Google Earth and Map Projections

Google Earth is a virtual globe, i.e. three-dimensional (3D) software representation of the Earth or any other celestial body on the screen of a computer monitor or smartphone. The mouse can be moved in any direction that allows the display in a number of different scales, and includes different layers of data. In a virtual globe, at one moment the viewer may be viewing the Earth from a distance, and at the next, zoom in to street level in a city. At the same time, a virtual globe presents a massive amount of real-world terrain, imagery, and vector datasets (Cozzi and Ring 2011). For the success of such a virtual globe presented in 2D, special attention should be paid to the way it is viewed, i.e. map projections. There is very little evidence in the literature on map projections used for virtual globes. As far as we know, there are no papers concerning this topic. Authors who have provided information on map projections used have given different opinions without proof. Allen (2009), Farman (2010), and Favretto (2014) write that Google Earth is presented in an equidistant cylindrical projection. Goodchild (2008), Goodchild et al. (2012) and Jenny et al. (2016) state that Google Earth is presented in an orthographic projection, while Eremchenko et al. (2015) and Bildirici (2015) write that map projections are not used at all in Google Earth. Di Palma (2009), Pezdich (2015) and Wikipedia (2015) state that Google Earth uses a general perspective projection, but without any proof.

On March 24, 2019, this question was asked online (https://support.google.com/earth/thread/2927796?hl=en):

"I am interested in map projection(s) used by Google Earth. Prof. Emer. Miljenko Lapaine ICA Commission on Map Projections, Chair"

Platinum Product Expert barryhunter of the Google Earth Help Community replied:

"It doesnt use a 'map' projection in the traditional sense, instead, the earth is rendered as a virtual sphere. A 'camera' is then looking at this sphere, the position of the camera can then be moved, to change where on earth looking.

... so if anything its a 3D projection rather than map projection

https://en.wikipedia.org/wiki/3D_projection

https://en.wikipedia.org/wiki/3D_rendering"

What is the truth of all the above? Since what we see when looking at Google Earth on a monitor screen looks like a map, it naturally begs the question whether some map projection was applied, or can it be interpreted as a map projection? And if so, what is the projection?

Display devices that we use today for viewing 3D models in most cases are two-dimensional. Before computers, this was piece of paper, and with computers, these are monitors or displays on laptops, tablets and smartphones. Representation of three-dimensional objects in two dimensions using a set of rules, belongs to the geometry discipline called descriptive geometry. While descriptive geometry has a main task to enable reconstruction of position and dimensions of 3D objects from a series of 2D views, in 3D computer graphics the position and dimensions of 3D objects already exist in numerical or symbolic form. 2D views in 3D computer geometry are mainly used for the visualisation purposes helping the process of design, editing and interaction.

Important fact for successful visualisation of 3D models is to use those types of 2D representations which are pertinent to human visual perception. For virtual globe, ideal case would be that users can see the Earth on computer display as if they are physically on the location of current view or as if they are looking at desktop globe. But, computer displays do not occupy our whole field of view, users can move around displays changing the distance and angle of view, meaning that 2D representation on display can only be relatively close to this ideal. Good overview of principles and projections used in computer graphics can be found in many books on this topic (e.g. Marsh 2004).

In the 3D rendering article, wikipedia teaches us about projections:

"The shaded three-dimensional objects must be flattened so that the display device - namely a monitor - can display it in only two dimensions, this process is called 3D projection. This is done using projection and, for most applications, perspective projection. The basic idea behind perspective projection is that objects that are further away are made smaller in relation to those that are closer to the eye. Programs produce perspective by multiplying a dilation constant raised to the power of the negative of the distance from the observer. A dilation constant of one means that there is no perspective. High dilation constants can cause a "fish-eye" effect in which image distortion begins to occur. Orthographic projection is used mainly in CAD or

Google Earth i kartografske projekcije

Google Earth je virtualni globus, tj. trodimenzionalni (3D) softverski prikaz Zemlje ili nekog drugog nebeskog tijela na ekranu računalnog monitora ili pametnog telefona. Mišem se može pokretati u bilo kojem smjeru, omogućuje prikaz u većem broju različitih mjerila i uključuje različite slojeve podataka. Virtualni globus se može u jednom trenutku gledati tako da se vidi cijeli model Zemlje, a u sljedećem zumirati na razinu ulice u gradu. Virtualni globus sadrži ogromnu količinu slikovnih i vektorskih podataka stvarnog terena (Cozzi i Ring 2011). Za uspjeh takvog virtualnog globusa prikazanog u 2D, posebnu pozornost treba posvetiti načinu na koji se preslikava u ravninu, među ostalim i o kartografskim projekcijama. U literaturi je vrlo malo podataka o kartografskim projekcijama za virtualne globuse. Koliko znamo, ne postoje radovi na tu temu. Autori koji su pružili informacije o primijenjenim kartografskim projekcijama dali su različita mišljenja. Allen (2009), Farman (2010) i Favretto (2014) pišu da je Google Earth prikazan u ekvidistantnoj cilindričnoj projekciji. Goodchild (2008), Goodchild i dr. (2012) i Jenny i dr. (2016) navode da je Google Earth prikazan u ortografskoj projekciji, dok Eremchenko i dr. (2015) i Bildirici (2015) pišu da se kartografske projekcije uopće ne primjenjuju u Google Earthu. Di Palma (2009), Pezdich (2015) i Wikipedia (2015) navode da je Google Earth prikazan u općoj perspektivnoj projekciji, no bez bilo kakvog dokaza.

