Understanding crowd behaviour

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Chapter 7

The role of leadership in crowds

The crowd at the beach festival described in chapter 1 represents a huge social event. Let's again take a bird's-eye view of the beach festival site, zooming in on the various identifiable groups. In addition to behaviour patterns of involving the queues at the bar and toilets, or the dancers in front of the stage, there were other very group specific patterns could be recognised. For instance, the group of visitors that attacked and chased the LEOs. The attack started when this group surrounded two LEOs, and formed a typical ring-shaped pattern. This was followed by the typical lanes when the attackers followed the withdrawing LEOs. Although these specific patterns are typical crowd behaviour patterns, they are a-typical in a festival context. The sequence of snapshots of this particular group keeps on displaying very group-specific behaviour, which is different from the other behaviour exhibited at the festival. While chasing the LEOs at a certain point, the group was stopped by a fence. Shortly after that, a few persons started shaking the fence, and a little while later, the majority of the group was tearing down the fence and continued the chase. Similar accounts can be given with regard to the count-down. The action was initiated by one or two persons, who were followed by a larger part of the group later on. The intergroup dynamics (i.e. the social context) were clearly dominant in the behaviour of these individuals.

This chapter will focus on exploring the role of leadership (i.e. a power relationship) in crowd behaviour patterns, using the CROSS model. From the density experiment it was learned that density can function as an intensifier on behaviour clustering. The density levels will therefore also be varied in order to explore the interplay with the role of leadership in crowd behaviour patterns, i.e. behaviour clustering. Current knowledge of crowd behaviour learns that social environment plays an important role (see chapter 2). The emergence of specific behaviour patterns is often the object of study. However, in order to gain a general understanding, it is necessary to concentrate on the mechanisms underlying behavioural patterns in general. Therefore, the emphasis lies on the rise of patterns of any kind of behaviour, instead of on the rise of a specific behavioural pattern.

Leadership is the phenomenon in which a person exerts more influence on his social environment than others influence theirs. Leadership research shows that ex-

erting influence on others can be described on the basis of the attributes or skills of an individual, the specific context in which leadership is exercised, or the interaction that has taken place. Although in these studies most attention is paid to the leader figures themselves, implicitly as well as by definition all these studies involve interpersonal interaction. However, much less attention is paid to the other interaction partners: the followers, the persons being influenced by leaders. In order to understand crowd behaviour, this perspective is very important, as it is the 'followers' that do or do not exhibit certain behaviour. In this thesis, leadership is therefore considered an inter-individual process, in which a leader is defined from a follower's perspective. It is only the perception of someone as a leader that will affect the behaviour selection process of individuals, not the attributes or skills of an individual identified as a leader.

In this study, leadership will be explored in a simulated festival setting using the CROSS model (see chapter 3 and 5). In the CROSS model, leadership is considered as a social influence factor that affects agents according to the representation an agent has of others, whether they are leaders or not. This individual, local and subjective perception of leaders will influence agent behaviour via the changes in cognition, i.e. some behaviour becomes more relevant due to the social context. The agents in the experiment are heterogeneous in terms of what they perceive, as their perception is limited and depends on their position. They are also heterogeneous in terms of how they perceive other agents, e.g. leaders. In this simulation experiment, the agents that are regarded as leaders are fixed. They are the same for everyone and no leader is aware of being a leader himself. This is a simplification that allows to explore leadership, rather than a realistic representation of differences in the perception of others as leaders. For this reason leader agents are not modelled with specific attributes. Furthermore, the role of the perception of a leader is moved away from the leader to the internal representation of a follower. This is an important theoretical stance taken by following the CROSS model perspective. By varying the number of leaders, the influence that leaders exert will vary as more agents will perceive a leader.

7.1 The role of leadership

Crowds are social phenomena. Describing a large event, such as the beach festival, and especially the aggression of the group that was attcking the LEOs, triggers a lot of questions: "What causes people to initiate certain behaviour", even more interestingly "What causes people to join in such activities" and "What is the behavioural effect of perceiving someone as a leader in a crowd setting?". Answers to these questions would improve the insight into the role of an agent's social context. To explore the role of leadership, the CROSS model integrates several relevant theories and viewpoints on leadership at the cognitive level of description. As discussed in chapter 3, research on leadership concentrates mainly on the characteristics and skills of the leaders themselves, and on the context giving rise to an outcome of 'followers', for instance followers imitating a leader or being obedient. This thesis will deal with the perspective of the followers: what is it that affects a person's behaviour when he considers someone a leader? Leadership is explored by incorporating the subjective perception of someone as a leader in relation to behaviour expectation. The effect of perceiving someone as a leader concerns the fact that behaviour shown by the leader

