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Bogusław Filipowicz*, Mirosław Zajdel*

Close Range Interactions in Crowd with Homogeneous Structure

1. Introduction

There are pretty interesting characteristics of each human crowd. We can study crowd, like pedestrians in the street, walking in the city, and they don't behave in a completely unpredictable way. When we look at a crowd as a collective formation, there is some degree of organization, which means that there are, for example, many streams of individuals being created in the crowd [16] and each stream has a special area of the space and way of appearing and disappearing simultaneously, and it depends on whether all the people are going in the same direction or there are opposite directions, or they is 90^{o} angle between them [9]. The Figure 1 shows an example of such streams in human crowd, which seem to create automatically and independently from one another. The number and size of these formations depends on organization characteristics of the crowd, like direction or directions of movement or density.

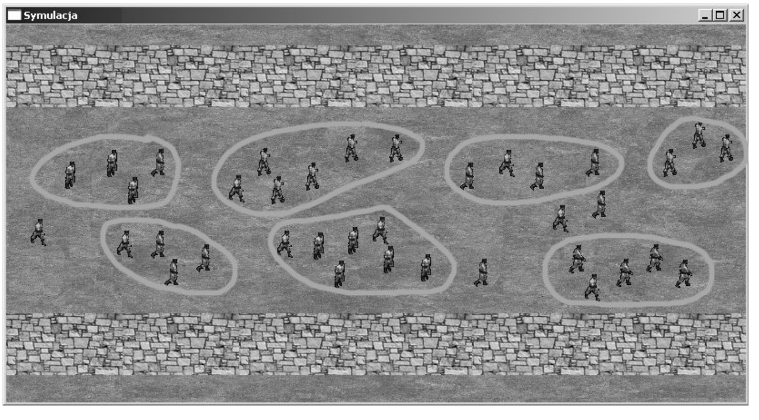

Fig. 1. Example of interactions in crowd making self-organization – creation of multi-streams

* AGH University of Science and Technology, Krakow

However this kind of view shows us, that crowd is self-organizing and adaptive and it depends on the traffic volume and many other factors of the environment. So the nice thing would be to increase the efficiency of pedestrian use of the space in such way. For example in points like bottlenecks made by door or any other objects or their arrangement, there often occurs oscillating passing pattern. It means that people are passing the door from one to the other side simultaneously [5–6, 9]. Firstly the movement is being made from one area to the other, and after a short period of time the direction changes, and such process is being repeated. Those two parts of the whole process are illustrated in the Figure 2. In that behaviour, self-organization reaches only small part of people, which are passing through the door at the moment, while the other part of the crowd remains in a little mess.

To improve the movement through bottlenecks like that, we need some artificial objects to be located in the area, in which crowd moves, or some changes to be made in the environment, for sure [4, 9]. The crowd seems to be pretty unconscious of its situation, of the environment's characteristics and even dangerous factors in the area.

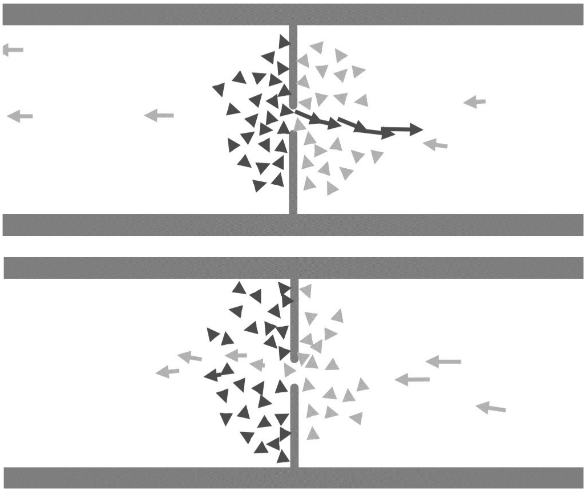

Fig. 2. Example of interactions in crowd making self-organization – oscillation in bottlenecks

But when we assume that crowd is homogenous and the area in which it is being got around, we can find some simple interactions between individuals, which make whole crowd to move intelligently and use the space in a quite effective way. In most of cases pedestrians are not even aware of participating in such a connected and complicated pattern of motion, it just happens by the interaction of the individuals [8]. It hasn't been noticed even through scientific research for a long time. Discovery of such interactions and patterns was possible by recording movement of the crowd and watching it again with accelerated speed [13]. That was the point, in which some human-animal connection phenomena were clearly visible.

