Artificial Chemistry by Sound Waves

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Abstract

We consider a chemical reaction network model in which selections of reaction are stochastic and depend on past history. In this chemical reaction network, we found the emergence of Auto-Catalytic Sets (ACS) and complex dynamics in which ACS are repeatedly created and destroyed; we have called this reaction system as the Self-Reinforcement Reactions, SRR. We developed a neural-networks system by using SRR and confirm the neural network of SRR can solve a linear classification problem.

Keywords: Artificial Chemistries, Chemical Reaction Networks, Computer Human Interaction, Fourier Analysis, Sound waves

1. Introduction

Living systems are composed of chemical reactions; almost all interactions in living systems are chemical reactions. However, bio-chemical reactions in living systems are complicated and it is difficult to consider and treat. Hence, abstract model of chemical reactions have been proposed and such Artificial Chemistry, AC has been used as a method of describing interactions for modeling; Multi Agent Systems, Petri Nets, etc. and the AC is one of the methods which based on the Stoichiometric Chemistry. The Stoichiometric Chemistry is a method for describing chemical reactions that treat chemical reactions as changes of quantity of chemical molecular. We have developed a simple computational model, the Abstract Rewriting System, ARMS based on stoichiometric chemistry and reaction rate model. When we consider fundamental mechanism of living systems. ARMS is a hybrid-model and it is a discrete and continuous model, so if the number of elements (molecules) is small, ARMS is discrete model but when the number of element is large it is equal to Differential equation.

Since living systems are composed of bio-chemical reactions, information processing are also chemical reactions. It is well-known that, in a living system such as a cell, the number of molecules is small and fluctuation of reactions also large. Hence, "noise canceling" in information processing would be important.

AC including ARMS, in the most of models, have been described as an algorithm and implemented in digital media and have not been able to communicate with physical environments.

2. An Artificial Chemistry, Abstract Rewriting System On Multisets

We have been proposed an artificial chemistry, based on the Abstract Rewriting System, ARS; the ARS is a theoretical model of computation; we expand ARS on rewriting system on the multiset. A multiset is defined as a simple set and a map, which returns the duplication of element. We denote the duplication (multiplicity) of an element as M (a), for a ∈ A and in case c /∈ A, M (c) = 0; for example M (a) and M (b) of {a, a, b, b} are 2, and M (c) = 0; in the mathematical description, a multiset is described as; < sup, M () >, in which sup is a simple set of elements, in this paper we describe a multiset by denoting the same alphabet in its number of multiplicity such as {a, a, b, b} or a vector w =(M (a1) M (a2) . . . M (an)).

The union of two multisets M1, M2 is the same as the union of simple set and in vector description, the union of multisets is addition of vectors w1 and w2. And inclusion of sets is also the same as the simple set, when M1(a) ≤ M2(a) for all a ∈ A, the multiset M1 is included in M2 and we write M1 ⊆ M2.

A reaction rule is a pair of multiset, we denote A# as a set of all combinations of multisets over A and in the combinations, an empty multiset is included. A reaction rule l → r, l, r ∈ A# is described as a pair of multiset likewise chemical equations or a pair of its vector expression; and in some case, we can describe a reaction rule as a vector r, r = −l + r, it is simple and good for examining the dynamics of an ARMS, but this description can not illustrate when there are the same species of element in the left-hand side and right-hand side such as a, b → a, c; in this case l = (1, 1, 0) and r = (1, 0, 1) and r = −(1, 1, 0) + (1, 0, 1) = (0, −1, 1).

A reaction is described as the rewriting of a multiset, if the left-hand side of a reaction rule is included in a mul- tiset, these elements in the multiset are excluded and the right-hand side of the rule is merged to the multiset; the case when the multiset is a, a, b, b and the reaction rule is a, b → c, d, the left-hand side of the rule is included in the multiset, {a, b} ⊆ {a, a, b, b} so the {a, b} is excluded from the multiset and it is transformed to {a, b} and the left-hand side of the rule {c, d} is merged to the set and we obtain {a, b, c, d} by this reaction.