Dana 24. ožujka 2019. postavljeno je ovo pitanje putem interneta (https://support.google.com/earth/thread/2927796?hl=en):

"I am interested in map projection(s) used by Google Earth. Prof. Emer. Miljenko Lapaine ICA Commission on Map Projections, Chair"

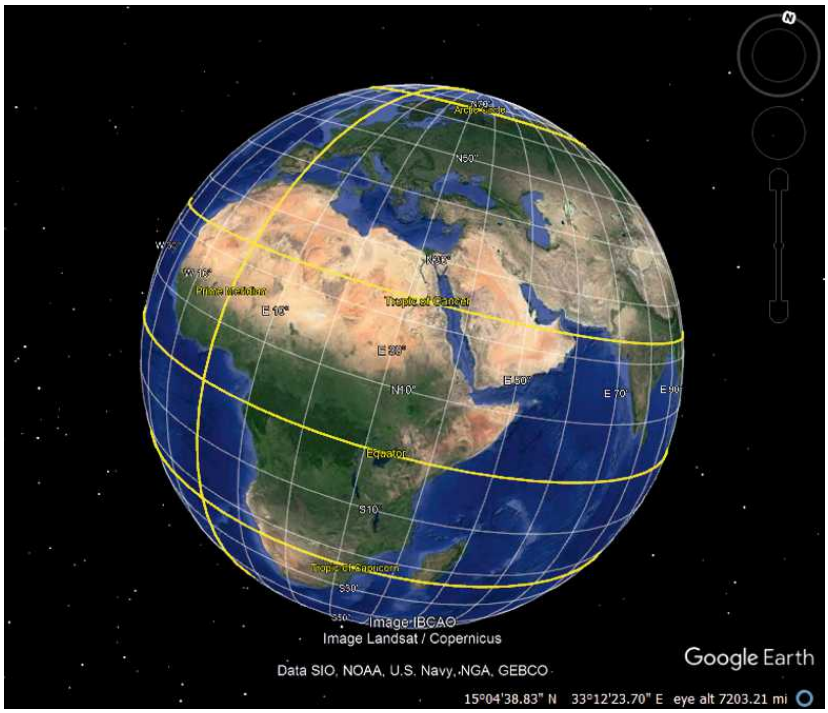


Fig. 1 Initial view of Google Earth™ with added meridians and parallels.
Slika 1. Početni prikaz Google Eartha s dodanom mrežom meridijana i paralela.

Odgovorio je Platinum Product Expert barryhunter of the Google Earth Help Community:

"It doesnt use a 'map' projection in the traditional sense, instead, the earth is rendered as a virtual sphere. A 'camera' is then looking at this sphere, the position of the camera can then be moved, to change where on earth looking.

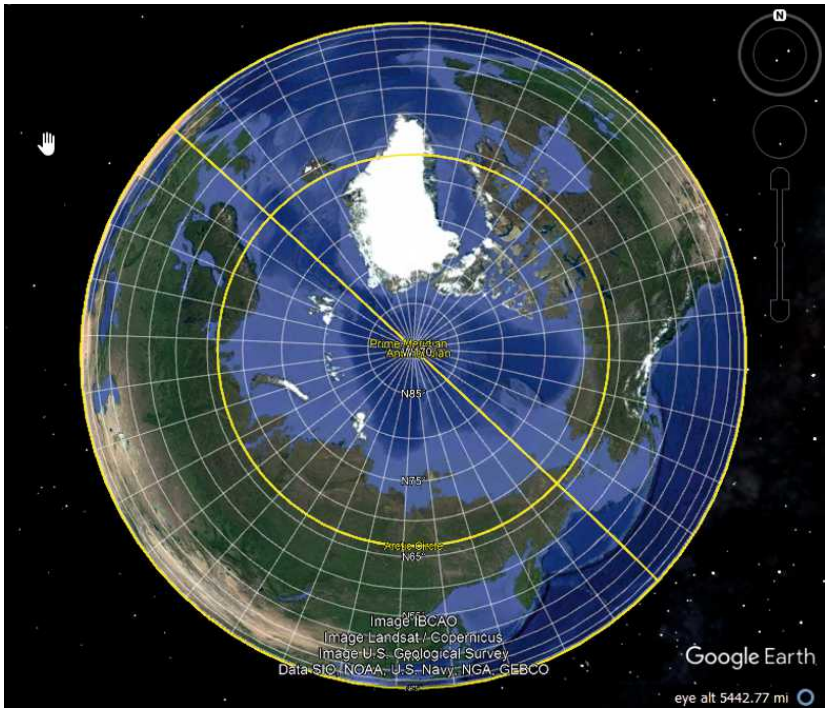
... so if anything its a 3D projection rather than map projection

