Space Diagrams

The Problem of Spatial Arrangement and the Automatic Generation of Architectural Plans

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Abstract. Decomposing typical hierarchies of architectural space we look to the use of agents to generate architectonic form in a process of distributed representation. This paper forms a part of this ongoing research; a component focusing on the problem of circulation. The work presented looks to swarm intelligence and the well-trodden field of computational wayfinding techniques based on the route finding means of social insects. Ant foraging algorithms are used generally towards optimization and tend to rely on a priori knowledge of the environment. Outlined here is an investigation of emergent route formation and spatial connectivity based on simple agent and pheromone interaction. Optimization is not the key, but emergent connectivity through blind local communication.

Keywords: Agents; self-organisation; circulation; ants; pheromones.

Looking at space

Our perception of the architectural ‘object’ changes as we move around it. In the case of architecture, we not only move around it, but we move through it as well. At its most elemental; architecture is defined by two distinct elements, solid and void. It is the solid that defines the void in which we move. The void is the theatre of the activities that take place in the building.

In general, these two elements are measured by their descriptive qualities aesthetic representations defining our understanding of the architectural object; for example, light/dark, open/closed, light-weight/heavy, and so forth. Conditions imposed upon the ephemeral to define the tangible; thereby, abstracting the problem measurable and quantifiable, with focus on the ‘object’.

Looking at space, upside-down.
The antithesis to this is the view that these base elements are intrinsically cohesive whose inherent properties may be defined and utilised for form generation and adaptation in relation to the specific requirements of a brief. On this basis this work focuses on the void as a theatre of activities, on the premise that space is a self-organising entity. The foremost principle of this work is therefore that the base level of architectonic form is spatial. Activity and the act of user movement engaged in activity is
the fundamental generator of space.

Lionel March, Philip Steadman and Bill Hillier have theorized about the abstraction of space, and determined analytical systems to understand its usage and combinatorial qualities. Steadman and March illustrated a syntactical approach to design, defining the ordering of spaces as the ordering of relations between people and the ordering of activities in relation to people’s routine. i.e.; people and activities can be linked by time, distance, and communication, etc. defining an order, which can be developed into a graphical representation of space diagrams.

**Generating space - diagrams**

Extending the analytical approach we propose to translate analytical techniques into generators. Further to the work of Steadman et al in the field of automatic plan generation, this study looks at the generation of self-organising emergent spatial configurations. Models of spatial configuration are to be generated using agents. These models or spatial diagrams are intended to illustrate possible architectonic assemblies in response to an architectural brief, on the premise that the associational requirements are inherently dynamic, and through reconsideration of the level of abstraction these associations may be redefined. This is ultimately the objective of this work, as outlined in a previous paper Form follows function: Activity defines function gesticulates space (Ireland, 2006). The focus here is route finding between spaces, defined as individual entities. The issue of circulation is an under-valued priority in the design of buildings, in that circulation is the ‘jam in the sandwich’: something that is generally an after thought or added on to a brief on the basis of a % value of total area; being that which is merely used to connect the parts stipulated in the brief.

**Ant pheromone routing.**
Models of social insect behaviour have been well documented (Bonabeau et al., 1999) and been applied to the design and modeling of complex systems. With reference to ant foraging behaviour and ant colony systems, studies have well-defined algorithms for combinatorial optimization and routing in communication networks.

The success of species such as the ant is due to their ability to organise themselves; from the level of being discrete individual entities into a cohesive global organism: achieved through low-level rules between interacting individual ants and their environment. This collective behaviour is achieved through the application of pheromones, which are used to mark destinations (such as food sources). Upon discovering such the ant will drop pheromone, marking a trail. This will gradually disappear through evaporation defining a gradient, which other ants will follow towards the destination point. Returning to the nest ants are understood to have some knowledge of the nest’s geographical location and that they can recognize landmarks through the ability to read polarized light.

This understanding has led to an array of ant foraging algorithms and models that successfully model such behaviour (Bonabeau et al., 1999 and Resnick, 1994). One such model uses two kinds of pheromones (Resnick, 1994) in which ants deposit one pheromone upon discovering a food source, forming trails leading between this and the nest and another pheromone, which is emitted by the nest. This nest pheromone is diffused throughout the environment creating a gradient on which the ants can ‘hill-climb’ to locate the nest. This method was developed in the present research as a means for the agents to leave trails between spaces, thereby defining routes and an emergent circulation pattern (see experiment 1, technique 1; figure 1). But the use of a second pheromone emitted by the nest is (here) deemed tautologous, in that it provides the agents with a compass therefore directing them to their destination. This method is illustrated here for reference to demonstrate the intention of this on-going work. The objective here is to determine a method that does not rely on a compass orientation but is simply an emergent outcome of the local interaction.
between agents and their immediate context of either destination or pheromone trail.

