How important are updating schemes in multi-agent systems? An illustration on a multi-turmite model.

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ABSTRACT

It is to date an open question to know how the updating methods affect the evolution of a multi-agent system. This question has been tackled for various complex systems such as cellular automata, Boolean networks, neural networks but little is known for multi-agent systems, especially for the models with a complex behaviour which emerges from simple local rules. This paper focuses on a multi-turmite model, namely the multiple Langton's ants model. All the agents are updated simultaneously and the variation of the updating scheme consists only in choosing different strategies for solving the conflicts produced when two or more agents want to go on the same location. We show that for the *same* formulation of the agents' behaviour, and the same initial conditions, the use of different updating schemes may lead to qualitatively different evolutions of the system. As a positive spin-off of this study, we exhibit new phenomena of the multi-turmite model such as deadlocks or gliders.

Categories and Subject Descriptors

I.2.11 [**Computing Methodologies**]: Distributed Artificial Intelligence—*multiagent systems*

General Terms

Algorithms,Experimentation

Keywords

multi-agent modeling, emergent behaviour, complex systems, turmites, Langton's ants

1. INTRODUCTION

An important topic in the multi-agent field regards the mathematical description of these systems and more particularly the way we updated the components of the system [20, 22]. Several authors have worked to establish a separation between the expression of the behaviour of the agents and the updating scheme. Ferber and Müller proposed the influence-reaction model as a first attempt to separate tentative actions from the environment reaction [11]. Following this direction, Michel designed a computational model that follows the influence-reaction principles [17]. This proposition was then precised by a framework which represents the environment as "a dynamical system that encapsulates and regulates its own dynamism" [14]. These propositions aim at removing the ambiguities of description that exist when a multi-agent system is described only in an informal way, or when it uses a specific simulation platform where the simulation engine is only partially known. A first step was undertaken by Müller who proposed a formalism based on extensions of DEVS [23] to unambiguously describe multi-agent systems from an event based point of view [18]. Despite these advances, the question to know how much the updating scheme contributes to the global behaviour of the system has been rarely tackled so far.

On the other hand, there exist several works which concern multi-agent systems [1, 4, 21, 19] or cellular automata [7] where the authors have focused on evaluating the effect of the updating scheme on the global behaviour of the system. They considered several variations in the updating scheme and demonstrated that it has an important influence on the global outcome of a simulation. Cellular automata were even shown to display phase transitions triggered by changes of the updating scheme, *i.e.*, in some cases, minor changes the synchrony of the updating can qualitative changes of the evolution of the system [10]. Most of these works focus on the evaluation of the changes of behaviours and do not necessarily examine a wide variety of updating schemes.

In short, it appears that authors so far have focused their efforts either on the formalisation side (how do we describe mathematically multi-agent systems?) or on the experimental side (how does the updating scheme affect the outcome of a simulation?). This article proposes to combine these two questions to illustrate how the variation of the updating scheme may produce a rich variety of phenomena, even for a simple multi-agent system, namely the multi-turmite system[1].

2. TURMITES AS CASE STUDY

Let us now describe our model. The agents evolve on a grid; their actions are limited to: (1) moving forward, (2) turning left or right and, (3) inverting the state of the cell on which they are located (an operation that we call *flipping* the cell). The most popular expression of the system was proposed by C. Langton in his pioneering paper on "artificial life" [16]. In Langton's view, we can gain insights on

[1]The work presented here corresponds to the experimental part of a wider study on how to describe multi-agent systems as discrete dynamical systems [5].

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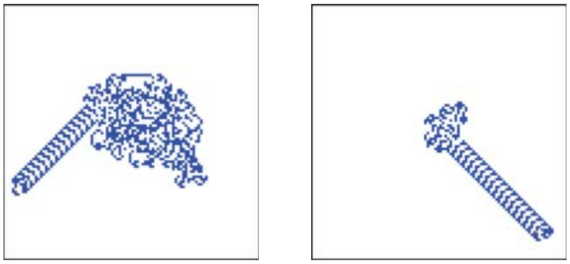

$t = 11500$ $\qquad$ $t = 3000$

Figure 1: Evolution of a single Turmite from $(0, 0, \textbf{North})$: (left) Initially, all cells in state `0`; (right) Same, except that cell $(0, 1)$ is `1`. `0`-cells and `1`-cells are displayed in white and blue (or dark), respectively. Turmites appear in red (or grey) but their position is by no means important.

