

A multi-ecological complex fungal growth prediction model based on Cellular Automata and interval estimation

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Abstract. As the decomposer of ecosystems, fungi play an indispensable part in the carbon cycle and energy cycle. We studied the impact of biodiversity and variation probability on decomposition efficiency with the mild climate data [1-2] with the semi-arid climate, and got qualitative conclusions. The establishment of this model follows the principle of total simplicity to complexity. In the process of continuously adding influencing factors to the model, the overall agreement of the results obtained from the various parts of the model is still maintained. And the conclusion of the model is basically similar to the actual situation. The feasibility of using Cellular Automata to solve the model has also been verified by past experience in the simulation of complex systems [3].

Keywords: Fungi, Climate, Differential Equation, Dynamical System, Cellular Automata.

1. Introduction

As the main decomposer of plant materials and wood fibers, fungi play an important role in the global carbon cycle. Microbial processes are increasingly incorporated into the biogeochemical model of the global carbon cycle, which can provide information for climate change predictions. Therefore, the study of fungi and decomposers is particularly important. When we are discussing the two characteristics of fungi (growth speed and moisture tolerance), we often need to consider the chemical mechanism of fungi in decomposing the main components of organic matter, lignin and cellulose [4]. Different types of fungi have the characteristics of competition, mutual benefit and symbiosis, and even tend to produce dominant species [5]. Because slow growing fungal strains tend to survive and grow better under environmental changes such as humidity and temperature, while fast growing fungal strains often cannot grow stably under the same changes [6-8]. We will build a mathematical model on a fixed piece of land to solve the problem[9-10].

2. The Foundation of Model

The solution we propose to explore the interaction between fungi is to first establish a differential equation by analyzing the growth rate of a fungus affected by humidity. We chose to use the Cellular Automata model (the design idea of CA itself is derived from the idea of biological self-reproduction), the process of CA's ecological dynamic changes happens to be in line with our fungal growth, reproduction and interaction. The process to simulate the interaction between fungi with different growth rates and different moisture resistance.

2.1. a single colony differential process model

When exploring the description of the mathematical model of colony growth, it is first related to the growth of the colony that requires nutrients (organic matter and energy substances), so when exploring its interaction with nature, energy is used as an intermediate medium.

According to the research results of the paper ("A trait-based understanding of wood decomposition by fungi") in the model problem, the growth rate of the fungus is affected by three factors: humidity, the growth rate of the fungus itself, and the moderate tolerance of the fungus. The results showed that there was a negative logarithmic relationship between the growth rate of fungi and humidity tolerance. For the humidity tolerance, we use the aquatic ecological quantile width

mentioned in the title, and integrate three indicators to build a model to evaluate and model the growth of a single fungus in a non-energy loss environment.

Based on previous assumptions, since the organic matter falling on the ground can be roughly divided into dry leaves and dry branches, and the surface of the fallen leaves is approximately regarded as a two-dimensional plane, while the dead wood is regarded as a three-dimensional space, we can imagine two situation:

1. Decomposition on the dead leaves (two dimensions)
2. Decomposition on dryness (body space)

Moisture affects the rate as a second-order function, which is a second-order function that opens downwards, when offset $\Delta W = 0, k_1 = k_0$; when $\Delta W = \pm 0.5L$, we know $k_1 = 0.5k_0$. The second-order function is shown in Equation 1:

$$k_1 = k_0 \left(\frac{2}{L^2} (W - 0.5L)(W + 0.5L) + 0.5 \right) \tag{1}$$

We make the growth rate is v , the growth rate is proportional to the energy absorbed by the colony, The growth rate of the colony is in proportion to the size of the boundary, and when the colony dies, priority is given to death without absorbing energy, and it has no effect on the energy absorbing part. Take the three-dimensional space as an example, As shown in Equation 2, 3:

$$\frac{dv}{dt} = \frac{du^{\frac{2}{3}}}{dt} = \frac{2}{3} u^{-\frac{1}{3}} v \varepsilon (v) \tag{2}$$

$$v = k_1 u^{\frac{2}{3}} - 0.3(u - (v[(\varepsilon(v) - 1)])) \tag{3}$$

From the initial state, there is only one spore on the organic fiber, and it splits only once per unit time, set the initial conditions:

$$U(0) = 1 \quad V(0) = 1 \tag{4}$$

2.2. Testing of basic models

Taking a three-dimensional space as an example, solving this differential process. As shown in the figure below, we found that the growth of different fungi in different environments was different. Among them, the humidity tolerance had a positive correlation with the growth of fungi in different humidity environments, and the growth rate determined the upper limit and the change of growth of fungi Moreover, it can be found that the fungi with slow growth rate can adapt to the changes of the environment, which just verifies the conclusion of the research article.