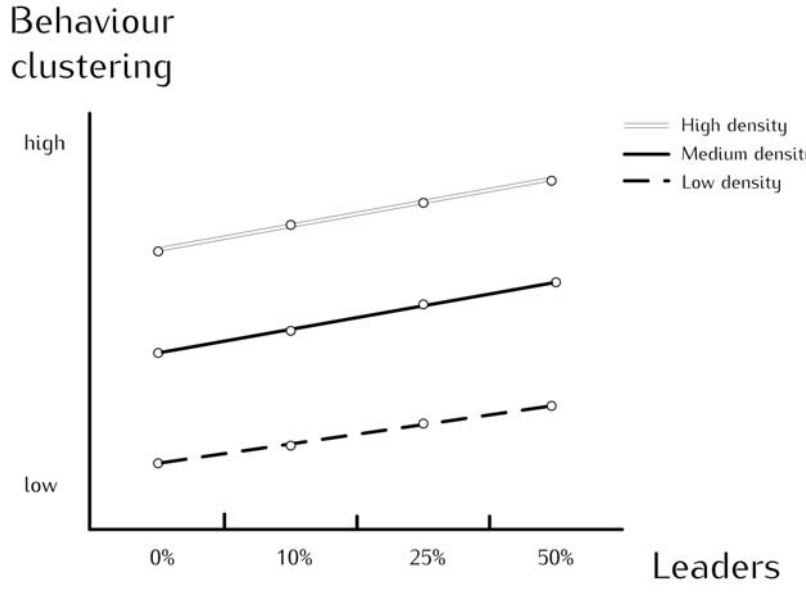

Figure 7.1: The expectation with regard to the role of leaders in crowd behaviour clustering.

becomes more relevant, which increases the probability of imitation.

The research conducted for this thesis specifically investigates how the presence of leaders influences behaviour clustering patterns in a crowd. For instance, does the presence of more leaders lead to a higher degree of behaviour clustering? What role does density play in this process? Like the previous chapter, a multi-level approach will be taken to answer the questions. Not only the relationship between leadership and behaviour clustering will be examined, but also the (intra-) individual level influences.

Leadership is expected to result in an increase in behaviour clustering. Leadership is defined as a process in which an individual exerts more influence on others than non-leaders do. The presence of a leader increases the probability of imitation. These expectations are visualised in figure 7.1. Behaviour clustering is expected to increase when the number of people that are perceiving a leader increases. A higher number of leaders will therefore increase behaviour clustering. At higher density levels, more people will be influencing each other, which will result in a rise in behaviour clustering (see chapter 6). An increase in density combined with an increase in the number of leaders is expected to establish an additive effect.

Table 7.1: Design of the leadership experiment: showing the twelve conditions of the leadership experiment resulting from the manipulation of the number of leaders and the density level.

Leadership	0%	10%	25%	50%
Density				
Low	Condition - 1	Condition - 2	Condition - 3	Condition - 4
Medium	Condition - 5	Condition - 6	Condition - 7	Condition - 8
High	Condition - 9	Condition - 10	Condition - 11	Condition - 12

The expectations can be formulated as the following hypothesis:

1. An increase in the number of leaders will lead to more behaviour clustering.

There are no specific expectations concerning an interaction effect. However, in order to be sure, it will be tested whether such an effect exists.

7.2 The CROSS experiment model

To investigate the role of leadership in behaviour clustering and to test the hypothesis above, a 4x3 experimental design was drawn up, manipulating both leadership and density. Leadership was manipulated in term of the percentages of the crowd that were leaders: `0%,10%, 25%,50%`. Density was manipulated as in the preceding experiment with `{low,medium,high}` density conditions. This manipulation and the resulting twelve conditions are displayed in table 7.1.

Before the leadership experiment, like the density experiment, can be run, the computational model must be prepared for experimental usage, i.e. phase 3 in the life cycle of simulation research (see section 4.2.3). Although this experiment focuses on leadership, the context and set-up of the experiment is the same as in the previous experiment. Consequently, most of the settings are the same. Each variable will be addressed, i.e. the leadership specific variables. The variables that are identical to those from the previous experiment will be set out in a summarised version of the previous chapter.

7.2.1 The leadership experiment variables

To perform a simulation experiment with the CROSS model, the independent variable (i.e. density) and the dependent variables (i.e. behaviour clustering and the life-history variables) need to be specified. Several variables (e.g. density, behaviour clustering) were already used in the density experiment and will be addressed only shortly in this chapter. For full details the reader is referred to the relevant sections in chapter 6.

The independent variables

In exploring the effect of leadership on crowd behaviour, two group level variables, *leader count* and *density* can be defined. These are the independent variables. `Leader count` concerns the relative amount of leaders in a crowd and will be represented as a percentage. The amount of leaders will be varied, distinguishing between *no leaders* and an increasing amount of leaders from *low* to *high*: {0%,10%,25%,50%}. Both 0% and 50% represent the extremes (i.e. no leaders and many leaders), whereas regarding the rising percentage of the leaders, more agents will observe and thus be influenced by a leader. `Density` concerns the group level description of a crowd, representing the number of people per m^2. It indicates crowdedness in three levels {low, medium, high}. This is identical to the manipulation in the density experiment, where a crowd of {227, 681, 1275} agents was created respectively. Please note that only density itself is manipulated, not the perception of density.

The dependent variables

Life-history variables. In explaining the group-level relation between leadership and density on behaviour clustering, individual *life-history* variables will be used. These life-history variables are measured for an individual or aggregate of individuals every time step, like in the previous chapter. For this experiment, the following individual life-history variables will be used: *observed leaders*, *behaviour expectation*, *behaviour utility*, and *behaviour*. During a simulation run, these in-depth descriptions of an agent will be used to give a rich explanation of the group level behavioural patterns. *Observed leaders* represent the leaders that are locally perceived by an agent. Of course, the perception of the number of agents and leaders is limited by the range of sight. In addition, the maximum number of visible agents is 13, given the range of sight. *Behaviour expectation* is an internal variable that represents the expectation whether a behaviour fact will satisfy an agent's social goal. This value is updated when an agent perceives a leader. It then changes the relevancy of a certain kind of behaviour according to the internal state at that moment. This is represented by *behaviour utility*. All these values play a role in the behaviour selection process, distinguishing between more suitable or less suitable behaviour at a certain moment in time.

