

Fusion and Fragmentation: a Statistical Physicist's Attempt to Understand Subcultures

In 2017, *the Economist* published an article on linguistic diversity in Papua New Guinea [1]; at the time of writing, the nation of about 8 million people had a collection of 839 actively spoken, indigenous languages. By contrast, our own islands of the UK have a grand total of 10 alive, indigenous languages [2]. How can such a difference be possible? What structures, past and present, permit almost a thousand languages to be spoken on one island, and barely 10 on another?

The history of languages in the Papua New Guinea and the UK is complex, controversial, and tragic. It is a history of colonialism, of oppression, and of globalization. But the processes at work are universal. Cultural erosion and the loss of subcultures to form larger, more homogeneous groups is a seemingly unavoidable process, and one which we all face in one way or another. Understanding this process is essential if we are to fight the loss of cultural diversity, and this understanding should come not just from linguists and historians, but from people engaged in all kinds of academia. The perspective below is brief introduction to the perspective taken by statistical physicists to the problem of cultural dynamics. There is a sea of ideas which I do not have space to touch on, and an even larger ocean of topics which are still areas of active research. My hope with this work is not to provide some kind of comprehensive overview on the statistical physics of cultural dynamics, but instead to provide an taste as to what statistical physics is, how we use it, and what kind of approaches might be valuable to understand our ever-changing world of subcultures.

Let's take a step back and first introduce statistical physics. The general interest of a statistical physicist is in systems of very many parts (molecules, particles, people; it doesn't matter!), where the *overall phenomenology* of the system is driven not by its individual parts but by interactions between these parts in very large numbers. While the parts themselves may (or may not) be simple, the overall behaviour of the system arises from millions of parts interacting, instead of from some obvious property of individual parts¹. Furthermore, a statistical physicist tries to use mathematical methods to understand this kind of behaviour, and describe it quantitatively. So, the field is called *statistical* because it studies systems of very many parts, and *physics* because it uses mathematical methods and physical principles to understand these systems.

Let me give an example. A single water molecule, consisting of one oxygen atom and 2 hydrogen atoms, is a relatively straightforward object, at least from an external perspective. It may bounce off other water molecules, and is lightly attracted to them if they're close enough. However, if you take a collection of a trillions of these water molecules, (which now slosh around), and cool them down to some exact temperature, they suddenly conspire to completely change in behaviour and instead form a rigid object called ice. How is it that this collective behaviour emerges from simple water molecules? Why does this *phase transition* happen suddenly, at a specific temperature, and not gradually? What is this thing we call temperature anyway? These are the kinds of questions which have been answered very

¹ The word *emergence* has recently become fashionable in social sciences and philosophy. While it's not quite true that statistical physics *only* studies emergent phenomena, the kinds of thing statistical physicists are interested in are well described by this word.

successfully by the methods of statistical physics. These methods have been used to study not just water, but also magnets, stars, superconductors, birds, and bacteria.

Let's now turn our attention to how statistical physics has been used to study subcultures. The most famous model of subcultures is called the Axelrod model, introduced by Robert Axelrod in a 1997 essay entitled "The Dissemination of Culture" [3]. While this model is almost laughably crude, it has been successful because it contains 2 mechanisms believed to be fundamental in the understanding of cultural assimilation. The first is *social influence*, the tendency of individuals to become more similar as they interact. The second is *homophily*, the tendency of individuals to interact with individuals who are similar to them. The Axelrod model is successful because it demonstrates that these 2 mechanisms do not tend (as we may expect) to drive populations towards cultural homogeneity, but can instead drive cultural diversity in quite a subtle manner.

Let's spell this model out more precisely². We define an individual as a point on a large network, usually taken to be a rectangular grid. Every individual has a set of F "cultural traits" ($\sigma_1, \dots, \sigma_F$), each of which may take q "values" $\sigma_f = 1, 2, \dots, q$, so that there are q^F possible "cultural identities" an individual may have;

Example: $F=2, q=3$ means each individual has 2 cultural traits, which may each take 3 values. My 2 cultural traits may be my political party of choice, and my favourite social media platform. Each of these may be chosen from 3 values; so I may choose my political party from the Tories, Labour, and the Greens, and I may talk to my friends on Twitter, Facebook, or Instagram.