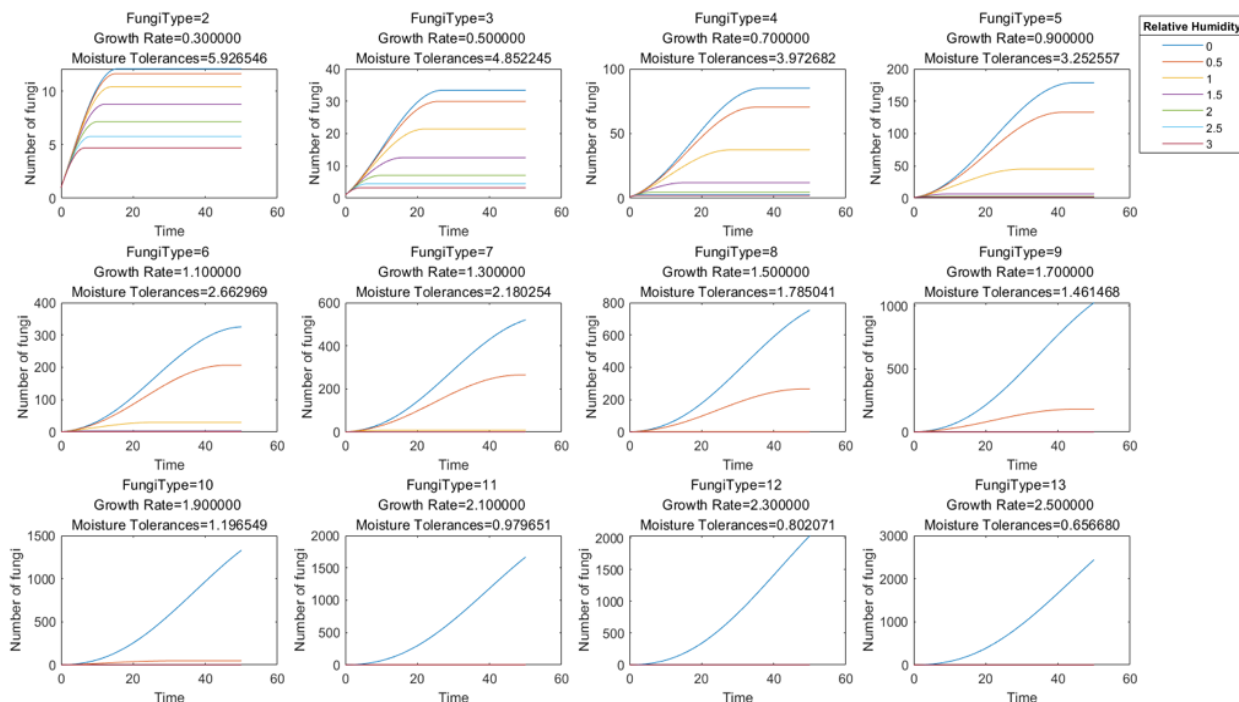


Figure 1. Effects of growth rate and humidity on the growth of fungi

It can be seen that different strains can meet the conditions of "originally fast-growing strains are affected by humidity" under different humidity conditions, and there is a certain limit for their growth.

2.3. Fungi Interaction Model

Based on the assumptions and differential processes given before, we have realized the establishment of a growth model for a single fungus affected by moisture, but this model has high limitations, and there is no single-acting fungus in nature. It is often the interaction of a variety of fungi to complete the decomposition of organic matter. It can be seen that different strains can meet the conditions of "originally fast-growing strains are affected by humidity" under different humidity conditions, and there is a certain limit for their growth.

