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Projection Wizard – An Online Map Projection Selection Tool

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The selection of map projections is difficult and confusing for many. This article introduces Projection Wizard, an online map projection selection tool available at projectionwizard.org that helps mapmakers select projections. The user selects the desired distortion property, and the area to be mapped on an interactive web map. Projection Wizard then proposes a projection, along with projection parameters (such as standard parallels). The tool also creates a preview map with the proposed projection, and provides the corresponding projection code in PROJ.4 format, if applicable. The automated selection process is based on John P. Snyder's selection guideline with a few adjustments. This article discusses the automated selection process, and the map projections suggested. Projection Wizard solves the problem of map projection selection for many applications and helps cartographers and GIS users choose appropriate map projections.

Keywords: Projection Wizard; map projection selection

THE MAP PROJECTION SELECTION PROBLEM

A common goal when selecting a map projection is to find a projection and projection parameters that minimize distortion of the mapped area. To meet this objective, a map projection has to satisfy the requirements set by the particular purpose of a map (Bugayevskiy and Snyder, 1995). The criteria for selecting a projection include the location of the mapped area, the directional extent of the mapped area, and the required distortion property. In some cases, especially when designing small-scale maps, cartographers are left with a number of projections that meet these requirements.

There is a plethora of map projections available for cartographers to choose from, and applying the selection criteria is a difficult task (De Genst and Canters, 1996; Finn et al., 2004; Slocum et al., 2009; Snyder, 1993). GIS and mapping software enable less experienced mapmakers to create maps, but the selection criteria for map projections are a mystery to many (De Genst and Canters, 1996; Finn et al., 2004, in press). Often, mapmakers use default projections, e.g., the Plate Carrée, which is commonly used for distributing geospatial data, or the Mercator projection when creating web maps (Battersby et al., 2014). This paper introduces *Projection Wizard*, an online map projection selection tool that is available for free at *projectionwizard.org*. The goal of *Projection Wizard* is to help mapmakers select appropriate map projections and thus create better maps.

SNYDER'S SELECTION GUIDELINE

John P. Snyder (1987) has so far provided the most systematic selection guideline (Nyerges and Jankowski, 1989, Slocum et al., 2009, Jenny, 2012). Snyder suggests a hierarchical selection tree organized according to the extent of the region that is mapped. The tree consists of three top-level groups for maps showing (1) the entire world, (2) a hemisphere, and (3) a region the size of a continent or ocean, or a smaller region.

In the next level of the selection tree, Snyder (1987) subdivides projections for maps showing the entire world according to their distortion characteristics: conformal, equal-area, equidistant, straight rhumb lines, and compromise distortion. For maps of a hemisphere, he distinguishes between conformal, equal-area, equidistant and orthographic projections. Projections for maps showing a continent, an ocean, or a smaller region are subdivided according to the predominant extent of the map (east-west, north-south, oblique, equal extent), the location of the mapped area (along the equator or away from the equator, polar, equatorial or oblique) and the distortion characteristics (conformal or equal-area).

While Snyder's selection guideline leads the cartographer through a hierarchical list to the appropriate projection for medium-scale or large-scale maps, Snyder leaves the cartographer considerable freedom for selecting projections for world maps. Jenny et al. (in print) extend Snyder's guideline for world map projections with commonly used projections,

such as the Winkel Triple, Plate Carrée and Wagner IV, V, and VII projections. They also include the Natural Earth (Šavrič et al., 2011) and Patterson (Patterson et al., 2014) projections, two recently developed compromise projections. They exclude conformal projections from the list of world map projections due to their enormous areal distortion, and subdivide the group of projections for maps showing the entire world according to projection distortion characteristics (equal-area, compromise distortion, interrupted equal-area graticule, and equidistant property) and the representation of poles (poles as points or as lines).

PREVIOUSLY DEVELOPED PROJECTION SELECTION TOOLS

The hierarchy in Snyder's selection guideline can be converted to a decision tree for an interactive decision support system, which has been done by several authors in the past. One of the first was the Map Projection Knowledge-Based System (MaPKBS), a prototype expert system for map projection selection introduced by Jankowski and Nyerges (1989) and Nyerges and Jankowski (1989). MaPKBS recommended a map projection based on the geographic area, function of the map, geometric properties, and extent. An interesting functionality of MaPKBS was that it was able to recommend pre-defined map projection parameters for selected geographic areas. For example, the system suggested the Albers or Lambert conic map projection with commonly used standard parallels for the contiguous United States. The disadvantage of MaPKBS was that it did not always return the best projection because users could not always answer all of the questions about specifying projection characteristics unambiguously (De Genst and Canters, 1996). Additionally, MaPKBS did not include all of the selection criteria, and it was limited to equal-area and conformal projections (Canters, 2002).

