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INTERACTIVE LOCAL AND GLOBAL LANDSCAPE DEFORMATION FOR PANORAMIC MAP CREATION

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Abstract: Panorama painters apply a number of design techniques to improve map legibility when manually creating panoramic maps. One of these techniques consists in intentionally deforming the geometry of the depicted landscape. In this article, methods and software are presented that allow the modern cartographer to interactively deform digital terrain models without needing artistic talent or specialized mathematical knowledge. These methods are inspired by manual techniques of panorama painters. Local terrain deformation can be useful when important map elements are occluded, strongly foreshortened or shown from an undesired side. In this article, interactive local deformation is achieved by applying inverse distance weighting and moving least squares to scale, rotate and move map elements. Global terrain deformation can be applied to combine an unoccluded, almost orthogonal view on the panorama foreground with a three-dimensional terrain appearance in the image background. An interactive surface deformation algorithm is presented that is conceptually based on the progressive projection, a technique applied by panorama painters to achieve global distortion. It is demonstrated how the presented methods can also be applied to straighten curved routes for the creation of panoramic strip format maps.

Keywords: Terrain bending, surface deformation, 3D map design, panoramic strip format map

INTERAKTIVE METHODEN ZUR LOKALEN UND GLOBALEN DEFORMATION VON GELÄNDEGEOMETRIE IM RAHMEN DER PANORAMAKARTENERSTELLUNG

Zusammenfassung: Bei der Herstellung hochwertiger Panoramakarten wenden Panoramamaler spezielle Techniken an, mit denen die Kartenlesbarkeit deutlich verbessert werden kann. Eine dieser Techniken ist die absichtliche Deformation der Landschaftsgeometrie. Der vorliegende Beitrag stellt algorithmische Methoden und Software vor, mit denen Kartografen ohne außerordentliche künstlerische Begabung oder mathematische Vorkenntnisse digitale Geländemodelle nach Art der Panoramamaler interaktiv verzerren können. Lokale Verzerrungsmethoden sind hilfreich, wenn wichtige Kartenelemente in Schrägansicht verdeckt, stark verkürzt oder von einer unvorteilhaften Seite gezeigt werden. Algorithmisch wird die Skalierung, Rotation und Verschiebung von Geländeelementen in diesem Beitrag durch inverse Distanzwichtung und „moving least squares"-Minimierung erreicht. Globale Deformation, inspiriert durch die manuelle progressive Perspektive, wird mittels Oberflächendeformation erzeugt, wobei eine unverstellte Aufsicht auf den Vordergrund mit einer plastischen Darstellung des Hintergrundes verbunden wird. Abschließend wird gezeigt, wie die vorgestellten Methoden auch zur Begradigung von Reiserouten bei der Erstellung von Streifenpanoramakarten Verwendung finden können.

Schlüsselwörter: Geländemodell, Oberflächendeformation, 3D-Karte, Streifenpanoramakarte

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1 LANDSCAPE DEFORMATION IN HAND-PAINTED PANORAMAS

Geometric deformation of terrain for the digital design of panoramic maps has received very little attention from the cartographic community. This contribution aims to fill the resulting research gap by developing digital methods that allow cartographers and GIscientists to redesign the geometry of 2.5D terrain models for the creation of static landscape panoramas. It finds inspiration in the manual deformation techniques of panorama painters, who apply geometric deformation to improve the legibility of important landscape elements as well as to raise the quality of the entire representation.

Panorama painters deliberately apply deformation to landscape geometry when confronted with a number of specific problems. Such challenges occur when creating panoramic maps (also called 3D maps) manually as well as digitally. However, with the exception of Patterson's contributions (2000, 2001), deformation techniques for 3D maps have so far received little attention by cartographic literature and by cartographic research groups.

