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CITS4403 Project Report

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Contents

1 Introduction

Slime mould usually refers to several kinds of unrelated eukaryotic organisms wit that have a life cycle with a free-living single-celled stage and the formation of spores [1]. Physarum polycephalum is widely known as a true acellular or multi-headed slime mould which consumes bacteria, spores, and other microorganisms and particles to grow. It can adapt literally any substrate by taking advantages of enough air humidity and using a network of protoplasmic tubes to connect scattered sources of nutrition when foraging [3]. During the foraging process, the slime mould will keep optimising its protoplasmic network that covers and connects all sources of nutrients and aims to achieve an efficient and rapid distribution of nutrients throughout the plasmodium.

This amazing foraging behavior has attracted the attention of biologists and computer scientists, leading to the emergence of the field of slime mold computing, which has been applied into deal with many real world problems. Adamatzky has surveyed and summarised 25 uses of slime mould in electronics and computing including shortest path and maze, logical gates, Voronoi diagram, Tactile sensor, etc. [2].

Accordingly, this project aims to design and develop a simulation model that can simulate the movement of the slime mould. The outline of this report is as follows. Section 2 will discuss prior research on the slime mould and relevant modelling techniques, Section 3 will introduce the motivation of the project. Section 4 will illustrate the method for modelling the proposed slime mould model. Section 5 will discuss the qualitative outcomes and present the simulation results with quantitative analysis.

2 Literature Review

This section will review and discuss the existing works and techniques in literature related to the proposed project to gain a brief overview and acquire the necessary knowledge, thereby coming up with an appropriate methodology to model the slime mould.

2.1 Slime Mould Models

Tero et al. [8] developed a mathematical model that leverage the iteration of local rules to capture the basic dynamics of network adaptability and generate solutions whose properties are reasonable or even better than the original infrastructure in the real-world. The model is biologically inspired by the network formation process of the slime mould *Physarum polycephalum*. They used the network data of the Tokyo rail system to conduct an experiment to validate the model they proposed. During the experiment, they found that the slime evolved to produce a network that has a very high similarity with the actual network of the Tokyo railway system.

Kalogeiton et al. [5] proposed a Cellular Automata (CA) model to mimic the foraging behaviour of the slime mould *Physarum* to simulate the selection of optimum tube for each individual in the crowd evacuation. The proposed CA model was tested under several simulation scenarios and was evaluated in quantitative analysis by comparing the simulation results with real data.They proved the adequacy, the fitness and the resulting dynamics of the proposed model by meticulously comparing the simulation results to several different similar evacuation models.

2.2 Graph Models

Downey [4] defined the graph as a representation of a system that contains discrete, interconnected elements. The elements in the graph are nodes, and the interconnections between each element are edges. He also introduced the "small world property", which includes two metrics to evaluate the graph model: clustering and path length. He pointed out that models which can produce graphs with higher clustering and shorter path lengths are better, as the average distance between nodes will be smaller and the graph connectivity will be higher in this case.

Ye et al. [6] proposed a graph convolution based spatial-temporal deep learning framework called Multi-STGCnet. The researchers use this proposed model to perform the passenger flow prediction at a station level on a graph-based subway network. The model applied LsTM based modules to extract temporal correlation between historical observation of the target station and its current flow. The proposed model was evaluated on a real world dataset from the metro system in Shenzhen, China. Through the experiment results, they found that the model outperforms multiple baselines.

2.3 Discussion

While most of the previous works related to this project were either focusing on illustrating modelling ideas in theories or describing the experiment results to prove the effectiveness of the models they proposed instead of explaining the actual methodologies of implementing the simulation, this project will implement the slime mould simulation by drawing on the details of the design of the slime mould modelling and graph evaluation metrics in the literature. In this case, this project will implement the slime mould simulation from scratch and then retrieve the graph from the connection made by the slime mould and validate the slime mould model by analysing the connected graph. The validation of the slime mould model will be performed on a real world dataset, which will be introduced in Section 3.

3 Project Motivation

3.1 Nanjing Metro System

The Nanjing Metro is a rapid transit system serving the urban and suburban districts of Nanjing, the capital city of Jiangsu Province in the People's Republic of China. The initial plans for building a metro system to serve Nanjing date back to 1984, with the permission by the State Planning Commission granted in 1994. The system has eleven lines and 191 stations running on 427 km of track. The metro system is operated and maintained by the Nanjing Metro Group Company, and 30 lines are planned to be set for future expansion within the next few years [7].

