A Sense Enhanced Game of Life (SEGoL)

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Abstract:

The Game of Life is arguably the most popular and productive cellular automaton ever discovered, with applications in evolutionary dynamics and Turing Machine Designs. The present work purports to the design, implementation and discussion of a Sense Enhanced Game of Life (SEGoL), which is essentially the original GoL including sense enhanced perceptibility. To achieve this, two grids, namely the Life Grid L and the Sense Grid S are defined, with L taking one of two values (alive or dead) and S taking one of three values (touch, sight and sound), with the value in a particular S grid affecting the neighborhood perceptibility in the corresponding S grid. Based on the design, the evolutionary patterns are studied for various rules, coupled with the entropy values and survival rates. Among various cases explored, certain interesting cases leading to self-organization in the sense grids, with or without accompaniment of clustering of certain senses are observed. It is seen that the proposed Sense Enhanced Game of Life (SEGoL), essentially adapting Conway's original Game of Life Rules, scaled for larger neighborhoods, and for enhanced perceptibility, displays a diverse range of interesting evolutionary dynamics, while also retaining the original features of the original Game of Life including the still-life and oscillating elements for the pure touch case. It is hoped that the results detailed here would form preliminary steps in transforming a reductionist, structural perspective of life to a radical and innovative holistic, information based understanding of life.

Keywords: Game of Life, Cellular Automata, Evolutionary Patterns, Entropy

1. Introduction

The remarkable efficiency with which various natural processes are carried out, be it simple proliferations of a virus or sophisticated cognitive processes, has never ceased to fascinated the human intellect [1-3]. Among multiple approaches developed to study evolution and life, the informational approach, enabled by the development of computation and visualization technologies in recent times, stands out [4-7]. Of particular mention in this context is the concept of cellular automata, which essentially is a simplified representation of a grid of cells whose evolution in discrete units of time is determined by neighborhood 'rules' [8-11]. This concept has enabled the study of multiple evolution patterns corresponding to growth of cancers, tumors and epidemics, spread of population and so on [12-15].

It is an undisputed fact that the most interesting cellular automaton ever developed is Conway's "Game of Life" (GoL), comprising of a two-dimensional Grid, where a 'dead' cell is born, or a 'live' cell survives only when a certain number of its neighbors are alive, so that neither overcrowding nor undercrowding occurs [16]. A significant result of the GoL is that certain stable patterns which either remain constant or oscillate with time are observed, with these patterns extremely useful in developing the GoL as a Turing Machine, a "universal constructor", capable of building many types of complex objects [16-19].

In the present work, the concept of Game of Life is extended to include not just dead/alive "life", but also the concept of senses. Thus, two separate grids, a life grid and a sense grid are defined for a 2D collection of cells. The sense grid has one of three values – fundamental 'sense of touch', where the life of a cell is decided only by its immediate Moore neighbors, a slightly advanced 'sense of sight' with a Von Neumann neighborhood field of influence, and a more advanced 'sense of sound', with an even more expanded neighborhood, covering Hamming distances of 1, 2 and √5. Rules derived from Conway's GoL are defined for both the sense and life grids, and evolution patterns pertaining to various cases of proliferation, stasis and decay are explored. In this formulation, the original Conway's GoL is retained for the life grid with the sense grid filled with the fundamental sense of touch, thus preserving the original oscillators, still-life and gliders in this case. Thus, it is seen that the Sense-Enhanced Game of Life (SEGoL) proposed in the present work enables a rich variety of possible outcomes useful in the study of evolution patterns, tumor growths and the like.

2. Design and Rule Definition

The Sense Enhanced Game of Life (SEGoL) is fundamentally a 2D array A of cells, defined as MxN. In the present work, M=N=50. Two grids, L representing the Life Grid and S, representing the Sense Grid, both of size 50x50 are defined.

All-pervading throughout the entire grid, the concept of "consciousness" is seen as the property that enables each cell in both the sense and life grids to be aware of its existence depending on the neighborhood cell values, irrespective of whether the concerned cell is dead or alive.

Three kinds of neighborhoods are defined as follows and illustrated in Fig. 1, all of them defined with respect to a cell denoted by x and y coordinates as (x,y), and all of them excluding the cell (x,y) [20,21]:

1. Moore-1 Neighborhood: This consists of immediate neighboring cells to (x,y) in the eight directions, (x-1,y-1), (x-1,y), (x-1,y+1), (x,y+1), (x+1,y+1), (x+1,y), (x+1,y-1) and (x,y-1). These are the cells that have a Chebyshev distance of 1 from (x,y).
2. Von-Neumann-2 Neighborhood: Apart from the eight cells of Moore-1 neighborhood, this neighborhood also consists of the cells (x,y+2), (x-2,y), (x,y-2) and (x+2,y). These twelve cells are the set of cells with a Manhattan Distance of 2 from (x,y).
3. Extended Nighborhood: Apart from the Von-Neumann-2 neighborhood, this neighborhood also includes (x+1,y-2), (x-1,y-2), (x-2,y-1), (x-2,y+1), (x-1,y+2), (x+1,y+2), (x+2,y+1), (x+2,y-1); thus, this neighborhood includes all cells with a Hamming Distance of 1,√2, 2 and √5 from (x,y).

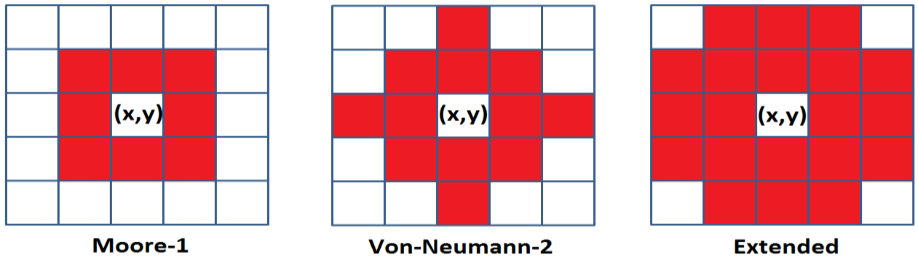

Figure 1 The Three Neighborhoods

Each cell in the life grid may have a value of either 0 or 1, corresponding to dead and alive respectively. Each cell in the sense grid may have one of three values, 0 corresponding to touch, 0.5 corresponding to sight and 1 corresponding to sound sense. From an evolutionary standpoint, these three senses determine the way an organism receives and perceives information from various kinds of neighborhoods, subsequently leading to increased awareness about its own self, as well as potential sources of nourishment and danger around it. The other two fundamental senses, namely taste and smell, are related to the manner in which an organism moves towards or away from nourishing/detrimental objects, and the implementation of these senses is succinct in the neighborhood rules, where underpopulation and overpopulation on either side of an optimal neighbor count causes death.

