

Appendix

The following are the ARC/INFO Version 7.2.1 commands and ArcView Version 3.2 menu choices we used to create Figure 7. Commands for producing other figures are available from the authors. It is necessary to have the GRID module for ARC/INFO and the Spatial Analyst extension for ArcView loaded to perform these operations.

ARC/INFO Procedure

- 1) Create 200m. contours from the DEM (named elev in this example)
 - Arc: Grid
 - Grid: cntr = contour (elev, interval, 200)
- 2) Create hillshading polygons representing equal 5° increments of the angle θ .
 - Grid: hlshd = hillshade (elev, 315, 45, shade)
 - Grid: hlshd1 = float (hlshd)
 - Grid: hlshd2 = hlshd1 / 255
 - Grid: theta_rad = acos (hlshd2)
 - Grid: theta = theta_rad * deg
 - (Deg is a built-in constant to convert radians to degrees, or use 57.29578 degrees/radian)
 - Grid: rcls = reclass (theta, remap.txt)
 - (Remap.txt is a text file containing ranges of values of θ , and the value to which these ranges will be reclassified.)
 - Remap.txt file format

0	5	:	1
5	10	:	2
...	...	:	...
80	85	:	17
85	90	:	18

 - Grid: hs_poly = gridpoly (rcls)
 - Grid: q
- 3) Intersect the contours with the hillshading polygons to transfer values of θ to the contour line segments.
 - Arc: intersect cntr hs_poly illum line
 - Resulting coverage is illum
- 4) Apply legend to the illuminated contour coverage (illum)
 - (See "About the Legend" below.)

ArcView Procedure

- 1) Load necessary extensions and DEM data
 - File: Extensions:
 - Spatial Analyst
 - Geoprocessing
 - View: Add Theme
 - Data source type: Grid data source
 - Add DEM data

- 2) Create contours from the DEM
 - Surface: Create contours
 - Contour Parameters
 - Contour interval: 200
 - Base contour: 0
- 3) Create hillshading polygons representing equal 5° increments of the angle θ .
 - Surface: Compute Hillshade
 - Compute hillshade:
 - Azimuth: 315
 - Altitude: 45

(N.B. This is the only step in ArcView that does not offer all of the flexibility of similar ARC/INFO commands. Shading as well as shadowed grid cell values are calculated, with shadowed grid cells given a "hillshading" value of 0. Shadowing can be prevented by choosing an illumination vector with an altitude (inclination) greater than the steepest slope.)

- Analysis: Map Calculator
- Map Calculation 1:
([Hillshade of Elev]).Float / 255)
- Analysis: Map Calculator
- Map Calculation 2:
([Map Calculation 1].Acoss) * 57.29578
- Analysis: Reclassify
- Reclassify Values

Old Values	New Values
0 5	1
5 10	2
...
80 85	17
85 90	18

- Select Reclass of Map Calculation 2
- Theme: Convert to Shapefile
- Name: hs_poly

- 4) Intersect the contours with the hillshading polygons to transfer values of θ to the contour line segments.
 - View: GeoProcessing Wizard
 - Geoprocessing
 - Intersect two themes
 - 1) Select input theme to intersect:
Contours of Elev
 - 2) Select an overlay theme:
hs_poly
 - Resulting shapefile: Intsct1.shp
- 5) Apply legend to the illuminated contour shapefile (Intsct1.shp)
 - (See "About the Legend" overleaf.)

About the legend

Visual balance is important to illuminated contour maps, and accomplished by having approximately the same area covered by black contours as by white contours. Tanaka's method varies placement of black and white contours and their thickness as a function of aspect only. If all aspect directions are represented equally in an area, the area covered by black and white contours will be equal. This balance is reflected in Figure A-1, which shows a cosine function for θ_T , with line thickness varying for all potential values of θ_T between 0° and 360° .

Visual balance is not as simple to achieve using the modified Tanaka method described in this paper. This method varies placement of black and white contours and their thickness as a function of a hill-shading value, traditionally used for tonal variations over areas of shaded relief maps. The hill-shading value varies between 0° and 90° , with 0° corresponding to the highest hill-shading value and 90° corresponding to the lowest hill-shading value (Figure A-2). The central hill-shading value does not occur at 45° but, rather, at 60° .

