Swarm Intelligence among Humans
The Case of Alcoholics

Andrew Schumann[1] and Vadim Fris[2]
[1]*Department of Cognitivistics, University of Information Technology and Management in Rzeszow,*
Sucharskiego 2, 35-225, Rzeszow, Poland
[2]*Private Health Unitary Enterprise "Iscelenie", Kazinca 120, 220000 Minsk, Belarus*

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Abstract: There are many forms of swarm behaviour, such as swarming of insects, flocking of birds, herding of quadrupeds, and schooling of fish. Sometimes people behave unconsciously and this behaviour of them has the same patterns as behaviour of swarms. For instance, pedestrians behave as herding or flocking, aircraft boarding passengers behave as ant colony, people in escape panic behave as flocking, etc. In this paper we propose a swarm model of people with an addictive behaviour. In particular, we consider small groups of alcohol-dependent people drinking together as swarms with a form of intelligence. In order to formalize this intelligence, we appeal to modal logics K and its modification K'. The logic K is used to formalize preference relation in the case of lateral inhibition in distributing people to drink jointly and the logic K' is used to formalize preference relation in the case of lateral activation in distributing people to drink jointly.

1 INTRODUCTION

Usually, a social behaviour is understood as a synonymous to a collective animal behaviour. It is claimed that there are many forms of this behaviour from bacteria and insects to mammals including humans. So, bacteria and insects performing a collective behaviour are called *social*.

For example, a *prokaryote*, a one-cell organism that lacks a membrane-bound nucleus (karyon), can build colonies in a way of growing slime. These colonies are called 'biofilms'. Cells in biofilms are organized in dynamic networks and can transmit signals (the so-called quorum sensing) (Costerton, Lewandowski, Caldwell, Korber, 1995). As a result, these bacteria are considered social. Social insects may be presented by ants – insects of the family *Formicidae*. Due to a division of labour, they construct a real society of their nest even with a pattern to make slaves (D'Ettorre, J. Heinze, 2001). Also, *Synalpheus regalis* sp., a species of snapping shrimp that commonly live in the coral reefs, demonstrates a collective behaviour like ants. Among shrimps of the same colony there is one breeding female, as well, and a labour division of other members (Duffy, 2002). The ant-like organization of colony is observed among some mammals, too, e.g. among naked mole-rats (*Heterocephalus glaber* sp.). In one colony they have only one queen and one to three males to reproduce, while other members of the colony are just workers (Jarvis, 1981). The same collective behaviour is typical for Damaraland blesmols (*Fukomys damarensis* sp.), another mammal species – they have one queen and many workers (Jacobs, et al., 1991; Jarvis, Bennett, 1993).

All these patterns of ant-like collective behaviour (a brood care and a division of labour into reproductive and non-reproductive groups) are evaluated as a form of *eusociality*, the so-called highest level of organization of animal sociality (Michener, 1969). Nevertheless, it is quite controversial if we can regard the ant-like collective behaviour as a social behaviour, indeed. We can do it if and only if we concentrate, first, on outer stimuli controlling individuals and, second, on 'social roles' ('worker', 'queen', etc.) of individuals as functions with some utilities for the group as such, i.e. if and only if we follow, first, *behaviourism* which represents any collective behaviour as a complex system that is managed by stimulating individuals (in particular by their reinforcement and punishment) (Skinner, 1976) and, second, if and only if we share the ideas of *structural functionalism*

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which considers the whole society as a system of functions ('roles') of its constituent elements (Parsons, 1975). In case we accept both behaviourism and structural functionalism, we can state that a collective animal behaviour has the same basic patterns from 'social' bacteria and 'social' insects to humans whose sociality is evident for ourselves.

However, there are different approaches to sociality. One of the approaches, alternative to behaviourism and structural functionalism, is represented by *symbolic interactionism*. In this approach, a collective behaviour is social if in the process of interaction it involves a thought with a symbolic meaning that arises out of the interaction of agents (Beni, Wang, 1969). In other words, social behaviour is impossible without material culture, e.g. without using some tools which always have symbolic meanings. Obviously, in this sense the collective behaviour of ants cannot be regarded as social. There are no tools and no symbolic meanings for the ants.

But not only humans perform social behaviour in the meaning of symbolic interactionism. It is known that wild bottlenose dolphins (*Tursiops* sp.) "apparently use marine sponges as foraging tools" (Krützen, Mann, Heithaus, Connor, Bejder, Sherwin, 2005) and this behaviour of them cannot be explained genetically or ecologically. This means that "sponging" is an example of an existing material culture in a marine mammal species and this culture is transmitted, presumably by mothers teaching the skills to their sons and daughters (Krützen, Mann, Heithaus, Connor, Bejder, Sherwin, 2005).