A method using two trails is in development here, based on previous work, which does not rely on ad-hoc methods to return to the nest (Panait and Luke, 2004). This model of communication is based on two trails leading from destinations left by agents. Which trail an agent lays is dependent on their state; either searching or returning to the nest. In this model the nest is referred to as home as this is an agent’s birthplace. An agent starts from a space, that space being its home. It leaves home, in state 1 [search] laying pheromone [homescent]. In state [search] an agent moves forward randomly in search for either another space or a trail left by an agent in state 2 [gohome], being an agent of state 1, which has successfully found space other than its own birthplace. An agent in state 2 does the exact opposite of state 1, in that it either moves forward randomly until it arrives home or follows the trail of an agent in state 1.

An agent obtains pheromone at destinations, providing it with a ‘smelly bag’. This is an amount of pheromone available to each agent for laying a trail. As the agent moves it lays this pheromone, ‘the smelly bag’ decreasing with each step. Pheromones diffuse and evaporate. These and the size of both the ‘smelly bag’ and the amount dropped at each step are variables, which can be manipulated. This provides a mechanism by which successful trails are more likely to develop, in that a limited amount of pheromone to drop prevents trails that lead off in entirely the wrong direction from being maintained (since an agent wandering in such a direction may still find other space as it moves randomly). Diffusion and evaporation slowly diminish trails and so agents following trails are more likely to reinforce those well-trodden routes.

The model developed here therefore works exclusively on local interaction between agent and trail, agent and destination. The agents effectively ‘sniff space’.

**Sniffing space**

The agent’s world consists of void, birthplace/home, other spaces and the trails left by other agents. The world is a grid of patches, in which values for the two trails exist. An agent sniffs its immediate context, being the eight-patch neighbourhood surrounding it (Moore’s neighbourhood). An agent hill-climbs the scent value of the trail. In motion an agent ‘wiggles’ forward, therefore those patches in front are checked for any trail scent first. If none exists the two patches immediate left and right are checked, moving backwards until finally the patch lying immediately to the rear is checked. This ensures the agent maintains a predominately forward motion. If no scent is found to exist in any of the patches the agent moves forward in a random direction. If a scent is picked up then the agent changes direction to face the direction of smell and moves forward, thereby following the trail. Upon finding ‘other’ space the agent changes state, collects the alternative ‘smelly bag’, turns (a random amount) and moves forward leaving the alternative trail, sniffing the environment for a trail which may lead it home.

**Experiments and techniques**

Both the compass and two trail techniques are illustrated here in order to outline the different emerging results and the principles behind the proposed method. Netlogo is the programmable modeling environment used, version 4.02.

**Experiment 1, technique 1.**

Firstly, a model using the compass method was built, in which agents are scattered randomly. This is a simple model in which agents leave a trail upon finding some space. When an agent finds space it takes the identity of that space, and searches for alternative space, leaving a trail. Agents are always searching; either for trail or space. If an agent sniffs a trail it follows that trail, along which it will find space. The result is a stable emergent outcome.
Experiment 2, technique 1.
This model was developed further, by arranging that the agents are born to homes. With their birthplace comes an identity. Each space is numbered and this number equals the agent’s identity. Each space emits a pheromone, for which each patch in the world holds a value of ‘smellyness’ relative to distance, thereby defining a gradient from each location to each space/home.

An agent leaves home in a random direction, as in the previous model searching for a trail to follow or for other space. When agent find other space in this model they return home, following the value of smell released by their home; thereby hill climbing the specific smellyness values held within the patches, leaving a trail.

A network of trails emerges between the spaces, with those trails which are of shortest length between spaces becoming most prominent. These primary trails are so for two reasons; first they lie between spaces which are closer to each other than others, which means they have a better chance of being found, and second the trail is less likely to evaporate once other agents pick up the trail due to the margins between rates of agents dropping pheromone, the number of agents following the path and the evaporation rate.

Although the model works to define a network of routes it is considered tautologous within the terms of this work, due to the ‘signal’ being emitted by the homes. Although (as noted previously) real ants are understood to have some a priori knowledge of the geographical location of their nest, this methodology does not satisfy what is desired here since it provides a generally predictable outcome and thereby serves to illustrate what may be achieved manually. The main outcome of this model is the shortest path between spaces, and this is not the focus of this investigation. Tabor (1976) stated, “… there is a feedback relationship between the overall topology and geometry of the overall network, which affects and in turn is affected by the particularities that occur within”.

Experiment 3, technique 2.
In development here is an algorithm based on ant foraging problems using two pheromones, one applied when searching and another when returning home (Panait and Luke 2004). As already outlined agents searching for space and returning home
leave trails. Trails are formed successfully but the stability of these trails is problematic. As illustrated below successful trails emerge but these are as likely to emerge leading ‘into the void’ as much as they are between different spaces.

The model has an array of variables, which may be manipulated, and the effect of these is very sensitive to minor changes in evaporation, trail strength, diffusion rate, etc having significant effects on the agent behaviour.