how living organisms obtain there distinguishing properties - as opposed to inert matter - by modelling an "artificial biochemistry" that would rely on interactions between "artificial molecules". These artificial molecules are modelled by virtual automata, whose behaviour is specified by simple rules that only rely on local interactions. Among many examples given by the author, a proposition concerns the study of artificial "insect colonies" where the insect, called *vant* (for virtual ant), obeys the simple rules [16]:

```
▶ The vant moves on a square lattice where
each cell can be blue or yellow; cells are
initially all blue.
▶ If it encounters a blue cell, it turns
right and leaves the cell coloured yellow.
▶ If it encounters a yellow cell, it turns
left and leaves the cell coloured blue.
```

As pointed out by A. Gajardo, this model was also discovered, independently by other authors, among whom L. Bunimovich and S. Troubetzkoy [3], and A. Dewdney [8]. These agents are known as Langton's ants and they belong to the family of *turmites* [8]. We adopt this latter name in this article as it underscores that each turmite, when considered isolated from the other turmites, is an example of a Turing machine that operates on a two-dimensional tape.

Authors observed that these simple rules produced a complex behaviour even when the system is composed of a single ant. We invite readers who are not familiar with this system to perform a few simulation steps "by hand". This small exercise is rather puzzling since predictions of behaviour are difficult to extend beyond a few time steps. One reason for this difficulty stands in the absence of clear repetitive patterns: a turmite passes through the same positions again and again but leaves a different trail behind it at each of its return. Long time simulations show that the behaviour of the turmite does not stay "chaotic" for ever: after ~ 10000 time steps, it enters into a cyclic behaviour where it repeats the same relative moves forever. These repetitions result in a regular displacement in one of the four diagonal axes, leaving a "self-limited pathway" behind it.

Figure 1-left illustrates the evolution of a single turmite on a grid that is initially empty. In order to show the sensitivity to the initial condition of the system, we flipped the cell $(0, 1)$. Figure 1-right shows the evolution of the system for this new initial condition. We observe that the turmite also reaches the "pathway regime", but at an earlier time ($t \sim 3000$). This experiment underlines how small changes may affect the evolution of the system. This property of sensitivity to the initial condition will be useful for demonstrating the benefits of separating the description of a model from its execution scheme.

The study of the behaviour on a single ant gave rise to numerous studies and readers may refer to the work of Gajardo et. al. for an overview (see *e.g.* [12]). Now we examine a question that has been much less examined: what happens when several ants are put together? To our knowledge the only references that considered multiple turmites are the work of Chopard and Droz [6] and the paper by Beuret and Tomassini [2]. Remark that before we study this model, we need to specify how turmites interact. According to Langton's own words [16]: " *There are so many ways that these virtual ants can encounter one another that the transition rules have not yet been worked out for all possible encounters.*" This lead him to propose to adopt the simple strategy that consists of leaving the ants "*pass through each other*" and react to the cells' state without taking account of the other turmites.

We may note that although the solution is perfectly acceptable, the problem of dealing with multiple ants is only half-solved. Indeed, how should simulation programs operate in the case where several turmites share the same cell and *simultaneously* change the state of their cell? As nothing is specified, we are allowed either to choose arbitrarily, or, what is wiser, to believe that the implicit assumption of the author is that the updating of the agents is *sequential*: Turmites (and their cells) are always updated one after the other in a fixed order. However, it a is well-known problem that this method of taking a sequential updating of agents is by no means a panacea:

- Ambiguities in the model exist if the order of updating is not well-specified. As a consequence, the reproduction of experiments with different simulation environments is made difficult, if not impossible.

- Even in the case where the updating scheme is well-specified, it may introduce an artificial causality and create unwanted effect such as biases in the simulation or an artificial symmetry breaking (see later for examples).

