WALKING,
OR
THE MORPHOLOGICAL COMPUTATION OF SONOLOGICALLY AUGMENTED AMBULATION

Angelo Bello
abello110@gmail.com

ABSTRACT

We describe walking in New York City – a regimen consisting of pre-planned courses – and then attempt to describe a model of this walking routine whereby pedestrians are considered particles upon which primitive logic can be built and that interact with each other and the environment. The analysis begins with a description of a "sound augmented walk", and the experience of the author under various scenarios and circumstances. We then model the entire experience – walkers, vehicles, streets, traffic signals, etc – as a complex interaction that obey underlying forces and processes. We attempt to show that such an abstract model could represent a form of computation where the morphology of the pedestrians and the interacting particles could correspond to primitive logic gates and states providing a means for calculation if the appropriate preconditions are identified and defined. Ultimately we suggest that such an abstract model could be applied towards defining a sonic composition.

1. INTRODUCTION

The motivation for the effort described in this paper is based on a desire to understand the underlying processes and mechanisms that may be at the foundation of aggregate sound mass synthesis. The origins of the effort are in the author's work and experiments with the New GENDYN Program (Hoffmann 2001), with which granular synthesis techniques were implemented and investigated (Bello 2012). It was learned that the GENDYN algorithm can lend itself to extensive granular sound synthesis applications. Within the framework of the theme of this symposium – Music and Ecologies of Sound – an opportunity presented itself to explore the notion of sound mass or sound aggregation from the perspective of everyday experiences that involves the interaction of large numbers of agents in and around their environment and with each other. Models of physical experiences, interactions and phenomena has provided fertile ground for application in the generation of sound – there are many examples – and the readily available computation power provided in today's average microprocessors has brought such techniques out of the lab and onto our laps with notebook computers. However what is also desired, and perhaps required, is an understanding of the underlying processes that define the interactions within and among the parameters of the model itself. One may certainly generate interesting timbres of large-scale sound masses based on mathematical equations that describe aggregate processes, for example, but one can also wonder what lies beneath or below the level of the equation itself, and what *those* mechanisms mean for the construction and definition of a framed sonic work. The work described here attempts to investigate some of those underlying mechanisms within the framework of a model of interacting agents involved in routine activity en masse, with an attempt to reduce the model of the process to the elementary building blocks of computation itself, the primitive logic gate.

Ecology is the branch of biology that deals with the relations of organisms to one another and to their physical surroundings[1]. In this paper, we will present a discussion on walking – a “sound augmented” walking regime – and an attempt at a model of such an experience with logic gates. Our ecological system will be the streets of New York City and associated environs, as experienced while walking. I walk three miles, or five kilometres, a day. I divide this exercise into two parts: the first is a 30 minute walk in the morning, and the second is a 30 minute walk in the late afternoon/early evening. I do this routine five days a week. This whole regimen initially started as a 40 minute walk during my lunch break. I decided to adjust the regimen when I realized I didn’t have the time during my lunch break to leave the office for 40 minutes – work became too busy. Instead, I split the routine as just described, replacing the subway ride to and from my office and Penn Station in New York City, and saving the $105 monthly fare for the metro card. I feel a lot better and see more of the city and its people.

At the time when my walks were at lunchtime, I would obsessively listen, using an iPod Touch device, to the recording “Indeterminacy: New Aspects of Form and Electronic Music” by John Cage and David Tudor[2]. This is the recording of John Cage reading various stories and observations, with David Tudor performing miscellaneous selections from Cage’s Concert for Piano and Orchestra and pre-recorded tapes of Fontana Mix. For me, this presented a very interesting juxtaposition while walking through mid-town Manhattan: a set of earbuds in your ears, watching all sorts of people walking past, in front, across from either side, and behind. I adjusted the volume so that the sounds of the recording weren’t masking the sounds of the environment “outside” me, or that the outside environment wasn’t masking the stories and sounds in the earbuds.

As a result of these walks, I realized there were other obsessive habits I tended to have. I would note the remaining time left on the recording on my iPod when I finished my walks. I would write down these times to determine if I was a consistent walker, and if I improved my performance (was I finishing the path

---

[1] Oxford and US English Dictionary definition.

[2] Indeterminacy: New Aspects of Form and Electronic Music, John Cage and David Tudor, Smithsonian Folkways, 1959.

more quickly as days went by?). Also, I found that it was difficult to deviate from an established path, even if I grew bored with it. I noticed that as I listened to John Cage and David Tudor, at certain points along the path I would expect to hear a specific story, or sentence from one of the stories, or a particular group of sounds that David Tudor was performing. For example, as I passed St. Patrick's Cathedral on Madison Avenue between 49 and 50 Streets, I realized that John Cage would say "[…] music is a means of rapid transportation to life everlasting […]". Then, once I crossed the street and walked past the same cathedral in the opposite direction, I would hear, "[…] remember the early Christian Gnostic statement, 'Split the stick, and there is Jesus'." Or, as I returned to the office along 42nd Street passing 2nd Avenue, I would expect to hear John Cage speak about how, when he was young, he almost joined a liberal Catholic Church in California, but was dissuaded by the priest of the congregation once the priest found out that Cage's parents were against the idea. There are many more of these sono-geographic associations.

One story, in particular and coincidentally, addressed how Christian Wolf once observed that "[…] no matter what we do it ends by being melodic". The anticipation of particular stories at geographical points along the walk path evolved into an experience that too became "melodic" in their totality over time. Anticipation grew to be a distinguishing quality of the walk. As a result, I then became curious about how long it would take before a new walking path would "become melodic". For me, that time was two weeks, maybe a little longer.

I would also change the recording that I would listen to during the walks, as an experiment. When the lunchtime walks stopped, and I started the two 30-minutes walks to and from Penn Station, I would listen to the recording of the Tudor and Cage collaboration called Rainforest II/Mureau[3]. Unlike the Indeterminacy recording, this work consisted of a long extended uninterrupted stream of sounds: David Tudor performing his Rainforest II piece with live electronics, and John Cage chanting syllables and phrases selected from texts by Henry David Thoreau that specifically related to aspects of sound and/or music. The combination of these two simultaneous performances, accompanying my walk through the city in the morning hours, resulted, for me at least, in something I very much looked forward to. After several months of this habit, I began to notice that at specific geographical landmarks along the path, certain audio cues from the recording would present themselves. Or, I should probably say that certain sounds eventually became audio cues at specific locations along the walk. One in particular was the ascension out from the bowels of Penn Station to the surface of the street. Tudor's chirping, warbling and whizzing electronics became imagined creatures waking up from their sleep while Cage's incantations and chants began, and became a meditative experience that juxtaposed with the concrete of the city that presented itself at the top of the exit stairs. At one particularly interesting point along the path on 32nd Street between

---

[3] Rainforest II/Mureau, David Tudor and John Cage, New World Records, catalog no. 80540, A live recording by Radio Bremen of a simultaneous performance of these two respective works, 1972.