During each timestep, a random individual (A) is selected. The selected individual A may then interact with one of her neighbours (B) with some probability p_{AB} , which is proportional to the number of traits that A and B have in common. If A and B interact, one of the *different* cultural traits of B is selected, and then B copies A's value of this cultural trait.

$$p_{AB} = \frac{1}{F} \sum_{f=1}^F \delta_{\sigma_f^{(A)}, \sigma_f^{(B)}}$$

Example: If I am a Labour supporter and I use Twitter, my probability of interacting with my neighbour who is a Green Twitter user is 50%, but my probability of interacting with my neighbour who is a Tory and uses Facebook is 0%. If I interact with my Green neighbour, he becomes a Twitter-using Labour supporter.

Now let's ask a question; what happens if we start in some culturally random initial state, and let the system evolve according to the rules above? I wrote a small simulation [4] to illustrate this process playing out.

² If you're not familiar with them, you can safely ignore all the mathematical symbols below, which are included only for completeness.

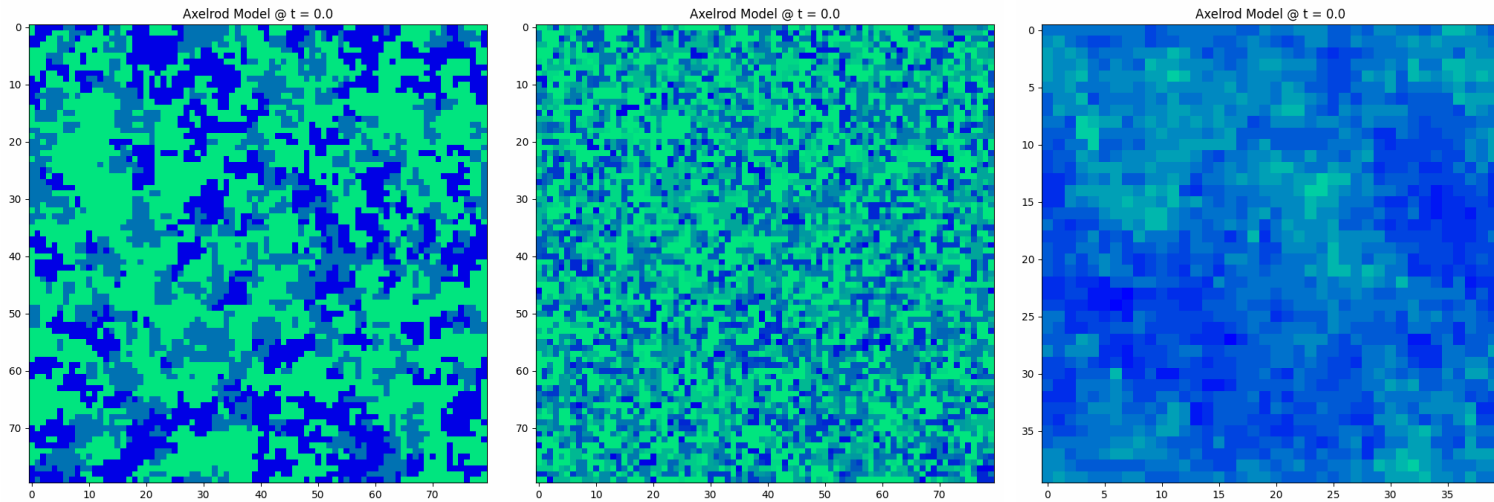


Figure 1. Typical simulation runs on a randomly initialised 80 by 80 grid. Colours indicate cultural similarity or difference. (Left) $F=2$, $q=2$: We see large islands of identical particles, but no global consensus is reached. This may be interpreted as the formation of subcultures. (Center) $F=2$, $q=10$: populations remain highly culturally inhomogeneous, with no large subcultures forming. (Right) $F=10$, $q=2$: a cultural consensus gradually forms; after a long time, only one set of cultural values remains.