Time is represented in the cellular automata by discrete steps, called 'ticks', where the values of all cells in both life and sense grids are updated with the tick values [9]. The neighborhood rules for the L and S grids are described in three categories, based on the current sense grid cell value S(x,y) as follows:

A. S(x,y)=0 (Sense of Touch)

This value is the most underdeveloped value possible for a sense cell. In this state, a cell in A is only sensitive to its nearest neighbors, defined by the Moore-1 neighborhood, and has no way of perceiving or being influenced by farther neighbors. Hence, with S(x,y)=0, the following hold for S(x,y) and the corresponding L(x,y).

1. A dead L(x,y) (0) becomes alive (becomes 1) if and only if exactly 3 of its Moore-1 neighbors are alive (1).
2. An alive L(x,y) continues to stay alive if the number of alive Moore-1 neighbors are within a range F0. By default, F0 is specified as the range [2,3].
3. In the absence of the above two conditions, a living cell dies, whereas a dead cell continues to be dead. This is because more than F0 alive neighbors correspond to overcrowding, whereas lesser than F0 alive neighbors correspond to undercrowding and loneliness.
4. The value of S(x,y) 'upgrades' to Sense of Sight, 0.5, if a certain range "a" of its neighbors have the value 0.5. By default, a is set to [3].
5. In the absence of the above condition, S(x,y) stays at 0.

B. S(x,y)=0.5 (Sense of Sight)

This value is more developed than sense of touch, described earlier. In this state, apart from being sensitive to its Moore-1 neighbors by touch, a cell also has the capacity to perceive by sight, a select set of farther neighbors. The neighborhood thus defined is the Von-Neumann-2 neighborhood, since the four additional cells in the non-immediate neighborhood correspond to the 'line of sight' cells in the four cardinal directions from (x,y). The following rules hold.

1. A dead L(x,y) becomes alive if and only if exactly 5 of its Von-Neumann-2 neighbors are alive.
2. An alive L(x,y) continues to live if a certain range F1 of its Von-Neumann-2 neighboring cells are alive. By default, F1 is set to the range [0,5]. This rule ignores the classical GoL clause of death by undercrowding.
3. In the absence of the above two conditions, a live cell dies, and a dead cell stays dead.
4. S(x,y) may upgrade to Sense of Sound, 1, if a certain range "b" of its Moore-1 neighbors have the value 1. By default, b is set to [2,3].
5. S(x,y) may retain the Sense of Sight, 0.5, if a certain range "c" of its Moore-1 neighbors have the value 0.5. By default, c is set to [5,8].
6. In the absence of the above two conditions, S(x,y) 'downgrades' to Sense of Touch, 0.

C. S(x,y)=1 (Sense of Sound)

The basic premise is that sound is neither restricted to a line of sight communication like sight, nor is restricted to actual physical contact such as touch. Moreover, sound propagation is not restricted to charged particles alone, unlike light and other electromagnetic radiation. Thus, Sense of Sound is the most advanced state possible for S(x,y). In addition to touch perceived in Moore-1 neighborhood and sight perceived in Von-Neumann-2 neighborhood, the cell S(x,y) also perceives by sound in the Extended neighborhood, where the 8 additional cells with a Hamming Distance of $\sqrt{5}$ neither correspond to line of sight nor immediate contact. The following rules hold:

1. A dead L(x,y) becomes alive if and only if exactly 8 of its extended neighbors are alive.
2. An alive L(x,y) continues to live if a certain range F2 of its extended neighboring cells are alive. By default, F2 is set to the range [0,8]. This rule also ignores the classical GoL clause of death by undercrowding.
3. In the absence of the above two conditions, a live cell dies, and a dead cell stays dead.
4. S(x,y) may retain the Sense of Sound, 1, if a certain range "d" of its Moore-1 neighbors have the value 1. By default, d is set to a nominal low-ended [0,5].
5. In the absence of the above condition, S(x,y) 'downgrades' to Sense of Sight, 0.5.

Applying these rules during a time instant 'i' effectively determine the status of both the L and S grids for the next instant 'i+1'. The rules of L have largely been adapted from Conway's original GoL rules, with the "Born" and "Stays Alive" ranges scaled to proportion for larger non-Moore neighborhoods [16]. However, the definition of a Sense Grid and corresponding rules are an entirely new addition, where senses are upgraded by influence of neighbors, senses are retained by virtue of an optimal level of use among the neighbors, and senses downgrading due to fall in usage (being made vestigial) or due to practical ineffectiveness due to other cells also developing the sense, thus reducing competitive advantage.

The configurations of any rule can in summary be described as the set R={a,b,c,d,F0,F1,F2}. The default rule set is then R0 = {[3],[2,3],[5,8],[0,5],[2,3],[0,5],[0,8]}.

In each iteration, the entropy, an information theoretic measure of randomness and uncertainty, is calculated for the L and S grids, according to the following relation [22]:

$$H = -\sum_{i} p_i log_2(p_i)\ (bits/symbol) \qquad (1)$$

where p_i denotes the histogram count of the ith bin. Depending on whether or not entropy increases as time evolves, the rule set defined can be classified as obeying or violating the Second Law of Thermodynamics respectively [22]. Also, the entropy value gives a quantitative indication of the underlying nonlinear and chaotic processes [23-24].