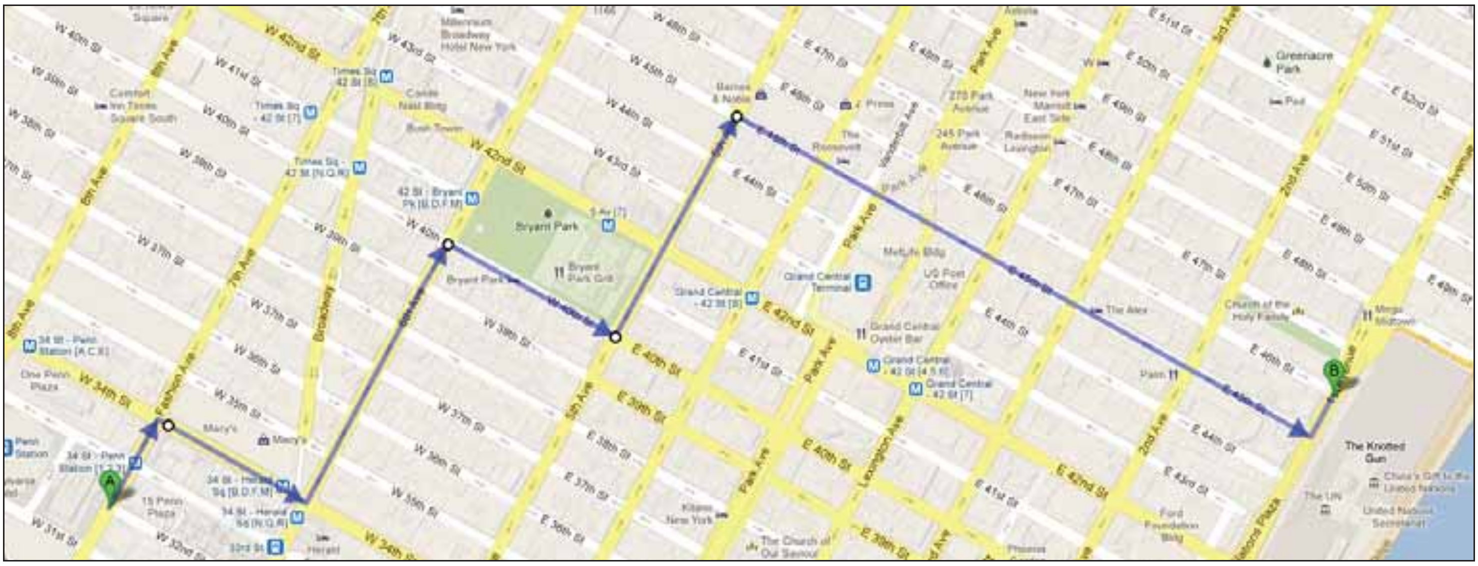
Broadway and 6th Avenue, a digital video billboard attached to one of the walls of a building, approximately 3 stories above the street, was malfunctioning for several weeks. Its purpose was to promote vacation travel to South Korea. The digital video was stalled, and fixed on a frozen image of a Korean woman and a Western woman, the Western woman staring at the Korean woman, and the Korean woman gazing out over 32nd Street. Not only was the image frozen at this particular frame, the billboard itself was defective, with randomly distributed light elements blacked out. The whole assemblage became a framed work in an of itself: the simultaneous sound streams of Tudor and Cage directly feeding my ears, the early morning light of the city, and the defective billboard, its frozen image, and the city folks rushing to their offices beneath it. The quote from Thoreau that Cage would be chanting at the moment I would pass the frozen billboard was:

> "His earthy contentment GETS EXPRESSIONWhen two or more bullfrogs trump together, it isit is a ten-pound-tenthe together, IT Is a ten-pound-
> ten noteTheir hand-*organs remind y*ou of the wild beasts those wh*ich reach h*
> *im the*re stir much more"

After approximately a year and a half of this walking regimen I somehow began considering how the interrelationships of the various aspects of the walking might be modelled as a logic circuit. And of course, if a logic circuit could be constructed, then that logic circuit could be applied to the generation of sound. The problem was eventually reduced to representing the act of walking using primitive logic gates, and then considering the large-scale en-masse aggregate whole of all the walkers in a typical scenario – e.g., during rush-hour when the aggregation of walkers on the streets of New York City are most complex. Would it be possible to represent human walking in logic in such a way that would then permit a further sonological representation? While researching recent experiments and the state of the art of artificial intelligence/robotics, I learned of the work of Chandana Paul, et al, in morphological computation. There, it is suggested that within the physical construction of a robot, logic is implied by the existence, and the specific construction of, the constituent parts of the robot themselves (a pair of legs, rollers, wheels, movement, etc). If such implied logic could be imposed on a robot in order to represent the movements of that robot, why not impose the same, or similar, logic on humans to represent aspects of human biped ambulation as well. As is described later, I decided to implement the XOR gate to represent human walking movement, as an initial step. Later it was decided that an additional representation could be imposed where human walking was not necessarily represented by a logic gate itself, but by a sequence of on and off states – or a clock signal – as an input to the logic gate. Multiple walkers in a scenario would be represented by multiple clock/data input streams, where these on-and-off streams then encounter various logic gates, where those logic gates now represent not walkers, but the *interactions* of those walkers with other walkers and/or traffic signals, or vehicles, etc.

