (Intersection_Index / Moving_Average_Index): in practice, this index – Dynamic Coherence Visibility Index (DCVI) – approximates the degree to which the visible cells alter for every three consecutive viewpoints.

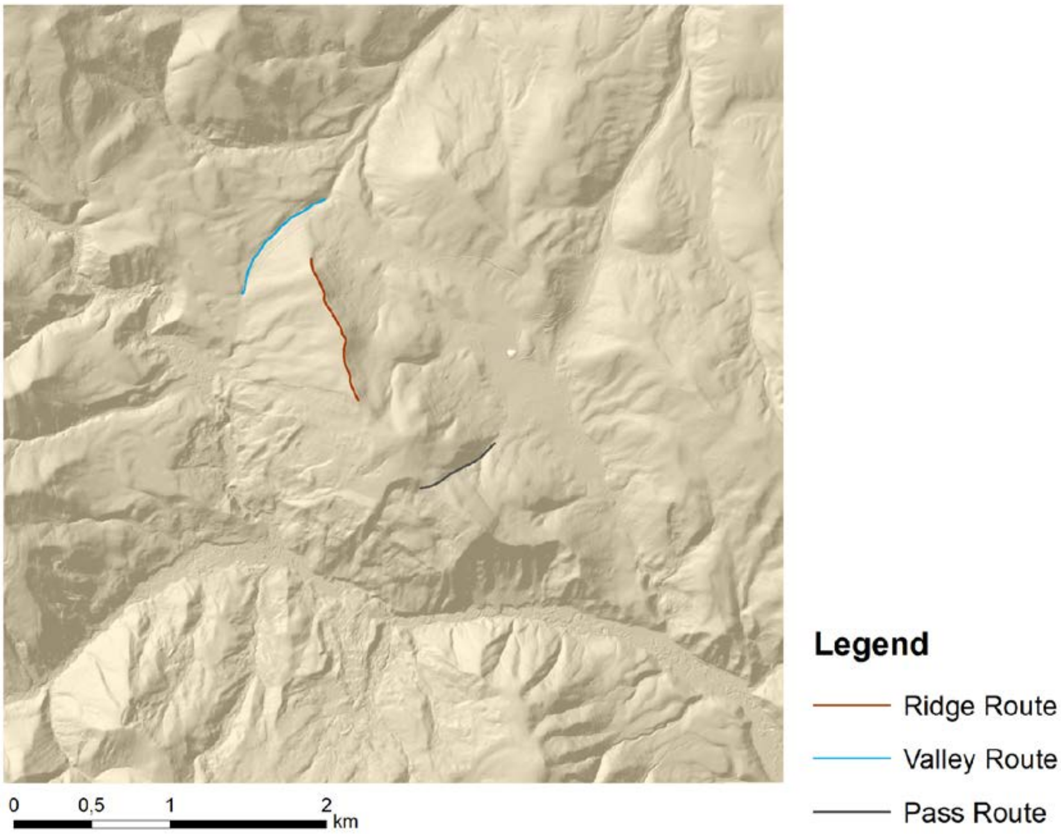
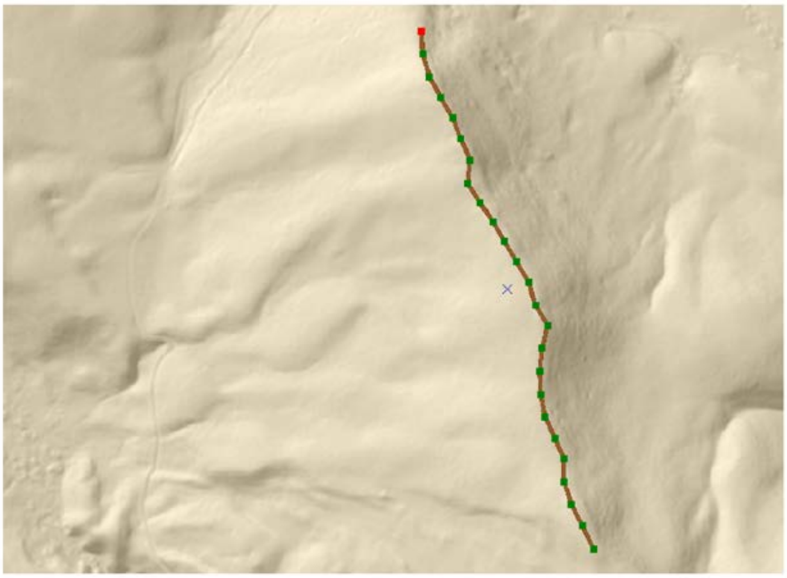
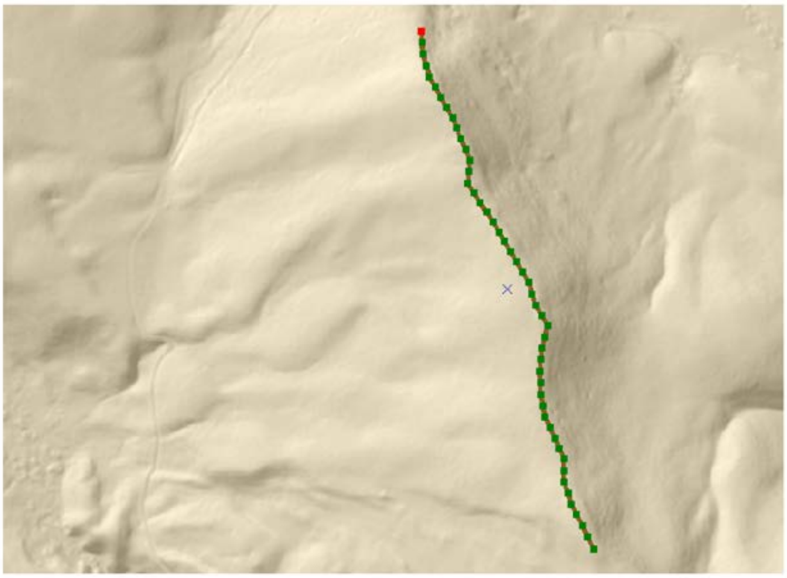


