

¹ r.earthworks: a GRASS tool for terrain modeling

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Software

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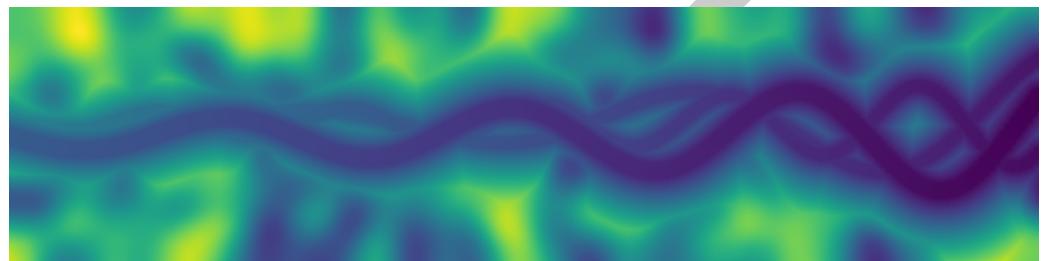


Figure 1: Channel modeled with r.earthworks

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Summary

⁵ r.earthworks is a tool for modeling terrain in GRASS, a free and open source geospatial processing engine ([GRASS Development Team et al., 2025](#)). 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. ⁶ r.earthworks models topographic change as cut or fill operations that add to or subtract ⁷ from a topographic surface. Topographic change can be calculated relative to a vertical ⁸ datum to model features at a given elevation or relative to the topographic surface to model ⁹ features that follow the terrain. While inspired by earthworking processes, r.earthworks can ¹⁰ be used to model natural as well as constructed landforms. Applications include procedurally ¹¹ generating terrain ([Figure 1](#)), designing earthworks ([Figure 2](#)), modeling landforms ([Figure 3](#)), ¹² simulating processes such as dam or levee breaches, reconstructing historic landscapes, and ¹³ removing anomalies. As part of the GRASS ecosystem, r.earthworks can easily be used in ¹⁴ conjunction with other tools for geomorphometry ([Jasiewicz & Stepinski, 2013](#)), hydrological ¹⁵ modeling ([Mitášová et al., 2004](#)), erosion modeling ([Harmon et al., 2019](#)), and temporal ¹⁶ analysis ([Gebbert & Pebesma, 2017](#)) in Python scripts and Jupyter notebooks ([Haedrich et al., ¹⁷ 2023](#)). ¹⁸

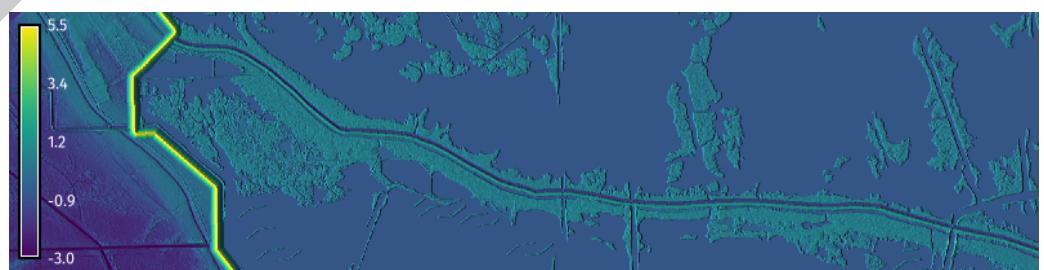


Figure 2: Levee improvements and ridge restoration modeled with r.earthworks

23 Statement of need

24 While modeling the shape of the earth's surface is of interest to many sectors, approaches and
 25 thus software vary widely across disciplines. Spatial scientists use remote sensing software,
 26 geographic information systems, and geospatial programming to reconstruct real terrain
 27 ([Grohmann et al., 2020](#)) and model the physical processes that shape it ([Barnhart et al., 2020](#);
 28 [Hobley et al., 2017](#)). The computer graphics community uses procedural terrain generators
 29 and simulations of physical processes to synthesize novel terrain ([Galin et al., 2019](#); [Musgrave](#)
 30 [et al., 1989](#)). The architecture, engineering, and construction sector uses computer aided
 31 design software to model and then build earthworks ([Hurkxkens & Bernhard, 2019a, 2019b](#);
 32 [Jud et al., 2021](#); [Petschek, 2012](#)). Workflows across disciplines can be complex because of the
 33 need to move between modeling paradigms in different, often proprietary software solutions
 34 with different data structures. While there are many tools for reconstructing, generating, and
 35 transforming terrain, there is a need for free and open source geospatial tools for procedurally
 36 reshaping terrain. `r.earthworks` was developed to fill this gap by providing a free and open
 37 source tool for transforming terrain that can be used in geospatial programming workflows.
 38 It brings terrain modeling concepts from computer graphics and computer aided design
 39 into a geospatial modeling and programming environment, eliminating the need for complex
 40 workflows across modeling paradigms. `r.earthworks` was designed so that spatial scientists
 41 can generate and transform terrain in a geospatial programming environment, providing the
 42 geospatial software community with missing capabilities for terrain modeling such as sketching
 43 or procedurally modeling landforms from local topographic extrema.