In the same year, Smith and Snyder (1989) presented the Expert Map Projection Selection System (EMPSS). The users of their system had to answer 10–24 questions about the purpose of the map. The system then proposed a projection with the minimum distortion out of 50 map projections included in the system (Smith and Snyder, 1989). Smith and Snyder (1989) did not discuss the algorithmic details of the system (Canters, 2002).

Another attempt was Kessler's Map Projection Selection System (MaPSS), which returned a list of projections ranked by their suitability (Kessler, 1991). The selection was based on the map type, size of the geographic area, directional extent, centre of the map, and the shape of the graticule. Users could also weight selection criteria to emphasize specific requirements. Kessler's system included 46 projections (Kessler, 1991).

Mekenkamp (1990) presented the Integrated Projection Design System (IPDS). He constrained the selection to only 11 map projections (Canters, 2002; De Genst and Canters, 1996). He based the selection on the purpose of the map and the shape of the mapped region. Mekenkamp's tool defined the regions as a one-point, two-point, and three-point area, and suggested azimuthal, cylindrical, and conic projections.

Unlike the systems described above, De Genst and Canters (1996) introduced a system with tools for minimizing the distortion of a map. They followed Snyder's selection guideline, and the user could adjust the projection parameters or optimize the distortion with a polynomial transformation (Canters, 2002; De Genst and Canters, 1996).

Eldrandaly (2006) and Zhao et al. (2007) each suggested prototype software that would work as a plugin application with Esri's ArcGIS 9 software. Their systems suggested projections based on the map's purpose, and the location, shape, and extent of the area to be mapped.

The Decision Support System for Map Projections of Small Scale Data (DSS), developed by the United States Geological Survey for the selection of small-scale projections (Finn et al., 2004, in press), is the most recent expert system for selecting map projections (http://mcmcweb.er.usgs.gov/DSS/). The system is based on three regions (global, continental, and regional), the desired distortion characteristic, the geographic location, and the directional extent. The system suggests equal-area or conformal projections for medium-scale and large-scale maps, and includes compromise projections for world maps. It is a Java web applet, which is a technology that modern web browsers no longer support by default.

Snyder (1993) and Canters (2002) point out that MaPKBS, EMPSS, and MaPSS were three projects that were abandoned after the first research stage. The DSS is the only system that is currently functional and available online. Most of the systems described in this review require users to answer a series of specific questions that seem difficult for inexperienced users to answer correctly. Mekenkamp's (1990) idea of simplifying the selection process by asking the user only for the extent of the mapped area and the map purpose simplifies the selection process, especially for less experienced users. *Projection Wizard*, the map projection selection tool presented in this article, was developed using a similar approach.

PROJECTION WIZARD USER INTERFACE AND FUNCTIONALITY

Projection Wizard (Figure 1) is a web application (available at *projectionwizard.org*) that helps cartographers and GIS users select an appropriate projection for their map. Depending on the geographic extent and the distortion property selected for the map, the application returns a list of map projections. Projection parameters are given when available. *Projection Wizard* is based on Snyder's selection guideline (Snyder, 1987) and on the extension of this guideline for world and hemisphere maps presented by Jenny et al. (in press). Thirty map projections are currently included which are suggested by Snyder (1987) and Jenny et al. (in print) (Table 1).