Figure 3: Three routes (viewroutes) for visual exploration on different topographic features on a hillshaded relief of the study area.



(a)



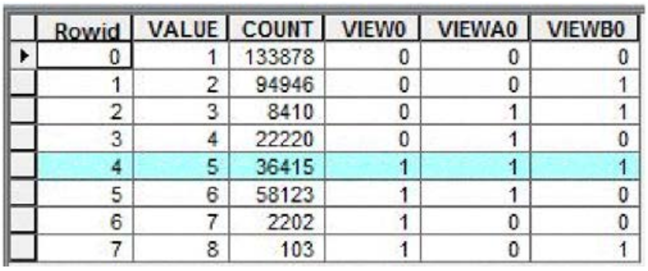
(b)

(c)

Figure 4: Various intervals of digitization for the ridge-line route: 40 m (a), 20 m (b) & 10 m (c).

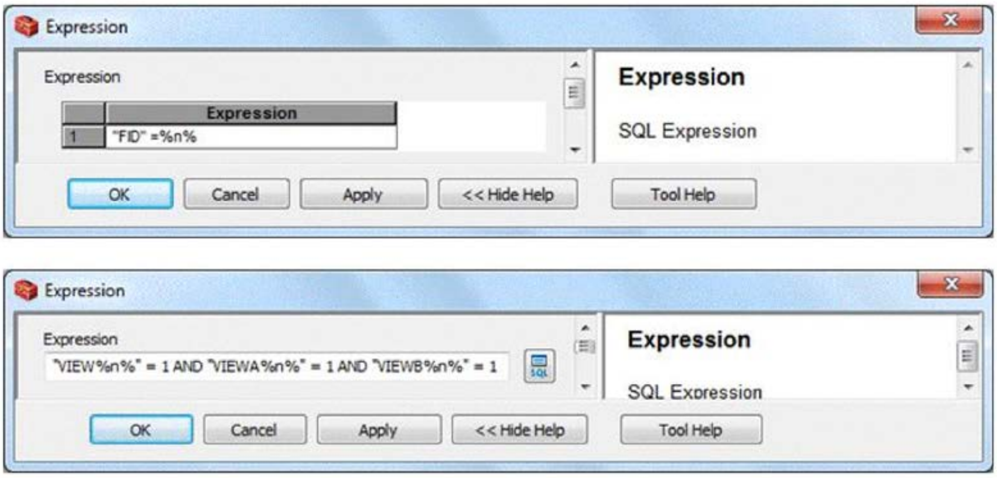
Figure 5: Workflow model of the conversion of the initial polyline feature class maintaining all the topographic feature routes into nine (9) separate point feature classes (shapefile layers) with XYZ coordinates.

The automation of the extraction of all those outputs, and most notably the intersected viewsheds' information required a special treatment due to its relative complexity by manipulating: *Geoprocessing Tools*, *Iterators*, *Variables* stated as *Expressions*, *SQL Queries* and output files' *suffix labeling* in the ModelBuilder environment. For exporting the viewsheds (geospatial and numeric) outputs, the *Viewshed Tool* and the *Table to Table Tool* were applied on the basis of: i) a simple type of iteration acting serially on the records (consecutive viewpoints) of the elected viewpoint layer (Expression: ''FID' = %n%') and ii) a simple SQL expression, applying on the created tables (Expression: ''FID' = 0'). In contrast, the extraction of intersected viewsheds with the *Combine Tool* required that we imported thrice the same viewpoint layer, and impose an iterative strategy for each triad of consecutive viewpoints (and their viewsheds); so, for each successive iteration the model runs for the next three consecutive points, until the process ends (Expressions ''FID' = '%n%', '%n%+1' and '%n%+2'' on each viewpoint layer). Now, since each of the (binary) viewsheds layer stores two records (visible/ not visible cells) and the tool applies upon three such layers, the final output contains eight (2^3) records, but only one comprises the cells that are visible simultaneously from the three viewpoints (Fig. 6). The pertinent numeric information was extracted in separate tables as previously and by applying a dual SQL expression that satisfied both the selection of the demanded combine output and of the appropriate record (Fig. 7). Figure 8 presents the Model for automating the whole workflow.



Rowid	VALUE	COUNT	VIEW0	VIEWA0	VIEWB0
0	1	133878	0	0	0
1	2	94946	0	0	1
2	3	8410	0	1	1
3	4	22220	0	1	0
4	5	36415	1	1	1
5	6	58123	1	1	0
6	7	2202	1	0	0
7	8	103	1	0	1

Figure 6: Attribute table of a typical combine output layer on each triad of (consecutive) viewsheds: only the highlighted record stores cells which are visible from each triad of consecutive viewpoints (values in all three view-fields are ‘1’).



