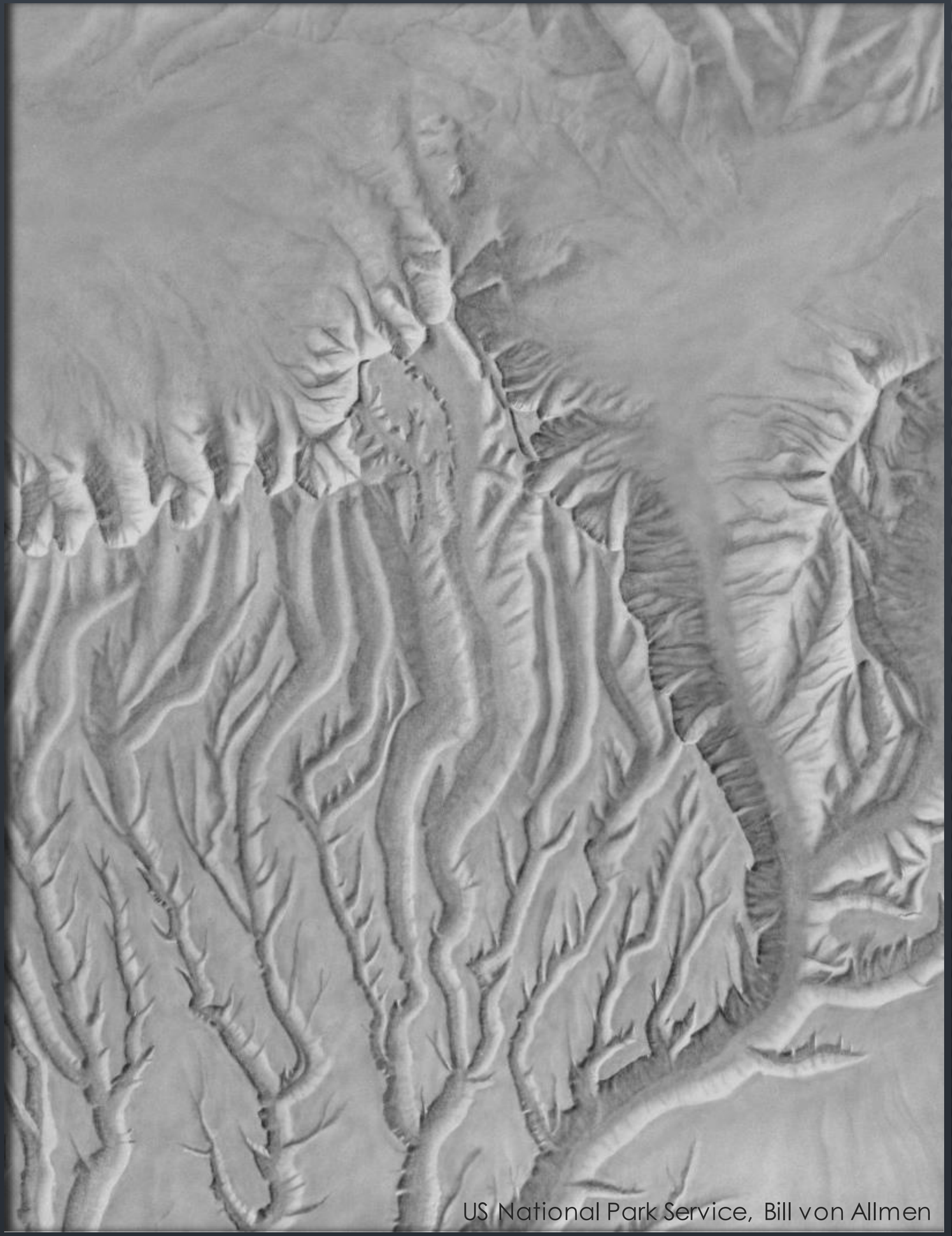
Gene Trantham
MGIS Capstone Project Proposal
Advisor: Dr Patrick Kennelly

Terrain Representation Using an Orientation Data Model



Terrain Representation

Foreshadowing:

- Hand-Drawn relief shading: time-consuming and expensive
- Analytic methods: Faster, consistent, reproducible results
- Often, the only data input is a DEM
- DEM may not be the most practical data model for terrain representation workflow
- Changing the data storage model:
  - Reduces run time for many analyses
  - opens the door to additional techniques
- Examples

BACKGROUND

ANALYTIC TERRAIN REPRESENTATION

THIS EXAMPLE

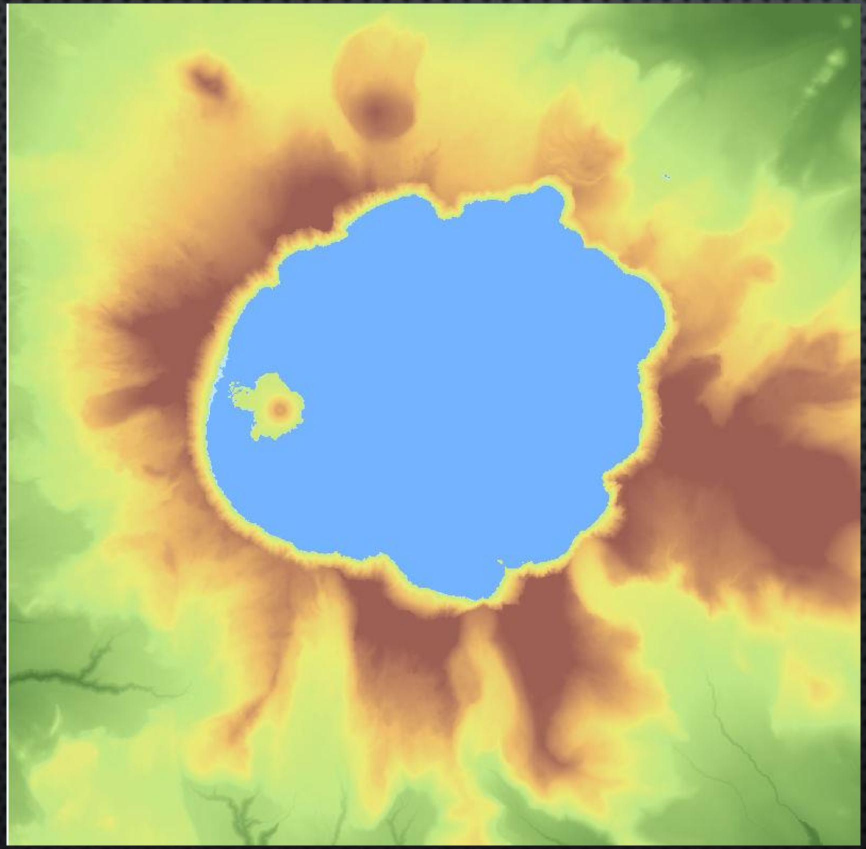
COMBINES HEIGHT &

ORIENTATION DATA

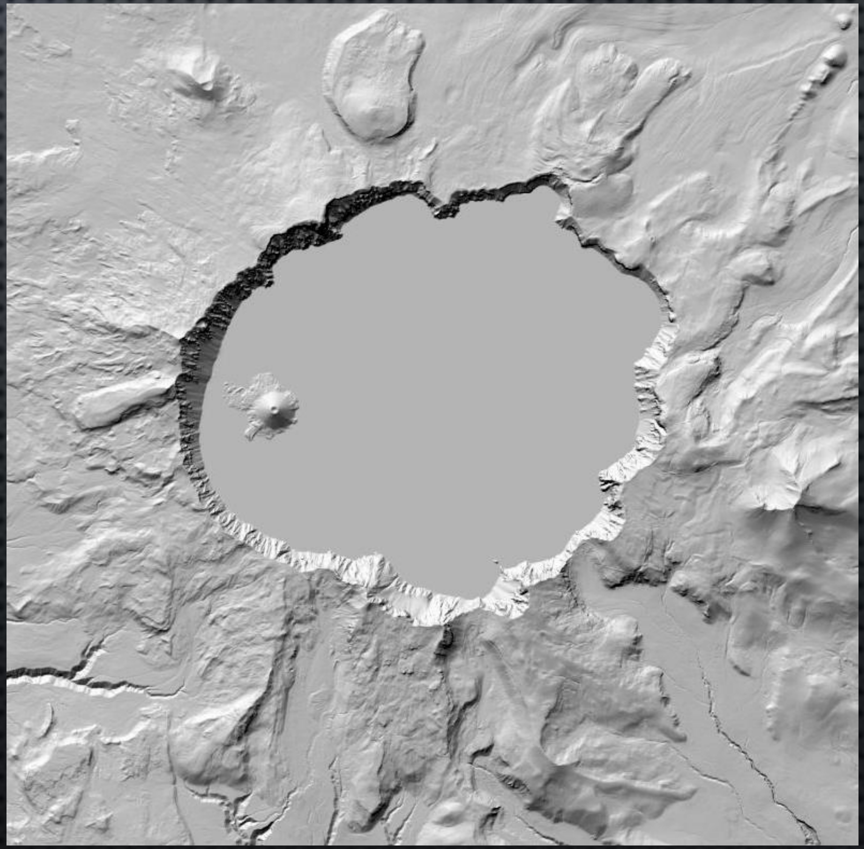
Crater Lake Elev ation Data: The Shaded Relief Archiv e http://shadedrelief.com/SampleElevationModels/