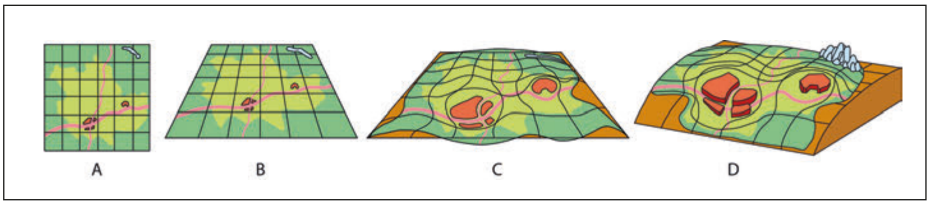

Figure 1: Combination of local deformation and progressive bending in manual panorama creation: landscape in orthogonal view (A), in central perspective projection (B), with local deformations (C), with local deformations and progressive bending (D) (according to Ribas Vilas & Nuñez Guirado 1990, simplified, colors adapted)

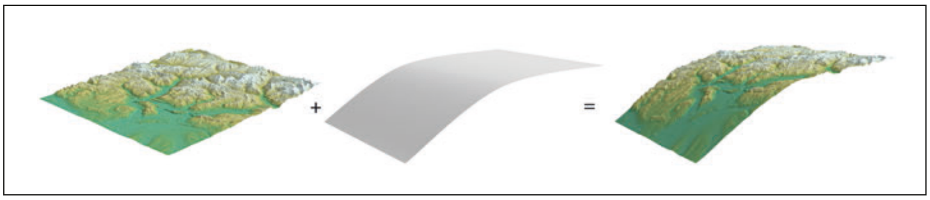

Figure 2: Concept of the global progressive bending method: altitudes in the undeformed elevation model (left) are combined with a bent terrain base (middle) into a bent elevation model (right) (Jenny et al. 2011b)

Panorama painters apply local and global landscape deformation to improve map legibility. When important map elements in oblique view are occluded, strongly foreshortened or presented from an inopportune angle, local scaling, rotation, or translation of landscape elements are applied to mitigate the situation (Patterson 2000, Ribas Vilas & Nuñez Guirado 1990). For example, panorama painters move and reduce occluding mountains, widen valley floors, straighten rivers, enlarge landmarks and level terrain to make essential map elements visible (Patterson 2000). They may also rotate reference landmarks to create a specific mountain silhouette or guide the observer's attention by enlarging an important mountain in a range of equally high mountaintops.

In contrast to local deformation, global deformation is applied to the entire landscape to improve overall map readability. Panorama painters sometimes use a specialized global deformation called progressive bending or progressive projection. The landscape is depicted from a steep viewing angle in the foreground, fading into a flat viewing angle towards the background. The background thus appears three-dimensional with a real horizon (Hake et al. 2002) while the foreground is shown almost orthogonally from above, which minimizes occlusion. Figure 1 shows local deformation and its combination with global surface bending.

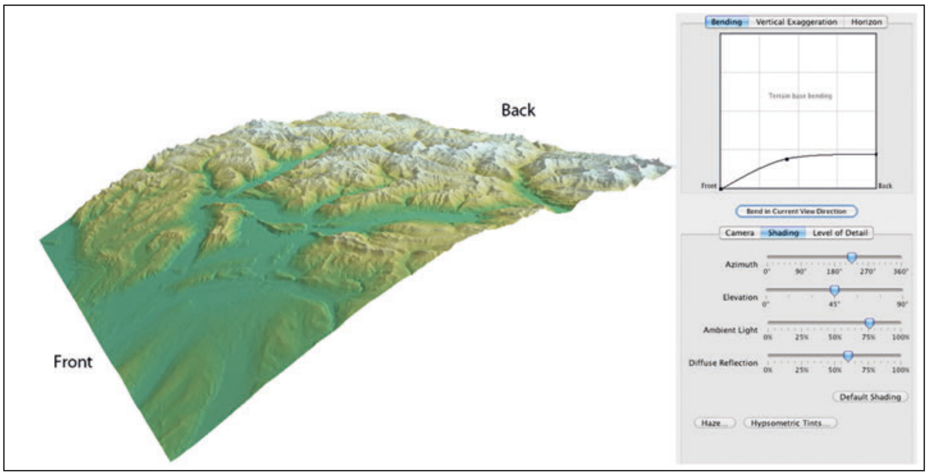

Figure 3: User interface of the Terrain Bender Sofware: preview of the terrain with global progressive bending (left), interactive curve graph for selecting a deformation profile (right) (Jenny et al. 2011b)

Selected aspects of terrain distortion have received the attention of computer graphics research (Falk et al. 2007, Degener 2011, Degener & Klein 2009). See Jenny et al. (2010) for a detailed review and classification of global surface distortion methods. Yet, a user-friendly deformation method tailored to terrain data models and exchange formats used in cartography and GIScience had hitherto not been available. This contribution identifies deformation concepts in hand-painted panoramas, formalizes these concepts as computer algorithms and explores their suitability to other cartographic representations. The resulting methods have been made publicly available as a user-friendly software package.

