Construction of an Ecological Tool to Generate 2D Natural and Urban Landscapes

A Project Report Submitted

in Partial Fulfillment of Requirements

for the Degree of

Bachelor of Technology

By

Sonu Kumar Giri (P2009CS1043)

Department of Computer Science & Engineering

Indian Institute of Technology Ropar

Rupnagar 140001, India

May 2013

Abstract

In landscape ecology synthetic 2D landscape generators can be used in theoretical models to test ecological processes, models and uncertainty in ecological data. Ecological studies using real data are restricted by available data and the cost of acquiring new data meaning that samples sizes tend to be small reducing the possibility of making generalizations. Conclusions derived may thus be specific to a particular area described by the limited data available. Studies that have a large sample size tend to use simulated landscapes (e.g. Li et al. 2005). In this project we constructed a tool to generate synthetic 2D landscape with natural and urban landscapes. This tool generates synthetic landscape with various features based on the input provided by user. In this paper, we describe the algorithms used in the tool to generate the landscapes, input parameters for the tool, results obtained, and future improvements.

Output obtained for a particular input parameter is presented. We also describe the installation procedure for our tool on linux machines. This tool is freely available and can be downloaded from github (`https://github.com/SonuGiriIITP/LandscapeSimGRASS_GIS`).

Acknowledgements

I would like to express our sincere thanks to Indian Institute of Technology, Ropar for providing us with the environment and resources to carry out our project.

Apart from the efforts of myself, the success of this project depends largely on the encouragement and guidelines of many others. I take this opportunity to express my profound gratitude and deep regards to my mentors Dr. Lucy Bastin and Dr. Alex Lechner for their exemplary guidance, monitoring and constant encouragement throughout the course of this project.

I am obliged to faculty of Computer Science at IIT Ropar, Dr. Apurva Mudgal, Dr. Sudarshan Iyengar, Dr. Nitin Auluck. I am grateful for their cooperation during the period of my project. They always kept us motivated to achieve more.

Honor Code

I certify that I have properly cited any material taken from other sources and have obtained permission for any copyrighted material included in this report. I take full responsibility for any code submitted as part of this project and the contents of this report.

Sonu Kumar Giri (P2009CS1043)

Certificate

It is certified that the B. Tech. project ”Construction of an ecological tool to generate 2D natural and urban landscapes" has been done by Sonu Kumar Giri (P2009CS1043) under my supervision. This report has been submitted towards partial fulfillment of B. Tech. project requirements.

Dr. Lucy Bastin

Project Supervisor

Senior Lecturer

School of Engineering and Applied Science

Aston University

Birmingham, UK

Contents

List of Figures

List of Tables

1 Introduction

1.1 Objective

The objective of this project is to improve on the current suite of synthetic landscape simulation software by developing algorithms to randomly generate natural features such as vegetation and topographical and hydrological features and geometric features such as roads, houses and agricultural fields.

1.2 Landscape Ecology an overview

Our world is an increasingly complex system where people, animals, and the environment interact on many levels. As science has improved and the environmental problems of our world have become clearer, a field called landscape ecology has proven extremely important. To make it simpler, let us break up the term by looking at both terms separately.

Landscape: Landscape comprises the visible features of an area of land, including the physical elements of landforms such as mountains, hills, water bodies such as rivers, lakes, ponds and the sea, living elements of land cover including indigenous vegetation, human elements including different forms of land use, buildings and structures, and transitory elements such as lighting and weather conditions.

Ecology: Used loosely, ecology is the study of the interaction of organisms and their non-living environment.

Using these definitions we can describe landscape ecology as a science that examines the appearance and patterns of land as a result of the interactions with its ecosystems.

1.3 Uses of Landscape Ecology: Motivation

There are a wide variety of problems that landscape ecology can address, ranging from the effects of global climate change to the management of forests for species conservation. The demand for ecosystem analysis is growing rapidly as information gathering and analysis options are increasing.

The identification and analysis of land use is one area that landscape ecology focuses. Human use of land in the form of agriculture and urban development plays a vital role in the interactions of landscape and ecosystems. How land is used may affect the migration of certain animal species as well as what land will be available for future use.

Forest management is also a field that landscape ecologists study. Many models have been constructed to predict where forests could migrate as a result of climate change and human encroachment. Landscape ecology has also helped forest managers decide how to use prescribed burns to help certain tree species survive.

Invasive species is also a concern of landscape ecology. Using mathematical models, remote sensing, and GIS, researchers are able to predict where invasive species such as the emerald ash borer, Asian long-horned beetle, or honey suckle are most likely to appear next. Generally, landscape ecology gives environment managers and administrators the information necessary to formulate effective environmental policies and programs.