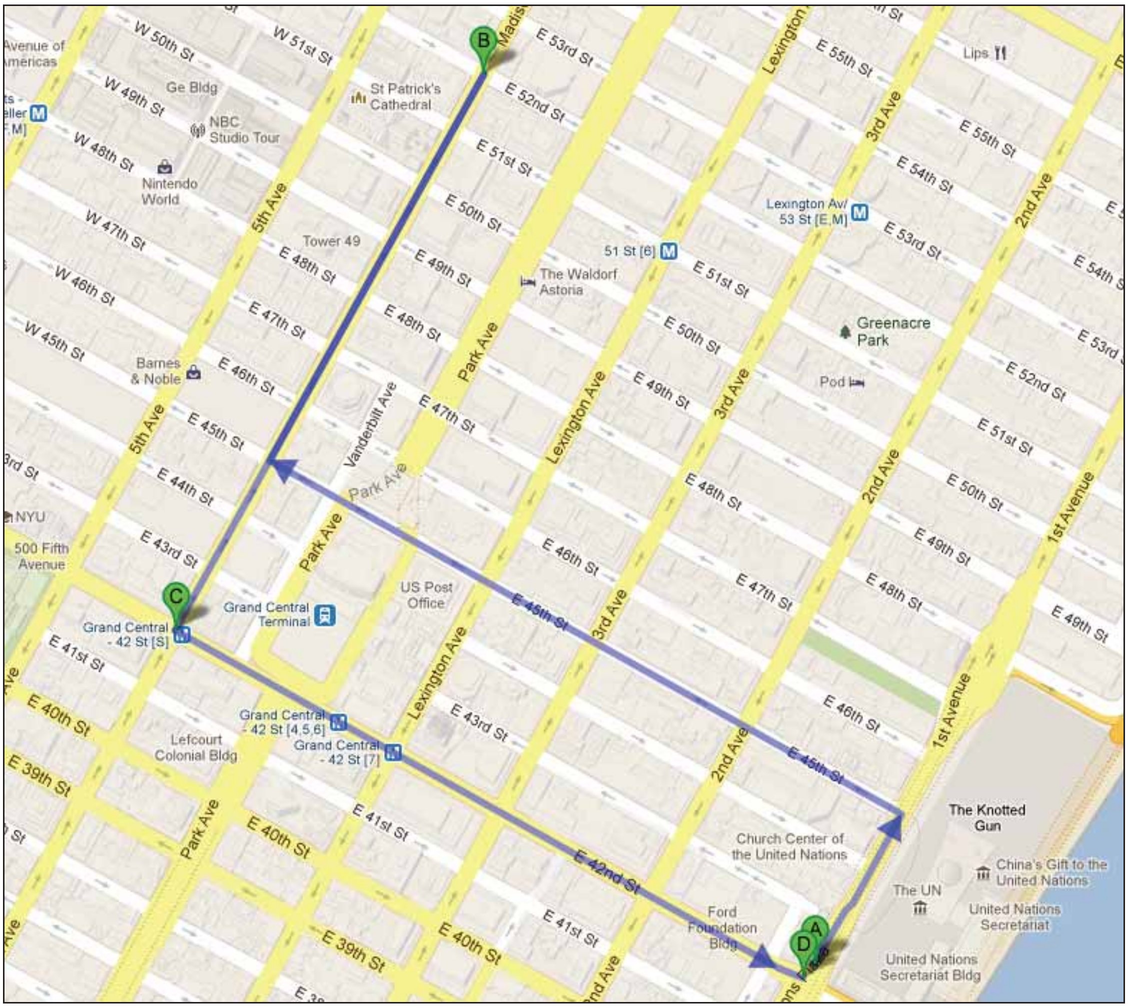
Bryant Park
Robert Moses Playground
The Knotted Gun

(a.)



Bryant Park
The Knotted Gun

(b.)



(c.)

Figure 1. Maps of the walking regimens described in the text.

2. REPRESENTING PEDESTRIANS

Let's imagine that as I walk through the city, I am a particle that interacts with forces as I travel along my path. The interactive forces that I may encounter could include the following:

(1.) Intersections of streets, where I may have to stop walking due to a traffic signal being red (as a walker in New York City, probably more so than in other large cities, it is most prudent to obey the traffic signals, as vehicular traffic has the potential to be lethal). There is a traffic signal at every intersection.

(2.) Avenue blocks and street blocks on the New York City grid have different lengths: an avenue block consists of four street block lengths. Therefore, our particle could be mobile for longer stretches at a time if it is travelling on an avenue as opposed to a street. Conversely, when travelling on a street, the particle would encounter three more traffic signals than it would if it were travelling on an avenue.

(3.) Other pedestrians, or other “particles” are omnipresent: As is expected, one encounters a host of other walkers that range from other New York City workers (moderate walking speeds), couriers and delivery service workers (relatively quick walking speeds), tourists (the slowest walkers, and often stationary and directly in the middle of a path), construction workers (random walking speeds that range from completely stationary to ambling this way and that following random patterns and speeds).

(4.) Vehicles: it is often the case that a vehicle wants to make a turn at an intersection at which a pedestrian has the “right of way”. The pedestrian needs to be very cognizant of these vehicle types, and constantly be vigilant and “look both ways” before or as one walks across a street where one has a green signal. In some of these cases, the particle must stop although there is a green signal. These are random events.

(5.) Commingling with other pedestrians: it is possible that the particle may find itself commingling and become part of another group of pedestrians – one has entered a “group space” that itself is moving at its own pace. We can consider this scenario to be a type of constellation of particles, moving at constant velocity, with a constant relative separation distance between the particles in the constellation. One can break free of such a configuration, but it takes added kinetic energy to separate from the pack, breaking the covalent bonds that are an attractive force between the particles.

(6.) Binary walker systems: This is the case when you find yourself walking along side someone who happens to be at the exact same pace as you are. You are practically in lock-step with each other. How could one find oneself in this situation? In one moment, you are walking “alone”, within your bubble, “minding your own business”. Then suddenly, you find yourself in a binary walking system. Typically, this happens when you approach a corner, and someone comes round the corner and is suddenly along side you, at the same pace, in the same direction. Until one of you splits off at another corner in another direction, you are a binary coupled system. Perhaps one way to describe this scenario would be to use the “wormhole” metaphor. One suddenly breaks through a dimensional boundary, and appears on the other side, being pulled together via attractive gravitational forces (however not rotating around each other, as this would cause unwanted collisions with other particles).

(7.) Runners: These are pedestrian particles that actually run on the city streets as opposed to Central Park. They may be travelling at 2, 3 or 4 times the rate of the clock reference (see further below).

(8.) Bicycle riders: Bike riders glide through pedestrian particles in a smooth uninterrupted fashion, weaving in and out of traffic, flowing between cars, buses and trucks. There are dedicated bike lanes on the street, where you will find them most of the time however they can choose to take any path they wish, and often do, including pedestrian paths.