The group level variable. At the group level, the same dependent variable is used as in the density experiment: *behaviour clustering*. Behaviour clustering describes a crowd behavioural pattern of identifiable subgroups composed of agents that exhibit the same behaviour at a given time step, i.e. crowd behaviour patterns. In other words, behaviour clustering captures the overall behaviour characteristics in one number, which is an aggregate of what the agents are doing (i.e. individual level → group level). Behaviour clustering is formalised as the number of dyads that exhibit the same behaviour at the same time-step, with the individuals in the dyads being in the physical vicinity of each other (see the (pseudo) algorithm 6.2 in the previous chapter).

Table 7.2 summarises the described variables that are used in this experiment to manipulate, to measure outcome and to explain crowd behaviour in the experimental

Table 7.2: An overview of the variables of the leadership experiment.

Leadership experiment variables				
Group level	Independent		Leadership [leader count - %]	{0%, 10%, 25%, 50%}
			Density [persons/m^2] [probability distribution]	Low = 1 Medium = 3 High = 5.5
	Dependent		Behaviour clustering	$[0, n(n-1)/2]$
Individual	Life-history	inter	Observed leaders	$[0, 13]$
			Behaviour	{walk,run,dance}
		intra	Behaviour expectation	$[0, 1]$
			Behaviour utility	$[0, 1]$

set-up.

7.2.2 Model settings

Now that the experimental design has been explained, the CROSS model can be specified for experimental usage. This includes specifying every aspect of the CROSS model: the physical environment, the social environment, the experimental settings and the agents themselves. The physical environment defines the relevant festival areas; the social environment describes the amount of agents and leaders as well as the social structure; and the agents are the actors in the simulation that are provided with relevant behaviour, knowledge and sensors for the festival context.

The physical environment

The physical environment is represented as areas that are walkable or non-walkable. Areas are represented by a collection of grid cells. The relevant areas for the festival scenario include: the toilets, the bar and the stage areas. Each area contains a point of interest that represents that area, for instance, the middle part of the front of the stage is attractive for the agents when moving towards the stage. A point of interest can thus be considered hard-coded common knowledge that concerns the meaning and implication of a certain place that can be regarded as a global perception. It does not concern regular perception, which is local. This simply means that being at or near a point of interest will satisfy a goal, for instance standing close to the stage will satisfy the identity goal (see sections 3.3.3 and 5.2.2).

The social environment

The social environment is that part of the crowd model that describes the group level characteristics. For this experiment, leadership (leader count), density and the social

structure are defined on group level, where leadership is a specific formalisation to test the leadership hypothesis. Note that each group level description is translated into settings at the cognitive level, as this is the level where the actual influencing takes place.

Leader count indicates a percentage of the crowd size created as leaders. The creation of leaders conveys an internal representation of the agents that are leaders, which is represented as knowledge in the memory of all the agents. This piece of knowledge allows agents to identify 'the leaders' as leaders. The variation in leadership is realised in terms of the percentage of the crowd that is regarded as a leader. Four categories were chosen : 0%, 10%, 25% and 50%. By varying the amount of leaders in a crowd, these categories will affect the influence leadership has. An increase in the number of leaders will influence the amount of agents that is perceiving a leader, and thus the amount that is influenced by a leader.

`Density` indicates the number of agents that is created for a given festival terrain ($persons/m^2$). Three levels are defined: low density ($1\ person/m^2$); medium density ($3\ person/m^2$); and high density ($5.5\ person/m^2$). This density range is chosen to achieve different the behavioural effects without moving into extreme levels. These levels of density correspond with the number of agents that is created, respectively 227, 681, and 1275 agents.

`Social structure` is the last group characteristic. Social structure represents the structure of the group in terms of *who knows who*. For the festival setting, social structure is reflected by the percentages of the crowd that came to the festival in pairs, triplets or quartets. People usually attend a festival together with other people, usually in groups of 2, 3 or 4 individuals. Like every group level characteristic discussed, this setting also has consequences for the individual level. At this level, companion groups are formalised in terms of number of people that an agent regards as its friends. These relationships are reciprocal, i.e. if A is befriended with B, then B is befriended with A. In the simulation, as no empirical data are available, these groups are arbitrarily set to: 30% pairs, 30% triplets and 40% quartets.

Agents

Agents are the individuals in a crowd that 'live' in the simulated world while attending the festival. Agents generate behaviour and are affected by the situation they are in. Each agent has bodily and mental properties that need to be set. These are represented in a framework explained in detail in chapter 3 and 5.

The bodily factors that need an initial setting only concern the physiology variables of arousal, bladder and stomach. The initial settings of physiology are exactly the same as for the density experiment. *Arousal* represents the level of attention, which is initially set on an average value (`0.5`). This average value indicates that the agent is in an average state of attention, not asleep (0) or overly excited (1). The *bladder* and *stomach* are initially set according to a beta distribution that follows an approximation of a normal distribution.

The mental part of the agent is defined as a memory structure consisting of goals, facts and rules. *Goals* represent needs that an agent strives to satisfy up to a certain preference level. The four goals (identity, social, safety and subsistence goals) must be set with an initial satisfaction value as well as a preference value (see section

3.3.2). The preference for the *identity*, *social*, and *safety* goals is 'normally' distributed using a beta(5,5) distribution. Note that in the previous experiment, the safety goal preference was manipulated, whereas in this experiment this value is fixed throughout all conditions. The initial satisfaction value is zero for the identity and the social goal. Zero is chosen as the default initial value, as the initial settings are not important for the future satisfaction of both goals. In addition, starting with zero as the initial value will prevent the occurrence of strange onset behaviour at `t=0`[1]. For the safety goal, the initial satisfaction value is set to `0.5`, once again to rule out strange onset behaviour. The last goal is *subsistence*. The satisfaction of this goal is directly linked to physiology, i.e. to the status of the bladder or stomach. The preference is set homogeneously at `0.8` for all agents, which is quite high because, when dominant these basic needs can affect behaviour to great extent.

