Collectives and How They Move: A Tale of Two Classifications

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Abstract. Collective phenomena and their associated movement patterns are ubiquitous in everyday life. However, even though we need to be able to reason about these phenomena, especially their movement patterns, research suggests that we do not currently possess the tools for doing so. Research has been carried out into the movement patterns of particular types of collective but there appears to be no research into the range of different movement patterns exhibited by collective phenomena as a class. In order to provide such a tool it is crucial that we understand the relation between the different types of collectives and the various movement patterns that they may exhibit. By means of examples, this paper compares a classification of collectives and a classification of movement patterns. A number of possible links are suggested and the need for a more comprehensive classification of movement patterns sensitive to the different kinds of collective is highlighted. Such a system could be integrated with the current classification of collective phenomena to form a more comprehensive system that once formalised, may allow the representation of a wide range of collective phenomena within an ontology.

Keywords. Collective, collective behaviour, movement patterns, behaviour patterns

1. Introduction

How would a crowd at a rock concert react in an emergency? What effect would additional road works have on traffic flow in the surrounding area? These are just two examples of collective phenomena. Such phenomena and their associated movement patterns are ubiquitous in everyday life. However, even though we need to be able to reason about a wide range of such phenomena, research suggests that we do not currently possess the tools for doing so. We wish to produce such a tool: a framework that allows us to adequately represent a wide range of collective phenomena and their behaviour patterns, including the relationship between the collective as a whole and its individual members.

We have begun the development of this model by initially studying a wide range of collective phenomena to see what different types of collectives exist and how they are related. This investigation has led to the development of a classification of collective phenomena [17]. From the point of view of behaviour, however, this classification system is incomplete since while it takes account of whether or not the collective and its associated members are moving, it does not identify anything about the type of movement that is being exhibited. As already suggested by the crowd and road-works examples, the movement of collective phenomena is vital and one of the most important features of collectives that we wish to reason about. It is also one way in which the relationship

between the collective as a whole and its members can be represented since it is from the motion of the individuals that the motion of the collective emerges.

Although research has been carried out into the movement patterns of particular types of collectives [1,6,4,5,8,10], there has been little research into the range of different movement patterns exhibited by collective phenomena as a class. Dodge et al [7] enumerate and to a certain extent classify a large number of movement patterns that can be exhibited by groups of individuals, but no attempt is made to investigate which type of movement patterns are characteristic of which type of collective phenomena. The present paper is a first attempt to draw systematic links between the classification of collective phenomena [17] and the classification of movement patterns [7].

We will focus on *spatial collectives*, i.e., collectives where both the collective and its members can be assigned locations in physical space. Examples of such collectives include a marching band and a football team during the times at which they meet (i.e., at a match or training). During periods when they are not meeting, members of the football team cannot be considered to constitute a bona fide spatial collective because while each individual has a spatial location it does not seem appropriate to speak of the location of the team as a whole. At such times the football team may be regarded as a non-spatial 'fiat collective': even though they lack any kind of spatial coherence, the players will still be deemed to form a football team. It is not until the team has been disbanded that this fiat collective will cease to exist. This is an important feature of many spatial collectives which meet on a regular basis. Between these meeting times, the collective will still be deemed to exist, both by the members themselves and by outsiders, making the collective at these points in time a fiat collective; by contrast, when the movement of the individuals becomes coordinated (e.g., by their coming together at a meeting place) the fiat collective assumes a more 'bona fide' character as a true spatial collective.

By means of examples this paper discusses the relationship between the classification of collectives developed by Wood and Galton [17] and the classification of movement patterns developed by Dodge et al [7]. Results from this discussion show that both classifications support each other and are in fact incomplete without each other. However, the discussion also notes the need for a more comprehensive and systematic classification of the movement patterns that are exhibited by collectives to supplement the classification of collective phenomena if the desired framework is to be produced.

An overview of related work is given in section 2, followed by brief descriptions of both the classification of collectives (section 3) and the classification of movement patterns (section 4). Section 5 examines examples of collective phenomena to see how dependent they are on movement and also which of the movement patterns defined by Dodge et al [7] they exhibit. Following this examination, a number of possible links between the two classification systems have been discovered and are suggested in section 6. The paper concludes with a list of further research that needs to be completed in order for a framework that adequately models collective phenomena to be developed.