(9.) Disappearing pedestrians: These are pedestrians who enter a building, subway station, or vehicle (taxi or bus, e.g.), and leave the sidewalk environment, sometimes suddenly. We can consider this scenario as a random process, where the cumulative whole is reduced by an amount equal to the number that “disappears” into their respective buildings.

(10.) Appearing pedestrians: This is the converse of (9.) above, whereby a pedestrian enters the sidewalk environment and becomes part of the walking group. Pedestrians may enter the sidewalk from buildings, subway stations, vehicles, etc, again sometimes suddenly. This is also a random process, and is comparable to the addition of a random number to the collective whole. We shall model this scenario as follows: If we consider, as an example, that there are 16 portals along the walking path through which an agent may pass (see Figure ___ further below), for a given interval of time (e.g. the sample period), that appearance of an agent from any one of the portals, and that then enters the collective, could be the combination "0010111100001011". This then is modelled as the addition of a random number into the collective at that precise time interval.

Let's assume that our reference pedestrian particle is travelling at constant velocity whereby every two steps – i.e. a right step followed by a left step – takes one second to complete. For a 30 minute walk, this would entail (30 minutes) x (60 seconds/min) x (2 steps/second) = 3600 steps. This will be our reference "clock". All other events that could possibly interact with our pedestrian particle will be relative to this reference rate of motion. It takes 240 steps to traverse an avenue block, and 64 steps to traverse a street block. It takes 10 steps to traverse an actual street, and 20 steps to traverse an avenue.

Pedestrian Particle Type	Rate ("sps" = strides per second)
Reference	2 sps
Bikers	10 sps
Runners	6 sps
Tourists	< 1 sps
Workers	Stationary
Binary Systems	1 < x < 2 sps
Constellations	1 < x < 2 sps

3. MORPHOLOGICAL COMPUTATION AND REPRESENTATION

Morphological computation is "computation obtained through interaction of physical forms"[4,5]. This branch robotics focuses on the capabilities of an agent, a robotic autonomous biped for example, to perform computation as a by-product of its own organization of parts, through natural and inherent movement. Morphological computation also describes the ability of a mechanical system to perform control functions. Through such techniques we shall represent the human body and its movements as logic primitives that interact with each other. We suggest that a human biped can be viewed as a primitive logic gate, and its interaction with other humans or objects will result in combinational or sequential logic circuit

[4] Chandana Paul, « Morphological Computation: A basis for the analysis of morphology and control requirements », Robotics and Autonomous Systems 54 (2006), p. 619-630.

[5] Chandana Paul, « Morphology and Computation », Proceedings of the International Conference on the Simulation of Adaptive Behaviour (2004), p. 33-38.

configurations that provide the equivalent of different types of calculations. "Morphological computations constitute a case of embodiment"[6], and for our discussion, the environment becomes part of the "computational experience" within which we are embodied. Or, computation itself is experienced through our interactions, or as a by-product of our interactions, with the world: interactive computation. The "world" – or, the "background" – becomes interconnected with the individual in our model. An interaction with an external force, whether that force is another pedestrian, a machine in the form of a vehicle, or a "Walk/Don't Walk" sign for example (within our world of the walking scenario), contributes to the global computation that is established and results, in our discussion here, in an emergent sonic work (we aim to apply the model to the synthesis of a sonic work). Our task is to describe the human body motions and its interactions with sufficient detail in order that a robust network is defined that permits computation to be realized. Ultimately, our computation is that of computable sound.

It is possible to consider humans as mechanical systems if one makes the appropriate preconditions on observations. For example, if we decide that we would like to consider for purposes of discussion those aspects of human walking that specifically relate to the motion of feet and legs only, and if we further stipulate that the motion of the feet and legs are restricted to specific capable movements, we can model the movement of feet and legs as the inputs to a logic primitive, such as an XOR gate. In the end, it's possible we can represent or model the totality of such physical movement with primitive logic gates. For example: forward movement is defined as the situation when one foot is placed in front of the other foot, and then the other foot is advanced in front of the first; neither foot is on the ground simultaneously as this would indicate a stationary situation, where no feet are advanced. Our truth table for this particular example could be as follows:

Foot 1 on ground	**Foot 2 on ground**	**Resultant Behaviour**
F	F	Stationary – 0
F	T	Forward Movement – 1
T	F	Forward Movement – 1
T	T	Stationary – 0

We are ascribing abstract logic representations to physical entities or agents, and to the actions performed by such agents. We can further represent other physical interactions with abstract logic, such as the following scenarios:

(1.) Let's assume we walk forward in a straight line between two streets on a sidewalk. Along this path, there is opposing traffic in the form of other pedestrians, whose movement is dictated by a given velocity

[6] Paco Calvo and John Symons, « Radical embodiment and morphological computation: Against the autonomy of (some) special sciences », in: Reduction and the Special Sciences (Tilburg, April 10-12, 2008).

which may or may not be the same as our own velocity. The point at which we pass the opposing pedestrian could be interpreted as an interaction. The point at which the opposing pedestrian's foot is on the ground may coincide with the moment our reference pedestrian's foot is on the ground, although they are travelling at different velocities.

(2.) Again, we assume we walk forward in a straight line between two streets. We encounter the intersection of two streets and must stop due to a "don't walk" sign. This could also be interpreted as an interaction with an appropriate logic primitive representation. When the pedestrian signal gives the command to "walk", we would represent this appropriately.

(3.) A third example scenario could be the following: We are engaged in the binary system described previously where two pedestrian particles are walking at the same velocity in the same direction. It's possible, however, that the two particles are placing their respective feet on the ground at precisely the same instant. It's also possible that they may be 180 degrees out of phase, yet at the same velocity: particle one's left foot is on the ground while particle two's right foot is on the ground. Thirdly, it could be that both particles are out of phase by a random angle yet at the exact same velocity.

What could a truth table for one of the above scenarios look like? Below is a truth table for example 1. We are interested in establishing success as defined by having one foot on the ground by each of the two pedestrians at the same time.

Pedestrian 1 (reference)		**Pedestrian 2**		**Result**
Foot 1 on ground	**Foot 2 on ground**	**Foot 1 on ground**	**Foot 2 on ground**	
F	F	F	F	0*
F	T	F	T	1
T	F	T	F	1
T	T	T	T	0*

*Note: We will impose that there will never be the situations where, for a given individual pedestrian, that both feet are off the ground at the same time (i.e., as if he/she were jumping up in the air). For the sake of our discussion and this specific example, we will assume that each foot is on the ground exclusive of the other foot in order to establish forward movement. So, this truth table, of this particular scenario, provides a representation of a four-input XOR gate. This is not the case in reality, as when one walks, both feet are on the ground simultaneously for a very short period of time while one is in forward movement (the heel of one foot and the toes of the other foot are on the ground simultaneously).