https://en.wikipedia.org/wiki/3D_projection

https://en.wikipedia.org/wiki/3D_rendering"

Što je na kraju istina od svega nabrojenoga? Budući da ono što vidimo gledajući Google Earth na ekranu monitora izgleda kao karta, prirodno se postavlja pitanje je li primijenjena ipak neka kartografska projekcija, odnosno može li se taj prikaz interpretirati kao kartografska projekcija? I ako može, koja je to projekcija?

Uređaji kojima se danas služimo za gledanje 3D modela u većini slučajeva su dvodimenzionalni. Prije računala to je bio papir, a s računalima, to su monitori ili zasloni na prijenosnim računalima, tabletima i pametnim telefonima. Prikazivanje trodimenzionalnih objekata u dvije dimenzije s pomoću skupa pravila, pripada geometrijskoj disciplini koja se naziva nacrtna geometrija. Dok nacrtna geometrija ima glavni zadatak omogućiti rekonstrukciju položaja i dimenzija 3D objekata iz niza 2D prikaza, u 3D računalnoj grafici položaj, veličina, oblik i izgled 3D objekata zapisani su u numeričkom



Slika 2. Perspektivna azimutna projekcija sa sjevernim polom u središtu (uspravna perspektivna azimutna projekcija) kao specijalan slučaj opće perspektivne projekcije.
Fig. 2 Perspective azimuthal projection with the North Pole in the map centre as a special case of general perspective projection.

CAM applications where scientific modeling requires precise measurements and preservation of the third dimension" (https://en.wikipedia.org/wiki/3D_rendering).

Furthermore, according to wikipedia:

"3D projection is any method of mapping three-dimensional points to a two-dimensional plane. As most current methods for displaying graphical data are based on planar (pixel information from several bitplanes) two-dimensional media, the use of this type of projection is widespread, especially in computer graphics, engineering and drafting." (https://en.wikipedia.org/wiki/3D_projection)

If map projection is the mapping of a curved surface, such as a sphere or an ellipsoid, into a plane, then it is a 3D projection, so it makes sense to find the answer to the question about map projection and Google Earth.

Google Earth is a virtual globe which can be moved in all directions at the click of the mouse, while the view can be zoomed to the largest scales, at which point individual houses can be seen on the screen. When Google Earth is started, a default view of the Earth appears, seen from a great distance (Figure 1). The graticule can be added by selecting Grid in the View menu.

In the comprehensive manual meant for users (Google, 2018c), information on map projections can only be found in the chapter *Importing Your Data Into Google Earth*. In the section headed *A Note About Projections and Datums*, the following explanation is given: "Google Earth uses a Simple Cylindrical projection with a WGS84 datum for its imagery base", followed by an illustration. Although the cited sentence states that the simple cylindrical projection is used to store raster images the text below the image led many to conclude that this projection was used for on-screen visualization (Frančula 2010).

Any mapping of a 3D model of the Earth model onto a plane can only be achieved using map projections. Google Earth requires DirectX9 and a 3D-capable graphic card (Google 2018a). 3D computer graphics uses perspective projections as a standard for creating 2D views of 3D objects (e.g. Carlbom and Paciorek 1978, Shreiner et al. 2013, Microsoft 2016).

In Google Earth, Google has used the maximum potential of digital technology, so that with every shift of the map on the screen using the mouse, the parameters of the projection change. At any moment, the image on the screen is in the adopted perspective projection, but with varying parameters and different objects displayed (Google 2018b). When the Earth's surface in this virtual globe is a sphere or a rotating ellipsoid, the plane view can also be defined by mapping as defined in map projections. Of all the map projections for this discussion, the following are important (Frančula and Lapaine 2008):

Perspective projection (*general*) is a map projection in which points from the surface of an ellipsoid or sphere are projected according to the laws of a linear perspective from the point of view onto the projection plane or the auxiliary surface. Perspective azimuthal projections have the greatest application in perspective projections, so the term perspective projection in map projections often refers only to that group of projections. *Perspective azimuthal projection* is a special type of azimuthal projection in which the Earth is considered a sphere, and points from the surface of the sphere are projected according to the laws of linear perspective from the point of view to the projection plane. The plane of projection is perpendicular to the line joining the observation point to the center of the sphere. *Azimuthal projection* is a map projection in which meridians of normal aspect projection are mapped as intersecting at one point (the image of a Pole), at angles equal to the corresponding differences of longitude, and parallels as arcs of concentric circles centered in the meridians' cross

ili simboličkom obliku. 2D prikazi u 3D računalnoj geometriji uglavnom služe za vizualizaciju, pomažući tako u procesu dizajniranja, uređivanja i interakcije.

