A Generative Dance Based on the Dynamics of a Family of 2D Cellular Automata

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Abstract

This paper presents a study of a generative dance based on the concepts of Generative Art and Choreographic Objects built from 2D boolean diamond-shaped topology cellular automata. These Choreographic Objects were analyzed, considering the dance meaning of the collective behavior, playing with different transition rules (transposing them to relations scores), and emergent configurations. We identify the sets of symmetrical, reversible, and sensitive to initial conditions cellular automata, which present characteristics suitable for the composition of generative dance. As a result, we create practical hypothetical examples of experimentation for these transition rules in a vivified practice of generative dance. Finally, we invite the reader to imagine generative dances using the dynamics of the selected rules, advancing a choreographic practice in the context of performance creation and community dance workshops.

1. Introduction

Performing Arts and Generative Art has traveled an intertwined path. Their practice was embedded in epistemological knowledge based on openness, evaluation, and interpretation of a question or idea through generative techniques.

According to Philip Galanter, [1], generative art is more than an art movement. It should be seen as a mode of artistic practice. For the author, Generative Art, rather than High-tech Art, corresponds to "*any art practice in which the artist cedes control to a system with functional autonomy that contributes to, or results in, a completed work of art. Systems may include natural language* *instructions, biological (...) and other procedural inventions*" ([2], p. 154).

Transposing this concept to dance, assuming the choreography as a set of instructions for the organization and reconfiguration of one or several bodies in space-time, where the choreographer defines the spatial organization and movement of the dancers [3], as well as a mode of composition in contemporary dance based on organizational principles, a logic that engenders the choreographic organization which overlaps with the logic of step chaining [4], and allows the emergence of patterns in space-time, by the multiple dancer inter-relationships, which merely had their relationships predefined, but not their final formations [4]. Regarding generative dance, the choreographer uses composition to moderate synergetic and structural balances, proposing that the performers adjust their actions and movements to co-create a collective joint dance. Creating a system of performers that interact following simple rules of interaction (generative principles), the choreographer facilitates the choreographic emergence of collective behaviors so that in generative dance, the choreographer, more than controlling the final result of the dance, suggests: a) a relational ontology, to encourage the investigation of movement places that potentially generate emergent collective behaviors; b) scores of simple interaction rules, open or closed [5], that allows performers to overcome their tendency to repeat previously learned and trained movements and concepts; c) the total or partial control of the artwork to the performer, acting as System Creator [6].

In this paper, we assume the role of generative dance choreographers and propose the construction of a relational ontology based on an agent-based model by approximating Forsythe’s (n.d.) choreographic objects. Forsythe’s choreographic objects are defined as a model of potential transition from one state to another in any imaginable space. This computational choreography portrays a group of self-aware dancers who rely on their peripheral vision to observe nearby performers. Therefore, at any given moment (T), each performer, while conscious of their own state, observes the state of their closest neighbors, and subsequently determines their state for the next moment (T+1) by applying a selected relational score.

2. Creation of a Choreographic Object

Assuming the function of a choreographer of a generative dance, we propose to create a system as a network of mutually interconnected performers. Each performer can be in one of two action states, S={0, 1}={a predetermined choreography with 8-counts, full-squatting posture for 8-counts}. The performers will collectively update their action states based on an initial choice, determined by a selected relation score (referred to as the local transition rule). This transition rule remains consistent for all performers, shaping the interconnected network within the system. In our specific scenario, we opt for a family of relation scores in which a performer's action depends on both their own actions and those of three neighboring performers: one to their left, one to their right, and one in front of him. However, in a real-world setting, limitations in a performer's peripheral vision can hinder their ability to perceive the state of all three neighbors simultaneously. To address this challenge, we adopt a diamond-shaped topology, allowing performers to observe their nearby counterparts situated diagonally to the front-left, directly in front, and diagonally to the front-right, see Figure 1.

