r.earthworks: a GRASS tool for terrain modeling

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DOI: 10.xxxxxx/draft

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Submitted: 01 January 1970
Published: unpublished

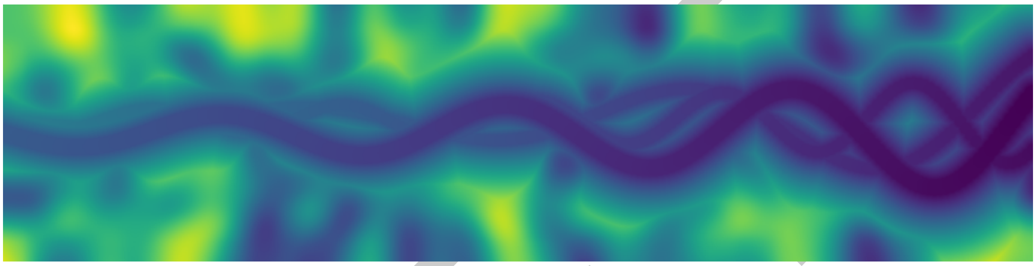

Figure 1: Channel modeled with r.earthworks

Summary

`r.earthworks` is a tool for modeling terrain in `GRASS`, a free and open source geospatial processing engine (GRASS Development Team et al., n.d.). This tool – inspired by earthworking operations that reshape the earth's surface – transforms existing terrain rasters. Earthworks are constructed by excavating or embanking soil and rock. In cut operations, earth is removed, dug out by machines such as excavators or pushed away by dozers. In fill operations, earth is added, deposited by machines such as loaders or pushed in place by dozers. `r.earthworks` models topographic change as cut or fill operations that add to or subtract from a topographic surface. Topographic change can be calculated relative to a vertical datum to model features at a given elevation or relative to the topographic surface to model features that follow the terrain. While inspired by earthworking processes, `r.earthworks` can be used to model natural as well as constructed landforms. Applications include procedurally generating terrain (Figure 1), designing earthworks (Figure 2), modeling landforms (Figure 3), simulating processes such as dam or levee breaches, reconstructing historic landscapes, and removing anomalies. As part of the `GRASS` ecosystem, r.earthworks can easily be used in conjunction with other tools for geomorphometry (Jasiewicz & Stepinski, 2013), hydrological modeling (Mitášová et al., 2004), erosion modeling (Harmon et al., 2019), and temporal analysis (Gebbert & Pebesma, 2017) in Python scripts and Jupyter notebooks (Haedrich et al., 2023).

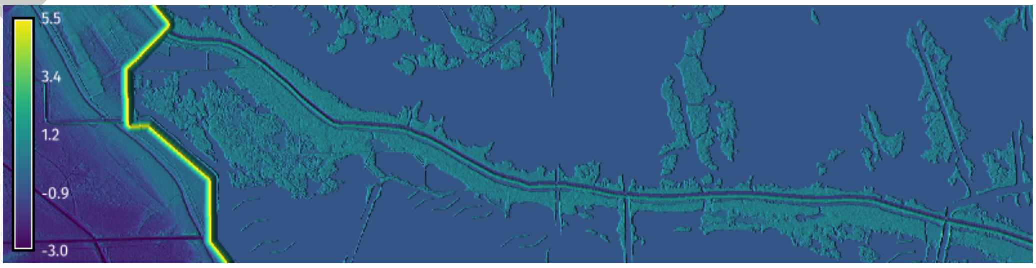

Figure 2: Levee improvements and ridge restoration modeled with r.earthworks

Statement of need

While modeling the shape of the earth's surface is of interest to many sectors, approaches and thus software vary widely across disciplines. Spatial scientists use remote sensing software, geographic information systems, and geospatial programming to reconstruct real terrain (Grohmann et al., 2020). The computer graphics community uses procedural terrain generators and simulations of physical processes to synthesize novel terrain (Galin et al., 2019; Musgrave et al., 1989). The architecture, engineering, and construction sector uses computer aided design software to model and then build earthworks (Hurkxkens & Bernhard, 2019; **?**; **?**; **?**). Workflows across disciplines can be complex because of the need to move between modeling paradigms in different, often proprietary software solutions. While there are many tools for reconstructing, generating, and transforming terrain, there is a need for free and open source geospatial tools for procedurally reshaping terrain. `r.earthworks` was developed to fill this gap by providing a free and open source tool for transforming terrain that can be used in geospatial programming workflows.

Gullies modeled with r.earthworks

Figure 3: Gullies modeled with r.earthworks

Functionality

`r.earthworks` functionality includes the transformation of terrain rasters and calculation of volumetric change. Its features include cut and fill operations, relative or absolute datums, growth and decay functions for determining slopes, flats at local minima or maxima, and volumetric calculations. It can be used not only to model basic landforms such as flats, peaks, ridges, shoulders, spurs, slopes, hollows, footslops, valleys, and pits, but also complex natural and anthropogenic features.