	Expression
1	"FID" =%n%

Expression: "VIEW%n%" = 1 AND "VIEWA%n%" = 1 AND "VIEWB%n%" = 1

Figure 7: The simplest case of successive selection based on the FID (top), and the more elaborate sequential selection, based on the simultaneous satisfaction of visibility value to be ‘1’ (bottom).

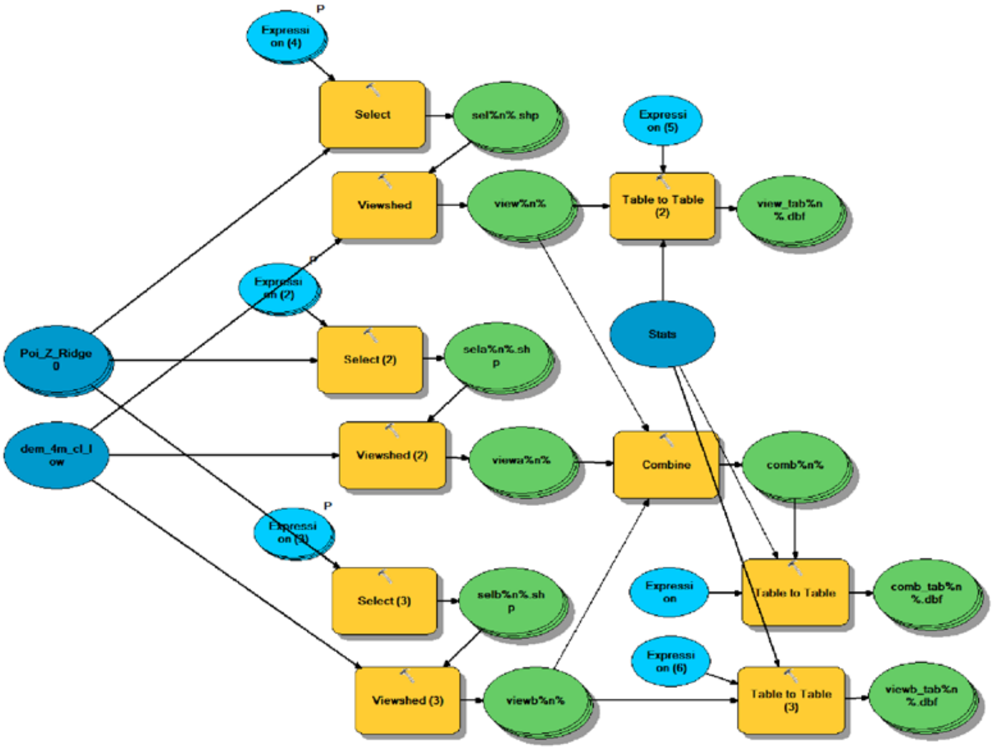


Figure 8: Model utilized to automate the workflow of the generation of i) multiple viewsheds and their numeric elements and ii) combined viewsheds and their numeric elements.

Subsequently, the next two steps were to: i) process the geospatial outputs and create the viewshed animated sequences (geovisualizations) to visually explore the propagating viewsheds and ii) manipulate the arithmetic results and statistically corroborate and evaluate the geovisualizations.

For an animated map to procure an effective visualization, it is vital that it is generalized – remaining minimal in terms of (cartographic) design and synthesis – and no other map components than those that actually do change are modified even slightly. This means that the layout design has to be identical for each frame and as simple and plain as possible. In our case, the design of each static map display should include aside from the viewsheds (visible/ not visible regions) their ‘generating’ viewpoint with which each of them is connected with. The topographic relief of the landscape should be also incorporated in this static map, for it is a viewshed determinant – along with the viewpoint location. Yet, it should be included in a ‘discreet’ but recognizable way. So, both the viewsheds and the viewpoints were overlaid against the hillshaded relief (background): whereas a percentage of transparency was applied on viewsheds, the viewpoints were placed on top of this layer superimposition, being totally opaque.

Another crucial parameter for the cartographic design refers to the colours utilized to depict the spatial distributions of visible/ not visible surfaces. After trial and error, we ended up assigning: a hue of green (RGB: 56, 168, 0) to the visible, and a hue of beige (RGB: 255, 235, 190) to the not visible ones. As Peterson (2009) suggests, the latter can be used to portray soils and generally land backgrounds, while the former is assigned to forest lands; green is also generally used to connote a feeling of goodness or likability, or environmental correctness. So, greenish hues being cool and vivid can link human cognition to something ‘relaxing for the eye’, or ‘worth observing’, while dull hues potentially imbue the respective patterns (i.e. the beige cells) with the meaning of something that does not extrude, or of something that is ‘covered’ or ‘unseen’. As for the viewpoints, they were symbolized with small sized (6 pt) red (RGB: 255, 0, 0) circles so as to be easily discernible without consuming ‘vital space’ (Fig. 9).

After having designated the static snapshots, the generation of the animated sequence ensued. It is worthy of note that this sequence is, from a standpoint, a special type of fly-over, while from another, an areal animation (see Lobben 2003; Slocum et al. 2009). In fact, it is a hybrid: it is an abstracted, ‘exocentric’ 2-d fly-over in which the changing locations of the locomotive observer are depicted by moving viewpoints, whereas changing panoramic vistas are portrayed by propagating viewshed spatial patterns. Granting that animating the patterns is much more complicated, it is this animation type that prevails, entailing the creation of proper frames between consecutive spatial distributions; from all the available techniques for animation (see Peterson, 1995), the most suitable for this case is the morphing technique.