Figure 1. Diamond-shaped topology system with 6 x 6 = 36 elements. All performers are facing downwards.

In our system, all performers are oriented towards the audience, which means that some performers may not have the three nearest neighbors required to define their next action state (as depicted in Figure 1). We refer to these performers as being situated at the system's boundary. To ensure a consistent transition rule for all performers, regardless of their position, we fix the action state of every missing performer. In essence, we establish specific boundary conditions for the system.

Among the various alternatives for boundary conditions, we choose the simplest option: fixed null boundary conditions. This implies that a performer situated at the boundary assumes that the action state of any missing neighbor is consistently zero. This choice has led us to propose that the most appropriate mathematical-computational model for our choreographic object is a 2D boolean cellular automaton with a diamond-shaped topology and fixed (null) boundary conditions.

We must emphasize that this family of 2D cellular automata is much simpler than those usually studied. Compared with the more common Moore and von Neumann neighborhoods, with five and nine elements, respectively, and periodic boundary conditions, our initial guess was that the collective dynamics possible for our family of cellular automata would not be interesting enough. This work shows that this is not the case.

Figure 2. Diamond-shaped topology system using two colors to distinguish the state (0 or 1) of each of its 36 elements.

From everything stated above, we can infer that a system has the potential to assume various forms beyond the tilted square presented above. This flexible characteristic is essential to the dance learning process and workshop context since it will make it possible to work with smaller groups. Furthermore, in the community dance context, where everyone’s participation is important, the possibility of such multiple shaped configurations is fundamental since sometimes we will not have the exact number of participants to fulfill a square.

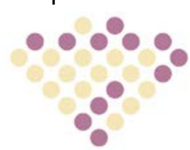

Figure 3. A system with a different shape, obtained by a suitable pruning of the diamond-shaped system above.

3. Analyzing the Dynamics of our Choreographic Object

A Boolean cellular automaton is a set of elements capable of being in one of two states, which we can take to be 0 or 1, interacting locally with some chosen nearest neighbors. In our case, we defined the elements of our Boolean cellular automaton as performers dancing. The state of each performer evolves in discrete time steps, according to a fixed deterministic transition rule, which is the same for all elements and all time steps. For our case, this rule specifies the performer's new state from its current value and the values of three of its closest neighbors: if we denote by σ the state the performer assumes at a given instant, σ_r the state of the performer at its diagonal-front-right, σ_l the state of the performer at its diagonal-front-left, and σ_f the state of the performer in front of him, then the state in the next instant, σ' , is given by

$$\sigma' = \varphi(\sigma_r, \sigma_f, \sigma_l, \sigma).$$

We can see that choosing a transition rule means specifying the value that the function φ takes for each of the 16 different possibilities for its four Boolean variables.

$d_0=\varphi(0,0,0,0)$	$d_1=\varphi(0,0,0,1)$
$d_2=\varphi(0,0,1,0)$	$d_3=\varphi(0,0,1,1)$
$d_4=\varphi(0,1,0,0)$	$d_5=\varphi(0,1,0,1)$
$d_6=\varphi(0,1,1,0)$	$d_7=\varphi(0,1,1,1)$
$d_8=\varphi(1,0,0,0)$	$d_9=\varphi(1,0,0,1)$
$d_{10}=\varphi(1,0,1,0)$	$d_{11}=\varphi(1,0,1,1)$
$d_{12}=\varphi(1,1,0,0)$	$d_{13}=\varphi(1,1,0,1)$
$d_{14}=\varphi(1,1,1,0)$	$d_{15}=\varphi(1,1,1,1)$

The justification for the notation used to distinguish the different values for the function φ is the so-called Wolfram integer representation: when referring to a transition rule φ, we use the integer number whose binary digits are precisely the values of the functionφpresented earlier, i.e.

$$N_\varphi=(d_{15}\, d_{14}\, d_{13\,\ldots}\, d_2\, d_1\, d_0)_2.$$

This means that, given any integer N_φ, between 0 and 2^{16}-1, its binary representation encodes the sixteen different values necessary to specify a transition rule φ.