2 Literature Review

The paper by "Saupe D. (1988) Algorithms for random fractals. In: Peitgen H. O. And Saupe D. (eds), The science of fractal images. Springer-Verlag, New York, pp. 71-113" gives complete mathematical description of algorithms used to generate DEM (Digital elevation model), these are fractional Brownian motion algorithm (fm2D) and Spectral Synthesis algorithm. After reading this paper one can easily implement FM2D or Spectral Synthesis method. "An Updated Algorithm for the Generation of Neutral Landscapes by Spectral Synthesis" by Joseph D. Chipperfield, Calvin Dytham and Thomas Hovestadt further examines spectral synthesis algorithm in great detail.

'Modeling scale-dependent landscape pattern, dispersal, and connectivity from the perspective of the organism' by Steven Walters examine the effects of fine- to broad-scale patterns in landscape structure on dispersal success of organisms with differing life-history traits.

Wang and Malanson (2008) give a great overview of 3 types of synthetic landscape generation methods and their advantages and disadvantages. Other landscape simulation methods not described by Wang and Malanson (2008) that produce natural like landscapes:

- RULE can also generate curdled hierarchical landscapes (Gardner 1999)
- Simap (Saura and Mart´ýnez-Millán 2000)
- Fourier synthesis can also be used to generate landscapes that appear similar to FM2D landscape (Keitt 2000). This method is commonly used outside of ecology such as for generating movie special effects.

Landscape simulation methods that combine real landscapes with synthetic landscapes or reproduce elements of geometric patterns:

- Synthetic map generation method - Hargrove et al. (2002)
- QRULE allows for real landscapes to seed synthetic landscapes (Gardner and Urban 2007).
- A landscape model created by merging simulated land cover maps with synthetic topographic surfaces (Walters 2007)

Following two URL's helps in understanding slope and aspect calculation in DEM.

- `http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=How%20Slope%20works`
- `http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=How%20Aspect%20(3D%20Analyst)%20works`

I have implemented these algorithms to calculate slope and aspect of DEM in previous code, now it is calculated using GRASS GIS.

Papers describing flow direction computation (D8, D-infinity algorithm), flow accumulation and depression filling include “A new approach for dealing with depressions in digital elevation models when calculating flow accumulation values” by Neil Arnold, Scott Polar Research Institute, UK. ‘A novel method for Filling the Depressions in Massive DEM Data’ by Jingwen Xu, Wanchang Zhang. Papers describing methods to assign vegetation based on elevation, river distance are also reviewed.

Methods for testing how realistic synthetic landscapes

Part of this project involves quantitatively testing how realistic the landscapes are and how they compare to current landscape generation methods. Li et al. (2004) is a good read in regard to this. Also Hargrove et al. (2002) compared synthetic maps to real by maps by asking over 100 map experts to distinguish the real map from the synthetic realization.

3 Technical definitions, Representation, Algorithms and Use

3.1 Digital Elevation Model (DEM)

Digital elevation models (DEMs) are data sets that represent the elevation of the earth's surface at discrete points in a regular, rectangular grid. The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems. The closer together the grid points are located, the more detailed the information will be in the file. The details of the peaks and valleys in the terrain will be better modeled with a small grid spacing than when the grid intervals are very large. This is referred as DEM cell resolution. Elevations other than at the specific grid point locations are not contained in the file.

The files can be in either ASCII or binary. In order to read the files directly you must know the exact format of the entire file layout. Usually the name of the file gives the reference location to some map corner point in the file. The files contain only the z value (elevation value) and do not contain the actual geographical location that is associated with that point. The actual location associated with that elevation data is calculated by software reading the actual DEM file, knowing the precise location of the data value inside the DEM file. In addition, there will be some needed reference information in the header of the file. The following is a sample input file to r.in.ascii used by grass to read ascii files:

Figure 1: Sample DEM ASCII file

```
north:                    4299000.00
south:                    4247000.00
east:                      528000.00
west:                      500000.00
rows:                             10
cols:                             15
null:                          -9999

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12 12 14 15
```

The figure shown below is a DEM of size 5 x 5. The DEM is represented as an array of integers representing elevation at a point.

13	14	14	13	12
12	13	15	14	11
12	11	13	10	10
10	10	12	11	9
8	9	11	8	10

5x5 DEM Example.

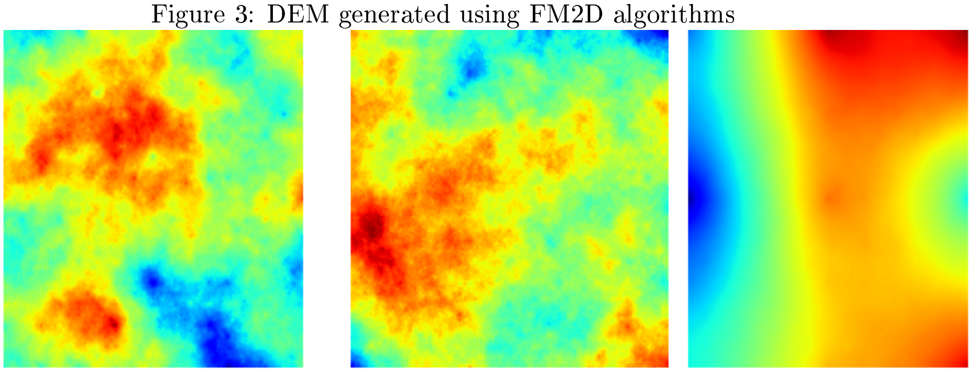
Figure 2: DEM representation as 2D array of integers

The DEM ASCII file can be generated using FM2D or spectral synthesis algorithm.

