3. Changing the rules of the game: lessons from immunology and linguistics for self-organization of institutions

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3.1 INTRODUCTION

Multiple agents use multiple services from most ecosystems. Without rules about who is allowed to consume which ecosystem service when and at what rate, conflicts may arise. To avoid tragedies, we need rules that shape interactions between people. The question is how to formulate these rules of the game, the institutions, in order to sustain the long-term development of the social ecological system. Game theory has been used to provide insights about which rules, or which mix of rules, lead to the best performance. However, the set of rules in game theoretical analysis is fixed. The puzzle is how new rules are created, and how effective rules get selected and are remembered. This may contribute to a better understanding of how institutions evolve.

Self-organization of institutions has been prominent in the field of common-pool resources. The reason is that laboratory experiments and field surveys show that people are able to create effective institutions without governmental intervention (Ostrom *et al.*, 1994). These findings are in contrast with conventional economic theory, which assumes rational selfish individuals. The picture of empirical research shows the existence of social norms (Ostrom, 2000) and reciprocity (Fehr and Gächter, 1998; Gintis, 2000a). The hypothesis in institutional science is that the existence of social norms explains observed reciprocity. The question remains how formal rules (such as law) and informal rules (such as social norms) have emerged and how they may evolve over time.

Similar questions on self-organization have been addressed in other disciplines such as immunology and linguistics. Immune systems are of interest since they are able to produce effective responses to new microbiological invasions, and remember successful responses. Key questions in linguistics are how a language can evolve in a group of agents, and how more complex syntaxes evolve. These two disciplines study the origins of rules in quite different systems. Besides being interesting analogies, these fields have developed computational models of their systems of interest and this led to the hypothesis that a better understanding of the self-organization of institutions might be derived when we cross-fertilize insights and tools with these other disciplines.

The next section discusses in more detail the research on management of common-pool resources. In Section 3.3 the puzzle on the origins of rules is reviewed in relation to immune systems and language development. Sections 3.4 and 3.5 describe the relevant dynamics of immune systems and language development. Methodology to simulate the evolution of rules is discussed in Section 3.6, while Section 3.7 relates this to a general framework of modeling self-organization of institutions. Section 3.8 concludes.

3.2 COMMON-POOL RESOURCES

When people have free access to a resource they will consume ecosystem services to the point where private costs equal the benefits, whereas the whole group is affected by external effects. This phenomenon is known as the tragedy of the commons (Hardin, 1968) and is in line with the solid theoretical models which predict how people behave in non-cooperative games. Conventional theory predicts that players in a non-cooperative game will follow a Nash equilibrium.

Laboratory experiments have been performed to study this prediction. Even in the simplest experiments, without communication between the participants, anomalies were found that are not in line with the predictions (Ostrom *et al.*, 1994). In none of the reported experiments on common-pool resources was the predicted Nash equilibrium observed. Furthermore, the total consumption of the common-pool resource fluctuates in time (Ostrom *et al.*, 1994). In additional laboratory experiments the role of institutions was analysed. It was found that communication could have an important influence on the level of cooperation in a group of players (Ostrom *et al.*, 1994). Furthermore, this cooperation will increase when sanctioning of defectors is allowed, especially when the players themselves have determined the rules of sanctioning.

Careful analysis of a variety of common-pool resources in different parts of the world shows that there are some common characteristics among self-organized institutions of common-pool resources. These include the presence of boundary rules, and authority rules related to allocation, and active forms of monitoring and sanctioning (Ostrom *et al.*, 1994). Furthermore, traditional societies, which have established a sustainable interaction with their environment, use rituals, and taboos as mechanisms to practice and remember ecosystem management (Berkes and Folke, 1998).

According to conventional economic theory, a solution to the tragedy of the commons is to calculate the optimal level of resource extraction and to allocate individual permits of harvesting to the individuals of the group. Based on these insights private property, or governmental ownership and control, was recommended. This implicitly assumes that the government has a perfect understanding of the system and acts in the public interest. The empirical evidence gives a radically different perspective. Cooperative solutions can emerge spontaneously. Unfortunately it is not known precisely under which circumstances this may happen. However, it is clear that mutual trust among the participants is important to derive such a self-organizing process. This might be the reason that governmental interventions, as recommended by conventional theory, are often not effective. The government is not one of the original participants with whom a trustful relationship has evolved.