In this project, the main focus is to design and develop a slime mould that can connect to each station in the subset of the Nanjing Metro system, so that optimizing the network route of the system based on the track of the slime mould. The reason for selecting the subset of the system is that the stations in the subset are mainly located in the central business district of Nanjing, which has more stations exists in comparison with other districts and thus more difficult to perform network design, which means it will be worth studying. The subset of the Nanjing metro is shown in Figure 1.

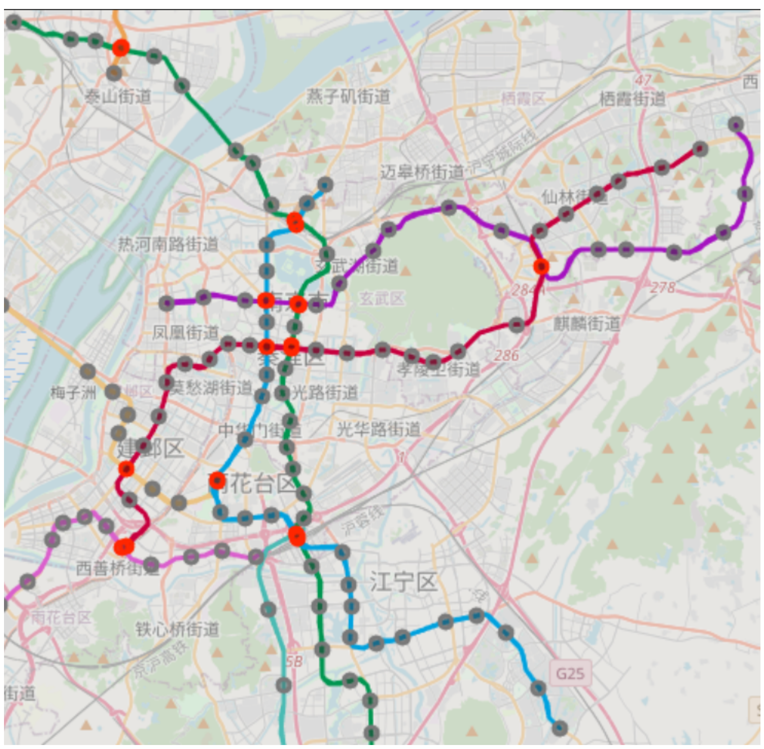


Figure 1: The subset of Nanjing Metro System

4 Methodology

4.1 Slime Mould Implementation

The simulation modelling of the slime mould includes several factors. According to the literature, when the *Physarum* is placed in the *substrate* (e.g. petri dish) which contains several *nutrients* (e.g. oatmeal), it will generate a network of protoplasmic tubes to connect all *nutrients*. So in this case, *Physarum*, *substrate*, *nutrients* are the main factors that will be considered in implementing the slime mould. The proposed slime mould model is built based on agent-based modelling technique for modelling the decision making process for the movement of *Physarum*. The model has four key elements: Lattice, Food, Mould, Slime.

The Lattice is a lattice graph representing the *substrate* where the slime mould modelling is performed. Each element in the Lattice is initialised with a Cell. The Lattice has two layers of information, the first layer is filled with Cells each with zero pheromone value, the second layer is a layer of pheromones that are used to signal the direction that the slime mould should move.

The *nutrients* in the *substrate* are modelled as the food sources (FSs), each of them is initialised with Food which has the highest constant pheromone value on the second layer of the Lattice. The slime mould will aim to surround and connect all the FSs in the whole Lattice. A Food is denoted as connected Food if it is connected by the Mould, otherwise it is unconnected Food.

Mould is the Slime "population" which represents the *Physarum*. The Mould maintains several global states which can help make global decisions for each Slime to make movements on the second layer of the Lattice. In this case, Capital Slime (CS) is introduced to setup the Target Food (TF) for the whole "population". The CS is randomly picked from the Slime located in four corners of the Mould. When the CS is selected, it will try to search an unconnected Food that is the nearest to the CS. The unconnected Food will be set to the TF until it is connected. Since the ultimate goal of the Mould is to cover and connect all the Food in the Lattice, the Mould will adaptively change the CS based on the circumstance in real-time, and continuously replicate agents (Slimes) towards the TF. This is denoted as the evolution process.