If we consider the scenario when our reference pedestrian encounters a worker who is stationary, our truth table could look like that given below. There is no forward movement by the reference pedestrian as a result of having encountered a stationary entity (the reference pedestrian becomes momentarily stalled.) This could be interpreted as a negation of the reference pedestrian's normal state. All feet are firmly on the ground and there is no movement by either entity until the reference pedestrian applies a correction and continues on. This scenario presents itself in another form when the pedestrian encounters a "Don't Walk" signal at an intersection. He/she must stop walking and in effect encounters a negation of the normal state forward motion. Therefore, both feet are on the ground simultaneously and there is no movement.

Pedestrian 1 (reference)		**Pedestrian 2 (Worker: Stationary)**		**Result**
Foot 1 on ground	**Foot 2 on ground**	**Foot 1 on ground**	**Foot 2 on ground**	
F	F	F	F	n/a
F	T	F	F	**1** (forward movement)
T	F	F	F	**1** (forward movement)
T	T	F	F	**0** (no forward movement)
F	F	T	F	n/a
F	T	T	F	**1** (forward movement)
T	F	T	F	**1** (forward movement)
T	T	T	F	**0** (no forward movement)
F	F	F	T	n/a
F	T	F	T	**1** (forward movement)
T	F	F	T	**1** (forward movement)
T	T	F	T	**0** (no forward movement)
F	F	T	T	n/a
F	T	T	T	**0** (no forward movement)
T	F	T	T	**0** (no forward movement)
T	T	T	T	**0** (no forward movement)

Pedestrian 1 (reference)		**Walk/Don't Walk Signal: F = "Walk" T = "Don't Walk"**	**Result**
Foot 1 on ground	**Foot 2 on ground**		
F	F	F	**0**
F	T	F	**1** (forward movement)
T	F	F	**1** (forward movement)
T	T	F	**0** (no forward movement)
F	F	T	**0**
F	T	T	**0** (no forward movement)
T	F	T	**0** (no forward movement)
T	T	T	**0** (no forward movement)

The next scenario we consider is that of the runner, who occasionally will "run in place" when he/she is at an intersection and a "Don't Walk" sign is present. The runner will stand and hop from one foot to the other, anxious to move on. This is another instance of the XOR primitive.

Pedestrian Scenario Runner: running in place		
Foot 1 on ground	**Foot 2 on ground**	**Result**
F	F	0
F	T	1
T	F	1
T	T	0

4. DISCUSSION

4.1 Aggregation and Representation of Movement En Masse

The circuit in the diagram represents the macroscopic view of the aggregate interaction among the pedestrians in our model. There are elements of the macro circuit that are implied such as the flip-flops and counter for example, however that resulting output recorded as a sequence of numbers is characteristic of the specific conglomeration of agents as they move about and interact with each other.

A critical component that contributes to the uniqueness of each "simulation" is the rate at which each of the agents moves about in our scenario. We have defined a reference agent, the individual indicated as walking at two strides per second. Other agents in the scenario are either slower or faster than this reference. In addition, agents' speeds can vary.

Aggregate sound mass can be characterized such that subtlety and nuance can be composed and determined. Aggregation of many individualized agents, each following an indeterminate path, can be modeled.

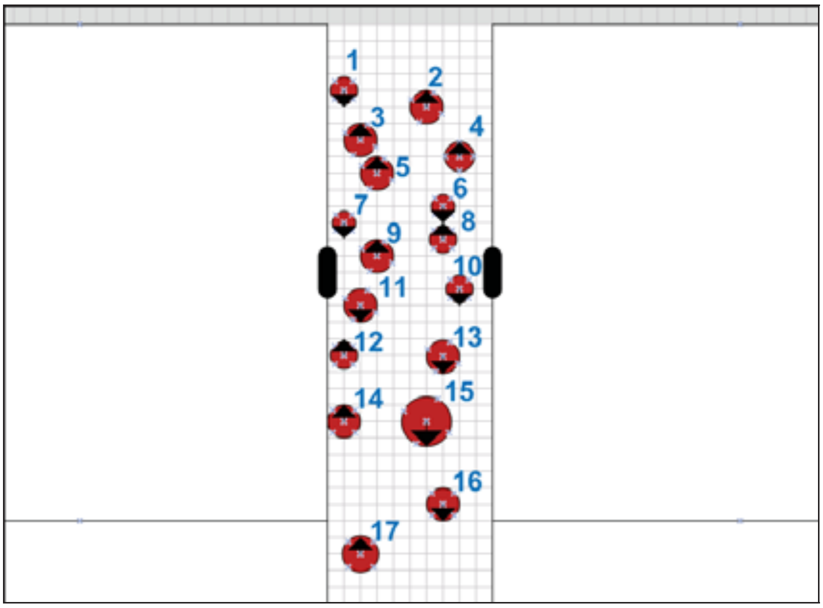


Figure 2. A conglomeration of agents in the walking path, showing a pair of portals through which agents may appear or disappear from the collective.