Fractional Brownian motion (FM2D) and Spectral Synthesis (SS) algorithms is used to generate Digital Elevation Model, Both of these algorithms are described in Saupe 1988 paper in great detail. FM2D is iterative in nature whereas SS is sequential. So, FM2D takes a larger time compared to SS to generate a DEM with same size and H (auto-correlation factor) value.

Few Digital Elevation models (DEMs): More the intensity of red (in figure shown below) higher is the elevation. The figure shown below are DEM obtained using FM2D algorithm. The 3rd image from left contains gradient.

Figure 3: DEM generated using FM2D algorithms



3.2 Slope in DEM

For each cell, Slope calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell. Conceptually, the Slope function fits a plane to the z-values of a 3 x 3 cell neighborhood around the processing or centered cell.

The rate of change in the x direction for cell 'e' is calculated with the algorithm: The neighbors are identified as letters from 'a' to 'i', with 'e' representing the cell for which the aspect is being calculated.

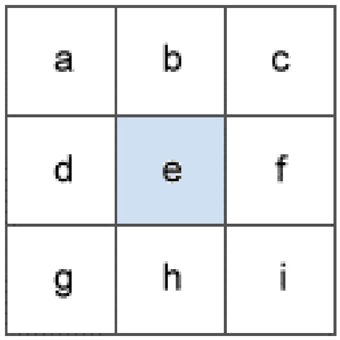


Figure 4: 3x3 window of cells

$$[dz/dx = ((c + 2f + i) - (a + 2d + g)/(8 * x_{cellsize})]$$

The rate of change in the y direction for cell 'e' is calculated with the following algorithm:

$$[dz/dy = ((g + 2h + i) - (a + 2b + c)/(8 * y_{cellsize})]$$

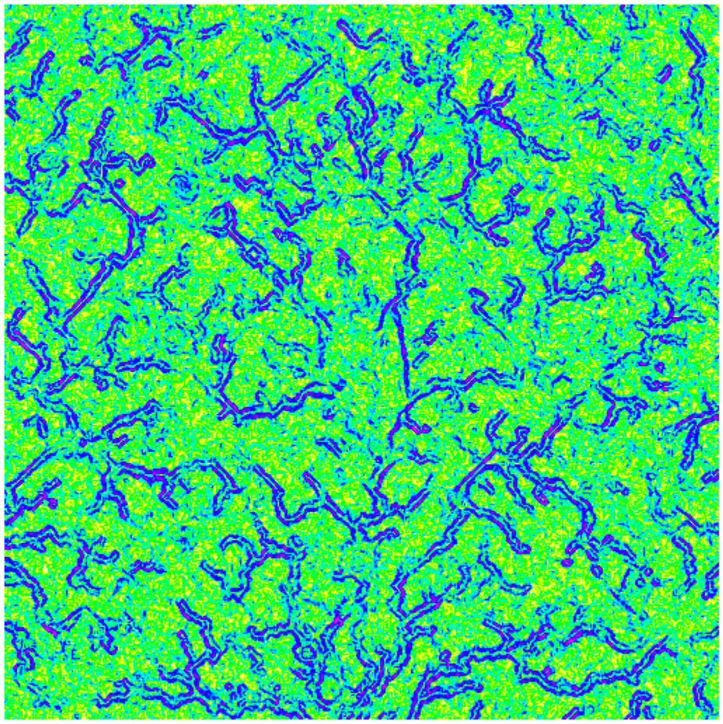


Figure 5: 3 Slope map of DEM calculated using GRASS GIS

3.3 Aspect in DEM

Aspect identifies the down slope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. The values of the output raster will be the compass direction of the aspect.

A moving 3 x 3 window visits each cell in the input raster and for each cell in the center of the window, an aspect value is calculated using an algorithm that incorporates the values of the cell's eight neighbors. The cells are identified as letters 'a' to 'i', with 'e' representing the cell for which the aspect is being calculated.