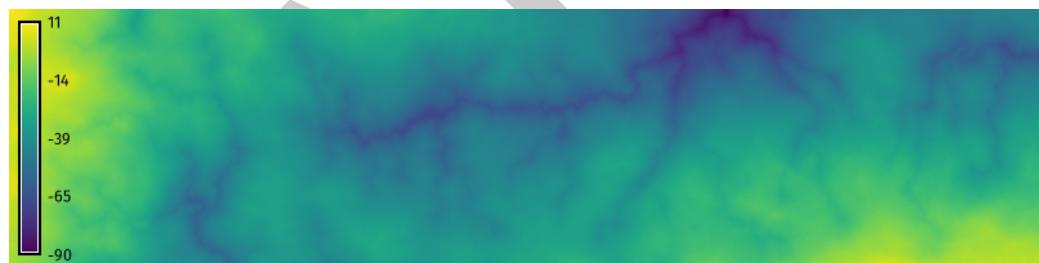


Figure 3: Gullies modeled with `r.earthworks`

44 Functionality

45 `r.earthworks` functionality includes the transformation of terrain rasters and calculation of
 46 volumetric change. Its features include cut and fill operations, relative or absolute datums,
 47 growth and decay functions for determining slopes, flats at local minima or maxima, and
 48 volumetric calculations. It can be used not only to model basic landforms such as peaks,
 49 ridges, slopes, valleys, and pits, but also complex natural and anthropogenic features. In
 50 `r.earthworks`, terrain – abstracted as a 2-dimensional manifold in 3-dimensional Euclidean
 51 space – is represented discretely as a raster grid for efficient storage, analysis, and transformation.
 52 Transformations are based on proposed local topographic extrema which can be derived from
 53 data, procedurally generated, or sketched. These extrema can be input as coordinates, points,
 54 lines, or a raster. The local minima and maxima are modeled as low points for cut operation or
 55 high points for fill operations. Transformations are a function of the existing elevation, change
 56 in vertical distance, and change in slope over horizontal distance. Vertical distance is calculated
 57 as the difference between proposed local extrema and a topographic datum, while change in
 58 slope is a function of growth and decay applied to horizontal change in distance. Growth and
 59 decay can be set to a linear, exponential, logistic, Gaussian, Cauchy-Lorentz, quadratic, or
 60 cubic function. The shape of the slope can be controlled by tuning the parameters of the
 61 chosen growth and decay function. Transformations are calculated independently for each local
 62 minima or maxima and are then accumulated before being applied to the existing terrain.

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

73 Usage

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

```
# 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",
    function="linear",
    linear=0.25,
    flat=25
)
```

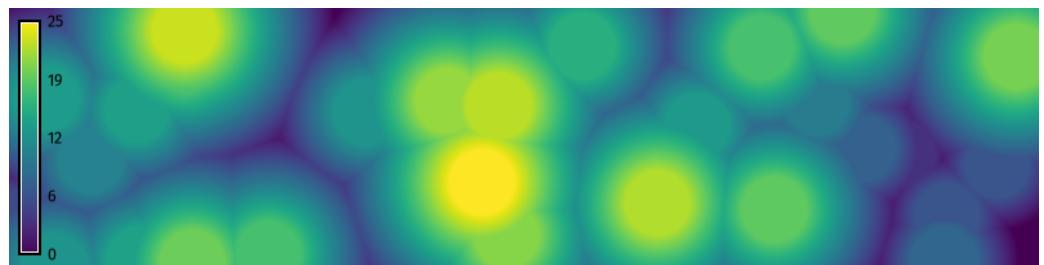


Figure 4: Random peaks modeled with `r.earthworks`

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 78 supported by the U.S. National Science Foundation under Grant [2303651](#).

