



## Of particles and bikers: Junior triathletes invent drafting tactics with agent-based models

**Sharona T. Levy**, [stlevy@edu.haifa.ac.il](mailto:stlevy@edu.haifa.ac.il)  
Faculty of Education, University of Haifa

**Alon Hirsh**, [hirsha65@gmail.com](mailto:hirsha65@gmail.com)  
Faculty of Education, University of Haifa

### Abstract

*The study involves the design and research of a model-based triathlon training unit about the aerodynamics of biking in groups (drafting), using this knowledge to construct new drafting tactics and testing them out in practice. The study was conducted with two groups of 14-17 years old youth: the Israeli national team (experts; 5 male, 3 female) and a local team (hobbyists; 5 male, 3 female). The goal was to explore whether using agent based models of bikers and air particles to learn about principles regarding drafting and in order to design new tactics could be used to enhance athletes' understanding and performance, and whether this depends on expertise. The athletes' designs introduce new tactics of drafting that incorporate an idea of uneven load distribution. Results of testing out these designs show superior performance, as seen in the shorter times, lower pulses and effort. The expert team invented a greater number of improved tactics.*

### Keywords

*Agent-based models; Complex systems; Competitive sports*

### Introduction

In this proposal, we describe research into young triathletes' invention and execution of new drafting tactics, through learning with computer models based on a complex systems approach. It is based on an assumption that understanding the causal structure of action and interaction supports improved skill in action (Schmidt & Lee, 2011)

The study focuses upon the phenomenon of drafting in road bicycle triathlon competitions. Drafting is when a group of cyclists move together and can be applied when it's a legal drafting competition (Figure 1). It is used to gain energy advantages in moving through the air (Hausswirth & Brisswalter, 2008). As such, it touches on the domain of competitive sports training and physical education. The phenomenon of drafting offers unique insights into the delicate balance between competition and cooperation among collectives, where at every time step, each athlete needs to decide whether to desert the group or stay. On one hand, drafting offers up to 40% savings on energy expenditure, rising with the biker's speed (McCole et al., 1990). On the other hand, the group speed may slow a biker down too much; in which case, a smaller group may "break-away" usually around a bend in the road. Thus the persistent question is "stay or break away", where the answer can change at any moment. In the particular sport of triathlon (sequence of swimming, biking and running), biking at a less than maximal rate and minimum energy expenditure is particularly advantageous in saving energy for the last leg of the competition, the running portion. Finally, drafting is in fact a general phenomenon viewed among



racing cars, cross-country skiing, tailgating trucks, birds, fish and more.



Figure 1: Drafting cyclists (Belgian Tourniquet formation - successively each cyclist leads the group)

The phenomenon of drafting was selected because of long-standing difficulties in its understanding by athletes<sup>1</sup> and the large energy advantage it offers. The most-commonly understood concept is that cycling through air causes the dynamics of the air to change around the biker in a way that forms a low-pressure area in the back and eddy streams (vortices) in the back/diagonals. Having another cyclist move in very close (professionals approach up to a number of inches!) into this region means there is low pressure in front of him, decreasing the air's resistance to his motion. Additionally, having the second cyclist behind the first one reduces the turbulence by smoothing the eddy streams in the back-diagonals and reducing the drag on the first cyclist, though to a much lesser extent. Based on this idea, most drafting tactics involve a one-dimensional formation made up of “cyclist-behind-cyclist” repeating units. A simple tactic in drafting that is commonly used is a single line of closely packed bikers, forming a diagonal in case of wind. The most efficient tactic to date is the Belgian Tourniquet, where the cyclists form an ellipse (essentially a bent line) and rotate it, so that successively each cyclist leads the group (Hauswirth et al, 2001). In this study, we wish to expand beyond these simple tactics and incorporate additional advantages one may obtain from a deeper understanding of the aerodynamics of clustered biking. This approach would be two dimensional, incorporating reasoning not only about the pressure between a front and back biker, but also along the sides. As hinted in the “smoothing the eddy streams” idea above, where the bikers may be able to manage the air collectively, by transforming turbulent flow to laminar (smooth, less resistant) flow.

We have developed a three-day training program “of particles and bikers” in which the athletes themselves invent new drafting tactics and test them out, based on constructionist principles of learning, propelling invention and construction as a superb form of learning (Papert, 1983).