2 COMPUTATIONAL METHODS FOR LOCAL AND GLOBAL LANDSCAPE DEFORMATION

2.1 PROGRESSIVE BENDING USING SURFACE DEFORMATION

The developed deformation methods are geared at geo-referenced, regular 2.5D terrain models, which are common data structures in cartography and GIScience. They can be easily combined with other raster datasets. To globally deform the terrain, the elevation values in the raster cells are manipulated. The algorithm creates a terrain base that the user can shape interactively by manipulating a curve graph representing the base profile (Figure 2).

The left end (Figure 3, labeled Front) of the curve controls the deformation applied to the altitudes of the grid cell closest to the viewer; the right end (Figure 3, labeled Back) steers the elevation deformation of the grid cell farthest away from the viewer. By clicking on the curve to add points and dragging them, the user can create a deformation profile. The altitudes of the original terrain model and of the deformed base are summed up. Combined, they form the deformed elevation model. The grid cell positions in the horizontal plane remain unchanged and the model's regular structure is unaffected, allowing for texturing of the deformed model.

Vertical background and foreground scaling can also be added. The scaling fades off progressively towards the opposite model end. Vertical scaling is also a technique often used by panorama painters, e.g. to let background mountain ranges appear more impressive or to make a mountainous relief better discernable on small-scale maps. The user can also curve the background of the terrain to form a curved horizon. This can be imagined as gripping the background corners of the terrain and pulling them downwards while the middle of the background is held in place, so that left, middle and right form an arc perpendicular to the viewing direction. The bending also fades out towards the foreground. See Jenny et al. (2010) for further detail on computing progressive global and vertical deformation and bending of the horizon.

2.2 LOCAL DEFORMATION USING MOVING LEAST SQUARES MINIMIZATION AND INVERSE DISTANCE WEIGHTING

By locally deforming elements of the landscape, the user is able to avoid occlusion and to emphasize important map elements. To apply local deformation, the user can add control points in the area of interest by clicking directly on the elevation model sur-

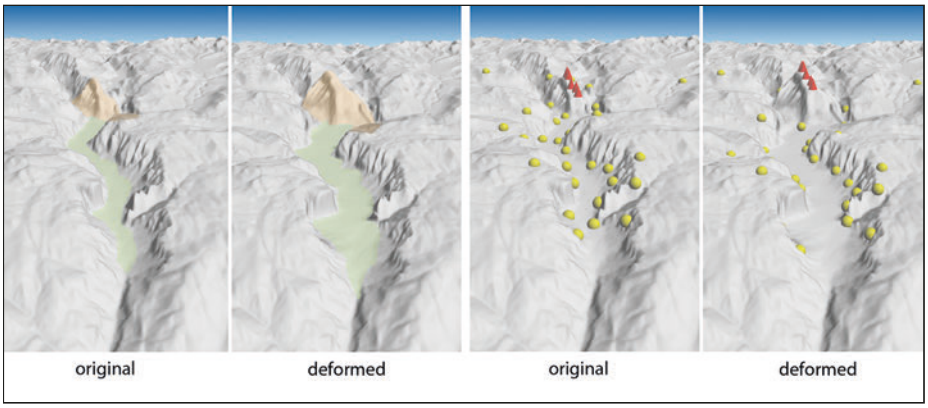

Figure 4: Examples of local deformations achieved with the method in the Yosemite Valley. Left pair: vertical scaling of Half Dome (orange), widening of a valley (green) and leveling of terrain (brown); right pair: control point location before and after deformation (based on USGS DEM) (Jenny et al. 2011c).