Our purpose is to illustrate how the choice of an updating scheme may play a central role in the production of a collective behaviour. We illustrate this claim on the multi-turmite system, whose simplicity and richness is particularly adapted for the study of it sensitivity to the variation of the updating scheme. But before we go further, let us reformulate the behaviour of turmites with a new perspective, intended to facilitate its transcription with influences and reactions:

```
▶ A cell can be in state 0 or 1.
▶ A turmite on a 0-cell attempts to flip the
cell, to turn right and to move forward.
▶ A turmite on a 1-cell attempts to flip the
cell, to turn left and to move forward.
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As readers might have noticed, this rewriting of the rules not only takes the agent's perspective but also describes the behaviour of the agent in terms of attempts, or *influences* [11], rather than in terms of effective actions.

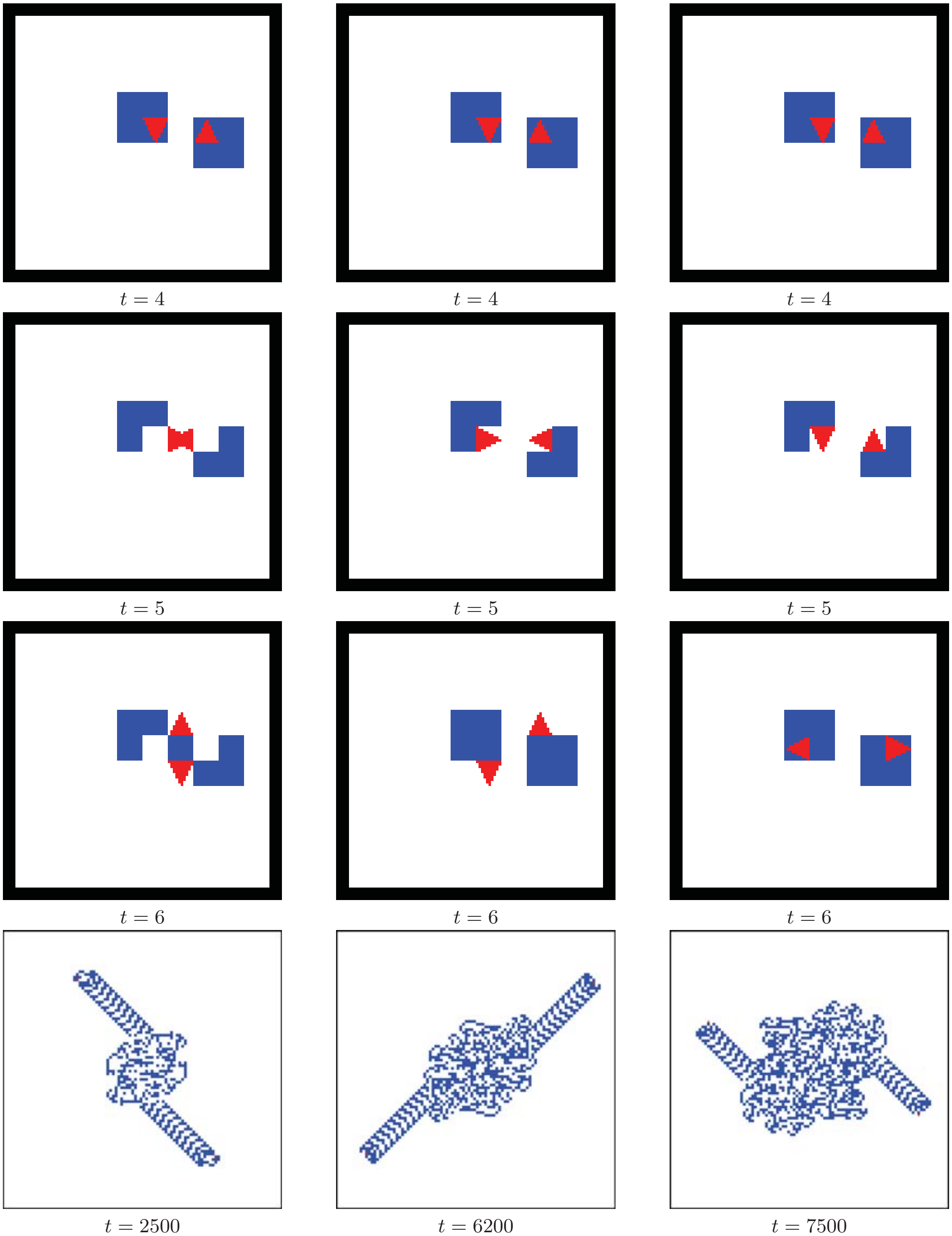


Figure 2: Initial condition: $(0, 0, \text{South})$ **and** $(2, 0, \text{North})$ **; comparison of the three systems: (Left)** $\mathcal{AL}$ **(Middle)** $\mathcal{TS}$**. (Right)**$\mathcal{EX}$**. The last figure shows the asymptotic evolution of the system (two paths).**

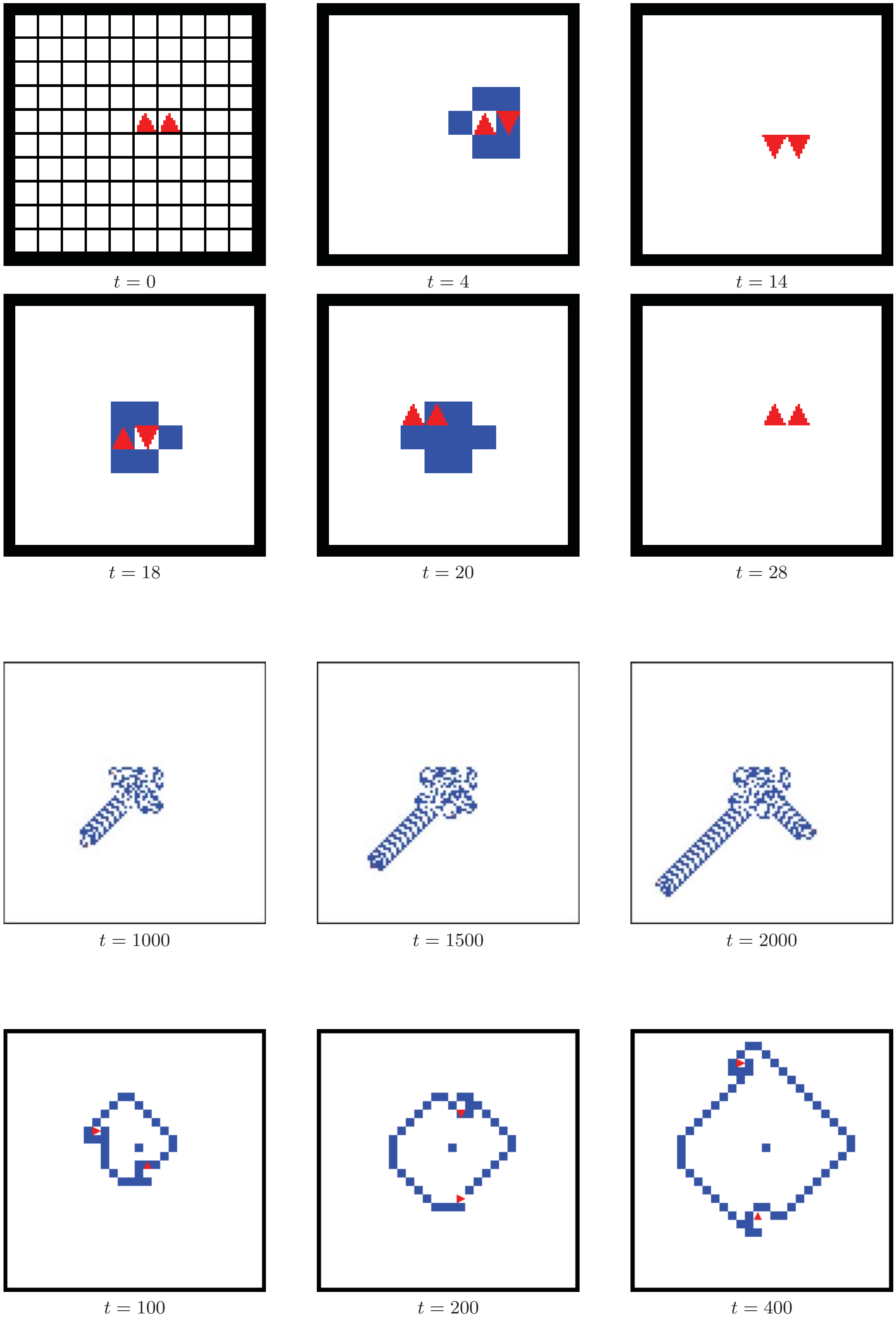


Figure 3: Evolution of two Turmites starting from initial condition $(0, 0, \textbf{North})$ and $(1, 0, \textbf{North})$. (Top) $\mathcal{AL}$, cyclic behaviour. (Middle) $\mathcal{TS}$, pathway building. (Bottom) $\mathcal{EX}$, ever-growing square.

3. DERIVING THREE SYSTEMS FROM THE MODEL

As a preliminary remark, we wish to draw the attention of the reader that in case of a single ant there is no major ambiguity on the definition of the system. In the case where multiple turmites are present on the same cell, we solve potential conflicts by defining three updating schemes:

AL Turmites are allowed to share the same cell.

TS Turmites are *not* allowed to share the same cell. In the case where two or more turmites try to move on the same cell, their move is blocked *but* their change of orientation is effective.

EX Turmites are *not* allowed to share the same cell. In the case where two or more turmites try to move on the same cell, their move is blocked and their orientation is kept unchanged.