3. ARMS by Sound Waves

We model the ARMS by using sound waves; where each type of element is characterized as a frequency of sin wave in fixed amplitude, A and n duplication (multiplicity) of an element is differed as nA,; for example, when we define a as *0.1Sin(2)* and b is *0.1Sin(3),* the multiset M_1={a, a, b, b} is denoted as W= $2\times 0.1Sin(2) + 2\times Sin(3)$; we denote a multiset in *Sin* wave form as W and amplitude (duplications) of a in W is denoted as W(a); when M(a)= empty set, $0\times Sin(2)$ .The union of two multisets M1, M2 is the synthesizing W_1 and W_2: and inclusion of W_i is $W_1(a) \leq W_2(a)$ for all a ∈ A, the W_1 is included in W_2 and we write $W_1 \subseteq W_2$. A reaction rule is a pair of *Sin* waves, we denote A# as a set of all combinations of elements over A and in the combinations, an empty multiset is included. A reaction rule $W_l \rightarrow W_r$, l, r ∈ A# is described as a pair of *Sin* waves likewise chemical equations.

A reaction is described as the transforming of a *Sin* wave, if the left-hand side of a reaction rule is included in W, waves represent left-hand side of the rules are filtered and the waves of right-hand side of the rule is synthesized; the case when the multiset is a, a, b, b and the reaction rule is a, b → c, d, the left-hand side of the rule is included in the multiset, {a, b} ⊆ {a, a, b, b} so the {a, b} is excluded from the multiset and it is transformed to {a, b} and the left-hand side of the rule {c, d} is merged to the set and we obtain {a, b, c, d} by this reaction.

4. Neural Networks implemented by ARMS

In the system, which we propose in this paper, Neural Network, NN is implemented by using ARMS; NN in this paper is Self-Reinforcement Neural Network, SRNN, which we have been proposed; in SRNN , we assumes that substances can interact with each other according to reaction rules which change the amounts of the substance, and that reaction tendencies change depending on the reaction history. Reaction rules are assumed to be of the form x → y, meaning that the amount of substance x decreases and the amount of substance b increases. Reactions occur at rates which depend on the amount of the first substance x and the strength of the reaction x → y . The strength of each reaction is increased in proportion to how often the reaction has occurred recently.

Specifically, we considered a form of this model which is implemented according to the following procedure. The state of the system is represented by the amounts [x] of the chemical substances, and strengths w of the reaction rules. (For generality, we use “amount” rather than “concentration” or “number of molecules”.) Reactions are executed one at a time. The first substance and the reaction rule are each selected stochastically. The probability of selecting substance x is proportional to the relative amount of the substance [x], and the

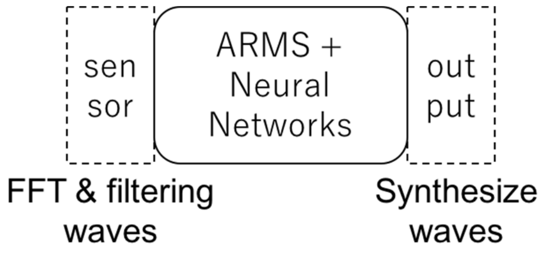

Fig. 1. Neural Networks implemented by ARMS (Self-Reinforcement Neural Networks) and the ARMS communicate with environment via waves; it analyzes input waves by using Fourier Analysis and filtered input waves can be detected by the it (detectable frequencies are given, in this paper but is not mandatory) and transform and synthesize output wave.

probability of selecting the reaction x → y is proportional to the relative strength $w_{x,y}$ of the reaction. When the reaction x → y occurs, the amount of substance x changes from [x] to [x]-1 and the amount of substance y increases from [y] to [y]+1. The strength of the reaction x→ y is $w_{x,y}$ = (q*R+1) where q is the number of times the reaction has occurred in the last M reactions of x and R is the strength of the reinforcement. If reactions have not been selected recently, or there is no reinforcement, then reactions have minimal strength of w = 1.