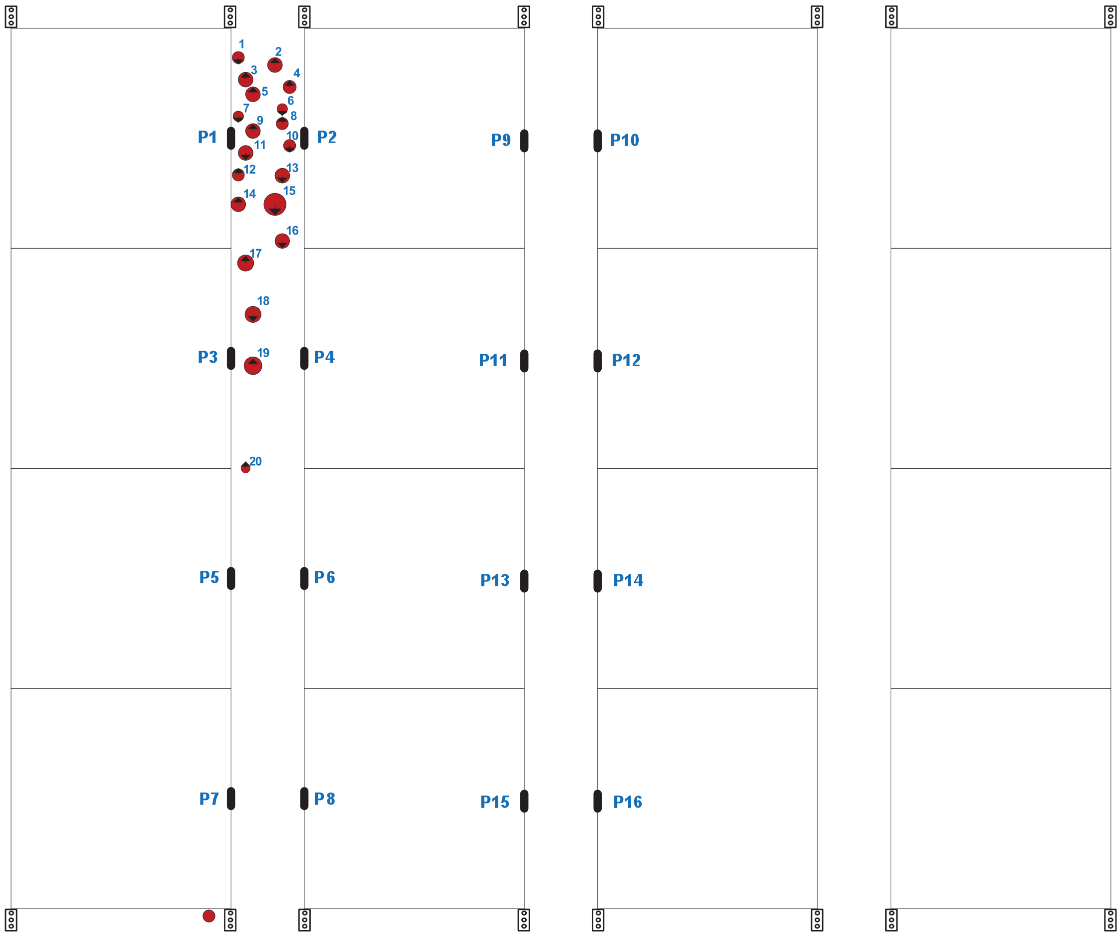
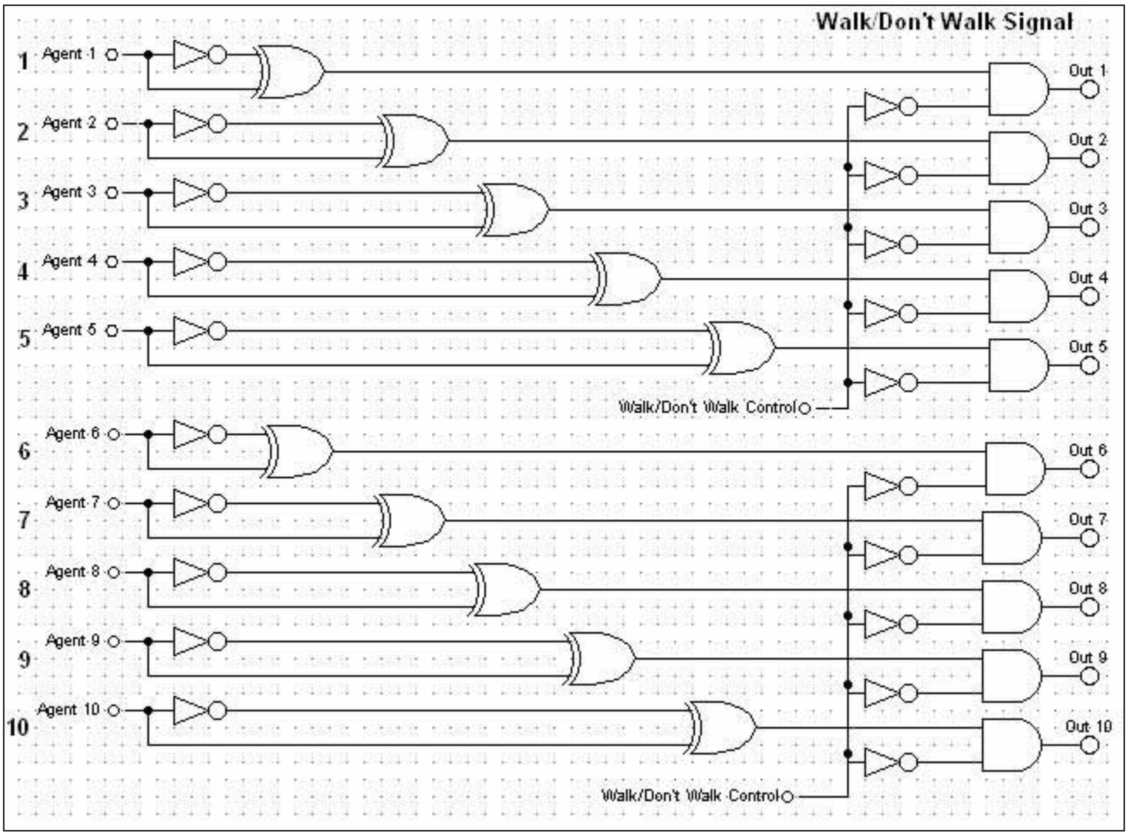
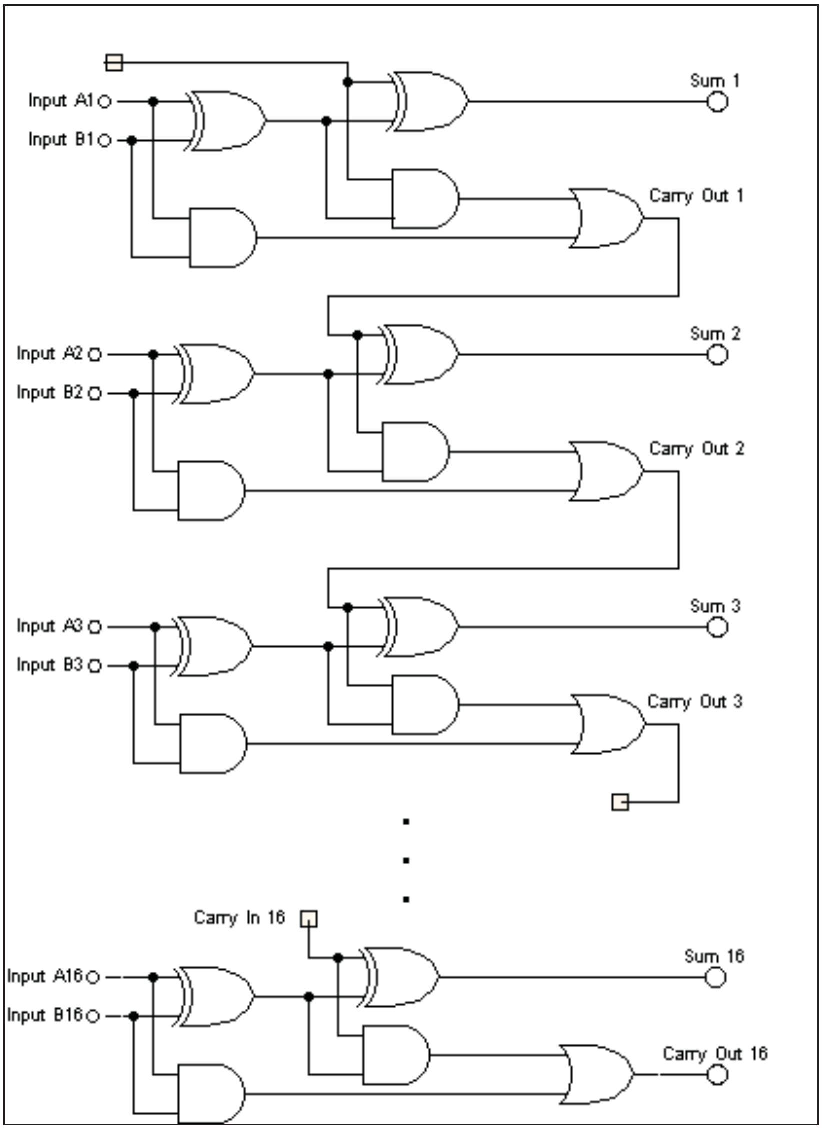


