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Macro and Micro Environment for Diversity of Behaviour in Artificial Life Simulation

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Abstract—**The complexity of artificial life is produced not only via their genotype, but also by the environment that they thrive in. Past artificial life research focuses on the evolutionary behavior of artificial organisms from an intrinsic perspective of how concepts such as crossover and mutation increase the fitness of the organism, others focus on the emergent macrostate of a simulation that arises out of the local interaction of entities. This research aims to introduce an additional ‘affector’ into artificial life simulations, namely, an enhanced environment where an added dimension of complex behaviour can be produced through the use of environment emitters.**

enhanced simulation environment, model resolution, environment emitters, microstate, macrostate, explicit condition

I. INTRODUCTION

Research in ‘soft’ artificial life has focused on creating life like behaviours in computers. Mainstream artificial life research concentrates on the production of emergent behaviour and self-organisation in the macro state of a population of entities. The general approaches for generating collective behaviours are mainly genetic algorithms, neural networks, and simple rules of interaction. For example, Sims [1] evolved the 3D morphology and behaviour of artificial life over generations, Specter [2] demonstrate the emergence of collective behaviour in evolutionary computation of flying agents, Komosiński [3] attempted to create nature-like simulation model of artificial creatures using neural network control, and Reynolds [4] illustrates the simple rules of interaction in creating collective behaviours such as flocks, herds and schools in computers. These examples reflect the general trend of artificial life research. Life however, must not be separated from her environment. Simple environments afford simple agents, but complex environments can affect diversity and create complex behaviours. Herbert Simon [5] illustrated the metaphor of the ant on the beach where the goal of the ant was to reach the source of food, whilst the movement of the ant seemed complex with turns and twists, the real complexity lies in the grains of sand and not of the ant. As Simon’s ant has taught us, the complexity and the diversity of a life entity is due to the complexity of the environment in which it thrives. Therefore, in order to create artificial life, we must also focus our research on integrating artificial life within an artificial environment that is complex in its affordances.

There are finite examples of artificial environments that support artificial life research. One of the most common is the physics-mapping of terrain collision and gravity such as Karl Sims’s virtual creatures [1]. Similar to Sims’s environment, Komosiński [3] included an environment where virtual creatures could walk and or swim, over land, hills and water. Sommerer and Mignonneau [6] created “A-Volve”, which uses evolutionary rules within an interactive environment influenced by human decision to catch, and protect preys against predators where the environment is influenced by human actions as external inputs. Simple ecosystems can also be found, such as Rönkkö’s ecosystem [7] consisting of two species of animals in a series of food chains beetles-worms-grass-water that depended on each other. These artificial life environments provided mainly a global nature without focusing on the local condition and climate of an artificial world. Ch’ng [8] created a more elaborate ecosystem that simulates implicit micro conditions and is defined by the number of adjacent agents in the surroundings which affect the effective sunlight, shade temperature, space, and nutrient availability in a local area. The selective survey of more prominent artificial environments indicates that more complex environments are needed if artificial life research were to reflect the world in which it aims to model, whether theoretically or for empirical model testing. A more explicit description of the environment is needed. Although usable artificial life simulation environments such as Breve [9], NetLogo and MASON [10] allow the creation of custom environments depicting various models of life are available, the explicit specification of local conditions and artificial environment integration for sophisticated modelling need to be formalised. As such, this paper aims to formalise these area of research.

This article focuses on the creation of explicit environmental conditions both macro and micro that coerce or constrain artificial life movements in the terrain, with a long-term goal of studying evolutionary behaviour in more complex theoretical environments. The introduction of environmental emitters, for explicit control of local environment will allow a greater control of behaviour for evolutionary phenomenon in future research. The next section describes the approach taken in the present research, followed by simulation results in section III depicting theoretical environments. Finally, the paper concludes with discussions and future work.

II. ENHANCED SIMULATION ENVIRONMENTS (ESE).

This section describes the approach taken to formulate environmental parameters for creating macro and micro environments. Prior to describing the model, we must first state the initial hypothesis, that complex simulation environment can facilitate the behavioural complexity in both the micro-dynamics and the macro-outcomes of the model. We can now begin to formulate the model environment, together with the overall model of the artificial life involved in the simulation.