2. Related Work

As a result of the introduction of technology such as GPS devices and mobile phones, there is an increasing amount of data available recording the movement of objects [14,4]. These datasets usually contain information on the movement patterns of a large number

of individual objects which may or may not be related; implicit in such data there may be a good deal of information on how individuals are participating in a collective. However, this vast amount of low-level data needs to be analysed and interpreted so that the high-level information (i.e., aspects of the data that are more meaningful to us), can be extracted. In order for this to be possible, sufficient extraction, analytical and interpretation tools need to be developed [15].

Researchers within many fields including GIS, Mathematics and Computer Science have recognised this and have begun to focus on a particular aspect of the problem: extracting and interpreting the behaviour of particular individuals [2] or the interactions between individuals [8]; or particular extraction methods that can be used with spatiotemporal data [9]. Although some have focused on particular types of collective phenomena such as traffic phenomena [13] or animal aggregates [4], it would appear that few have looked at the behaviour patterns of collective phenomena in general. Dodge et al [7] have begun to look at the different behaviour patterns that can be found in large datasets which record the movement of individuals; many of these behaviour patterns can be related to collective phenomena. However, the movement patterns have not been systematically related to the specific types of collective phenomena that exhibit them.

Andrienko and Andrienko [2] have focused on the extraction and interpretation of information about a single individual's movement patterns from a large dataset. The dataset records an individual's car position over a period of five months. Since data was only recorded when the car was moving, periods when the car was stationary are only implicitly stored in the data. In their opinion, the dataset is too large to extract movement patterns using visual techniques alone, and therefore they have used various extraction methods including database queries, computational analysis methods, data transformations and other computer-based operations. Although they only look at behaviour patterns of an individual, rather than of a collective, they do suggest a number of techniques that could be used to identify different behaviour patterns such as the detection of important places in the individual's life and also routes used to traverse between such places. For example, important places could include the individual's home and place of work, and they may have a particular route for getting between them.

Researchers have begun to investigate the movement patterns exhibited by specific types of collective phenomena such as crowds [1,6] or animal aggregations [4,5,8,10], but the main focus appears to be on the interactions between pairs of individual members of a collective rather than the motion patterns of the collective as a whole. For example, Eftimie et al [8] have built a mathematical model to help explain the way in which animal groups form and move in response to the information that they receive. Like Wood and Galton [17], Eftimie et al note that groups can be influenced by either internal or external factors, but they choose to focus only on the internal factors and in particular three interactions that can occur between the individual animals of a group: attraction, repulsion and alignment. Although a reasonably detailed account is given of the spatial patterns resulting from these three social interactions, the interactions have not been used to explain the movement of all collective phenomena and it is unclear whether they will suffice to provide an adequate model. Gueron et al [10] have also developed a mathematical model which is based on the decisions that individuals make within a herd and how these decisions affect the movement, shape and cohesion of the group over time. They note that their model is only a 'starting point' and tools must be developed that allow the details of movement rules to be explored.

Modelling social interactions and the decisions made by the individual members of a collective constitutes a 'bottom-up' approach to identifying the movement patterns of a collective. Even though some may argue that the movement of a collective is simply the aggregation of the movement arising from the interactions between its members, we believe that a 'top-down' approach is needed which could be used to identify the type of collective from its global movement patterns. Once the type has been identified, a bottom-up approach may be needed to explain or predict how the individual members of a collective will interact and therefore the movement patterns of the collective that will follow. By focusing on the interactions between particular individuals, it is difficult if not impossible to see the behaviour of the collective as a whole. As humans, we are very good at seeing the 'big' picture and therefore seeing the motion of the collectives as a whole. How can we duplicate this ability in a machine?