In addition to goals, memory consists of facts and rules, which each need their specific settings. The main difference between the density and the leadership experiment can be found in the content of the facts, i.e. the leader fact is added. *Facts* involve either behaviour facts or person facts. Both a *friend fact* and a *leader fact* concerns the internal representation of a friend or leader. This element enables an agent to recognise a fellow agent as a friend or a leader. This is indicated by a boolean value {`true,false`}. At this level, the crowd characteristics of the social structure are set. In other words, when an agent is assigned part of a pair, this means that two agents have an internal representation of each other as a friend. This reciprocity does not apply to leadership, as viewing someone else as a leader does not imply anything about how this 'leader' perceives the agent that perceives him as a leader. *Behaviour facts* are pieces of knowledge that represent the expectation of satisfying a goal when choosing this behaviour (see sections 3.3.2 and 5.2.2). This value is used to compare behaviour in terms of relevancy. The expectation values are fixed values that represent a relative value, not only between goals but also between behaviour. In table 6.3 in chapter 6 the expectations for each behaviour are given. The expectation values are selected on the basis of the festival scenario. The expectation values were assigned to each behaviour according to the degree of satisfaction of a particular goal. For example, dancing is expected to satisfy the social and identity goals, but not the safety goal. This is formalised by *dance* being expected to satisfy the identity goal with `0.3`, the social goal with `0.3`, the safety goal with `0.0`, and the subsistence goal with `0.0`. The behaviours *walk* and *run* are formalised in a similar way. Finally, the *rules* must be specified. The behaviour rules known by an agent are walking, running and dancing. Formalisation of these rules simply means that the agent is only able to exhibit behaviour it knows, and no others.

In general, the settings in memory represent the knowledge of an agent. In the simulation, this knowledge is fixed meaning that the expectations, the number of friends, who is a leader, and the behavioural options do not change over time. The settings determine the boundaries for the number of agents and the social structure they belong to. The settings also enable agents to read information from the world they reside in, to be affected by this world, and thus to be influenced in choosing their behaviour. An overview of the relevant settings of the CROSS model is visualised in table 7.3. Like in the density experiment, the simulation is repeated 30 times for each

[1]The onset behaviour can be called strange when the agent would act on the basis of a setting that is not affected by the context it is living in at that moment.

of the 12 conditions of the leadership experiment, with each run taking 1000 ticks. For the behaviour clustering measure, the average over a run is taken, excluding the onset[2]. The life-history variables are measured at each tick.

[2]The average is taken over tick [100,1000]. See the behaviour clustering pseudo-algorithm 6.2.

Table 7.3: The settings for the leadership experiment.

CROSS - Leadership experiment setting								
Physical Environment	Area	toilet, bar, stage		Non-walkable, point-of-interest (x,y)s				
Social Environment	Leader count	{0%,10%,25%,50%}						
	Density level	{low,medium,high} = {1.0,3.0,5.5}						
	Social structure	Pairs	30%					
		Triplets	30%					
		Quartets	40%					
Agents	Physiology	Arousal	0.5*					
		Bladder	beta(5,5)*					
		Stomach	beta(5,5)*					
	Memory	Goal	Identity	pref	beta(5,5)			
				satis	0.0*			
			Social	pref	beta(5,5)			
				satis	0.0*			
			Safety	pref	beta(5,5)			
				satis	0.5*			
			Subsistence	pref	0.8			
				satis	Physiology-based			
		Fact	PersonFact	Friend	{true,false}			
				Leader	{true,false}			
			behaviourFact	**expectation**	id	soc	safe	subs
				walk	0.3	0.3	0.2	0.1
				run	0.1	0.1	0.4	0.1
				dance	0.3	0.3	0.0	0.0
		Rule	walk,run,dance					

*Initialisation setting

7.3 Results

This thesis focuses on revealing the underlying mechanisms in crowd behavioural patterns. The CROSS model was designed to reflect the relevant levels of description. The precision and detail used to describe the CROSS model will now be applied to be able to describe, relate and analyse from a multi-level perspective. To relate leadership to behaviour clustering, a group level relationship is explored. However, in line with the CROSS model perspective, the route of explanation travels via the cognitive level. Therefore, the results of this experiment will be displayed starting from the path of influence at the cognitive and individual levels, before addressing the relationship at group level.

7.3.1 Looking under the hood - the cognitive and individual levels

Crowd behavioural patterns emerge at the individual level. Agents interact with their environment and choose behaviour on the basis of their internal state of that moment (see chapters 3 and 5 for a detailed description). Leadership was said to influence agents in by making the behaviour a leader exhibits more 'suitable' at a given time. When an agent perceives a leader behaving in a certain manner, the expectation of this behaviour fact to satisfy the social goal is increased.