3. Results and Discussion

The design and rules detailed in the previous section are implemented using MATLAB to study evolutionary patterns in the proposed SEGoL. The implementations can be broadly grouped into two categories, first the semi-random category where the initial grids for either of S or L are non-random, and second a purely random category where the initial conditions for both S and L are purely random.

The grid is 50x50 and the timesteps range from 1 to 50. For each case, the snapshots of the L and S grids during every ninth interval are shown. Black corresponds to 0, Gray to 0.5 and White to 1.

Also, the "Survival Index" of L or S is defined as the Average value of all the cells in the grid taken during the final timestep.

A. Semi-Random Initiation

In the first case corresponding to "Pure Touch", the default rule set R0 is used, with all initial values in the S grid initially set to 0 and L grid randomly set. The evolution and entropy plots are plotted in Fig. 2 and 3 respectively.

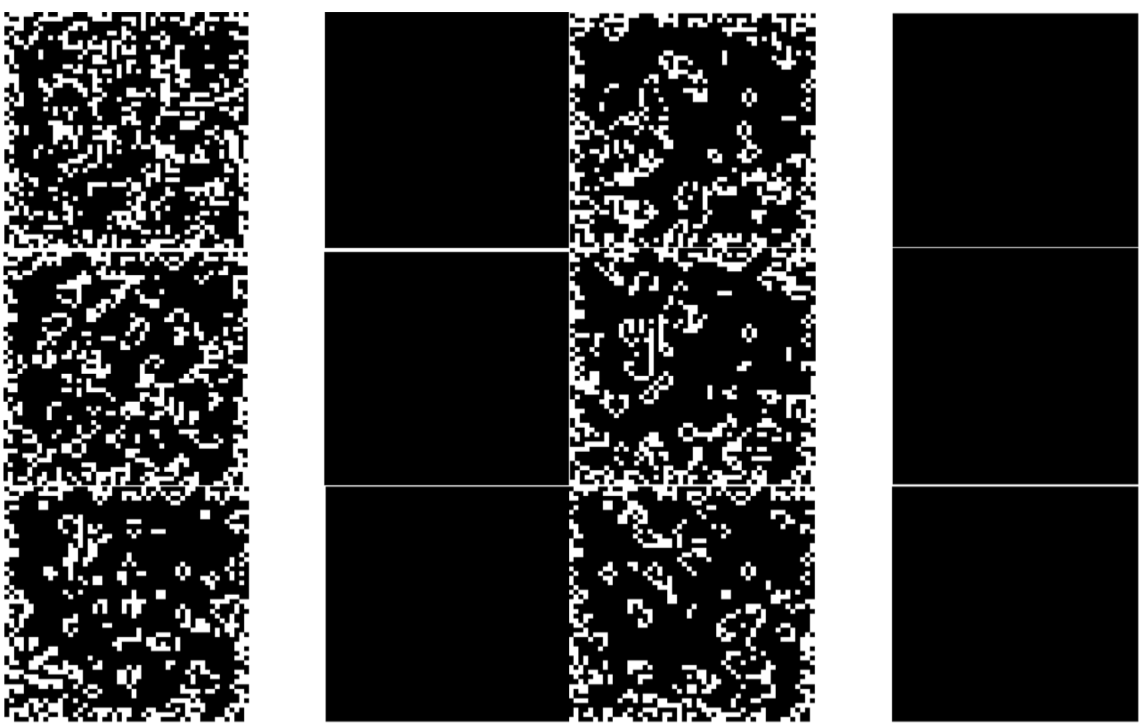

Figure 2 Evolution of L and S (anticlockwise from top-left) for default R0 and Pure Touch S

This case corresponds to Conway's Original Game of Life design with neighborhood rules defined for Moore-1 neighborhood and no influence of S grid. Consequently, still-life and oscillating patterns seen in Conway's GoL, such as blocks, beehives, loafs, boats, blinkers, toads, beacons, pulsars, pentadecathlons, gliders, spaceships, R-pentominos, diehards, acorns and glider guns are also observed here. In general, the population decreases to a less than average concentration of Live cells. The entropy curve shows a slightly decreasing entropy with progress of time. The L-Survival Index is low at 0.2192.

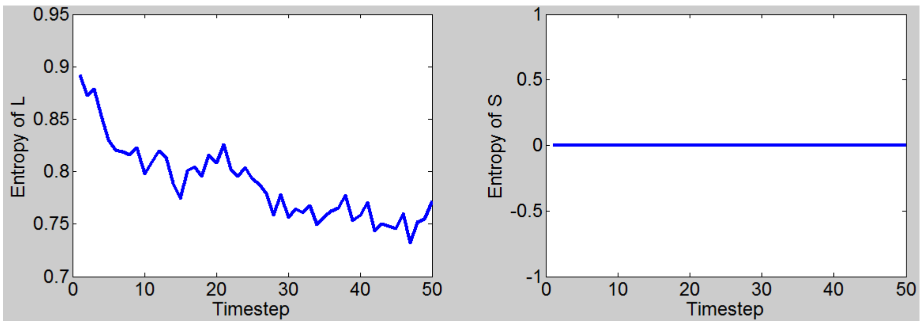

Figure 3 Entropy of L and S (anticlockwise from top-left) for default R0 and Pure Touch S

Next, the evolution with default rule set R0 but initially gray S grid, corresponding to "Pure Sight" case is studied, and the plots are as seen in Fig. 4 and Fig. 5.