In all cases, the flipping influences are combined into a single flipping influence and turmites are updated synchronously. For the sake of conciseness, we do not describe formally the systems resulting from the application of these three updating schemes; interested readers may refer to a more detailed presentation of the multi-turmite system [5]. We denote by $\mathcal{AL}$, $\mathcal{TS}$ and $\mathcal{EX}$ the three discrete dynamical systems which result from the application of the updating schemes AL, TS and EX, respectively. We denote by (x, y, d) a turmite's state with coordinates $(x, y) \in \mathbb{Z}^2$ and direction $d \in \{\text{North}, \text{East}, \text{South}, \text{West}\}$. Initial conditions will be defined by the list of the turmites states and, unless otherwise stated, all the cells are assumed to be initially in state `0`.

Figure 2 shows the evolution of the three systems with two turmites initially at $(0, 0, \text{South})$ and $(2, 0, \text{North})$.

For the four first steps of the simulation, as there is no interaction between the agents, the systems evolve identically. The divergence appears at time $t = 5$ when two agents attempt to go on the same cell. From that time, the evolution of the three systems diverges. Eventually, we find that their asymptotic evolution is qualitatively similar (two paths are created), but it is quantitatively different: the two paths appear at different time steps and have different directions.

This small experiment illustrates how the use of two updating schemes may lead to different evolutions even though the agents have the same definition. Starting from this observation, one may wonder to which extent one simple initial conditions may lead to qualitatively different collective behaviours depending on which updating scheme we use.

4. EXPERIMENTS AND OBSERVATIONS

We now illustrate the qualitative differences between the three systems that result from different updating schemes. We are particularly interested in the cases where we observe qualitatively different behaviours even when we start from the same initial condition. The experiments presented here are not meant to be an exhaustive exploration of the behaviours displayed by the multi-turmite model. However, two novel phenomena will be exhibited; they are strongly related to our description of the model with three different formulations.

4.1 Paths, Cycles and Ever-Growing Squares

Let us first observe a simple evolution of a two-agent system where the two turmites are placed next to each other with the same orientation: $(0, 0, \text{North})$ and $(1, 0, \text{North})$. This initial configuration illustrates how the choice of an update leads to different evolutions:

- Figure 3-top presents the evolution of the system $\mathcal{AL}$. This system has a cyclic behaviour: the system returns to its initial state in 28 steps. Similar cyclic behaviours were also observed in the synchronous multi-turmite model considered by Chopard and Droz [6] and in the sequential system considered by Beuret and Tommassini [2]. An open question is to know under which conditions cyclic patterns appear.