The effect of leadership starts with the perception of leaders in the local vicinity. An increase in the amount of leaders at group level does not necessarily imply that all agents will observe a leader. The variation in the local perception of leaders (`Observed leaders`) for Agent 2 is displayed in figure 7.2 for agent 2. The amount of perceived leaders varies over time, as does the type of behaviour these leaders display. In accordance with the perception of leaders behaving in a certain manner, the corresponding behaviour expectation, in the agent's memory, is increased. Figure 7.3 shows the expectation values that fluctuate due to the changing amount of leaders that is observed. For example, Agent 2 is perceiving a running leader on tick 317, tick 322 and tick 327. The behaviour expectation of the BehaviourFact 'run' is peaking on the corresponding ticks.

In the behaviour selection process, the comparison between different kinds of behaviour is affected directly, as the expectation is employed to calculate the `utility`, which allows for comparing between types of behaviour and selecting the most suitable behaviour in a given setting[3]. Utility is based on the goal dominance settings and on the expectation value at a certain moment (see equation 5.6 in chapter 5). For each type of behaviour the utility values are showing similar dynamics as the expectation value due to the observed leaders (see figure 7.4). For example, none of the observed leaders are dancing. Consequently, the expectation for dancing remains constant. Apparently, the social goal did not change either. The utility value for dancing is therefore also constant.

In accordance with the internal state, a behaviour is chosen on the basis of these utility values. Figure 7.5 shows the behaviour of Agent 2. It shows that the Agent 2's dominant goals best.

The cognitive and individual level dynamics show that the group level manipulation of leadership moves via the way an agent and its internal state is affected. It was

[3]The comparison of behaviour is restricted by time

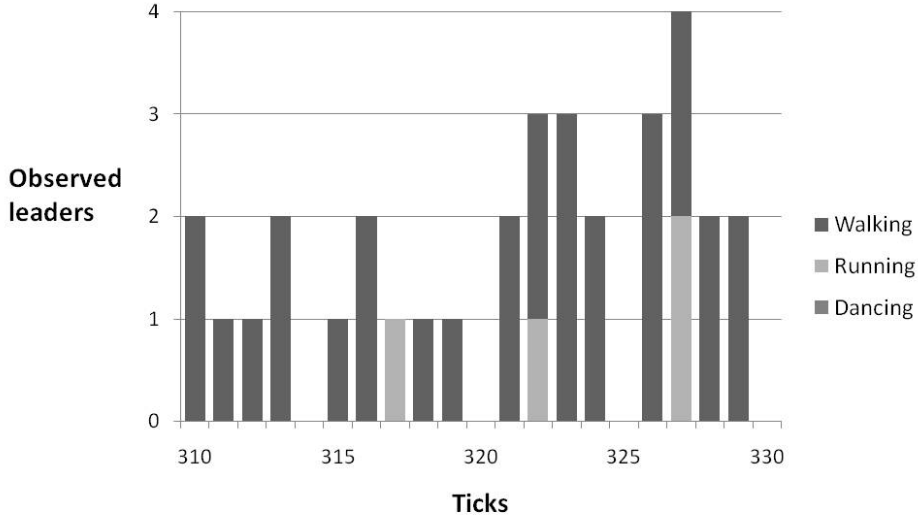

Figure 7.2: The number of leaders observed by Agent 2 together with the behaviour they exhibit between ticks 310-330. The leaders are displaying walking and running behaviour, but no dancing.

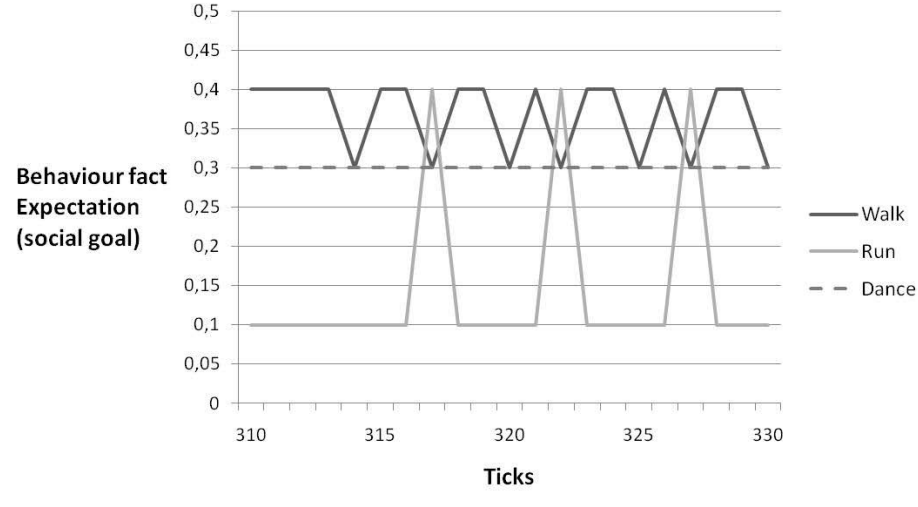

Figure 7.3: For each behaviour fact, the expectation of satisfying the social goal is shown for Agent 2 between ticks 310-330. When a leader is perceived, the expectation of the behaviour exhibited by the leader is influenced.