2. Close Interactions in the Herd

2.1. Fish Shoals Theory for Human Crowd

Main benefits, which result from gathering fishes into shoals are better protection against predators and improvement of feeding efficiency [1]. That second advantage appears from transferring signals through the shoal about clusters of food. But the first one is strictly connected with some non-verbal interactions between individuals, what brings making dodges by the shoal as an effect. It seems that in homogeneous fish shoal just a few simple rules cause that the overall safety of fishes is being improved. Like we can observe in the Figure 3, homogeneous fish shoal can pretend one, huge, virtual organism under normal circumstances, but it may also easily avoid obstacles, feed or react on the appearance or attacks of predators, staying in all of those situations together and being coherent.

There have been created some models of fish shoal movement and they have appeared to be pretty similar in simulations to models of other herd species, like antelopes herds or birds flocks [2, 10, 12, 15]. But it is important, that fish movement models were the clearest ones among all of them, because of its homogeneous structure. Not only shoal are usually pretty homogeneous, but also the water environment is much more homogeneous than solid land environment, and to it quite devoid of obstacles. Those things make the research to be easier and that's why shoal rules are easy to notice and to be mathematically specified.

Fig. 3. Homogeneous fish shoal with visible self-organization

Fish shoal is not organized hierarchically and it doesn't have its internal structure. All the individuals are taking the same position in the shoal and no one of them is global or local leader. It would be pretty difficult to achieve the situation, in which there would be one or more leaders, because of the dynamics of movement of the shoal. In case of rapid turn, the role of the leader ought to be transferred to the individual on the other side of the shoal [11]. That's why it is impossible to achieve.

Similar situation we can observe among human crowd, which behaves like one, huge, tight organism, making some synchronic movements to avoid dangers or to escape through bottlenecks like doors, passageways or tunnels.

There are more similar behaviours within fish shoals and human crowds. In case of danger source, for example, both of them can spread rapidly in all of the directions (assuming that there is enough space) or gather into tight herd. From time to time the main direction for whole crowd changes. That's because some close range interactions appear between individuals, their movement direction is strictly connected and more or less dependent on the movement direction of individual's neighbours [3].

As people in the human crowd influence on one another, so do fishes. Alarmed fish individuals starts to make some warning moves, which other fishes recognize and become more stimulated, and so the signal is being transmitted through the shoal [7]. Similar phenomenon we observe in human crowd under danger, in which panic and bad feelings spread pretty rapidly through the crowd.

2.2. Model Details

All of those similarities in characteristics of fish shoal and human crowd behaviour persuaded us to create a model, which consists of a few most similar phenomena, which actually were close-range distance interactions, and apply it to human crowd movement overall interpretation. Such model is not sufficient and not complete of course, but it may be pretty helpful to fill up the model of crowd basing on herd animals instinct behaviour in dangerous and panic situations. Pointing out some simple rules of human crowd behaviour contributes to creation of completed model of behaviour heterogeneous crowd among heterogeneous environment and to its control as a target.

2.2.1. Local Zones

Movement of each individual is represented by the product of force vectors, coming from environment and from neighbours of the individual. The influence of environment is connected with its diagnosis, interpretation and as a result – the action, which individual wants to take. The influence of neighbours is being taken according to circular zones round the individual, shown in the Figure 4.

Those zones can be described as:

– Repulsion zone – it is the zone with quite minimal radius, but its main aim is to minimize collisions and help to avoid situations with unnatural blockades; the closer another individual is, the greater repulsion force is,
– Neutral zone – it is also the thin ring, which is to separate repulsion and attraction zones, and therefore force vectors dynamics and changes are more natural; in that zone all of force vectors are "zero vectors",

– Attractive zone – from that, wide zone, all the force vectors of attraction come from,
– Searching zone – when an individual is staying in the point, where no neighbours are in its internal zones, it starts to search for the herd and attractive zone becomes a part of attractive zone.