The software facilitating this technique is GIMP. The animation creation process began with the import of the frames/ image layers which were manipulated as follows: initially, they had to be prepared to constitute compatible layers for a video-type generation; afterwards, between each consecutive layer pair, several *in-between* frames were created. So, in the *Morph* mode, certain specifications were required to be set, with the number of steps (‘morph-tweens’) being the most crucial one. Finally, by executing successive *tweening* processes, and by exporting their outputs in proper moving image sequences (*.gif), the nine different visualizations were generated (Fig. 10) and converted to video files (*.avi).

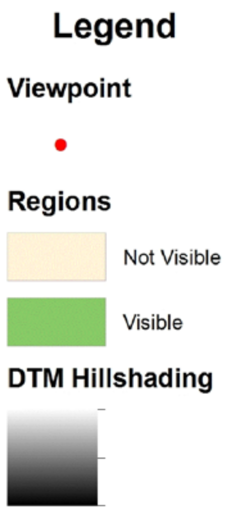
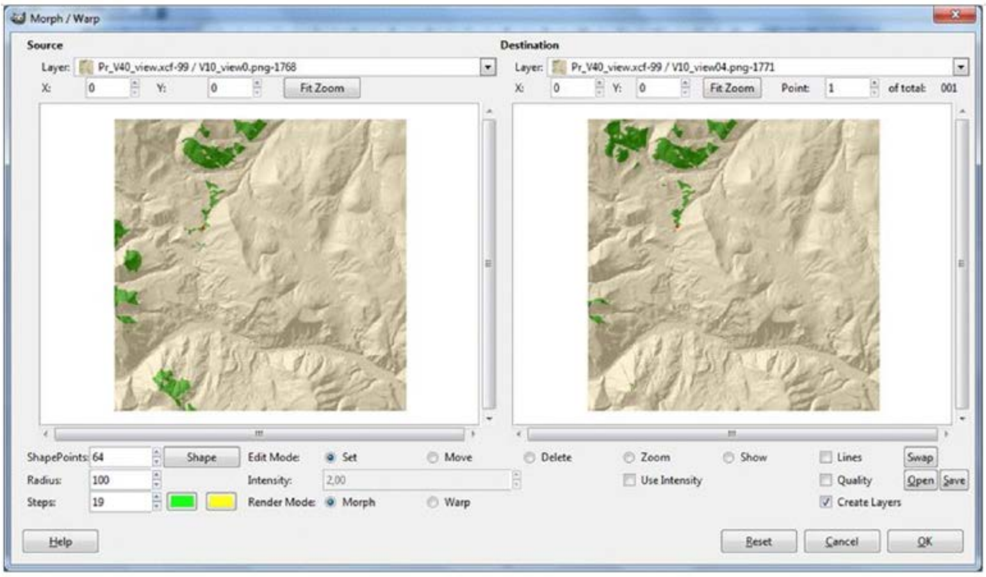


Figure 9: Legend for the interpretation of the visualizations: Hillshading comprises the background on which the visible/ not visible regions are superimposed, while the (moving) viewpoint is on the top of the visual hierarchy.



Source
Layer: Pr_V40_view.xcf-99 / V10_view0.png-1768
X: 0 Y: 0

Destination
Layer: Pr_V40_view.xcf-99 / V10_view04.png-1771
X: 0 Y: 0 Point: 1 of total: 001

ShapePoints: 64
Radius: 100
Steps: 19
Edit Mode: ● Set ○ Move ○ Delete ○ Zoom ○ Show
Intensity: 2,00
☐ Use Intensity
Render Mode: ● Morph ○ Warp
☐ Lines
☐ Quality
☑ Create Layers

(a)

GIF Options
☑ Interlace
☑ GIF comment: Created with GIMP
☑ As animation

Animated GIF Options
☑ Loop forever
Delay between frames where unspecified: 100 milliseconds
Frame disposal where unspecified: I don't care
☐ Use delay entered above for all frames
☐ Use disposal entered above for all frames

(b)

Figure 10: Crucial parameters' specifications in the Morph/ Warp Window (a) and in the Export Image Window (b).

The values set on these specifications/ parameters rely on a hypothesis which proceeds as follows: Since we are to visually explore a landscape from three different viewpoint intervals (for the three viewroutes) at this 'abstracted fly-over', then for each of the three triads of animations to be comparable, it seems rational to have the same duration. Also, they should be overall equally smooth. So, they should exhibit the same rate of change (DiBiase et al., 1992 – dynamic variables). The overall magnitude of each of the triads is the same, as the starting and the ending route viewpoints are the same; but, the existing intervals are different. In order to faithfully approximate the inherent propensity of viewsheds evolving along a route one should render a viewshed sequence with infinitely small viewpoint distances; since this practice is simply impossible in the digital world, we clung to the continuously diminishing space intervals to adjust to this propensity. This means that for attaining the same rate of change, the number of the intervening steps should be regulated properly. Constructing such equivalent animations with a typically same rate of change, and treating as an axiom that the minimization of the space intervals leads towards the approximation of the inherent nature of this evolving pattern, it can be deduced that:

- Starting from animations that refer to the sparsest viewpoints, if no significant differentiations in the spatial pattern sequence occur in comparison to animations that correspond to denser intervals, it is safe to keep the animation generated by a lesser interval; contrariwise, significant alterations in the animations call for the election of the densest sampled viewshed frames,.
- There can be discerning differences in animations among the different topographic features on which the viewroutes abut for each visual exploration; for instance, while the exploration for a valley-route could equally approximate the evolution under any interval, the exploration for a ridge-route could not retain its coherence from animations emanating from 20 or 40m viewpoint intervals.