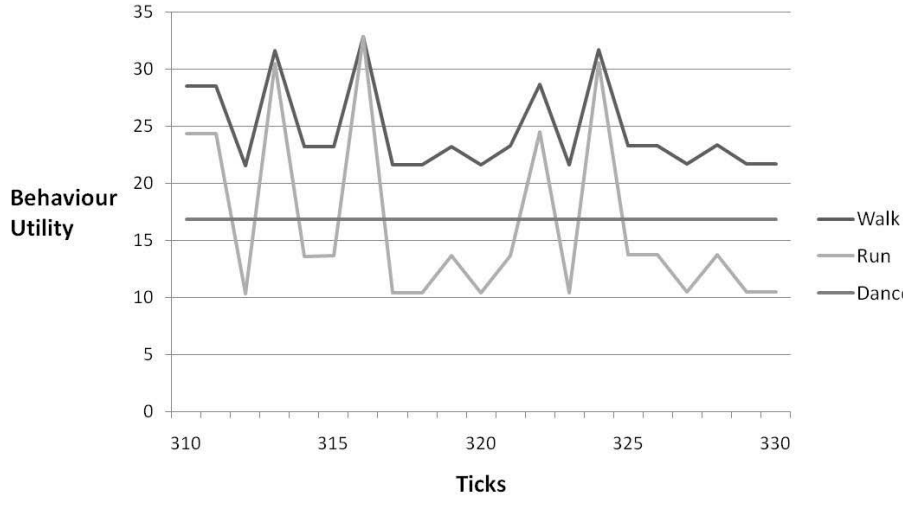

Figure 7.4: The utility for each behaviour (walk, run, and dance) of Agent 2 between ticks. The utility value represent the relevancy of certain behaviour given the setting at that point. It is used to compare and choose behaviour.

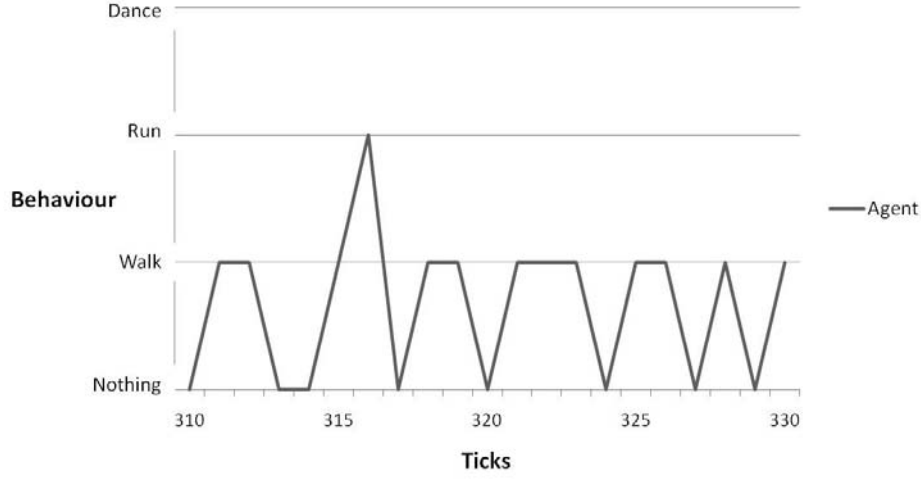

Figure 7.5: The behaviour that is exhibited by Agent 2 on each tick between ticks 21-32.

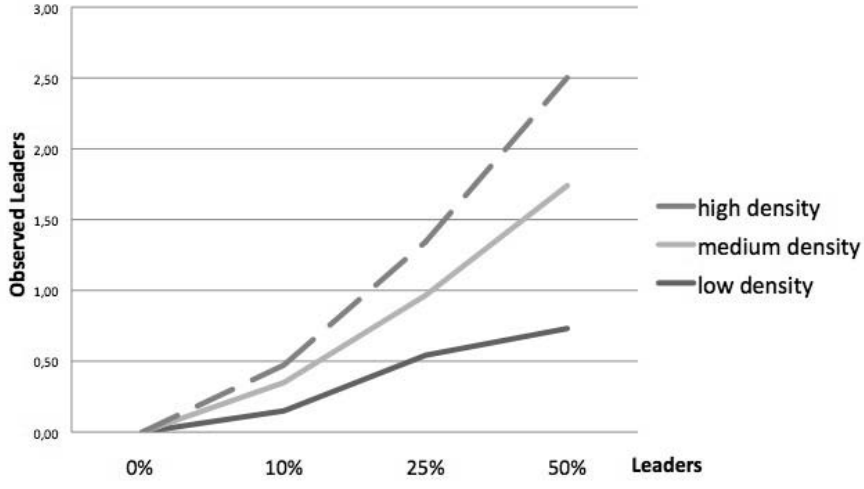

Figure 7.6: The average number of leaders that are observed by agents for each of the different leadership {0%, 10%, 25%, 50%} and density {low, medium, high} settings.

indicated in the experiment that when moving between the levels, manipulation at the group level would affect the agents differently, as each agent has its own unique environment. However, when moving back to the group level, the behaviours are reflected in a general effect. Figure 7.6 displays this general effect by indicating, for each condition, the overall number of leaders that are observed by agents.

7.3.2 The group level

The effect of the manipulation at the group level is tested against the stated hypothesis, using statistics as a method from the traditional social sciences, like in the density experiment.

The relationship between leadership and behaviour clustering.