Also, chimpanzees involve tools in their behaviours: large and small sticks as well as large and small stones. In (Whiten, Goodall, McGrew, Nishida, Reynolds, Sugiyama, Tutin, Wrangham, Boesch, 1999), the authors discover 39 different behaviour patterns of chimpanzees, including tool usage, grooming and courtship behaviours. It is a very interesting fact that some patterns of chimpanzees are habitual in some communities but are absent in others because of different traditions of chimpanzee material cultures (Whiten, Goodall, McGrew, Nishida, Reynolds, Sugiyama, Tutin, Wrangham, Boesch, 1999). Hence, we see that the collective behaviour of chimpanzees can be evaluated as social, as well.

So, within symbolic interactionism we cannot consider any complex collective behaviour, like the ant nest, as a social behaviour. The rest of complex behaviours can be called a *swarm behaviour*. Its examples are as follows: swarming of insects, flocking of birds, herding of quadrupeds, schooling of fish. In swarms, animals behave collectively, e.g. in schools or flocks each animal moves in the same direction as its neighbour, it remains close to its neighbours, it avoids collisions with its neighbours (Viscido, Parrish, Grunbaum, 2004).

A group of people, such as pedestrians, can also exhibit a swarm behaviour like a flocking or schooling: humans prefer to avoid a person conditionally designated by them as a possible predator and if a substantial part of the group (not less than 5%) changes the direction, then the rest follows the new direction (Helbing, Keltsch, Molnar, 1997). An ant-based algorithm can explain aircraft boarding behaviour (John, Schadschneider, Chowdhury, Nishinari, 2008). Under the conditions of escape panic the majority of people perform a swarm behaviour, too (Helbing, Farkas, Vicsek, 2000). The point is that a risk of predation is the main feature of swarming at all (Abrahams, Colgan, 1985; Olson, Hintze, Dyer, Knoester, Adami, 2013) and under these risk conditions (like a terrorist act) symbolic meanings for possible human interactions are promptly reduced. As a consequence, the social behaviour transforms into a swarm behaviour.

Thus, *we distinguish the swarm behaviour from the social one*. The first is fulfilled without symbolic interactions, but it is complex, as well, and has an appearance from a collective decision making. In this paper, we will show that an addictive behaviour of humans can be considered a kind of swarm behaviour, also. The risk of predation is a main reason of reducing symbolic interactions in human collective behaviours, but there are possible other reasons like addiction. An addiction increases roles of addictive stimuli (e.g., alcohol, morphine, cocaine, sexual intercourse, gambling, etc.) by their reinforcing and intrinsically rewarding.

It is known that any swarm can be controlled by replacing stimuli: attractants and repellents (Adamatzky, Erokhin, Grube, Schubert, Schumann, 2012), therefore we can design logic circuits based on topology of stimuli (Schumann, 2016). For swarms there are no symbolic meanings and the behaviour is completely determined by outer stimuli. In this paper, we will consider how the alcohol dependence syndrome impacts on the human behaviour.

We claim that alcohol-dependent humans embody a version of swarm intelligence (Beni, Wang, 1969; Schumann, 2016; Schumann, Woleński, 2016) to optimize the alcohol-drinking behaviour. Our research is based on statistic data which we have collected due to the questionnaire of 107 people who sought help for their alcohol dependence at the Private Health Unitary Enterprise "Iscelenie," Minsk, Belarus.

In Section II we consider some basic features of collective behaviour of alcohol-addicted people. In Section III we formalize preference relations for their swarm intelligence.

2 BASIC FEATURES OF SWARM INTELLIGENCE OF ALCOHOL-DEPENDENT PEOPLE

According to our survey, all the respondents have affirmed that they prefer to drink in small groups from 3 to 7 people, but the same respondents can join different small groups in due course. The number of stable friends to drink commonly is from 2 to 5. The alcohol-addicted people distinguish their groups from relatives or colleagues and 63% of the respondents think that their family and job hinder them to drink safely.

Thus, these small groups from 3 to 7 people can be regarded as human swarms which help their members to drink safely and to logistically optimize the task to drink. 85% of the respondents have responded that members of the group can pay for drinks if the respondent does not have money and 91% of the respondents have claimed that they can buy alcohol for somebody from the group who does not have money. So, we deal with a form of solidarity in helping to drink.

35% of the respondents drink in groups consisting only of men and 65% drink in mixed-gender groups. In the meanwhile, a sex/gender behaviour is mainly reduced in these groups.

In the case of involving new members into groups the main reasons are as follows: they are neighbours or colleagues and they can treat/pay. Entering new groups is possible if a friend/acquainted has invited to join them because it is more safe and interesting for the respondent to join the new group. Without an invitation it is impossible to enter the group.