The parameterization values selected for the various viewroutes and intervals and their derived figures are summarized in table 1. In any case, the overall duration was to be kept low (less than one minute); this was due to two reasons: i) mitigation of the cognitive load – increase of the cartographic visualization effectiveness – and ii) adhesion to the principle of temporal abstraction – animations are not to visualize processes in real time (Harrower 2007; Harrower and Fabrikant 2008). This dual purpose was partially achieved by filtering the visibility information (election of viewroutes) and by further segmenting the animation sequence into three parts according to the respective linear topographic feature. Thus, having adopted the exploration of the visibility structure of a landscape without any ‘guide’, other than prominent linear topographic features (viewroutes), the quintessence of our venture could be summarized as: “which are the most suitable locations within each viewroute to optimally approximate the process at work minimizing uncertainty and maximizing animation coherence, while in parallel mitigating the computation load and automating the procedure?” (Fig. 11).

As for the numerical data, descriptive statistical analysis was employed to quantify both the visibility magnitude along different viewroutes, and the appropriateness of the viewpoint sampling for producing viewshed geovisualizations. For the former purpose DVI was juxtaposed to the viewroute and to the viewpoint space interval, while DCVI was utilized to establish an index for the animation coherence.

Since DVI is a normalized index, comparisons can be made even for areas of different extent. DCVI exhibits a normalized quantification of the animation cohesion: as the index is approaching 100%, the variation of the successive viewsheds tends to be minimized, and the animation is deemed to be coherent. Therefore, a considerable fluctuation of this index under the effect of different viewpoint space intervals should mean that the change of the density of viewpoints induces a significant alteration to the cohesion of the viewshed visualization. Nevertheless, the viewroute itself could entail different requirements in viewpoint density selection, since the evolution of the viewshed visualization process along different viewroutes may be inherently different.

Table 1: Summary of the: i) run time of the Model utilized to automate the workflow, ii) number of transitions, in between steps, total frames and iii) animation time according to different viewroutes and varying viewpoint intervals. The aim is to produce comparable animations: a) of the same duration within the same viewroute assessing their evolution depending solely on the intervals and b) of the same in between frames number for the same viewpoint interval in order to evaluate their behavior on the different type of viewroute.

Viewroute		**Viewpoint Interval (m)**	**# of Viewpoints/ Transitions/ Runs**	**Run Time (sec) in Model**	**# of 'In Between' Frames (Steps)**	**Total # of Frames**	**Animation Time (sec)**
Type	***Length***						
Pass	569 m	40	15/ 14/ 13	115	19	19*14 +15 = 281	≈28
		20	29/ 28/ 27	262	9	9*28 + 29 = 281	≈28
		10	57/ 56/ 55	519	4	4*56 + 57 = 281	≈28
Ridge	989 m	40	25/ 24/ 23	237	19	19*24 +25 = 481	≈48
		20	49/ 48/ 47	393	9	9*48 + 49 = 481	≈48
		10	97/ 96/ 95	988	4	4*96 + 97 = 481	≈48
Valley	851 m	40	22/ 21/ 20	177	19	19*21 +22 = 421	≈42
		20	43/ 42/ 41	397	9	9*42 + 43 = 421	≈42
		10	85/ 84/ 83	842	4	4*84 + 85 = 421	≈42

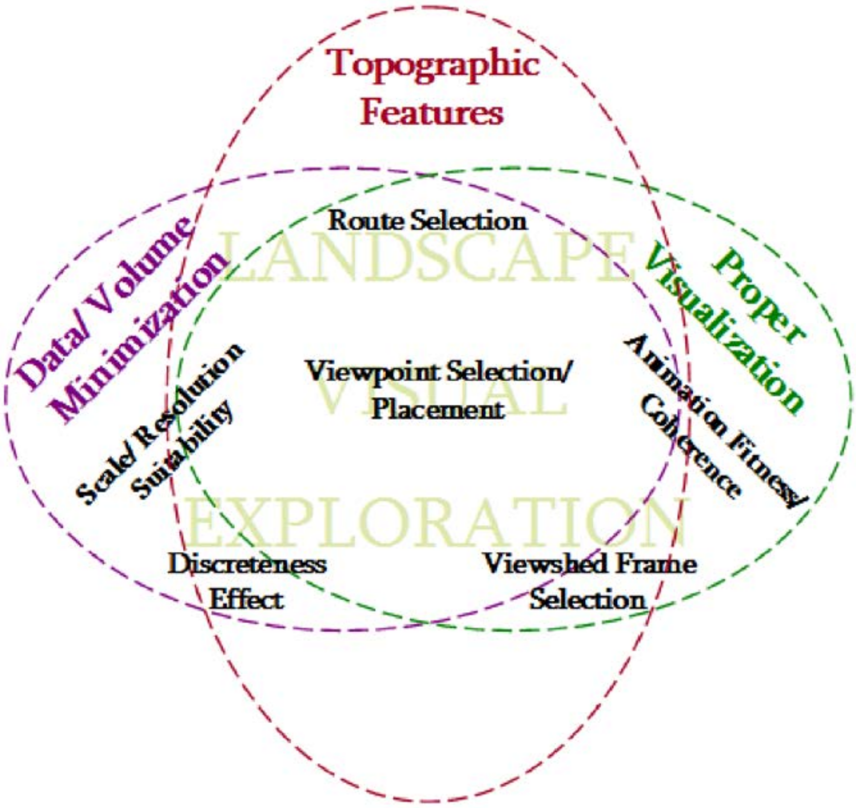


Figure 11: Interrelated aspects for visual landscape exploration: a conceptual scheme.