Based on the previously established single strain growth differential equation model, we introduce the competition factors of multiple strains. The competition mode is mainly reflected in the fact that one strain cannot obtain nutrients from the position occupied by other strains. In view of the fact that the growth of each species is complex and the growth shape is stochastic, based on the above differential equation and the interaction factor, we established the following differential dynamic model in the dimension plane, and simulated the numerical solution of the Cellular Automata. Limited by the solution model, the growth shape is rectangular without contact with other bacteria.

And re-add the following assumptions:

1. Cells that don't make ends meet will die.
2. After the cell dies, ignore the energy loss, re-decompose it into organic matter, which is absorbed by the surrounding cells, and this position becomes a position that can be used again.
3. Taking into account the fungus's life and reproduction ability, when the colony dies and only a single cell is left, it is converted to spores and no longer consumes energy. Only when the conditions are too bad (relative humidity > 2 times) When the status of (the width of the water quantile), it will cause death.
4. According to the diagram in the question ("A trait-based understanding of wood decomposition by fungi"), There is a negative logarithmic relationship between the ecological water potential width of common fungi (L) and the rate constant of body growth (k_0) [4], assuming it is $L = 8e^{-k_0}$.
5. There is an upper limit for cell energy storage, which is set not higher than the energy that can provide all aspects of its reproduction

Then we get modified differential dynamic system (Fungi Interaction Model), as shown in Equation 5:

$$\begin{cases} N_{ij}^{t+1} = [k_{1i} i^t (W) E_{ij}^t - 0.3 + L_{ij}^t] \\ k_{1i}^t = k_{0i} \left\{ \frac{2}{L_i^t} (0.5L_i - W^t)(0.5L_i + W^t) + 0.5 \right\} \\ L_{ij}^t = k_1^{t-1} (W) E_{ij}^{t-1} - 0.3 + L_{ij}^t - 1 - N^t \\ L_{ij}^t = 0 \\ U_i(0) = 1 \end{cases} \quad (5)$$

2.4. Testing of Fungi Interaction Model

Based on this model, we can simulate the growth of the colony under the combined action of multiple colonies. By setting the humidity change rule and the two-way parameters of the introduced bacteria, the growth of the colony in a certain period includes the number of each bacteria, distribution, decomposition amount of organic matter and decomposition speed are solved. Set eight strains, using simulation programs to simulate the environment with increasing humidity gradient

We get growth curve:

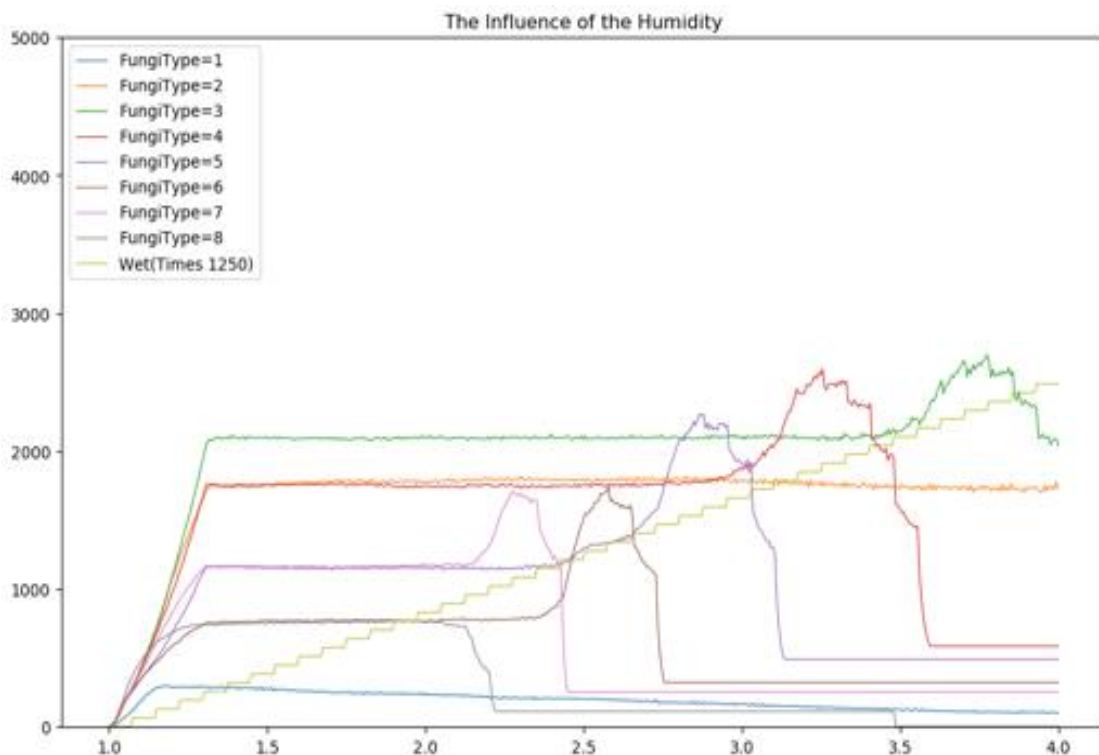


Figure 2. Growth curve of fungi under the influence of humidity gradient Comparing with the Figure 1, it can be seen that the agreement is good.

3. Model solving and analysis

3.1. Interaction analysis

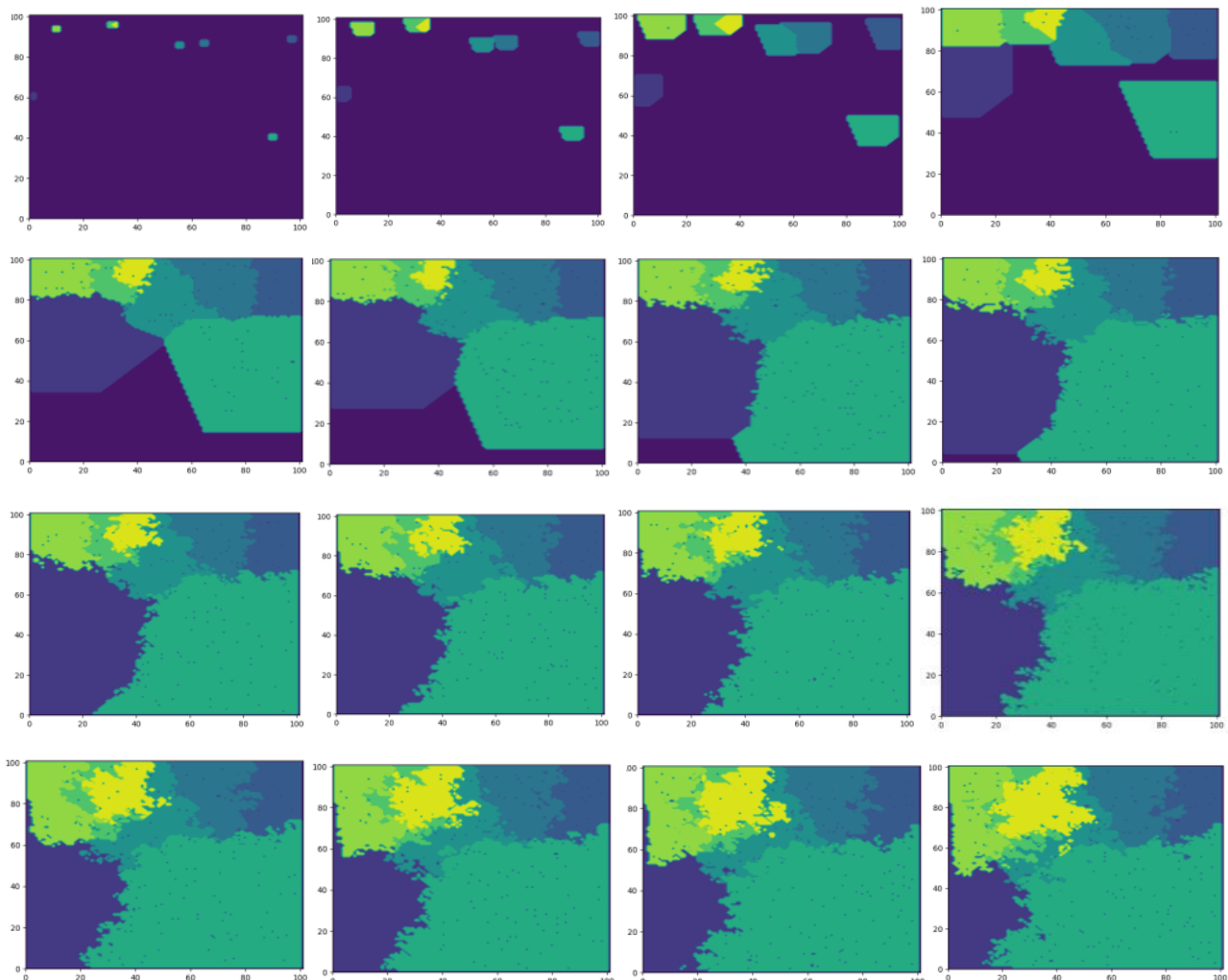
Then, based on the Figure I results, we analyze the competition between different fungi and the growth status of the whole community. We intend to establish a difference equation to simulate the survival model between fungal populations by using Cellular Automata. Through the growth