Groups are very friendly and the only reason to expel somebody from the group is that (s)he quarrels (in particular, (s)he does not want to pay). 32% of respondents have noticed that it would be better to expel one member in their groups.

Only 28% of respondents have stated that in their groups there are leaders. They are men or women more than 40 years old. The leadership consists in a support of the group to drink together.

We have discovered that alcoholics form a *network consisting of several small groups*. And the task of optimizing common drinks is solved not by a small group, but by the whole network, i.e. by several groups whose members are interconnected. The point is that each small group of alcoholics appears and disappears under different conditions, but the network, these alcoholics belong to, is almost the same. We have studied that small groups of alcohol-addicted people are not stable and, by exchanging their members, *they can fuse or split in the optimization of drinking*. The same behavioural patterns are observed in the slime mould (Schumann, 2015, 2016): fusing and splitting in front of attractants to optimize their occupation. Outer stimuli (attractants) for the slime mould are pieces of nutrients scattered before this organism. *Attractants for alcoholics are represented by places where they can drink in small groups safely*: flat or outside. 38% of the respondents prefer to drink at the same place and 62% at different places. The arguments in choosing the places are as follows: the short distance from the home, low price, quality of drinks.

To sum up, the alcohol-dependent people realizes a version of swarm intelligence to optimize drinking in the way of fusing or splitting the groups under different conditions. In case the groups are rather splitting, we face a *lateral activation effect*; and in case the groups are fusing, we deal with a *lateral inhibition effect* of alcoholic networks.

Small groups of alcoholics are considered by us as kind of *human swarms*. These swarms build a network and within the same network alcoholics can freely move from one swarm to another. As a consequence, the swarms fuse or split.

3 PREFERENCE RELATIONS FOR SWARM INTELLIGENCE OF ALCOHOL-DEPENDENT PEOPLE

So, the alcohol-addicted people prefer to drink in small groups from 3 to 7 persons. These groups are said to be *agents* of swarm intelligence (that is really intelligence, because an appropriate network of alcoholics solves always optimization tasks to drink effectively). Each agent is virtual, namely with an unconscious collective decision-making mechanism that is decentralized and distributed among all members of the group. The same situation of distribution of intelligence is observed in any swarm. The agents are denoted by small letters *i*, *j*,… As well as all swarms, these agents can fuse and split to optimize a group occupation of attractants. Usually, there are many agents who communicate among themselves by exchanging people (their members), e.g., someone can be a member of agent *i* today and later became a member of agent *j*.

The places where agents *i*, *j*,… (appropriate small groups of alcohol-dependent humans) can drink safely are called *attractants* for swarm intelligence. The attractants are denoted by *S*, *P*, ...

There are two different ways in occupying attractants by swarm agents: (i) with high concentration of people (lateral inhibition effect) at places of meeting and (ii) with low concentration of people (lateral activation effect) at places of meeting (Jones, 2015; Schumann, 2016). In the first case much less attractants are occupied. In the second case much more attractants are occupied. For instance, in snow winter there are less attractants (places to drink jointly and safely) and this causes a lateral inhibition effect in alcoholic swarming. In sunny summer there are more attractants (places to drink in a group) and this implies a lateral activation effect in alcoholic networking.

Lateral inhibition and lateral activation can be detected in any forms of swarm networking. For example, this mechanism is observed also in the true slime mould (plasmodium) of *Physarum polycephalum*. The plasmodium has the two distinct stages in responding to signals: (i) the sensory stage (perceiving signals) and (ii) the motor stage (action as responding). The effect of lateral activation in the plasmodium is to decrease contrast between attractants at the sensory stage and to split protoplasmic tubes towards two or more attractants at the motor stage (Fig. 1A). The effect of lateral inhibition is to increase contrast between attractants at the sensory stage and to fuse protoplasmic tubes towards one attractant at the motor stage (Fig. 1B).

In human groups there are (i) the one sensory stage consisting in perceiving signals (as well as for the plasmodium) and the following two motor stages consisting in actions as responding: (ii) illocutionary stage and (iii) perlucotionary stage.

For the first time the well-known 20th-century philosopher John L. Austin has investigated speech acts as a way of coordination for human behaviour by a verbal communication as well as by a non-verbal communication (e.g. by gestures or mimics). His main philosophical claim that was accepted then by almost all later language philosophers has based on the idea that we coordinate our joint behaviour by

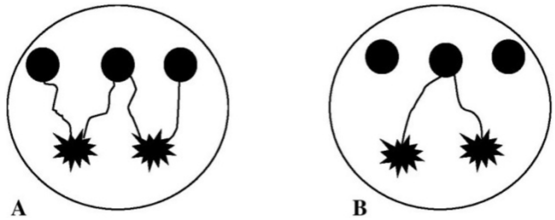

Figure 1: The two plasmodia propagate protoplasmic tubes towards three attractants denoted by black circles: A. *Lateral activation*. The splitting of protoplasmic tubes of each plasmodium. B. *Lateral inhibition* The fusion of two plasmodia by the fusion of their protoplasmic tubes.