Results and Discussion

The nine (three triads of) animated sequences visualizing the viewshed propagation can be found at: http://carto.survey.ntua.gr/theses/vis_map. By meticulously and repeatedly visually inspecting and comparing the overall spatiotemporal trends of the visibility patterns for each of the three viewroutes animation (without at present focusing on the varying viewpoint sampling) the following findings occurred:

- *Pass-Route*: The locomotion of the viewpoint exposes a considerably distinguishable behavior for the dynamic visualscape of this viewroute, the direction of which is SSW – NNE. This visualization encompasses an extremely abrupt change, breaking the otherwise sufficiently cohesive viewshed propagation. This 'rupture' emerges at the segment at which the locomotive observer is transcending over the pass point. Prior to this stage, the observer is able to 'look' only at the SW part of the landscape: the constantly increasing visual spatial patterns spreading from south and SW parts of the landscape towards the location of the viewpoint are suddenly 'leaping' to another, more gently varying pattern. Thereafter, the visualscape remains generally stable, consisting from a non-fragmented distribution; it includes chiefly a fan-shaped pattern being 'diffused' from the moving viewpoint, and a few 'patches' located at some adjacent peaks or at slopes opposite to the viewpoint locations.

- *Ridge-Route*: In contrast with the pass viewroute, ridge-route viewsheds display a much more rough and 'erratic' performance. As the observer moves from SSE to NNW, the visible cells cover a large proportion of the landscape at first; these cells, east of the ridge are initially declining and then are gradually being augmented, whereas at the WSW portion of the landscape they are quickly being withdrawn to a significant extent. After a while, landscape's western part is reclaiming part of its viewshed, and visible cells remain almost still in general. Moving further NNW, after a 'moment' of diminution of the NW viewsheds, the visible regions west of the ridge remain relatively unaltered, while at the same time the eastern part is changing constantly. At the last third of the animation, the viewshed east of the ridge is retaining a stable pattern, changing only in the vicinity of the viewpoint, while the western domain is constantly varying. Last, the viewshed is modified in a very gentle way mainly east of the ridge-line.
- *Valley-Route*: This route's dynamic visibility patterns are characterized by their small covering area and their 'patchiness'; they are more fragmented than these of the pass-route, but not as irregular and expanded as those of the ridge-route. The valley-route approximates a circular sector directed from SW to NE. The dynamic behaviour of its viewsheds at the beginning of the animation resembles the pass's initial transitional steps: the visible regions existing diametrically opposite (WSW) to the direction of the observer locomotion are 'vanishing' after a few moments; only a few patches reoccur later on and for a little while at this part of the landscape. At the southern, SE and eastern region of the landscape no cells are visible. The viewsheds are mainly spatially clustered around few dissected 'growing-shrinking' patches at the northern part and generally lie within a small field of the observer's view: the vistas are mostly evolving as linear occurrences within the valley itself, and are emerging and re-emerging on adjacent or more distant opposite slopes – or upon the ridge-line of the elected ridge-route.

Besides, both an intra- and inter-viewroute comparison yield some useful remarks about the role different viewpoint intervals serve, and how these intervals can be modified depending on the viewroute's topographic feature. By comparing these equivalent animations – as triads of the same viewroute – several results occur; furthermore, the animations are 'self-assessed' promoting the ones which best fit for each viewroute visualization. As a matter of fact, it appears that:

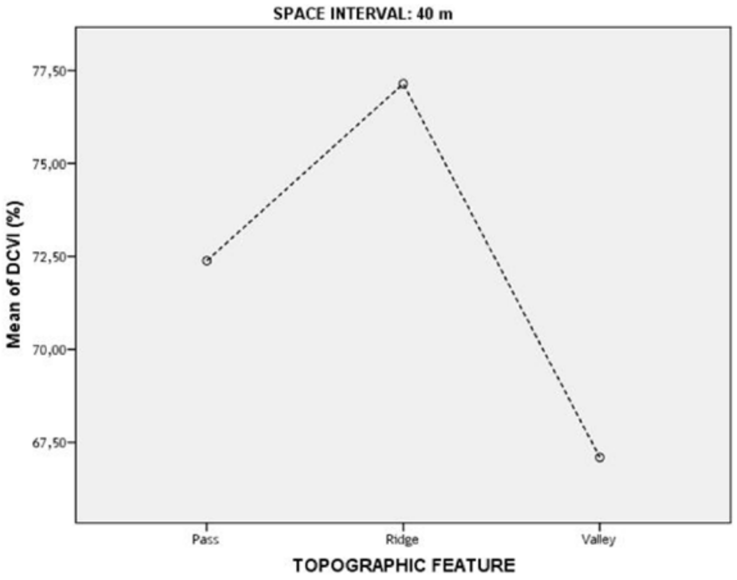
  - By inspecting the triad of different viewpoint intervals in *ridge-viewroute*, it emerges that when the visualization is materialized with the densest available viewpoint interval, significant pattern variations are revealed: in several cases many visible regions that dwindle and then re-appear cannot be portrayed in a less dense viewpoint interval, owing to a more 'flattened' dynamic visualscape occurring from less 'representative' viewpoint changes;
  - The *pass-viewroute* is not that dependent on a dense viewpoint interval to visualize all the prominent and less prominent visibility pattern variations, even with the sparsest viewpoint spacing; exception to the selection of this spacing interval might constitute the abrupt change coming about at a specific location (pass point) disrupting the cohesion of viewsheds;
  - The approximation of what happens in the dynamic visualscape from the *valley-viewroute* does not seem to require as densely located viewpoints as possible.