Slime represents the individual "agent" in the Mould. Each Slime maintains its own local states to make local decisions for movements. In general, each Slime has two main stages: sensory and diffusion. During the sensory stage, the Slime will setup a food path (FP) which is the shortest path from the nearest connected Food to the TF. Each Food in the FP is denoted as step food (SF) to the TF. After the FP is set, the Slime will then going into the diffusion stage, which is to diffuse itself by checking the conditions of the neighbourhood. The Slime's diffusion action contains six key features: 1.the pheromone of the Slime will decrease each time after the diffusion is performed. 2. diffusion will be performed on the next main diffusion place first, which is located in the direction to the next SF. 3. diffusion will be performed on the rest neighbourhoods if it has enough pheromone left. 4. the Slime will not diffuse if it is too far from the nearest connected Food. 5. new replicated Slime with possibly mutated attributes will be generated during the diffusion stage. 6. different conditions of the neighbourhood will affect the change of the pheromone value of the Slime differently.

4.2 Slime Mould Simulation

As mentioned in Section 3, The project is performed on the subset of the stations in the Nanjing metro system. This will be done by modelling each station as a FS which has infinity amount of capacity for the slime mould to consume. The first thing we need to do is to preprocess the dataset by scaling up the values of latitude and longitude of each station in the metro system to facilitate the simulation in a controllable 2d array. Then we can initialise the simulation environment by setting up the starting location and initial coverage of the slime mould and initialising all the elements mentioned in Section 4.1. Animations will be generated during the simulation so that we can see how the slime mould evolves and connect each FS in the Dish. A parametric study will also be introduced to test how different values of the input parameter can affect the performance of the slime mould. In this case, we will focus on testing the parameter 'decay', which is the rate that controls the decay of the Slime after diffusion. Qualitative and quantitative analysis will also be performed during the parametric study, which will be shown in Section 5.

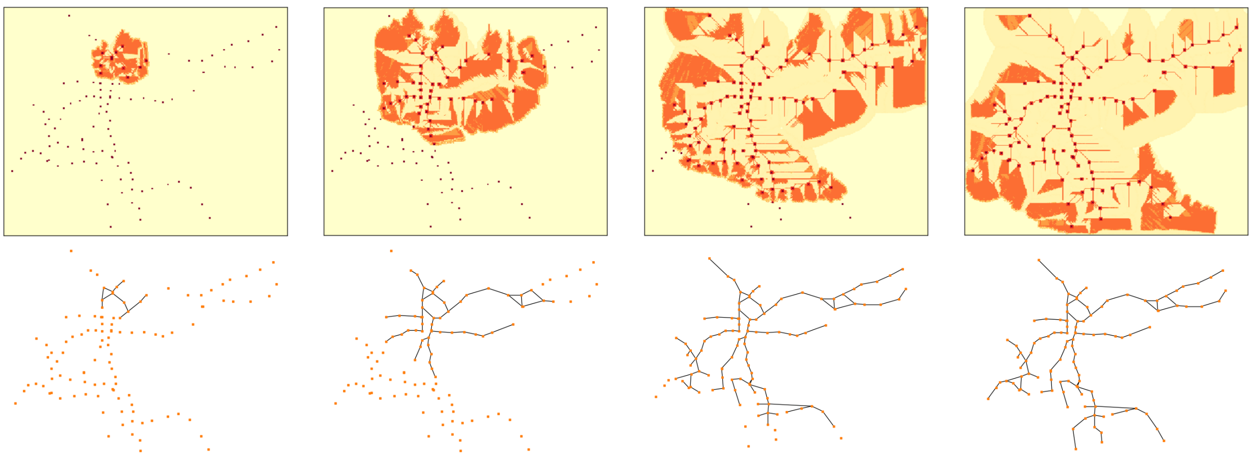
5 Experiments and Analysis

5.1 Qualitative Discussion

As the goal of this implemented model is to reconfigure and optimise the Nanjing Metro System, which is a transportation network, evaluation metrics need to be considered to evaluate the effectiveness of the graph connected by the slime mould model in comparison with the original graph. So in this case, "small world property" is selected to be the main evaluation metric to assess the quality of the generated graphs in this project. As mentioned in Section 2.2, a graph with "small world property" can have high connectivity and short average distance between each node, which will be of great benefits to a transportation network as high connectivity can allow people to take less stations to reach their destinations, and short average distance can allow people to take less time for each trip.