In `r.earthworks`, terrain – abstracted as a 2-dimensional manifold in 3-dimensional Euclidean space – is represented as a raster grid for efficient storage, analysis, and transformation. Transformations are based on proposed local topographic extrema which can be derived from data, procedurally generated, or sketched. These local minima and maxima are modeled as low points for cut operation or high points for fill operations. Transformations are a function of the existing elevation, change in vertical distance, and change in slope over horizontal distance. Vertical distance is calculated as the difference between proposed local extrema and a topographic datum, while change in slope is a function of growth and decay applied to horizontal change in distance. Transformations are calculated independently for each local minima or maxima and are then accumulated before being applied to the existing terrain.

This tool was designed for use in spatial science workflows working with large terrain datasets. Since `r.earthworks` is raster based, it is efficient, scalable, flexible, and interoperable; it can process large elevation datasets, be used in workflows with other raster-based tools, and its results can be exported in common raster, point cloud, and array formats. After `r.earthworks` has been used to model topographic change, other `GRASS` tools can be used to analyze the resulting terrain and simulate physical processes such as surface flows of water and sediment. Through the `GRASS` Python application programming interface (API), `r.earthworks` can easily be integrated into data science workflows in Python. This tool includes automated tests, documentation, tutorials, and computational notebooks.

Usage

To model random peaks with `r.earthworks` in Python (Figure 2), start a `GRASS` session and run the following code:

```python
# Import GRASS package
import grass.script as gs

# Install extension
gs.run_command("g.extension", extension="r.earthworks")

# Set computational region
gs.run_command("g.region", n=500, e=500, s=0, w=0, res=1)

# Generate base terrain
gs.mapcalc("elevation = 0")

# Generate random surface
gs.run_command("r.surf.random", out="surface", min=0, max=25)

# Sample random points
gs.run_command(
    "r.random",
    input="surface",
    npoints=50,
    raster="random",
    flags="s"
    )

# Model earthworks
gs.run_command(
    "r.earthworks",
    elevation="elevation",
    earthworks="earthworks",
    operation="fill",
    raster="random",
    rate=0.25,
    flat=25
    )
```

Random earthworks

Figure 4: Random earthworks

Acknowledgements

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References

Galin, E., Guérin, E., Peytavie, A., Cordonnier, G., Cani, M.-P., Benes, B., & Gain, J. (2019). A review of digital terrain modeling. *Computer Graphics Forum*, *38*(2), 553–577. https://doi.org/https://doi.org/10.1111/cgf.13657

Gebbert, S., & Pebesma, E. (2017). The GRASS GIS temporal framework. *International Journal of Geographical Information Science*, *31*(7), 1273–1292. https://doi.org/10.1080/13658816.2017.1306862

GRASS Development Team, Landa, M., Neteler, M., Metz, M., Petrášová, A., Petráš, V., Clements, G., Zigo, T., Larsson, N., Kladivová, L., Haedrich, C., Blumentrath, S., Andreo, V., Cho, H., Gebbert, S., Nartišs, M., Kudrnovsky, H., Delucchi, L., Zambelli, P., … Bowman, H. (n.d.). *GRASS GIS* (Version 8.4.0). https://doi.org/10.5281/zenodo.4621728

Grohmann, C. H., Garcia, G. P. B., Affonso, A. A., & Albuquerque, R. W. (2020). Dune migration and volume change from airborne LiDAR, terrestrial LiDAR and structure from motion-multi view stereo. *Computers & Geosciences*, *143*, 104569. https://doi.org/https://doi.org/10.1016/j.cageo.2020.104569

Haedrich, C., Petráš, V., Petrášová, A., Blumentrath, S., & Mitášová, H. (2023). Integrating GRASS GIS and jupyter notebooks to facilitate advanced geospatial modeling education. *Transactions in GIS*, *27*(3), 686–702. https://doi.org/https://doi.org/10.1111/tgis.13031

Harmon, B. A., Mitášová, H., Petrášová, A., & Petráš, V. (2019). r.sim.terrain 1.0: a landscape evolution model with dynamic hydrology. *Geoscientific Model Development*, *12*(7), 2837–2854. https://doi.org/10.5194/gmd-12-2837-2019

Hurkxkens, I., & Bernhard, M. (2019). *Docofossor* (Version 0.904).

Jasiewicz, J., & Stepinski, T. F. (2013). Geomorphons – a pattern recognition approach to classification and mapping of landforms. *Geomorphology*, *182*, 147–156. https://doi.org/https://doi.org/10.1016/j.geomorph.2012.11.005

Mitášová, H., Thaxton, C., Hofierka, J., McLaughlin, R., Moore, A., & Mitáš, L. (2004). Path sampling method for modeling overland water flow, sediment transport, and short term terrain evolution in open source GIS. In C. T. Miller & G. F. Pinder (Eds.), *Computational methods in water resources: Volume 2* (Vol. 55, pp. 1479–1490). Elsevier. https://doi.org/https://doi.org/10.1016/S0167-5648(04)80159-X

Musgrave, F. K., Kolb, C. E., & Mace, R. S. (1989). The synthesis and rendering of eroded fractal terrains. *ACM SIGGRAPH Computer Graphics*, *23*(3), 41–50. https://doi.org/10.1145/74334.74337