illocutionary acts – some utterances which express our intentions and expectations to produce joint symbolic meanings for symbolic interactions: "I hereby declare," "I sentence you to ten years' imprisonment", "I promise to pay you back," "I pray to God", etc. These utterances can produce an effect on the hearer that is called a *perlocutionary act*. Hence, according to Austin, in order to commit a group behaviour, the humans should start with illocutionary acts (uttering illocutions) to coordinate their common symbolic meanings. As a result, their group behaviour appears as a kind of perlocutionary act grounded on previous illocutionary utterances.

Thus, the motor stage for the plasmodium is just a direct behaviour, while the motor stage for the humans starts from illocutionary acts to produce symbolic meanings for performing an interaction and then this stage is continued in perlocutionary acts (a direct coordinated behaviour of a human group).

Attractants *S*, *P*, ... are detected by alcoholics at the sensory stage. Then alcoholics perform illocutionary acts to share preference relations on detected attractants. Later they commit perlocutionary acts to occupy some detected attractants. A data point *S* is considered empty if and only if an appropriate attractant (the place denoted by *S* to drink within a group) is not occupied by the group of alcohol-dependent people. Let us define syllogistic strings of the form *SP* with the following interpretation: '*S* and *P* are comparable positively', and with the following meaning: *SP* is true if and only if *S* and *P* are reachable for each other by members of the group *i* and both *S* and *P* are not empty, otherwise *SP* is false. Let **S** be a set of all true syllogistic strings.

Now we can construct an *illocutionary logic of alcohol-dependent people*. In this logic we deal with preference relations about detected attractants from **S**.

3.1 Agents in Case of Lateral Inhibition

Let us construct an extension of modal logic **K**, please see (Bull, Segerberg, 1984) about **K**, for preference relations of agents in case of lateral inhibition. Let '*A*' and '*B*' be metavariables ranging over syllogistic letters *S*, *P*, ... or over standard propositional compositions of syllogistic letters by means of conjunctions, disjunction, implication, negation. Let us introduce two modalities $\bullet$ and $\circ$ with the following meaning:

$$\bullet A \Rightarrow \circ A,$$

i.e., $\bullet A$ is modally stronger and $\circ A$ is modally weaker, e.g., $\bullet A$ means 'I like *A*' (or 'I desire *A*') and $\circ A$ means 'maybe *A*' (or 'it can be *A*'). So, the performative verb of $\bullet$ is stronger and the performative verb of $\circ$ is weaker with the same type of performativity (modality) to prefer *A* (Schumann, Woleński, 2016).

In our logic **K** for preference relations we have also only two axioms as in the standard **K** (the inference rules are the same also):

Necessitation Rule:

If *A* is a theorem of **K**, then so is $\bullet A$.

Distribution Axiom:

$$\bullet (A \Rightarrow B) \Rightarrow (\bullet A \Rightarrow \bullet B).$$

The operator $\circ$ can be defined from $\bullet$ as follows:

$$\circ A ::= \neg \bullet \neg A,$$

where $\bullet$ are any performative verbs for expressing a preference relation with a strong modality: 'like', 'want', 'desire', etc.

Now let us add countable many new one-place sentential connectives $\bullet k_i$ to the language of **K**:

if *A* is a formula, then $\bullet k_i$ is a formula, too.

These $\bullet k_i$ are read as follows: "the *k*-th utterance of preference relation uttered by agent *i* to fulfil an illocutionary act". The weaker modality $\circ k_i$ is defined thus:

$$\circ k_i A ::= \neg \bullet k_i \neg A.$$

We assume that $\bullet k_i$ and $\circ k_i$ satisfy the necessity rule and distribution axiom as well.

Let us denote the new extension by **Ki**.

Now let us define in **Ki** the four basic preference relations as atomic syllogistic propositions: k_i(all *S* are *P*), k_i(some *S* are *P*), k_i(no *S* are *P*), k_i(some *S* are not *P*). They are defined as follows.

$$k_i(\text{all } S \text{ are } P) ::= \bullet k_i (S \Rightarrow P) \qquad (1)$$

The atomic proposition k_i(all *S* are *P*) means: "for agent *i*, alternative *P* is at least as good as alternative *S* by the *k*-th utterance". *In the model of alcohol-addicted swarms* it means: "for the grouping of alcohol-dependent people *i*, alternative *P* is at least as good as alternative *S* at the *k*-th utterance".

Let us define a model **M**.