simulation process of fungal community over time, we capture the growth status map at certain intervals, as follows:

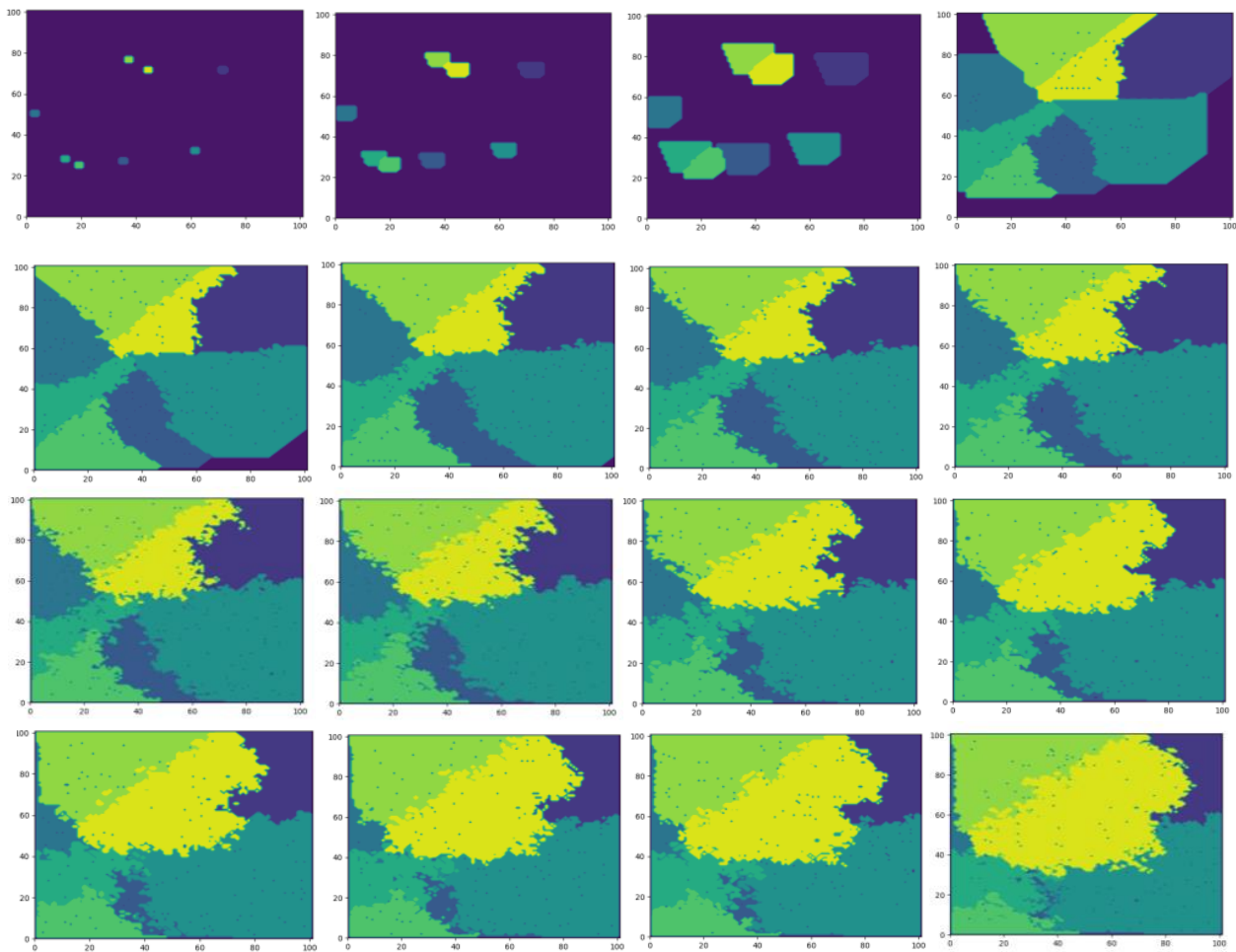
Through the observation of the growth status of the whole community and the growth simulation map under the competition between different fungi, we obtained the interaction between fungi, as shown in the following diagram, The first is that fungi grow on their own until they come into contact with other fungi. The untouched part continues to absorb nutrients, while the contacted part can no longer absorb nutrients. Both sides consume by themselves, resulting in cell death at the boundary and producing vacancies. The vacancies produced by two kinds of fungi are often different due to the growth rate of the two fungi. Therefore, when this process is repeated continuously, the two kinds of fungi have different growth rates Species will expand or shrink.