Projection Wizard's interface consists of four parts: a user control panel, a web map, a list with proposed map projections, and a preview map (Figure 1). The user selects the desired distortion property of the map from four options: equal-area, equidistant, conformal, and compromise. Not all distortion properties are available for all map extents. Compromise projections are only available for world maps, and conformal projections are only proposed for large-scale maps.
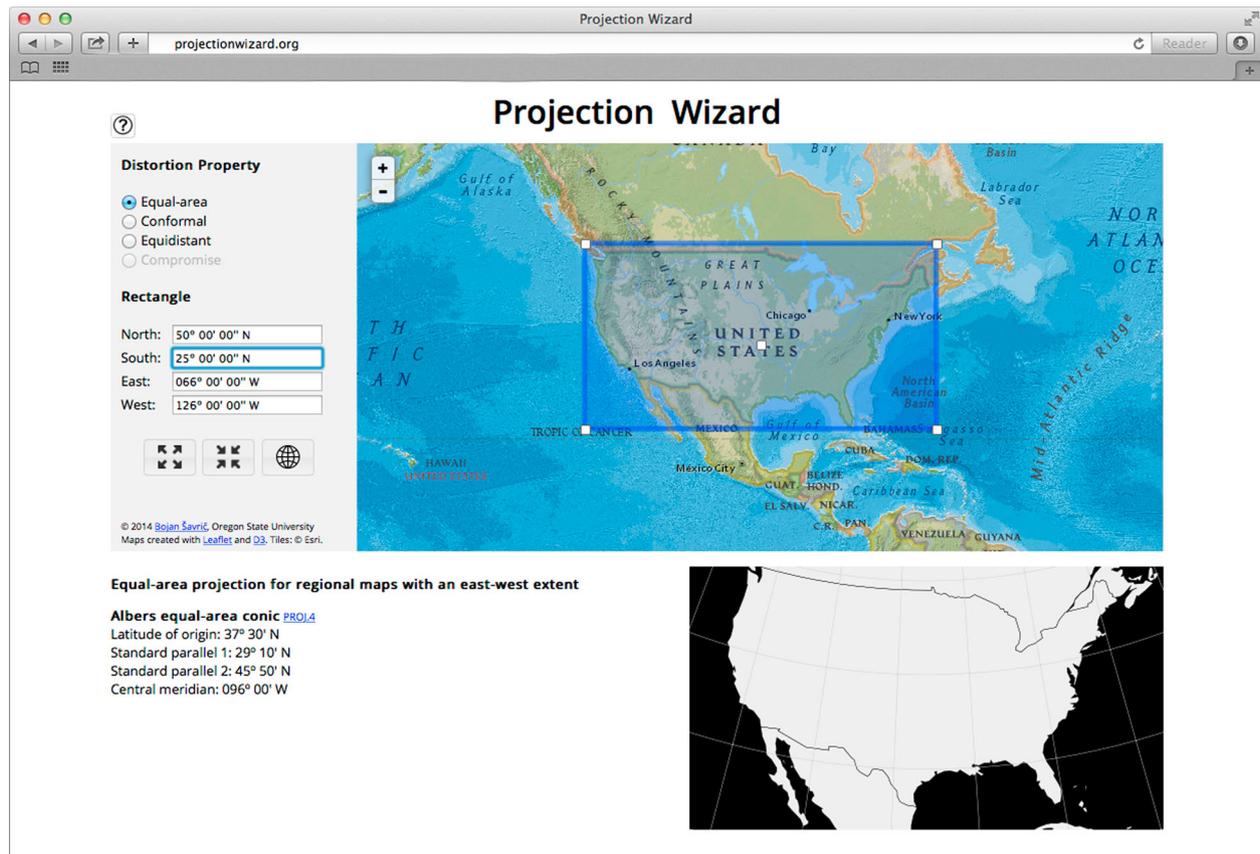
Figure 1.   *Projection Wizard* interface: a control panel (top left), a web map for selecting the mapped extent (top right), a list with proposed projections (bottom left), and a preview map (bottom right).

The web map in the upper area of the interface contains an interactive rectangle that allows the user to select the area to map by moving the corner handlers. The rectangle can also be repositioned to another area. Alternatively, the user can enter the geographic coordinates of the north, south, east, and west borders of the rectangle in the text fields on the left side of the web map. The map with the interactive rectangle uses the web Mercator projection, which does not display poles. To select a polar area, the user drags the rectangle towards the north or south end of the map, and *Projection Wizard* returns a map projection that is appropriate for polar regions. A better projection for the interactive map would be the Plate Carrée projection, as it displays the poles. However, we were unable to find a freely available, detailed, pre-existing web map in the Plate Carrée projection with multiple zoom levels.

Projection Wizard lists proposed projections and their parameters for the mapped area in the lower left corner. If available, PROJ.4 projection codes (Evenden, 2008) are provided next to each proposed projection. PROJ.4 codes are compatible with some web mapping and GIS software packages. *Projection Wizard* also displays a map preview with the suggested projection. Any changes to the rectangle or distortion property update the list of proposed map projections and the map preview.

Projection Wizard was built with Leaflet, an open-source JavaScript library for web mapping (leafletjs.com), using web map tiles from Esri's National Geographic World Map

(http://services.arcgisonline.com/ArcGIS/rest/services/Nat-Geo_World_Map/MapServer). The preview map is rendered with D3.js, a JavaScript library for producing data visualizations in web browsers (Bostock et al., 2011).

MAP PROJECTION SELECTION

The only required user inputs are the distortion property and the area to be mapped, which is marked with the interactive rectangle or entered in the text fields. *Projection Wizard* proposes map projections based on the distortion property and three selection parameters derived from the selected geographic area. The derived selection parameters are the extent of the geographic area, its central latitude and longitude, and its height-to-width ratio.

When the rectangle covers at least two-thirds of the sphere, *Projection Wizard* proposes world map projections. When the rectangle covers between one-sixth and two-thirds of the sphere, azimuthal projections appropriate for hemisphere maps are returned. For smaller geographic extents, cylindrical, conic, or azimuthal projections are suggested. Table 1 lists the thirty projections included in *Projection Wizard*.

Projections for world maps

Depending on the desired distortion properties, *Projection Wizard* suggests equal-area, equidistant, and compromise

Table 1. The thirty projections included in Projection Wizard.