Common-pool resources have evolved and nowadays we experience multiple-use resources too (Steins and Edwards, 1999). A common-pool resource can be, for example, a lake where fishermen catch fish. In a multiple-use resource, other uses of the lake become important such as tourism, natural conservation and industry. The involvement of different stakeholder groups makes the management of resources more complex. Steins and Edwards (1999) advocate the use of platforms for resource use negotiation. Such participatory approaches are discussed in Chapters 12 and 13. From an analytical perspective the question appears on how multiple use may influence the possibilities to reach a collective action.

3.3 THE ORIGIN OF RULES

The general aim of this paper is to outline an agenda for the understanding of the evolution of rules, by recognizing that similar questions are addressed in immunology and linguistics. This section formulates a number of research questions for such an agenda.

Emergence of new rules relates to the difference between individual selection (individual rules) and group selection (cultural rules). Various scholars provide different explanations for cooperative behavior (Sober and Sloan Wilson, 1999). Some argue that cooperative behavior does not exist due to individual selection (selfish genes), while others argue that genetic selection operates on different levels which explains that groups that contain altruistic individuals can have a higher fitness. Institutions can be seen as an expression of cultural rules. We want to understand how such rules emerge in social-ecological systems.

Rules can be formal, like law, taxes and fences, but also informal such as norms, taboos and rituals. The aim is to understand general system characteristics. How do rules of interaction between agents, and between agents and the environment, emerge, selected and remembered? How does the expected self-organization of rules depend on the dynamics of the environment?

As an organizing framework the social-ecological system is approached from both an immune system perspective as well as a language development perspective. The purpose of using these rather different systems is to derive inspiration about how to analyse the evolution of rules, like lymphocytes evolve in an immune system, and words and grammar evolve in languages. Obviously, there are important differences. For example, social-ecological systems are not organisms such that the analogy of the immune system perspective is limited.

Janssen (2001) argues that there are a number of fascinating similarities between social-ecological systems and immune systems. Social-ecological systems can be viewed as distributed systems in which organisms (humans, animals, and plants) respond to local changes. Traditional ecosystem management, that has proved to be successful over long time periods, has developed mechanisms to detect anomalies, develop effective responses and remember successful policies. These characteristics of successful ecosystem management are similar to the functioning of biological immune systems. Nevertheless, the analogy can be useful to explore. A detailed discussion on the immune system perspective for the evolution of rules can be found in Janssen and Stow (2002).

Language consists of words and grammar. Language development is a dynamic process. Words and grammar change in time. The meaning of words can be different for each person. Sometimes the meaning of words overlap and sometimes we cannot find words to express our feelings. Notwithstanding the complexity of language, children are able to learn to speak without having experienced all possible utterances. This relates to the problem of learning in complex environments. When a stranger enters a group (s)he has to learn the formal and informal rules of this group. This is a complex task since the stranger would not be taught the rules explicitly. (S)he has to learn the institutional rules like a child learns to speak.

Before the discussion on self-organization of institutions is continued, the general system dynamics of immune systems and language developments are reviewed in more detail.

3.4 THE IMMUNE SYSTEM

The immune system protects the body from harmful pathogens. Pathogens include a large set of micro-organisms such as bacteria, parasites, viruses and fungi that constantly invade the body. These pathogens are the source of many diseases. Rapid recognition and elimination of harmful pathogens is therefore required for sustaining the health of the organism. Furthermore, the immune system is able to remember successful solutions to overcome harmful invaders. A brief sketch of how the immune system functions follows. It is primarily based on Hofmeyr (2001), who provides a clear description of the immune system from the perspective of systems dynamics.

