

4. A MATHEMATICAL MODEL OF SOCIOCULTURAL EVOLUTION

The mathematical models and principles discussed in Chapter 3 refer mainly to *social* evolution only, which I already conceded in connection with TRISOC. In addition they are basically macrotheoretical ones, as they analyse systems as a whole and take (artificial) actors just as variables with different states. Both deficits now have to be filled in order to sketch at least the principles of a theory of sociocultural evolution. The main model in this context is the sociocultural algorithm (SCA), which is the subject of the next subchapter and which I constructed together with Jörn Schmidt. However, speaking of sociocultural evolution also contains the problem of individual learning and that is cognitive ontogenesis. When Habermas (1976) speaks of the learning of social systems he is of course aware of the fact that this is only a metaphor. In a strict sense only individual actors learn and the learning processes of social systems are on the one hand the sum of individual learning processes, determined by individual *and* social factors, and on the other hand the impact of these learnings on the society as a whole. How this interdependency of individual and "systemic" learning is to be understood is the core of the SCA. However, to get a precise understanding of the logic of cognitive ontogenesis I shall (together with Christina Stoica) sketch a preliminary model of it and give some aspects of the dependency of individual learning on environmental factors, and vice versa. A complete understanding of the manner in which *social* actors learn, generate new ideas and construct new roles according to new ideas and in this way realise sociocultural evolution is possible only if one has at least some ideas about the logic of individual learning as well. In this general sense sociocultural evolution has to be understood as the learning process of the human species.

4.1 THE SOCIOCULTURAL ALGORITHM (SCA) (TOGETHER WITH JÖRN SCHMIDT)

4.1.1 *The meaning of algorithms*

In 2.3. culture was defined as an ensemble of problem solving algorithms and the logical meaning of the concepts of algorithms in general was sketched accordingly. As the mathematical model of sociocultural evolution that we explain in this subchapter is called an algorithm, it is useful to consider the theoretical meaning of using algorithms as mathematical models for dynamical processes. Mathematical models, as has been mentioned at the beginning of Chapter three, are usually identified with sets of equations that describe the behaviour of dynamic systems. As those equations usually are t-invariant (independent of the time direction), it is possible to explain the past behaviour of the system as well as to make some prognostications about its future behaviour; nevertheless, there are a lot of systems where this assumption cannot be made (see below 5.2).

Such equation models are usually seen as contrary to algorithms, which serve as procedures to solve problems. However, the use of computer programs has demonstrated that the seeming difference between mathematical laws, expressed in the form of equations, and algorithms, is a bit superficial. The simulations, e.g., of astronomical systems by computer programs use as their mathematical basis usually the well known equations of celestial mechanics, including those of general relativity theory. However, because the simulations shall capture the dynamics of these systems the equations have the function (as basis for the programs) to *generate* the transitions of the system from one previous state to the next. In this sense the equations are nothing more than the mathematical formulation of a "generator", which drives the system along its trajectory of different states. In the program therefore, the equations function as an algorithm for determining the succession of states and for realising them. When dynamics was defined as a rule governed succession of different states, and evolution as the additional changing of rule ensembles in order to cope with environmental demands, then algorithms are simply the mathematical expression for this unfolding of a system's dynamics and evolution.

We would like to illustrate this point with the example of evolutionary biology. It is a well known fact that important characteristics of biological evolution can be captured with differential equations which, e.g. Eigen demonstrated in his famous hyper cycle (Eigen and Schuster 1979), for the subject of prebiotic evolution. It is equally possible to use the mathematical tools of Game Theory as Maynard Smith (1982) showed. And of course one can very efficiently use Holland's genetic algorithm, which models *directly* the generating mechanisms of variation and selection in regard to the genome. In particular the last model captures the generative forces of evolution in a very clear manner, as it refers to the mechanisms themselves, which are known from evolutionary genetics. Therefore the use of an algorithm as a mathematical model is the most suitable way if one wants to capture the generative mechanisms that drive evolution. It is not by chance, by the way, that often Darwin's greatest achievement is said to have demonstrated that biological evolution must be understood as a complex algorithm (Dawkins 1986; Dennett 1995).