A. Macro Environment

The macro environment can be simplified into average conditions of a given factor (temperature, sunlight, carbon dioxide, nutrient, etc). These models of a real environment can be stored in a set as follows,

$$T_{pres} = \{0,5,10,15,20,25,25,20,15,10,5,0\}$$

$$S_{pres} = \{0.3,0.3,0.5,0.5,0.7,0.7,0.7,0.5,0.5,0.5,0.4,0.4\}$$

Where T_{pres} and S_{pres} are respectively the average states of temperatures and sunlight in a given month. Temperature and sunlight variations based on T_{pres} and S_{pres} are simulated using a stochastic function X with variation T_{var}. For example, changes in the global temperature is given by,

$$T_{global} = \begin{cases} T_c + XT_{\mathrm{var}} & if\, X_{thr} \le g_c \\ T_c - XT_{\mathrm{var}} & if\, X_{thr} > g_c \end{cases} \quad (1)$$

Where $T_c \in T_{pres}$, X is a function from $\mathbb{R}$ to $[0,1]$ and is a stochastic variable, T_{var} is the range of temperature change, and g_c is a constant that defines the threshold when temperature will change. The global temperature at a given time is in the range $-T_{\mathrm{var}} + T_c \le T_{global} \le T_{\mathrm{var}} + T_c$.

A further refinement can be added to describe the altitude changes in temperature,

$$T_{eff} = \frac{-0.6E}{100} + T_{global} \quad (2)$$

Where T_{eff} is the effective temperature, *E* is the current altitude where a plant is at, and T_{global} is the seasonal global temperature defined in Eq.1.

Continuous condition can be defined using equation 3. Take for example, the moisture level of the soil,

$$W_{eff} = L\frac{1}{e^{\left(E - W_{surface}\right)g^{-1}}} \quad (3)$$

Where W_{eff} is the effective moisture level, *L* is the moisture level below the water surface (*L=0.5*), *E* is the current altitude where a plant is at, $W_{surface}$ is the height of the water surface, *g* is the gradient. A more controlled environment used in this paper introduces greyscale height map with gradients of 0-255 depicting conditions of the soil (see Figure 1).

B. Micro Environment

Explicit local environmental conditions can be described using environment emitters. These emitters can be strategically placed in regions of landscapes so that artificial creature at proximity is affected by it. Emitters can emit any number of conditions. As an example, a temperature model of a single emitter is given by,

$$\varepsilon_k = T_k \left(e^{d_k / g_k}\right)^{-1} \quad (4)$$

Where ε_k is an emitter of temperature type with maximum temperature at its core ($T_k = 100$ emits heat, $T_k = -100$ emits cold), d_k is the distance between the emitter and an artificial creature, which dissipates as the distance between the core and the agent increases, and g_k is the gradient. The total effective macro and local temperature sensed by an artificial creature in its specific position is,

$$T_{total} = T_{eff} + \sum_{k=0}^{n-1} \varepsilon_k \quad (5)$$

C. Simple Rules in Sessile Organisms

In this section, the formulae for the fitness and competition of sessile organisms are defined. Greater details of their implementation are obtainable [11]. Sessile artificial organisms reproduces ζ progenies after age *a* at ρ probability (See Table 2). They adapt via the adaptability measure [12], which measures the fitness of the organism. The adaptability measure measures each environmental factor which is multiplied to produce the fitness f_i^t for individual organism *i* at time *t* (Eq. 6) in each simulation cycle. The fitness of an artificial creature here is a dependent variable associated with how well the creature is doing at its present location with all of the environmental factors and competition:

$$f_i^t = \varphi_i C_i T_{total} S_i \quad (6)$$

Where the output of adaptability measure for individual fitness related to the biotic and abiotic interactions are computed: φ_i is adaptability to the condition of the soil where the organism is located. The soil condition is the value of the greyscale pixel (between 0-255) normalised in comparison with the preference of the organism (defined in Table 1, so also all subsequent fitness measures). C_i is the adaptability to the competition for space c_i^t (Eq. 8) and is the only biotic factor measured, T_{total} is the adaptability of the agent to the current temperature (Eq. 5), and S_i is the adaptability of the agent to the effective sunlight. The non-linear interaction of the factors is a logical way for deciding the fitness of the sessile organism.

An organism interacts with its neighbour if the condition (Eq. 7) below is fulfilled:

$$\sqrt{(O_x^t - u_x^t)^2 + (O_y^t - u_y^t)^2} - \left[O_{size}^t + u_{size}^t\right] < 0 \tag{7}$$

Where $O_{x,y}^t$ is the position of an opponent organism at time t and $u_{x,y}^t$ is the position of the source plant. O_{size}^t and u_{size}^t are respectively the diameter of the organisms. A neighbouring organism is a threat only if $O_{size}^t > u_{size}^t$.