Važna činjenica za uspješnu vizualizaciju 3D modela je upotreba onih vrsta 2D prikaza koji su relevantni za čovjekovu vizualnu percepciju. Za virtualni globus idealan bi slučaj bio kad bi korisnici mogli vidjeti Zemljin model na zaslonu računala kao da se fizički nalaze na mjestu trenutnog prikaza ili kao da gledaju stolni globus. No, računalni zasloni ne zauzimaju cijelo naše vidno polje. S druge strane, korisnici mogu mijenjati udaljenost i kut gledanja, što znači da 2D prikazi na zaslonu mogu biti relativno blizu ovom idealu. Dobar pregled načela i projekcija primijenjenih u računalnoj grafici može se naći u mnogim knjigama o ovoj temi (npr. Marsh 2004).

U članku o 3D prikazivanju (*3D rendering*) wikipedija nas uči ovo o projekcijama:

"The shaded three-dimensional objects must be flattened so that the display device - namely a monitor - can display it in only two dimensions, this process is called 3D projection. This is done using projection and, for most applications, perspective projection. The basic idea behind perspective projection is that objects that are further away are made smaller in relation to those that are closer to the eye. Programs produce perspective by multiplying a dilation constant raised to the power of the negative of the distance from the observer. A dilation constant of one means that there is no perspective. High dilation constants can cause a "fish-eye" effect in which image distortion begins to occur. Orthographic projection is used mainly in CAD or CAM applications where scientific modeling requires precise measurements and preservation of the third dimension" (https://en.wikipedia.org/wiki/3D_rendering).

Nadalje, prema wikipediji:

"3D projection is any method of mapping three-dimensional points to a two-dimensional plane. As most current methods for displaying graphical data are based on planar (pixel information from several bitplanes) two-dimensional media, the use of this type of projection is widespread, especially in computer graphics, engineering and drafting." (https://en.wikipedia.org/wiki/3D_projection)

Ako je kartografska projekcija preslikavanje zakrivljene plohe, npr. sfere ili elipsoida, u ravninu, onda je to i 3D projekcija, pa ima smisla potražiti odgovor na pitanje o kartografskoj projekciji i Google Earthu.

Google Earth je virtualni globus koji se može gledati u svim smjerovima, dok se pogled može zumirati do tako krupnih mjerila, u kojima se mogu vidjeti pojedine kuće. Kad se pokrene Google Earth, pojavit će se prikaz modela Zemlje gledan s velike udaljenosti (slika 1). Mreža meridijana i paralela može se dodati odabirom Grid u izborniku View.

U opsežnom priručniku namijenjenom korisnicima (Google 2018c) informacije o kartografskim projekcijama mogu se naći samo u poglavlju *Importing Your Data Into Google Earth*. U odjeljku pod naslovom *A Note About Projections and Datums* dano je sljedeće objašnjenje: *Google Earth uses a Simple Cylindrical projection with a WGS84 datum for its imagery base*. Iako u citiranoj rečenici piše da ekvidistantna (jednostavna) cilindrična projekcija služi za spremanje rasterskih slika, tekst ispod slike naveo je mnoge na pogrešan zaključak da je ta kartografska projekcija primijenjena za vizualizaciju na ekranu (Frančula 2010).

Google Earth zahtijeva DirectX9 i grafičku karticu koja podržava 3D grafiku (Google, 2018a). 3D računalna grafika koristi se perspektivnim projekcijama (linearnom perspektivom) kao standardom za stvaranje 2D prikaza 3D objekata (npr. Carlbom i Paciorek 1978, Shreiner i sur. 2013, Microsoft 2016).