The training unit is framed within a complex systems approach to understand the aerodynamics of drafting. According to this approach, a system's behaviour arises from the local interactions

<sup>1</sup> The second author is an ITU competitive triathlon level 2 coach, with many years of experience in training, was the triathlon national team head coach and today, trainer of coaches. This claim is based on his personal experience and through his many conversations with other coaches.



between its parts (Viscek, 2002). Advantages to learning within this approach involve a greater generativity of understood phenomena from a smaller set of principles (Blikstein & Wilensky, 2007), thus supporting a deeper understanding (Levy & Wilensky, 2009). This approach is implemented in the study with computerized NetLogo (Wilensky, 1999) agent-based models: one with moveable cyclists and air particles (Bacalo, Kakoon & Levy, 2011) and one based on an existing NetLogo model of birds flocking (Wilensky, 1998) with an addition of air particles and their interactions with the birds (Hirsh, Haviv-Gal & Levy, 2011) (see Appendix). Effort is viewed as the rate at which air particles hit a cyclist: when the rate is greater, the air resistance to his motion is greater as well. In representing the aerodynamics of drafting, these models are much simpler to understand with respect to the classical approach that is based on fluid dynamics. One needs to understand only simple two-body collisions (between bikers and air particles; modelled similarly to two billiard balls in motion colliding with each other). This makes the notions of the flow, waves and pressure topographies an emergent result of these interactions, rather than principles one needs to incorporate into reasoning about the system *ab initio*. These models were used as an explorative medium to understand the phenomenon of drafting. Furthermore, they are used as a constructive medium to design new tactics in drafting, by creating a variety of spatial formations of the cyclists among the sea of particles.

We expected that learning would be deeper and the resulting tactics would be more variable also through harnessing the athletes' prior knowledge of competitive bicycle riding (Williams et al, 2010; Mann et al., 2007). To test out this idea, the study was conducted with two teams of differing levels of expertise – the Israeli youth national team (experts) and a local team (hobbyists). Whether and how prior knowledge could be activated and used becomes comparable.

While the study addresses the possible learning advantages of such training, the main goal is to obtain better results in a competition. Thus both biking performance and cognitive measures are employed to gauge learning.

## Research Questions

The research project addresses various aspects of learning and the learning process. In the current paper, we report on a subset of these, guided by the following research questions:

- How does young triathletes' drafting in biking performance change as a result of training with the “Of bikers and particles” program in terms of pulse, effort and time?
- What is the relationship between expertise and change in performance?
- What typifies new drafting tactics invented by the triathletes?

By the time of the conference, it will be possible to report on additional results that include the triathletes' changed understanding of the aerodynamics of drafting and how it relates to changes in athletic performance.

## Method

### Participants

Participants included 15 junior triathletes from two teams that trained separately. Their ages were 14-17 years old youth: the Israeli national team (experts; 5 male, 3 female) and a local team from the north of Israel (hobbyists; 4 male, 3 female). The national team triathletes have been training for over three years, 7-12 training sessions a week, 15-20 hours a week with much experience in national and international competitions. This team trains at a boarding school for gifted youth in



sports. Some of them are the national champions for their age groups. The local team triathletes have been training for at least a year in an after/before school program, 5-8 training sessions a week, 8-12 hours a week. They have participated in at least five competitions. A prior requirement was fluent use of computers and parental consent.

## Research design

The study was conducted as a comparison group pretest-intervention-posttest design. It commenced about 1.5 months into the training season. Two teams of athletes of differing initial abilities and practice participated separately in an identical sequence of training, made of up of two consecutive days, and then, a month later, one more day (Figure 2). This paper focuses on the first two days.

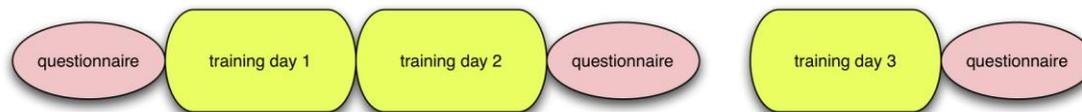


Figure 2: Research design

## Training sessions

A triathlon training program named “of particles and bikers” was created. It is made up of some short lectures (e.g. on the relationship between pulse and effort), several discussions, exploring computer models of flocking birds and bikers in various configurations and then using the models to create new efficient configurations (Appendix), testing them out on the road (five testings, four heats each) and collaborative analysis and discussion of the pulse, time and effort data. Training sessions were based on the following design principles: (1) Trusting that the athletes can invent new and better drafting tactics, based on their experience and motivation; (2) Anchoring in a physical world phenomenon, biking in formation; (3) Successive shifting between theory and practice, and relating the two explicitly – designs were tried out with the models, discussed and soon tested in practice, this process repeating five times; (4) Beginning with two distinct representations of the phenomenon (collision interactions; bird flocking) and gradually merging the two; (5) Using measurable performance goals with respect to which understanding is gauged.