3.2. Micro environment analysis

With the support of the above simulation results, in order to be close to the uncontrollability and variability of real life, we add the influence of time and environmental fluctuation to the fungal community growth model with competitive relationship. In order to simplify the model, we first regard daily precipitation as normal distribution. For different climates, The variance of the microscopic daily precipitation distribution may be different,, so we select large variance ($\sigma^2 = 2.4$)and small variance ($\sigma^2 = 0.6$)to detect the effect of day fluctuation on strain, detect the impact of weather fluctuations on the growth of bacteria, and establish a simulation process that changes with time and humidity; Secondly, a fixed time point is intercepted during the entire continuous change process for comparison, as shown in the following two graphs:



The humidity variance is large



The humidity variance is small

Figure 3. Effect of weather fluctuation on the growth of fungi

The brighter the color in the picture, the faster the growth rate of the fungus, and the time nodes of the corresponding pictures in the two groups of pictures are the same. By studying the growth of fungi in the same group of pictures over time, it is found that no matter how fast the growth rate is, the growth rate of fungi changes the most in the first few days, and then gradually decreases with time until the growth tends to be stable, indicating that in the short term, the fungi have sufficient nutrition and grow rapidly; in the long term, the nutrient absorption caused by expansion and competition decreases, so the growth tends to be stable.

Comparing different groups of pictures at the same time point, we can find that for the simulation map with small variance, we can observe that in the case of small weather variance, high-speed and low humidity resistant bacteria show great advantages, constantly eroding the area with low growth speed; for the simulation map with large weather variance, low speed and high humidity resistant bacteria show more advantages, the areas where other bacteria are constantly eroding, and the high-growth fungi that showed a huge advantage under the previous set of simulations turned into a more conservative stalemate.

4. Conclusions

Conclusions of the problem Aiming at the process of fungi decomposing organic matter on the ground, we use the rate of nutrient absorption as an index to measure the growth rate of fungi, and abstract it as a differential equation in a two-dimensional plane and three-dimensional space. Using the differential equation dynamic system, we analyzed the influence of the competition between fungi, environmental fluctuations on the growth of fungi, the types of fungi that may persist in different

environments, and the impact of biodiversity and variation on the overall decomposition efficiency of fungal communities.

The first is the competition between fungi. The competition between fungi is carried out through the competition for nutrients. The space left by the dead cells of both sides is seized at the border, and the phenomenon of colony expansion or colony atrophy occurs.

The second is the impact of environmental fluctuations on the growth of fungi. From the simulation results and sensitivity analysis, we can see that fungi with high growth rate are very sensitive to environmental fluctuations. In the sensitivity image, the part with small L value generally exists in the steep region of this large gradient. When the environmental bias reaches a certain degree, the actual growth rate may be lower than that of the bacteria with low growth rate. For low growth rate, environmental factors are not so important. There is a large flat area in the part with large L value in the sensitivity image. For fungi in this range, large environmental fluctuations can only cause small changes.

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