These findings are corroborated by statistical results as well. Descriptive statistics (Tab. 2) demonstrate that with reference to the DVI, it is apparent that its arithmetic mean is much greater for ridge-viewroutes – approximately five times greater than the DVI means of pass-routes and 14 than the DVI means of valley-routes. Furthermore, the DVI means within the same route remain practically unaltered with interval changes. These results show that the aggregate visibility is affected (quantitatively) by the topographic feature on which the viewpoints are placed, but not by their spacing. The DVI range and standard deviation (stdev) in ridge- and valley-routes remain constant or tend to dwindle, and only the pass-route exhibits a rising trend for these descriptive measures, a fact that can be attributed to its innate morphological character that does not hold the 'topographic purity' of the other two – the elevation of this feature mounts until the pass point and subsequently it declines; so, the densification of viewpoints will include locations that are higher in the route, and, probably, with augmented visibility.

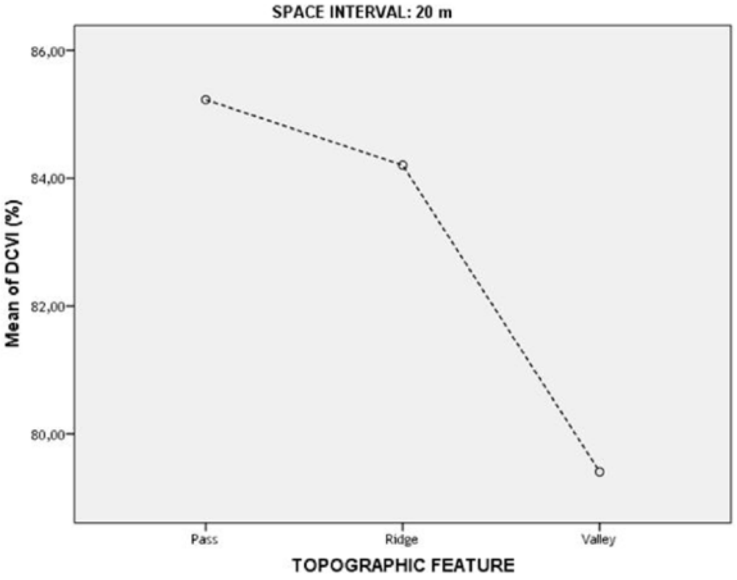
The coherence of the viewshed visualization is statistically examined with the DCVI. As it can be clearly observed, a decrease in space interval imposes a rise in the coherence – the DCVI mean. Nonetheless, its growth is not 'homogeneous' across intervals and viewroutes. For the pass- and valley-viewroutes, the transition from 40 m towards 20 m involves much more percentage units of DCVI mean increase than the transition from 20 m towards 10 m, while for the ridge-viewroute the increase is roughly the same between the two transitions. (In fact, by a 20-m densification of the initial 40-m viewpoint interval for pass-viewroute, its coherence has been significantly enhanced to an extent that it has surpassed the DCVI mean of the 20-m viewpoint interval ridge-viewroute – even though at the 40-m interval the ridge DCVI mean has been higher than the respective pass DCVI mean.) This is in part expected i) since we have posited that variation below 10 m would be insignificant, and thus this interval acts as a kind of a limit, and ii) because the absolute drop in the viewpoints' distance for the first transition is 20 m, whereas for the second transition is only 10m. Additionally, the pass-route's DCVI stdev remains relatively high, even for the 20-m interval, when the ridge's DCVI stdev is much lower, even for the 40-m interval. But, the seeming contradiction of how this calculation can be consistent with the visual exploration evaluation of the most suitable interval for each viewroute (pass: 20 m, ridge: 10 m, valley: 20 m) is explained as follows: In spite of the adequate coherence of the viewsheds (frames) for the ridge-route even from the 40-m spacing, the increased DCVI involves a considerably larger amount of real changes. Even though the DCVI coefficient of variation (CV) is much lower for the ridge-route, the sheer figures (and the spatial patterns) of visible cells are that larger (and that more irregularly distributed) that the ridge dynamic viewshed visualization requires the densest available interval. These DCVI means variations are presented in figure 12.

Table 2: Descriptive statistics for DVI and DCVI across different topographic features and space intervals.