## Data collection tools

Several forms of data and its collection are described (Table 1).

Research variable	Data collection tools
Performance in drafting	Time to complete a constant distance of flat road riding Pulse measurement right after cycling RPE (Rate of Perceived Exertion) effort self-report
Creative products	Athletes’ invented tactics for drafting
Conceptual understanding of drafting	Questionnaire administered three times Interviews with athletes during training
Attitudes towards drafting	Questionnaire administered three times
Qualitative process data	Videotapes of all the training sections

Table 1: Research variables and data collection tools.



In this study we focus on the triathletes' performance in drafting and their creative products. The athletes wore the pulse meters and took a reading within a minute of finishing each heat. The basic pulse at the aerobic threshold was subtracted from the reading to make the results comparable across participants. Similarly, RPE effort results had a basic effort reading (single riding heat) subtracted from them.

## Results

In this section we report on the athletes' designed tactics and their performance in drafting.

The triathletes were excited by the opportunity to participate in the design of new tactics. The training sessions generated much interest in the broader community.

Figure 3 displays the work of one athlete as he drafted a few ideas on paper before testing them with the model. Top-left configuration is the final one. However, reaching this design, one can see elements in the other drawings: bottom-right is an attempt to incorporate internal motion into the design that didn't make it to the final design; middle-right we see two staggered columns – containing one-behind-the-other units and diagonal relative positions; bottom-left is a configuration that he used in the final design. The final design elaborates on this by adding direction of motion and the names of the triathletes in each position (the strong ones are in the front; the national champion is in the middle).

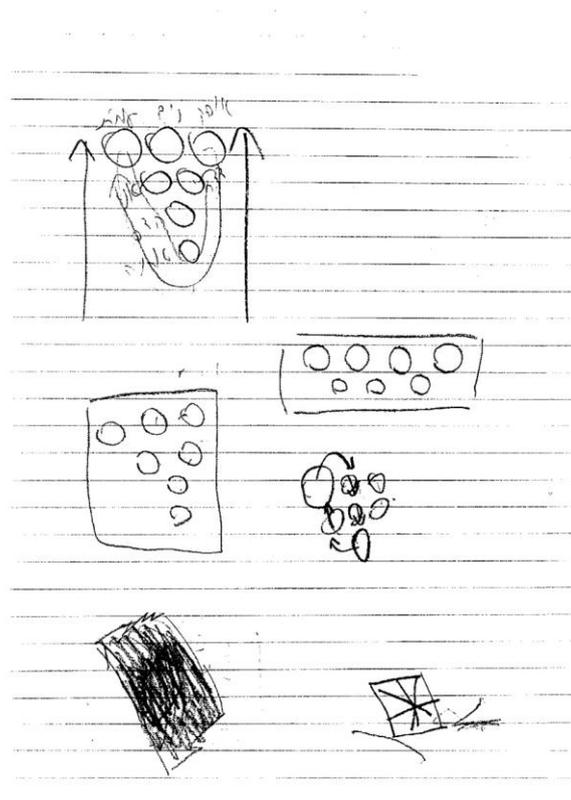
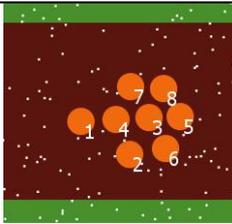
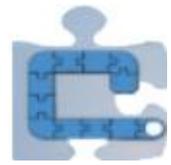
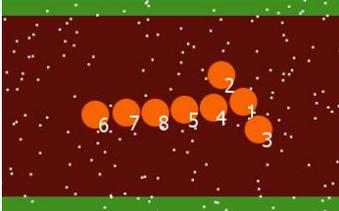


Figure 3: Working draft of a design in the making.

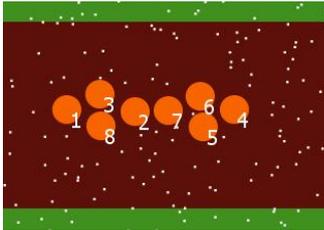
Eleven of the triathletes' initial designed tactics were analysed. All tactics are new in terms of being unfamiliar in the sport. They fall into four general forms (Figure 4):



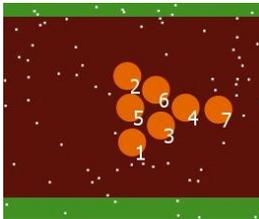
Mallet: A rounded shape with a tail (some called it the flower) has the weaker riders in the middle, wrapped from all directions (5/11 designs).