Figure 5: Jungfraubahn, hand-painted panorama (H. C. Berann 1947)

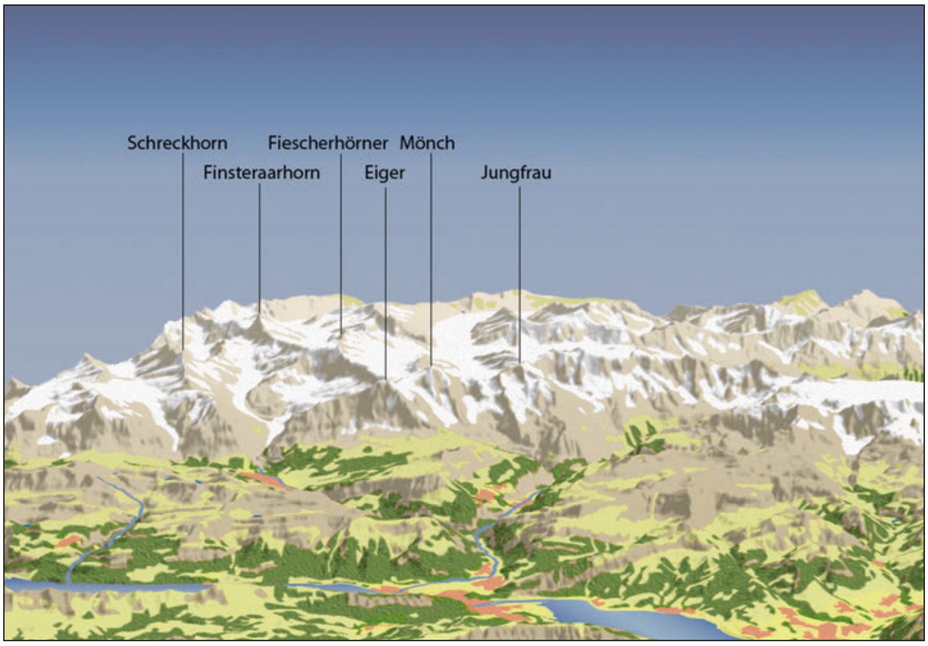

Figure 6: Rendered terrain model, Jungfrau region (Jenny et al. 2011c), based on SWISSTOPO dataset

face preview (Figure 4). The control points can then be dragged to new positions. At the control point positions, the deformed terrain assumes the location of the dragged points; the rest of the model is smoothly interpolated. Control points, which are not moved, act as counterweights to the deformation and keep the region in place. Local deformation can be applied in vertical (altitude) as well as in horizontal direction. The closer a landscape region is to the summed influence of the control points, the stronger it is deformed. Far-away landscape regions are barely influenced and transition zones between deformed and mostly undeformed areas look smooth.

To compute a horizontal displacement vector for each grid cell in the 2.5D terrain model, a moving least squares minimization approach is extended based on Schaefer et al. (2006). The algorithm solves for the optimal warping function for all elevation model points that minimizes the weighted sum of squared distances between the control points' mapped and dragged positions. As the weights depend on the distance between control point and elevation grid point, the mapping function is different at every grid point and small distances have larger impact. For deformation in the vertical direction (altitudes), inverse distance interpolation (Shepard 1968) is applied. For deformation in the horizontal plane, the moving least squares approach was visually compared to inverse distance weighting (Jenny at al. 2011c). In the 3D map test series, the visually detectable differences were negligible in oblique view (panoramic view), while in orthogonal view (2D map view) strong, unintended deformations resulted when applying an inverse distance interpolation approach.