The rate of change in the x direction for cell 'e' is calculated with the following algorithm:

$$[dz/dx = ((c + 2f + i) - (a + 2d + g)/(8 * x_{cellsize})]$$

The rate of change in the y direction for cell 'e' is calculated with the following algorithm:

$$[dz/dy = ((g + 2h + i) - (a + 2b + c)/(8 * y_{cellsize})]$$

Taking the rate of change in both the x and y direction for cell 'e', aspect is calculated using:

$$[aspect = 57.29578 * atan([dz/dy], -[dz/dx])]$$

The aspect value is then converted to compass direction values (0–360 degrees), according to the following rule:

if aspect < 0
    cell = 90.0 - aspect
else if aspect > 90.0
    cell = 360.0 - aspect + 90.0
else cell = 90.0 - aspect

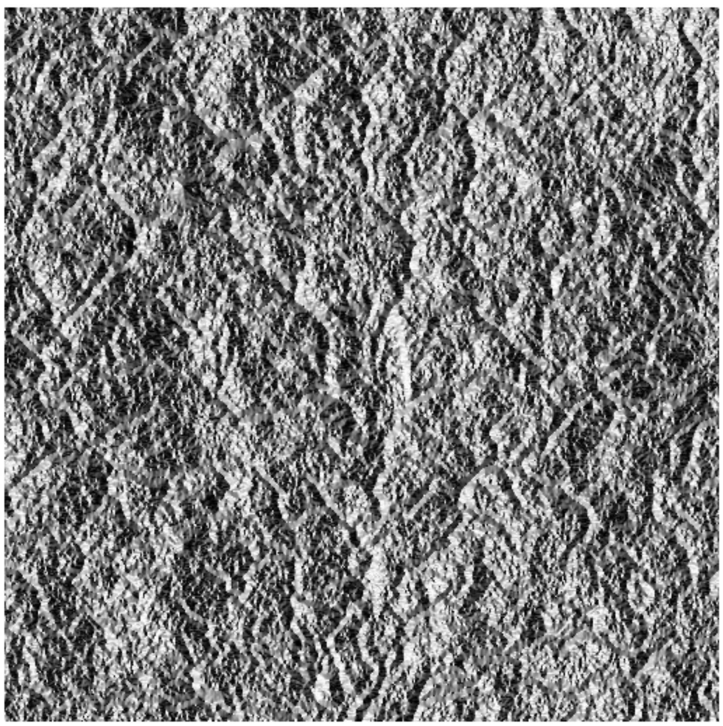


Figure 6: Aspect map of DEM Calculated using GRASS GIS

3.4 Decision tree

A decision tree is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences. We create a decision tree from the input training data. The training data contains a DEM, land-cover class classification and river presence and absence information. From River presence and absence algorithm we get the river distance matrix. The leaf nodes in decision tree represent the land-cover class. We query in decision tree just like a binary search tree. We use this decision tree to assign land-cover class values to synthetic landscape which in turn is used to assign suitability values to each and every pixel.

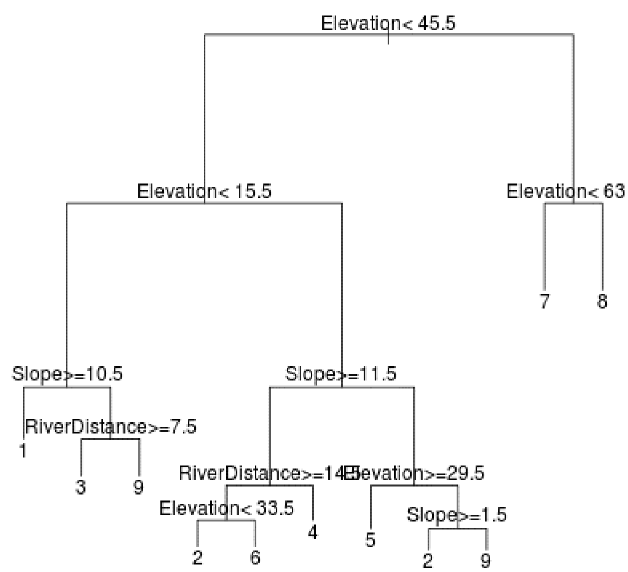


Figure 7: Decision tree generated from training data

3.5 Flow Direction (Hydrologic)

Water flows in the direction of the steepest downhill gradient.

D8 Algorithm (For 3x3 window)

Every pixel is potentially surrounded by eight neighboring pixels. The slope in each of these eight directions may be calculated by taking the difference in elevation indicated by the DEM value at each of these eight neighboring locations and the value at the pixel being examined. This difference in elevation is then divided by the center-to-center distance between these pixels (this distance will be the cell size in the cardinal directions and the cell-size $\times$ $\sqrt{2}$ in each of the diagonal directions. The direction that yields the steepest downhill slope is the inferred direction of water flow. (This basic algorithm is sometimes referred to as the D8 method.)

Consider the following 3x3 DEM with a horizontal resolution of 30 meters and reported in vertical units of meters:

Figure 8: 3x3 window of a DEM

13	11	12
9	10	11
6	6	8

The figure shown below is a flow direction map using D8 flow algorithm obtained using GRASS GIS.