TWO COMPONENTS:

Elevation = Tint

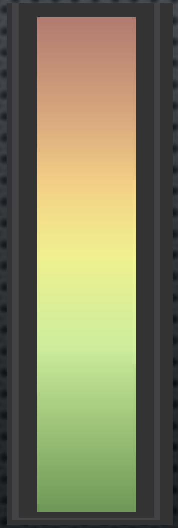


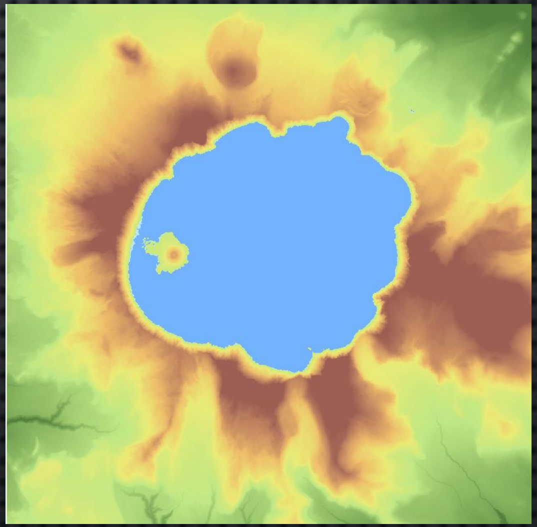
Orientation = Shade



HEIGHT / ELEVATION

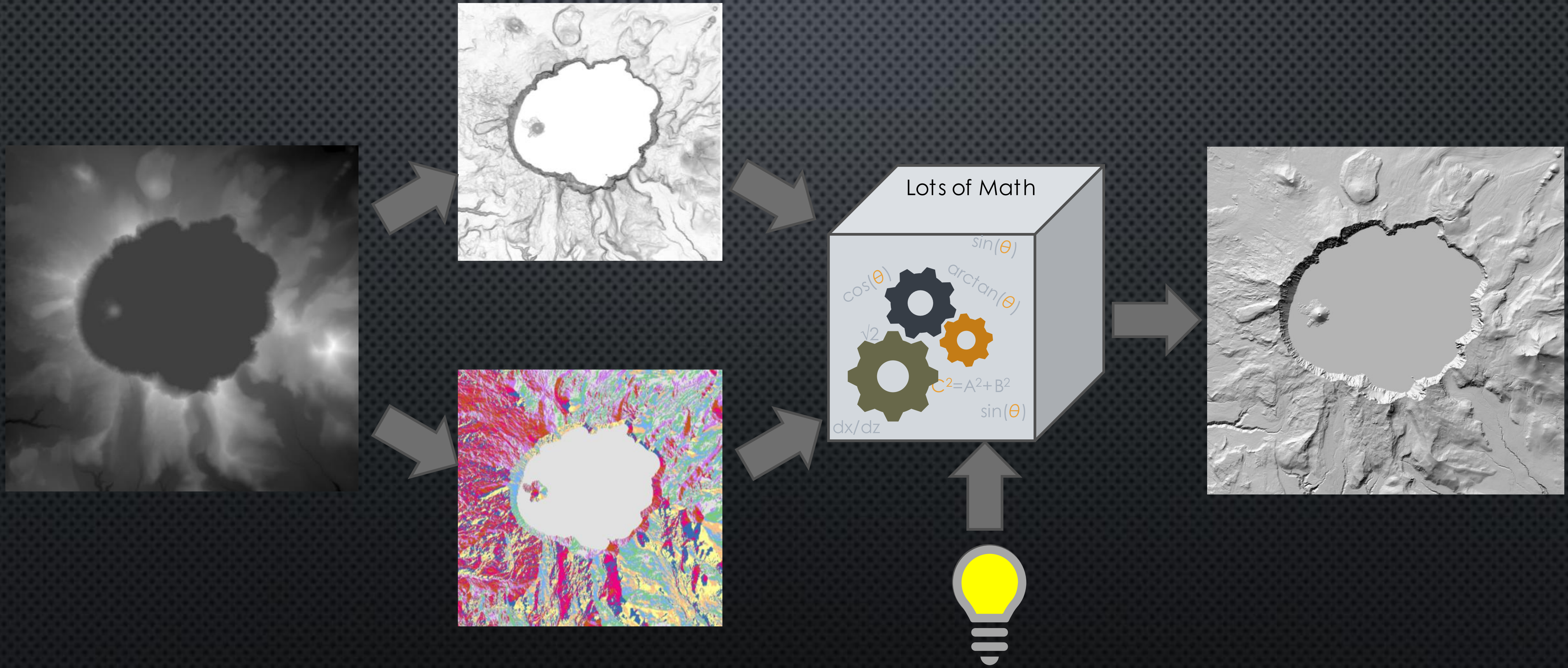
DEM is symbolized directly – Easy and Fast





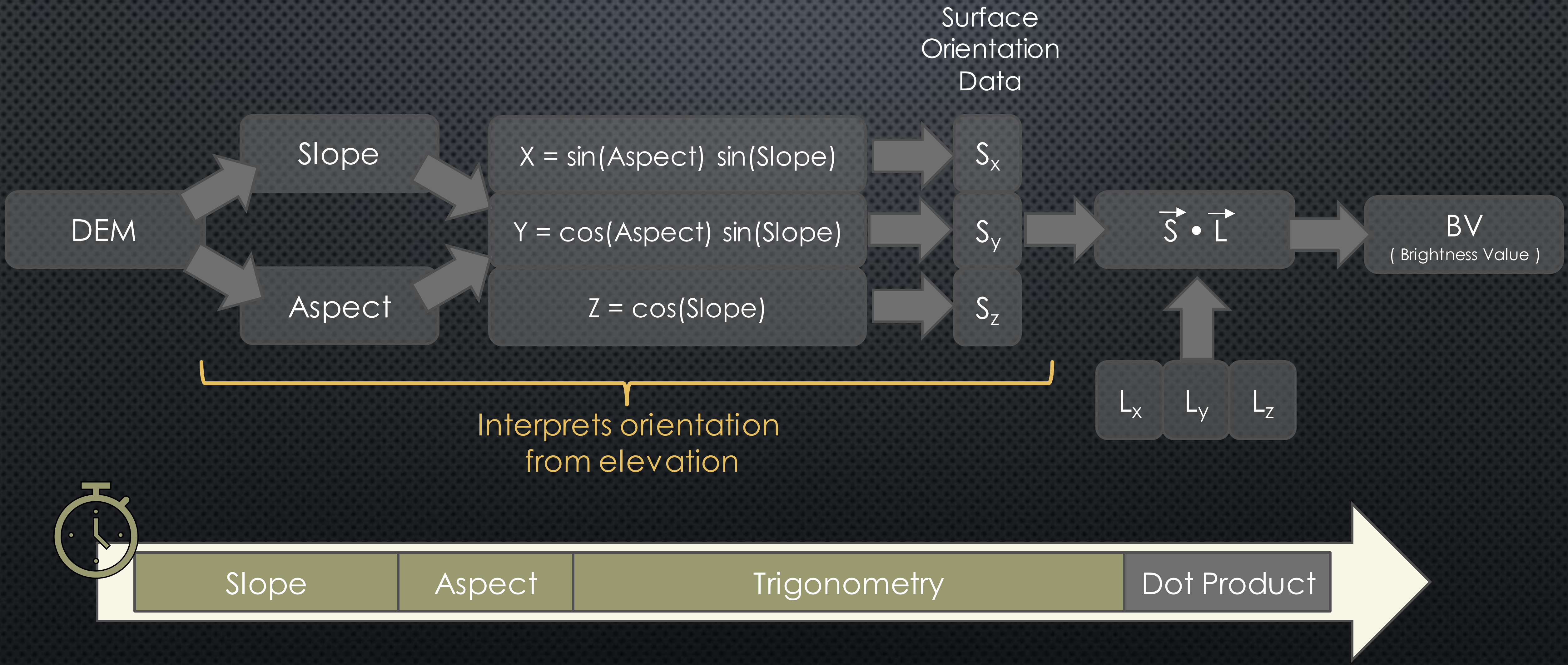
ORIENTATION

DERIVED FROM THE DEM USING A LENGTHY INTERNAL PROCESS



RELIEF SHADING

A.K.A. "HILLSHADING"