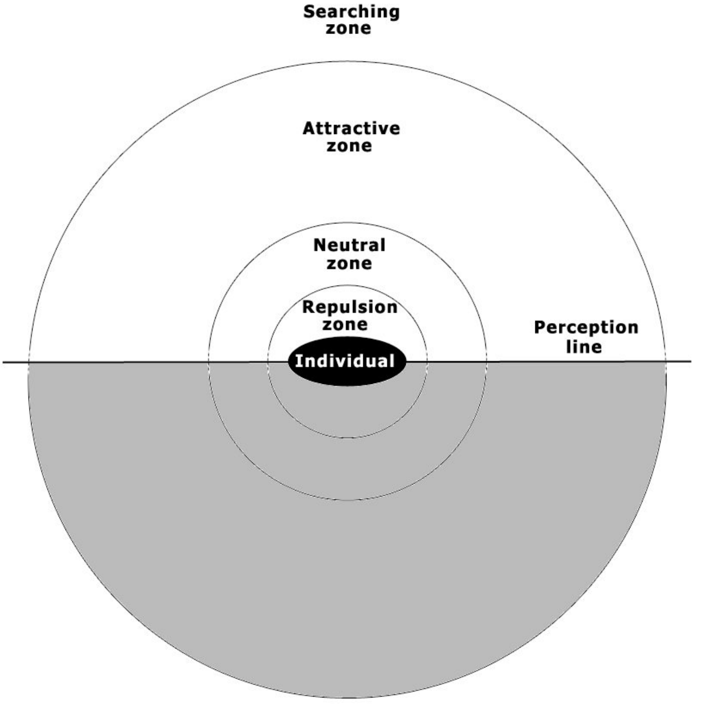

Fig. 4. Circular zones for each individual in the herd

There are also two specific parts of getting stimula from the zones by individual. They are created by a line called perception line. It represents the ability of seeing and "feeling", what is around the individual, connected with the specification of its sight. Individuals normally are recognizing events taking part in front of them, so the backwards part is being taken into consideration with smaller priority.

2.2.2. Position in the Herd

It has been proved, that individuals separated from the herd are being more often attacked by predators. What is more, the security for an individual is higher in numerous groups of herd (assuming that overall the herd is more or less grainy). That is why each individual tries to stay close to the most numerous part of the herd [14]. But it is not always true.

Security of an individual depends not only on quantity of the group which it is in, but also on the efficiency of movement and reactions on external events, like sources of danger.

The problem is that the herd is hardly ever clearly homogeneous. So why does shoal look like homogeneous structure? That is, because there is some kind of sort, a specific arrangement of individuals of different size or species. Individuals of same characteristics are trying to follow one another, because in homogeneous group they are more efficient in their overall reactions, and when such state occurs, there is no problem in staying even totally different groups of individuals on the opposite parts of the shoal!

Following that reasoning, we can specify a desirable move of each individual as an important component of environment influence vector of force as:

$$\vec{F}_p = \sum_{i=1}^{n} m_i \cdot \sum_{j=1}^{m_i} \vec{F}_{ij} \tag{1}$$

where:

- n – the number of different types of individuals in the herd (it may vary according to chosen model quantization),
- m_i – the quantity of individuals of type i,
- $\vec{F}_{ij}$ – the vector of movement for the individual number j of type i.

2.2.3. Spreading and gathering

Different factors may cause the spread of the tightly coupled herd of animals or human crowd. They can be attacking predators, fire, things thrown into the crowd, crushing parts of environment, etc. There appears a question, what should individuals do in such situations and what ought to be their algorithm of improving their security.

As it has been discussed above, individuals are trying to chose and joins that group in the herd, in which the number of individuals is the highest and at the same time that group has to be located in individual's near neighbourhood. But not always it is profitable to join a group, which is quite far from us. It might be more efficient first to join a smaller group, which is closer and then to look for an opportunity to switch to bigger one, and finally, as a result of gathering, main part or whole tightly coupled herd.

Therefore part of individual's behaviour, connected with improving its security searching for numerous part of herd, can be described according to equation:

$$\vec{F_g} = \sum_{i=1}^{p} R_i(\ ) r_{IC_i} \cdot \vec{F_p} \tag{2}$$

where:

- p – the number of groups (components; visible parts of the whole herd),
- $R_i() \to]0;1[$ – function, which represents the security level of action of joining group number i,
- $\vec{r}_{IC_i}$ – the distance vector from the location of specific individual (I) to the center of group number i (C_i).

3. Conclusions

The main and overall conclusion of discussion above is that we don't notice some simple interactions in crowd, when its structure is pretty heterogeneous and to it, the environment, in which the situations takes place is strongly complicated. Under such circumstances we are unable to recognize simple rules and connect them with those seen in another type of crowd, in animal herds like fish shoals. In this way we lose many opportunities to improve control, which crowd is under, and to it increase the security level in many dangerous situations.

Connecting crowd research with animal herds shows out, that the conventional design of architectural elements, including corridors, bottlenecks or intersections can all be improved for sure after proper simulations of human-animal model of the crowd movement in specific area. That means it can increase and enhance the efficiency of evacuation under danger.