For example, consider the integer number N_φ=46273. Given its binary representation

$$N_\varphi=(1011010011000001)_2,$$

we have all sixteen binary digits required to define the corresponding transition rule φ, i.e.:

$d_0=\varphi(0,0,0,0)=1$	$d_1=\varphi(0,0,0,1)=0$
$d_2=\varphi(0,0,1,0)=0$	$d_3=\varphi(0,0,1,1)=0$
$d_4=\varphi(0,1,0,0)=0$	$d_5=\varphi(0,1,0,1)=0$
$d_6=\varphi(0,1,1,0)=1$	$d_7=\varphi(0,1,1,1)=1$
$d_8=\varphi(1,0,0,0)=0$	$d_9=\varphi(1,0,0,1)=0$
$d_{10}=\varphi(1,0,1,0)=1$	$d_{11}=\varphi(1,0,1,1)=0$
$d_{12}=\varphi(1,1,0,0)=1$	$d_{13}=\varphi(1,1,0,1)=1$
$d_{14}=\varphi(1,1,1,0)=0$	$d_{15}=\varphi(1,1,1,1)=1$

A graphical representation of this transition rule φ is given in Figure 4, where on the left side we have all sixteen possible settings for the neighborhood, while the corresponding values achieved by the top element in the next time step are given on the right side. In this case, we choose a lighter color to represent the state 0 and a darker one to represent the state 1.

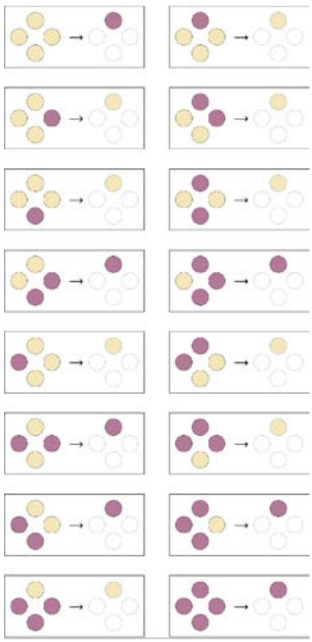

Figure 4: Graphical representation of the transition rule with Wolfram code 46273.

We can translate this transition rule into dance language as a set of closed verbal scores where the darker performers move according to an 8-counts predetermined choreography. At the same time, the lighter elements stay for eight counts in a full-squatting posture.

By employing a transition rule, we can calculate the state of each performer within the system over a specified number of time steps, thereby simulating the collective behavior over a particular time interval. To illustrate this process, let's examine an example using transition rule 46273, depicted in Figure 4, for a system with 6 x 6 elements, with the configuration shown in Figure 2 as initial configuration. In this instance, we have computed the collective system configurations for time instants ranging from T=1 to T=20, as demonstrated in Figure 5.