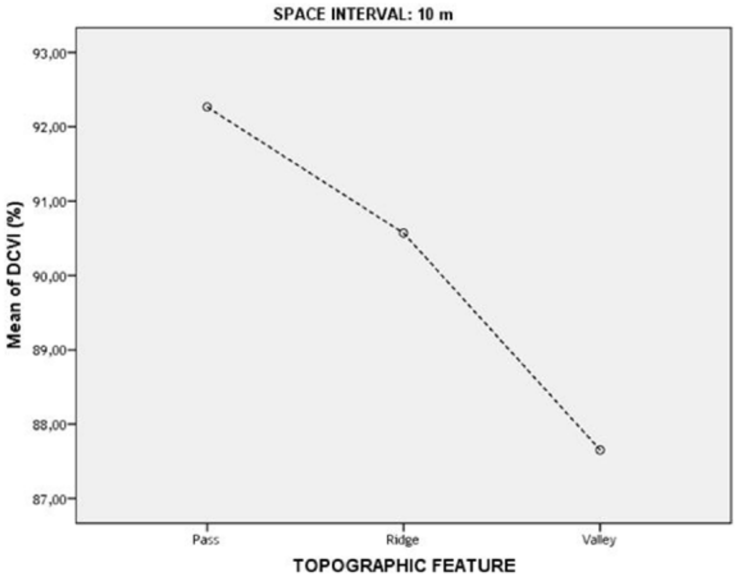
TOPO. FEATURE	SPACE INTERVAL		Range	Mean	Std. Deviation	Coef. of Variation (CV)
	40 m	DVI (%)	5,17	5,80	1,62	27,93
		DCVI (%)	90,74	72,38	26,87	37,13
		DVI (%)	6,48	5,82	1,69	28,99
Pass	20 m	DCVI (%)	75,74	85,23	18,02	21,15
		DVI (%)	9,01	5,84	1,80	30,90
		DCVI (%)	53,11	92,27	9,78	10,60
	10 m	DVI (%)	19,75	24,80	5,24	21,12
		DCVI (%)	38,86	77,14	11,02	14,29
	40 m	DVI (%)	19,75	24,94	5,15	20,66
		DCVI (%)	37,39	84,20	8,49	10,09
		DVI (%)	20,21	25,04	4,96	19,79
Ridge	20 m	DCVI (%)	32,29	90,57	5,64	6,23
		DVI (%)	3,19	1,83	0,94	51,23
		DCVI (%)	31,41	67,09	9,62	14,34
	10 m	DVI (%)	3,19	1,83	0,89	48,93
		DCVI (%)	34,14	79,41	8,81	11,09
	40 m	DVI (%)	3,19	1,82	0,87	47,66
Valley	20 m	DCVI (%)	24,59			
	10 m			87,65	6,30	7,19


SPACE INTERVAL: 40 m
Mean of DCVI (%)
77,50
75,00
72,50
70,00
67,50
Pass
Ridge
Valley
TOPOGRAPHIC FEATURE

(a)


SPACE INTERVAL: 20 m
Mean of DCVI (%)
86,00
84,00
82,00
80,00
Pass
Ridge
Valley
TOPOGRAPHIC FEATURE

(b)



(c)

Figure 12: ANOVA means Plots linking the DCVI with the different topographic feature: 40-m space interval DCVI means (a); 20-m space interval DCVI means (b); 10-m space interval DCVI means (c).

Conclusions

In the introduction we posited that the exploration of visibility patterns through animated sequences by harnessing appropriate series of observation points could comprise a viable alternative. After having modeled the procedure, generated the animated maps and visually/ statistically evaluated them, it occurred that the merits of such geovisualizations are conspicuous, while their effectiveness does not relate only to the viewpoint sampling irrespectively of the viewroute's topographic character. More precisely:

- According to our first research hypothesis, the geovisualization of visualscapes equals to an abstracted fly-over. Harrower's and Sheesley's (2005) modest suggestion that depictions "on the 2-d map all of the terrain currently visible in the 3-d map (i.e., viewshed analysis in GIS)" could function as overview windows to overcome the visual occlusion problem in 3-d oblique fly-overs was significantly expanded herein. In practice, by visualizing the moving viewpoint and its respective viewsheds in animated sequences, we reconstituted 2-d generalized flows of panoramic vistas of a landscape for 'every possible' position along viewroutes. Even though such sequences was used as a medium to explore viewshed evolution from a moving point of observation, they can serve as communicative means for simulating the succession of vistas along 'flight-paths'.
- As a response to our second hypothesis, it emerges that the densest possible viewpoint sampling is not necessarily the optimal for the approximation or apprehension of the evolving visualscape. Since there are no 'hard' actual benchmarks (of *the real* spatio-temporal process) against which visibility's propagation visualization in digital terms could be tested, but rather data-driven and cognitive-driven ones, the faithful simulation of *the* process cannot be established. Besides, when utilizing very densely spaced viewpoint, the visualization can be swamped with extreme, unwanted details (patches), and the cognitive capability can be impaired. Therefore, a nexus interlocking: DEM

resolution, viewroute election and viewpoint sampling, and animation coherence and apprehensibility was employed. Experimentation showed that by holding the DEM size and resolution as low and as refined as reasonably possible respectively, for the viewshed animations to be coherent and perceivable the viewpoint sampling density was greatly affected by the topographic nature of the viewroute. Both the Congruence Principle, and the sampling theorem for terrain cross-sectioning delineated the background framework, but the viewshed geovisualization was evaluated based on the cognitive limits that each viewroute imposed; even though the Apprehension Principle provided a pragmatic solution, the innate propensity of dissimilar routes to respond to viewsheds distinctively led this venture far from being ostracized to an anti-realistic heaven.

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