The immune system consists of certain types of white blood cells, called lymphocytes, which cooperate to detect pathogens and assist in the elimination of those pathogens. Each of these lymphocytes is a kind of mobile independent detector which circulates around the body via the blood and lymph system. There are millions of these lymphocytes, forming a system of distributed detection without central control. The surfaces of lymphocytes are covered with various receptors, while the surfaces of the pathogens are covered with epitopes. Both the receptors and the epitopes have complicated three-dimensional structures. The more complementary the structure of the receptor and the epitope, the more likely it is that binding will occur. The strength of this is called affinity. Therefore each lymphocyte is specific since it can only bind a particular set of similar pathogens. Pathogens can have different types of epitopes, thus several different lymphocytes can be specific for a single kind of pathogen.

This functioning of receptors leads to local signals of recognition that mediates the immune response. Local recognition of a harmful pathogen occurs when the number of bounded receptors on a cell exceeds a certain threshold.

The detection and elimination of pathogens is a consequence of trillions of cells interacting through simple, localized rules. Detection of pathogens focuses on the identification of harmful ‘non-self’ pathogens. The immune system has evolved in such a way that false negatives and false positives are rare. A false negative is a non-detected non-self, and a false positive is an element corresponding to self but recognized as a non-self. Consequently, the immune system is very resilient to the failure of individual components and attacks on the immune system itself.

The immune system has a repertoire of various types of responses because different pathogens must be eliminated in different ways. New types of responses are generated continuously like a kind of random generator. When a particular harmful pathogen has been detected, the immune system selects an appropriate response triggered by chemical signals. So-called antibodies are generated which neutralize pathogens by binding pathogens and self cells.

The immune system is adaptive, because it adjusts the distribution of different kinds of proteins as a response to its recognition of specific classes of pathogens, and retains a memory of the successful responses to speed up future response to those and similar pathogens. This adaptation occurs during the first response when a new pathogen invades. This initial response is slow and the organism will experience an infection, but the immune system retains a memory of the kind of pathogen that caused the infection. If the body is infected again by the same kind of pathogen, the response of the immune system is faster, because it remembers the earlier response to this pathogen.

The memory of the immune system is related to the fact that it is unable to contain a sufficient diversity of proteins to respond to all possible pathogens. The immune system contains about 10^6 different proteins, while there is a potential of 10^{16} different foreign pathogens to be recognized (Hofmeyr, 2001). Therefore, the immune system needs to contain enough diversity to respond to new kinds of pathogens. One of the main mechanisms for producing the required diversity is a pseudo-random process involving the recombination of DNA. Furthermore, it needs to have a memory function sufficiently powerful to respond rapidly to pathogens that invade frequently. How an immune system is able to remember successful responses can be understood in the following way. Once the immune system experiences pathogens of a type it has not experienced before, it may take several weeks to eliminate the infection. During these few weeks the immune system is learning to recognize the new type of pathogen. This occurs due to generation of new designs of receptors and replication of cells that are able to recognize the pathogen. If the pathogen invades the body again, the response is more rapid and effective. However, this is dependent on the response being remembered. There is only a limited capacity for remembering successful responses. When the body is not infected for a long time, memory can be lost. A good example is immunity to malaria infection. When persons are not exposed to the malaria parasite for longer periods, immunity declines.

3.5 LANGUAGE DEVELOPMENT

Language is a dynamic system of information exchange between agents. Language emerges at the intersection of three processes which act on different time scales: *learning* (children learn a language in order to communicate with their environment), *cultural evolution* (languages change over generation when words enter or leave languages, meanings shift and phonological and syntactic rules adjust), and *biological evolution* (the mechanism to learn and process language adapt over evolutionary time) (Kirby and Hurford, 2001). A traditional approach of linguistics was to unravel the universal elements of languages. There are indeed universal tendencies in natural languages, such as the distinction between subject, object(s) and verb, but also languages exist which do not fit with these universal patterns (Steels, 2000). The reason for the hypothesis of universality lays in genetic information, such as a language organ inside the brain (Steels, 1997). Language, from this perspective, would largely be transmitted genetically. Children learn their mother tongue through parameter setting. Empirical evidence exists that lower animals like crickets, quails and song birds have stored their species-specific communication patterns in highly localized hard-wired neurological structures (MacWhinney, 1998). However, an important difference between lower animals and humans is that children learn language gradually. Besides biological characteristics of humans, which determine the ability to speak, the social environment determines the languages that can be learned. For example, a Chinese child who grows up in the Netherlands can learn to speak Dutch perfectly, and may even not be able to learn to speak Chinese very well if (s)he is not taught to speak Chinese during his/her youth. Another example is a simple test that was used during World War II to check whether somebody was really Dutch. If you are able to pronounce ‘Scheveningen’ in the right way, one is almost sure that you have learned to speak Dutch during your childhood because the pronunciation of ‘sch’ in Dutch is something very specific. Thus the right pronunciation of ‘Scheveningen’ is an indicator for the identity of Dutch persons.