Because the theoretical model postulated in this book is founded on the assumption that there are basically only actors who think, believe and act on the basis of these belief systems and generate by these actions the dynamics and evolution of sociocultural systems, we take an algorithm as a mathematical model too. The units of this model are artificial actors who take roles, or sometimes not, who learn and invent new ideas, who create new social roles or abandon them again and who are generating in these manners an artificial sociocultural evolution. The model of course is rather simple compared to real sociocultural evolution. However, even with this simple model quite interesting insights into the principles of sociocultural evolution are possible.⁴²

⁴² In the last years models like these are often called "multi agent systems" (MAS) or the modelling of "intelligent agents". We leave it to the readers whether the term "agent", which makes sense in the natural sciences, is very appropriate in the social sciences. As sociology has long ago introduced the concept of actor, we prefer to speak of artificial actors instead of agents.

4.1.2 *The model SCA*

In the sense of the "generative" modelling of biological evolution by the genetic algorithm, though not with the same model, we intend to model sociocultural evolution in a similar generative aspect: we attempt to model sociocultural evolution as the result of actions and interactions of social actors as problem solvers. These actions generate a culture as well as a particular social structure, defined as a set of roles with certain relations. The social structure emerging from these actions in turn determines the individual actions, i.e. problem solvings. Thus, at least basically, our model, termed sociocultural algorithm SCA, comprises both sides of sociocultural evolution.

The SCA operates in an artificial society typically consisting of 400 individuals. The "world" incessantly confronts the individuals with problems to be solved by them. The society has a (virtual) environment, which requires certain achievements of the society in order to maintain its existence. These achievements are differentiated according to a certain number of categories; these categories may be understood as an attempt to model real achievements of a society, like production of food, production of material goods, integration by law and so on. For practical reasons the model is confined to 5 categories, represented by a so-called "environmental vector" U with real components between 0 and 1; we leave these categories abstract because their content is irrelevant for our model. We assume that these restrictions, like various others in our model, though admittedly severe, will not impair the generality of results.

The environmental vector is applied as target vector and is compared with a corresponding vector L equally with 5 categories containing the actual achievements of the model society (see below); the degree to which the artificial society meets the environmental demands is defined as a measure of its adaptivity. Since absolute measures for different categories of achievements are meaningless, we have normalised both vectors so that the sum of components amounts to 1; thus adaptivity in our model refers to the relations of different achievement categories or an appropriate balance of different achievements. The basic measure of adaptive performance of our system is defined as deviation from environmental requirements sys , with

$$sys = | L - U |$$

being the distance between the two vectors.

Environmental requirements are modelled as problems that are posed by the environment and have to be solved by the society. For our model it was sufficient to represent problems by a number and the ascribed allocation to one of the 5 achievement categories which, in this respect, may be interpreted as different areas of knowledge. The complete set of problems of the "world", with assigned achievement categories distributed corresponding to the relative sizes of the components of the environmental vector, is held in a special set of typically 5000 problems initially, growing over time so that new problems continuously emerge; the increase or historical dynamics of the number of problems in this set is determined by an appropriate parameter. Other parameters can designate a range of "standard problems" (typically problem numbers < 2000) which are posed with higher frequency.

Posing of problems is modelled by a second pool, the actual problem pool, of typically 600 problems randomly chosen (in case of the existence of standard problems with emphasised frequency of the latter) out of the whole set of problems. Out of this actual pool the individuals of our artificial society have to take the problems that they want to solve; after each time step the actual pool is filled up according to the same distribution as described above. The individuals take on problems assigned to their own area of knowledge with priority, or the first available problem (with consequences for the ease of solving) in case the actual pool does not contain appropriate problems.

Whenever an individual has solved a problem the "solution", i.e. the problem index number, is stored in the individual's memory. Furthermore, any solution reached by any individual is stored in a memory termed "memory of the society"; the number of these solutions is evaluated as the knowledge of the model society and may be interpreted as a quantitative indicator of the culture of the model society.

Individuals possess a certain life span and die at a predefined maximum age (typically 50 - 100 time steps); the program starts with a population of equally distributed ages. If an individual dies it is substituted by a new individual with age 0. A fixed knowledge area out of the 5 categories is attributed to each of the individuals. An individual can take a role out of 5, corresponding to this knowledge area, according to certain conditions explained below. Moreover, 4 individual strategies

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Kluever, J.

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