Agent Based Modelling Progress Report

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History is rarely a subject involved with mathematical analysis, yet is a perfect backdrop for modelling complex social dynamics. This project seeks to investigate conflict between settled and nomadic tribes through the lens of Agent Based Modelling, looking specifically at how different strategies endure resource scarcities and aggressive neighbours, and whether a broadly stable cycles as seen historically were inevitable or outliers.

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1. INTRODUCTION

Agent Based Modelling is a useful way of simulating and studying large scale systems that emerge from local interactions. It is a form of stochastic modelling in which boundedly rational agents interact with each other and the environment following simple rules. Boids[1] are the most well known example, in which only 3 rules for behaviour give rise to realistic looking flocking. Agent Based Modelling (ABM) is used to study a wide range of topics such as sociology[2] and economics[3], and has recently seen success in modelling the Covid-19 pandemic[4].

Agents obey simple rules, and do not have complex decision algorithms or machine learning. ABM instead seeks ”Emergent Behaviour” in dynamical systems represented by simple autonomous agents. Emergent Behaviour is characterised by complex large scale patterns or processes arising from small scale interactions. In the case of Boids these rules merely determine the acceleration and rotation of each bird due to a small number of birds around it. Rules as simple as ”Avoid Collisions”, ”Stick Together” and ”Match Speed” produce motion ”corresponding to the observer’s intuitive notion of what constitutes ”flock-like motion.””[1]. This becomes a very powerful tool for simulating unpredictable systems without relying on equilibria or complex equations as complex patterns and behaviours arise as a result of the system, not as an assumed part of it.

History doesn’t typically lend itself well to mathematical analysis. There is one data set, with a huge number of wildly unpredictable one time events and inconsistent trends. There is however huge value in modelling and contrasting potential histories, using Bayesian Analysis to determine the impact of factors such as geography and resource availability on the development of communities, or analysing the viability of various theories to explain historical processes. Peter Turchin proposed a field of study in which the scientific method is applied to history: Cliodynamics[5].

The main aim of Cliodynamics is the formalisation of History, either by grouping and analysing commonalities between events and trends, or by the empirical testing of theories. It is not a predictive science, nor can it be an especially rigorous one due to lack of reliable data, but it can become a useful tool for collating data and allowing discussion based on statistics, not consensus.

The field of Cliodynamics has thus far been predominantly focused on either quantifiable patterns or progression, whether that be development of technology[6] or cycles of growth and decline[7]. The lens through which this is viewed is typically conflict, as this generally has more numerical data and more prior analysis to compare results to.

The aim of this project is to study conflict between settled and nomadic tribes. Agent based modelling is well suited to analysis of different strategies[8], and studying the interplay between agriculture and animal husbandry should give an interesting perspective on technological determinism[9] and adaptability[10]

2. THE MODEL

The map is represented as a rectangular grid of tiles, with tiles that share an edge being considered neighbours. Each civilisation (or tribe) has a set of tiles it controls, and each tile has a number of people (pops) living on it . Currently uncontrolled land is considered empty, but adding unorganised pops could represent the difficulty in conquering and controlling new land, or small tribes who's influence doesn't expand far geographically. Each tile also has Terrain, given as 4 types: Plain (or Steppe), Desert, Mountain and Sea, with Sea tiles unable to support population. Each tribe also has access to a small number of technologies, currently agriculture, horse use, and boats. These map well to "Ultrasocial Traits"[6], with emphasis placed on infrastructure over warfare. Agriculture increases food production, but requires centralised population and water access. Horses are found on Plain tiles, and can be spread by any tribe that has them, increasing travel distance and combat strength on Plains. Boats allow river crossing, access to sea tiles and fast movement along rivers, giving the emergent behaviours of large scale fishing for coastal populations and use of rivers for logistics rather than just defence.

Many different technologies could be added, but for simplicity will be omitted: There are many potential tiers of agriculture technology, ranging from crop rotation, use of fertilisers and going up to tractors and canning, but this merely represents a bigger population number for any tribe with this technology without meaningfully differentiating it from it's peers. The other obvious technologies to add are centralisation, allowing governments, taxation and standing armies which is (currently) outside the scope of this project; and roads and bridges, which would have a simple effect of increasing travel distance, however are difficult to represent in a simple manner from a cost and maintenance standpoint.