Semantic meaning of k_i(all *S* are *P*):

$\mathbf{M} \models k_i$(all *S* are *P*) ::= at the utterance *k* uttered by *i*, there exists a data point $A \in \mathbf{M}$ such that $AS \in \mathbf{S}$ and for any $A \in \mathbf{M}$, if $AS \in \mathbf{S}$, then $AP \in \mathbf{S}$.

Semantic meaning of k_i*(all S are P) in alcohol-addicted swarms*: there is a group of alcoholics *i* at a place *A* such that places *A* and *S* are connected by exchanging of some members of *i* and for any place *A*, if *A* and *S* are connected by exchanging of some members of *i*, then *A* and *P* are connected by exchanging of some members of *i*.

$$k_i(\text{some } S \text{ are } P) ::= \circ k_i (S \wedge P) \qquad (2)$$

The atomic proposition k_i(some *S* are *P*) means: "for agent *i*, alternative *P* is not at least as bad as alternative *S* by the *k*-th utterance". *In the model of alcohol-addicted swarms* it means: "for the grouping of alcohol-dependent people *i*, alternative *P* is not at least as bad as alternative *S* at the *k*-th utterance".

Semantic meaning of k_i(some *S* are *P*):

$\mathbf{M} \models k_i$(some *S* are *P*) ::= at the utterance *k* uttered by *i*, there exists a data point $A \in \mathbf{M}$ such that both $AS \in \mathbf{S}$ and $AP \in \mathbf{S}$.

Semantic meaning of k_i*(some S are P) in alcohol-addicted swarms*: there exists a group of alcoholics *i* at *A* such that *A* and *S* are connected by exchanging of some members of *i* and *A* and *P* are connected by exchanging of some members of *i*.

$$k_i(\text{no } S \text{ are } P) ::= \bullet k_i (S \Rightarrow \neg P) \qquad (3)$$

The atomic proposition k_i(no *S* are *P*) means: "for agent *i*, alternative *P* is at least as bad as alternative *S* by the *k*-th utterance". *In the model of alcohol-addicted swarms*: "for the grouping of alcohol-dependent people *i*, alternative *P* is at least as bad as alternative *S* by the *k*-th utterance".

Semantic meaning of k_i(no *S* are *P*):

$\mathbf{M} \models k_i$(no *S* are *P*) ::= at the utterance *k* uttered by *i*, for all data points $A \in \mathbf{M}$, *AS* is false or *AP* is false.

Semantic meaning of k_i*(no S are P) in alcohol-addicted swarms*: for all groups of alcoholics *i* at places *A*, *A* and *S* are not connected by exchanging of some members of *i* or *A* and *P* are not connected by exchanging of some members of *i*.

$k_i(\text{some } S \text{ are not } P) ::= \circ k_i (S \wedge \neg P)$ (4)

The atomic proposition k_i(some S are not P) means: "for agent i, alternative P is not at least as good as alternative S by the k-th utterance". *In the alcohol-addicted swarms*: "for the grouping of alcoholics i, alternative P is not at least as good as alternative S by the k-th utterance".

Semantic meaning of k_i(some S are not P):

$\mathbf{M} \models k_i$(some S are not P) ::= at the utterance k uttered by i, for any data points $A \in \mathbf{M}$, AS is false or there exists $A \in \mathbf{M}$ such that $AS \in \mathbf{S}$ and AP is false.

Semantic meaning of k_i(some S are not P) *in alcohol-addicted swarms*: for all groups of alcoholics i at places A, A and S are not connected by exchanging of some members of i or there exists place A such that A and S are connected by exchanging of some members of i and A and P are not connected by exchanging of some members of i.

We can distinguish different swarms according to the acceptance of stronger or weaker modality:

Weak Agent:

agent i prefers $\circ k_i A$ instead of $\bullet k_i A$ iff $\bullet k_i A \Rightarrow \circ k_i A$.

Strong Agent:

agent i prefers $\bullet k_i A$ instead of $\circ k_i A$ iff $\bullet k_i A \Rightarrow \circ k_i A$.

An example of the weak agent: (s)he prefers not to like not-A instead of that to like A. An example of the strong agent: (s)he prefers to desire A instead of that to accept A.

Hence, in logic **Ki** we have the four kinds of atomic syllogistic propositions: k_i(all S are P), k_i(some S are P), k_i(no S are P), k_i(some S are not P) for different k, i, S, and P. All other propositions of **Ki** are derivable by Boolean combinations of atomic propositions. Models for these combinations are defined conventionally:

$$\mathbf{M} \models \neg A \text{ iff } A \text{ is false in } \mathbf{M};$$

$$\mathbf{M} \models A \vee B \text{ iff } \mathbf{M} \models A \text{ or } \mathbf{M} \models B;$$

$$\mathbf{M} \models A \wedge B \text{ iff } \mathbf{M} \models A \text{ and } \mathbf{M} \models B;$$

$$\mathbf{M} \models A \Rightarrow B \text{ iff if } \mathbf{M} \models A, \text{ then } \mathbf{M} \models B.$$

Proposition 1. Logic **Ki** is a conservative extension of **K**.