79 References

- 80 Barnhart, K. R., Hutton, E. W., Tucker, G. E., Gasparini, N. M., Istanbulluoglu, E., Hobley,
 81 D. E., Lyons, N. J., Mouchene, M., Nudurupati, S. S., Adams, J. M., & others. (2020).
 82 Landlab v2. 0: A software package for Earth surface dynamics. *Earth Surface Dynamics*,
 83 8(2), 379–397. <https://doi.org/10.5194/esurf-8-379-2020>
- 84 Galin, E., Guérin, E., Peytavie, A., Cordonnier, G., Cani, M.-P., Benes, B., & Gain, J.
 85 (2019). A review of digital terrain modeling. *Computer Graphics Forum*, 38(2), 553–577.
 86 <https://doi.org/10.1111/cgf.13657>
- 87 Gebbert, S., & Pebesma, E. (2017). The GRASS GIS temporal framework. *International
 88 Journal of Geographical Information Science*, 31(7), 1273–1292. [https://doi.org/10.1080/13658816.2017.1306862](https://doi.org/10.1080/

 89 13658816.2017.1306862)
- 90 GRASS Development Team, Landa, M., Neteler, M., Metz, M., Petrášová, A., Petráš, V.,
 91 Clements, G., Zigo, T., Larsson, N., Kladivová, L., Haedrich, C., Blumentrath, S., Andreo,
 92 V., Cho, H., Gebbert, S., Nartíšs, M., Kudrnovsky, H., Delucchi, L., Zambelli, P., ... Bowman,
 93 H. (2025). *GRASS GIS* (Version 8.4.0). <https://doi.org/10.5281/zenodo.4621728>
- 94 Grohmann, C. H., Garcia, G. P. B., Affonso, A. A., & Albuquerque, R. W. (2020). Dune
 95 migration and volume change from airborne LiDAR, terrestrial LiDAR and Structure from
 96 Motion-Multi View Stereo. *Computers & Geosciences*, 143, 104569. <https://doi.org/10.1016/j.cageo.2020.104569>
- 98 Haedrich, C., Petráš, V., Petrášová, A., Blumentrath, S., & Mitášová, H. (2023). Integrating
 99 GRASS GIS and Jupyter Notebook to facilitate advanced geospatial modeling education.
 100 *Transactions in GIS*, 27(3), 686–702. <https://doi.org/10.1111/tgis.13031>
- 101 Harmon, B. A., Mitášová, H., Petrášová, A., & Petráš, V. (2019). `r.sim.terrain` 1.0: a
 102 landscape evolution model with dynamic hydrology. *Geoscientific Model Development*,
 103 12(7), 2837–2854. <https://doi.org/10.5194/gmd-12-2837-2019>
- 104 Hobley, D. E., Adams, J. M., Nudurupati, S. S., Hutton, E. W., Gasparini, N. M., Istanbulluoglu,
 105 E., & Tucker, G. E. (2017). Creative computing with Landlab: An open-source toolkit
 106 for building, coupling, and exploring two-dimensional numerical models of Earth-surface
 107 dynamics. *Earth Surface Dynamics*, 5(1), 21–46. <https://doi.org/10.5194/esurf-5-21-2017>
- 108 Hurkxkens, I., & Bernhard, M. (2019a). Computational terrain modeling with distance
 109 functions for large scale landscape design [Conference Paper]. *Journal of Digital Landscape
 110 Architecture*, 2019(4), 222–230. <https://doi.org/10.14627/537663024>

- 111 Hurkxkens, I., & Bernhard, M. (2019b). *Docofossor* (Version 0.904).
- 112 Jasiewicz, J., & Stepinski, T. F. (2013). Geomorphons – a pattern recognition approach to
113 classification and mapping of landforms. *Geomorphology*, 182, 147–156. <https://doi.org/10.1016/j.geomorph.2012.11.005>
- 115 Jud, D., Hurkxkens, I., Girot, C., & Hutter, M. (2021). Robotic embankment. *Construction
116 Robotics*, 5(2), 101–113. <https://doi.org/10.1007/s41693-021-00061-0>
- 117 Mitášová, H., Thaxton, C., Hofierka, J., McLaughlin, R., Moore, A., & Mitáš, L. (2004). Path
118 sampling method for modeling overland water flow, sediment transport, and short term
119 terrain evolution in open source GIS. In C. T. Miller & G. F. Pinder (Eds.), *Computational
120 methods in water resources: Volume 2* (Vol. 55, pp. 1479–1490). Elsevier. [https://doi.org/10.1016/S0167-5648\(04\)80159-X](https://doi.org/10.1016/S0167-5648(04)80159-X)
- 122 Musgrave, F. K., Kolb, C. E., & Mace, R. S. (1989). The synthesis and rendering of
123 eroded fractal terrains. *ACM SIGGRAPH Computer Graphics*, 23(3), 41–50. <https://doi.org/10.1145/74334.74337>
- 125 Petschek, P. (2012). *Grading for landscape architects and architects*. Birkhäuser. ISBN: 978-
126 3-0346-0987-6

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