Leadership was expected to demonstrate a positive relationship with behaviour clustering. The 4 (leader count: 0%, 10%, 25%, 50%) x 3 (density: low, medium, high) ANOVA with behaviour clustering as the dependent variable, see table 7.4, shows that there is a significant relationship between leadership and behaviour clustering: ($F = 309.90$, $df = 3$, $p < 0.001$). However, this effect seems to be marginal, especially compared to the significant effect of density on behaviour clustering ($F = 170387.67$, $df = 2$, $p < 0.001$). The same conclusion can be drawn from the visualisation of

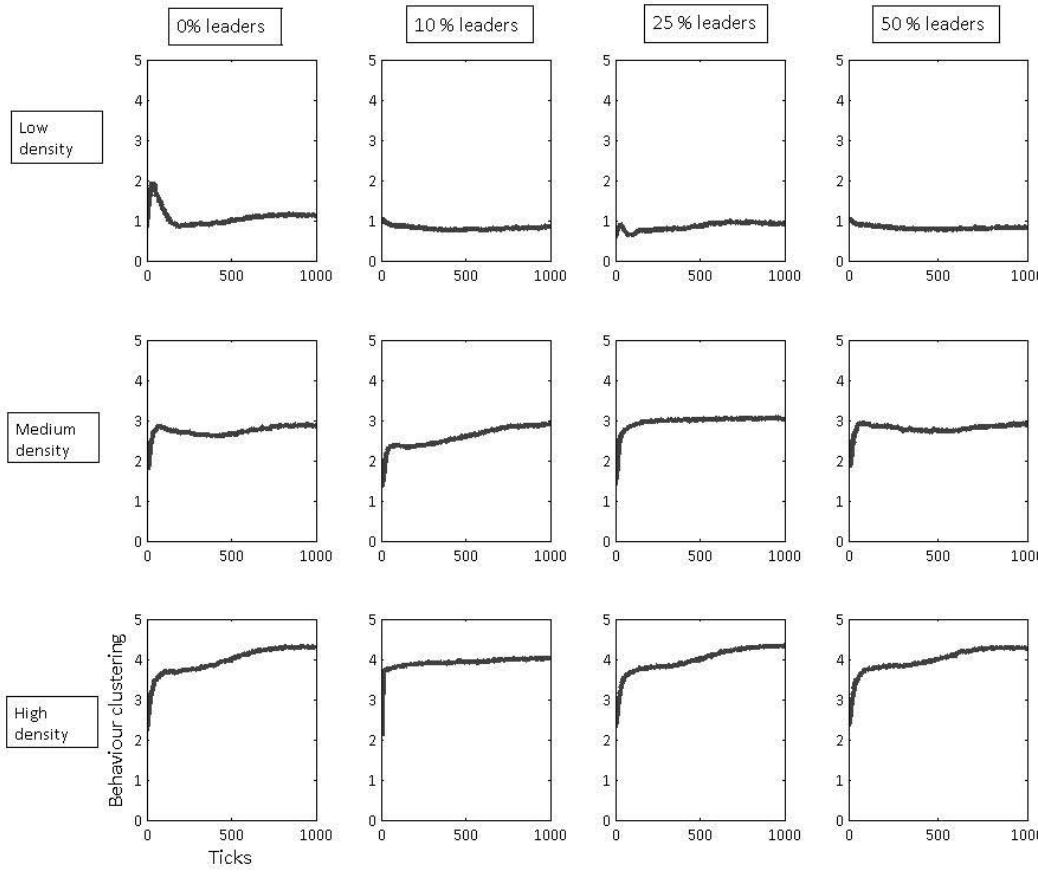

Figure 7.7: Overview of the behaviour clustering average for all conditions over 30 runs. The rows represent the density levels {low, medium, high}, whereas the columns represent the leader count percentage {l0%, 10%, 25%, 50%} is varied given the columns.

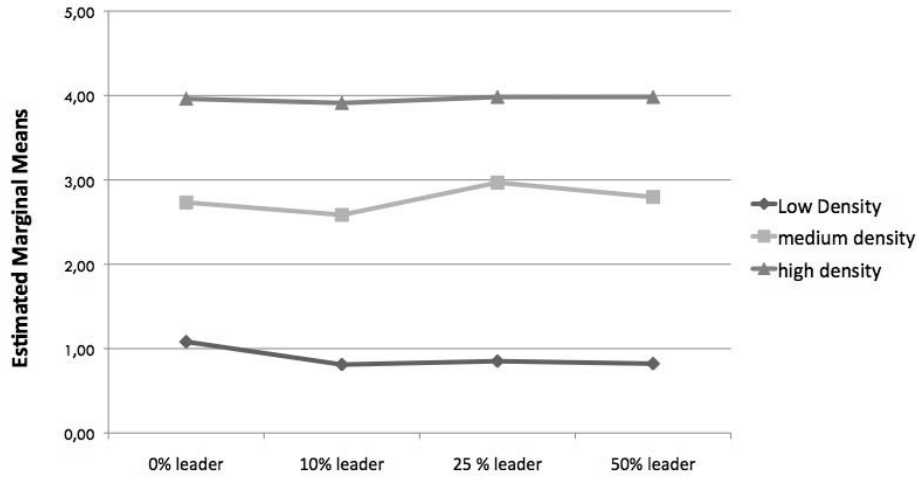

Figure 7.8: The estimated marginal means of behaviour clustering, visualised for all 12 conditions.

Table 7.4: The descriptive statistics of the dependent variable: behaviour clustering.

Descriptive statistics Source	Sum of Sq	df	Mean Sq	F	Prob > F
Leader Cond	1.57	3	.52	309.90	.00
Density Cond	574.17	2	287.09	170387.67	.00
Density x Leader	2.27	6	.38	224.58	.00
Error	.59	348	.00		
Total	2901.93	360			

the 12 conditions over time in figure 7.7 . The average behaviour clustering remains fairly stable, comparing the columns (i.e. leader count) from left to right. In other words, when there are more leaders agents, the increase in agents that exhibit the same behaviour as other agents in their vicinity is minimal.