Extent	Distortion Property	Projection
World	Equal-area	Mollweide
		Hammer (or Hammer-Aitoff)
		Boggs Eumorphic
		Sinusoidal
		Eckert IV
		Wagner IV (or Putnins P2')
		Wagner VII (or Hammer-Wagner)
		McBryde-Thomas flat-polar quartic
		Eckert VI
		Goode homolosine
		McBryde S3
	Compromise	Natural Earth
		Winkel Tripel
		Robinson
		Wagner V
		Patterson (cylindrical)
		Plate Carrée (cylindrical)[1]
		Miller cylindrical I
	Equidistant	Azimuthal equidistant[2]
		Two-point equidistant
Hemisphere	Equal-area	Lambert azimuthal equal-area
	Equidistant	Azimuthal equidistant[2]
Continent, ocean, or smaller area	Equal-area	Lambert azimuthal equal-area
		Albers conic
		Cylindrical equal-area
		Transverse cylindrical equal-area
	Conformal	Stereographic
		Lambert conformal conic
		Mercator
		Transverse Mercator
	Equidistant	Azimuthal equidistant[2]
		Plate Carrée[1]
		Equidistant conic

Notes: [1]The Plate Carrée projection is suggested twice, for world maps with compromise distortion and for continents, oceans or smaller areas with equidistant distortion property.
[2]The azimuthal equidistant projection is suggested for all three extents.

world map projections. Conformal projections, such as the Mercator projection, are not available in *Projection Wizard* for world maps, because they grossly distort the areas away from the map centre.

The list of suggested equal-area projections includes projections that represent poles as points (Mollweide, Hammer, Boggs Eumorphic, and sinusoidal) and lines (Eckert IV, Wagner IV, Wagner VII, McBryde-Thomas flat-polar quartic, and Eckert VI). *Projection Wizard* also includes equal-area projections that are commonly interrupted, despite the fact that map-readers clearly prefer projections without interruptions (Šavrič et al., 2015).

For world maps with compromise distortion properties, *Projection Wizard* suggests pseudocylindrical (Natural Earth (Šavrič et al., 2011), Winkel Triple, Robinson, and Wagner V projections) and cylindrical (Patterson (Patterson et al., 2014), Plate Carrée, and Miller cylindrical I) projections.

Projection Wizard suggests multiple equal-area or compromise projections for world maps. The projections are ordered by mean scale distortion, from least to greatest, using the weighted mean error in the overall scale distortion index (Canters, 2002).

At small scales, three map projections with equidistant distortion are suggested by *Projection Wizard*: the azimuthal equidistant (centred on a pole), the oblique azimuthal equidistant (centred on an arbitrary point), and the two-point equidistant (relative to two arbitrary points).

Projections for maps showing a hemisphere

For maps showing a hemisphere, *Projection Wizard* suggests the Lambert azimuthal equal-area projection and the azimuthal equidistant projection. Both projections are centred on the central point of the rectangle on the web map, which results in azimuthal projections with various aspects. Snyder's (1987) guideline also includes the conformal azimuthal stereographic projection for hemisphere maps. Since this projection grossly distorts shapes and areas along the border of the projected hemisphere, it is not included in *Projection Wizard*.

Projections for maps showing a continent or smaller area

For maps showing continents or smaller areas, Snyder (1987) suggests cylindrical, conic, or azimuthal projections. The classification of projections according to developable surfaces (cylinder, cone, and plane) is useful for the

Figure 2. The three developable projection surfaces cylinder, cone, and plane. (Only half of the cylinder and cone are shown.)

Figure 3. Square format maps use the Lambert azimuthal equal-area or the conformal stereographic projection for polar, oblique, and equatorial aspects (from left to right).

comprehension of selecting projections and their parameters (Figure 2). However, while developable surfaces are a useful conceptual tool, it needs to be emphasized that most map projections cannot be constructed geometrically, but are instead defined mathematically.

The selection of a developable surface depends primarily on the orientation and location of the area shown on the map. Cylindrical and conic developable surfaces touch the sphere along a line of tangency, whereas the plane of an azimuthal projection meets the sphere at a point of tangency (Figure 2). Distortion can be reduced by using secant developable surfaces, where the developable surfaces intersect the sphere (Figure 4). Distortion is minimized by selecting and orienting a developable surface such that the line (or lines) of secancy centres on, or aligns with, the directional extent of the mapped area. *Projection Wizard* recommends projections and suggests appropriate standard parallels for some projections to minimize distortion.