RELIEF SHADING

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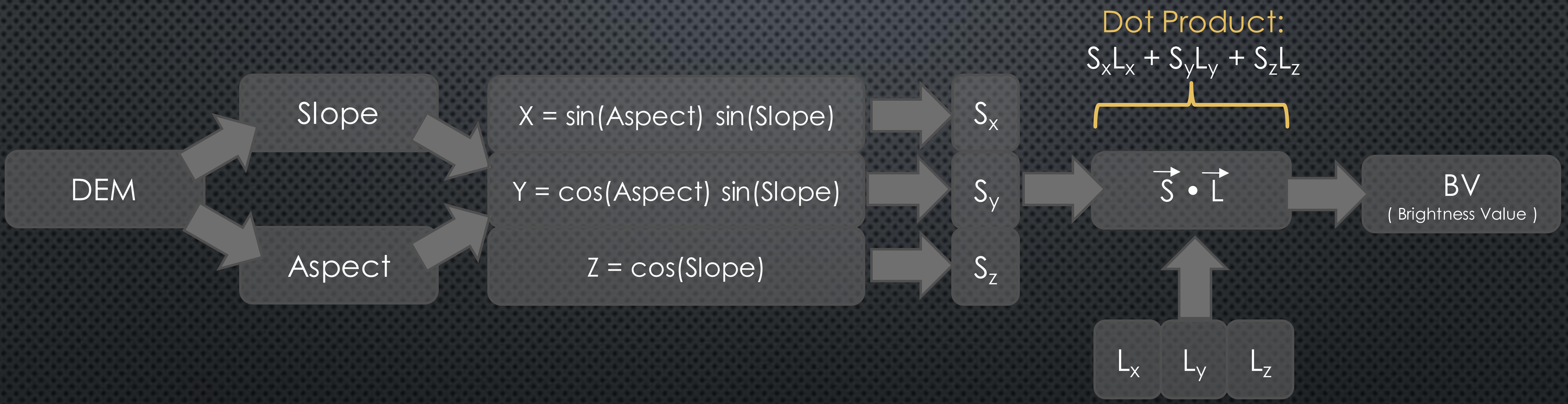
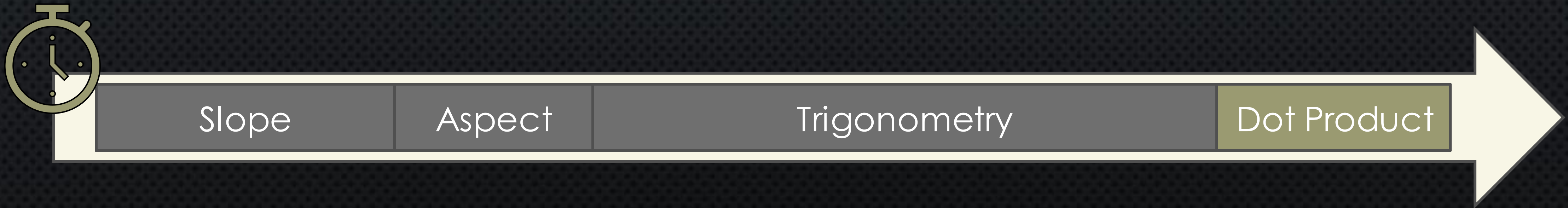




ORIENTATION DATA:

"SURFACE NORMAL VECTOR"

Reduces computational cost of hillshades and the workflows that depend on them.

Surface Normal Vectors can help us do other cool stuff borrowed from the computer graphics world.

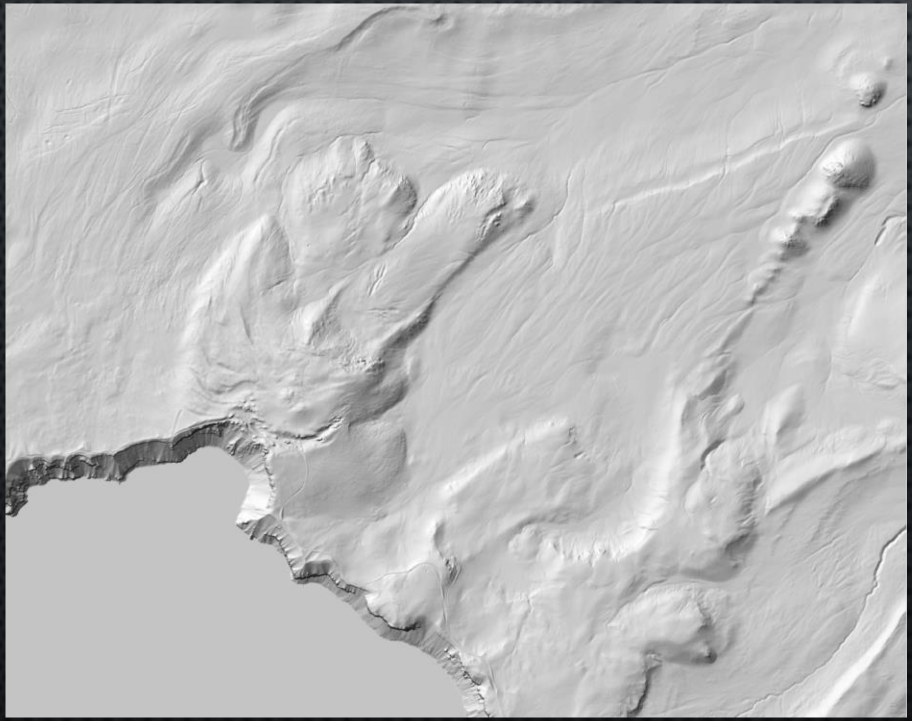
THE HIDDEN COSTS OF USING DEMs FOR ORIENTATION

- Calculating orientation internally from the DEM is expensive.
- The intermediate data layers are discarded when hillshade completes.
- Memory requirements are higher.
- For single-pass hillshades, this is not a big deal.
- For multi-directional hillshades, the cost is substantial.

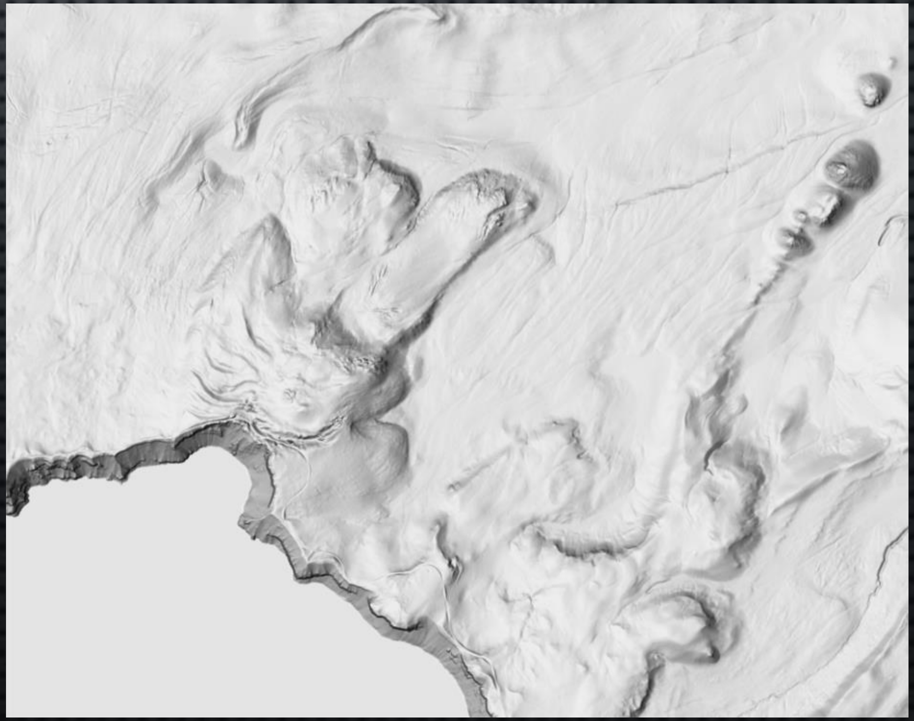
Mult-Direction Hillshades

A useful case study to examine orientation-sensitive symbology

Traditional



Multi-Directional



Some Multi-directional Methods

MDOW

Multi-Directional Oblique Weighted
Combines four traditional hillshades obtained from light sources at low altitude.

Multi-Directional (Esri)

A built-in multi-directional hillshade tool from the Raster Toolbox. Combines six traditional hillshades using a weighted sum.

Sky Illumination Model

The sky is partitioned into many zones, each of which carries an illumination source. Theoretically similar to MDOW, but with hundreds of light sources.