A specific characteristic of the human language is the use of writing to transmit information. There are various writing systems. The distinction between writing systems is the division of *logographic* writing (like Chinese) and *phonographic* writing (like English) (Sampson, 1985; Robinson, 1995). Japanese is a special language since it is a mixture of both language systems by combining Chinese characters and Japanese and English letters. The phonographic writing system has its origins in Mesopotamia about 5000 years ago. The number of letters varies between different languages. The original Semetic alphabet probably consisted of 22 letters, the Romans had a 21-letter alphabet, while the English alphabet consists of 26 letters. The Chinese writing system is at least 3000 years old. The writing systems have to balance flexibility and efficiency. For example, the Chinese writing system is hard to learn, and its interpretation is very context dependent, but once one is able to use it, one can read and write much faster compared to the English language, which is however easier to learn, and less context dependent. One may expect that writing systems become more efficient and context dependent when they are not much influenced by other languages.

A more recent approach to languages is rooted in the study of complex adaptive systems. Language is seen as the result of local interactions of language users (Steels, 2000). Like species of organisms, languages evolve due to local interaction, selection, mutation, adaptation, etc. Agents produce and interpret sentences partly in an automatic way but occasionally novel situations or errors lead to adjustment of language (Steels, 2000). Languages are the result of a self-organizing process. Since agents benefit from being understood, agents benefit from having the same language as those with whom they communicate frequently. By imitation and teaching children to speak a certain language, local clusters evolve of the same language. This explains linguistic diversity (Nettle, 1999). Often expressions and pronunciation differ between two neighboring villages.

Language evolves as we are confronted with new situations, other languages and due to social processes. New technology such as computers leads to new terms like *e-mail*, *zip-drive* and *internet*, but also adapts the meaning of existing words like *apple*, *window* and *mouse*. Due to contact with other languages new words invade the native language. In the Netherlands language is very much influenced by English through English music and television programs. On the other hand, countries like France and Germany try to limit the invasion of other languages by dubbing foreign television programs into their own language. Social processes also play an important role. Younger generations want to derive their own identity and start to use their own expressions and words which may be adopted by older generations later on. Furthermore, languages differ slightly between social classes due to local adaptations and selection of specific terminology. This is very prominent in science, where specialists have trouble explaining their research to non-specialists without using jargon.

3.6 METHODOLOGY

The possible analogies with language development and immune systems provide a basis for studying system characteristics that are of interest for understanding observed phenomena in the management of common-pool resources. In this section the main formal approaches of studying immune systems and language developments are discussed.

Within the studies of artificial immune systems (Dasgupta, 1999; Hofmeyr and Forrest, 2000) and computational linguistics (Steels, 2000; Cangelosi and Parisi, 2001), three types of approaches are frequently used to capture the system dynamics: game theory, neural and immune networks, and evolutionary computation. Although other methods are available such as differential-equation models and cellular automata models, these three approaches can serve as starting points for the development of the stylized models of social-ecological systems.

3.6.1 Game Theory

Game theory is a powerful tool for the selection of strategies of interaction and is currently one of the formal approaches for studying institutions. Game theory is also used to study evolutionary processes in language. The players have the chance of using different rules, whether this is grammar or vowels, and they will benefit when other players understand their messages. Evolution of cooperation is in this case the evolution of communication. Results of these games show clusters of rules, or the dominance of one rule. De Boer (1997), for example, describes the use of adaptive imitation games to simulate the emergence of vowels. The question is how agents can come to share a system of vowels without having been given a pre-programmed set and without central supervision. Agents produce random sounds from their repertoire, which other agents will try to reproduce. The agents may have to learn new sounds, reinforce sounds from their own repertoire or may not recognize these sounds. Robotic simulation leads to a repertoire of shared sounds that emerges through self-organization. Furthermore, the kinds of vowel systems that emerge have similar characteristics as those of natural vowel systems (De Boer, 1997).

