BICYCLE PATHWAY GENERATION THROUGH A WEIGHTED DIGITAL SLIME MOLD ALGORITHM VIA TOPOGRAPHICAL ANALYSIS

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Abstract. Cities are growing into larger suburbs which increasingly become dependent on cars as the primary mode of transport. Cycling is an alternative transport mode, but topography can often turn daily transport into cardiovascular exercise - not always a desirable outcome. Addressing this, planners can design cycle pathways that coincide with the landscape by planning the shortest path between two points, whilst considering the need to minimise effort (muscle power) to reach the destination. Using a Slime Mold algorithm the paper discusses possibilities of cycle pathway generation which utilises topographic gradients as the initial framework for the growth. The cycle path optimises the amount of effort required to travel between specified points, and adhere to a set of rules predefined by the user (e.g avoid occupied cadastral). A vector analysis determines the gradient sizes that define areas of the topography which are too steep for the algorithm to grow. The algorithm can be observed to generate cycling infrastructure that is both reflective of the environment and the amenities of humans. This investigation, its proposed hypothesis, methodology, implications, significance, and evaluation are presented in the paper.

Keywords. Cycle pathway; slime mold; infrastructure generation; topography analysis; route choice.

1. Background
Cities are growing and much of this growth will happen in suburbia, areas highly depending on cars as the prime travel mode. Research suggests that high car dependency in combination with other lifestyle choices can result in health issues such as obesity (Frank, Andresen and Schmid 2004). Urban planning can partially address this problem by providing other modes of travel such as appropriate cycle paths. Yet cycling uptake is not only a matter of cycle paths, as research suggests, uptake also has a strong correlation to the topography of the area - people in flat areas tend to cycle more than people in mountainous regions. Cyclist movement in the urban environment is heavily dictated by the available routes which are offered.
for each journey. The mode of transport chosen for each individual’s journey is also influenced by the available infrastructure (Borst, de Vries et al. 2009). As strategic plans increasingly highlight cycling by putting more emphasis on the concepts of urban traversal by bicycle, new infrastructure and pathways need to be built which respond to cycling in a meaningful and adequate manner (Gehrke and Clifton 2017). Desirability of pathways are dictated by various factors, pathways with the smallest slopes or the least gradient changes are favoured by elderly and disabled pedestrians, requiring the least effort to traverse to their destination (Borst, Miedema et al. 2008), hence these principles can be adopted as well for ‘effort reduced’ cycling. This inherent planning transition into urban cycling could create various negative social perceptions and unwillingness for individuals to start cycling (de Boer and Caprotti 2017), however, using a system to generate a pathway that contains certain criteria regarding gradients and the least effort can be employed to develop desirable bicycle paths that may attract more individuals to transition into cycling.

Furthermore, local government councils throughout Sydney, Australia have started to adjust and plan road infrastructure that includes cycling pathways. However, there are no dedicated cycling pathways that are categorised other than recreational. This means that individuals who wish to traverse from one point to another in the means of using the bicycle as transport will need to use roads which either have a single dedicated bicycle lane or roads with no bicycle lanes (Pucher, Garrard and Greaves 2011). This notion of sharing a busy road with vehicles is one of the fundamental deterrents that bicycle riders confront not only for leisure, but also for purpose. The potentially dangerous mix of vehicles and bicycles have proven to be a deadly, as seen during a research conducted between 2007-2015 in the Australian state of Victoria. 893 cyclists were hospitalised for a road traffic-related injury with major trauma, 3.4% of these patients died in hospital. This is in conjunction with the pre-hospital deaths totaling 74 (Beck, Cameron et al 2017). Thus it is imperative that investments be made into dedicated and road separated bicycle pathways, this promotes not only a healthier mode of transport, but also a safer route for individuals to traverse (Australian Bicycle Council 2010).

2. Objective

The objective of this paper is to create a working process and develop a tool that allows for the autonomous creation of a bicycle pathway that follows predetermined effort and safety constraints. The tool should be able to be used on any site or location as long as there is an usable topography. The tool should demonstrate an alternate method for bicycle infrastructure planning in an urban context using a digital Slime Mold algorithm that uses topography analysis as the base for navigation. The research should also be insightful for planners and digital designers who look for data-driven and optimised methods for bicycle pathway planning.

The following are the detailed objectives that are included into the research and development of the algorithm based on the background research above:

- **Topography Analysis** in order to determinate the effort (muscle power)
used and to define either a pathway with very little effort required (to allow and encourage cycling as a mode of public transport) or large effort (as cardiovascular exercise).