One — Number of Illumination Sources — Many

Traditional / Lambert

Relief shading technique based on a single light source and the assumption of a Lambertian surface. Shadows & specular reflections are ignored.

Multi-Directional Clustered

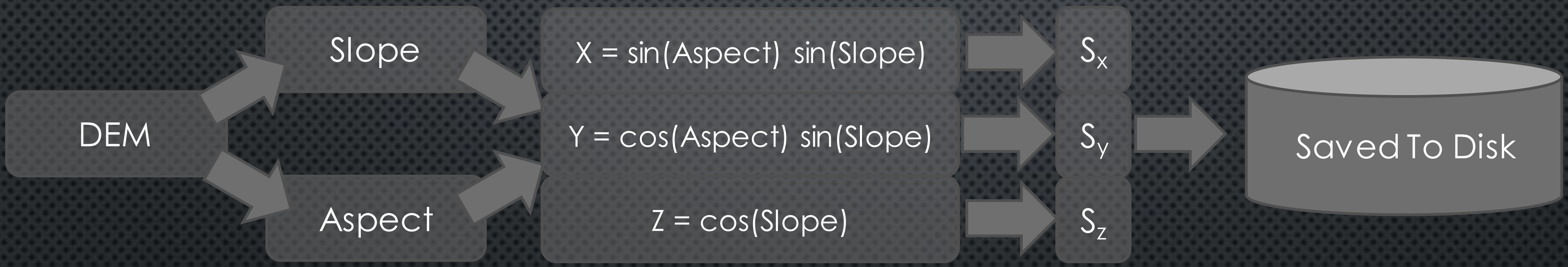
Dynamic technique using a variable illumination vector. Direction is tied to aspect; the terrain is divided into zones of similar aspect with a different illumination source applied to each zone.

DESCRIPTION OF THE PROBLEM

A height data source is ill-suited to methods symbolizing orientation.

SURFACE ORIENTATION DATA

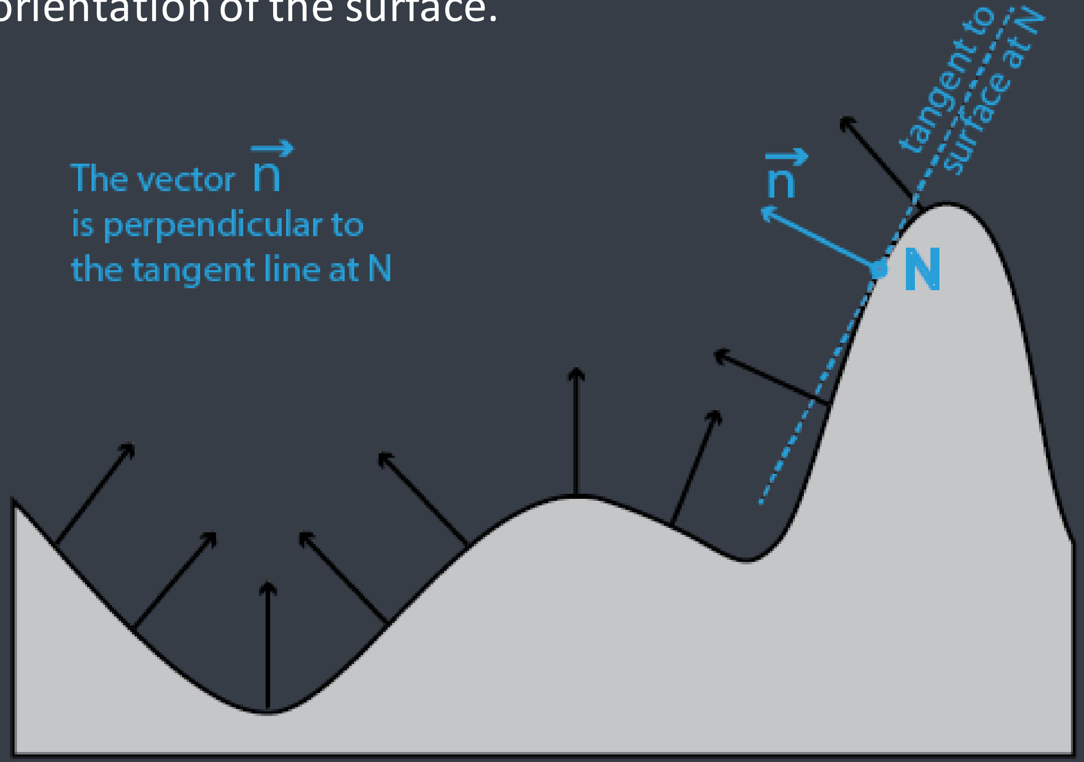
How to represent orientation as a dataset



HOW TO REPRESENT ORIENTATION DATA

Surface Normal Vectors are perpendicular to the local tangent.

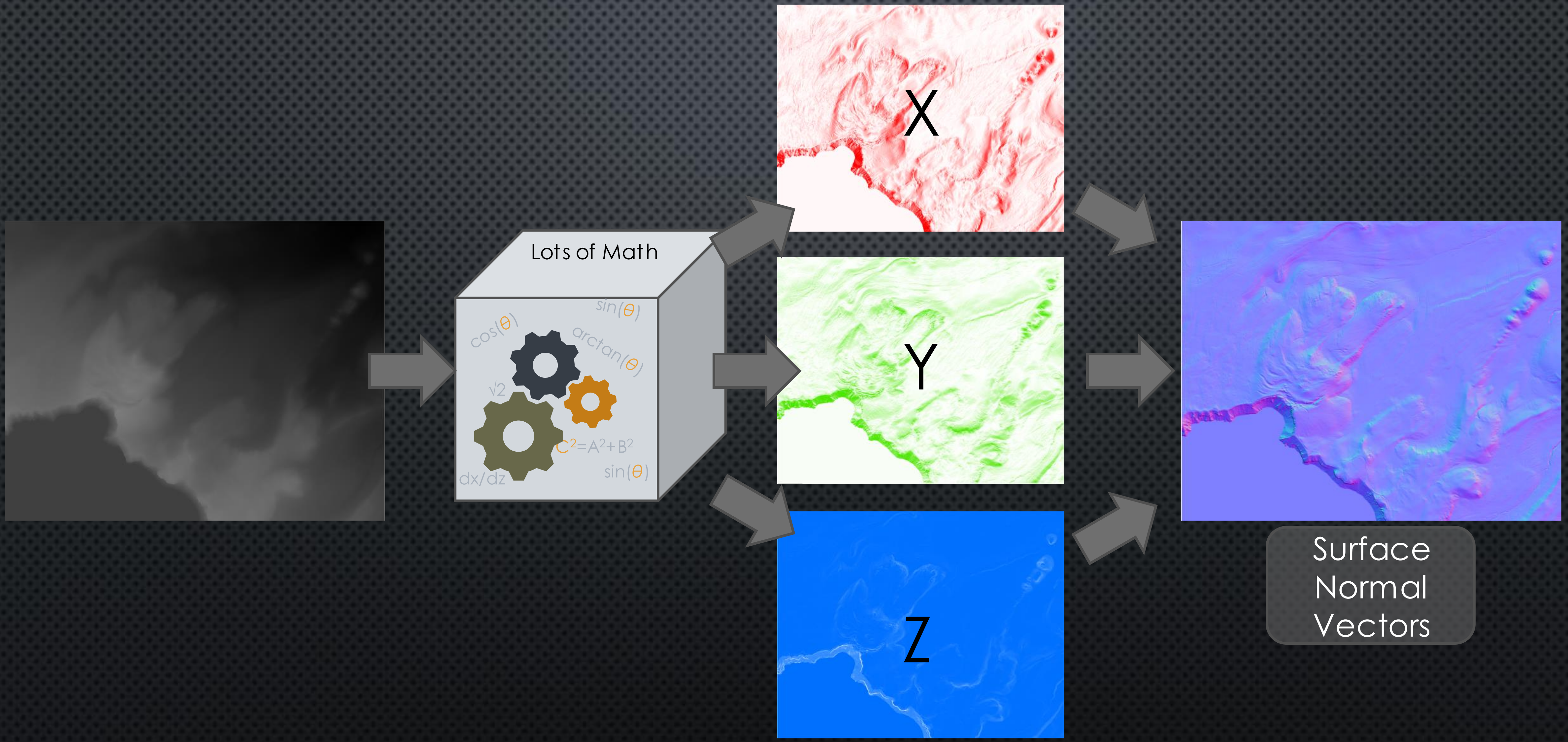
A 2D example: A line tangent to the surface generalizes its slope at that point. The vector perpendicular to that line encodes the orientation of the surface.