An example on the evolution of grammar is given in Nowak *et al.* (2001) who describe a game where players benefit when they understand each other. Since players with a higher payoff generate more offspring, Nowak *et al.* (2001) can analyse the conditions under which a universal grammar emerges, and when rules-based grammar can evolve compared to a list-based grammar. Emergence of universal grammar depends on the accuracy of the learning process and the number of candidate grammars. The condition for rule-based grammar depends on the number of sentences types related to accuracy of learning and candidate grammars. If a population can effectively communicate by remembering only a few sentence types, a list-based grammar will evolve, otherwise a rule-based grammar will evolve.

3.6.2 Networks

Neural networks are powerful learning tools in complex environments. In a neural network, knowledge is represented in the strengths of the connections. Learning must be a matter of finding the right connection strengths so that the right patterns of activation will be produced under the right circumstances (McClelland and Rumelhart, 1986). Due to these system characteristics, neural networks are used for learning and remembering complex patterns. An illustration is a language development project where neural networks were used to study how children learn the rules when to use ‘die’, ‘der’ or ‘das’ in the German language, where ‘die’, ‘der’ and ‘das’ are used for ‘the’ in different circumstances (MacWhinney, 1998).

Networks also play an important role in immunology. Immune systems can be described as networks of molecules which simulate the dynamics of lymphocytes (Jerne, 1973; Perelson, 1989). The immune network dynamically maintains the immune memory using feedback mechanisms. Thus if something has been learnt, it will be remembered if it continues to be reinforced by other parts of the network.

3.6.3 Evolutionary Computation

Evolutionary computation covers a wide range of algorithms that contain the basic mechanisms of mutation and selection. The most prominent algorithm is the genetic algorithm, which in addition to mutation and selection includes crossover (Mitchell, 1996). Evolutionary algorithms are powerful in generating robust solutions of problems in a noisy environment.

Evolutionary algorithms are often used to generate new combinations of ‘genetic’ information. For example, new vowels are created by a random combination of articulatory controls, or mutation of existing vowels (De Boer, 1997). Simulation experiments to study the effects of evolution on the genetic encoding for antibody molecules were based on genetic algorithms (Hightower *et al*., 1995). They found that an optimal solution to the antigen recognition task requires a balance between the conflicting issues of coverage redundancy and coverage gaps.

3.7 MODELING THE SELF-ORGANIZATION OF INSTITUTIONS

This section describes different stages in the self-organization of institutions: coding, creation, selection and remembering of rules. The hypothesis is that different types of rules emerge under distinct socio-economic and ecological conditions. It is expected that the methods already discussed can be used to develop a kind of computational laboratory. By careful experiments with such a laboratory it is expected to be possible to derive better understanding under which conditions observed rule-systems can evolve.

3.7.1 Coding of Possible Rules

To understand the emergence of rules, we have to understand the decoding of rules. Just as DNA is the code by which living beings can be described, we need a genetic structure of rules. Interestingly, Crawford and Ostrom (1995) provide us with a useful starting point with the introduction of a grammar of institutions which provides a theoretical structure for analysis of the humanly constituted elements of institutions like rules, norms and shared strategies. There has been a discussion in institutional science whether institutions are rules, norms or strategies. Crawford and Ostrom (1995) propose a broader framework, which encompasses all three concepts. The grammar of institutions enables them to generate structural descriptions of institutional statements. The syntax of the grammar institutions contains five common components. Different compositions of these components lead to strategies, norms or rules. Crawford and Ostrom (1995) argue that such a framework can help to identify and classify institutional statements. Besides the grammar, Ostrom *et al.* (1994) distinguish seven types of rules within institutions (see also Chapter 2).