- Figure 3-middle presents the evolution of the system $\mathcal{TS}$. The behaviour is more "common" since the two turmites escape to infinity by building two paths in different directions (this path-building behaviour was also observed in the three evolutions in Figure 2). The first turmite starts building its path at $t \sim 400$ and the second turmite reaches the path-building behaviour at $t \sim 1700$.

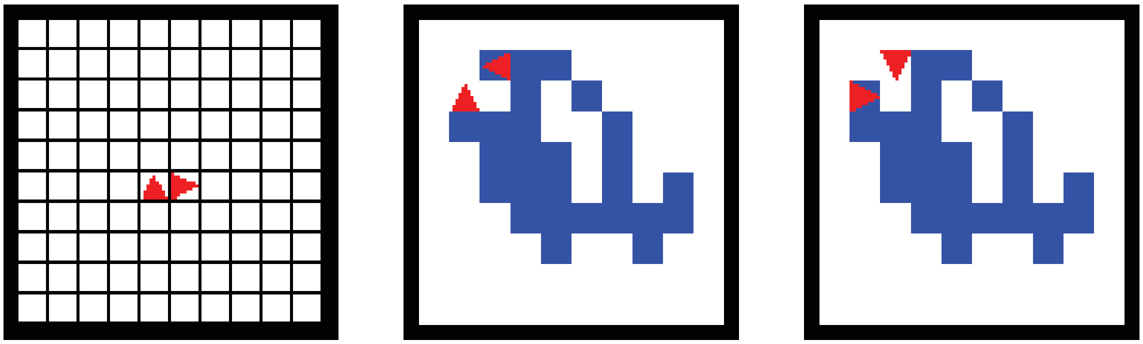
- Finally, Figure 3-bottom presents the evolution of the system $\mathcal{EX}$. We observe that the two turmites follow each other's path but with a difference of one cell (at the right of the previous path). This results in the apparition of a square constituted of cells in state `1`, this square grows for ever, its width is increased by one at each of the turmite's return. Such behaviour was already observed by Langton, for whom they were a good a example of a "collaboration" between turmites to build patterns. We raise the question to know whether more elaborate patterns can be built with similar cases of "collaboration".

4.2 Deadlocks

Figure 4 shows the system $\mathcal{TS}$. The two turmites are again put next to each other, but with the second turmite turned by 90 degrees: $(0, 0, \text{North})$ and $(1, 0, \text{East})$. We observe that after 60 steps the system reaches a configuration where the two agents will not move. At time $t = 60$, the agents attempt to move to the same cell, as they turn and flip their cell. At time $t = 61$, they turn simultaneously and flip their cell. Again, their attempt to move to the same cell is blocked. As consequence, the configuration reached at time $t = 62$ is identical to the configuration at time $t = 60$ and the evolution is then cyclic with two static turmites and two "blinking" cells. We call *deadlocks* the configurations where the turmites are static. It is to our knowledge the first time that these phenomena are observed.

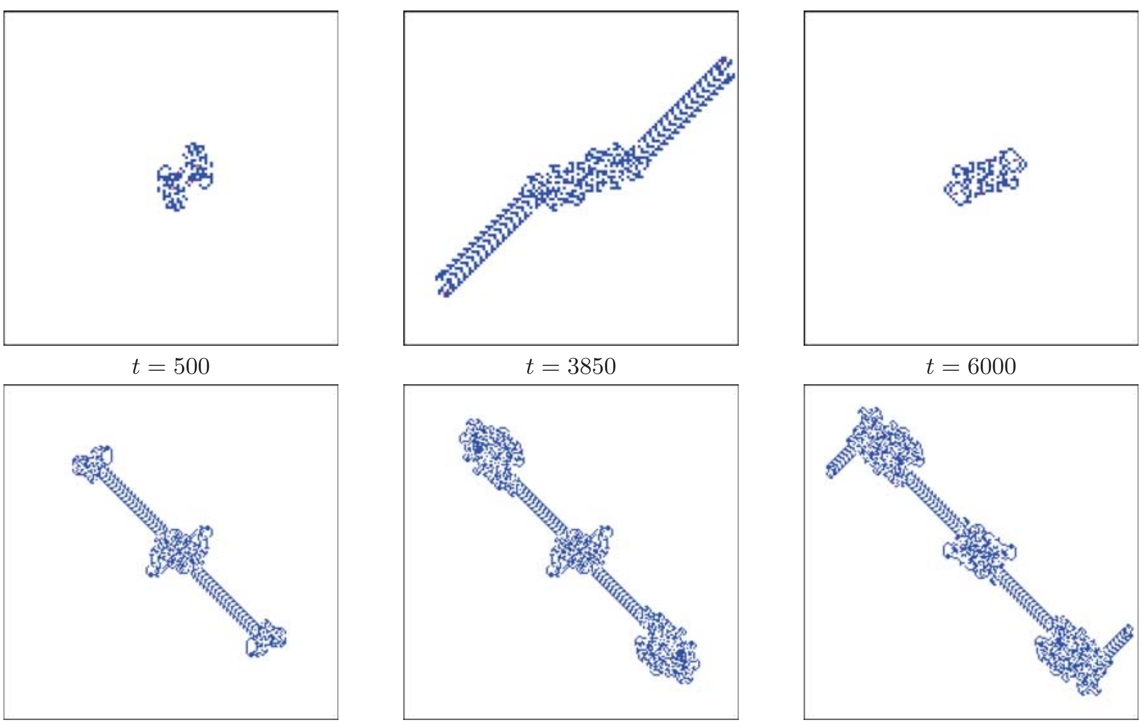
4.3 Path Retraction and Path Turn

Figure 5 shows a curious evolution of the system $\mathcal{AL}$: two symmetric paths develop and retract cyclically. This phenomenon is obtained with four turmites initially placed on a horizontal line, at distance 3 from each other, with alternating orientations. The cycle has length 6576 and can be decomposed into five parts: (a) from time $t = 0$ to time $t = 1182$, the system evolves in the "chaotic" regime, the pattern of `1`-cells extends and then shrinks until the space is all-`0` (the turmites are in different positions than at $t = 0$);