It has been noted by many that we need ways to analyse and interpret moving object data. Laube et al [14] give an overview of the problems current database management systems have with 'moving point objects' (MPOs) and the problems current GIS software has when trying to handle the temporal dimension of information, a key area when trying to adequately represent moving objects. The research reported in [14] tries to increase the 'analytical power' of GIScience when exploring the motion of objects. They have developed the 'RElative MOtion (REMO) analysis concept' which allows motion attributes of point objects to be compared over space and time and also an object's motion to be related to that of others in the dataset. REMO also allows predefined motion patterns to be described and detected. The concepts and ideas used by the REMO analysis concept may allow a wider-range of motion patterns to be defined and extracted for database datasets. However, as noted by Benkert et al [4], REMO only allows single time steps to be considered and therefore is unable to detect sequences of change over much longer periods of say a month or even a year.

Certain types of collective phenomena such as crowds and processions can involve dynamic clusters. A large amount of research has been carried out into static clusters [12,16] but the analysis and interpretation of moving clusters is in its infancy. Kalnis et al [11] have formally defined moving clusters and given three algorithms that can be used to identify them from spatiotemporal datasets. Importantly they have also allowed for variable membership within these clusters; this is a feature of many of the collective phenomena that we have studied. It may be possible to incorporate these algorithms into the developed classification scheme of the behaviour of collective phenomena.

Research has indicated that the increase in data recording the movement of objects has led to an increase in the need to be able to analyse and interpret it. Particular collective phenomena have been studied to some degree but the majority of research appears to focus on the movement patterns of the individuals within a collective. There appears to be little research carried out into developing a general framework that models the movement patterns of a wide range of collective phenomena or even identifying that a collective exists in a dataset. Given a dataset which records the movement patterns of a large number of individuals known to be participating in a collective:

1. How do we identify the movement patterns of the collective?
2. Given the movement patterns of the collective, can we identify the type of collective?

The following sections will show that a classification of collectives supplemented by a detailed classification of the movement patterns exhibited by each type of collective is needed in order to answer these questions.

3. A Classification of Collectives

The classification system that has been developed to understand the different types of collective phenomena and the relationships between them is based on the classification criteria of membership, location, coherence and the differentiation of roles within the collective. This section gives a brief overview of each section of the classification but a more comprehensive explanation can be found in [17].

The term 'collective' is often taken to imply some form of purposive organisation, and might therefore be thought to be inappropriate as a designation for the full range of phenomena that we wish to study. None the less, in this paper we will use the term to designate any phenomenon in which a multiplicity of individuals exhibits some form of coherent behaviour, from whatever source this behaviour may originate.

Our classification system for collectives is based on four sets of criteria, which are discussed in turn in the following four subsections. The classification is provisional and not intended to be exhaustive, having been derived by extracting the key distinguishing features of the various collective phenomena that we have studied.

3.1. Membership

Collectives may be classified according to the identity and cardinality of their members. A collective could have the same members throughout its lifetime (constant membership) or different members (variable membership). Collectives with variable membership can be further classified by whether the cardinality of its members is constant or variable. If variable cardinality, must the collective always have more than one member to exist or can it survive such a depletion? A football team and a quartet are collectives with variable membership but constant cardinality; a queue has variable membership and variable cardinality which may reduce to 1; however, a crowd, which also has variable membership and variable cardinality, must always have more than one member in order to exist.

[M1] Constant membership
[M2] Variable membership

- [M2a] Constant cardinality
- [M2b] Variable cardinality

  - [M2bi] Cardinality necessarily > 1
  - [M2bii] Cardinality may reduce to 1

3.2. Location

Collectives may also be classified with respect to the location of both the collective as a whole and its individual members. If the location of the collective is fixed the location of its members could either be fixed or variable. For example, a queue is fixed but the location of its members changes as they move towards the front of the queue whereas the

location of a forest and the trees within it are both fixed. If the location of a collective is variable then the location of its members could either be fixed (e.g., a Mexican wave), or variable (e.g., a procession). If the locations of both the collective and its members are variable, the classification can be extended to look at whether the collective and its members share the same type of motion (as with a marching band or a procession, whose trajectory is closely correlated with those of its individual members) or exhibit quite different motions (e.g., a crowd which exhibits a gradual northward drift even though its constituent individuals may come and go, milling around in many different directions). Variable location can result in a wide range of possible patterns of movement and these will be considered in section 5 below.

[L1] Location of collective is fixed.