The collective occupation of the space of a group of sessile organisms sensed by organism *i* contribute to the accumulated use of space c_i^t for the adaptability measure C_i in Eq. 6,

$$c_i^t = \begin{cases} 1 & if \sum_{i=1}^{n} P_i > 1 \\ \sum_{i=1}^{n} P_i & if 0 \le \sum_{i=1}^{n} P_i \le 1 \\ 0 & otherwise \end{cases} \tag{8}$$

Where *n* is the number of competing plants, and P_i is the effective space used by each competing plant. If a competing plant is a threat, a competition unit *0.1* is added to P_i. It is apparent that c_i^t is within the interval $[0,1]$.

D. Simple Rules in Vagile Organisms

Artificial creatures navigate the terrain in relation to the positions of environment emitters and prey. The movement vector is as follows,

$$x_j^{t+\Delta t} = x_j^t + \sigma_j \cos(\omega_j^t) \tag{6}$$

$$y_j^{t+\Delta t} = y_j^t + \sigma_j \sin(\omega_j^t) \tag{7}$$

Where $\left[x_j^{t+\Delta t} \quad y_j^{t+\Delta t}\right]$ is the vector of creature *j* with speed σ_j (length of the vector) at time *t*+Δ*t*. The orientation ω_j^t depends on the local condition $T_{total}^{t+\Delta t}$ generated by the target emitter *k* (see Eq.5) or a collection of emitters within the vicinity of the creature,

$$\omega_j^{t+\Delta t} = \begin{cases} \omega_j^t & \text{if } T_{total}^t > T_{total}^{t-\Delta t} \\ \theta_j^{t+\Delta t} & otherwise \end{cases} \tag{8}$$

Where $\omega_j^{t+\Delta t}$ is the orientation of the creature at time $t+\Delta t$, $\theta_j^{t+\Delta t}$ is the heading of the creature *j* as it seeks its environmental niche, $\theta_j^{t+\Delta t}$ is defined below,

$$\theta_j^{t+\Delta t} = \begin{cases} +\theta_j^t & \text{if } \alpha_j^t < \beta_j \\ -\theta_j^t & otherwise \end{cases} \tag{9}$$

$$\alpha_j^{t+\Delta t} = \begin{cases} 0 & \text{if } T_{total}^t > T_{total}^{t-\Delta t} \\ \alpha_j^t + 1 & otherwise \end{cases} \tag{10}$$

Where the polarity of θ_j^t is defined by changes in the counter α_j^t. If the counter is less than a constant β_j, the polarity is positive, negative otherwise. This non-stochastic simple rule causes the creatures to swap direction as they seek their niches.

Creatures also seek food (prey in the lower chain) using two simple rules: 1) if prey is within proximity (*d*) and field of view (*v*), 2) if prey is on the left, turn left with rotation angle (*θ*), vice versa. When food is within the feeding distance (λ), energy (*κ*) is obtained from the food, when the energy is over the reproduction threshold (*τ*), a number of progenies (*ζ*) for the creature is produced. The values are defined in the simulation parameter Tables. These rules are standard implementations and are not elaborated here due to the limitation of space. Avoidance of predators or emitters is implemented by negating the polarity of rotation (*θ*). In this theoretical study, the attraction/repulsion towards emitters has a higher priority than the attraction/avoidance of preys/ predators, meaning that preys/predators will avoid coming close to emitters or be attracted towards emitters even though they are in danger of being captured, or will have the reward of capturing food.