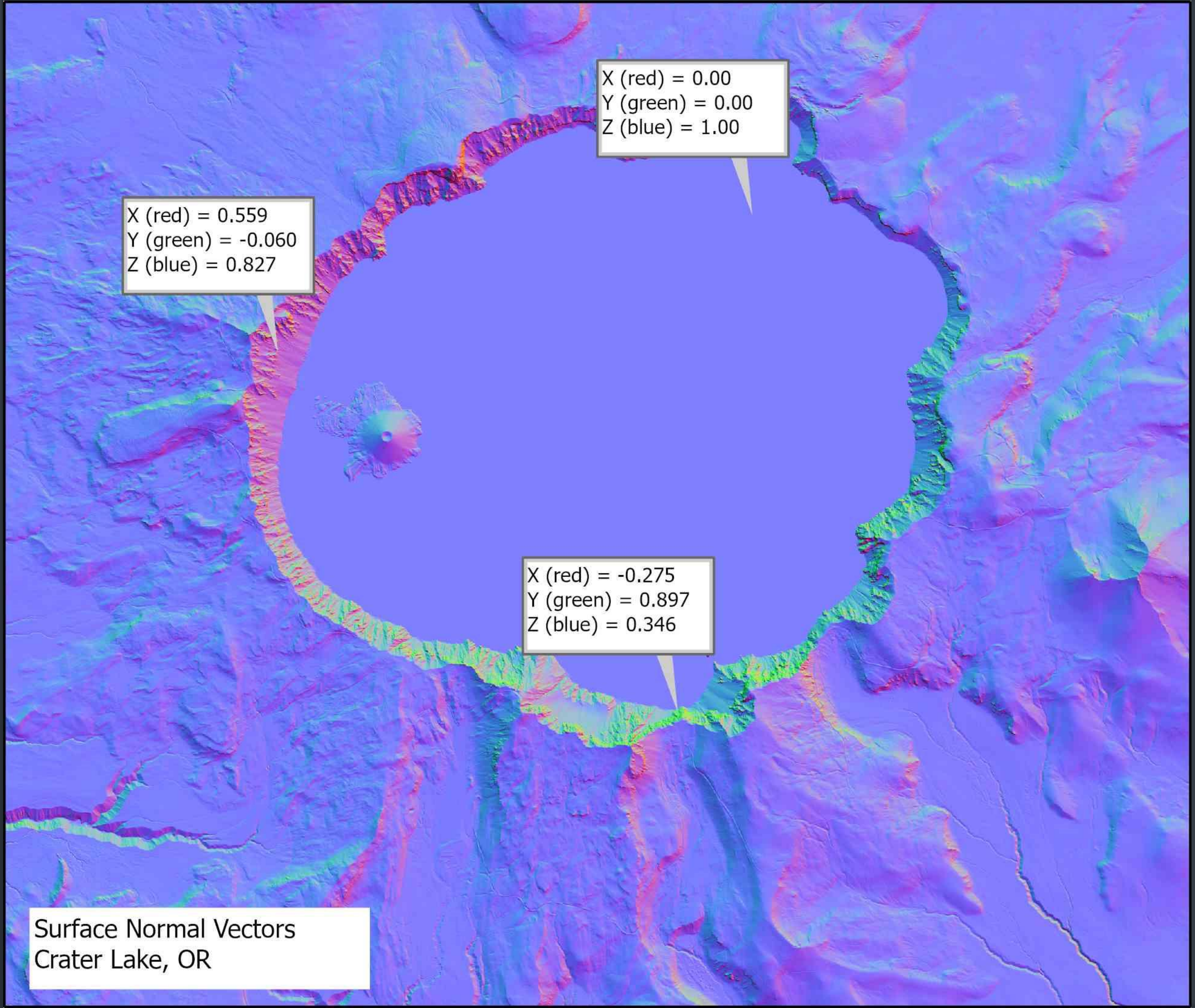
In 3D, the surface tangent is a plane, which captures slope and aspect. The normal vector is perpendicular to that plane.

3D vectors have three components: X, Y, & Z
"Normalized" to length one.

From DEM to Surface Normals

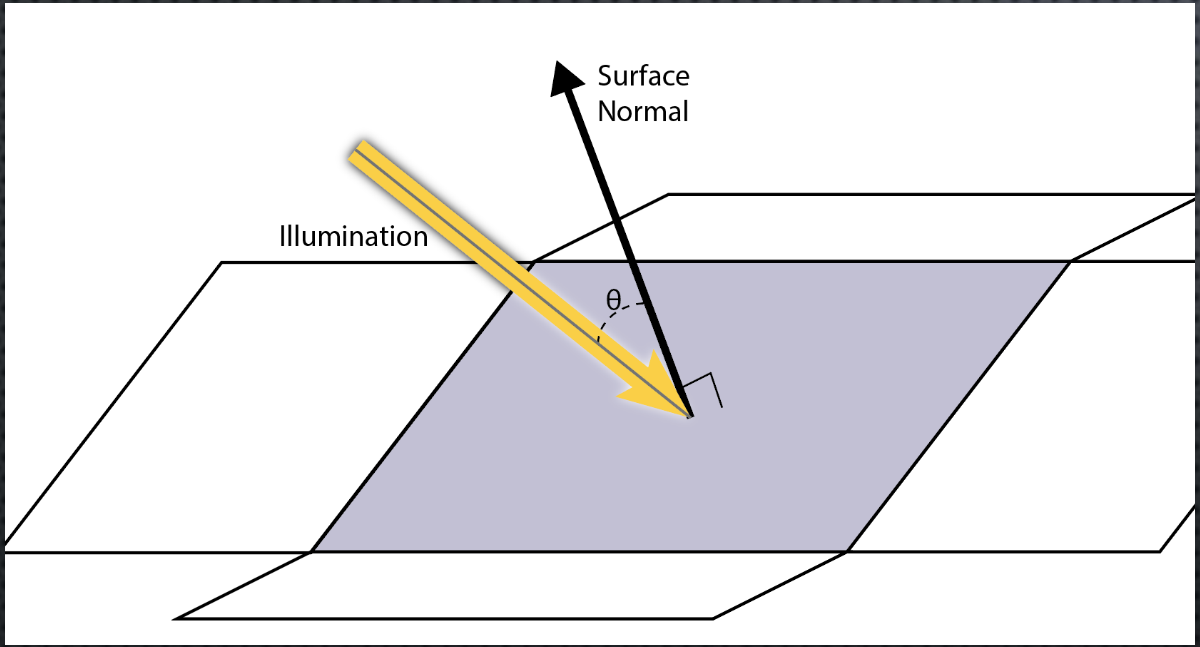


SURFACE NORMAL VECTOR AS RGB IMAGE



Relief Shading

Surface Normals Simplify Shading



The brightness value is

$BV = |S|\ |L|\ \cos(\theta)$

These vectors are normalized to length one:

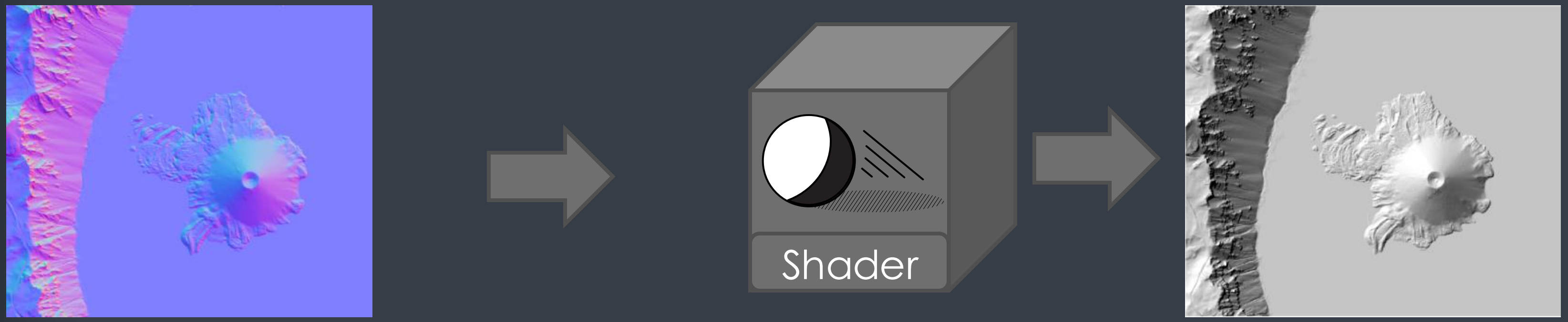
$BV = \cos(\theta)$

$\cos(\theta)$ is the dot product of these two vectors.

$$
\begin{aligned}
BV &= \cos(\theta) \\
&= S \bullet L \\
&= S_x L_x + S_y L_y + S_z L_z
\end{aligned}
$$