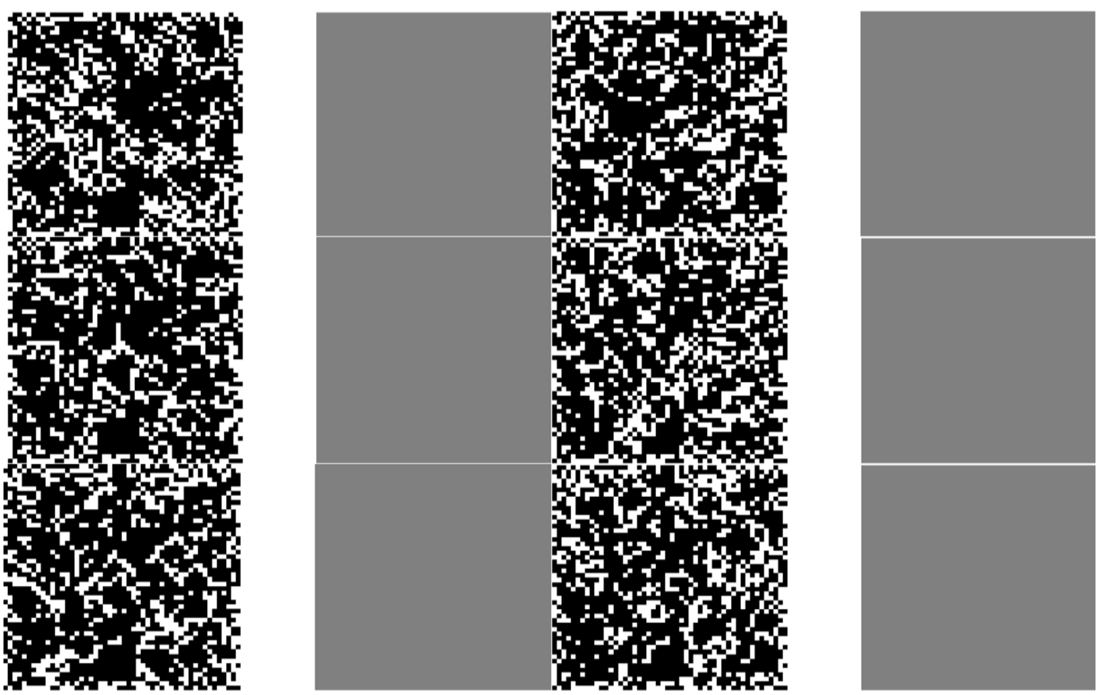

Figure 4 Evolution of L and S (anticlockwise from top-left) for default R0 and Pure Sight S

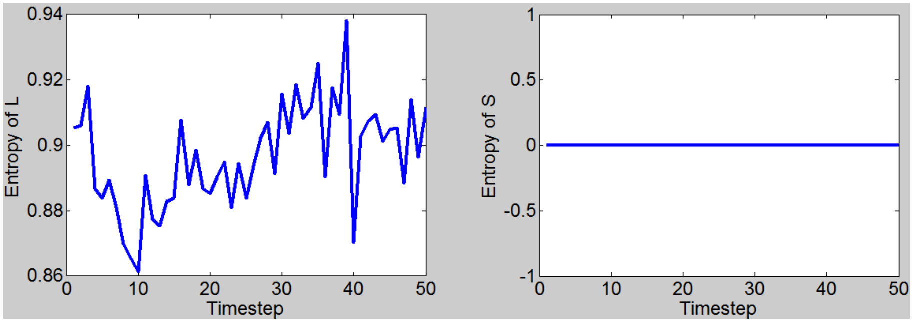

Figure 5 Entropy of L and S (anticlockwise from top-left) for default R0 and Pure Sight S

Here the evolution is primarily dictated with Conway's GoL rules scaled and applied to theVon-Neumann-2 neighborhood. Entropy is more or less maintained around 0.9, and the L-Survival Index is much higher at 0.3268. In this case and the previous case, the S Survival Index is maintained at 0.5 and 0 respectively.

Next, the default rule set R0 is applied to a random initial L grid and an S initial grid defined purely by 1, a "Pure Sound" case. The results are as shown in Fig. 5 and 6.

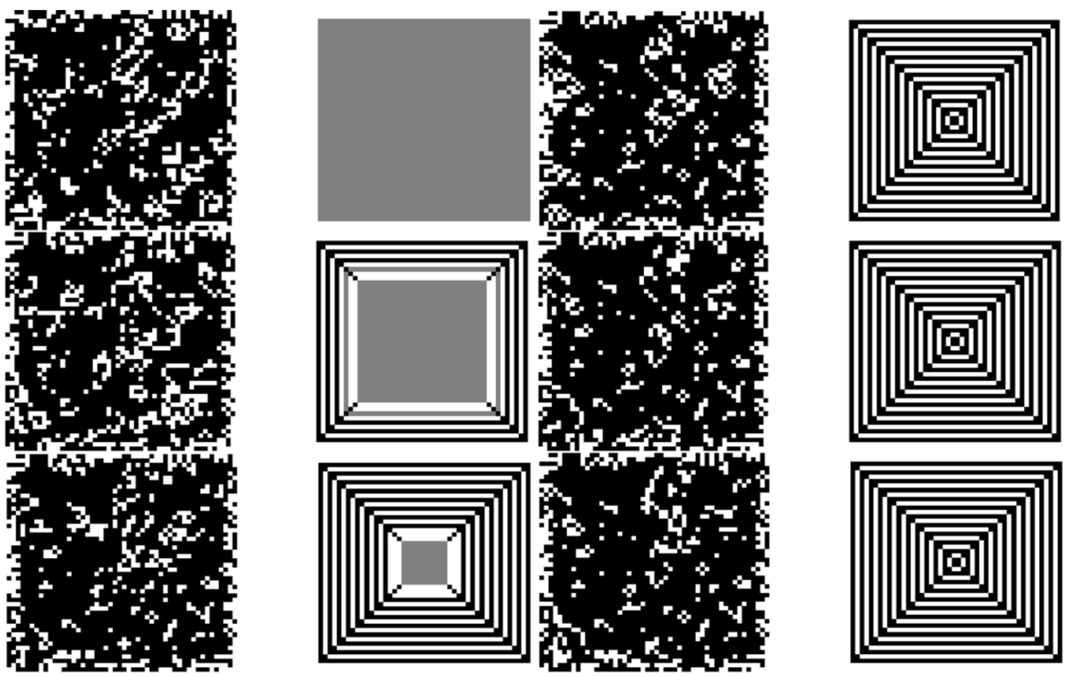

Figure 6 Evolution of L and S (anticlockwise from top-left) for default R0 and Pure Sound S