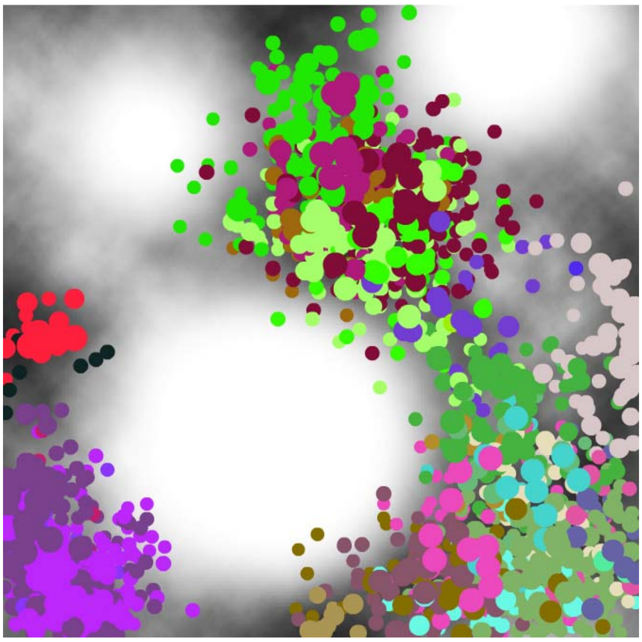

Figure 1. Sessile organisms thriving in niches of a combination of global and implicit micro environment. Species grouping are seen. Organisms of the same colour possess the same parameter genotypes.

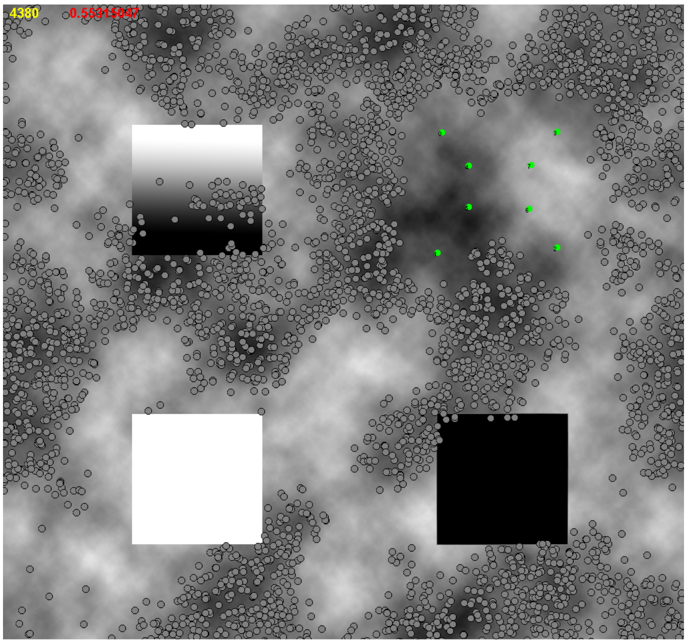

Figure 2. 4000+ vegetation thriving in niches of the environment. The four quadrants show four different conditions where sessile creatures either thrives or dies.

III. SIMULATION RESULTS

This section shows the diversity of a non-evolutionary behaviour of sessile and vagile artificial organisms generated using the approach in section II. The global parameters for the simulation are listed in Table 1.

Figure 1 is the simulation result showing a hundred species of a sessile creature settling down on niches, a combination of macro temperature, sunlight, local competition for resources (sunlight and nutrients), and soil condition. Notice that species (of the same colour, having the same parameter genotypes) cluster together. The different species are indicated by colour hues and the genotype of each species is randomly generated. The scenario simulated 100 species of sessile organisms at the start of the simulation using a random genotype generator for sunlight, temperature, soil, space, seed count, maximum age, and reproduction age. In the figure, only 12% of the species survived as many have ceased to exist due to the selective pressure of the environment as a result of their inability to adapt.

In the second scenario (Figure 2), 4000+ organisms possessing the genotypes in Table 2 can be observed thriving in an environment consisting of four conditions in the four quadrants of the landscape. The first quadrant (top left) shows a