Google je u Google Earthu iskoristio maksimalni potencijal digitalne tehnologije, tako da se sa svakim pomakom karte na zaslonu mijenjaju parametri perspektivnog projiciranja. Slika se u svakom trenutku nalazi u perspektivnoj projekciji, ali s različitim parametrima

Google je u Google Earthu iskoristio maksimalni potencijal digitalne tehnologije, tako da se sa svakim pomakom karte na zaslonu mijenjaju parametri perspektivnog projiciranja. Slika se u svakom trenutku nalazi u perspektivnoj projekciji, ali s različitim parametrima i različitim objektima prikaza (Google 2018b)

In Google Earth, Google has used the maximum potential of digital technology, so that with every shift of the map on the screen using the mouse, the parameters of the projection change. At any moment, the image on the screen is in the adopted perspective projection, but with varying parameters and different objects displayed (Google 2018b).

i različitim objektima prikaza (Google 2018b). Kada je ploha Zemlje u tom virtualnom globusu sfera ili rotacijski elipsoid, prikaz u ravnini može se definirati i s pomoću preslikavanja kakva se definiraju u kartografskim projekcijama. Od svih kartografskih projekcija za ovu raspravu važne su nam sljedeće (Frančula i Lapaine 2008):

Perspektivna projekcija (*opća*) je kartografska projekcija u kojoj se točke s plohe elipsoida ili sfere projiciraju prema zakonima linearne perspektive iz točke promatranja na projekcijsku ravninu ili pomoćnu plohu. Od perspektivnih projekcija najveću primjenu u praksi imaju perspektivne azimutne projekcije, pa se terminom perspektivne projekcije u kartografskim projekcijama često označuje samo ta skupina projekcija. *Perspektivna azimutna projekcija* posebna je vrsta azimutnih projekcija kod koje se Zemlja smatra sferom, a točke s plohe sfere projiciraju se prema zakonima linearne perspektive iz točke promatranja na projekcijsku

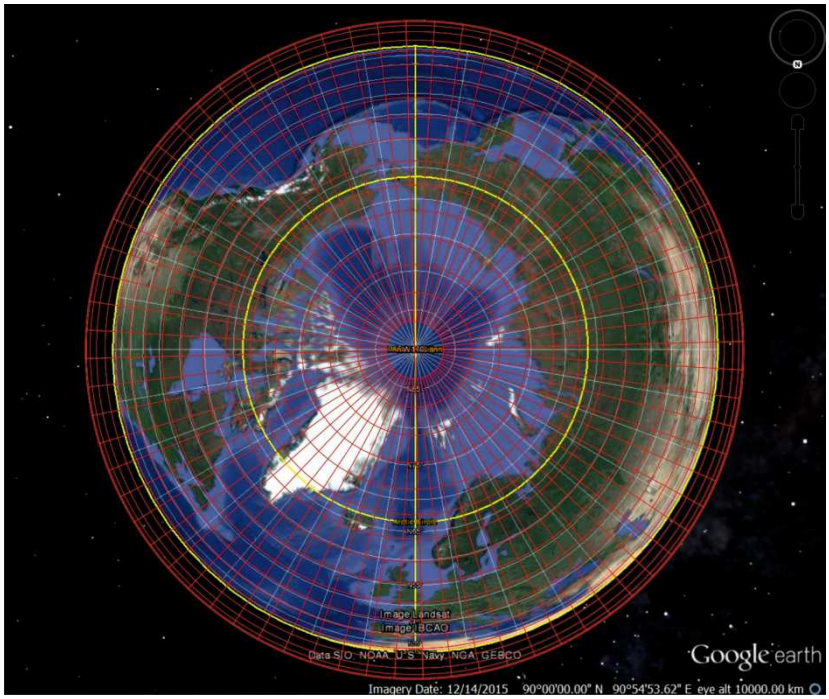


Fig. 3 Overlay of a graticule in orthographic projection (red) on the Google Earth™ image. The networks overlap at the North Pole and Tropic of Cancer.
Slika 3. Preklop mreže meridijana i paralela u ortografskoj projekciji (crveno) i projekciji u Google Earthu. Mreže su preklopljene u Sjevernom polu i na Rakovoj obratnici.

Fig. 5 General (tilted) perspective projection.
Slika 5. Opća perspektivna projekcija (nagnuta, kosa).