7.4 Discussion and conclusion

In this chapter, the role of leadership on behaviour clustering patterns in a crowd was investigated. Unlike the previous experiment, the agents in a festival context were not only exposed to different density levels (i.e. , a physical factor), but also to leadership (i.e. a social factor). The outcome of the simulation experiment leads to a rejection of the expectation that leadership plays an important role in the rise of behaviour patterns. What does this mean? Leadership does affect the type of behaviour an individual is likely to imitate. The individual life-history variable shows that this imi-

tation effect takes place. However, imitation does not lead to an increase in behaviour clusters. Behaviour clustering represents the amount of dyads that exhibit the same behaviour at the same time. This number increases rapidly when behaviour becomes more homogeneous. This is not necessarily a consequence of perceiving leaders, as different leaders can influence in different directions. The explanation of the result of the experiment probably lies in the fact that behaviour clustering does not distinguish between behaviours. Leaders will influence a certain type of behaviour, and the overall effect could even be a decrease in the amount of behaviour clustering. Imagine five agents in each others vicinity that are dancing. The perception of each other dancing will stimulate repetition of the current behaviour. However, when a leader walks by, he can 'overrule' this behaviour pattern by enhancing the probability of walking for the agents that are perceiving this leader. The results actually emphasise the importance of the choice of outcome variable. Apparently, behaviour clustering as defined here is too abstract to catch the effects of leadership. To explore leadership, and probably other social factors as well, the outcome measure should be able to distinguish between the types of behaviours. The exploration of general mechanisms can still continued, but the level of abstraction should not exceed the level on which the behaviour types exist. The role of the social environment is thus related to the type of behaviour clusters that arise. More specifically, leadership can be said to influence the types of behaviour exhibited and thus to affect the direction in the atmosphere of a crowd setting, e.g. hostile or peaceful, passive or active.

The social context influences *how* behaviour will be affected, and thus *which* specific behaviour will be chosen. This awareness is the main insight gained from this experiment. In the search for generic mechanisms, it is therefore crucial to define a dependent variable that is sensitive to specific behaviour types. In line with the current dependent variable, behaviour clustering could, for instance, be specified in terms of the amount of dyads, based on both agents in the dyad, displaying specific behaviour, such as dancing. This refinement would enable to explore leadership by relating the type of behaviour that leaders exhibit to the increase in behaviour clustering of that specific behaviour. Consequently, the design of the experiment should to be changed as well. An example of an experiment testing the effect of leadership would be to compare the behaviour clustering of dancing. Let's say that 10% of the crowd is set to dancing during the simulation. In one condition this 10% is made up of leaders, whereas in another 10% of the agents is dancing in a crowd without leaders. Comparing the number of dancing clusters in the two conditions would make the group level consequences of leadership clear. To conduct this kind of experiments, the CROSS model must be adapted slightly and the experimental design must to be thought through[4]. This refinement makes it possible to explore the social context more deeply.

The importance of the social context has real-world implications. The leadership

[4]The design and adaptation of CROSS to perform this experiment involves specifying not only behaviour clustering for a specific type of behaviour (i.e. the dependent variable), but also the settings of specific agents and the way they behave. It is not simply a matter of defining 10% with a fixed type of behaviour, also their spatial position needs to be fixed in order to compare the influence both conditions have. Moreover, it has consequences to freeze behaviour, not only in the way behaviour is chosen by a specific agent, but also in the way others are affected. Changing the behaviour of the social agent entails changing both the physical and social context, and thus whether agents are influencing and how they are influenced. These dynamics must be taken into account in the experimental set-up.

experiment explores the power-relationships in the CROSS model. In this experiment, leadership is represented in a basic form that does not allow for making claims about leadership itself. The contribution of this experiment lies in a different aspect. The experiment illustrates a different way of looking at a phenomenon such crowd behaviour. Instead of sticking to a traditional common-sense view, e.g. the hierarchical view on leadership, a dynamic, context-sensitive stance has become necessary. By framing theories and ideas within the structure of the CROSS model, the way of explaining and thinking about group dynamics is already changing. Leadership research can benefit not only from this interaction perspective, but also from the concreteness in defining leadership that this approach calls for.

For crowd research, the main contribution of the experiments lies in the fact that it can give direction to further research. As discussed in chapter 3, leadership concerns the subjective perception of someone else as a leader, but it may also concern the perception of oneself as a leader. Therefore, it would be interesting to explore these leader-follower dynamics and see how they affect the leader's choice of behaviour when he considers himself as a leader and perceives others imitating him. It addition, it would be interesting to investigate what would happen if someone did not perceive himself as a leader but was imitated anyway. If the fixed setting of the few people regarded as a leaders were changed into a heterogeneous subjective perception, the simulation would become more complex, but also more realistic. In social simulation studies concerning leadership, leadership arises. It would be interesting to include this aspect too. It would involve defining all relationships with other agents as power-relationships that are subjectively perceived. Some relationships are equal (i.e. between friends), some do not have any value (i.e. with strangers), some are unequal (i.e. exerting more/less influence). These relationships may change over time and leadership may emerge as a pattern due to the subjective perceptions of a set of agents or to the behaviour these agents display.

Experiments with the CROSS model clearly demonstrates its conceptual power due to the way it forces detail and preciseness, which in return can be used to explain and analyse. Even when using a basic representation of leadership and density, both experiments explored a physical as well as a social factor. To represent an individual in terms of a cognitive system allows for incorporating theories from the social and behavioural sciences, which does not only build a bridge, but also leads to cross-fertilisation. Even though the conceptual power in this project is clear, further implementation, validation and experimentation will add more precision to the above mentioned contributions.