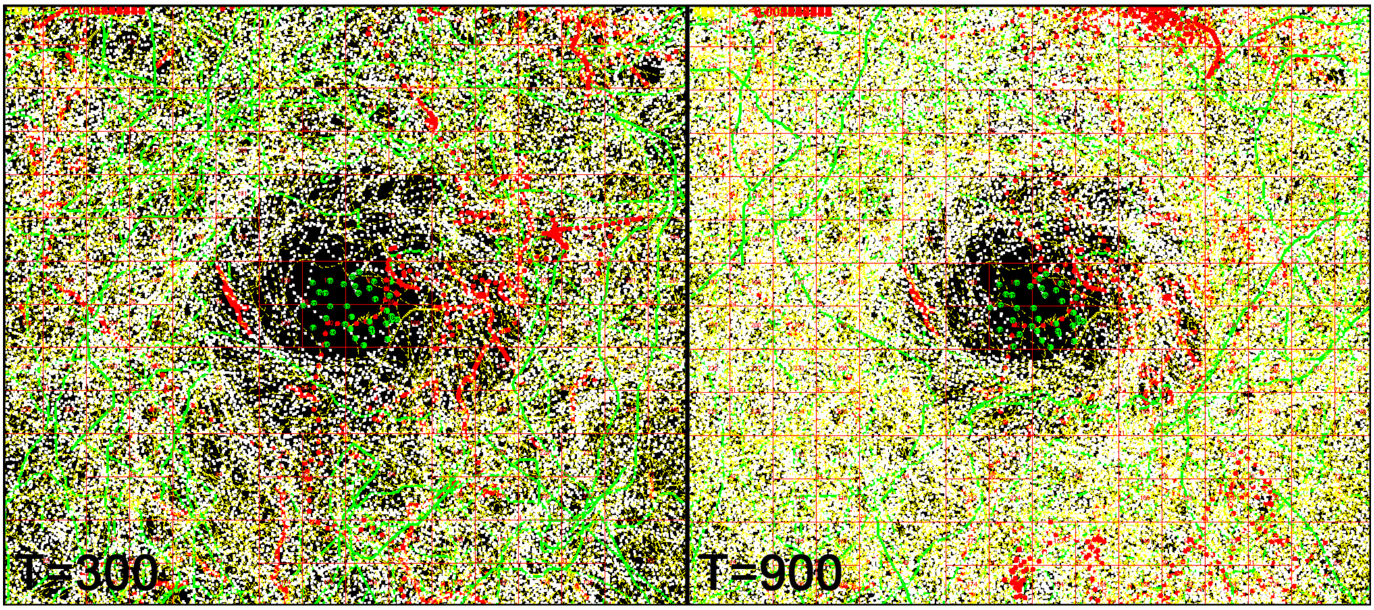

Figure 3. Emitters at the centre of the landscape (green dots) created a vortex of repulsion for virtual creatures (fluid lines of creature paths). The figure shows a predator/prey trophic chain of 8 sessile and vagile species of artificial organisms (vegetation-herbivore1-herbivore2-carnivore1-carnivore2-carnivore3-carnivore4-carnivore5). The two image shows simulation cycles at T=300 and 900 respectively.

gradient where vegetation only survives partially at the bottom half of the gradient height map. The second quadrant (top right) shows eight environmental emitters and the adaptation of sessile creatures around the emitters. The two other quadrants show extreme conditions where little to no organisms live.

Scenario three (Figure 3) shows a simulation with emerging patterns generated from repulsion emitters (high temperatures) placed at the centre of the landscape. The path of each artificial creature is traced over time. The emitters created a wall of repulsion, together with the predator/prey trophic chain of 8 sessile and vagile species of artificial organisms (vegetation-herbivore1-herbivore2-carnivore1-carnivore2-carnivore3-carnivore4-carnivore5) generated the emerging pattern seen in Figure 3. The model parameters of the organisms are roughly similar with the ones listed from Table 2-4. Each vagile organism in the lower trophic chain avoids being captured by organisms in the higher chain by manoeuvring away from them as seen in the high angle of turning in the trails. Other observations show that Population size grows via reproduction over time and causes greater interactions amongst the organisms. Reproduction occurs as a result of the accumulation of energy from predation. After 300 simulation cycles the landscape shows a vortex of repulsive emitters and creature avoidance and interaction. The vortex intensifies with movements of creatures at 900 simulation cycles.

Figure 4 contains two artificial creatures of type A, B, and a light emitter C (Table 2-4). Artificial creatures of type A has inbuilt rules to avoid the emitter, it is repulsed by it. Artificial creatures of type B are attracted by the light emitter and move towards the emitters yet never reaches it. The proposed hypothesis that type B creatures never reaches the emitters is by reason of the turning angle and the counter (Eq. 8-10). Artificial creatures of type A also avoid B, and type B creatures are attracted by A. Similar to the preceding simulation, population size grows over time from reproduction as predation turns stored energy into progenies after a threshold is reached. The sequence of figures shows how patterns emerge from the attraction and repulsion of the emitters. The emergent macro state is also influenced by the attraction and repulsion of predator-prey interaction as a result of the different types of creature behaviours. The simulation time-steps shows the emergence of vortices where attraction occurs with high entropy patterns in the majority of the environment.