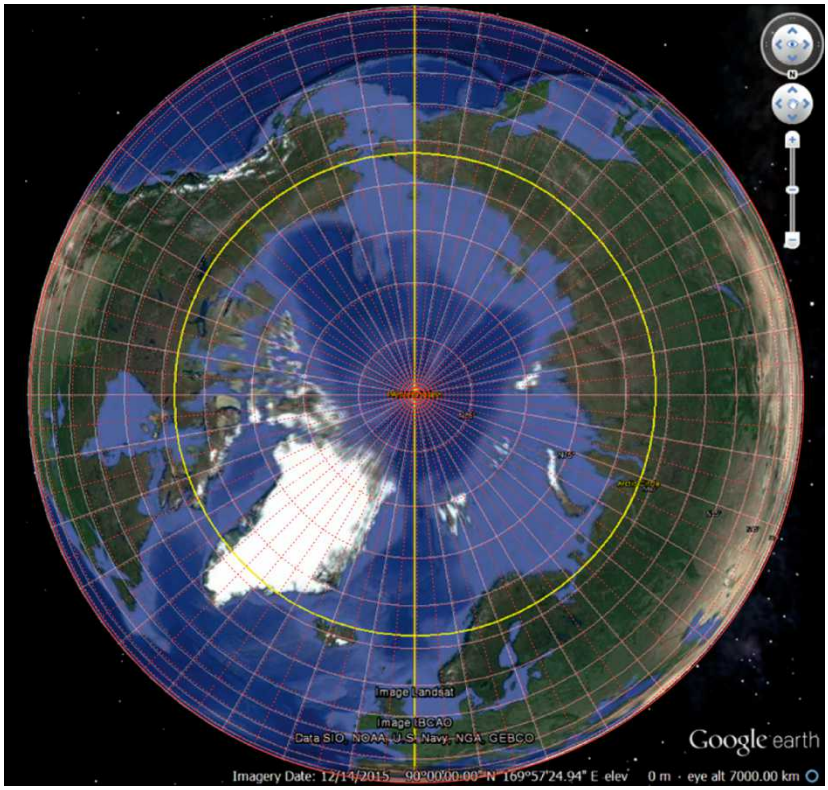
ravninu. Ravnina projekcije okomita je na pravac koji spaja točku promatranja sa središtem sfere. *Azimutna projekcija* je kartografska projekcija u kojoj se meridijani uspravne projekcije preslikavaju kao pravci koji se sijeku u jednoj točki (slici pola), pod kutovima jednakim odgovarajućim razlikama geografskih dužina, a paralele kao lukovi koncentričnih kružnica sa središtem u presjeku meridijana. *Ortografska projekcija* je perspektivna azimutna projekcija u kojoj se točka promatranja nalazi u beskonačnosti, pa su projekcijske zrake međusobno paralelne.

Cilindrična projekcija je kartografska projekcija u kojoj se meridijani uspravne projekcije preslikavaju kao međusobno paralelni pravci, a paralele također kao pravci okomiti na meridijane, i to na udaljenostima koje ovise o uvjetima preslikavanja. *Ekvidistantna projekcija* je kartografska projekcija u kojoj je faktor lokalnog linearnog mjerila uzduž jednoga glavnog pravca jednak jedinici, odnosno deformacija duljina je nula.

Lako je pokazati da Google Earth nije prikazan u (ekvidistantnoj) cilindričnoj projekciji. Stvarnu projekciju najlakše je utvrditi kada se prikaže sjeverna ili južna polutka, tj. kada su paralele koncentrične kružnice, a meridijani pravci koji se sijeku u polu (slika 2). To je svojstvo svih azimutnih projekcija u normalnom (uspravnom) aspektu. Kad mrežu meridijana i paralela u ortografskoj projekciji preklopimo na Google Earth, tako da se pol i Rakova obratnica preklapaju, razlika između ortografske projekcije i projekcije u Google Earthu jasno je vidljiva (slika 3).

Razlika u položaju paralela između ortografske projekcije i projekcije u Google Earthu na slici 3 upućuje na zaključak da je u Google Earthu u tom slučaju primijenjena vanjska perspektivna azimutna projekcija, kao poseban slučaj opće perspektivne projekcije, što potvrđuje i preklapanje mreža meridijana i paralela na slici 4.

U općoj perspektivnoj projekciji ako je projekcijska ravnina okomita na spojnicu točke promatranja i



Slika 4. Preklop mreže meridijana i paralela u vanjskoj perspektivnoj azimutnoj projekciji ili vertikalnoj perspektivnoj projekciji (crveno) i Google Eartha; Točka promatranja je 7000 km udaljena od sfere.

Fig. 4 Overlay of a graticule in external perspective azimuthal projection or vertical perspective projection (red dotted graticules) on the Google Earth™ image. The observation point is 7000 km away from the sphere.

središta sfere, tada je to vertikalna perspektiva ili perspektivna azimutna projekcija. Ako nije okomita, tada je to nagnuta (kosa) perspektivna projekcija (Snyder 1987, slika 35).

U korisničkom priručniku Google Eartha (Google 2018c) termin perspektiva se također koristi nekoliko puta, npr. kada se objašnjava navigacija: "You can also manipulate your view of the Earth by tilting the terrain for perspectives other than a top-down view. Finally, you can reset the default view for a north-up, top-down view wherever you are." Perspektiva odozgo prema dolje označuje vertikalnu perspektivu ili perspektivnu azimutnu projekciju. Kada se projekcijska ravnina nagne, tada su karte Google Eartha u općoj perspektivnoj projekciji (nagnutoj, kosoj) (slika 5).