- **Context** as the research concentrates on suburban areas one has to assume that a mix of brownfield (development with a low to medium density exist) and greenfield (nothing yet been built) areas are present. Hence the algorithm considers existing road networks and classifies them into primary, secondary and tertiary roads to address also the next point.

- **Safety** as argued prior with Beck, Cameron et al (2017) is a main concern for picking up cycling. Thus through a classification of roads one can define a potentially safer route by choosing tertiary roads which are mostly residential side routes.

3. **Methodology**

The research team applied an agile method to the project as it allowed, via a series of three sprints that focuses on the three objectives, a development of the overall Javascript as individual pieces and at the last sprint as a whole. Here each sprint produced either a process or set of rules to be followed in calculations (i.e. the gravity of each point as shown in Figure 3) or the problem-solving operations (such as classifying primary, secondary or tertiary road). Each sprint was backed up by a literature review, discussed and published in Yu et al (2017a, 2017b) that provided insights and knowledge upon achieving the goals listed in the objectives (see also references quoted when discussing the developing and testing of the script). Though the tool could be applied to any site around the world, for the purpose of developing the tool, selected suburban areas in Sydney’s western region were selected to develop the Slime Mould algorithm.

3.1. **WHY SLIME MOLD?**

The research team is aware that there are other methods to establish shortest path analysis (such as agent-based modeling) but the presented paper sits within the framework of researching, testing, evaluating and developing Slime Mould algorithms, furthermore, all in the context of cycling and cycle path optimisation. More specifically, Slime Mould algorithms have proved to only inspire research due to the nature and difficulty of replicating the organism in a digital environment (Schmickl and Crailsheim 2006). This research paper provides a new application of the Slime Mould behaviour to the specific task of bicycle pathway generation, one that is initiated and produced by user constraints of effort and comfortability. Due to the limitation of this paper this research is not further discussed at this point but has been subject to publications presented elsewhere (Yu et al 2017a, 2017b).

4. **Development and testing of algorithm**

4.1. **TOPOGRAPHY ANALYSIS**

To use the topography of the site for the Slime Mould generation, first, the base mesh needs to be analysed for gradient and slope weights. Here a user has the possibility to select any given site out of a GIS model / Mapbox / etc. For the
purpose of this research, first a randomly generated topography is used to test and develop the analysis method, then a local suburban context was selected to address the objectives raised in the bullet points above.

A point cloud is scattered on the topography mesh at a predetermined scale defined by the user (See Figure 1, above). Gravity or weight is then applied to the point cloud requiring each point to move in a downward motion along the topography itself. The gradient or weight of the slope is calculated through the difference in height from the initial point and the subsequent points which are propagated on the topography in a descending direction (See Figure 2, also above).
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Figure 3. Five iterations of downward propagation resulting in the difference of x in height from the original point and the end point.

Figure 4. User specified regions which are determined to be a suitable gradient for bicycle pathway generation (green), and the gradients that are not suitable (red).

For the forced downward propagation of each point, a spherical mesh is created around each point. Then a point is created at the lowest intersection between the spherical mesh and the topography mesh, thus, after every iteration, the original point is forced to move in a descending motion.

The difference in height (x) is translated into a vector size component with the direction of the downward propagation as the vector direction (See Figure 3, above).
Using the vector sizes and directions to create or define areas of the topography in which the user can specify which gradients or slope angles are suitable for the bicycle pathway to be generated on, it is obvious that for comfort to be maximum and effort to be minimum, the most plausible gradients of the topography would be flat (See Figure 4, above).

This final process for the topography analysis creates a culling system of the initial scattered point cloud. If the difference in height (x) is lower than the user-specified amount, the surrounding points merge together to form a larger vector cell size. Therefore the flatter gradients amalgamate into larger areas or cells which can be defined as flat, and the points that have larger changes in height will not merge and is configured to produce smaller cells. The user-defined topography analysis ultimately creates the initial framework and allows the Slime Mold algorithm to generate the bicycle pathways.

4.1.1. Generating bicycle pathway via algorithm with different degrees of effort (muscle power used)

Following the topography analysis, a digital Slime Mold algorithm is used to generate pathways which connect points of interest defined by the user.