The transition from grayness of lines to thickness of black and white lines for illuminated contours requires that an angle be chosen that divides black from white contours. In our study, we used $\theta = 45^\circ$, an angle which roughly divides our lengths of contours equally between black and white. This value of $\theta = 45^\circ$ is the result of using an illumination vector with an inclination from horizontal 45° and a predominance of gently sloping topography. Length of black and white contours has been divided approximately equally; however, this does not ensure that areas covered by black and white contours will be equal.

Black and white contours change thickness in a non-symmetric manner moving away from the central value of 45° . This asymmetry is illustrated in Figure A-3. Contour lines associated with values of θ between 40° and 45° will be the thinnest white contours, and those associated with values of θ between 45° and 50° will be the thinnest black contours. Also, contours must thicken towards $\theta = 0$ and $\theta = 90$. One method to meet these requirements would be to calculate $\cos(\theta)$, subtract the value of $\cos(45)$, and normalize all thickness to the thickness value of the thinnest contours. This method, displayed in Figure A-3, shows that white lines near $\theta = 90$ would be more than twice as thick as black lines near $\theta = 0$. Thus, although approximately equal in total lengths, black contours would

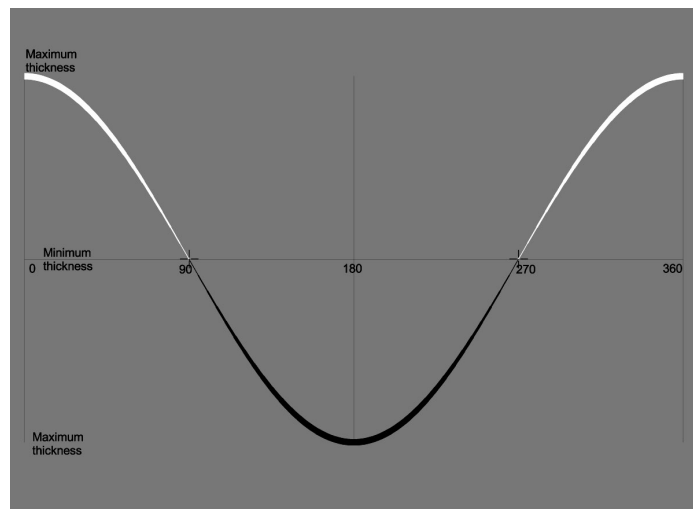


Figure A-1. Tanaka's method for assigning black and white line thickness based on $\cos(\theta_T)$. θ_T can have any value between 0° and 360° and is based on an angle defined by the vector in the direction of aspect and the azimuth of an illumination vector.

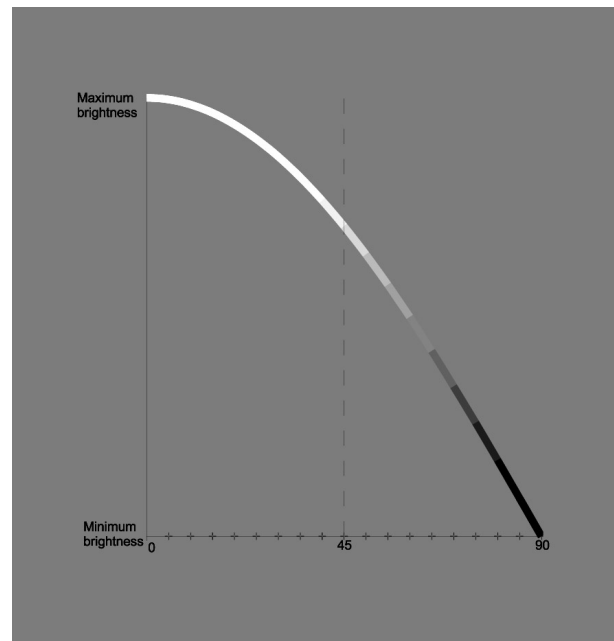


Figure A-2. The analytical hillshading method for assigning brightness to line segments based on $\cos(\theta)$. θ can only have values between 0° and 90° and is based on an angle defined by the surface normal and illumination vector.

cover a greater area than white contours with this method.