[L1a] Location of members is fixed.
[L1b] Location of members is variable.

[L2] Location of collective is variable.

[L2a] Location of members is fixed.
[L2b] Location of members is variable.

[L2bi] Motion of individuals and collective is coordinated.
[L2bii] Motion of individuals and collective is not coordinated.

3.3. Coherence

This criterion focuses on the source of the coherent behaviour that is exhibited by a collective. Coherent behaviour can be due to purpose or cause. The participation of individuals in a purposive collective arises from their goals or purposes; these may be individual purposes, each individual participating in the collective to further its own ends (as in a queue or a concert audience), or a shared collective purpose where each individual is participating in order to further an agreed common end (as in a committee, a choir, or a football team). Coherent behaviour resulting from some non-purposive cause or causes can be further classified by considering whether the cause is internal or external to the collective. An example of the former is a star cluster, which is held together by the mutual gravitation of the constituent stars; of the latter, the water droplets in a shower, which individually fall in response to the earth's gravitational attraction. In some cases the external cause is in fact the intentional action of an external agent; for example, the coherence of a collection of coins is due to the intention of the collector bringing them together. It is important to note that there is not always a clear distinction as to whether coherent behaviour is due to a purpose or a cause; often it is a combination of the two.

[C1] Cause

[C1a] External cause
[C1b] Internal cause

[C2] Purpose

[C2a] Individual purposes
[C2b] Collective purpose

3.4. Differentiation of Roles

This criterion concerns the structure of the roles played by individuals within a collective and classifies a collective into one of several different models accordingly. It should be noted that these models are not intended as an exhaustive list; there are gradations between them leading to other possible models. In an *oligarchic* collective there is a leadership role which is played by one or a small number of members; the remaining members do not have a specific role and are considered as 'followers'. A *partitioned* collective is one where there are a small number of differentiated roles each played by many members. Partitioned collectives can be thought of as consisting of subcollectives, each of which consists of a group of individuals that play a certain role within the overall collective. For example, an orchestra follows a partitioned model with each section being a subcollective. In general, it is possible for these subcollectives to overlap so some individuals play more than one role simultaneously; individuals could also move from one subcollective to another, thus changing roles during their period of membership in the collective. Subcollectives can be further classified according to their role-differentiation model. An *individualistic* collective is one where each individual plays a distinct role within the collective (e.g., a string quartet).

[R1] Members of collective are not differentiated by role.
[R2] Members are at least partly differentiated by role.

- [R2a] Oligarchic
- [R2b] Partitioned
- [R2c] Individualistic

4. A Classification of Movement Patterns

Dodge et al [7] note that there is little agreement on the various types of movement patterns, and although there are a few isolated definitions of particular types of movement patterns, there appears to be no research into movement patterns in general. Such research is needed if efficient data mining algorithms and analytical tools are to be developed to use with the ever increasing amounts of data recording the movement of objects. The goal of Dodge et al is to build a comprehensive definition of the different types of movement patterns. The work reported in [7] proposes a conceptual framework for movement behaviour which is used as a basis for a detailed taxonomy of the different movement patterns. They list and name many different types of movement patterns, loosely grouped into a number of general types, and in what follows we shall refer to this taxonomy simply as the Dodge classification. We shall sometimes quote from their definitions, but for full details we refer the reader to [7].

The conceptual framework of movement looks at the types of movement patterns that can be formed taking as primitives the variables that define movement and the constraints and external factors which may affect movement. Within the framework it is noted that the behaviour exhibited by moving objects will depend on whether they are travelling alone or as part of a group. Dodge et al believe that a more functional approach is needed than that of [3] to handle collective movement behaviour and instead differentiate between *individuals*, *groups* that 'share a behaviorally relevant functional relation-

ship' like a flock or herd, and *cohorts* which simply 'have a factor in common that may be statistically relevant' — our coherence criterion (section 3.3) is clearly relevant here.

The taxonomy of movement patterns distinguishes between two types of movement patterns: 'generic patterns' and 'behaviour patterns'. Generic patterns, such as convergence, divergence, symmetry, and constancy, are those that can be found in any form of behaviour. Behaviour patterns are 'higher-level movement patterns' formed using the generic patterns as building blocks. Examples of behaviour patterns include fighting and play, which are combinations of the generic patterns of leadership and trendsetting.