It is quite surprising, what kind of control improves that efficiency. Sometimes even placing something, which looks like useless and even unfavourable obstacle is beneficial for the efficiency of walking, because it helps to separate different flow directions, and also can reduce the pressure in a pushing crowd and similar kind of things. There is also possibility to use architectural features, which can have psychological effect to attract people to a certain location or lead them through a specific path. Using light of other visual cues can help to organize the crowd in specific, desirable way, as well. All of that things can be used much more than has been done in the past and much more than we have thought up till now. The is a lot of potential in physical human crowd control method using animal herds investigation.

The problem is, that most of people still are afraid of solutions, which are based on different rules than central control. The main reason is that in most cases only centralized mechanism can lead us to optimized solutions. In fact, the orientation and type of control of the system is not the one and only condition for getting optimal result and to it, such solutions not always lead to it. In many cases pretty grainy distribution of control brings us significant outcome. Mechanisms without centralized control can be used in a very beneficial way, it can be resource-efficient, can make use of creativity much better than a centralized system can do, to it allows to improvise and to be creative.

The main point is to create optimal close range distance interactions conditions, so that self-organization would create good solution. Such process would be an evolutionary process, leading models and systems, basing on animal herds observation and getting rules from them, to a higher level of quality and efficiency.

References

[1] Cai E., *Emergence in collective animal behaviour.* 2009.
[2] Couzin I.D., Krause J., Franks N.R., Levin S.A., *Effective leadership and decision-making in animal groups on the move.* Nature, nr 433, s. 513–516, Nature Publishing Group. 2005. ISSN 0028-0836.

[3] Donner S., *Going with the flow: learning from fish could prevent crowd panic.* 2009.
[4] Dyer J.R.G., Johansson A., Helbing D., Couzin I.D., Krause J., *Leadership, consensus decision making and collective behaviour in humans.* Philosophical Transactions of The Royal Society: B – Biological Sciences, nr 364, s. 781–789, 2009, ISSN 1471-2970.
[5] Foudil Ch., Noureddine D., *An autonomous and guided crowd in panic situations.* Journal of Computer Science & Technology, nr 7(2), s. 134–140, ISTEC, Albuquerque, 2007, ISSN 1666-6038.
[6] Foudil Ch., Noureddine D., *Crowd simulate in panic situations.* 2006.
[7] Gautrais J., Jost Ch., Theraulaz G., *Key behavioural factors in self-orginised fish school model.* Helsinki 2008.
[8] Han J., Li M., Guo L., *Soft control on collective behavior of a group of autonomous agents by a shill agent.* Journal of Systems Science and Complexity, nr 19, s. 54–62, Institute of Systems Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, 2005, ISSN 1009-6124.
[9] Helbing D., Molnar P., Farkas I.J., Bolay K., *Self-organizing pedestrian movement.* Environment and Plannib B – Planning and Design, nr 28, s. 361–383, Pion, 2001, ISSN 0265-8135.
[10] Pitcher T.J., *Behaviour of teleost fishes.* Londyn 1992, ISBN 978-0412429408.
[11] Tegeder R. W., Krause J., *Density dependence and numerosity in fright stimulated aggregation behaviour of shoaling fish.* Philosophical Transactions of The Royal Society: B – Biological Sciences, nr 350, s. 381–390, 1995, ISSN 1471-2970.
[12] Tien J.H., Levin S.A., Rubenstein D.I., *Dynamics of fish shoals: identifying key decision rules.* Evolutionary Ecology Research, nr 6, s. 555–565, Evolutionary Ecology Ltd., 2004, ISSN 1522-0613.
[13] Wasilkowska A., Nowak A., Batty M., Erbel J., Helbing D., De Landa M., Solomon S., *Ekspektatywa_3.* Fundacja Bęc Zmiana, Warszawa 2009.
[14] Wołoszyn P., *Modeling the dynamics of chaotic biological systems using multi-agent methods* (in Polish) *Modelowanie dynamiki chaotycznych systemów biologicznych z użyciem metod multiagentowych*) (Ph.D. thesis)*,* Kraków 2004.
[15] Woo Lee S., *A bio-inspired group evasion behavior.* 2009.
[16] Zajdel M., *Multi-stream pattern of crowd dynamics in dangerous situations basing on animals social behaviour (*in Polish: *Wielostrumieniowy wzorzec dynamiki tłumu w sytuacjach zagrożenia oparty na zachowaniach stadnych zwierząt)* [w:] Kierunki działalności i współpraca naukowa Wydziału Elektrotechniki, Automatyki, Informatyki i Elektroniki – materiały konferencji zorganizowanej z okazji Jubileuszu 90-lecia AGH, Kraków 2009.