Snyder (1987) distinguishes between four possible cases of map orientation for maps showing a continent or smaller area: (1) an east–west extent, resulting in a landscape-format map; (2) a north–south extent, resulting in a portrait-format map; (3) an equal extent, resulting in a square-format map; and (4) an oblique orientation of the mapped area. When the
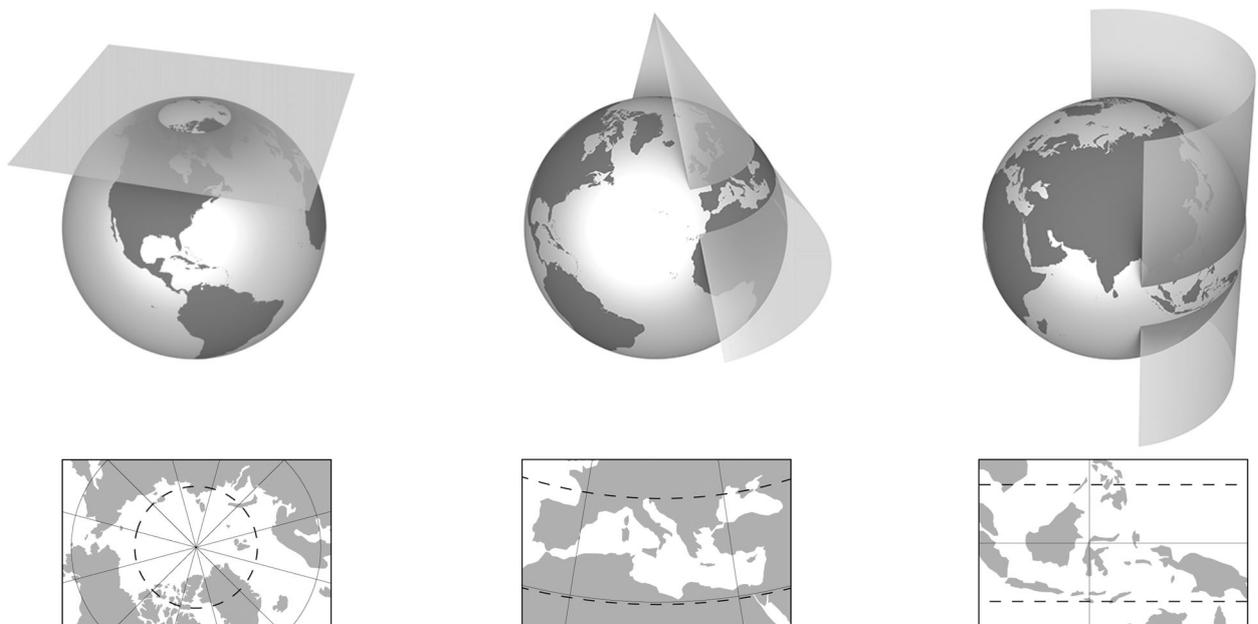

Figure 4. Maps with an east–west extent use the azimuthal projections for poles, conic projections for intermediate latitudes, and cylindrical projections for equatorial areas.
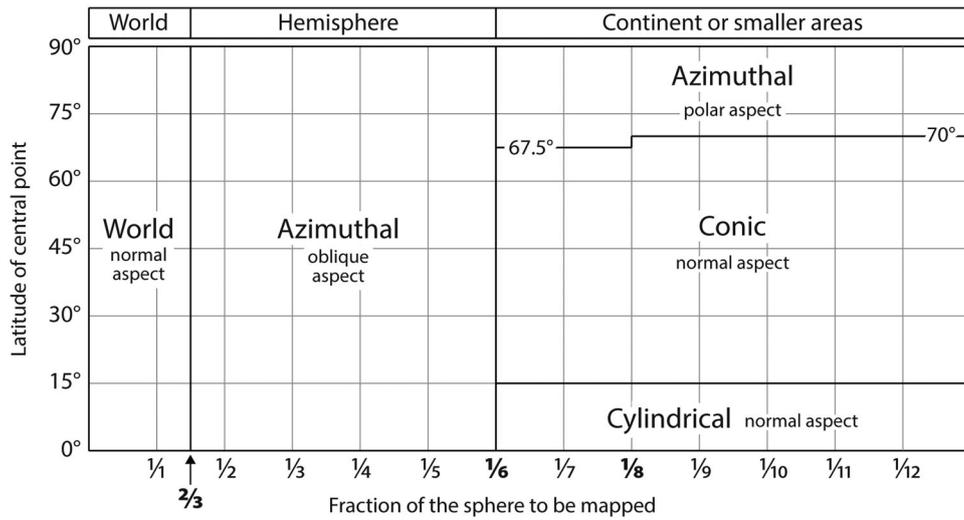
Figure 5.   Projection classes and aspects for maps with an east–west extent. The vertical axis represents the central latitude of the mapped area; the horizontal axis displays the portion of the spherical surface to be mapped.

height-to-width ratio is less than 0.8, *Projection Wizard* suggests projections for landscape-format maps; for ratios larger than 1.25, suggested projections are for portrait-format maps; for all other height-to-width ratios, projections for square-format maps are suggested. *Projection Wizard* does not currently support maps with an oblique orientation.

Regional maps in square format

Snyder (1987) recommends azimuthal projections for maps showing areas of approximately equal extent in all directions (Figure 3). The conceptual projecting surface of azimuthal

projections is a plane touching or intersecting the sphere. Due to this geometric arrangement, the distortion pattern is circular around the central point. This circular arrangement aligns well with regions having no predominant length in one direction.