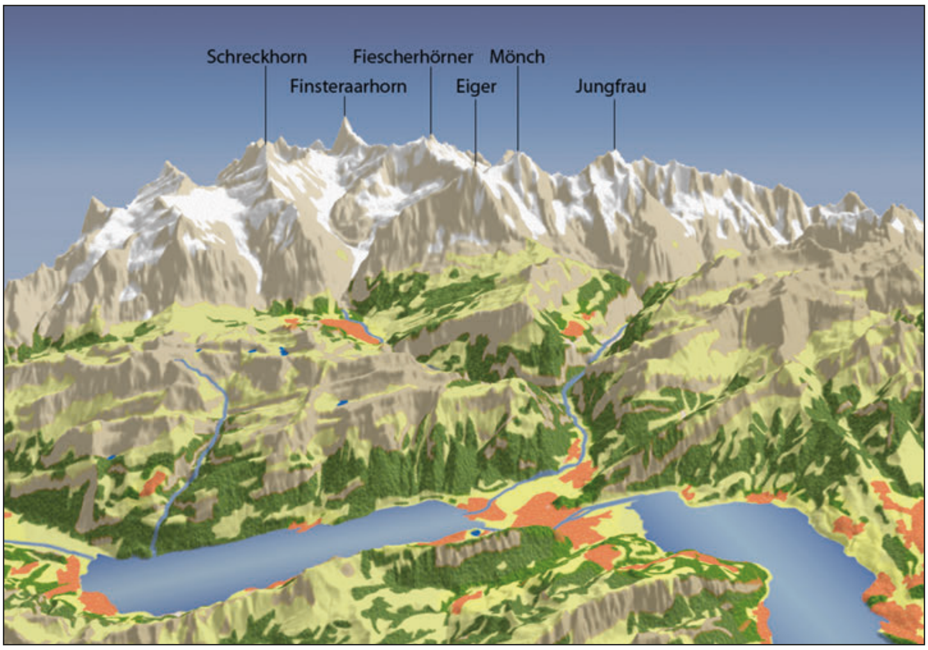

Figure 7: Progressive bending and vertical exaggeration applied terrain model and rendered in oblique view (Jenny et al. 2011c)

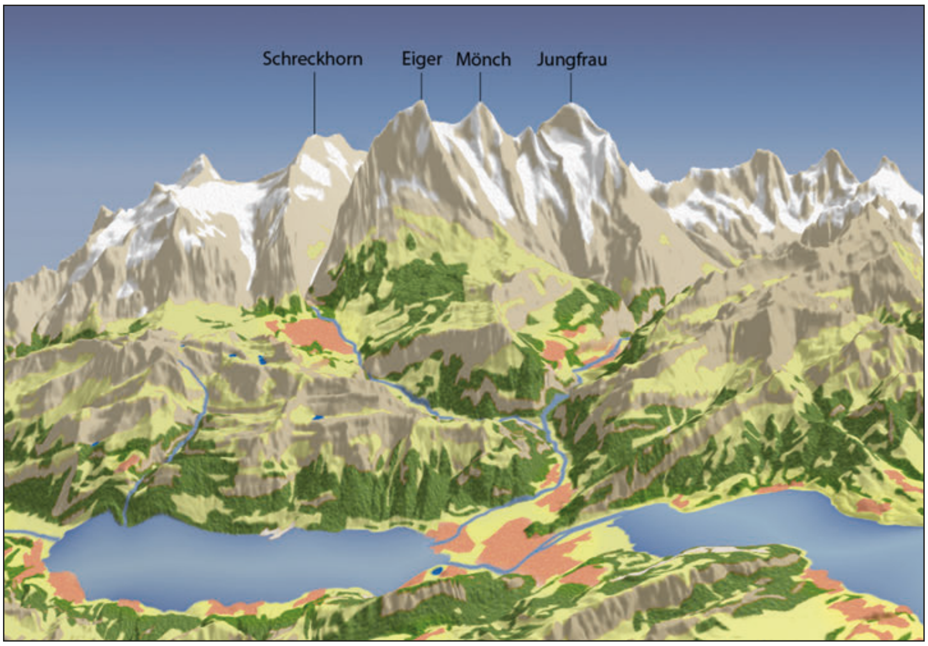

Figure 8: Local deformation, progressive bending and vertical exaggeration applied to terrain model and rendered in oblique view (Jenny et al. 2011c)

2.3 DEFORMED PANORAMIC MAP SERIES

To demonstrate the developed terrain deformation methods, two deformed 3D map series were created with digital means. Each series shows the global and local deformation steps necessary to imitate a hand-painted (Figures 5 and 9) landscape using a digital elevation model. When comparing Figures 6 and 7, observe that vertical exaggeration and progressive bending improve three-dimensional appearance of the mountain ranges in the background. More image space is available to the lakes in the image foreground. Through local deformation (Figure 8), the valley bottoms of the river in the center of the image as well as the river Aare connecting the two lakes are less occluded; the lakes are slightly rotated so that their longest side is aligned parallel to the bottom panorama border, an aesthetic consideration; the three very popular mountain tops (Eiger, Moench and Jungfrau) are exaggerated in size and dominate clearly the background mountain range, where some mountain tops deemed less important are now no longer visible.