From Neural Network viewpoints, strength of weight can be regarded as Hebb rule and change of concentrations as anti-Hebb rule; because the concentration of left hand side of the fired rule is decreased and the firing probability of this rule is decreased. We confirmed that SRNN can work as a NN.

5. Communicating with ARMS via waves

In proposed model, input wave is analyzed by Fourier analysis with Fast Fourier Transform, FFT; for the system, detectable frequencies are given, it corresponding to the hearable frequencies (in the case of humankind, it is around 30Hz to 20,000Hz); so even if amplitude is large, if its frequency is out of hearable frequencies, it cannot detect it; practically selecting hearable frequencies is realized by a sensor, which detects frequencies and their amplitudes (Fig. 1). So, in case detectable frequencies are $a_0,\dots,a_m$ inputted wave *f* is transformed as $W = \sum A_i Sin(a_i)$, (i = 0,…,m), and input to SRNN is $\{A_0, A_1, A_2,\dots,A_m\}$. The SRNN changes amplitude of inputted wave, in this paper we propose unsurprised learning.

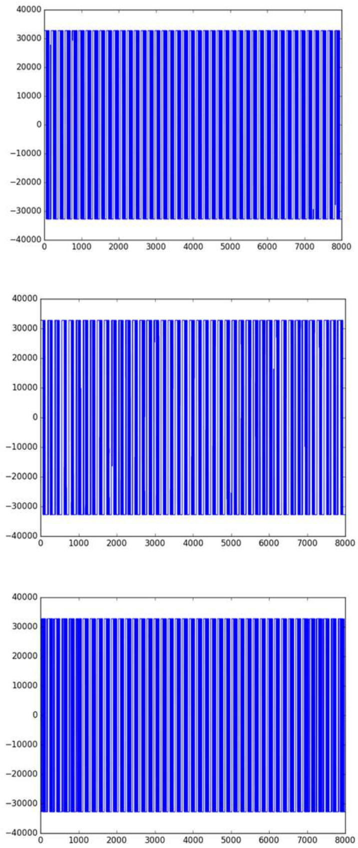

Fig. 2. Sample run of the system with frequency spectrums and time developments is up to bottom; in the sample run, we used the equipped microphone in the PC (MacBook) and record environment sounds for 30 sec; the synthesized wave was outputted through equipped sound speaker.

6. Communicate with SRNN via Sound Waves

As the input device, we used a microphone, which is equipped with the Personal Computer, PC (MacBook); the system record environment sound for 30 seconds then analyzes sound wave by using FFT and filtered detectable frequencies and their amplitude. In the sample runs reported in this paper, we did not define specific reaction rules but the system changes amplitude of frequencies; the system selects a frequency randomly, where the probability of selecting frequency is in proportion to its amplitude; then the amplitude is decreased by A_{df}; then selects a frequency to be added by A_{df}; in the beginning, it is selected randomly according to its amplitude and by the interaction the conditional probability of P(x|y) is changed; which denotes the probability of selecting y when the frequency x is selected and it corresponds to weight of link w_{ij} in SRNN.

In the sample run, environmental sound was created by voice, making noise by hitting desk for 30 sec. then the system analyzes sounds and create sound output; sound spectrums of system illustrate the system changes output sounds through environmental sounds changing (Fig. 2).

7. Future Remarks

We propose a method to communicate with computational models implemented inside a PC from outside via sounds. This framework would be applicable in Artificial Life, Robotics and Human Computer Interactions and Evolutional Language; by using several PCs or robots having this framework can interact with each other by using this sound communications; by integrating computational vision, these agents would be able to create link between sounds and visual information and novel language would emerge among agents / robots; it is important that animals or our human also can participate the process of this emergence of a common language among agents, robots, animals and humankind.

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