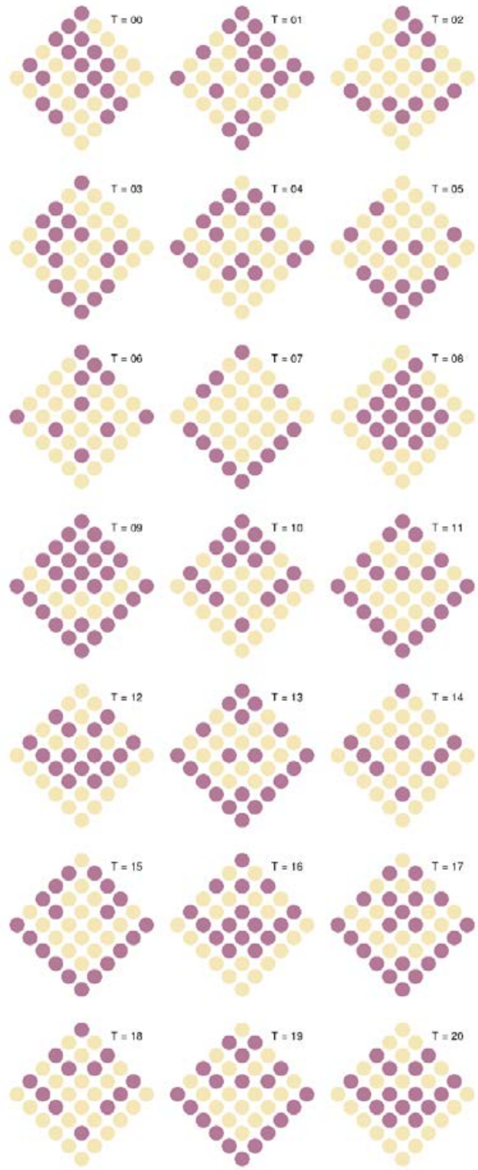

Figure 5. Dynamic obtained for a system with 6 x 6 elements, using the transition rule 46273, for T = 0 to T=20.

When dealing with systems with a finite number of elements, it is known that every dynamic necessarily ends with the system repeating one or more configurations. In our example, we can see that the choreographic object finds its final cycle, of period eight, after 11 instants of time (the set of configurations a system assumes until it enters the final cycle is called the dynamic's transient). In addition to these dynamic characteristics, we can observe that, beginning at time T=9, the system adopts symmetrical configurations with respect to the vertical axis. This observation leads us to propose the term *symmetric cellular automata* for cellular automata whose final cycles consist of symmetrical configurations.

In order to make a choreographic analysis of our choreographic object, a 2D diamond-shaped lattice cellular automaton, with a four element neighborhood, and fixed null boundary conditions, we use the interaction factors of movement developed and described by Walsh, Leray, and Maucouvert, [7]. In 1997, Walsh, Leray, and Maucouvert considered that in dance, as in a choir or an orchestra, dancers should be aware of the action of their companions once the individual gesture only finds meaning when embedded in the collective.

Let Figure 5 corresponds to an emergent choreography where the dark elements correspond to dancers performing an 8-count sequence, and the light elements correspond to dancers staying 8-counts in a full-squat posture. In the beginning, T=0, some performers assume the squat posture, while others dance. At the next instant, T=1, everybody updates their state using the transition rule 46273, changing the overall configuration. They repeat the same action 20 times and conjointly bring out global patterns with symmetrical configurations. We analyzed the emergent choreography using Walsh, Leray, and Maucouvert interaction factors of movement, taking into account spatiotemporal relations between elements. Even if at the individual level the dancers can only choose between two states S = {a predetermined choreography with 8-counts, full-squatting posture for 8-counts}, at a group level, it is possible to observe a visual effect similar to creating groups, lines, solos, duets, and trios, composed within a common structure and based on moments of synchrony and successions. Table 1 shows Walsh, Leray, and Maucouver interaction factors of movement that we can observe within our emergent choreography.

For example, there is a displacement effect for T=7 and T=8, where performers form a group (ensemble). At T=8 and T=9, we can see a splitting effect of the group in two, constituting a group at the top and a line at the bottom. Even though all elements have the same common structure, an effect of independence and complementarity is sometimes created. For example, at the transition from T=13 to T=14, we observe the emergence of 3 dance solos that seem independent of the surroundings, composed of performers in a full-squatting posture. Performers follow a model of relationships based on transition rules, with a successive rhythm over time, for which everyone updates their state after analyzing their surroundings at T=T+1. On a global level, the choreography presents a dynamic composed of unison and alternations, for example, a line composed by dancers dancing simultaneously for T=11; alternation of performer's states at the lower border for the instants T=18, T=19, and T=20, respectively.