Figure 3. The pedestrian agent model showing the streets of the walking paths, the traffic signals, and 16 portals.


Walk/Don't Walk Signal
1
Agent 1
2
Agent 2
3
Agent 3
4
Agent 4
5
Agent 5
Walk/Don't Walk Control
6
Agent 6
7
Agent 7
8
Agent 8
9
Agent 9
10
Agent 10
Walk/Don't Walk Control
Out 1
Out 2
Out 3
Out 4
Out 5
Out 6
Out 7
Out 8
Out 9
Out 10

(a.)



(b.)

Figure 4. (a.) and (b.) A logic circuit representation of 10 pedestrian agents and a "Walk/Don't Walk" signal. These agents are the 10 from figures 2, 3, and 4 above. 5(b) shows the logic circuit for a 16-bit full adder. The adder is used to introduce the random agents into our model (random agents are introduced into the model through the portals). The 16-bit adder accommodates the 16-bit word – 2 bytes – that is the default bit depth of our model.

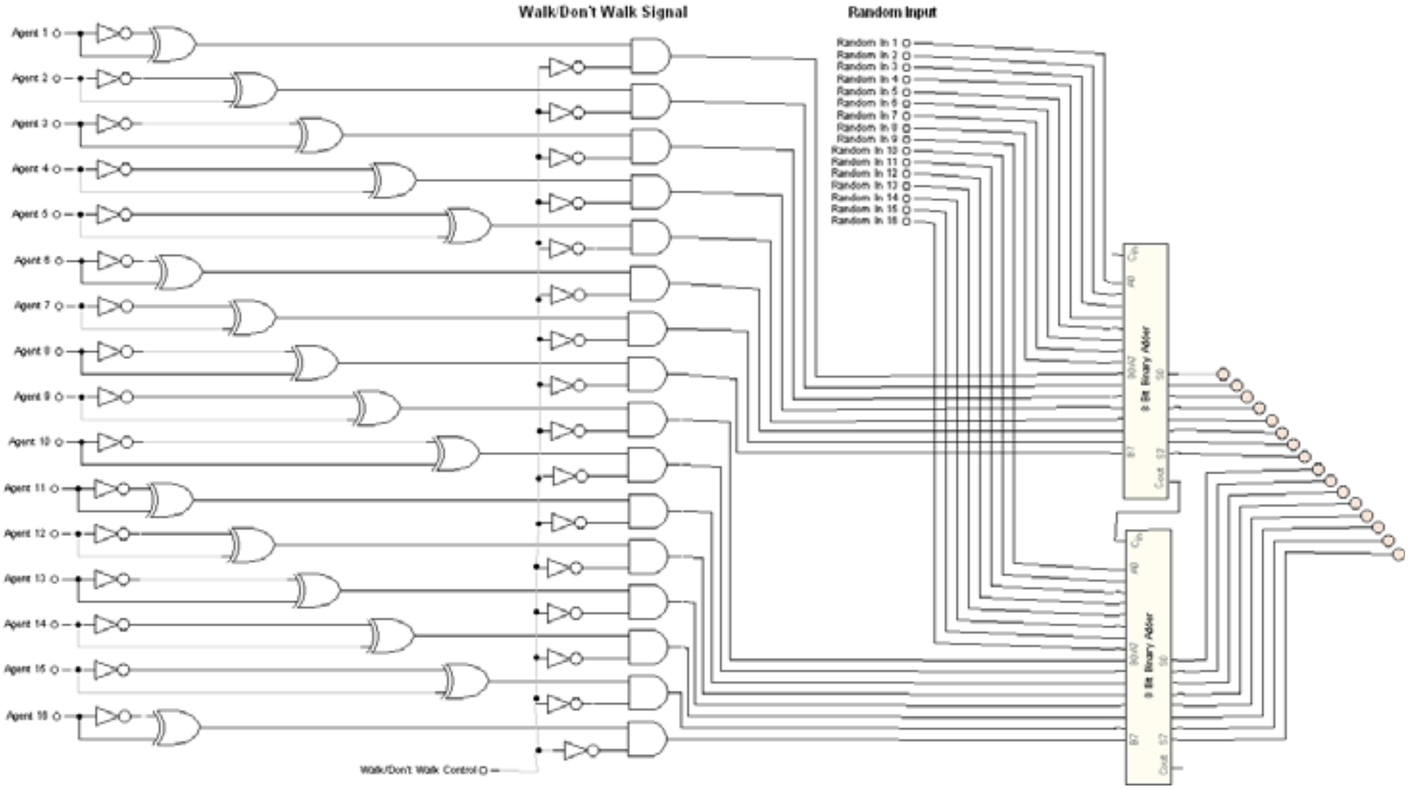


Figure 5. A representation in logic gates of a subset of the pedestrian agents, a Walk/Don’t Walk signal, and the full adders used to introduce a random number of additional agents into the collective.