In the next series, the Tetons in Yellowstone National Park (see mountain range in background of yellow rectangle on Figure 9) are painted from an angle that does not reflect reality. The painter possibly intended to add a more aesthetic silhouette to the panorama showing well-known mountaintops that would otherwise not be visible. Figure 10 shows a digital elevation model of the area rendered from a similar viewing position. Figure 11 shows a rendering after applying vertical exaggeration and progressive bending to the model. More image space is provided to the lake in the image foreground due to progressive bending. After rotating the Tetons by about 50° using the local deformation method (see insert in lower right corner of Figure 12), the silhouette of the Tetons in Figure 12 is similar to the one shown on the hand-painted panorama.

3 FURTHER APPLICATION: PANORAMIC STRIP FORMAT MAPS

The local deformation algorithm is also useful when creating digital panoramic strip format maps. These maps show panoramic

Figure 9: *Greater Yellowstone National Park, hand-painted panorama (H. C. Berann)*

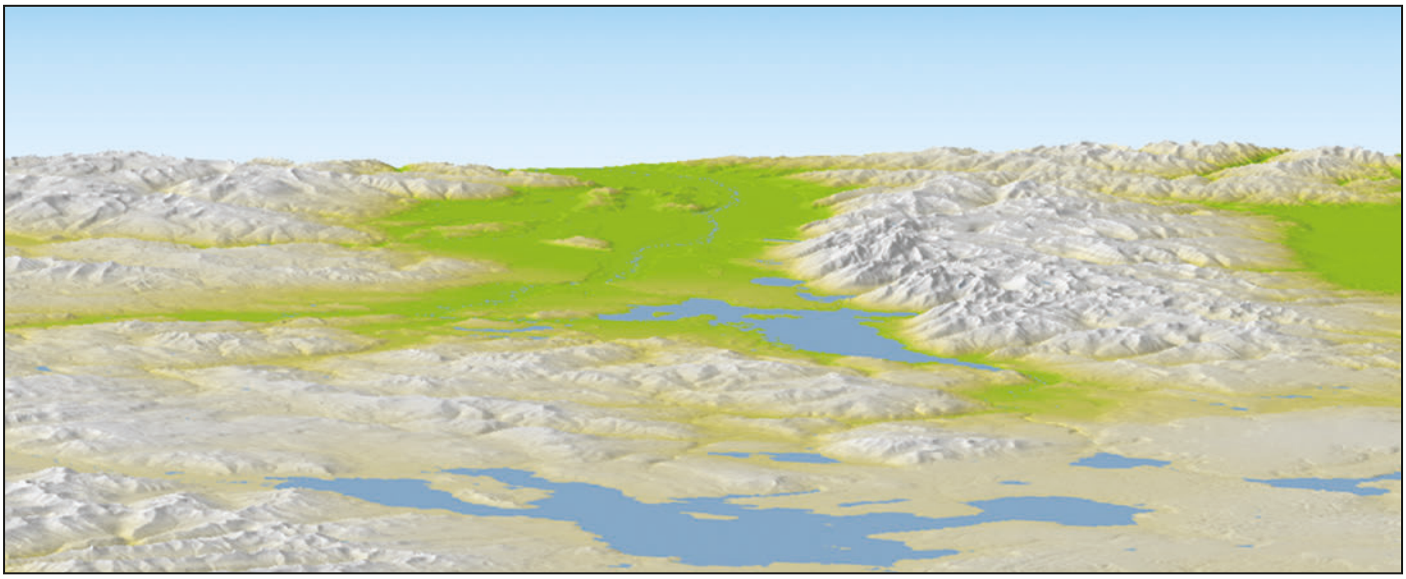

Figure 10: *Rendering of a digital elevation model of the Yellowstone region in oblique view (Jenny et al. 2011b)*