If we let the simulations run for a long time we see only 2 kinds of situation are possible in the long term. Either the system tends towards a culturally *homogeneous state*, where everyone has the same cultural attributes, or the system becomes frozen in a *heterogeneous state*, meaning there are many islands of culturally different individuals which do not interact with one another. This is perhaps surprising; we may have guessed that since the model contains only *homophily* and *social influence*, there is nothing to drive cultural diversity. But somehow, cultural diversity emerges not from rules of the model itself, but from the many random interactions in the statistical system! We can make this more precise. We see the homogeneous state if q is *small* (i.e. each cultural variable has only a few options), and the heterogeneous states if q is *large*.

The transition between the homogeneous and heterogeneous states is quite sharp at a specific q ; this sudden change in behaviour is called a *phase transition* (see Figure 2). This kind of sharp change in behaviour between ordered and disordered systems is ubiquitous in nature.

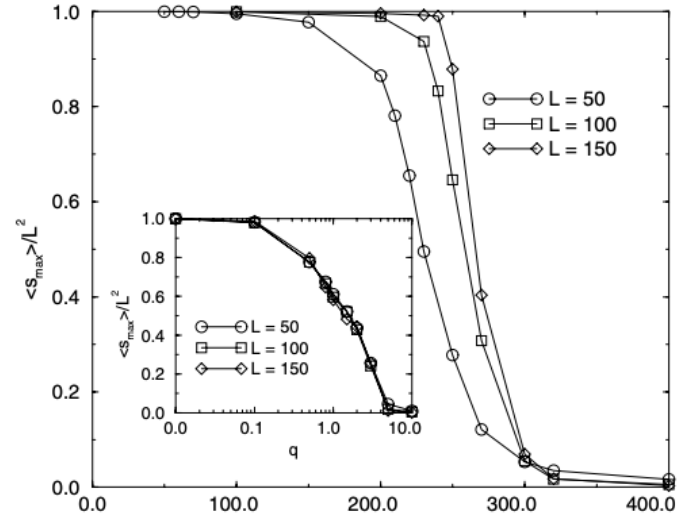


Figure 2: cultural homogeneity vs q , from [6]. The vertical axis is the size of the largest “cluster” of culturally uniform individuals as a proportion of the total system size, and the horizontal axis is q , the number of values each cultural variable can take. The large figure is for $F=10$; the small inset is for $F=2$.

Let's take a step back and look at what we've achieved. In the Axelrod model, we take the most basic elements of cultural interaction (homophily and social influence), and let them play out in a random way. Despite simple rules, we observe very rich behaviour. Our model system can either remain culturally diverse (heterogeneous), or tend towards cultural uniformity (homogeneous). Which of these outcomes is realised depends on how many different values each cultural feature can have, i.e. the parameter q , and there is a sharp transition between these behaviours at a specific q .

Of course, the Axelrod model is far too simple to be a realistic model of cultural assimilation. It completely neglects migration of individuals, the intricate network of influences each person has, external factors such as geography, and a million other things. But we might hope that through studying such models using the powerful tools of modern mathematics and computing, we may learn something about how subcultures are born and how they die. Even in the Axelrod model, interesting emergent behaviour is visible; the presence of a phase transition challenges our intuition that a small change in the conditions must result in a small change in the outcome of the system. Such "tipping points" are not an artifact of the simple model we are working with, but an observed effect in real-life cultural evolution [5].

How long will it be until we have the tools to understand questions like the diversity of language in Papua New Guinea as compared to the UK? My guess is, we're pretty far off. But we may still hope to learn a great deal in the not-so-distant future. Studying subcultures through the lens of statistical physics reveals how simple rules can give rise to surprisingly complex patterns of cultural diversity and assimilation. Models like Axelrod's demonstrate the role of simple social effects in shaping whether societies remain fragmented or become more uniform. While these models simplify reality, they capture key dynamics, such as sudden tipping points, that mirror real-world cultural phenomena. By exploring these patterns in more sophisticated models, we gain not just insights into how cultures evolve, but also tools to better understand and preserve the richness and complexity of culture in an ever more connected world.

Bibliography

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