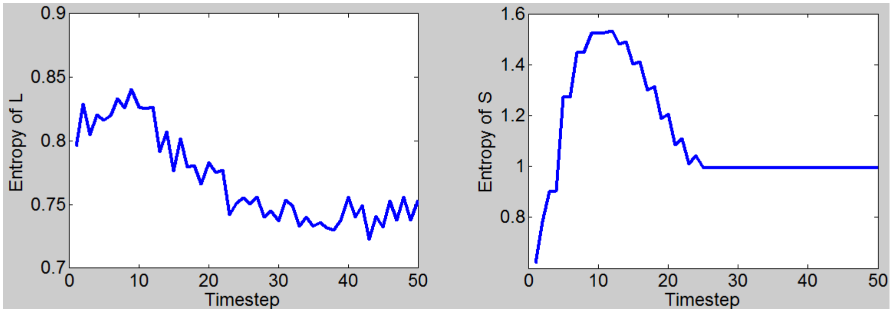

Figure 7 Entropy of L and S (anticlockwise from top-left) for default R0 and Pure Sound S

While essentially a scaled application of Conway's GoL rules to the extended neighborhood, the Pure Sound case shows a very interesting self-organization phenomenon of the S matrix. Subsequently, the S entropy shows a rather increase to an enormous 1.5 before falling and settling down to a value of 1. However, the L entropy shows a general decrease over time. The L Survival Index has decreased to 0.2164, while the S Survival Index marginally increases to 0.5408.

Thus, from the above three results, it can be seen that while an increase in sensory capabilities correspond initially to an increase in survival rates, a full-fledged development in sensory capabilities quickly gives rise to social organization, with survival rates and entropies decreasing to stable values.

B. Fully-Random Initiation

The default rule set R0 is applied with randomly initiated L and S grids. The results are shown in Fig. 8 and 9.

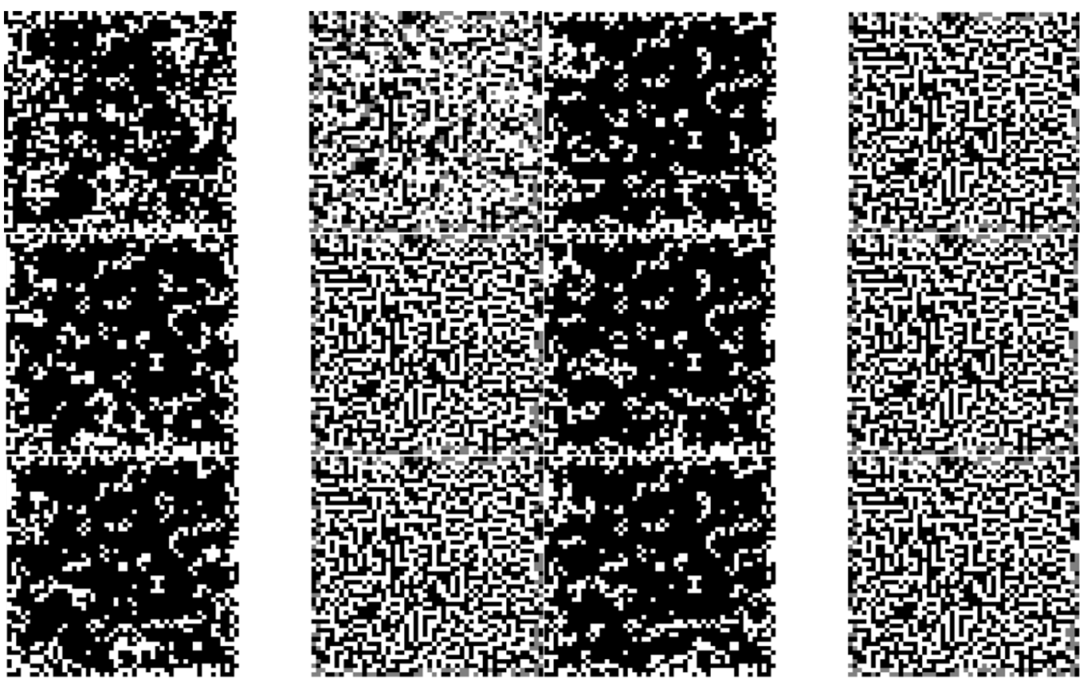

Figure 8 Evolution of L and S (anticlockwise from top-left) for default R0 with random initiation

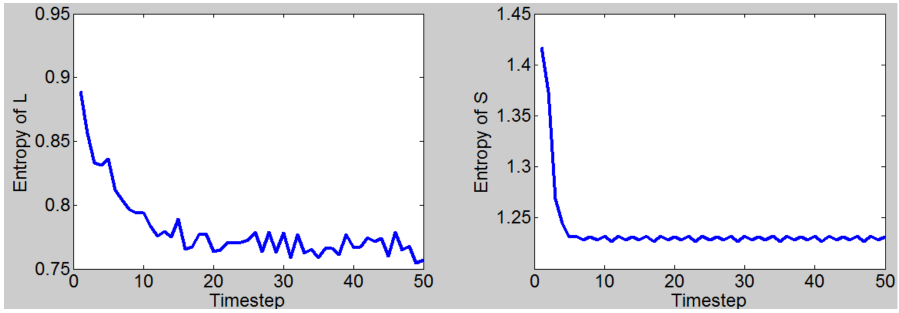

Figure 9 Entropy of L and S (anticlockwise from top-left) for default R0 with random initiation

It is seen that, after an initial decrease in survival the survival rate of L maintains almost constant, ending with a L Survival Index of 0.2184. S however, organizes the initial randomness into some sort of complex intricate pattern, with the final survival index of 0.5038. The entropies of both L and S show an initial steep decrease followed by stability.