Ako imamo 3D prikaz terena i zgrada, to je perspektiva, koja u tom slučaju nije kartografska projekcija, jer više ne preslikavamo plohu sfere ili elipsoida, već neke druge geometrijske plohe i/ili tijela (slika 6). Međutim, i takvim se prikazima bavi kartografija. Prema Lovriću (1988), kartama srodni 2D prikazi su crteži nastali primjenom paralelne ili centralne projekcije, kao što su panorame, profili, blokdijagrami i dr. Odustajanjem od tlocrtnog prikaza, dobiva se crtež stvarnog izgleda objekta.

Uzimajući u obzir sve navedeno i principe računalne grafike (Carlbom i Paciorek 1978), opravdano je zaključiti da dio perspektivnih prikaza virtualnog globusa u Google Earthu jesu i kartografske projekcije i to opća perspektivna projekcija, a u specijalnim slučajevima i perspektivna azimutna projekcija. Prvi slučaj imamo kada je prikazani model Zemlje sfera ili elipsoid, a drugi kada je uz to projekcijska ravnina okomita na spojnicu točke promatranja i središta sfere.

Slika 6. Perspektivni prikaz trodimenzionalnog modela terena i zgrada u Petrčanima. To je prema Lovriću (1988) karti srodan 2D prikaz.
Fig. 6 Perspective representation of 3D terrain and buildings in Petrčane. According to Lovrić (1988), this is a map-like 2D representation.

section. *Orthographic projection* is a perspective azimuthal projection in which the observation point is at infinity, so the projecting rays are parallel to each other.

Cylindrical projection is a map projection in which the meridians of the norml aspect projection are mapped as parallel straight lines, and the parallels are also straight lines perpendicular to the meridians at distances that depend on the conditions of the mapping. An *equidistant projection* is a map projection in which the local linear scale factor along one major direction is equal to one, that is, the length distortion is zero.

It is easy enough to illustrate that the views in Google Earth are not in an equidistant cylindrical projection. The actual projection can most easily be determined by viewing the northern or southern hemisphere on the screen where the parallels are concentric circles, and the meridians straight lines radiating from the poles (Figure 2). This is the characteristic of all azimuthal projections in the normal aspect. When we overlay a graticule in orthographic projection on the Google Earth image, so that the pole and Tropic of Cancer overlap, the difference between orthographic projection and Google Earth projection is clearly visible (Figure 3).

The difference in position of the parallels between the orthographic projection and the Google Earth projection in Figure 3 suggests that external perspective azimuthal projection, also special case of general perspective projection, was applied in Google Earth, which confirms the overlap of the graticules in Figure 4.

For the general perspective projection, if the projection plane is perpendicular to a line between the point of perspective and the centre of the sphere, then it is a vertical perspective projection or perspective azimuthal projection. If it is not perpendicular, then it is a tilted perspective projection (Snyder 1987, Figure 35).

In the Google Earth™ user manual (Google 2018c) the term perspective is also used several times, e.g. when navigation is explained: "You can also manipulate your view of the Earth by tilting the terrain for perspectives other than a top-down view. Finally, you can reset the default view for a north-up, top-down view wherever you are." The top-down perspective denotes a vertical perspective or external perspective azimuthal projection. When the projection plane is tilted with the mouse, then Google Earth maps are in general perspective projection (Figure 5).

If we include a 3D view of the terrain and buildings, then this is a general perspective projection, which in this case is not a map projection, because we no longer map the surface of a sphere or ellipsoid, but some other geometric surfaces and/or bodies (Figure 6). However, cartography also deals with such representations. According to Lovrić (1988), maps related to 2D representations are drawings created using parallel or central projection, such as panoramas, profiles, block diagrams, etc. By abandoning the floor plan, a drawing of the actual appearance of the object is obtained.

Considering all of the above and the principles of computer graphics (Carlbom and Paciorek 1978), it is reasonable to conclude that part of the perspective views of the virtual globe in Google Earth are map projections, namely general perspective projection, and in special cases perspective azimuthal projection. The first case is when the model of the Earth is a sphere or an ellipsoid, and the second case when the projection plane is perpendicular to the junction of the observation point and the center of the sphere.

Nedjeljko Frančula, Dražen Tutić, Miljenko Lapaine, Marina Viličić ■

References / Literatura

Allen D Y (2009) A Mirror of Our World: Google Earth and the History of Cartography. Coordinates Series B (12). http://purl.oclc.org/coordinates/b12.pdf, accessed 20 Aug 2018 (no longer available)

Bildirici I O (2015) The Web Mercator Projection: A Cartographic Analysis. In G. Gartner (Ed.), H. Huang (Ed.), Proceedings of the 1st ICA European Symposium on Cartography. (pp. 221–231) Vienna: Research Group Cartography, Vienna Unversity of Technology. http://cartography.tuwien.ac.at/eurocarto/wp-content/uploads/2015/10/Online_Proceedings.pdf, accessed 6 Sep 2019

Carlbom I, Paciorek J (1978) Planar Geometric Projections and Viewing Transformations. ACM Computing Surveys 10 (4), 465–502. doi: https://dl.acm.org/citation.cfm?doid=356744.356750

Cozzi P, Ring K (2011) 3D Engine Design for Virtual Globes. New York: CRC Press, Taylor and Francis Group.