Although the stability of the model is questionable, the formation of trails between spaces is clear. The stability of these trails is dependant upon the degree of traffic and the settings, as some trails can fade upon emergence, whilst others can remain for the duration of the model’s run. A nice effect of the model is that those emerging trails between two spaces have a variable stability in that they waver. Such a route is not specific, as it is highly dependant of the congregation on agents and a crowd of agents (which may occur due to a failing route, or a group wandering from a failed route) can change the course of a route, causing it to fluctuate, as can be visualized in the following example.

**Experiment 4, technique 2.**

As noted, the sensitivity of the model can cause dramatic fluctuations in the model. Manipulation of the variable settings does provide more stability to the trails as may be seen below, by increasing the rate of diffusion, minimizing the rate of evaporation, altering the amount of pheromone an agent drops and the maximum amount of pheromone that can be dropped at any point along a trail. The dynamics of the system are animated by the fluctuating trails.

**Conclusions**

A well-trodden route is one that appears most perceptible or interesting and is an emergent outcome of the local interaction between agents in their immediate context. The model is dynamic, the outcome is emergent and the fluctuating stability of successful trails is a pleasing manifestation, but the capacity of the model as it stands for use as a generative tool for circulation routes between spaces, within the context of generating architectural plans is questionable.

The model relies completely on the conglomeration of agents discovering a space and leaving a trail,
which leads back home and other agents picking up this trail, reinforcing it. Currently, this does not provide a definitive model, which is successful at each run. Agents discovering other spaces leave trails, but the success of trails connecting spaces is variable, as it is almost as likely that agents will reinforce those trails that are connecting spaces, as it is that agents will reinforce any other trail. When trails connecting spaces are successfully reinforced then the emerging patterns can be successfully stable through the model’s run and interesting route patterns emerge.

**Is circulation optimization?**

The tendency of routes emerging in the model is to fluctuate. This raises the question as to the nature of circulation and its priority within architectural plans. Le Corbusier (1929) noted “Man walks in a straight line because he has a goal and knows where is going;
he has made up his mind to reach some particular place and he goes straight to it”. The ambition of modernism was efficiency. Standardization requires economy and optimization, and this legacy has transferred (quite naturally) through to architectural methodologies today, independent of style, context or building type. Computational techniques and the application of algorithms towards the problems of optimization are well documented and successfully applied in many projects in varied fields. Ant colony optimization (ACO) and minimal spanning trees, provide obvious methods of linking spaces and defining shortest paths but the premise of this study is focused on an understanding that architecture is necessarily optimization.

Hillier notes that space is a significant aspect of human behavior; encountering, congregating, avoiding, interacting, dwelling, etc are not just activities that happen in space. In themselves they constitute spatial patterns. The nature of buildings is that they are shells to house a host of activities which a variety of individuals will perform. Encountering, congregating, avoiding, interacting, dwelling, etc are not attributes of individuals, but patterns or configurations, formed by groups or collections of people. He states that the relation between space and the act of living lies in the relations between configurations of people and configurations of space (Hillier, 1994).

Spatial behaviour should not be seen as static and culture bound, but continuously variable, defined primarily by context, such as the local rules governing the behaviour of social insects (i.e. ants), from which local interactions global behaviour emerges (Asquith, 2006).

Circulation is a significant aspect of architectural design, yet this is often considered rudimentary, as the need to connect spaces or areas of a building. The relationship between path, space, boundary, approach, vista can have significant affects upon configuration and how integral circulation is to a building. As in the approach to a building, circulation may be considered a path along a journey of exploration in which the user takes in views, rests, etc. Human beings do not move in straight lines as Corbusier proposed, they wander, hesitate, change objective, fluctuate and meet.

This work is not an illustration of that but it does aspire to develop a computational system of generative design in a way which focuses on simple interaction between discrete entities towards the generation of architectural plans and building forms; as Hillier notes (in, Hanson, 1998).

“Any open space is a space in which possibilities have not yet been eliminated, and every open space is continuously structured and restructured by the human activity, which takes place in it… Human activity is never actually structured by space. In structuring space by physical objects we suggest possibilities by eliminating others. But the spaces in the interstices of the physical forms are still ‘open’. Within these limits, the infinite structurability of space still prevails. In our cells, we may dance.”

**Future work**

This work forms part of on-going PhD research. A significant amount of work needs to be done, clearly towards the main intention of this work as a generative
tool for spatial layouts and the larger project put forward at the outset, but further work is required to enhance the model illustrated here.

The algorithm implemented in the initial experiments illustrated (see experiment 2, technique 1) did employ agents with a birthplace, to which they returned upon finding other space by following the scent emitted by their home. This has yet to be implemented in the two-trail model, and it is anticipated that this may provide the motivation for agents to form stronger defined routes as currently agents appear satisfied with pheromone following, leaving no stimulation to return home.

Upon successfully implementing this algorithm then the next step will be to develop the associational network between individual spaces, thereby developing a model of two systems. With these two system operational then analytical techniques for spatial permeability, visibility and integration may be implemented.

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References


Ireland, T.: 2006, Form follows function: activity defines function, gesticulates space, eCAADe, Volos, Greece.