Projection Wizard recommends the Lambert azimuthal projection for equal-area maps, and the stereographic projection for conformal large-scale maps. Both projections can be used with different aspects (Figure 3). When the centre of the map is close to the equator (between 15°N and 15°S), an equatorial aspect is suggested because the equatorial aspect shows the equator as a straight line. When the centre of the
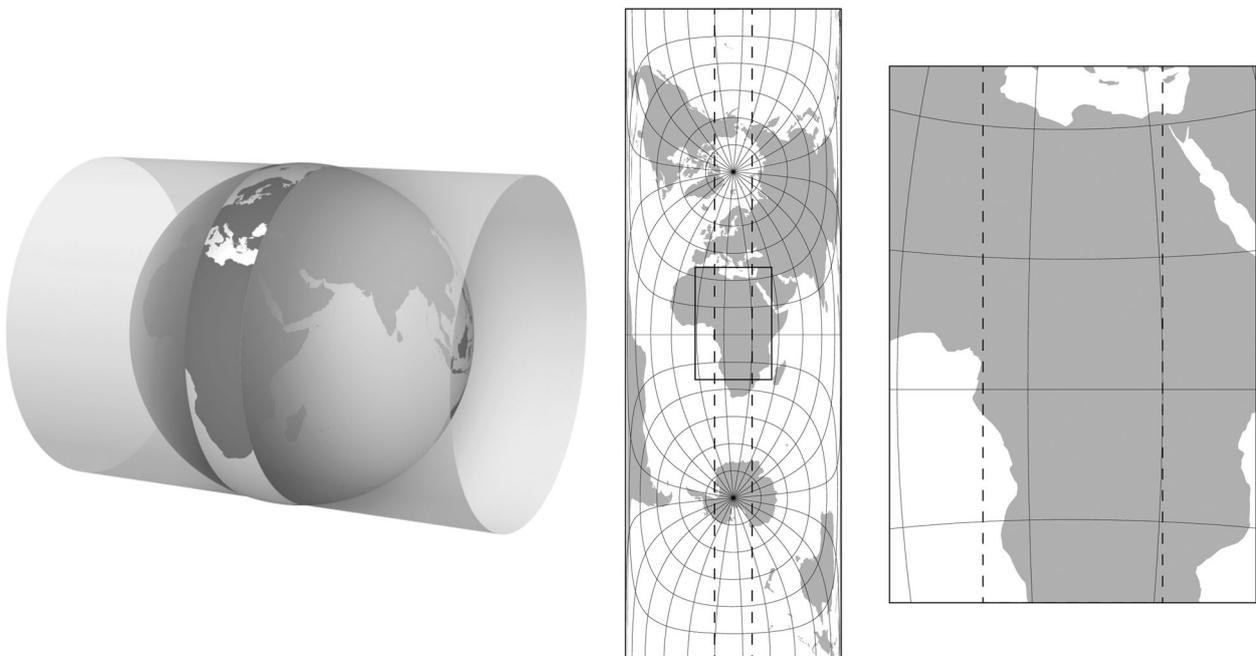

Figure 6.   Maps with a north–south extent use the transverse cylindrical equal-area projection or the transverse Mercator projection. The figure on the right is the map for the rectangle selected by the user.

map is close to a pole (beyond 75°N or 75°S), a polar aspect is suggested, which shows parallels as concentric circles and meridians as straight lines radiating outward from the pole. For maps of areas in-between polar and equatorial latitudes, an oblique aspect is suggested; the projections are centred on the central latitude of the rectangle.

Regional maps with an east–west extent

Projection Wizard recommends cylindrical, conic, or azimuthal projections for maps with an east–west extent (Figure 4). The selection of the developable surface depends on the range of latitude covered by the map. For areas close to the equator (between 15°N and 15°S), either the cylindrical equal-area or conformal Mercator projection is used, depending on whether area or angular distortion is to be avoided. Since the main axis of the mapped area has an east–west orientation, a normal-aspect cylindrical projection is used (Figure 4, right).

For areas at intermediate latitudes, the equal-area Albers conic or the Lambert conformal conic projection are suggested. Conic projections show meridians as straight, radiating lines and parallels as concentric arcs. The cone is oriented upward in order to align the standard parallels with the east–west extent of the map (Figure 4, centre). *Projection Wizard* suggests conic projections with two standard parallels and places the standard parallels at a distance of one-sixth the height (in spherical coordinates) from the upper and lower map borders. A distance of one-sixth of the map height was suggested by Deetz and Adams (1934) and Snyder (1987).

For mapping polar areas at regional scales, it is rare to use a landscape format, and Snyder did not include this format in his selection guideline. However, the azimuthal projections suggested for square-format maps are also usable for polar maps in landscape format. They show all meridians as straight lines radiating outward from the pole (Figure 4, left). Azimuthal projections with polar aspects are suggested when the central latitude of the rectangle is beyond 70°N or 70°S. For maps that show a comparatively large area of the sphere, a limit of 67.5°N and 67.5°S is used instead, because the conic projections would show poles as lines and the resulting graticule would not cover the entire canvas. We set the limit at 67.5°N and S when the area of the selection rectangle covers between one-sixth and one-eighth of the sphere (Figure 5).