It is possible to create more symmetrical contours from the angle θ in a number of ways. The method we used was to calculate the line thickness as a function of $\cos(2\theta)$ (Figure A-4). With this function, black and white contours change thickness symmetrically away from the thinnest contours in a fashion similar to Tanaka's method. Line thick-

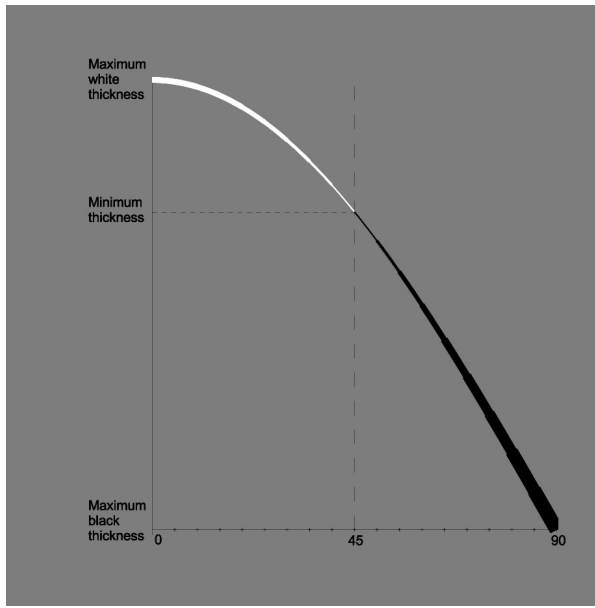


Figure A-3. Black and white line thickness based on $\cos(\theta)$. Due to the asymmetry of the cosine function between 0° and 90° , the resulting black line is thicker than the white line. This would result in a illuminated contour map out of visual balance.

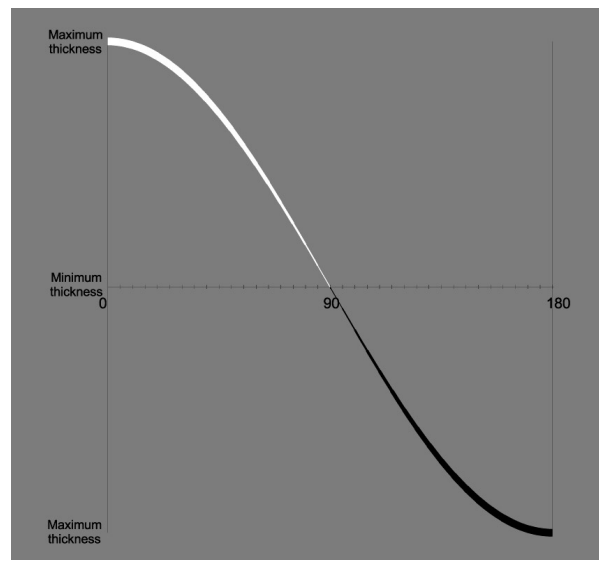


Figure A-4. Black and white line thickness based on $\cos(2\theta)$. The symmetry of this function between 0° and 180° results in visual balance, as well matching the thickness patterns of Tanaka's method presented in Figure A-1.

θ	$\cos(2q)$	Thickness (pt)
90	-1.000000	-2.88
85	-0.984808	-2.84
80	-0.939693	-2.71
75	-0.866025	-2.49
70	-0.766044	-2.21
65	-0.642788	-1.85
60	-0.500000	-1.44
55	-0.342020	-0.98
50	-0.173648	-0.50
45	0.000000	NA
40	0.173648	0.50
35	0.342020	0.98
30	0.500000	1.44
25	0.642788	1.85
20	0.766044	2.21
15	0.866025	2.49
10	0.939693	2.71
5	0.984808	2.84
0	1.000000	2.88

Table A-1. Relationship between black and white contour thickness values and the angle θ . Positive numbers represent white contours and negative numbers represent black contours. [Thickness is given in points].

ness values used in this paper are presented in Table A-1. The final column normalizes all values so that the thinnest contour has a thickness of 0.5 pt. Positive numbers represent white contours and negative numbers represent black contours. The shaded portion of the table accounts for 99.7 percent of the line segments by length in this study.