Next, a rule set R1 is defined as R1 = {[3],[2,3],[5,8],[4,8],[2,3],[0,5],[5,8]}, differing from by R0 that it does not declare sound retention d as a low-ended [0,5], but rather as a high-ended range [4,8]. The results are shown in Figure 10 and 11.

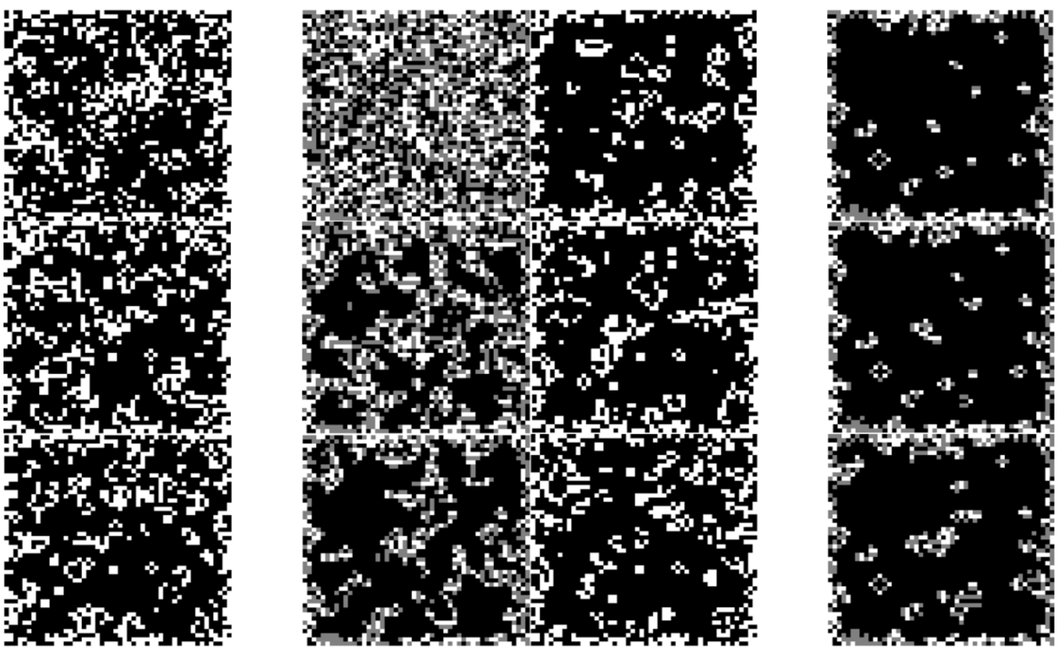

Figure 10 Evolution of L and S (anticlockwise from top-left) for R1 with random initiation

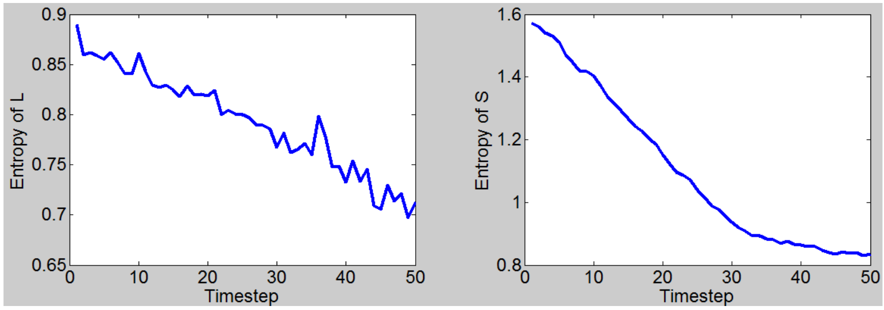

Figure 11 Entropy of L and S (anticlockwise from top-left) for R1 with random initiation

This case shows a gradual decrease in survival of both L and S grids, with the Final L and S Survival Indexes obtained as 0.1956 and 0.1270 respectively. The entropies of both grids show an almost monotonous decrease.

The next case is defined by R2 = {[3],[2,3],[0,4],[4,8],[2,3],[0,5],[5,8]} for purely random initiation, with R2 differing from R1 in the range of c. The results are plotted in Fig. 12 and 13.

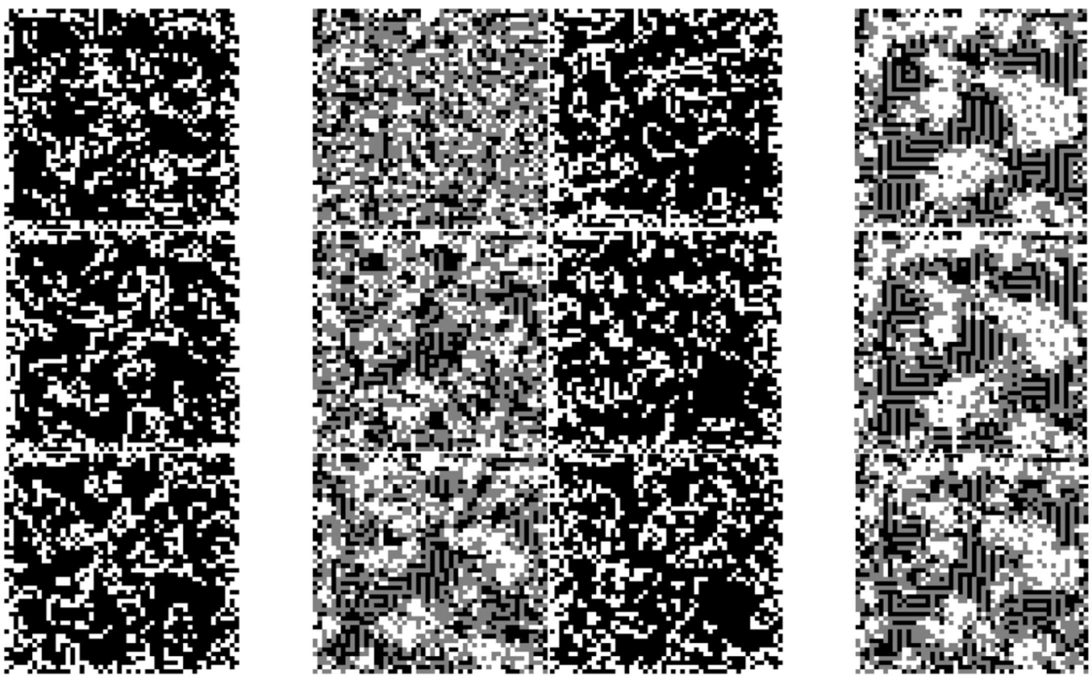

Figure 12 Evolution of L and S (anticlockwise from top-left) for R2 with random initiation