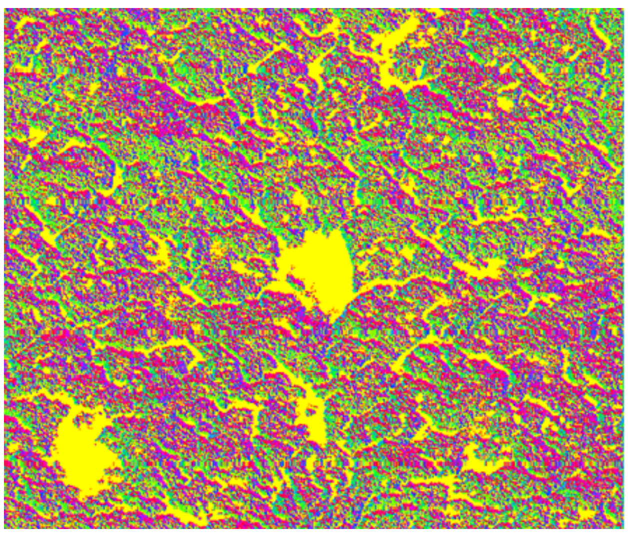


Figure 9: Flow direction map of a DEM calculated using GRASS GIS

3.6 Flow Accumulation (Hydrologic)

Water accumulates along the flow paths dictated by the topography and defined earlier as the flow direction. Using the flow directions determined earlier, flow accumulation at a given location is determined by following two rules:

1. If the pixel has no neighboring pixels draining to it, a value of "1" is assigned.

2. If the pixel drainage from neighboring pixels, it is assigned the value of "1" plus the sum of the flow accumulation draining from each of the neighboring pixels.

Rules 1 and 2 are repeated across the entire DEM.

Figure shown below is the flow accumulation map obtained using GRASS GIS on a DEM.

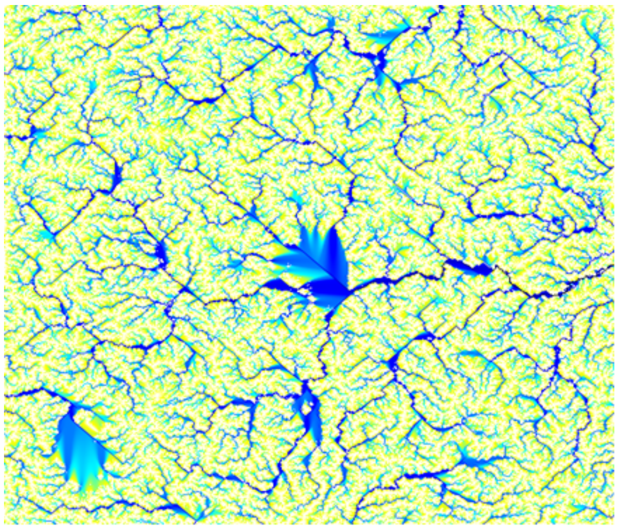


Figure 10: Flow accumulation map of a DEM calculated using GRASS GIS

3.7 Erosion Modelling

Erosion is the process by which soil and rock are removed from the Earth's surface by natural processes such as wind or water flow, and then transported and deposited in other locations. We carry out iterative erosion modelling once we get the flow accumulation map. It is an iterative process repeated by no of times specified by user. Once we erode DEM then again hydrological modelling (flow direction and flow accumulation) is performed followed by erosion modelling. This process repeats itself the no of times specified by user.

Figures shown below is a DEM with and without erosion.

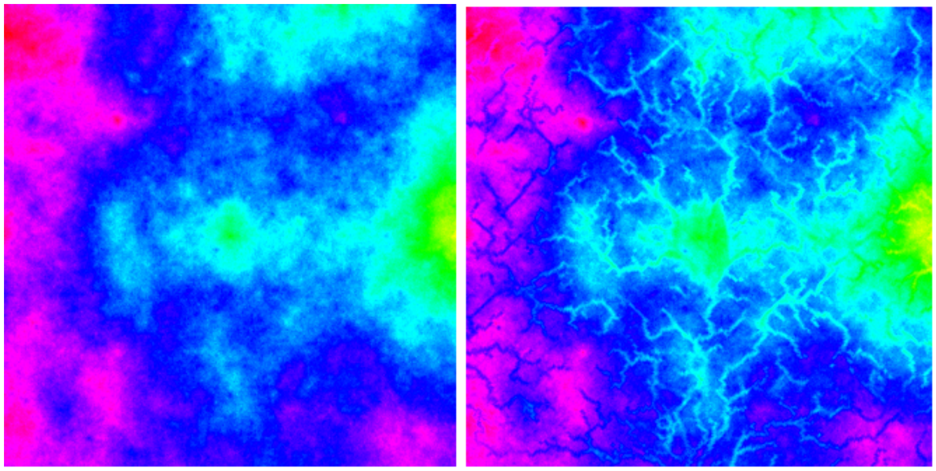


Figure 11: DEM with (Right) and without (Left) erosion

3.8 GRASS GIS

GRASS GIS (Geographic Resources Analysis Support System) is a free, open source geographical information system (GIS) capable of handling raster, topological vector, image processing, and graphic data. We write python script to use GRASS GIS functions to carry out hydrological modelling, finding least cost path.