Table 1. Global Simulation Properties and Macro Climate

Global Properties	Symbols & Value(s)
Simulation cycle *t*	$\Delta t=0.012sec$
Counter for orientation polarity	$\beta=10$
Macro Climate	
Temperature variation	$T_{var}=2.0$
Sunlight variation	$S_{var}=0.35$
Threshold for temperature change	$g_c=8$
Random range for threshold	$X_{thr}\in [0,10]$
Micro Climate	
Heat emitter max temperature	$T_k=100$
Cold emitter max temperature	$T_k=-100$
Gradient	$g_k=90$

Table 2. Parameters for Sessile Organism

Property Description	*Symbols & Value(s)*
Age at start of simulation (seconds)	*1*
Maximum age	$A=30$
Size (pixels)	$U_{size},O_{size}=7px$
Energy	$\kappa=1.0$
Reproduction probability	$\rho=0.08$
Reproduction age	$a=2$
Number of progenies	$\zeta=16$
Dispersal distance (pixels)	$D=150$
Sunlight (L=lower range, P=preferred, U=upper range)	*L:0.3, P:0.9, U:1.0*
Temperature (°C) (L=lower range, P=preferred, U=upper range)	*L:-10, P:38, U:50*
Soil (P=preferred, U=upper range)	*P:0.4, U:0.6*
Space (P=preferred, U=upper range)	*P:0.1, U:0.2*

Table 3. Creature A (Green in Figure 3)

Property Description	*Symbols & Value(s)*
Speed (pixels)	$\sigma=1$
Thrust	$\varepsilon=2$
Fleeing Thrust	$\varepsilon =3$
Thrust Limit	$\tau^{lim}=0.5$
Rotation Angle	$\theta =10^{o}$
Eyesight	$d=180$
Field of View	$\nu=90^{o}$
Feeding distance	$\lambda=3$
Safe distance (from predation)	*80*
Energy	$\kappa=0.3$
Reproduction threshold	$\tau=4.5$
Number of progenies	$\zeta=1$

Table 4. Creature B (Orange in Figure 3)

Property Description	*Symbols & Value(s)*
Speed (pixels)	$\sigma=1$
Thrust	$\varepsilon=2$
Feeding Thrust	$\varepsilon =3$
Thrust Limit	$\tau^{lim}=0.5$
Rotation Angle	$\theta =10^{o}$
Eyesight	$d=180$
Field of View	$\nu=90^{o}$
Feeding distance	$\lambda=4$
Energy	$\kappa=0.4$
Reproduction threshold	$\tau=4$
Number of progenies	$\zeta=1$

The series of simulation and their results have taught us that the inclusion of complex environmental factors using macro and micro climate can result in an increase in the diversity of artificial creature behaviour. The theoretical modelling of artificial organisms here is inspired from nature, using simple rules abstracted from the attraction and repulsion of environmental niche or threats, the adaptability of organisms based on genotype parameters, and by implementing predator-prey interaction. As a result, it is possible that the model has given us a glimpse of how macro states emerge from the microdynamics of positive and negative feedback loops. Therefore, conclusions can be drawn from biological and ecological systems that exhibited similar behaviours. The nature-inspired model can also be applied in engineering applications using the mechanisms that drive emergent behaviour. These mechanisms are positive and negative feedbacks such as attraction and repulsion as a result of the simple rules established in this model. Hardware emitters such as the ones shown in figures 3 and 4 could be installed in locations to attract or repulse robot swarms tasked with search and rescue operations, for example. A virtual greyscale terrain (Figure 1 and 2) could be used to map a physical terrain for sensor-based microcontrollers that detect the most adaptable location for specific engineering applications that require a fine digital resolution of the environment.

IV. CONCLUSION

Artificial life research needs to consider the complexity of the environment for supporting simulations related to emergent behaviour and evolution. It can be argued that evolution occurs through the mutation of genotypes facilitated by natural selection in the environment. With regards to the macro state of a complex system, it can also be argued that emergent phenomena and self-organisation in nature arises through the interactions of simple rules with the complexity of the