A. Assumptions

In order for the model to exhibit emergent behaviour, it should be as simple as possible and have only a limited number of parameters, such as growth rate, travel distance and food production. Agents will not have complicated decision making processes for growth and conquest: currently pops will move to a new tile if they lack food, and one tribe will attack another if more of its citizens are dying to starvation than old age.

1. Population

It is assumed populations belong to their tiles, and tiles to states, such that when a tile changes ownership, so too do the pops that live there. People can move between tiles if there is insufficient food. Currently pops are produced on a per tile basis directly proportional to the tile's current population. In the current model pops are unable to die, but the 3 main causes of death will be combat, starvation and potentially old age, if population is taken literally as people rather than a representation of stable population numbers. The largest real world source of death being omitted is disease, however implementing a large scale pandemic simulation is outside the scope of this project. It is assumed infant death is accounted for by the growth rate, and that the excess disease deaths between tribes due to war can be taken as combat deaths instead, due to poor conditions and lack of access to medicine.

2. Food

As each tick covers at least one full harvest cycle, food is not created and used but rather a property of each tile, with the travel distance of each tribe determining how far away they can access and transport food. Food production is represented as low taxation growth seen in [11]. This allows for increased population density for settled land, as well as nomadic tribes being able to cover large stretches of land without large groups starving. Currently food per tile is determined by two factors: Terrain and civilisation Technology. Mountains and Desert producing very little food, while Sea tiles only produce food for those with coastal tiles. Technology isn't as decided: while agriculture will simply be a multiplier to food production, horses are a little trickier. While they do eat food, they generally graze, using a lot of land but few resources. Currently their only effect is to increase travel times and combat strength. Boats are slightly simpler: by allowing travel on sea tiles fishing becomes possible, with fast river travel presumably developing long dense communities along waterfronts, rather than the wide swathes of land claimed by nomads.

3. Combat

This project follows a Darwinian or Malthusian approach to resource scarcity; while it is possible for cooperation between competing agents to arise from first principles[12] this will not be studied here. When a tribe runs out of resources, it will attack it's neighbours for more.

As neither standing armies or military technologies are to be implemented, armies are considered to be made of levies and militia, meaning a proportion of local population. Locality is determined by the tiles within travel distance of the combat. A multiplier to a tribes combat strength will be added if they have access to horses, representing cavalry or chariots. It is presumed that both agriculture and horses will therefore be very strong strength bonuses, as local strength is directly proportional to population and proportional to speed squared. Access to boats will be less of a direct combat bonus, but will instead allow use of rivers as strong defensive borders, as well as an increase to coastal populations.

B. Implementation

While it is possible to simulate each person as their own individual agent, it is instead more practical to only represent civilisations and the tiles they hold. Tribes are represented as objects, with a list of tiles they own as well as methods for pop growth and expansion. Tiles are also objects, with position, terrain, which tribe owns it and how many live there. It also has a list of it's neighbours for optimisation reasons. The map is a numpy array of tiles.

Every tick each agent is iterated over, with their pop growth calculated and combat executed. Pop growth per tick is $p_{new} = p \times \gamma$, where γ is the growth rate, p is the current population and p_{new} is the number of new pops born. If a tile has more people than food capacity, and a neighbouring tile is unoccupied, the tribe will grow into the new square taking control of it. If there are no free tiles, the population will reduce down to food capacity and combat may occur. Should combat between tribes occur, the chance of victory for the attacker is

$$\frac{p_a \times mod_a}{p_a \times mod_a + p_b \times mod_b} \tag{1}$$

where p is the population controlled by each tribe within travel distance and mod represents combat modifiers. Should the attacker win, they gain control of the tile, and should the defender win nothing happens. A number of pops involved in the fighting will die.

3. METHOD

The model analysed in this report doesn't have population or terrain implemented, so only the number of tiles controlled determines who wins combat. This allows analysis of how borders change the speed with which the map is conquered, but the single winner is determined by starting position and random chance of how it expands.

Multiple simple combat types were tested, with deterministic combat leading to predictable results and random chance taking a very long time to resolve. The most interesting was calculating euclidean distance from the combat tile to each tribes starting position, which produced straight lines.

4. RESULTS

In this iteration the winner of combat is weighted purely by who has more tiles, so there is no stable equilibrium and a single winner always emerges. Borders create separate groups, with bottlenecks leading to slower conquest.

5. CONCLUSIONS

While much of the analysis in this report has been on an older model, it has given useful insight on both how to analyse general results and how to best develop the current model.

It is hoped that further developments in how Population and Terrain are represented will lead to interesting historical patterns, and that variance between tribes will show different viable strategies, as was seen historically.