When given the correct constraints and conditions, the natural Slime Mold would create a network between itself and the food source with the shortest path (Beekman and Latty 2015).
Translating the full behaviour of the Slime Mold is difficult, however, the essence of the Slime Mold or its motive based behaviour can be translated into a digital framework. Age and certain aspects of the environment are major factors which dictate how the Slime Mold behaves. The Slime Mold algorithm recreates these conditions and empowers them with other user-defined constraints to generate a bicycle pathway that has the essence and behaviours of Slime Molds.
The initial testing of the Slime Mold growth algorithm was set in a mountainous area near Sydney. This was to test the robustness of the algorithm where there are multiple inclines and declines. The cycle pathway also must be suitable for multidirectional traversal. The algorithm requires two or more user set points, however, at least one point needs to be set as the start and the end point. The topography analysis creates an area in which the Slime Mold is allowed to grow, limiting or constraining the algorithm to only use defined gradients.

In this iteration of the algorithm, the artificial Slime Mold algorithm recognises the user set start and end points, therefore, it removes the initial function of the organic Slime Mold’s behaviour which is to find the food source (endpoint).

Effort as a criterion for the generation has been derived from various aspects which affect a cyclist. Most importantly is the rate and strength in which the rider is required to pedal to gain distance over a certain gradient, both proportionate to the other. Thus minimal effort can be determined by the least pedals and required strength, which gains the most distance (Stamford and Noble 1974). Translated into a selection criterion for the algorithm, this includes the gradient cells of the topography analysis, the generation distance between each point, the growth gradient between each point, and the aggregated distance of the entire generated pathway.

4.2. CONTEXT AND SAFETY

The final iteration of the algorithm was implemented in a suburban area with secondary and tertiary roads, this is in contrast to the initial tests where the context was a greenfield site. The existing road infrastructure has also been allowed to be used for the bicycle pathway generation, which adds the hierarchical distribution of growth attractiveness between primary, secondary, and tertiary roads. These categories of road infrastructure are based on the type of road they are, where
primary roads are multi-carriage heavy vehicle roads, and tertiary roads are quiet residential roads. For the cyclist’s safety, it is more desirable to cycle on quiet tertiary roads (Moudon, Lee et al. 2005), where no Slime generation is needed, this is achieved through giving the tertiary roads attractor values which the Slime Mold algorithm is pulled towards. The tradeoff for minimised effort was the generation of the cycle pathways on predominantly secondary roads, whilst the less effort pathways generated on tertiary roads were longer in distance.

5. Research Results and Contribution

In recalling the three objectives addressed in this research, topographic analysis, context, and safety all three objectives could be addressed.

From the initial greenfield site test to the suburban implementation of the algorithm (with context and safety), it is clear to see that a level of autonomous design which applies user set criteria has been achieved to generate bicycle pathways. The bicycle pathways are a complex system to negotiate, especially the suburban iteration where existing roads had to be incorporated to make the algorithm more plausible for real-world use. When evaluating, the tool performs an excellent job at generating pathways on both greenfield and brownfield sites.

The generated pathways from the digital Slime Mold may not be perceived as the shortest path, however, the pathways may be the most comfortable and require the least effort (both user-defined) in relation to the distance an individual has to traverse. Using an effort slider on the algorithm, a user could potentially generate hundreds of iterations of pedestrian pathways by just changing the effort percentage. This process and methodology creates a new and alternate way of pedestrian pathway planning which is more appealing to a large majority of individuals as compared to a straight pathway which traverses over hilly terrain. The findings could also be used to examine existing cycling infrastructure to assess the effort required to traverse them. The research displays a similarity to skiing slopes that range from beginner to the ‘black slopes’ for advanced Skiers and thus encourage individuals to pick up cycling depending on their level.

6. Future Research

At this stage, the research is able to provide various cycle path iterations depending on the type of user living in an undefined defined area. Yet this raises the question:

What type of users live in a specific area and where are cycling hot spots (points of which cycling journeys start or end) and can both be embedded into the algorithm to define better start and end points of cycle paths as well as specifying them for potential users living in the area?

Possible future research will include real data and data mining, where real bicycle use amongst cyclists may dictate the start and end points for the Slime Mold generation. Here, a live feed of cyclist behaviour and usage such as RiderLog (Citydata, 2017) could provide insights into where cyclists start and end their journey. Combining this with demographic data such as ABS (Australian Bureau of Statistics) data or similar could help provide an overview of the potential user groups. This would drive the algorithm towards a more plausible and practical
application which would increase the desirability of the pathway for strategic planners. Ultimately this iteration paves another stepping stone in not only user-centered and controlled pathway generation, but also into further studies and applications of the Slime Mold algorithm to be used in infrastructure planning.

References