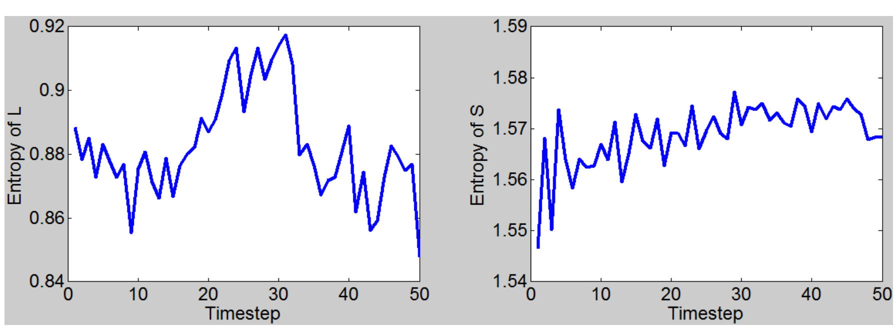

Figure 13 Entropy of L and S (anticlockwise from top-left) for R2 with random initiation

It is seen that while the L grid shows a constancy of survival, the Sense grid shows a remarkable self-organizing accompanied by clustering of the most evolved sense (sound). This phenomenon can be attributed to the c from [5,8] to [0,4], which implies an adverse sensitivity to the sense of sight to overcrowding causing the gray cells of S to organize into a pattern of maximum entropy, followed by a clustering of sound sense due to long range similarity in the pattern formation. The L and S Survival rates are given by reasonably high 0.2744 and 0.5424 respectively.

Finally, the last case is given by R3 = {[3],[3],[2,3],[2,3],[2,3],[0,5],[0,8]}, differing from the earlier cases by having limited ranges for a, b, c and d, all four sense determining variables. The results are shown in Fig. 14 and 15.

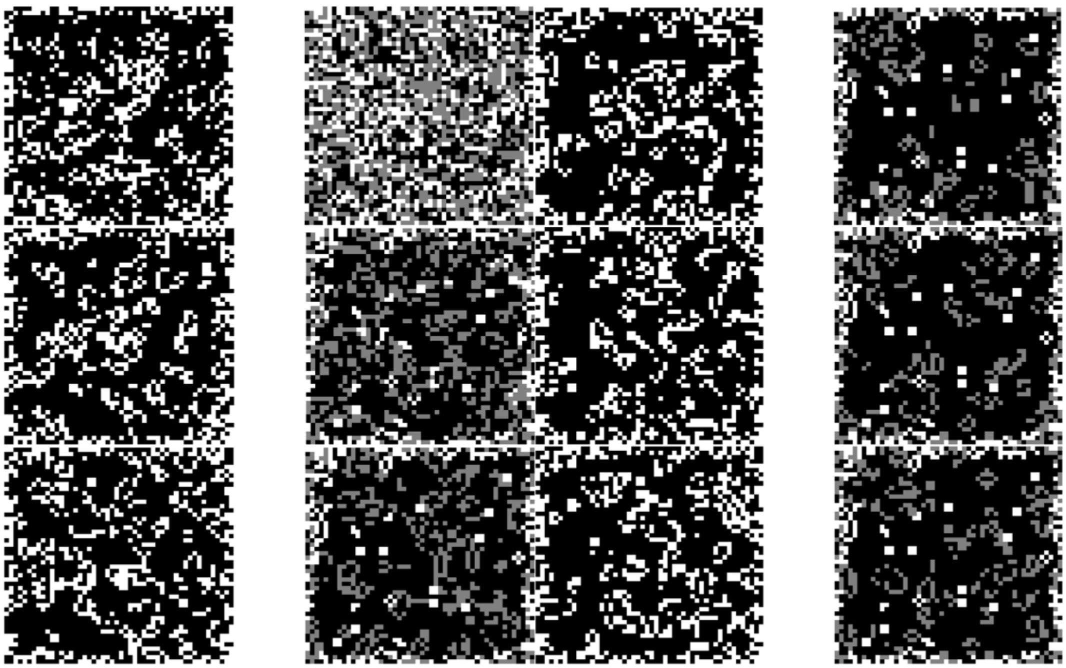

Figure 14 Evolution of L and S (anticlockwise from top-left) for R3 with random initiation

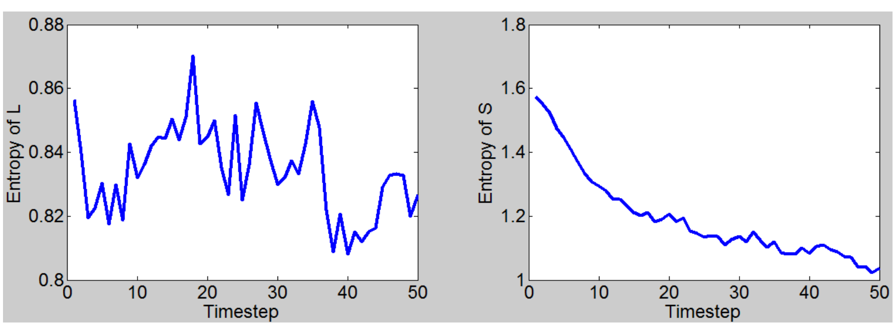

Figure 15 Entropy of L and S (anticlockwise from top-left) for R3 with random initiation

From the results and the L and S end Survival Indices obtained as 0.26 and 0.1712, it is clearly seen that the restrictions in the values of a, b, c and d considering both overcrowding and undercrowding results in a reasonable increase in Survival with fluctuating L Entropy, while causing a gradual degradation in the sense grid, accompanied by monotonously decreasing entropy.