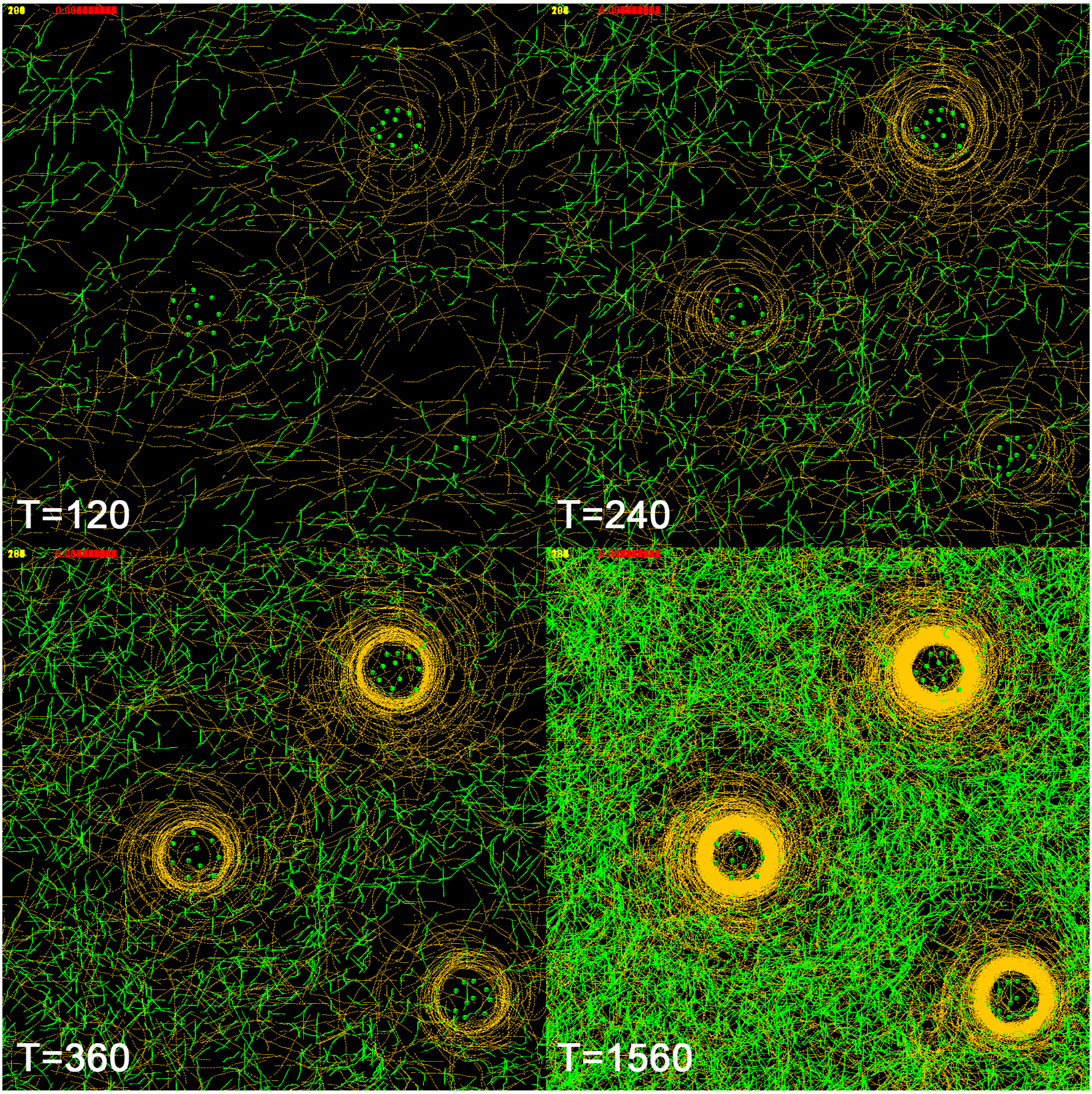

Figure 4. Two artificial creatures A, B, and a light emitter C. Creature A (green paths) is repulsed by emitter C (green dots) and Creature B (orange paths) is attracted by C. The sequence of figures show how patterns emerged due to the attraction and repulsion of the emitters to different types of creatures.

environment as catalysts. In this article, an artificial environment supporting macro and micro climate for artificial life simulation has been formalised. The macro average climate and the high resolution of the local environment are introduced. In particular, focus is placed on the generic emitters that are capable of representing any categories of environmental condition that dissipates over distances. Simulation results in the paper illustrate the diversity of patterns and behaviours on niches of the artificial creatures' environment. Whilst the simulations are not evolutionary, they demonstrated diversity and complexity in both the micro and macro state of the artificial organisms. The ground work laid in this research will provide a base from which emergence, self-organisation and evolution of various forms of artificial life can be simulated. Future work will look into extending the model to include other environmental complexity, and the application of the macro-micro model formulated in this paper to the study of complex adaptive systems and artificial evolution in complex environments.

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