Hammer-head: A diagonal of stronger riders leads the pack; a column follows them, with the weaker riders up ahead (3/11 designs).



Two-headed: The front triangle are the strongest riders; the ones in the middle are the weakest; the triangle in the back are of medium strength (2/11 designs).



Arrow-head: One rider the front, with rest following at diagonals of the previous ones (2/11 designs).

Figure 4: Categories of invented tactics (Day 2, initial designs). The riders (orange circles) are moving from left to right. The air particles are white. Number of designs in each category are in parentheses.

Figure 5 portrays the designs by features they contain. Three features were included in all designs. One is the use of one-behind-the-other elements, a feature they had known from prior experience. Two features relate to a division of labor that is distinct from the classical Belgian Tourniquet: rather than divide the leading time equally, the weaker riders do not lead at all, as they will slow down the group. The weaker riders are “wrapped” in a variety of forms by the rest, so they need to expend very little energy in the process. This idea is novel in the domain. While most designs tried to benefit the individual riders, only half considered the global shape of the group by making it aerodynamic.

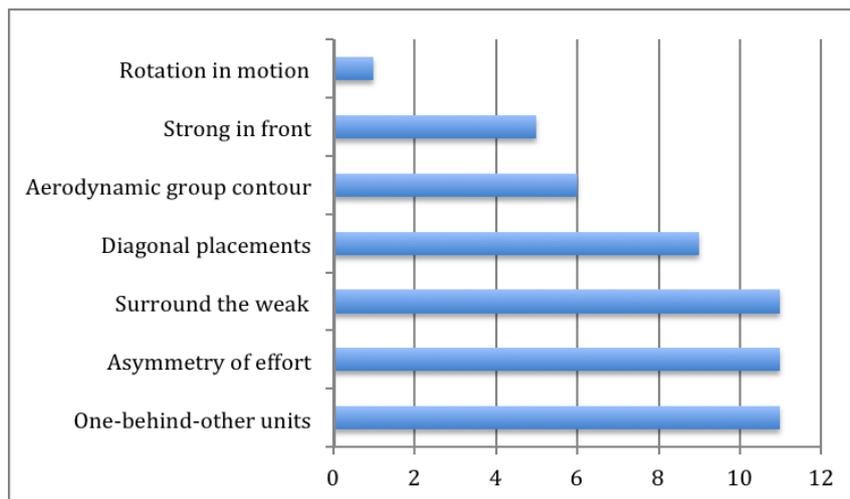


Figure 5: Features of triathletes' designed tactics (initial designs on training day 2)

Table 2 presents the triathletes' biking performance results in the variety of tactics they had designed and selected to try out on the second day of training. The main comparison is between the invented tactics and the Belgian Tourniquet (hence, BT), a commonly used tactic. This comparison shows that for the hobbyists, one invented tactic (Invented tactic 4) was faster than the BT, and the rise in pulse and effort were smaller. For the experts, all four invented tactics were faster than the BT. However, the rise in pulse was also higher and the effort expended was similar. Therefore, triathletes using the model to form new tactics succeeded at designing more efficient tactics than those commonly used. This effect is stronger for the experts than for the hobbyists.

Group	Hobbyists <sup>1</sup>			Experts <sup>2</sup>			
	Heat	Time <sup>3</sup>	Pulse <sup>4</sup>	Effort <sup>5,6</sup>	Time	Pulse <sup>4</sup>	Effort <sup>5</sup>
Single		4:50	58 (49)		3:52	15 (29)	
Belgian Tourniquet		4:09	39 (22)	1.9 (2.1)	3:28	45 (17)	-0.9 (1.1)
Invented tactic 1		4:55	53 (21)	3.7 (3.0)	3:15	62 (27)	0.0 (2.0)
Invented tactic 2		4:57	16 (18)	-3.2 (3.7)	2:50	60 (20)	0.3 (1.9)
Invented tactic 3		5:22	26 (16)	-2.2 (4.1)	3:14	53 (21)	-1.2 (1.3)
Invented tactic 4		4:08	21 (22)	-0.3 (3.9)	3:10	58 (22)	-0.8 (1.2)

Table 2: National team and local team group drafting performance results.