The diagram in Figure 5 summarizes map projection selection for maps with an east–west extent. The vertical axis represents the central latitude of the rectangle. The horizontal axis shows the portion of the spherical surface to be mapped. For the southern hemisphere, the diagram is reflected along the horizontal axis. The selection of projections for world and hemisphere maps is identical for all height-to-width ratios, as discussed in the preceding sections.

Regional maps with a north–south extent

The transverse cylindrical equal-area projection and the transverse Mercator projection are recommended for maps with a north–south extent (Figure 6). Because distortion rapidly increases when moving east or west from the centre of the

map, *Projection Wizard* sets the central meridian to the longitude of the rectangle's central point.

Selection of regional maps with correct scale along some lines

In some cases, it is useful to retain scale along great circles in regional and large-scale maps to allow for distance measurements along these lines. It is important to remember that no projection is able to correctly display all distances and that only some distances are retained correctly by these 'equidistant' projections.

Snyder (1987) suggests the polar azimuthal equidistant projection for mapping distance relative to one of the poles. He recommends the Plate Carrée projection for maps centred along the equator when distances are to be measured along meridians. When the map is centred away from the pole or the equator, Snyder recommends the equidistant conic projection. The equidistant conic projection preserves distances along meridians. In addition to these projections, *Projection Wizard* also includes the oblique azimuthal equidistant projection, which is useful for measuring distances along any line passing through the central point of the map. All equidistant projections are suggested regardless of the directional extent of the mapped area.

Very large map scales

At very large map scales, it is often advisable to apply the coordinate reference system (which includes a projection) used by the local National Mapping Agency or a similar entity. These coordinate reference systems not only minimize the distortion of the mapped area, but also simplify the cartographer's work, because data are often made available in these local coordinate systems. *Projection Wizard* displays a note when a very small area is selected, recommending use of the local official coordinate reference system.

CONCLUSION

Projection Wizard is available online at *projectionwizard.org*, and it is currently the only system running in all major web browsers. It helps mapmakers and GIS users produce maps with less distortion. Using *Projection Wizard* is easy and requires only two steps: (1) selecting the distortion property of the map, and (2) selecting the map extent by entering boundary values in the text boxes or by adjusting the interactive rectangle on the web map. The tool is easier to use than previously developed expert systems, and it also generates a preview map, which provides the user with an instant impression of how the map will appear with the proposed projection.

Projection Wizard focuses on minimizing the overall distortion of the mapped area. However, in some cases, it might be desirable to apply distortion, e.g., for an inset map with an orthographic projection or for a map with an oblique perspective projection that shows a spherical horizon. *Projection Wizard* is not designed for these cases.

It must be noted that *Projection Wizard* does not always return the best possible projection. In the case of azimuthal

and cylindrical projections, *Projection Wizard* does not currently support the secant cases. These projections are commonly parameterized with a scale factor for creating a secant case and minimizing distortion (Snyder, 1987). *Projection Wizard* currently suggests determining the scale factor with a trial-and-error approach, comparing the distortion patterns along the centre and the border of the map. The tool could be extended to provide an estimate for scale factors that would minimize distortion and create secant cases depending on the mapped area. It could also optimize the selection of standard parallels, for example, using the model for conic map projections described by Šavrič and Jenny (submitted for publication). Additionally, instead of using the mean scale distortion index by Canters (2002) to order suggested projections for world maps, *Projection Wizard* could list suggested projections according to user preferences, as documented by Šavrič et al. (2015).

The number of projections included in *Projection Wizard* could be extended in the future. For maps of smaller areas, *Projection Wizard* could suggest projections and coordinate reference systems using an ellipsoid instead of a sphere. Alternatively, pre-defined coordinate reference systems, such as national coordinate reference systems, could be suggested. It could also be extended to support regional maps with oblique extents. In addition to the PROJ.4 library codes, *Projection Wizard* could return EPSG codes (spatialreference.org). Finally, the selection of a distortion property could be replaced with the selection of a map type, similar to the MaPSS system by Kessler (1991).

It is the authors' hope that *Projection Wizard* will help map authors to select appropriate projections for their maps. The ideas and selection guideline outlined in this article might help others in the future to create more sophisticated selection models and maybe even automate the map projection selection process in GIS software.

BIOGRAPHICAL NOTES

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REFERENCES

Battersby, S. E., Finn, M. P., Usery, E. L. and Yamamoto, K. H. (2014). 'Implications of web Mercator and its use in online mapping', *Cartographica: The International Journal for Geographic Information and Geovisualization*, 49 (2), pp. 85–101.

Bostock, M., Ogievetsky, V. and Heer, J. (2011). 'D³ data-driven documents', *IEEE Transactions on Visualization and Computer Graphics (Proceedings Scientific Visualization/Information Visualization 2011)*, 17 (12), pp. 2301–2309.