5.2 Visualising the Simulation

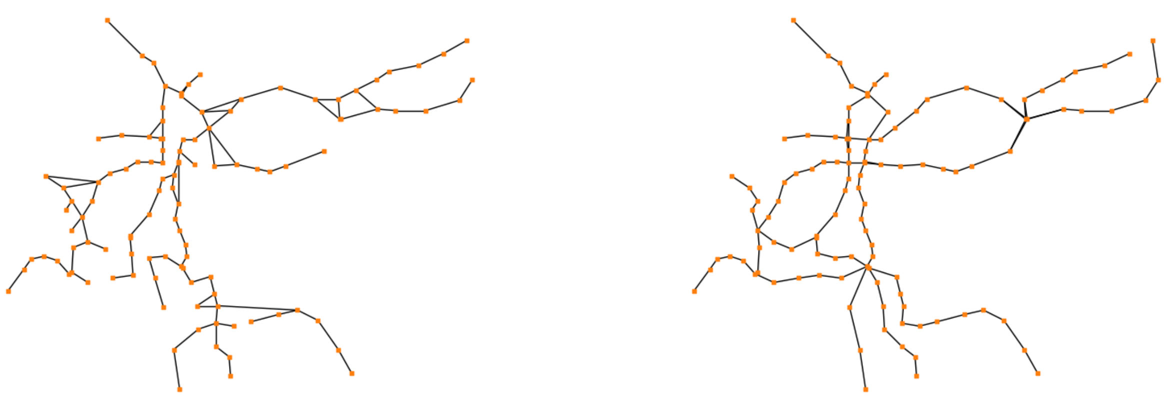
The slime mould simulation is visualised in the animation form. 4 screenshots of different steps in the slime mould animation and the results of the corresponding connected networks are shown in Figure 2. The animation is performed under "decay=0.2". We can see that the slime mould evolves over steps. In Figure 2d, the slime mould covered and connected all the FSs in 350 steps and it presented a retracting trend where there is no FS and a surrounding and connecting trend to where there is.



(a) 50 steps (b) 150 steps (c) 250 steps (d) 350 steps

Figure 2: Visualising slime mould simulation

Figure 3 shows the comparsion between the graph connected by the slime mould (Figure 3a) and the original graph from the dataset (Figure 3b). We can see these two graphs are similar in general, which means the implemented slime mould model can form an appropriate network in terms of the real-world dataset.



(a) slime mould graph (b) original graph

Figure 3: Comparison between the slime graph and the original graph

5.3 Quantitative Analysis

This part will illustrate and summarise the collected statistics of the graph and the slime mould model during the simulation. A parametric study will be performed to analyse how the decay can affect the effectiveness of the implemented model. In this case, 0.15, 0.2, 0.25 are chosen to conduct the experiments.

Table 1 shows some general statistics for the graph generated by the Slime mould and the original graph. In this case, clustering coefficient, path length, number of edges, and number of nodes are attributes recorded for the graphs generated by the slime mould with 0.15, 0.20, 0.25 decay respectively. We can see that the decay may not affect the attributes of the connected graph too much, and these statistics are very close to those of the original graph. And Figure 4 shows the PMF distribution of the degree of the graph in linear scale, which are also very similar with the original graph.

Table 1: Graph Statistics

graph type	clustering coefficient	path length	edges	nodes
slime mould with decay=0.15	0.041392	14.925676	118	112
slime mould with decay=0.20	0.030466	16.125322	121	112
slime mould with decay=0.25	0.044326	15.195785	119	112
original graph	0.042574	12.475386	122	112