Proposition 2. In **Ki**, the conventional square of opposition holds, i.e. there are the following tautologies:

$$k_i(\text{all } S \text{ are } P) \Rightarrow k_i(\text{some } S \text{ are } P);$$

$$k_i(\text{no } S \text{ are } P) \Rightarrow k_i(\text{some } S \text{ are not } P);$$

$$\neg(k_i(\text{all } S \text{ are } P) \wedge k_i(\text{no } S \text{ are } P));$$

$$k_i(\text{some } S \text{ are } P) \vee k_i(\text{some } S \text{ are not } P);$$

$$k_i(\text{all } S \text{ are } P) \vee k_i(\text{some } S \text{ are not } P);$$

$$\neg(k_i(\text{all } S \text{ are } P) \wedge k_i(\text{some } S \text{ are not } P));$$

$$k_i(\text{no } S \text{ are } P) \vee k_i(\text{some } S \text{ are } P);$$

$$\neg(k_i(\text{no } S \text{ are } P) \wedge k_i(\text{some } S \text{ are } P)).$$

Proof. It follows from (1) – (4).

The fusion of two swarms i and j for universal affirmative syllogistic propositions is defined in **Ki** in the way:

$$\frac{k_i\,(\text{all } S_1 \text{ are } P); \quad m_j\,(\text{all } S_2 \text{ are } P)}{(k \cup m)_{i \cup j}\,(\text{all } (S_1 \vee S_2) \text{ are } P)}$$

The splitting of one swarm $i \cup j$ is defined in **Ki** thus:

$$\frac{(k \cup m)_{i \cup j}\,(\text{all } S \text{ are } (P_1 \wedge P_2))}{k_i\,(\text{all } S \text{ are } P_1); \quad m_j\,(\text{all } S \text{ are } P_2)}$$

Hence, the illocutionary logic **Ki** describes the preference relations of alcoholics towards attractants under the conditions of lateral inhibition.

3.2 Agents in Case of Lateral Activation

When the concentration of attractants (different places of grouping for common drinks) is high, the logic **K** for preference relations is unacceptable. Instead of **K** we will use its modification **K'** (with the same inference rules) (Schumann, 2013; Schumann, Woleński, 2016):

Necessitation Rule:

If A is a theorem of **K'**, then so is $\bullet A$.

Distribution Weak Axiom:

$$\bullet (A \wedge B) \Rightarrow (\bullet A \wedge \bullet B).$$

Now let us construct **K'i** by adding countable one-place sentential connectives $\bullet k_i$ and $\circ k_i$ to the language of **K'** and then define the four basic preference relations k_i(all S are P)', k_i(some S are P)', k_i(no S are P)', k_i(some S are not P)' in the following manner:

$\bullet k_i(S, P)' ::= \bullet k_i (S \wedge P)$ (5)

The atomic proposition $\bullet k_i(S, P)'$ means (Schumann, Woleński, 2016): "for agent i, alternative P is at least as good as alternative S by the k-th utterance". *In the model of alcohol-addicted swarms*: "for the group of alcoholics i, alternative P is at least as good as alternative S by the k-th utterance".

Let us define a model **M'**.

Semantic meaning of $\bullet k_i(S, P)'$:

$\mathbf{M'} \models \bullet k_i(S, P)'$ ::= there exists a data point $A \in \mathbf{M'}$ such that $AS \in \mathbf{S}$ and for any $A \in \mathbf{M'}$, $AS \in \mathbf{S}$ and $AP \in \mathbf{S}$.

Semantic meaning of $\bullet k_i(S, P)'$ *in alcohol-addicted swarms*: there is a string AS and for any place A which is reachable for S and P by exchanging of members of i, there are strings AS and AP. This means that we have an occupation of the whole region where the places S and P are located.

$$k_i(\text{some } S \text{ are } P)' ::= \bullet k_i (\neg S \wedge \neg P) \qquad (6)$$

The atomic proposition k_i(some S are P)' means (Schumann, Woleński, 2016): "for agent i, alternative P is not at least as bad as alternative S by the k-th utterance". *In the model of alcohol-addicted swarms*: "for the group of alcoholics i, alternative P is not at least as bad as alternative S by the k-th utterance".

Semantic meaning of k_i(some S are P)':

$\mathbf{M'} \models k_i$(some S are P)' ::= for any data point $A \in \mathbf{M'}$, both AS is false and AP is false.

