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## Andrew Schumann

University of Information Technology and Management in Rzeszow

### Ludmila Akimova

State Scientific and Production Amalgamation "The Scientific and Practical Center of the National Academy of Sciences of Belarus for Bioresources"

# SYLLOGISTIC SYSTEM FOR THE PROPAGATION OF PARASITES. THE CASE OF *SCHISTOSOMATIDAE* (TREMATODA: DIGENEA)

**Abstract.** In the paper, a new syllogistic system is built up. This system simulates a massive-parallel behavior in the propagation of collectives of parasites. In particular, this system simulates the behavior of collectives of trematode larvae (miracidia and cercariae).

*Keywords*: Physarum polycephalum, Trichobilharzia szidati, Schistosomatidae, Digenea, syllogistic, cercaria, miracidium.

## 1. Introduction

Now we are working on designing a biological computer on the medium of *Physarum polycepalum* [2]. This project is supported by FP7 (FP7-ICT-2011-8)<sup>1</sup> The point is that the plasmodium of *Physarum polycepalum* behaves and moves as a giant amoeba and its behavior can be considered a computer processor [1]. This allows us to use the plasmodium of Physarum as a spatial computing programmed by different configurations of attractants (substances with potentially high nutritional value) and repellents (some illumination-, thermo- and salt-based conditions). In [24], we showed that the behavior of plasmodium of *Physarum polycephalum* has its own spatial logic which is one of the natural implementations of process calculus. This logic, called *Physarum spatial logic*, can be used as a programming language for a biological computer based on plasmodia. Also, this logic can simulate the behavior of *Schistosomatidae* (Trematoda: Digenea) [25].



Figure 1. The stimulation of the following operations in cercariae motions: (A) the fusion of cercariae collectives, (B) the multiplication of cercariae collective, where the human beings are attractants

The basic acts of plasmodium are as follows: (i) *Direction*: the plasmodium moves towards the attractant; (ii) *Fusion*: the two plasmodia fuse after meeting the same attractant; (iii) *Split*: the plasmodium splits in front of many attractants. The same acts are observed in the behavior of *Schistosomatidae* cercariae (see Fig. 1) and many other parasites. The difference is just in different attractants: plasmodia are attracted by nutrients and cercariae are attracted by the fatty acids of bird or human skin.

We are constructing an object-oriented programming language [26] for modelling the behavior of plasmodia by thousands of attractants on the basis of the basic acts mentioned above. This complex behavior with many and many attractants, on the one hand, can implement complex computer algorithms and, on the other hand, show, how intelligent the Physarum plasmodium is. Within this object-oriented language we can model the behavior of collectives of the genus *Trichobilharzia* Skrjabin & Zakharov, 1920 (*Schistosomatidae* Stiles & Hassall, 1898) and the behavior of many other parasites, as well.

*Schistosomatidae* have been studied recently because of cercarial dermatitis which they cause in humans by the secretion of penetration glands. Notice that the cercaria begins the incorporation into the human skin approximately in 8 seconds (the range from 0 to 80 seconds), just after first contact [9]. The process of full penetration into the skin takes about 4 minutes (the range from 83 seconds till 13 minutes 37 seconds). In human children, the cercariae can be brought by venous blood into the lungs, causing hemorrhages and inflammations [3]. Many other complications can come because of repeated infestations [3].

The meaning of the behavior of parasites such as cercariae consists in the propagation of their collectives in all possible directions in looking for hosts and then their further propagation according to their life cycle. That behavior is concurrent and not linear (it continuously splits and fuses). In this paper, we propose a syllogistic system for a computer modelling of this complex behavior within our language [26]. In this system, attractants for parasites are considered syllogistic letters. Any two neighbor attractants which can be immediately reached by the one collective of parasites are considered a syllogistic string that is true if both attractants are occupied by parasites and false otherwise. A good science-fiction example of the propagation of parasites is presented by the movie World War Z(2013) directed by Marc Forster. Zombies in this movie are attracted by the chemotaxis from able-bodied humans' sounds and motions, which causes the propagation of zombies in all possible directions. Cercariae are attracted by the chemotaxis from the skin of potential hosts, the turbulence of water, and lights. Note that the syllogistic system for modelling the propagation of parasites is proposed in this paper for the first time.

## 2. Trichobilharzia szidati (Diginea: Schistosomatidae) and their Life Cycle

All representatives of subclass *Digenea* Carus, 1863 (Platyhelminthes: Trematoda) including *Trichobilharzia szidati* are endoparasites of animals. Their life cycle has the form of heterogony: there are amphimictic and parthenogenetic stages. At these stages, digeneans have different outward, different ways of reproduction, and different adaptation to different specific and incompetent hosts. The majority of them have a life cycle with the participation of three hosts: intermediate, additional (metacercarial), and final. Molluscs are always the first intermediate hosts, while different classes of vertebrate animals are final hosts.