<sup>1</sup> – Local team

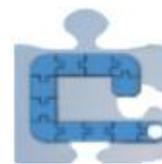
<sup>2</sup> – National team

<sup>3</sup> – The hobbyists rode for a longer distance of 2 kilometres. The experts rode for a shorter distance of 1.5 kilometres. This results from contextual constraints of the local geography and roads, as a safe flat length of road was necessary.

<sup>4</sup> – Subtraction of aerobic threshold pulse as baseline, measured after warm-up ride

<sup>5</sup> – Subtraction of aerobic threshold effort rating as baseline, measured from first single heat

<sup>6</sup> – Effort is measured on an RPE (Rate of Perceived Effort) scale



By the time of the conference, we will have finished analysing the learning resulting from the training unit based on the questionnaires and interviews and will report on these as well.

## Discussion

This study approaches learning as evidenced in athletes' design of collaborative action in competition and in their execution of these designs. We have used a complex systems approach to the aerodynamics of drafting while biking in a triathlon to use and create several models that offer a simple way of making sense of the system. We have also used agent-based computer models as a creative medium for the athletes as they designed new drafting tactics.

We have found that the athletes introduced several new tactics into the field of competitive bicycle riding in triathlons. These new tactics are based on an idea of uneven load distribution among the riders, by having the stronger riders work harder than the weaker ones. They used a variety of spatial configurations to implement this general idea. What characterizes their designs is a greater resolution in viewing the air surrounding and interacting with the bikers. Being able to discern differences in such interactions as a result of position in the configuration supported a more detailed view of the aerodynamics of the group and individual motion. They then used this understanding to create and test new forms of action that harness this greater resolution to bettering the group's speed and effort. They continued using the well known principles of keeping behind somebody else and smoothing the drag by moving on the diagonals. However, they incorporated a variety of ways by which the slowest riders would not slow the group, mainly by nesting them within additional riders.

Execution of these tactics showed a difference between the two teams. The experts (youth national team) were able to generate several distinct tactics that were superior to the classical most efficient one, while the hobbyists (local team) could produce only one. As described in the introduction, greater expertise involves more efficient and adaptive action. Moreover, it is possible that the experts greater experience in competitions and practice, results a broader knowledge base from which to draw ideas that could be incorporated into the new tactics.

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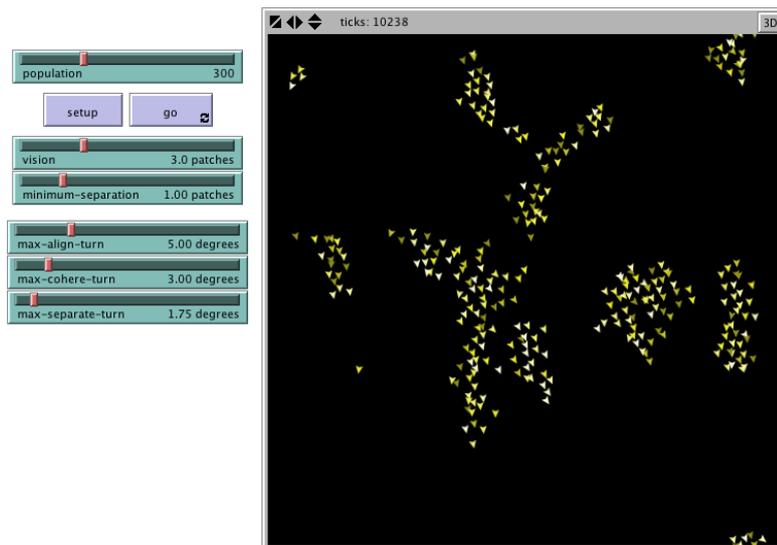
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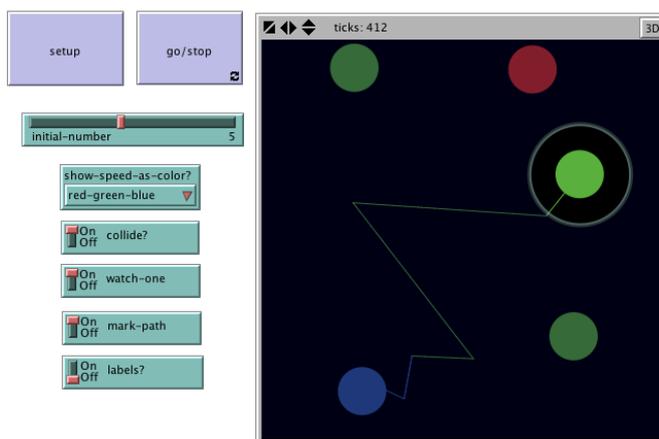