$t = 0$ $t = 60$ $t = 61$

Figure 4: Evolution of two Turmites starting from initial condition $(0, 0, \textbf{North})$ and $(1, 0, \textbf{East})$, $\mathcal{TS}$ system. The system reaches a deadlock at time $t = 60$. The configuration at time $t = 62$ is identical to time $t = 60$.



$t = 4000$ $t = 8000$ $t = 11000$

Figure 5: Initial condition is: $(0, 0, \textbf{North})$, $(3, 0, \textbf{South})$, $(6, 0, \textbf{North})$, $(9, 0, \textbf{South})$. (Top) $\mathcal{AL}$, cyclic retracting path phenomenon. (Bottom) $\mathcal{TS}$, turning path phenomenon.

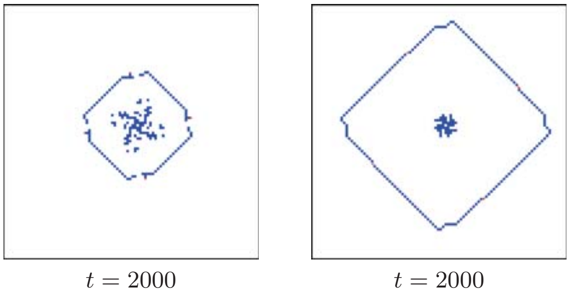


Figure 6: Evolutions of two systems with initial condition: $(0, 0, \textbf{North})$, $(0, 4, \textbf{East})$, $(4, 4, \textbf{South})$, $(4, 0, \textbf{West})$. **(Top)** $\mathcal{TS}$**, ever-growing square rotating counter-clockwise. (Bottom)** $\mathcal{EX}$**, ever-growing square rotating clockwise.**

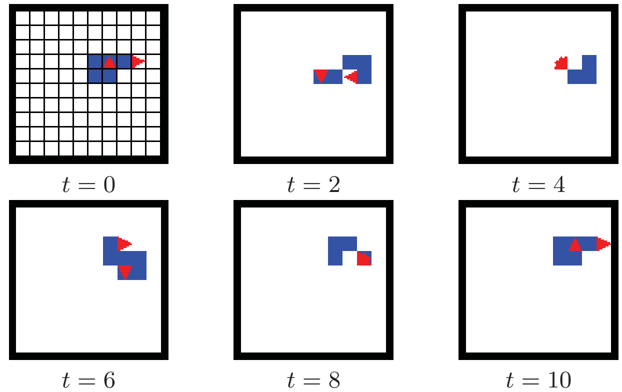


Figure 7: Focus on the translation cycle of a glider observed with the $\mathcal{AL}$ **system.**

(b) from time $t = 1183$ to time $t \sim 2400$ a new chaotic regime is started; (c) at time $t \sim 2400$ two turmites start building a pathway, (d) they are then rejoined by the two other turmites and they interact at time $t \sim 3850$; (e) the result of this interaction is to create a path retraction and the erasing of the 1-pattern until the initial condition is attained at time $t = 6576$.

This observation shows that paths can be retracted during their construction when two turmites interact. Moreover, it appears that this path retraction is a particular case of a "pattern erasing regime" where the past actions of the turmites are reversed. It is an open problem to analyse under which conditions this pattern erasing regime appears. An explanation of this phenomenon as a time-reversal symmetry is given by Chopard and Droz in [6]. From the first observations conducted, it seems that it is a consequence of a "collision" between two turmites.

Interestingly, starting from the same initial condition with the system $\mathcal{TS}$ leads to observe a "turning path" phenomenon (see Fig. 5-bottom. This phenomenon is obtained in five phases: (a) The four paths evolve in a chaotic regime; (b) Two turmites T_1, T_2 build a path while the two others T_3 and T_4 stay in a chaotic regime; (c) T_3 and T_4 enter into the path built by T_1, T_2 and follow this path until they "collide" with T_1, T_2; (d) This collision initiates a new chaotic phase with the four turmites; (e) A new pair of turmites emerges T'_1 and T'_2 from the chaotic regime and builds a path that is here orthogonal to the first path.