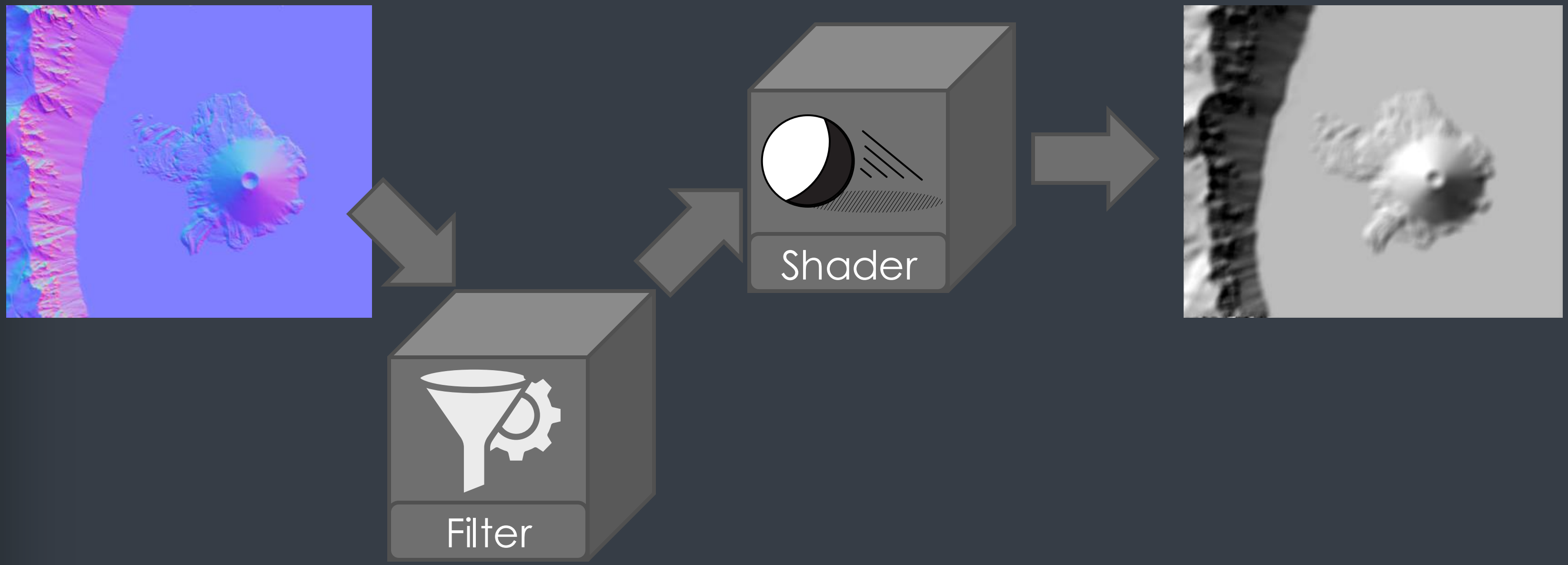
WORKFLOW:

SURFACE NORMAL & SHADER



NEW (TO GIS) METHODS:

SURFACE NORMAL FILTERING



- Generalization via low-pass filters
- Sharpen edges with a sharpening filter
- "Bump Mapping"

SURFACE NORMAL FILTERING

Preppernau(2020) *Normalizing the Normal Map*. Cartographic Perspectives. No96
DOI : 10.14714/CP96.1669

OBJECTIVES

Describe and implement a data model comparable to other industries.

Code GP tools for ArcGIS Pro to use data in this form. Create simplified versions of selected terrain representation methods:

- MDOW
- Sky Illumination
- Illuminated Contours

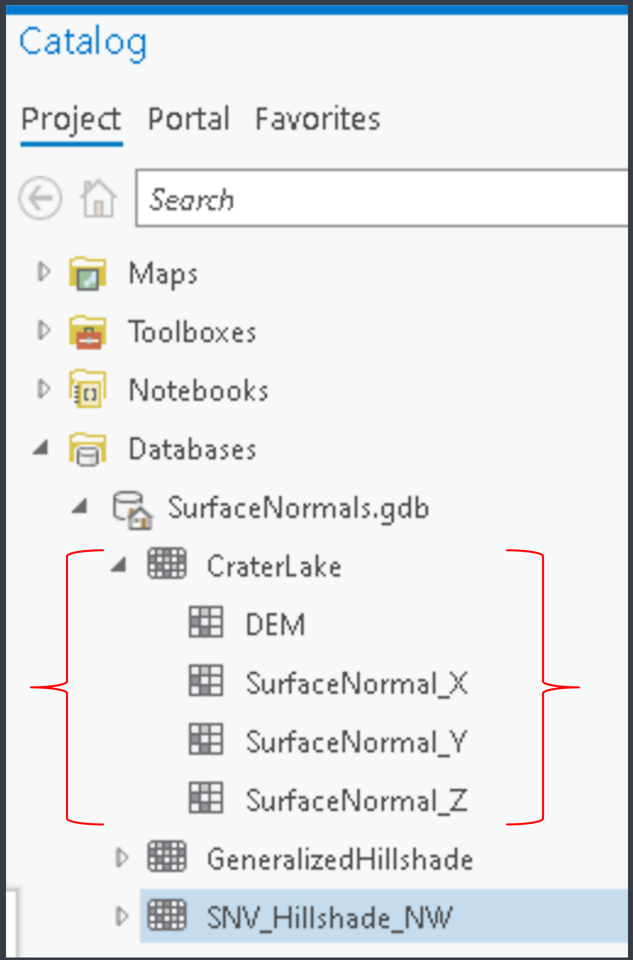
Code new GP tools to implement CG effects within ArcGIS Pro:

- Bump Mapping
- Specular Highlights

Suggest future uses of a vector data model for cartography.

METHODS

SAVE AS MULTI-BAND RASTER



The 'CraterLake' Raster Dataset contains 4 bands, named for their content.

Storing as a multi-band raster ensures consistency with:

- Coordinate system
- Projection
- Cell size
- Snap / alignment

IMPLEMENT TOOLSETS

ArcGIS Pro Python Toolboxes

Relief Shading

- Data converstion tool
- Re-implement the stock hillshade algorithm
- Recreate multi-directional method chains (MDOW, Sky Illumination, etc)

Extra Tools — Other uses for vector data

- 3D graphics effects.
- Analyses involving gradient:
  - Line Integral Convolution
  - Hydrology

COMPARE SPEED AND RESOURCE UTILIZATION

Speed is easily measured within the ArcGIS environment using programming tools.

Memory consumption is also measurable from the programming environment.

Compare vs the published implementations in Esri's TerrainTools

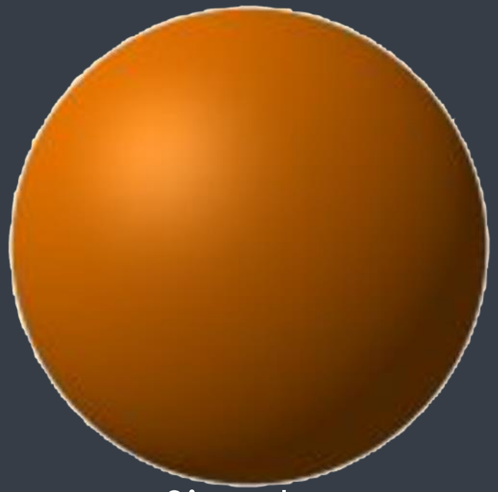
DEMONSTRATE NEW METHODS

BORROWED FROM CG FOLKS

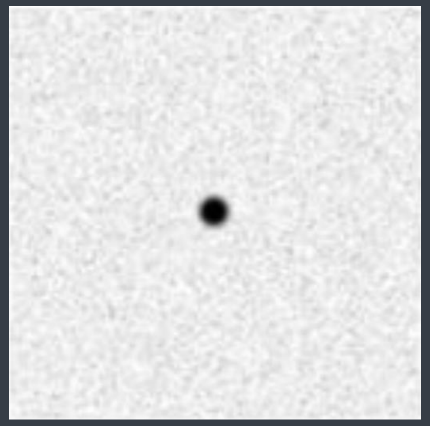
Bump Mapping: Gives the illusion of texture on a surface.

Specular Highlighting: Identifies areas of spot reflection.