3.9 Algorithm used to generate and place the agricultural patch onto map

- Generate a continuous 'suitability map' to guide placement. Areas which match the rules for existing agriculture will have suitability 100%. Other pixels should be labelled according to simple rules e.g., 'slope $<$ 20%, elevation $<$ x, moisture $>$ y' and weighted by the current land-cover.

- Threshold this suitability map at a desired percentage (e.g., 'we want to end up with 70% of the landscape covered in agriculture') to discover the minimum suitability level to tolerate. i.e., if 70% of landscape pixels are above 32% suitability, make this the threshold.

- Generate the first patch - first, Get a min area, max area, and aspect ratio from the user. Generate a grid of pixel row- column coordinates for a shape of that aspect ratio and required area - e.g., 0,0 to 9,9. For the first block, this could be the mean area. Subsequent blocks will only ever get smaller, so it could be the max. We choose maximum.

- Rotate the feature by a random quantity, and recalculate the coordinates of the pixels.

- Find a highly suitable pixel in the map, and get its row and column coordinate, r and c. After a few patches have been created, the algorithm should look for suitable pixels close to other patches, to mimic spread.
- Translate the rotated feature to this location by adding r and c to each pixel
- Investigate whether each pixel of the feature now lies in a suitable location. Rules for removing that pixel include 'overlaps an existing patch', 'on unsuitable habitat' and, optionally, if inter-patch strips are required ' <2 pixels from an existing patch)
- Count the pixels that remain. If these are less than the specified minimum area, don't keep this patch. If it's big enough, then give this patch a unique ID, (by labelling all the pixels in this or a separate 'patch map' and record its area, perimeter, state etc in the patch list.
- If an adjacency matrix is being maintained, update the cells which tell us about all the neighbors of this patch.
- Calculate the new area covered - if it doesn't meet the stopping threshold, continue to create and lay down patches.

4 Methodology

The flow chart shown below describe the control flow within program.

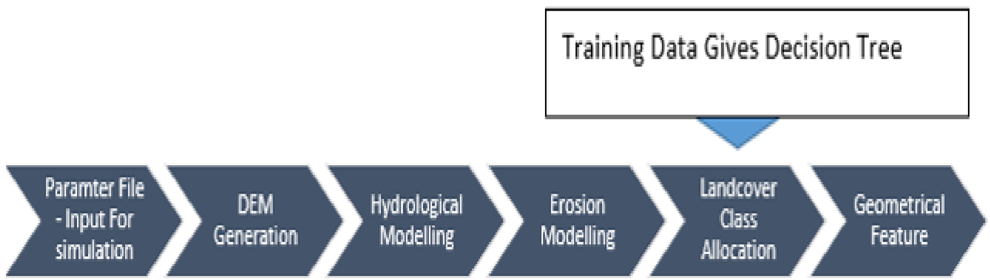


Figure 12: Program Control Flow

Following steps describe the methodology followed:

4.1 Input from parameter File

User specify the simulation parameter in a parameter file. The program reads the parameter from parameter file and then it starts landscape simulation.

4.2 Generation of Digital Elevation Model (DEM)

A DEM is generated either by using Fractional Brownian motion with midpoint displacement (midpointfM2D) or Spectral Synthesis (SS) method. A set of DEMs are generated which are then linearly combined using a weighted ratio specified in parameter file by the user. The DEM generation consists of a set of parameter specified by user ,such as a list of H (spatial autocorrelation) values, list of H weights, list of seed values for random number generator, choice of method used to generate DEM, size of DEM, gradient as true or false in case of midpointfM2D.The parameter file is described in appendix. At the end of this step we get a DEM which is a combination of DEM's generated for given parameters.

DEM = (DEM1*H_wt1) + (DEM2*H_wt2) + ... + (DEMn*H_wtn)

4.3 Hydrological Modelling and Erosion

We carry out iterative hydrological modelling using GRASS GIS followed by Erosion modelling. This process is repeated many times. The value of counter in parameter file controls the number of iterations.

4.4 Generation of decision tree for land-cover classification

To assign land cover class to the synthetic DEM, we generate a decision tree based on an input elevation map, land-cover map for the elevation map and river presence/absence information for each and every pixel. Using the elevation map, we calculate slope and aspect map. From river presence/absence map, we get city block distance for each and every pixel. Based on the information (elevation, slope, aspect, river distance, land-cover class), we get a decision tree using rpart command in rpy python library.

4.5 Land-cover class mapping

Using the decision tree, we assign the land-cover class to each and every pixel of synthetic DEM generated in previous steps by first calculation the slope, aspect, and distance from river for synthetic DEM.

4.6 Generation of geometrical Features

Once we assign the land-cover classes to each and every pixel, we generate an agricultural suitability map. The suitability is assigned based on some observation and common sense. Once we assign the suitability values then we placed the agricultural patches (agricultural fields of a specified aspect ratio, min area and maximum area) until we cover specified part/fraction (fraction of area to be covered is supplied by the user) of the map. After placing all the patches we carry out patch labelling i.e. to assign unique ID to each patch. The algorithm is described in the chapter 3, section 3.9. Once we get all the patches we treat them as a graph. We try to connect patches using least cost path. After that some patches can be converted to urban settlements.