Among digeneans, there are parasites belonging to the family of *Schistosomatidae*, which have adapted to parasitizing in the circulatory system



Figure 2. The life cycle of *Trichobilharzia regenti*: (a) mature worms lay the eggs in the nasal mucosa of ducks, then the eggs get to water and from these eggs miracidia hatch; (b) miracidia infect the intermediate hosts; (c) from these hosts cercariae are released; (d) they penetrate the skin of a specific host or (e) the skin of an incompetent mamma-lian host such as a human being (from [16])

of vertebrate animals. This family includes the following three subfamilies: *Schistosomatinae* Stiles and Hassall, 1898, which parasitize a variety of birds and mammals, including human beings; *Bilharziellinae* Price, 1929 and *Gigantobilharziinae* Mehra, 1940, which parasitize birds. *Schistosomatidae* can penetrate the human skin, where they perish and, therefore, invoke allergic dermatitis.

The life cycle of all representatives of the family *Schistosomatidae* is identical (see Fig. 2). Its members have the following two free-swimming stages: miracidia and cercariae, which actively search for their hosts (intermediate and final, respectively). Miracidial and cercarial host-finding is initiated mainly by response to some gravitational, light, and chemical attractants.

## 2.1. Miracidia (Genus Trichobilharzia): Morphology and Behavior

Miracidia are a free-swimming larval stage (Fig. 3). Their body surface is covered with four rows of epithelial plates that carry a multitude of cilia involved in the active motions of miracidia (Fig. 3, B). The anterior part of the body contains terminal openings of the following penetration unicellular glands: two cells of apical glands and two cells of lateral glands.



Figure 3. The morphology of miracidia. A. the general morphology of *Trichobilharzia szidati* (from [23]); B. the general morphology of *Trichobilharzia regenti* (left) and the arrangement of ciliated plates (right), scale bar = 25mm (from [16])

The posterior part of the body contains clusters of germ cells from which daughter sporosysts are formed subsequently. Miracidia lack any digestive system and they cannot feed.

Miracidia of *Trichobilharzia szidati* [23] hatch from eggs within a short time, 5-10 min. In order to survive, miracidia must infect a snail host within 20h at 24°C before they die [23]. The positive photo- and negative geotactic orientation is an adaptation to reach the preferred habitats of their host-snail species [11], [12], [14], [33], [34]. Also, it is now confirmed that miracidia are attracted by some chemical host signals [19], [23], [31], [32]. Snail-hosts release various secreted/excreted products into water. Miracidia are activated by the macromolecular components of these products, which consist of glycoproteins larger than 30 kDa, termed "miracidia attracting glycoproteins" [17]. These glycoproteins produced by different species of snails have a similar peptide-base, but differ by saccharide component. Miracidia can differentiate between these glycosylation patterns in order to find and infect mainly specific snail species [17], [18]. Thus, the chemical cues secreted by the freshwater gastropod Lymnaea stagnalis stimulate behavioral responses of *Trichobilharzia szidati* miracidia. In other words, a miracidium moves towards an appropriate chemical signal. Other kinds of attractants for miracidia are presented by light (there is a positive phototaxis) and gravitation (negative geotaxis). We will designate all miracidian attractants by syllogistic letters  $S_{m_1}, S_{m_2}, \ldots, S_{m_n}, P_{m_1}, P_{m_2}, \ldots, P_{m_n}$  $M_{m_1}, M_{m_2}, \ldots, M_{m_n}$ . They can differ by their power and intensity.

#### 2.2. Cercariae (Genus Trichobilharzia): Morphology and Behavior

Cercariae are free-swimming larvae of pubertal generation parasitizing vertebrate animals. Their length is about 1.0mm. They are capable of insinuating into the skin of a human being who is for them an incompetent host. As a result, they cause an allergic reaction, the so-called *cercarial dermatitis*. This term was proposed by V. V. Cort [4], who for the first time correlated this disease with molluscs of certain kinds, and then with cercariae.

Cercariae of the genus *Trichobilharzia* belong to the bunch of furcocercariae; their posterior tail part consists of two branches (furcae), and the length of furca is approximately half the length of the tail. Even in a small zoom its pigmented eye-spots are well visible. The cercarial body is translucent. During motion it is strongly reduced, receiving various forms (Fig. 4).



Figure 4. The appearance of *Trichobilharzia szidati*. A detection place: the lake of Naroch (the Minsk region, the Mjadelsky destrict). *Lymnaea stag-nalis* is an intermediate host

All European species of *Trichobilharzia* possess five pairs of penetration glands (Fig. 5). Two pairs are presented by circumacetabular glands located round the ventral sucker, and the three other by postacetabular glands located sequentially one after another below. The secreta of penetration glands helps larvae to break the dermal barrier of vertebrate hosts.

Cercariae of the genus *Trichobilharzia* after leaving a mollusc actively swim in the water for an hour. Such active behavior of larvae after leaving a mollusc provides a cercarial distribution in the water space. Then cercariae pass to a passive behavior. Free-swimming cercariae need to insinuate into a final host during a limited time interval (1–1.5 days Syllogistic system for the propagation of parasites...



Figure 5. The constitution of *Trichobilharzia szidati*. A. The schematic structure of cercaria (from [5]), B. The photo of cercaria. 1. Penetration organ, 2. Penetration gland ducts, 3. Pigmented eye-spots, 4. Ventral sucker, 5. Penetration glands (5 pairs), 6. Tail stem, 7. Furcae

at temperature  $24^{\circ}$ C) [23]. In a resting state, cercariae are attached to a vascular wall or on a water film by means of acetabulum. Active motions are characteristic only by the strong shaking of a pot or by water interfusion.