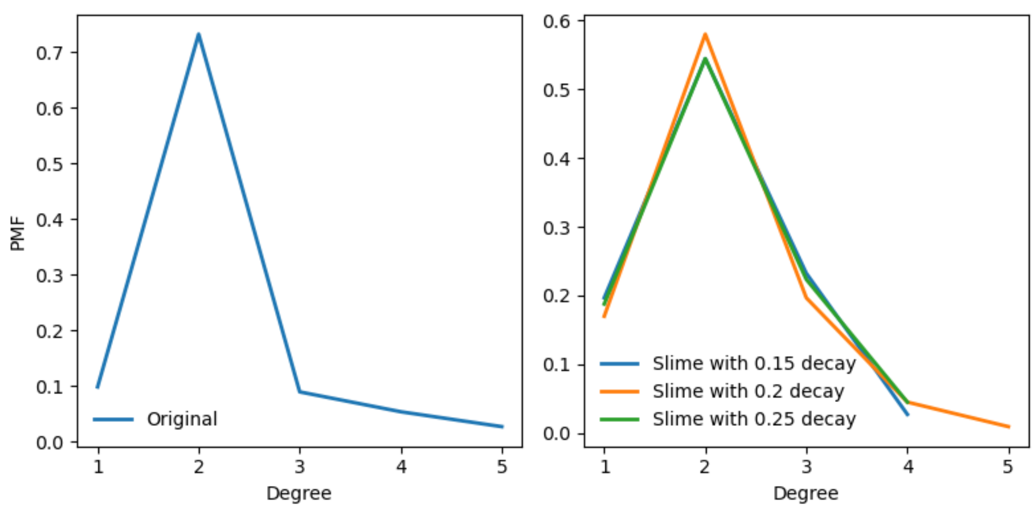
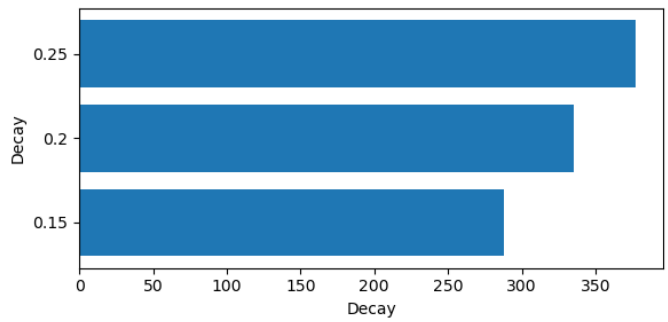


Figure 4: PMF in linear scale

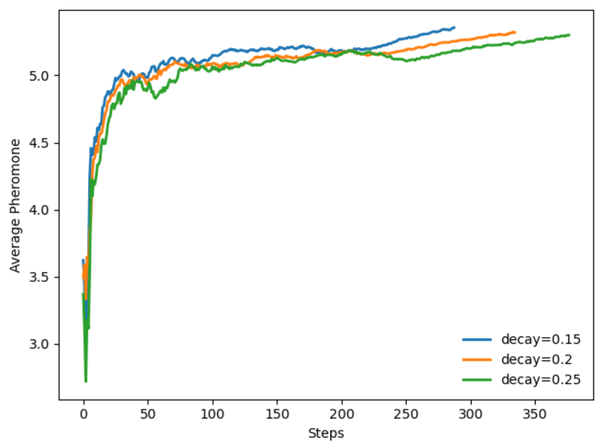
Finally, some statistics of the slime mould are visualised in Figure 5. Figure 5a shows the number of steps required for the slime mould to connect all the FSs under different decays. We can see that the slime mould with a higher decay needs to take more steps. In addition, Figure 5b and Figure 5c shows the average pheromone of active agents and total number of connected food respectively. In Figure 5b we can see that the average pheromone value increases rapidly in the first 50 steps, and fluctuating around 5 late on until finally stabilised. Slime mould with a lower decay (e.g. 0.15) tend to stabilise itself faster and have a relatively higher average pheromone value than others. In Figure 5c we can see the slime mould with a lower decay can connect the food faster than others. Furthermore, Figure 5d shows the number of agents (Slime) by steps. In the left figure we can see that the total number of agents increased exponentially, but the active agents shows a decrease trend in the later steps. In the right figure we can see that the total number of agents in the slime mould with a lower decay tend to increase faster than others. The active agents are the Slimes that have enough pheromone value to perform diffusion while the inactive agents are the Slimes that do not have enough pheromone value. The reason for the decrease trend of the number of active agents in the later stage is because the FSs in the Lattice were mostly connected by the Mould, resulting in the retraction of the pheromone value for most of the Slimes from ineffective pathways to the FSs, leaving more and more Slimes with low pheromone values behind.