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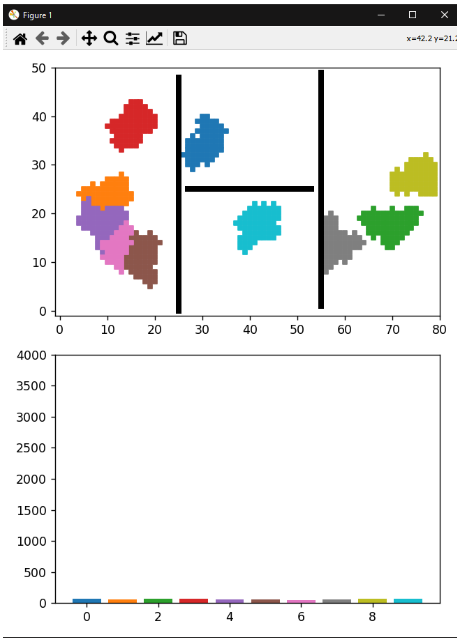

FIG. 1: This figure shows the map and a bar chart of population for each tribe. After a few iterations groups are starting to grow, and some are already fighting each other

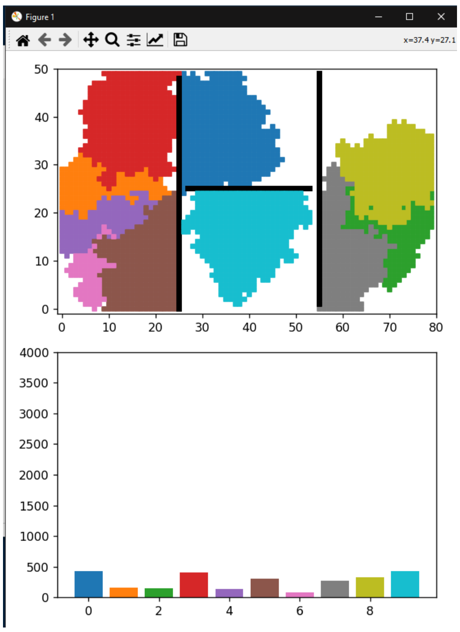

FIG. 2: There are now few free tiles left, there is now more combat than growth

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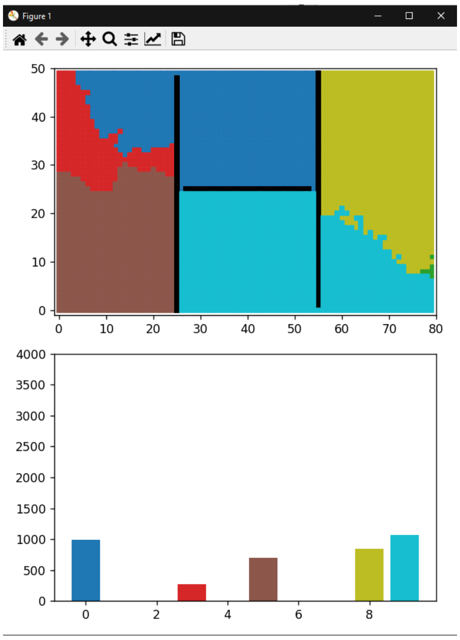

FIG. 3: As there are now no free squares, so large agents will slowly eat the small ones

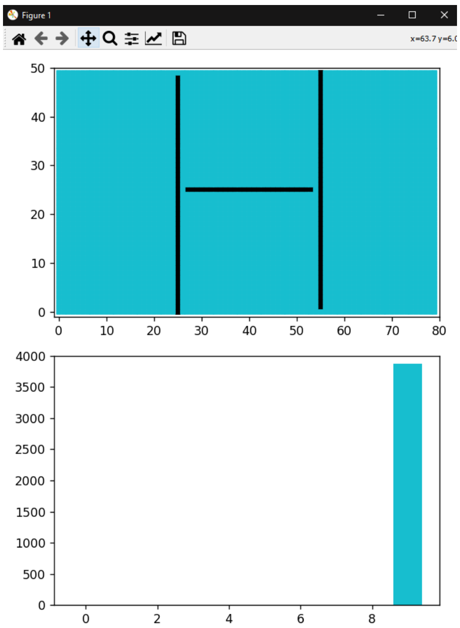

FIG. 4: The simulation is now finished, with a single winner

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6. APPENDIX

A. Computer Code

`https://github.com/tomtom304/ABM/blob/main/Main/Main.py`