The cercarial behavior of bird schistosomes (family *Schistosomatidae*) has been well studied due to representatives of the genus *Trichobilharzia* [16]. Their behavior is characterized by the specific taxis implying their looking for specific hosts, their affixion to the surface of a host body as well as their incorporation into a host's cutaneous covering, and their penetration into a circulatory system, where a parasite reaches sexual maturity. Thus, taxis is presented by a large enough family of attractants: larvae of digeneans of *Trichobilharzia* possess a positive phototaxis, negative geotaxis, chemotaxis, and also actively react to turbulence of water [8].

Larvae have chemoreceptors which receive appropriate chemical signals proceeding from the skin of a potential host. The similarity of compound of fatty acids of bird and human skin leads to cercariae equally reacting to bird or human appearance in water: they move in their direction, and then they are attached to the skin and begin penetration into it [10]. In experimental research, it has been shown that any attachment of cercariae of *Trichobilharzia* to the skin is stimulated by cholesterol and ceramides, and incorporation into the skin by linoleic and linolenic acids, all materials present on the skin of both the bird and the human being [9], [20]. Thereby the surface lipids of human skin invoke a higher frequency of cercarial incorporations into the skin than the surface lipids of birds [10].

Hence, the chemotaxis from the skin of potential hosts, the positive phototaxis, the negative geotaxis, and the water turbulence should be considered cercarial attractants, which will be designated by  $S_{c_1}, S_{c_2}, \ldots, S_{c_n}, P_{c_1}, P_{c_2}, \ldots, P_{c_n}, M_{c_1}, M_{c_2}, \ldots, M_{c_n}$ .

#### 3. Syllogistic System for the Propagation of Schistosomatidae

The alphabet of the syllogistic system for modelling the propagation of *Schistosomatidae* contains

- as descriptive signs the syllogistic letters  $S_x$ ,  $P_x$ ,  $M_x$ , ..., where  $x \in \{m, c\}$ ;
- as logical-semantic signs the syllogistic connectives
  - $\mathbf{a}_t, \mathbf{e}_t, \mathbf{i}_t, \mathbf{o}_t \text{ at time } t = 0, 1, ..., n, ...,$
  - $-\mathbf{a}_{\infty}, \mathbf{e}_{\infty}, \mathbf{i}_{\infty}, \mathbf{o}_{\infty}$  for infinite time;
- and the propositional connectives  $\neg$ ,  $\lor$ ,  $\land$ ,  $\Rightarrow$ .

Simple propositions are defined as follows:  $S_x \star P_x$ , where  $\star \in \{\mathbf{a}_t, \mathbf{e}_t, \mathbf{i}_t, \mathbf{o}_t, \mathbf{a}_\infty, \mathbf{e}_\infty, \mathbf{i}_\infty, \mathbf{o}_\infty\}$ . All other propositions are defined thus: (i) each simple proposition is a proposition, (ii) if X, Y are propositions, then  $\neg X, \neg Y, X \star Y$ , where  $\star \in \{\lor, \land, \Rightarrow\}$ , are propositions, too.

Syllogistic letters  $S_m, P_m, M_m, \ldots$  are interpreted as attractants for miracidia as follows: a data point  $S_m$  is evaluated as empty if and only if an appropriate attractant for miracidia denoted by  $S_m$  is not occupied by any miracidium. Syllogistic letters  $S_c, P_c, M_c, \ldots$  are interpreted as attractants for cercariae in the following manner: an item  $S_c$  is evaluated as empty if and only if an appropriate attractant for cercariae denoted by  $S_c$  is not occupied by any cercaria.

Let us define syllogistic strings of the form  $S_m P_m$  and  $S_c P_c$  at time t with the following notation:  $S_m is_t P_m$  and  $S_c is_t P_c$ , and with the following meaning:

•  $S_m P_m$  at time t = 0, 1, 2, ... is true if and only if  $S_m$  and  $P_m$  are cells occupied by miracidia at t and there is a path between  $S_m$  and  $P_m$ and this path consists of cells also occupied by miracidia at t (i.e. both  $S_m$  and  $P_m$  are not empty at t and between them there is a path of non-empty cells), otherwise  $S_m P_m$  is false (e.g. in Fig. 6 there are paths  $S_4 S_5, S_4 S_{10}$  at t = 0); •  $S_c P_c$  at t is true if and only if both  $S_c$  and  $P_c$  are not empty cells at t and between them there is a path of non-empty cells at t, otherwise  $S_c P_c$  is false.

Now, we define syllogistic propositions 'All ... are ...', 'No ... are ...', 'Some ... are ...', 'Some ... are not ...' in a non-Aristotelian way to construct a syllogistic of propagation. The meaning of the proposition 'All Sare P' is that between points S and P we observe a propagation in all possible directions. The meaning of the proposition 'Some S are P' is that between points S and P we cannot observe a propagation in all possible directions and the propagation is just contingent and casual. So, while in the Aristotelian syllogistic the propositions 'All ... are ...' and 'No ... are ...' are contrary, in the syllogistic of propagation the propositions 'All ... are ...' and 'Some ... are ...' are contrary. Other propositions are understood conventionally: 'No  $\ldots$  are  $\ldots$ ' := It is false that 'Some  $\ldots$ are  $\ldots$ ; 'Some  $\ldots$  are not  $\ldots$ ' := It is false that 'All  $\ldots$  are  $\ldots$ '. The point of this non-Aristotelian interpretation is that we cannot exclude propagation at all. There are always some forms of propagation from massive-parallel (when 'All ... are ...' is true) to casual (when 'Some ... are ...' is true). For more details about this non-Aristotelian system, please see [27], [28].