4.4 Ever-Growing Squares with Opposite Rotating Directions

Figure 6 presents an example where the same initial condition leads to the formation of ever-growing squares, but with squares growing in opposite directions. The system $\mathcal{TS}$ gives birth to a square which grows with turmites rotating *counter-clockwise* while the turmites of the system $\mathcal{EX}$ turn *clockwise*. We also observe that the transient phase before starting building the square is shorter for $\mathcal{TS}$ than for $\mathcal{EX}$.

This indicates that is no general law of "conservation of momentum" in the multi-turmite system. However, in some restricted cases, other conservation laws exist. For example, the fact that position and the orientation of the turmites changes at each time step implies that parity conservation laws can be derived rather easily.

4.5 Gliders

To end this experimental study of the multi-turmite model, we report the observation of a new kind of translating pattern which we name "gliders" by analogy with cellular automata. Contrarily to many cellular automata, like the game of Life, the apparition of gliders with the multi-turmite model is rare. We could observe only one configuration which gave birth to gliders and this configuration was found by chance out of dozens of experiments. This configuration is obtained with the system $\mathcal{AL}$ with four turmites disposed in a square pattern: $(0, 0, \textsc{East})$, $(0, 4, \textsc{North})$, $(4, 4, \textsc{West})$, $(4, 0, \textsc{South})$. Note that the orientation of the turmites is such that the initial condition is symmetric with respect to the central symmetry but it is *not* rotationally symmetric. This system evolves chaotically until two gliders are "ejected" from the central pattern at time $t \sim 550$. Figure 7 shows a close-up on the translation mechanism of a glider: it is constituted of a pair of turmites, which translate by $(\pm 1, \pm 1)$ every 10 time steps.

An interesting question is to know whether it is possible to take gliders as a basis for building a universal Turing machine with the multi-turmite model. This is one of the numerous questions that remain to examine in order to have a more comprehensive view of the multi-turmite model.

5. DISCUSSION AND PERSPECTIVES