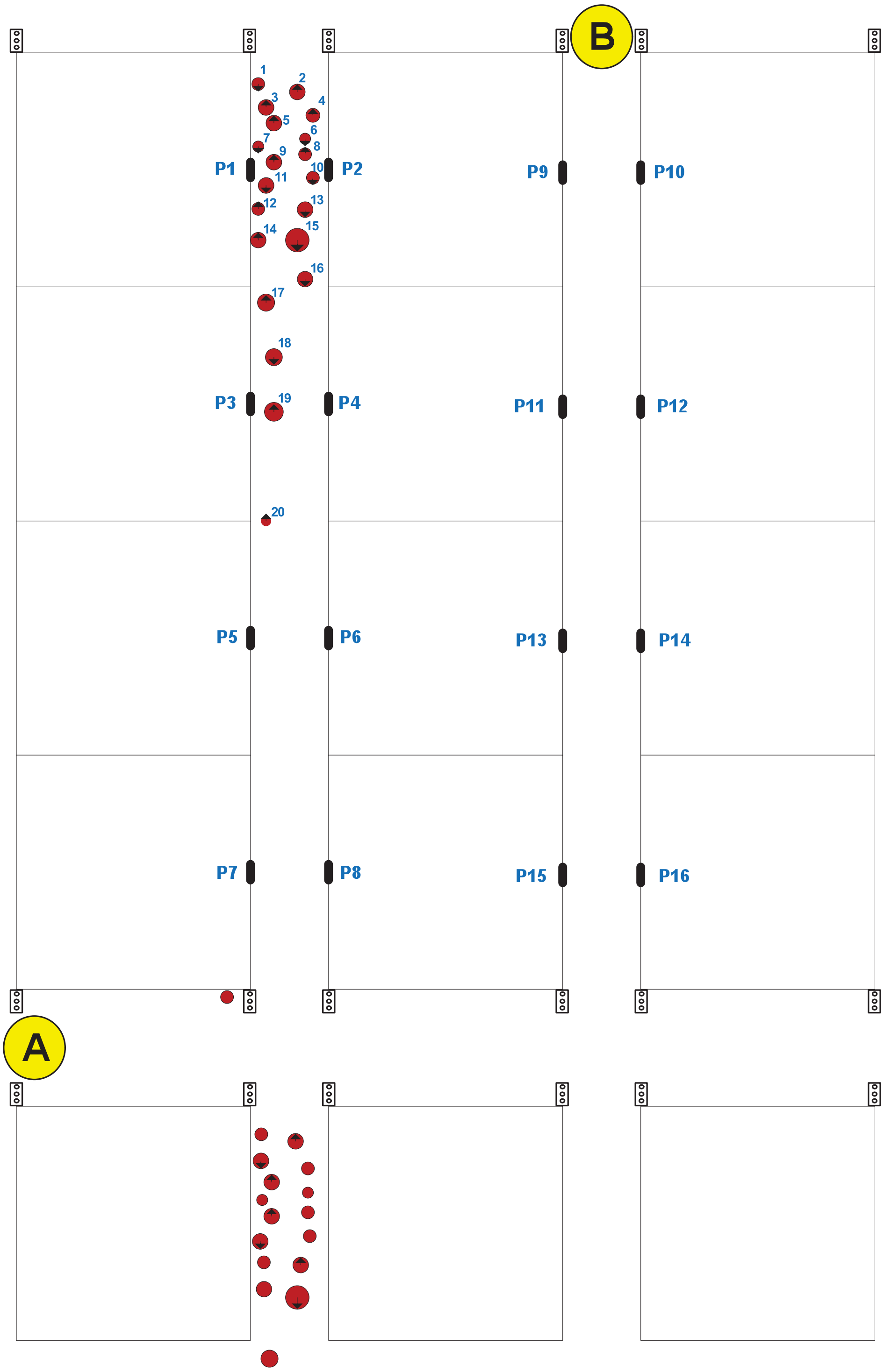


Figure 6. The framed subsection of the entirety of the pedestrian environment under consideration in the text for the logic circuit model. Points "A" and "B" indicate the start and end locations of the model.

We define the limits within which the model will operate. Location A is the starting point, and location B is the end point. The intervening streets, avenues, portals and associated interactions therein will define the various aspects of the model. Pedestrian agents can flow in either direction within the framed paths. Agents will enter and exit through the portals; in this case, there are 16 portals. The Walk/Don't Walk signals (indicated as traffic signals), will dictate movement and pauses across the streets and avenues. We will begin with a predefined number of pedestrian agents that exist within the framed subdivision. Each agent will travel at their own rate, and there will be one agent who shall travel at the reference rate of two strides per second.

5. CONCLUSION

In this exercise, we have attempted to demonstrate a way to represent a process of large-scale multi-agent behaviour with discrete logic gates. The process in this case was the mass movement of pedestrians among city streets and the environment in which the agents migrate. The motivation for this analysis is based on an earlier project that addressed large-scale granular sound synthesis through an implementation of the New GENDYN Program. An underlying goal of this exercise was the attempt to represent in an agnostic way the mechanisms of computation within multi-agent processes, if any, such that they are platform independent. It is hoped that this article presented a framework within which an implementation of the model described therein could be implemented. We suggest that a platform independent description of processes such as those described here could provide a launching point from which a generalized description of computable sound might find a place, providing a means to identify, record, and publish those computational primitives that make up computable sound itself.

6. REFERENCES

Bello, Angelo (2012), « Extending GENDYN », Proceedings of the international Symposium *Xenakis. La musique électroacoustique / Xenakis. The electroacoustic music*, Makis Solomos, (ed.), université Paris 8, May 2012.

Calvo, Paco and Symons, John, « Radical embodiment and morphological computation: Against the autonomy of (some) special sciences », in: Reduction and the Special Sciences (Tilburg, April 10-12, 2008).

Chandana Paul (2004). « Morphology and Computation ». Proceedings of the International Conference on the Simulation of Adaptive Behaviour: pp. 33-38.