BUMP MAPPING EXAMPLE OUTPUT



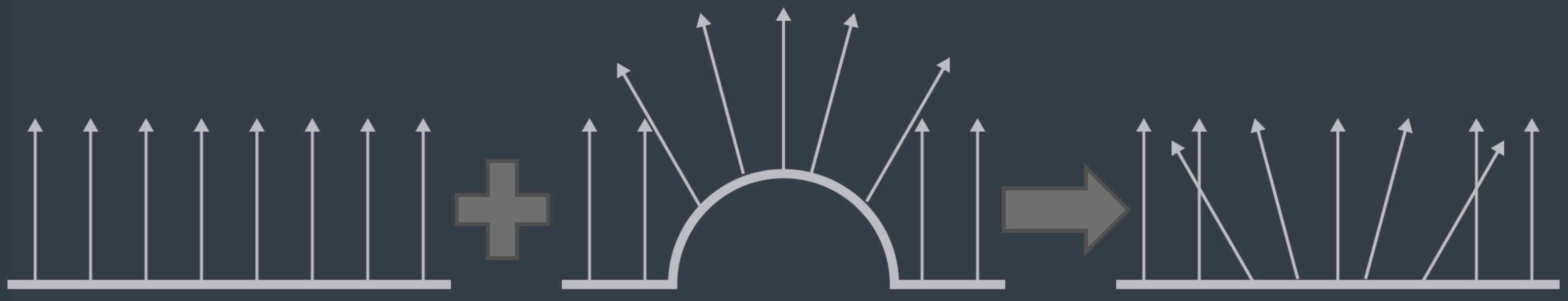
Simple Geometry



Bump Map

Abate, T & Bachtel, G (n.d.) Tangent Space & Bump/Parallax/Horizon Mapping. https://creativecoding.soe.ucsc.edu/courses/cmpm164/_schedule/BumpmappingEtc.pdf

BUMP MAPPING



The bump map defines how the original surface vectors are to be adjusted or perturbed.

The shader works on these adjusted normals, not the surface, so the effect is as if the surface itself were perturbed.

The underlying surface is not modified.

SPECULAR HIGHLIGHTS

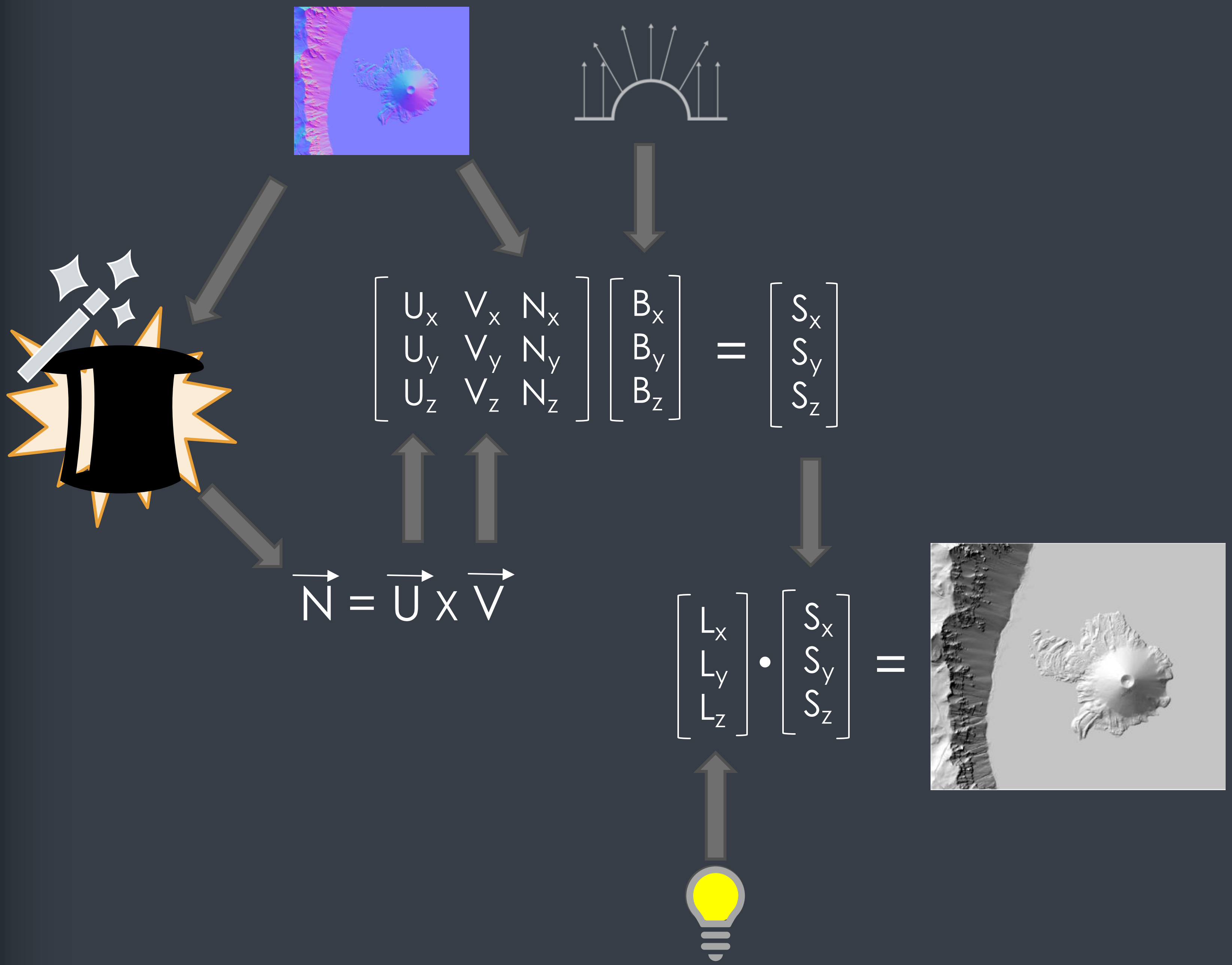
Treats the surface as if it is glossy or reflective.

Highlights are independent of shading. Depend on light source and camera location.

CG METHODS

SCARY
LINEAR ALGEBRA

COMPLEX BUT WELL-MAPPED PROCEDURES



EXPECTED RESULTS & DELIVERABLES

GP TOOLS:

SMALLER & FASTER

Deliverable: Python toolbox implementing orientation-aware tools.

- Time trials will show speed improvements over currently published tools.
- Speed improvements proportional to the number of constituents in a multi-directional method.

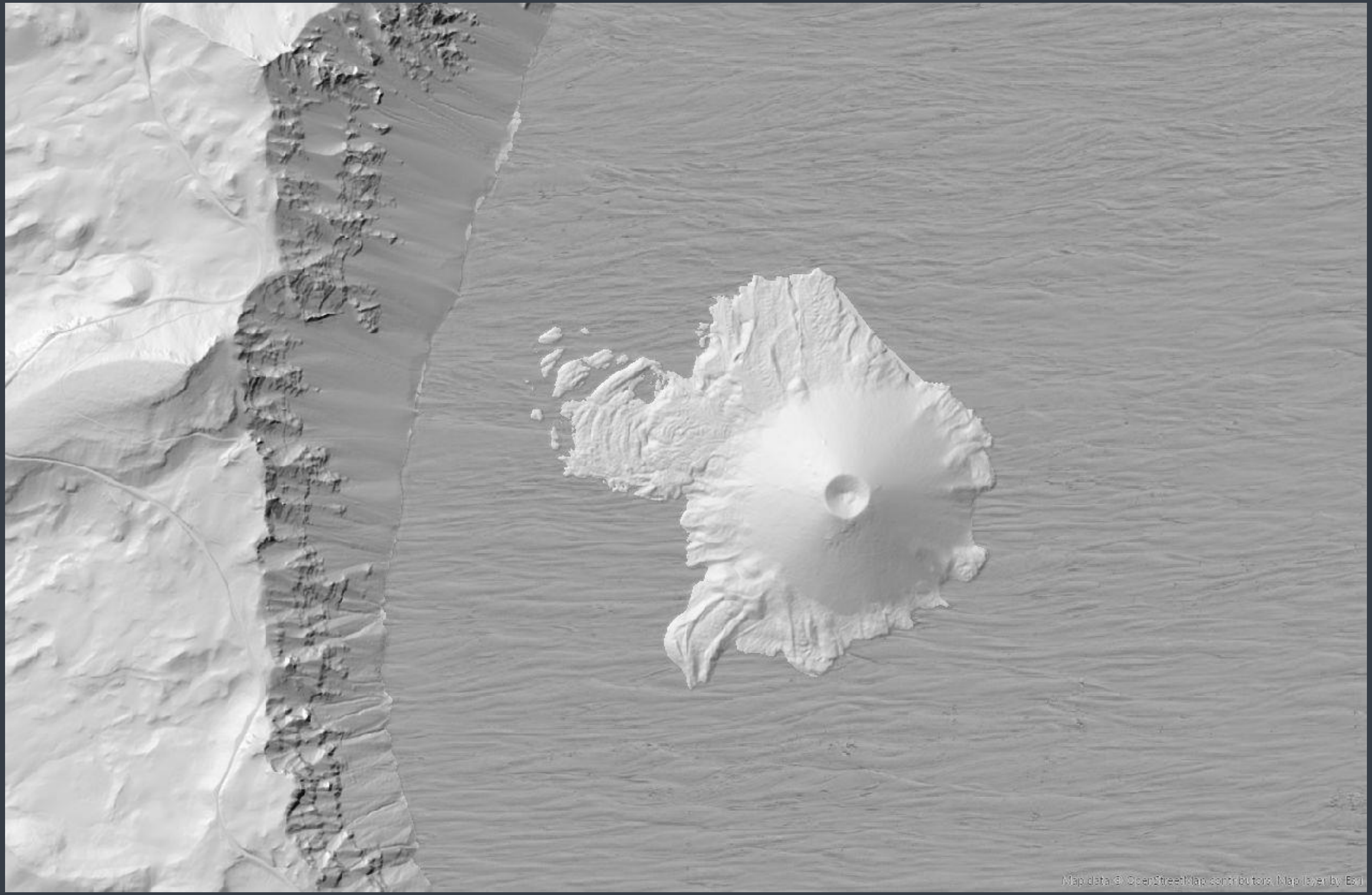
DELIVERABLE:

NEW TOOL: BUMP MAPPING

BUMP MAPPING TOOL:

A MORE PRACTICAL EXAMPLE

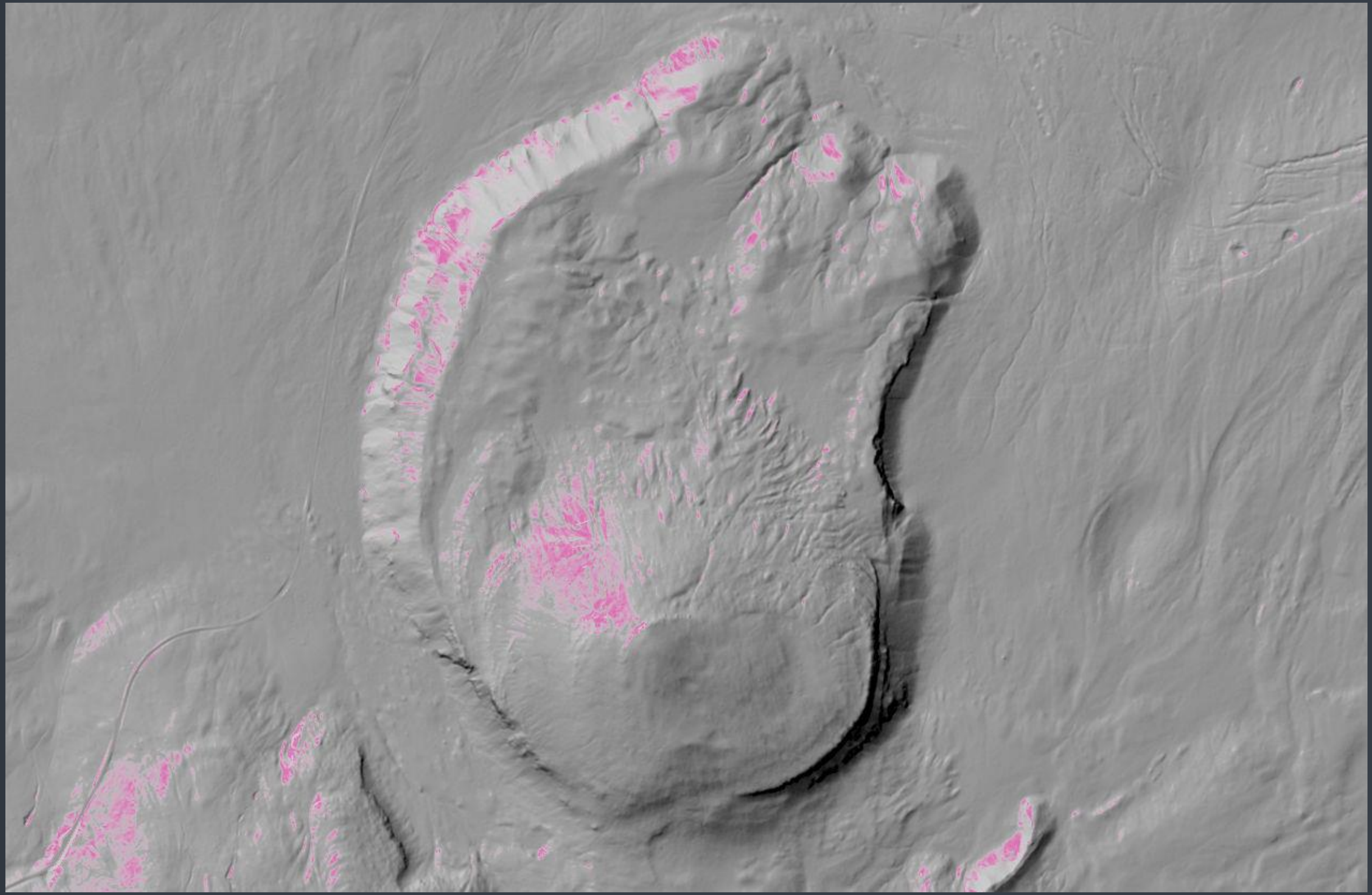
"Wave" bump map masked to area of water surface only



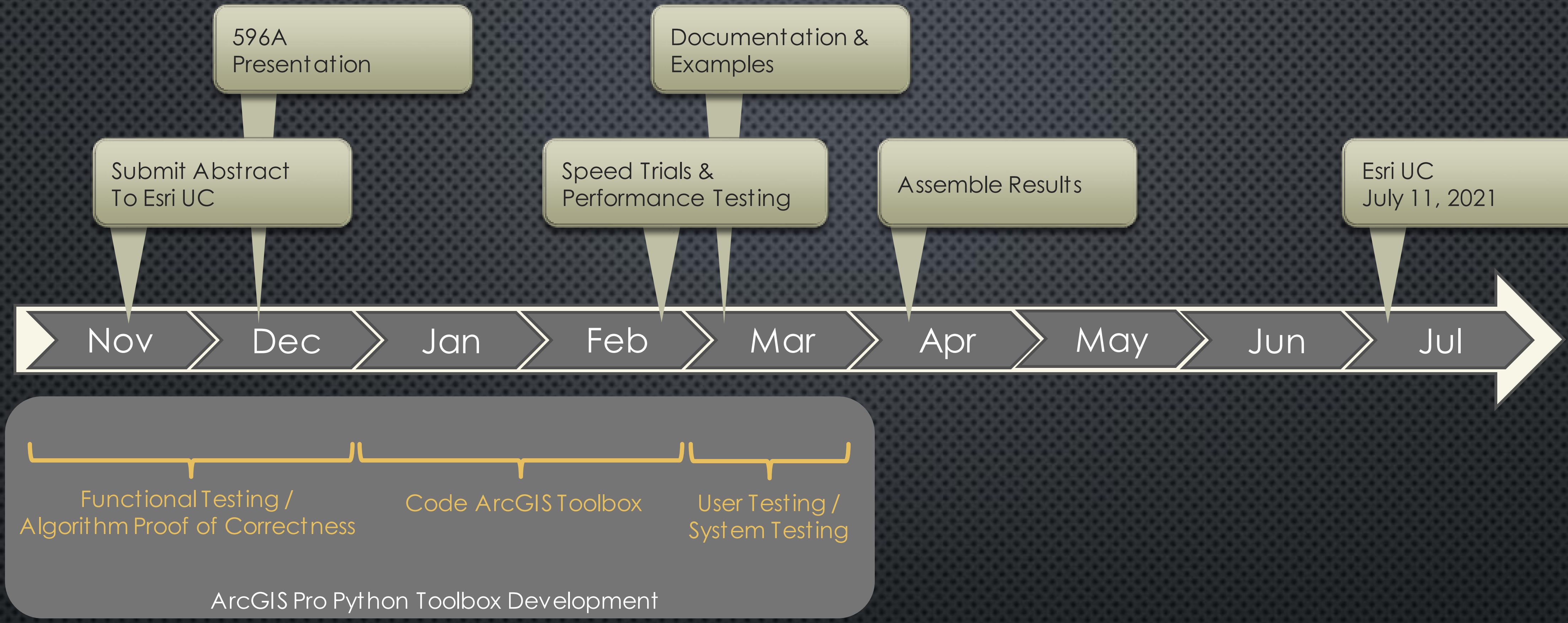
DELIVERABLE:

NEW TOOL: SPECULAR HIGHLIGHTING

This example uses a false color highlight to emphasize placement.



TIMELINE



PROGRESS & MILESTONES

THANK YOU

Questions & Comments: gzt5142@psu.edu

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