Semantic meaning of k_i(some S are P)' *in alcohol-addicted swarms*: for any place A which is reachable for S and P by exchanging of members of i, there are no strings AS and AP. This means that the group of alcoholics cannot reach S from P or P from S immediately.

$$k_i(\text{no } S \text{ are } P)' ::= \circ k_i (S \vee P) \qquad (7)$$

The atomic proposition k_i(no S are P)' means (Schumann, Woleński, 2016): "for agent i, alternative P is at least as bad as alternative S by the k-th utterance". *In the model of alcohol-addicted swarms*: "for the group of alcoholics i, alternative P is at least as bad as alternative S by the k-th utterance".

Semantic meaning of k_i(no S are P)':

$\mathbf{M'} \models k_i$(no S are P)' ::= there exists a data point $A \in \mathbf{M'}$ such that if AS is false, then $AP \in \mathbf{S}$.

Semantic meaning of k_i(no S are P)' *in alcohol-addicted swarms*: there exists a place A which is reachable for S and P by exchanging of members of i such that there is a string AS or there is a string AP. This means that the group of alcoholics i occupies S or P, but not the whole region where the places S and P are located.

$$k_i(\text{some } S \text{ are not } P)' ::= \circ k_i (\neg S \vee \neg P) \qquad (8)$$

The atomic proposition k_i(some S are not P)' means (Schumann, Woleński, 2016): "for agent i, alternative P is not at least as good as alternative S by the k-th utterance". *In the model of alcohol-addicted swarms*: "for the group of alcoholics i, alternative P is not at least as good as alternative S by the k-th utterance".

Semantic meaning of k_i(some S are not P)':

$\mathbf{M'} \models k_i$(some S are not P)' ::= for any data point $A \in \mathbf{M'}$, AS is false or there exists a data point $A \in \mathbf{M'}$ such that AS is false or AP is false.

Semantic meaning of k_i(some S are not P)' *in alcohol-addicted swarms*: for any place A which is reachable for S and P by exchanging of members of i there is no string AS or there exists a place A which is reachable for S and P by exchanging of members of i such that there is no string AS or there is no string AP. This means that the group of alcoholics i does not occupy S or there is a place which is not connected to S or P by exchanging of members of i.

Models for the Boolean combinations of atomic proposition of **K'i** are defined thus:

$$\mathbf{M'} \models \neg A \text{ iff } A \text{ is false in } \mathbf{M'};$$

$$\mathbf{M'} \models A \vee B \text{ iff } \mathbf{M'} \models A \text{ or } \mathbf{M'} \models B;$$

$$\mathbf{M'} \models A \wedge B \text{ iff } \mathbf{M'} \models A \text{ and } \mathbf{M'} \models B;$$

$$\mathbf{M'} \models A \Rightarrow B \text{ iff if } \mathbf{M'} \models A, \text{ then } \mathbf{M'} \models B.$$

Proposition 3. Logic **K'i** is a conservative extension of **K'**.

Proposition 2. In **K'i**, the unconventional square of opposition holds, i.e. there are the following tautologies:

$$k_i(\text{all } S \text{ are } P)' \Rightarrow k_i(\text{no } S \text{ are } P)';$$

$$k_i(\text{some } S \text{ are } P)' \Rightarrow k_i(\text{some } S \text{ are not } P)';$$

$$\neg(k_i(\text{all } S \text{ are } P)' \wedge k_i(\text{some } S \text{ are } P)');$$

$$k_i(\text{no } S \text{ are } P)' \vee k_i(\text{some } S \text{ are not } P)';$$

$$k_i(\text{all } S \text{ are } P)' \vee k_i(\text{some } S \text{ are not } P)';$$

$$\neg(k_i(\text{all } S \text{ are } P)' \wedge k_i(\text{some } S \text{ are not } P)');$$

$$k_i(\text{no } S \text{ are } P)' \vee k_i(\text{some } S \text{ are } P)';$$

$$\neg(k_i(\text{no } S \text{ are } P)' \wedge k_i(\text{some } S \text{ are } P)').$$

Proof. It follows from (5) – (8).

Now, let us consider pairs $\bullet k_i\, A$ and $\bullet m_i\, \neg A$, where different performative verbs $\bullet k_i$ and $\bullet m_i$ occur and these verbs belong to different groups of illocutions in expressing a preference relation, i.e., both cannot be simultaneously representatives, directives, declaratives, expressive, or comissives.