ELEMENTS OF ANALYSIS OF INTERACTIONS IN A CHOREOGRAPHY	
RELATIONSHIPS AS A FUNCTION OF SPACE	**Correlation:** • Face to face; • Back to back; • Side by side; • Cross each other; • One behind the other; • Around; • Close; • Far; • In contact. **Actions:** • Meet; • Split up; • Cross each other; • Stay in an ensemble; • In opposition, • In décalage, • In contact;
GROUP-BASED RELATIONSHIPS	• Contact; • Common structure; • Independent structures.
ROLE-BASED RELATIONSHIPS	• Similar; • Opposite; • Different; • Be complementary; • Be a model, • Follow a model; • Move as a mirror; • Move in action-reaction.
OBJECT-BASED RELATIONSHIPS	• Sign; • Support of the action; • Origin of transformations • Support of the action; • Origin of transformations; • Element of mediation.
TIME RELATIONSHIPS	• Unison (simultaneity); • Alternations (conversation, questions, and answers); • Successive; • In canon (if a sequence of movement is presented and reintroduced by other dancers at regular intervals).
SIGNAL-BASED RELATIONSHIPS	• By contact; • Gestural; • Sonorous; • Spatial; • By the mediation of the object.

Table 1. Elements of analysis of interactions in dance (adapted from [7])

4. Playing with the Rules of a Choreographic Object

This section presents some other transition rules studied with the help of our choreographic object with interesting characteristics to generate emergent collective choreographies.

First, we found 16 symmetrical transition rules for which the final cycles of the dynamic are symmetrical configurations. By employing a symmetrical transition rule, the performers inevitably collaborate to generate a sequentially concentric and symmetric movement from any selected initial configuration. All global concentric choreographies generally present ensembles, lines, solos, duos, and trios.

We also found 160 transition rules that when applied in our choreographic objects produce cycle dynamics from the beginning, i.e., the dynamics have no transient. They are called *reversible transition rules*. On a performance choreographic level, these rules produce emergent choreographic cycles that begins and ends with the same configuration. In this case, we can define an initial configuration and, without determining the duration of the performance, the performers will know the choreography's end by assuming the initial configuration again. For example, imagine the following choreographic proposal, a real-time performance of 36 dancers organized in a diamond-shaped lattice topology, facing the public. For every performer, we offer the same reversible transition rule. Furthermore, we ask all performers initially to form vertical lines of S = {a predetermined choreography with 8-counts, full-squatting posture for 8-counts}. We let performers apply the transition rule and ask them to stop as they feel all have returned to their initial configuration. The example presented seems straightforward; however, it is attractive on a choreographic performance level and interesting to qualitative studies on dance-related issues like group sense, being together, trust in the collective, or even group synergy.

After a spatio-temporal analysis, we used our choreographic object to evaluate the resilience of each transition rule, i.e., we checked how much a tiny mistake by one of the performers could modify the resultant emerging choreography. We looked for the most sensitive rules to performers' mistakes. We argue that the spatiotemporal effect of sensitive rules on emergent choreographies requires further investigation. Nevertheless, we know that the effect of this rule is like a wave that dissolves a configuration. So, we can visualize a sensitive rule that makes the system enter a fixed point, for example, all performers squatting. At a particular instant, if one of the performers changes his response, we would perceive a global wave-like effect that would make some performers start moving again by contamination effect.

Taking the role of generative dance choreographers, transferring computation to live performance, lets us create a non-high-tech generative dance and its emergent choreography. Consider a Greek Amphitheater, a real-time performance of 36 dancers organized in a diamond-shaped lattice topology facing the public, all of them following successively the following sets of relational rules (transition rules):