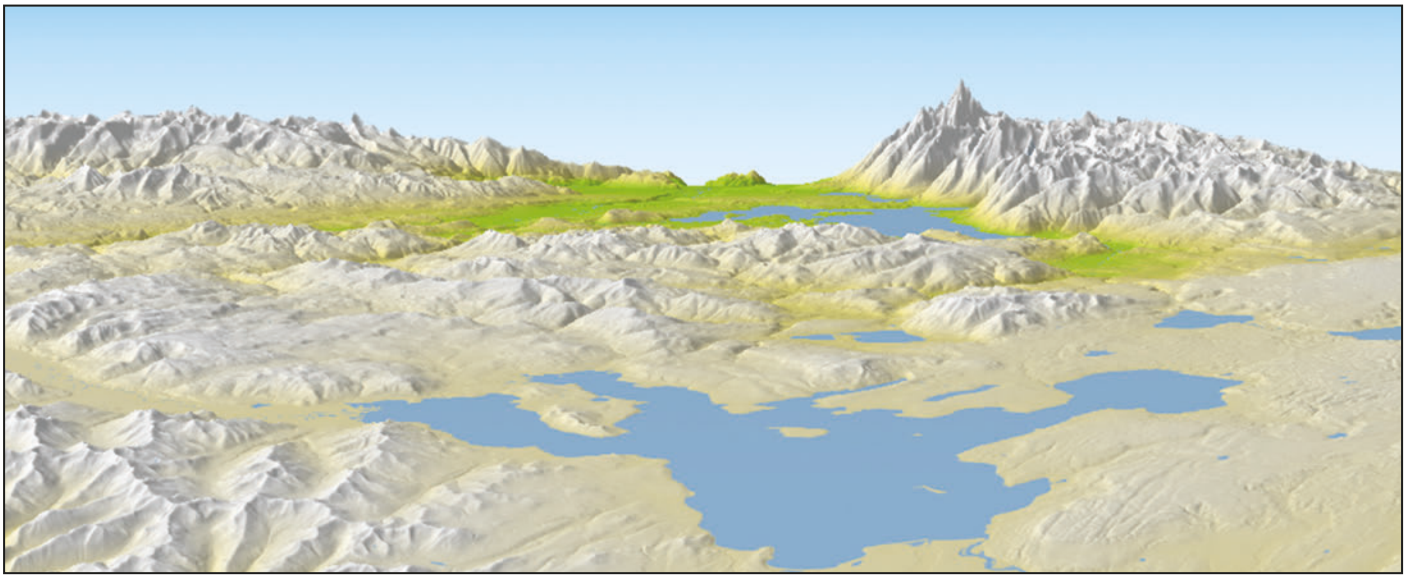

Figure 11: *Progressive bending and exaggeration applied to the digital elevation model rendered in oblique view (Jenny et al. 2011b)*