Thus, using the definition of syllogistic strings, we can define simple syllogistic propositions as follows:

- 1. 'All  $S_m$  are  $P_m$  at time t'  $(S_m \mathbf{a}_t P_m)$ : there is a string  $A_m S_m$  at time t and for any  $A_m$  which is a neighbor for  $S_m$  or  $P_m$ , there are strings  $A_m S_m$  and  $A_m P_m$  at t. This means that we have a massive-parallel occupation of the region at t, where the cells  $S_m$  and  $P_m$  are located, i.e. the propagation holds in all possible directions.
- 2. 'All  $S_c$  are  $P_c$  at time t'  $(S_c \mathbf{a}_t P_c)$ : there is a string  $A_c S_c$  at time t and for any  $A_c$  which is a neighbor for  $S_c$  or  $P_c$ , there are strings  $A_c S_c$  and  $A_c P_c$  at t.
- 3. 'Some  $S_m$  are  $P_m$  at time t'  $(S_m \mathbf{i}_t P_m)$ : for any  $A_m$  which is a neighbor for  $S_m$  or  $P_m$  at t, there are no strings  $A_m S_m$  and  $A_m P_m$ . This means that the collective of miracidia cannot reach  $S_m$  from  $P_m$  or  $P_m$  from  $S_m$  immediately at t, but it does not mean that there are no propagating miracidia. Some forms of their propagation ever exist.
- 4. 'Some  $S_c$  are  $P_c$  at time t'  $(S_c \mathbf{i}_t P_c)$ : for any  $A_c$  which is a neighbor for  $S_c$  or  $P_c$  at t, there are no strings  $A_c S_c$  and  $A_c P_c$ .
- 5. 'No  $S_m$  are  $P_m$  at time t'  $(S_m \mathbf{e}_t P_m)$ : there exists  $A_m$  at time t which is a neighbor for  $S_m$  or  $P_m$  such that there is a string  $A_m S_m$  or there is a string  $A_m P_m$ . This means that the collective of miracidia occupies  $S_m$  or  $P_m$ , but surely not the whole region at time t, where the cells  $S_m$  and  $P_m$  are located.

- 6. 'No  $S_c$  are  $P_c$  at time t'  $(S_c \mathbf{e}_t P_c)$ : there exists  $A_c$  at time t which is a neighbor for  $S_c$  or  $P_c$  such that there is a string  $A_c S_c$  or there is a string  $A_c P_c$ .
- 7. 'Some  $S_m$  are not  $P_m$  at time t'  $(S_m \mathbf{o}_t P_m)$ : for any  $A_m$  which is a neighbor for  $S_m$  or  $P_m$  at time t there is no string  $A_m S_m$  or there exists  $A_m$  which is a neighbor for  $S_m$  and  $P_m$  such that there is no string  $A_m S_m$  or there is no string  $A_m P_m$ . This means that at time t the collective of miracidia does not occupy  $S_m$  or there is a neighbor cell which is not connected with  $S_m$  or  $P_m$  by the same propagated collective of miracidia.
- 8. 'Some  $S_c$  are not  $P_c$  at time t'  $(S_c \mathbf{o}_t P_c)$ : for any  $A_c$  which is a neighbor for  $S_c$  or  $P_c$  at time t there is no string  $A_c S_c$  or there exists  $A_c$  which is a neighbor for  $S_c$  or  $P_c$  such that there is no string  $A_c S_c$  or there is no string  $A_c P_c$ .

Formally:

$$S_m \mathbf{a}_t P_m := (\exists A_m (A_m \, is_t \, S_m) \land (\forall A_m (A_m \, is_t \, S_m \land A_m \, is_t \, P_m))); \quad (1)$$

$$S_c \mathbf{a}_t P_c := (\exists A_c (A_c \, is_t \, S_c) \land (\forall A_c (A_c \, is_t \, S_c \land A_c \, is_t \, P_c))); \tag{2}$$

$$S_m \mathbf{i}_t P_m := \forall A_m (\neg (A_m \, is_t \, S_m) \land \neg (A_m \, is_t \, P_m)); \tag{3}$$

$$S_c \mathbf{i}_t P_c := \forall A_c (\neg (A_c \, is_t \, S_c) \land \neg (A_c \, is_t \, P_c)); \tag{4}$$

$$S_m \mathbf{e}_t P_m := \neg \forall A_m (\neg (A_m \, is_t \, S_m) \land \neg (A_m \, is_t \, P_m)), i.e. \\ \exists A_m (A_m \, is_t \, S_m \lor A_m \, is_t \, P_m).$$
(5)