## Appendix

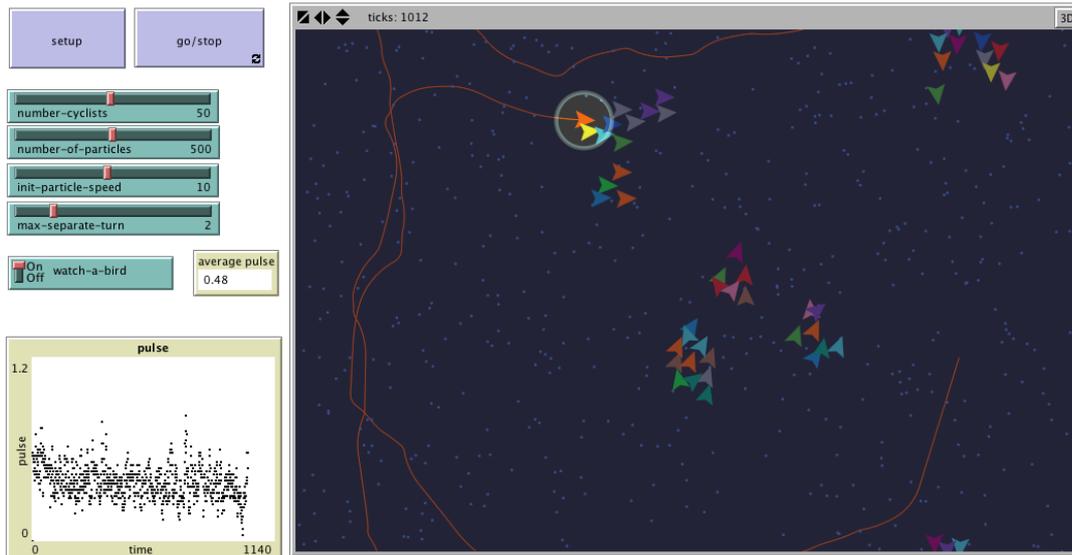
Models used in the study



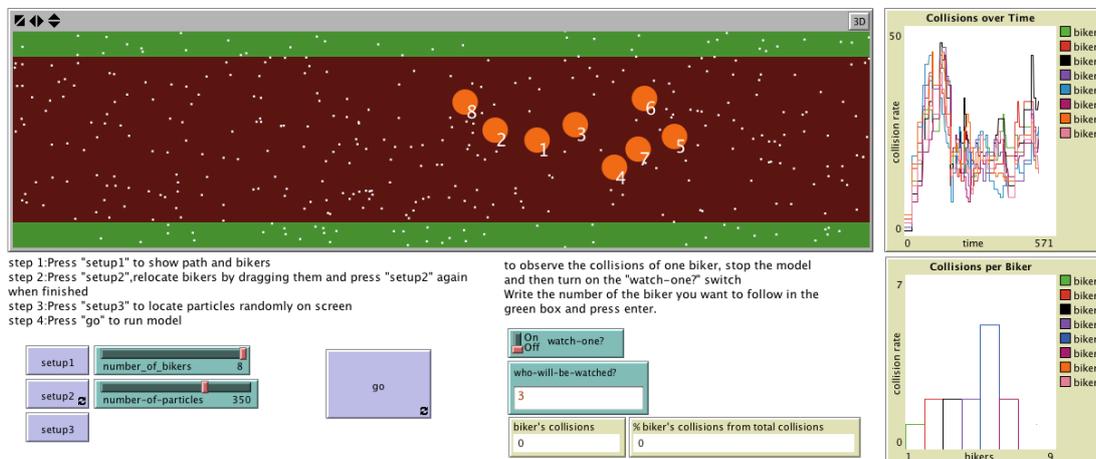
1. Flocking (Wilensky, 1998).



2. Adaptation of the “Connected Chemistry 3 Circular Particles” model (Wilensky, 2005).



3. Birds and particles: adaptation of the flocking model above, to include air particles and their interactions (Hirsh, Haviv-Gal & Levy, 2011).



4. Of particles and bikers: bikers (orange circles) move from left to right. One can adjust several features in the model, and most importantly change the spatial configuration of the bikers. On the right, one can observe the rate at which each biker is getting hit by particles, and how this changes over time. This rate is related to the effort expended by the moving through the air.