Bugayevskiy, L. M. and Snyder, J. P. (1995). *Map Projections: A Reference Manual*, Taylor & Francis, London.

Canters, F. (2002). *Small-scale Map Projection Design*, CRC Press, London.

Deetz, C. H. and Adams, O. S. (1934). *Elements of Map Projection with Applications to Map and Chart Construction*, 4th ed., U.S. Coast and Geodetic Survey Special Publication 68, Washington.

De Genst, W. and Canters, F. (1996). 'Development and implementation of a procedure for automated map projection selection', *Cartography and Geographic Information Science*, 23 (3), pp. 145–171.

Eldrandaly, K. A. (2006). 'A COM-based expert system for selecting the suitable map projection in ArcGIS', *Expert Systems with Applications*, 31, pp. 94–100.

Evenden, G. I. (2008). libproj4: A Comprehensive Library of Cartographic Projection Functions (preliminary draft) [pdf]. Falmouth. Available at: <http://home.comcast.net/~gevenden56/proj/manual.pdf> [Accessed 10 December 2013].

Finn, M. P., Usery, E. L., Posch, S. T. and Seong, J. C. (2004). A decision support system for map projections of small scale data. Scientific Investigations Report 2004–5297. U.S. Geological Survey, Department of the Interior.

Finn, M. P., Usery, E. L., Woodard, L. N. and Yamamoto, K. H. (in press). 'The logic of selecting an appropriate map projection in a decision support system (DSS)', in *Choosing a Map Projection, Lecture Notes in Geoinformation and Cartography*, ed. By Lapaine, M. and Usery, E. L., Springer, Berlin, Heidelberg, New York.

Jankowski, P. and Nyerges, T. (1989). 'Design considerations for MaPKBS-map projection knowledge-based system', *The American Cartographer*, 16 (2), pp. 85–95.

Jenny, B. (2012). 'Adaptive composite map projections', *IEEE Transactions on Visualization and Computer Graphics (Proceedings Scientific Visualization/Information Visualization 2012)*, 18 (12), pp. 2575–2582.

Jenny, B., Šavrič, B., Arnold, N. D., Marston, B. E. and Preppernau, C. A. (in press). 'A guide to selecting map projections for world and hemisphere maps', in *Choosing a Map Projection, Lecture Notes in Geoinformation and Cartography*, ed. By Lapaine, M. and Usery, E. L., Springer, Berlin/Heidelberg/New York.

Kessler, F. C. (1991). The Development and Implementation of MaPPS: An Expert System Designed to Assist in the Selection of a Suitable Map Projection, M. A., Geography Department, Penn State University, State College.

Mekenkamp, O. G. M. (1990). 'The need for projection parameters in a GIS environment', in *EGIS '90: Proceedings, First European Conference on Geographical Information Systems*, ed. By Harts, J. J., Ottens, H. F. L. and Scholtes, H. J., EGIS Foundation, Utrecht, pp. 762–769.

Nyerges, T. L. and Jankowski, P. (1989). 'A knowledge base for map projection selection', *The American Cartographer*, 16 (1), pp. 29–38.

Patterson, T., Šavrič, B. and Jenny, B. (2014). 'Introducing the Patterson cylindrical projection', *Cartographic Perspectives*, 78, pp. 77–81.

Šavrič, B. and Jenny, B. (submitted for publication). 'Automating the selection of standard parallels for conic map projections', *Computers & Geosciences*.

Šavrič, B., Jenny, B., Patterson, T., Petrovič, D. and Hurni, L. (2011). 'A polynomial equation for the Natural Earth projection', *Cartography and Geographic Information Science,* 38 (4), pp. 363–372.

Šavrič, B., Jenny, B., White, D. and Strebe, D. R. (2015). 'User preferences for world map projections', *Cartography and Geographic Information Scienc*, 42 (5), pp. 398–409.

Slocum, T. A., McMaster, R. B., Kessler, F. C. and Howard, H. H. (2009). *Thematic Cartography and Geovisualization*, 3rd ed., Pearson education, Upper Saddle River.

Smith, D. G. and Snyder, J. P. (1989). 'Expert map projection selection system', in *United States Geological Survey Yearbook Fiscal Year 1988*, Denver: U.S. Government Printing Office, pp. 14–15.

Snyder, J. P. (1987). *Map Projections: A Working Manual*, US Geological Survey, Washington, DC.

Snyder, J. P. (1993). *Flattening the Earth. Two Thousand Years of Map Projections*, University of Chicago Press, Chicago/London.

Zhao, H., Zhu, H., Li, L. and Xing, Y. (2007). 'COM-based expert system for map projection selection', *Geoinformatics 2007: Cartographic Theory and Models*, ed. By Li, M. and Wang, J., Bellingham: Society of Photo-Optical Instrumentation Engineers, pp. 675115–65125.