$$S_c \mathbf{e}_t P_c := \neg \forall A_c (\neg (A_c \, is_t \, S_c) \land \neg (A_c \, is_t \, P_c)), i.e. \\ \exists A_c (A_c \, is_t \, S_c \lor A_c \, is_t \, P_c).$$

$$(6)$$

$$S_m \mathbf{o}_t P_m := \neg (\exists A_m (A_m \, is_t \, S_m) \lor (\forall A_m (A_m \, is_t \, P_m \land A_m \, is_t \, S_m))),$$
(7)  
$$i.e. (\forall A_m \neg (A_m \, is_t \, S_m) \land \exists A_m (\neg (A_m \, is_t \, P_m) \lor \neg (A_m \, is_t \, S_m)));$$

$$S_{c}\mathbf{o}_{t}P_{c} := \neg (\exists A_{c}(A_{c} is_{t} S_{c}) \lor (\forall A_{c}(A_{c} is_{t} P_{c} \land A_{c} is_{t} S_{c}))),$$
  
$$i.e.(\forall A_{c} \neg (A_{c} is_{t} S_{c}) \land \exists A_{c}(\neg (A_{c} is_{t} P_{c}) \lor \neg (A_{c} is_{t} S_{c})));$$
  
$$(8)$$

Notably, this system is essentially non-Aristotelian, in particular  $S_m \mathbf{a}_t P_m \Rightarrow S_m \mathbf{e}_t P_m; S_m \mathbf{i}_t P_m \Rightarrow S_m \mathbf{o}_t P_m; S_m \mathbf{a}_t P_m \Rightarrow P_m \mathbf{a}_t S_m; S_m \mathbf{e}_t P_m \Rightarrow P_m \mathbf{e}_t S_m; S_m \mathbf{i}_t P_m \Rightarrow P_m \mathbf{i}_t S_m; S_m \mathbf{o}_t P_m \Rightarrow P_m \mathbf{o}_t S_m.$ 

The topology of attractants changes permanently (see Fig. 6), because different attractants become occupied in due course. Therefore for different time  $t = 0, 1, 2, \ldots$ , we observe different true syllogistic propositions (see Fig. 6).

Syllogistic system for the propagation of parasites...



(a) t = 0; the four attractants denoted by  $S_4$ ,  $S_5$ ,  $S_9$ ,  $S_{10}$  are occupied by the parasites



(b) t = 1; the seven attractants denoted by  $S_4$ ,  $S_5$ ,  $S_6$ ,  $S_7$ ,  $S_8$ ,  $S_9$ ,  $S_{10}$  are occupied by the parasites



(c) t = 2; the eleven attractants denoted by  $S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}$  are occupied by the parasites

Figure 6. Example of propagation of parasites. First of all, parasites are located in the center of pictures (a), (b), (c). Attractants which are not occupied by parasites are denoted by white circles. Attractants which are occupied by parasites are denoted by black circles. Each attractant is the center of a suitable Voronoi cell. The radius of Voronoi cell is a maximal distance of power to attract parasites in one direction. At time t = 0, 1, 2, different syllogistic propositions are true: (a) S<sub>7</sub>i<sub>0</sub>S<sub>11</sub>, S<sub>11</sub>i<sub>0</sub>S<sub>7</sub>, S<sub>1</sub>i<sub>0</sub>S<sub>3</sub>, S<sub>3</sub>i<sub>0</sub>S<sub>1</sub>, S<sub>1</sub>e<sub>0</sub>S<sub>10</sub>, S<sub>1</sub>e<sub>0</sub>S<sub>1</sub>, S<sub>1</sub>e<sub>0</sub>S<sub>9</sub>, S<sub>9</sub>e<sub>0</sub>S<sub>1</sub>, S<sub>1</sub>e<sub>0</sub>S<sub>4</sub>, S<sub>4</sub>e<sub>0</sub>S<sub>1</sub>, etc.; (b) S<sub>1</sub>i<sub>1</sub>S<sub>11</sub>, S<sub>11</sub>i<sub>1</sub>S<sub>1</sub>, S<sub>2</sub>o<sub>1</sub>S<sub>6</sub>, S<sub>6</sub>o<sub>1</sub>S<sub>2</sub>, etc.; (c) S<sub>7</sub>a<sub>2</sub>S<sub>11</sub>, S<sub>11</sub>a<sub>2</sub>S<sub>7</sub>, S<sub>1</sub>a<sub>2</sub>S<sub>3</sub>, S<sub>3</sub>a<sub>2</sub>S<sub>1</sub>, S<sub>1</sub>a<sub>2</sub>S<sub>10</sub>, S<sub>10</sub>a<sub>2</sub>S<sub>1</sub>, S<sub>1</sub>a<sub>2</sub>S<sub>9</sub>, S<sub>9</sub>a<sub>2</sub>S<sub>1</sub>, S<sub>1</sub>a<sub>2</sub>S<sub>4</sub>, S<sub>4</sub>a<sub>2</sub>S<sub>1</sub>, etc.