5 Input Parameter File and It's Description

5.1 Input Parameter file

The content of parameter file looks like this:

```
---
H: [0.85, 0.7, 0.6, 0.4]
H_wt: [0.6, 0.2, 0.1, 0.1]
seed: [19, 17, 11, 37]
elev_range: [0, 1300]
max_level: 9
river_drop: 10
counter: 1
DEMcreator_option: fm2D
output_dir: Output
min_area: 100
max_area: 600
aspect_ratio: 2.1
next_patch_orientation_probability: 0.8
agri_area_limit: 0.25
training_data_elev: new_elev.asc
training_data_landcover: new_land.asc
training_data_river: new_rivers.asc
...
```

Figure 13: Parameter File

5.2 Parameter File Description

Table 1: Parameter File Description

General parameters	
Output_dir	The directory where output results (output images and files) will be saved. Data-type: String
H	List of auto-correlation values
H_wt	List of weight for each correlation values specified in H list. Data-type: [float, float, ...]
seed	List of values(ints preferably prime no's) to be used as a seed for random number generator. Data-type: [int, int, ...]
elev_range	Range of elevation in DEM[min elevation, max elevation] Data-type: [float, float]
max_level	Size of the DEM grid 2^(max_level) .Data-type: int
river_drop	Maximum extent of erosion, a fraction of this value is subtracted from the DEM based on river distance. Data-type: float
counter	No of iteration of DEM erosion to be performed. Data-type: int
DEMcreator_option	Choice of the Algorithm used to generate DEM fm2D or SS Parameters related to Decision tree module
training_data_elev	Name of the training data file in which elevation data is kept. Data-type: String
training_data_landcover	Name of the training data file in which Landcover data is kept. Data-type: String
training_data_river	Name of the training data file in which River presence/absence data is kept. Data-type: String
min_area	Minimum area of the fields allowed. Data-type : integer
max_area	Maximum area of the field allowed. Data-type: integer
aspect_ratio	Ratio of width to the height of the fields(rectangle). Data-type: float
next_patch_orientation_pr	Probability of next patch having the same orientation as the previous patch placed. Data-type: float , Domain: 0 - 1
agri_area_limit	Fraction of area in the grid to be covered by agricultural patches. Data-type: float , Domain: 0 - 0.99

6 Conclusion

We start with a parameter file and carry out landscape simulations. We get the following outputs;

1. DEM with and without Erosion
2. Flow Accumulation Map
3. Land-cover classification Map
4. Geometrical Feature map

We have discussed the algorithm used to get the above layers in previous chapters. The next chapter discusses about the future enhancements in the project. Shown below is Land-cover classification map obtained from decision tree and agricultural patch map.

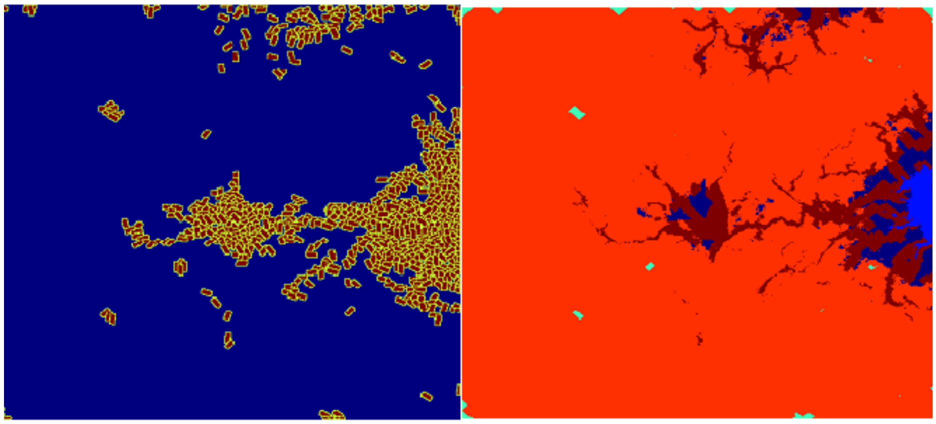


Figure 14: Agricultural patch map (left) land-cover classification map (right)

The DEM layer, flow accumulations layers were shown in previous chapters. Currently the hydrological modelling is carried out using GRASS GIS. We used Scotland training data to produce the synthetic landscapes.

7 Future work

7.1 GUI Interface

In future a GUI Interface can be added to make it more convenient to use.