4. Conclusion

Based on the concept of senses, and the ability to perceive both immediate and non-immediate neighbors using advanced senses such as touch, sight and sound, a Sense Enhanced Game of Life (SEGoL) is proposed and designed using two grids, a Life Grid and a Sense Grid. With the Life Grid taking one of two possible values (dead or alive), the sense grid takes one of three values corresponding to touch, sight and sound. Based on the values of the Sense Grid cells, the perceptibility and hence the values of Life Grid Cells are determined, with the Sense Grid values themselves determined by proximity, utilization and competitive advantage. Based on these rules, various evolution patterns, both involving semi-random initialization and purely random initializations are explored. Among the results, three interesting facts stand out. Firstly, the semi-random initialization with a Pure Sound based Sense Grid results in a remarkable self-organization of the sense grid, albeit with decreased survival in the life grid. Secondly, altering sensitivity of light from overcrowded to undercrowded configuration results in self-organization of sense grid into interesting patterns accompanied with clustering of the sound sense. Thirdly, it is seen in general that survival rates, both in life and sense, are largely mirrored by corresponding changes in entropy values.

In conclusion, it is seen that the proposed Sense Enhanced Game of Life (SEGoL), essentially adapting Conway's original Game of Life Rules, scaled for larger neighborhoods, and for enhanced perceptibility, displays a diverse range of interesting evolutionary dynamics, while also retaining the original features of the original Game of Life including the still-life and oscillating elements for the pure touch case. With Turing Machines constructed for Conway's Game of Life, the logical future step would be to explore enhanced universal construction and computation capabilities of the SEGoL, while also exploring more complicated Sense rules, with more enhanced perceptibility. It is hoped that the results detailed here would form preliminary steps in transforming a reductionist, structural perspective of life to a radical and innovative holistic, information based understanding of life.

References

[1] Levine, Milton Isra, and Jean Hortense Seligmann. The Wonder of Life: How We are Born and how We Grow Up. Simon and Schuster, 1952.
[2] Mayr, Ernst. Evolution and the diversity of life: selected essays. Harvard University Press, 1997.
[3] Rhodes, Andrew James, and Clennel Evelyn Van Rooyen. Textbook of virology. Williams and Wilkins, 1968.
[4] Scott, Alwyn C. The nonlinear universe: chaos, emergence, life. Springer Science & Business Media, 2007.
[5] Frenk, C. S., S. D. M. White, and M. Davis. "Nonlinear evolution of large-scale structure in the universe." The Astrophysical Journal 271 (1983): 417-430.
[6] Chaos, Alvaro, Max Aldana, Carlos Espinosa-Soto, Berenice García Ponce de León, Adriana Garay Arroyo, and Elena R. Alvarez-Buylla. "From genes to flower patterns and evolution: dynamic models of gene regulatory networks." Journal of Plant Growth Regulation 25, no. 4 (2006): 278-289.

[7] Nowak, Martin A., and Robert M. May. "Evolutionary games and spatial chaos." Nature 359, no. 6398 (1992): 826-829.
[8] Wolfram, Stephen. Cellular automata and complexity: collected papers. Vol. 1. Reading: Addison-Wesley, 1994.
[9] Wolfram, Stephen. Theory and applications of cellular automata. Vol. 1. Singapore: World Scientific, 1986.
[10] Chopard, B., and M. Droz. Cellular automata. Cambridge University Press, Cambridge, UK, 1998.
[11] Langton, Chris G. "Computation at the edge of chaos: phase transitions and emergent computation." Physica D: Nonlinear Phenomena 42, no. 1 (1990): 12-37.
[12] White, S. Hoya, A. Martín del Rey, and G. Rodríguez Sánchez. "Modeling epidemics using cellular automata." Applied Mathematics and Computation 186, no. 1 (2007): 193-202.
[13] Ribba, B., Tomas Alarcón, K. Marron, Philip K. Maini, and Z. Agur. "The use of hybrid cellular automaton models for improving cancer therapy." In Cellular Automata, pp. 444-453. Springer Berlin Heidelberg, 2004.
[14] Kansal, A. R., S. Torquato, G. R. Harsh, E. A. Chiocca, and T. S. Deisboeck. "Simulated brain tumor growth dynamics using a three-dimensional cellular automaton." Journal of theoretical biology 203, no. 4 (2000): 367-382.
[15] Barredo, José I., Marjo Kasanko, Niall McCormick, and Carlo Lavalle. "Modelling dynamic spatial processes: simulation of urban future scenarios through cellular automata." Landscape and urban planning 64, no. 3 (2003): 145-160.
[16] Conway, John. "The game of life." Scientific American 223, no. 4 (1970): 4.
[17] Bah, Per, Kan Chen, and Michael Creutz. "Self-organized criticality in the ‘Game of Life’." Nature 342 (1939): 14.
[18] Beer, Randall D. "Autopoiesis and cognition in the game of life." Artificial Life 10, no. 3 (2004): 309-326.
[19] Rendell, Paul. "Turing universality of the game of life." In Collision-based computing, pp. 513-539. Springer London, 2002.
[20] Toffoli, Tommaso, and Norman Margolus. Cellular automata machines: a new environment for modeling. MIT press, 1987.
[21] Fredkin, Edward. "An informational process based on reversible universal cellular automata." Physica D: Nonlinear Phenomena 45, no. 1 (1990): 254-270.
[22] Aczél, János, and Zoltán Daróczy. "On measures of information and their characterizations." New York (1975).
[23] Leff, Harvey S., and Andrew F. Rex, eds. Maxwell's demon: entropy, information, computing. Princeton University Press, 2014.
[24] Diamond, Phil, and Aleksej Pokrovskii. "Chaos, entropy and a generalized extension principle." Fuzzy Sets and Systems 61, no. 3 (1994): 277-283.