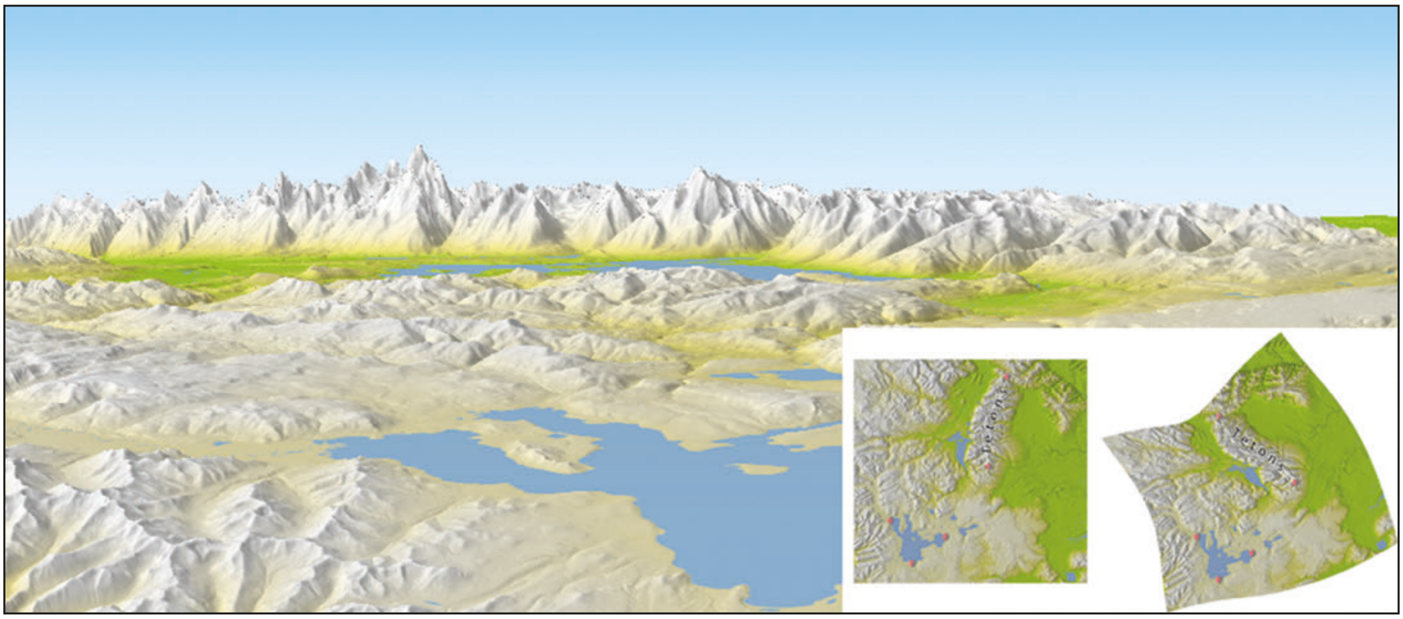

Figure 12: Local deformation applied to digital elevation model in addition to vertical exaggeration and progressive bending (Jenny et al. 2011b). The insert in the lower right corner shows the rotation of the Tetons in the horizontal plane; the topmost control point is dragged to the left to rotate the mountain range while the other control points serve as counter weights to preserve lake shape and location of bottom tip of the Tetons.

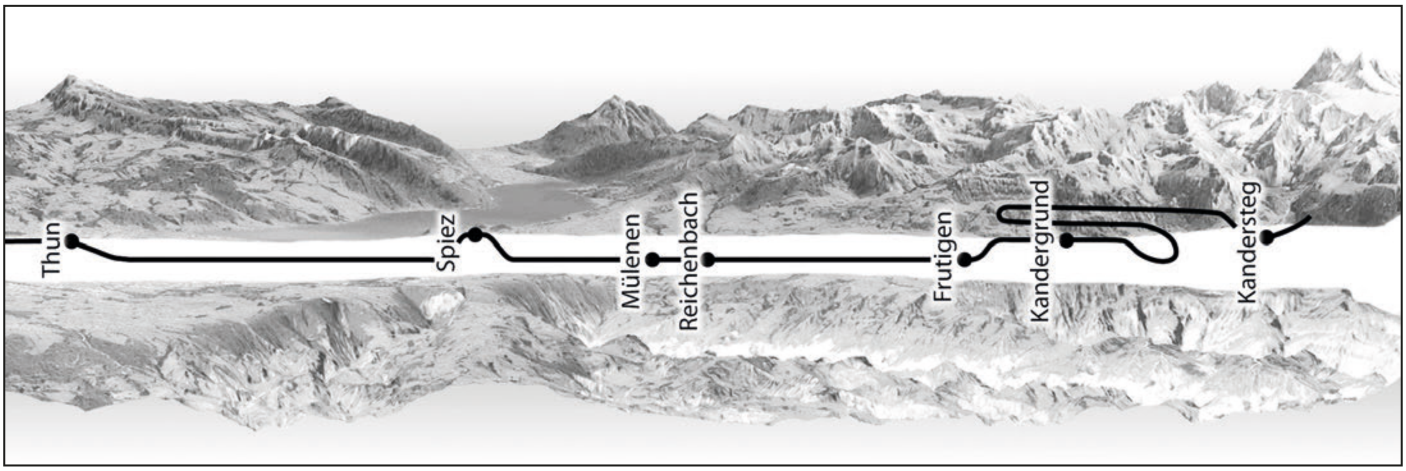

Figure 13: Example of a digital panoramic strip map where the route was straightened in the horizontal plane with the local deformation method (Jenny et al. 2011a)

depictions of the landscape along a linear path. As the route on the terrain may be curved, the local deformation method can be applied to interactively straighten the terrain model along the route before rendering panoramic views (Figure 13). For a detailed description of panoramic strip format maps and their digital creation with pseudo code see Jenny et al. (2011a).

4 CONCLUSION

The overall goal of developing surface deformation methods for 2.5D terrain models was to enable cartographers to design better legible and aesthetically appealing topographic 3D maps with digital means. Painters of panoramic maps remodel the geometry of the displayed landscape, where appropriate, to improve map communication. Such techniques are also needed for digital 3D map making. Inspired by the deformation concepts of panorama painters, the local and global deformation methods described in this contribution enable cartographers and the general public to apply such concepts to digital terrain without the need for artistic talent or deeper mathematical understanding.

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