1. Symmetric cellular automaton; transition rule 47329;

2. Symmetric cellular automaton; transition rule 31693;

3. Reversible cellular automaton; transition rule 38293;

4. Most sensitive cellular automaton; transition rule 40099;

Each rule is associated with a piece of music and two movement phrases. For example, symmetrical transition rule 1 corresponds to S={a predetermined choreography with 8-counts, full-squatting posture for 8-counts}, and reversible transition rule 3 corresponds to S={an upper body movement improvisation for 4-counts, floor improvisation for 4-counts}. The performers know all the relational rules and their correspondence to movement and music. The initial performer's setup movement is predetermined. The music is played on a jukebox and pulled over by an element outside the system, such as the audience. People in the audience can change the music whenever a green light goes on the jukebox. By playing the music on the jukebox, the audience can modify the collective choreography and interact with the performance. In Figure 6, we present the **QR** code for the video of a generative dance, with an example of a performance obtained from a particular audience choice.

Figure 6. **QR** code for the choreographic object video for performance with the audience choice (1+3+2+4).

Playing with the jukebox and building a choreography, the audience will observe the following:

- ➔ Creation and variation of successive spatio-temporal symmetries, composed by ensembles, solos, duets, trios, quartets, lines, and circles;
- ➔ Moments of disorder;
- ➔ Pauses (fixed configurations) or choreographic moments that remain the same during all correspondent music pieces;

- ➔ Chain reaction correspondent to the propagation of a mistake.

5. Conclusions

In 1968, Merce Cunningham, one of the forerunners of this interdisciplinary between dance and computation stated in his book Changes: Notes on Choreography [8] that:

"*Electronic technology has given us a new way of looking. Dances can be made on computers, images can be punched into them, why not a notation for dance that is immediately visual?*" ([8], pp.3)

In this sense, the relationship between dance and computing, like Forsythe's choreographic objects rather than trying to mimic dance movements, is intended to add a dimension to visualize dance and the choreographic process [9]. Thus, in this work, innovation arises from the concept of dance experimentation and the capacity of visualization that allows us to perceive the evolution of group behavior. Therefore, with this paper, more than focusing on how to plot the transitions of generative dance, we advanced with an observational way to perceive what happens in emergent collective choreographies built from simple rules of transition. In this way, we designed a choreographic object from a given family of 2D diamond-shaped lattice cellular automata, with a neighborhood of four elements, and fixed null boundary conditions. The systematic study of this choreographic object allowed us to approach the generative dance as a selforganized dynamical system and, with that, to know:

- ➔ The emergent spatio-temporal behavior of the collective of dancers;
- ➔ The attractors and transients of the system of dancers;
- ➔ The spatio-temporal variations for random initial conditions;
- ➔ And its resilience to error.

Tracing the emergent collective behaviors, we could extrapolate the possible emergent choreographies. Moreover, we experienced these choreographies in bodies that are sensitive to other bodies around them in the three-dimensional space, creating non-high-tech generative art collective emergent choreographies. In the dance workshop context, our experience revealed that the participants recognize the global emergent effect using these relational rules. Although we are still beginning to investigate possible links between generative dance and cellular automaton, we think that this can be the starting point to build a digital choreographic research instrument, like some of those introduced in the past:

- ➔ LifeForms(1986) by Merce Cunningham and Dr. Thomas W. Calvert [10];
- ➔ William Forsythe's Improvisation Technologies (1994) by William Forsythe [11];
- ➔ Choreographic Language Agent (2004) by McGregor and Scott deLahunta, [12];
- ➔ Pathfinder (2014) by Onformative Studio [13].

The major differentiating factor of the choreographic object described by this paper focuses on the research, adjustment, and play with collective behaviors. Nevertheless, for the generative dance choreographic object to have greater applicability, it will be necessary to work on visual plotting and interfacing to facilitate choreographers to play, observe and extrapolate collective emergent behaviors. Finally, we would like to say that this paper is part of a more extensive study in the area of experimental mathematics and phenomenological analysis of performance, which includes: the definition of Generative Dance as a kind of Generative Art and the ethnographic concept of togetherness (feeling of the others) in cooperative choreographies.

6. References

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