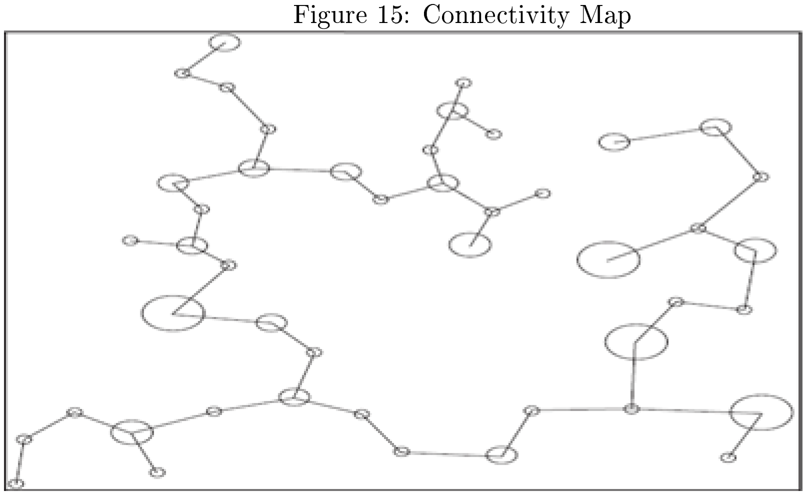
7.2 Improvement in Erosion Modelling

More realistic erosion modelling algorithm can be incorporated to make the DEM more realistic. Better the erosion modelling algorithm better is the quality of DEM.

7.3 Improvement in Patch Connectivity

We use least cost path to connect cluster (set of patches which are close to each other) of patches. We can treat patches as set of nodes in a graph and then we can connect them using least cost path. Some patches can be converted to urban features based on suitability rule. Patches can be combined based upon requirements. Patches can even be more fragmented. The figure shown below treat each patch as a node and connect them using least cost path. The figure is included just to illustrate the idea.

Figure 15: Connectivity Map



8 Appendix

Software and Packages Required

Following software and packages need to be installed on Linux-Ubuntu before running the grass script

1. Grass

2. Python

- numpy

- scipy

- pylab

- rpy

- yaml

RunMe.sh contain executable shell script code which will automatically Install the given packages and software's.

To run the RunMe.sh file

–> Select the file -> press enter–> click on Execute

OR

Open the terminal, go to the directory in which RunMe.sh file is placed using cd (change directory) command. Type "sh RunMe.sh" and press enter.

***************************After Installation************************

1. Specify the parameters for landscape simulation in parameters.yaml file in source code directory.

2. Now to run the simulation code, go to source code directory using cd command in terminal and type "python main.py" (without quotes) and press enter.

References

[1] Burrough, P. A. and McDonell, R.A., 1998. Principles of Geographical Information Systems (Oxford University Press, New York), p. 190.

[2] Emilio Rafael D.-V., Manuel Francisco M.-P., Pedro Á.-Á. (2009) Use of simulated and real data to identify heterogeneity domains in scale-divergent forest landscapes. For. Ecol. Manage. 258:2490–2500

[3] Gardner R. H. (1999) RULE: map generation and a spatial analysis program. In: J.M. K. andR.H. G. (eds), Landscape Ecological Analysis: Issues and Applications. Springer, New York, pp. 280–303

[4] Gardner R. H., Urban D. L. (2007) Neutral models for testing landscape hypotheses. Landscape Ecol. 22(1):15-29

[5] Hargrove W. W., Hoffman F. M., Schwartz P. M. (2002) A fractal landscape realizer for generating synthetic maps. Conserv. Ecol. 6(1)

[6] Keitt T. H. (2000) Spectral representation of neutral landscapes. Landscape Ecol. 15(5):479-494

[7] Li X., He H. S., Bu R. et al (2005) The adequacy of different landscape metrics for various landscape patterns. Pattern Recognition 38(12):2626-2638

[8] Li X., He H. S., Wang X., Bu R., Hu Y., Chang Y. (2004) Evaluating the effectiveness of neutral landscape models to represent a real landscape. Landscape Urban Plann. 69(1):137-148

[9] Riitters K. H., Vogt P., Soille P., Kozak J., Estreguil C. (2007) Neutral model analysis of landscape patterns from mathematical morphology. Landscape Ecol. 22(7):1033-1043

[10] Saupe D. (1988) Algorithms for random fractals. In: Peitgen H. O. and-Saupe D. (eds), The science of fractal images. Springer-Verlag, New York, pp. 71-113

[11] Saura S., Mart´ýnez-Millán J. (2000) Landscape patterns simulation with a modified random clusters method. Landscape Ecol. 15(7):661–678

[12] Shen W., Darrel Jenerette G., Wu J., H. Gardner R. (2004) Evaluating empirical scaling relations of pattern metrics with simulated landscapes. Ecography 27(4):459-469

[13] Walters S. (2007) Modeling scale-dependent landscape pattern, dispersal, and connectivity from the perspective of the organism. Landscape Ecol. 22(6):867-881

[14] Wang Q., Malanson G. P. (2008) Neutral Landscapes: Bases for Exploration in Landscape Ecology. Geography Compass 2(2):319-339

[15] http://softwright.com/dem.html

[16] http://grass.osgeo.org/grass64/manuals/r.in.ascii.html

[17] http://geography.about.com/od/physicalgeography/a/landscapeecolog.htm