6 Conclusion and Future Works

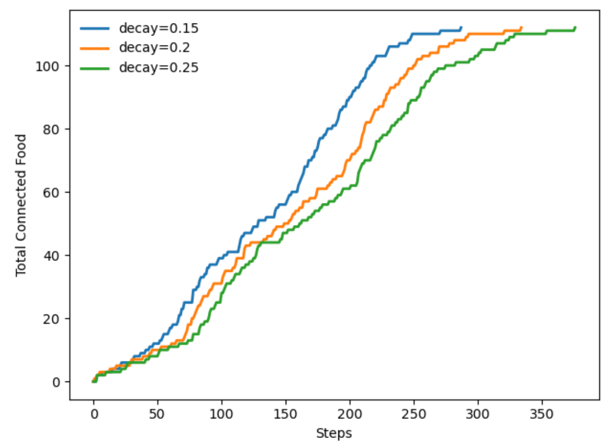
In this project, we first introduced the background of the project and reviewed the previous works in literature related to the slime mould modelling and graph theory. Then we explained the goal of the project and described the methodology to implement and evaluate the slime mould model, In addition to discuss the qualitative criteria and summarise the quantitative outcomes with a parametric study. We find that the implemented slime mould model can form a network that is similar to the original network, but the performance still need to improve. In addition to the 'decay' parameter introduced in the parametric study in Section 5, the implemented the slime mould also has several parameters that can be adjusted. These parameters can control several attributes of the slime mould such as diffusion speed (DIFFUSION_THRESHOLD), diffusion radius (DISTANCE_FOR_DIFFUSION_THRESHOLD), maximum pheromone value (MAX_PH), etc. Although these parameters can have a huge influence on the simulation results, they are set by default after performing several sensitivity analysis in this project due to the time limit. So for future works, we can try to adjust these parameters appropriately and see the different between the results, In addition, we can come up with more parameters and rules to get a better control of the discussion-making processes of the implemented slime mould.



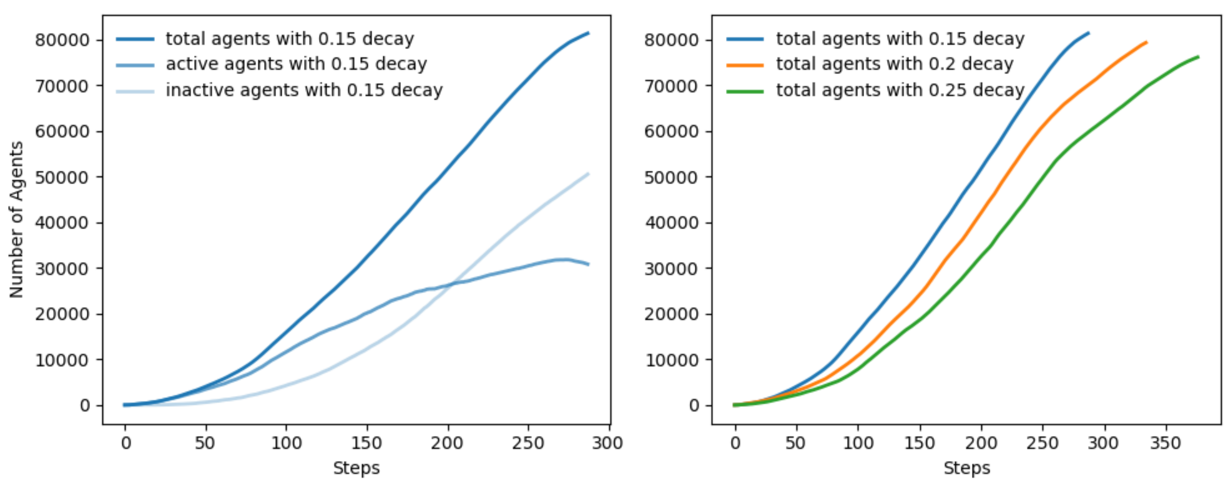
(a) Number of steps



(b) average pheromone of active agents



(c) total number of connected food



(d) number of agents

Figure 5: slime mould statistics

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