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Also, we can assume that the attractants can move at t = 0, 1, 2... Let us postulate that their motions at different time are limited by the following rules, where t + 1 means the next step of life cycle:

$$S_m \mathbf{a}_t P_m \Rightarrow S_m \mathbf{e}_{t+1} P_m. \tag{9}$$

$$S_c \mathbf{a}_t P_c \Rightarrow S_c \mathbf{e}_{t+1} P_c. \tag{10}$$

From this we have

$$S_m \mathbf{i}_{t+1} P_m \Rightarrow S_m \mathbf{o}_t P_m. \tag{11}$$

$$S_c \mathbf{i}_{t+1} P_c \Rightarrow S_c \mathbf{o}_t P_c. \tag{12}$$

Attractants for miracidia and cercariae are different, but they live in the same lake. We can postulate that if the whole region is occupied by miracidia (cercariae) at time t, then surely the part of this region is occupied by cercariae (miracidia) at time t + 1. So, the propagation of collectives of miracidia at t causes the propagation of collectives of cercariae at t + 1:

$$S_m \mathbf{a}_t P_m \Rightarrow S_c \mathbf{e}_{t+1} P_c. \tag{13}$$

$$S_m \mathbf{i}_{t+1} P_m \Rightarrow S_c \mathbf{o}_t P_c. \tag{14}$$

Furthermore, the propagation of collectives of cercariae at t causes the propagation of collectives of miracidia at t + 1:

$$S_c \mathbf{a}_t P_c \Rightarrow S_m \mathbf{e}_{t+1} P_m. \tag{15}$$

$$S_c \mathbf{i}_{t+1} P_c \Rightarrow S_m \mathbf{o}_t P_m. \tag{16}$$

Now, we can define simple syllogistic propositions for infinite time:  $S\mathbf{x}_{\infty}P := \lim_{t\to\infty} S\mathbf{x}_t P$ , where  $\mathbf{x} \in \{\mathbf{a}, \mathbf{e}, \mathbf{i}, \mathbf{o}\}$ . The informal meaning of these propositions is that we put forward syllogistic propositions about the whole of one life cycle of *Schistosomatidae* in the same lake. So, we may generalize equations (9)–(16) in the following way:

$$S_m \mathbf{a}_\infty P_m \Rightarrow \exists t. S_m \mathbf{a}_t P_m;$$
 (17)

$$S_c \mathbf{a}_{\infty} P_c \Rightarrow \exists t. S_c \mathbf{a}_t P_c;$$
 (18)

$$S_m \mathbf{a}_{\infty} P_m \Rightarrow \exists t. S_c \mathbf{a}_t P_c; \tag{19}$$

$$S_c \mathbf{a}_{\infty} P_c \Rightarrow \exists t. S_m \mathbf{a}_t P_m;$$
 (20)

$$S_m \mathbf{i}_{\infty} P_m \Rightarrow \forall t. S_m \mathbf{i}_t P_m; \tag{21}$$

$$S_c \mathbf{i}_{\infty} P_c \Rightarrow \forall t. S_c \mathbf{i}_t P_c;$$
 (22)

$$S_m \mathbf{i}_{\infty} P_m \Rightarrow \forall t. S_c \mathbf{i}_t P_c; \tag{23}$$

$$S_c \mathbf{i}_{\infty} P_c \Rightarrow \forall t. S_m \mathbf{i}_t P_m.$$
<sup>(24)</sup>

Formula (17) means that if the whole region is occupied by miracidia for one life cycle of *Schistosomatidae*, then there exists time t such that the whole region is occupied by miracidia. Formula (18) means that if the whole region is occupied by cercariae for one life cycle of *Schistosomatidae*, then there exists time t such that the whole region is occupied by cercariae. Formula (19) means that if the whole region is occupied by miracidia for one life cycle of *Schistosomatidae*, then there exists time t such that the whole region is occupied by cercariae. Formula (20) means that if the whole region is occupied by cercariae for one life cycle of *Schistosomatidae*, then there exists time t such that the whole region is occupied by miracidia.

Formula (21) means that if there is just a casual propagation of miracidia for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of miracidia. Formula (22) means that if there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae. Formula (23) means that if there is just a casual propagation of miracidia for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of miracidia for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae. Formula (24) means that if there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*, then for all time t of this life cycle there is just a casual propagation of cercariae for one life cycle of *Schistosomatidae*.

Other axioms are as follows (for  $x \in \{m, c\}$ ):

$$S_x \mathbf{a}_t P_x \Rightarrow S_x \mathbf{e}_t P_x; \quad S_x \mathbf{a}_\infty P_x \Rightarrow S_x \mathbf{e}_\infty P_x;$$
 (25)

$$S_x \mathbf{a}_t P_x \Rightarrow P_x \mathbf{a}_t S_x; \quad S_x \mathbf{a}_\infty P_x \Rightarrow P_x \mathbf{a}_\infty S_x; \tag{26}$$

$$S_x \mathbf{i}_t P_x \Rightarrow P_x \mathbf{i}_t S_x; \quad S_x \mathbf{i}_\infty P_x \Rightarrow P_x \mathbf{i}_\infty S_x; \tag{27}$$

$$S_x \mathbf{a}_t M_x \Rightarrow S_x \mathbf{e}_t P_x; \quad S_x \mathbf{a}_\infty M_x \Rightarrow S_x \mathbf{e}_\infty P_x;$$
 (28)