The series of experiments we conducted allowed us to see that *one* single model, here the multi-turmite model, may be defined differently, depending on what interpretation is chosen on its updating scheme. The simulations of three derived systems allowed us to reproduce previous observations as well as to discover new qualitative behaviours such as deadlocks and gliders. In a more general case, some authors also observed that under-specifying a model may lead difficulties in the reproduction of a multi-agent simulation [9].

The non robustness of a simple multi-agent model to its updating scheme suggests that in some cases, the under-specification of the dynamics of a system may introduce a bias which is not due to the local rules but mainly to the updating scheme (see *e.g.*, [15]). We call for a greater attention to these questions and we underline that understanding the role of the updating becomes a necessity if we want to guarantee that the collective behaviour observed can be reproduced without ambiguity. In the simple examples we studied, the ambiguities result from conflicts, which correspond to simultaneous attempts to move to a cell or to modify the cell state. More complicated models should generate an even wider range of updating schemes. Ideally, simulation programs should allow their users to define the agents' behaviour in a first step and then to test different updating schemes for each agent's definition.

In this article, we focused our attention on displaying cases of *non-robustness*. However, the converse problem is also interesting: in which cases does the system behave robustly to the modifications of its updating scheme? Our point is that if we consider natural models, such as real ants models, it may well be that the multi-turmite system is rather an exception than a representative example. As underlined by Grimm and Railsback, many studies have shown that updating scheme can affect the results of an individual based model *although it is not clear that such artefacts are likely to be strong in individual-based models rich in biological structure* [13] (see p.114). A wider exploration program would be need to evaluate how the robustness of the natural systems can somehow be conserved into the models themselves. In this case, the global behaviour of the model would qualitatively resist to small modifications of the simulation scheme. The presence of such a robustness would then explain why so few authors have paid attention evaluating the influence of the updating scheme on the qualitative behaviour of their models.

As a next step for our future research ; our orientation is now to widen the scope of the models in order to gain insight on what makes a multi-agent system robust or sensitive to its updating scheme.

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