Di Palma V (2009) Zoom – Google Earth and Global Intimacy. In V. Di Palma (Ed.), D. Periton (Ed.) and M. Lathouri (Ed.), Intimate Metropolis, (pp. 239–270). Abingdon: Routledge.

Eremchenko E, Tikunov V, Ivanov R, Massel L, Strobl J (2015) Digital Earth and Evolution of Cartography. Procedia Computer Science, 66, 235-238. doi: 10.1016/j.procs.2015.11.028

Farman J (2010) Mapping the Digital Empire: Google Earth and the Process of Postmodern Cartography. New Media & Society, 12 (6), 869-888. doi: 10.1177/1461444809350900

Favretto A (2014) Coordinate Questions in the Web Environment. Cartographica: The International Journal for Geographic Information and Geovisualization, 49 (3), 164–174. doi: 10.3138/carto.49.3.2255

Frančula N (2010) Google Earth and Map projections / Google Earth i kartografske projekcije. Kartografija i geoinformacije 9, 13, 84-85. https://hrcak.srce.hr/56805 (6. 9. 2019.)

Frančula N, Lapaine M (2008) Geodetsko-geoinformatički rječnik. Državna geodetska uprava, Zagreb. https://dgu.gov.hr/geodetsko-informaticki-rjecnik/163 (6. 9. 2019.)

Goodchild M (2008) What does Google Earth Mean for the Social Sciences? In M. Dodge (Ed.), M. McDerby (Ed.), M. Turner (Ed.), Geographic Visualization: Concepts, Tools and Applications (pp. 11–23), Chichester: John Wiley and Sons. doi: 10.1002/9780470987643.ch2

Goodchild M F, Guo H, Annoni A, Bian L, Bie de K, Campbell F, Craglia M, Ehlers M, Genderen van J, Jackson D, Lewis A J, Pesaresi M, Remetey-Fülöpp G, Simpson R, Skidmore A, Wang C, Woodgate P (2012) Next-Generation Digital Earth. In K. Wachter (Ed.) Proceedings of the National Academy of Sciences, 109 (28), 11088-11094. doi: 10.1073/pnas.1202383109

Google (2018a) Earth System Requirements. https://support.google.com/earth/answer/20701?hl=en, accessed 15 Jul 2018

Google (2018b) Google Earth API: GEView Interface Reference. https://developers.google.com/earth/documentation/reference/interface_g_e_view, accessed 30 Jun 2016 (no longer available).

Google (2018c) Google Earth User Guide. http://earth.google.com/intl/ar/userguide/v4/index.htm, accessed 2 Nov 2018

Jenny R, Šavrič B, Liem J (2016) Real-time raster projection for web maps. International Journal of Digital Earth, 9 (3), 215–229. doi: 10.1080/17538947.2014.1002867

Lovrić P (1988) Opća kartografija. SNL, Zagreb

Marsh D (2005) Applied Geometry for Computer Graphics and CAD. Second edition. Springer-Verlag London. http://www.math.uni.lodz.pl/~maczar/ggk/Marsh,%20Applied%20Geometry%20for%20Computer%20Graphics%20and%20CAD.pdf, accessed 7 Nov 2018

Microsoft (2016) Projection Transform (Direct3D 9). https://msdn.microsoft.com/en-us/library/windows/desktop/bb147302(v=vs.85).aspx, accessed 10 Jul 2018

Pedzich P (2015) From Cartography of the Universe to Molecular Cartography: The Use of Map Projections. Polish Cartographical Review, 47 (4), 191-201. doi: 10.1515/pcr-2015-0014

Shreiner D, Sellers G, Kessenich J, Licea-Kane B (2013) OpenGL Programming Guide. Eight Edition, Upper Saddle River: Addison-Wesley. https://www.cs.utexas.edu/users/fussell/courses/cs354/handouts/Addison.Wesley.OpenGL.Programming.Guide.8th.Edition.Mar.2013.ISBN.0321773039.pdf, accessed 2 Nov 2018

Snyder J P (1987) Map Projections – A Working Manual. U.S. Geological Survey, Professional Paper 1395. Washington, DC: U.S. Government Printing Office. http://pubs.usgs.gov/pp/1395/report.pdf, accessed 20 Aug 2018

Wikipedia (2015) General Perspective Projection. https://en.wikipedia.org/wiki/General_Perspective_projection, accessed 10 Jul 2018

Nedjeljko Frančula, Dražen Tutić, Miljenko Lapaine, Marina Viličić ■