$$M_x \mathbf{a}_t P_x \Rightarrow S_x \mathbf{e}_t P_x; \quad M_x \mathbf{a}_\infty P_x \Rightarrow S_x \mathbf{e}_\infty P_x;$$
 (29)

$$(M_x \mathbf{a}_t P_x \wedge S_x \mathbf{a}_t M_x) \Rightarrow S_x \mathbf{a}_t P_x; \tag{30}$$

$$(M_x \mathbf{i}_t P_x \wedge S_x \mathbf{i}_t M_x) \Rightarrow S_x \mathbf{i}_t P_x; \tag{31}$$

$$(M_x \mathbf{a}_\infty P_x \wedge S_x \mathbf{a}_\infty M_x) \Rightarrow S_x \mathbf{a}_\infty P_x; \tag{32}$$

$$(M_x \mathbf{i}_{\infty} P_x \wedge S_x \mathbf{i}_{\infty} M_x) \Rightarrow S_x \mathbf{i}_{\infty} P_x.$$
(33)

Some basic formal properties of that axiomatic system closed over axioms (1)-(8) and (25)-(33), where **a**, **e**, **i**, **o** do not depend on time, are considered in [27], [28]. Probabilistic semantics for the time-dependent version of that system for slime mould behavior is proposed in [29].

Notice that formulas (31) and (33) are axioms of the syllogistic system of propagation, while they are not valid in the Aristotelian system. Indeed,  $(M_x \mathbf{i}_t P_x \wedge S_x \mathbf{i}_t M_x) \Rightarrow S_x \mathbf{i}_t P_x$  means that

$$[\forall A_x(\neg(A_x is_t M_x) \land \neg(A_x is_t P_x)) \land \forall A_x(\neg(A_x is_t S_x) \land \neg(A_x is_t M_x))] \Rightarrow \forall A_x(\neg(A_x is_t S_x) \land \neg(A_x is_t P_x)),$$

the latter formula is valid.

#### 4. Conclusion

In this paper, we have constructed a syllogistic system for the propagation of *Schistosomatidae*. This system contains all tautologies of the syllogistic system for the propagation of *Physarum polycephalum* proposed in [29], but not vice versa. And in return, the syllogistic system for the propagation of *Physarum polycephalum* contains all tautologies of the performative syllogistic proposed in [27], [28], but not vice versa. This means that as more complex intelligent behavior is observed in propagations, more axioms are contained in an appropriate syllogistic system.

In syllogistics for the explication of propagations, the inverse relations hold true for all syllogistic connectives:

$$SaP \Rightarrow PaS;$$
  
 $SeP \Rightarrow PeS;$   
 $SiP \Rightarrow PiS;$   
 $SoP \Rightarrow PoS.$ 

This is inferred from definitions (1)-(8). These properties fix propagations in all possible directions.

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#### NOTE

<sup>1</sup> http://www.phychip.eu/.

#### $R \in F \in R \in N \subset E S$

- A. Adamatzky, Physarum Machines: Computers from Slime Mould (World Scientific Series on Nonlinear Science, Series A). World Scientific Publishing Company, 2010.
- [2] A. Adamatzky, V. Erokhin, M. Grube, Th. Schubert, A. Schumann, "Physarum Chip Project: Growing Computers From Slime Mould," *International Journal of Unconventional Computing*, 8 (4), pp. 319–323, 2012.
- [3] S. A. Bear, M. V. Voronin, Cercariae in Urbanized Ecosystems. Moskow: Nauka, 2007 (in Russian).
- [4] W. W. Cort, "Schistosome dermatitis in the United States (Michigan)," Journal of the American Medical Association, vol. 90, pp. 1027–1029, 1928.
- [5] T. A. Ginetsinskaya, Trematodes, their Life Cycles, Biology and Evolution. Leningrad: Nauka, 1968 (in Russian).
- [6] W. Feiler, W. Haas, "Trichobilharzia ocellata: chemical stimuli of duck skin for cercarial attachment," Parasitology, vol. 96, pp. 507–517, 1988.
- [7] W. Haas, "Host finding mechanisms a physiological effect," in *Biology, Structure, Function: Encyclopedic Reference of Parasitology* (Y. Mehlhorn, ed.), edn 2, 1988, pp. 382–383.
- [8] W. Haas, "Physiological analysis of cercarial behavior," *Journal of Parasitol-ogy*, vol. 78, pp. 243–255, 1992.
- [9] W. Haas, S. Haeberlein, "Penetration of cercariae into the living human skin: Schistosoma mansoni vs. Trichobilharzia szidati," Parasitology Research, vol. 105, No. 4, pp. 1061–1066, 2009.
- [10] W. Haas, A. Roemer, "Invasion of the vertebrate skin by cercariae of *Trichobil-harzia ocellata*: penetration processes and stimulating host signals," *Parasitol-ogy Research*, vol. 84, No. 10, pp. 787–795, 1998.
- [11] W. Haas, "Parasitic worms: strategies of host finding, recognition and invasion," Zoology, vol. 106, pp. 349–364, 2003.
- [12] W. Haas, B. Haberl, M. Kalbe, M. Körner, "Snail-host-finding by Miracidia and Cercariae: Chemical Host Cues," *Parasitology Today*, vol. 11, pp. 468–472, 1995.
- [13] W. Haas, B. Haberl, "Host recognition by trematode miracidia and cercariae," Advances in Trematode Biology. CRC Press, Boca Raton, Florida, 1997, pp. 197–227.
- [14] J. Hertel, A. Holweg, B. Haberl, M. Kalbe, W. Haas, "Snail odour-clouds: spreading and contribution to the transmission success of *Trichobilharzia ocellata* (Trematoda, Digenea) miracidia," *Oecologia*, vol. 147, pp. 173–180, 2006.
- [15] P. Horák, L. Kolárová, "Bird schistosomes: do they die in mammalian skin?" Trends in Parasitology, vol. 17, No. 2, pp. 66–69, 2001.
- [16] P. Horák, L. Kolárová, C.M. Adema, "Biology of the schistosome genus Trichobilharzia," Advances in Parasitology, 52, pp. 155–233, 2002.