For instance, ‘believing’ and ‘knowing’ are both representatives and ‘ordering’ and ‘insisting’ are both directives. Assume, ‘believing’ be denoted by $\bullet k_i$ and ‘advising’ by $\bullet m_i$. Notice that ‘assuming’ is modally weaker than ‘believing’, and ‘advising’ is modally weaker than ‘insisting’. So, ‘assuming’ can be denoted by $\circ k_i$, and ‘advising’ can be denoted by $\circ m_i$, such that $\bullet k_i A \Rightarrow \circ k_i A$ and $\bullet m_i A \Rightarrow \circ m_i A$. The construction $\bullet k_i A \Rightarrow \bullet m_i \neg A$ (respectively, $\circ m_i A \Rightarrow \circ k_i \neg A$) fits the situation that a belief that *A* is ever stronger than some other illocutions (belonging to other illocution groups) related to not-*A*.

Let us distinguish different swarms according to the acceptance of stronger or weaker modality:

Meditative Agent:

(i) agent *i* prefers $\bullet m_i \neg A$ instead of $\bullet k_i A$ iff $\bullet k_i A \Rightarrow \bullet m_i \neg A$; and (ii) agent *i* prefers $\circ k_i \neg A$ instead of $\circ m_i A$ iff $\circ m_i A \Rightarrow \circ k_i \neg A$.

Active Agent:

(i) agent *i* prefers $\bullet k_i A$ instead of $\bullet m_i \neg A$ iff $\bullet k_i A \Rightarrow \bullet m_i \neg A$; (ii) and agent *i* prefers $\circ' A$ instead of $\circ k_i \neg A$ iff $\circ m_i A \Rightarrow \circ k_i \neg A$.

An example of the meditative agent: (s)he prefers to believe that not-*A* instead of that to order that *A*. An example of the active agent: (s)he prefers to insist that *A* instead of that to believe that not-*A*.

The fusion of two swarms *i* and *j* universal affirmative syllogistic propositions is defined in **K'i** as follows:

$$\frac{k_i\,(\text{all } S_1 \text{ are } P)'; \quad m_j\,(\text{all } S_2 \text{ are } P)'}{(k \cup m)_{i \cup j}\,(\text{all } (S_1 \wedge S_2) \text{ are } P)}$$

The splitting of one swarm $i \cup j$ is defined in **K'i**:

$$\frac{(k \cup m)_{i \cup j}\,(\text{all } S \text{ are } (P_1 \wedge P_2))}{k_i\,(\text{all } S \text{ are } P_1); \quad m_j\,(\text{all } S \text{ are } P_2)}$$

The illocutionary logic **K'i** is to express the preference relations of alcoholics towards attractants under the conditions of lateral activation.

4 CONCLUSIONS

We have shown that a habit of joint drinking of alcohol-addicted people in small groups can be considered a swarm behaviour controlled by outer stimuli (places to drink jointly). These swarms can be managed by localization of places for meeting to drink. Generally, the logic of propagation of groups of alcoholics has the same axioms as the logic of parasite propagation for *Schistosomatidae* sp. (Schumann, Akimova, 2015) as well as the same axioms as the logic of slime mould expansion (Schumann, 2015, 2016). The difference is that instead of syllogistics for *Schistosomatidae* sp. (Schumann, Akimova, 2015) and for slime mould (Schumann, 2016), where preference relations are simple and express only attractions by food, we involve many performative actions (verbs), which express a desire to drink together, within modal logics **Ki** and **K'i**. The logic **Ki** is used to formalize lateral inhibition in distributing people to drink jointly and the logic **K'i** is used to formalize lateral activation in distributing people to drink jointly.

The main outcome of our research is to show that some forms of human group behaviour are not social in fact. A kind of unsocial group behaviours is designated by us as swarm behaviour. Many forms of human swarming have recently been studied – from crowds of people in escape panic (Helbing, Farkas, Vicsek, 2000) to aircraft boarding (John, Schadschneider, Chowdhury, Nishinari, 2008). However, some stable patterns of interconnected people have never been analyzed as a swarm.

We have proposed to consider a network of coordinated alcoholics as human swarming. The reasons are as follows: (1) their behaviour is controlled by replacing stimuli: attractants (places where they can drink jointly and safely) and repellents (some interruptions which can appear for drinking); this control is executed by the same algorithms as for standard swarms from social bacteria to eusocial mammals; (2) the behaviour of alcoholics is collective and even cooperative, but it is subordinated to the only one uncontrolled intention, namely, how to drink; so, this motivation bears no symbolic meanings in the terms of symbolic interactionism (Blumer, 1969) and, then, it cannot be evaluated as social.

Each alcoholic realizes a group adaptation and belongs to a network of people with the same addiction. This network allows its members to optimize the task to drink. Therefore, it is a substitute of social groups (from family to other institutions) and it is a displacement of standard social behavior.

One of the effective means to recover alcoholism is a back replacement of ways of group optimization how to drink by that how not to drink. It is possible within a network of the so-called Alcoholics Anonymous where alcoholics can help each other to stay sober.

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