3.7.2 Creation of Rules

Given the space of possible rules, how do new rules emerge? The development of language is a process of probing, imitation and mutation of words and rules (Tada, 1997). This leads to local clusters of linguistic rules. Sometimes words from other languages try to invade the language. When this is perceived as not distorting meaning, the new word is tolerated. Another factor that triggers creation is the pressure that is experienced. For example, our immune system is constantly confronted with microbiological invasions, but is organized efficiently to recognize and eliminate harmful cells or molecules. One of the reasons for the success of immune systems is the continuous random generation of new responses, the lymphocytes.

Translated to institutions and rules, new rules emerge due to experimentation and by contacts with different types of institutions for diverse ecosystems. In the spirit of Jacob (1977), creation of new rules can be viewed as tinkering. In contrast to an engineer, a tinkerer does not know exactly what (s)he is going to produce but uses whatever (s)he finds around him or her. Once new rules are proposed, the selection process takes over.

3.7.3 Selection of Rules

Before proposed rules become effective, that is, before becoming a social norm or a law, a selection process tests the rules. In fact all rules are nested in another set of rules which defines how the first set of rules can be changed. Kiser and Ostrom (1982) distinguish three levels of rules. An operational rule which relates to day-to-day decisions, collective-choice rules which determine decisions that affect the operational rules of individuals. At the collective-choice level decisions are imposed on individuals. Those who are monitored and break rules can be sanctioned. Constitutional-choice rules define formal procedures on how to change collective-choice rules. An example is to have elections for a new parliament that can decide on new regulation that may affect the daily decisions of the citizens.

Besides formal constitutional mechanisms, informal mechanisms are also important, such as the spreading of trust in a social network. It is known that the level of trust is higher if the network has a higher density (Granovetter, 1985), and the connectiveness of a social network – especially links between clusters – influence the spread of information (Granovetter, 1973). Models of trust can be formalized by repeated games, where agents derive information about each other due to repeated confrontation (Janssen and Ostrom, 2002). An interesting example of a more advanced computational model on the evolution of trust and cooperation between strangers is developed by Macy and Skvoretz (1998). This model combines a social network in which agents play iterated prisoner dilemma games. Using a genetic algorithm, and decoding characteristics like greeting behavior and distrust of strangers, clusters of trust relationships emerge.

The selection process of rules can also be endogenous. Constitutions change over time, but this is a much slower process than the actual selection process of the operating rules between agents. This relates to the concept of resilience (Holling, 1986). These slow variables can be a source of collapse. Therefore it is important to test institutions, by violating the rules or by social debates.

3.7.4 Remembering Rules

Even though rules have been selected, they might not be useful in every situation. It might be efficient to limit the number of rules. However, in a system that is influenced by variability, a diversity of rules can be used to spread risks. This can be compared with the functioning of ecosystems, which are adapted to a certain amount of variability. Reduction of functional biodiversity can reduce the ability of ecosystems to recover from disturbances (Holling, 1986; Levin, 1999). Due to this functional diversity, ecosystems maintain a memory of useful responses in a large set of situations. This is related to institutional diversity. Although many different institutions exist, and even overlap in their functionality, a certain level of redundancy is essential for the resilience of social ecological systems. Low *et* *al.* (2002) suggest a number of conditions that make redundancy advantageous: when information transfer across subsystems is inefficient or slow, redundant local systems may be more efficient and in large, spatially heterogeneous systems, redundant local systems may work better. A possible reason for the importance of redundancy relates to the ability of local systems to have better access to local information and a more rapid response than higher system levels.

3.8 DISCUSSION

This contribution provides ingredients for an approach to study the self-organization of institutions. The main question is how rules are created, selected and remembered. Rules can be seen as an outcome of a continuous process of tinkering, experimentation, making errors, breaking rules, selection and competition. To understand how rules between people organize themselves these processes have to be investigated. During the last 20 years, computational models have been used to study immune systems and language systems in order to understand the key characteristics of these systems such as novelty, learning, selection and memory. These tools can provide a good starting-point for studying self-organization of institutions.

The computational models and methods of immune systems and language systems can be used to develop systems that are able to generate self-organization of institutions. These computational laboratories can be used to perform repetitive experiments under which social and ecological conditions for self-organization of institutions can emerge. Such experiments can provide a deeper understanding of institutional change. Besides better understanding of observed phenomena in the past, new situations can be explored.

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