- [17] M. Kalbe, B. Haberl, W. Haas, "Finding of the snail host by Fasciola hepatica and Trichobilharzia ocellata: compound analysis of 'Miracidia attracting glycoprotein'," Experimental Parasitology, vol. 96, pp. 231–242, 2000.
- [18] S. Kock, "Investigations on intermediate host specificity help to elucidate the taxonomic status of *Trichobilharzia ocellata* (Digenea: Schistosomatidae)," *Parasitology*, vol. 123, pp. 67–70, 2001.
- [19] A. J. MacInnis, "How parasites find their hosts: some thoughts on the inception of host-parasite integration," *Ecological Aspects of Parasitology (ed. C. R. Cennedy).* Amsterdam: North-Holand, 1976, pp. 3–20.
- [20] L. Mikes, L. Zidková, M. Kasný, J. Dvorák, P. Horák, "In vitro stimulation of penetration gland emptying by *Trichobilharzia szidati* and *T. regenti* (Schistosomatidae) cercariae. Quantitative collection and partial characterization of the products," *Parasitology Research*, vol. 96, No. 4, pp. 230–241, 2005.
- [21] D. H. Molyneux, "Control of human parasitic diseases: context and overview," Advances in Parasitology, vol. 61, pp. 1–45, 2006.
- [22] W. Neuhaus, "Biologie und Entwicklund von Trichobilharzia szidati n. sp. (Trematoda, Schistosomatidae), einem Erreger von Dermatitis beim Menschen," Zeitschrift fuer Parasitenkunde, vol. 15, pp. 203–266, 1952.
- [23] K. S. Saladin, "Behavioral parasitology and perspectives on miracidial hostfinding," *Zeitschrift fuer Parasitenkunde*, vol. 60, Nr. 3, pp. 197–210, 1979.
- [24] A. Schumann, A. Adamatzky, "Physarum Spatial Logic," New Math. and Nat. Computation, vol. 7, No. 3, pp. 483–498, 2011.
- [25] A. Schumann, L. Akimova, "Simulating of Schistosomatidae (Trematoda: Digenea) Behavior by Physarum Spatial Logic," Annals of Computer Science and Information Systems, Volume 1. Proceedings of the 2013 Federated Conference on Computer Science and Information Systems. IEEE Xplore, 2013, 225–230.
- [26] A. Schumann, K. Pancerz, "Towards an Object-Oriented Programming Language for Physarum Polycephalum Computing," [in:] M. Szczuka, L. Czaja, M. Kacprzak (eds.), Proceedings of the Workshop on Concurrency, Specification and Programming (CS&P'2013), Warsaw, Poland, September 25-27, 2013, 389–397.
- [27] A. Schumann, "On Two Squares of Opposition: the Lesniewski's Style Formalization of Synthetic Propositions," Acta Analytica, vol. 28, pp. 71–93, 2013.
- [28] A. Schumann, "Two Squares of Opposition: for Analytic and Synthetic Propositions," Bulletin of the Section of Logic, vol. 40(3/4), pp. 165–178, 2011.
- [29] A. Schumann, "p-Adic Valued Fuzzyness and Experiments with Physarum Polycephalum," The 11th International Conference on Fuzzy Systems and Knowledge Discovery. IEEE Xplore, 2014 (accepted).
- [30] J. D. Smyth, D. W. Halton, *The Physiology of Trematodes*. 2nd edition. Cambridge: Cambridge University Press, 1983.
- [31] M. V. K. Sukhdeo, D. F. Mettrick, "Parasite behaviour: understanding platyhelminth responses," Advances Parasitology, vol. 26, pp. 73–144, 1987.

- [32] M. V. K. Sukhdeo, S. C. Sukhdeo, "Trematode behaviours and the perceptual worlds of parasites," *Canadian Journal of Zoology*, vol. 82, pp. 292–315, 2004.
- [33] T. Takahashi, K. Mori, Y. Shigeta, "Phototactic, thermotactic and geotactic responses of miracidia of *Schistosoma japonicum*," *Japanese Journal of Para*sitology, vol. 110, pp. 686–691, 1961.
- [34] M. Podhorsky, Z. Huzova, L. Mikes, P. Horak, "Cercarial dimensions and surface structures as a tool for species determination of *Trichobilharzia* spp." Acta Parasitologica, vol. 50, pp. 343–365, 2009.