Unlike the conceptual framework the taxonomy only distinguishes between individual and group movement patterns; Dodge et al note that the relationship between individuals participating in a collection (the distinguishing feature between cohorts and groups) is not needed in defining movement patterns.

5. How Dependent are Spatial Collectives on Movement?

There are a number of collective phenomena such as a swarm of bees that are defined by their movement patterns (i.e., when the movement stops the collective ceases to exist). For other collectives, it is not movement that defines the collective but what they are doing. Here we look at some examples that have been classified using the existing classification of collective phenomena [17] and specifically their dependence on movement.

5.1. A football team

Without movement, a football match or training session (i.e. the times when a football team forms a spatial collective) could not take place. The events depend on movement in order for them to occur, and to a considerable extent are constituted by that movement. Just think of a football match where team members simply stood in their initial positions for the duration of the match!

The classification of collective phenomena classifies a football team, when considered as a spatial collective (i.e. at a match or training session), as:

[M1] Constant membership
[L1b] Location of collective is fixed but location of members is variable.
[C2b] Coherence is due to a collective purpose.
[R2a/c] Following an oligarchic and partitioned model.

The members of a football team do not change in the course of a match or training session, hence the classification of M1; but does this have any effect on the team's movement patterns? It will constrain the individual member's movements. For example, if variable membership is allowed individuals could leave the spatial area in which the collective is located. If membership is constant, individuals will not be allowed to leave the collective and therefore could not leave the space which the collective occupies.

The Dodge classification acknowledges the possibilities of fixed or variable membership by qualifying their movement patterns *meet* and *moving cluster* by means of the additional attributes 'fixed' and 'varying', which refer to whether the membership of the group can change. The difference between a meet and a moving cluster is that the former stays within a stationary region over the period of its existence whereas the latter follows

a trajectory through space. Thus, taking the football pitch to be the relevant 'stationary region' here, we can say that the football team, during the match, exhibits the pattern of a 'fixed meet'.

By classifying a football team as of type L1b the presence of movement is simply acknowledged, but nothing is said about the type of movement that is exhibited by the team members. Overall, the team's spatial position is constrained to the pitch. Within this area they move around individually while working as a team. The object of the game means that team members are likely to move towards the ball and the goal; attempts at scoring the goal will be repeatedly taken. Since they are working as a team they will also run in the same direction simultaneously. These movement patterns have been identified in the Dodge classification:

- *Spatial concentration*: the team are all confined to the pitch.
- *Full synchronization*: team members will (sometimes) run in similar directions simultaneously.
- *Encounter*: groups of individuals will move towards the ball.
- *Repetition*: many attempts to score a goal.
- *Trend-setting*: an individual player may anticipate other players' moves.

Full synchronization occurs when 'similar changes of movement variables ... occur at the same time'; it can be an indicator of collective purpose (C2b) but is unlikely to be the only movement pattern characteristic of collectives of this type. Although the movement pattern of *leadership*, and therefore an oligarchic model (R2a), is identified by the classification of movement patterns, there is no recognition of the movement patterns identified by collectives of type R2b (a partitioned model) and R2c (an individualistic model). Are there particular movement patterns that are exhibited by collectives of these types which need to be introduced to a comprehensive classification of movement patterns exhibited by collective phenomena?

A match involves interacting with another team and therefore another spatial collective; this must affect the movement patterns exhibited by each collective. The movement patterns exhibited by each team arise primarily from its collective purpose of winning the match, but the spatial patterns involved in winning the match are oppositely oriented for the two teams. The resulting complementarity of the movement patterns forms a new type of movement pattern in its own right, not present in the Dodge classification. We could regard the two teams as partitions of a single partitioned collective, whose overall movement pattern arises from a particular type of (antagonistic) spatial interaction between the two subcollectives; this kind of phenomenon has yet to be incorporated into either the classification of collectives or the classification of movement patterns.

5.2. A procession

A procession may be classified using our criteria as follows:

[M2bi]	Variable cardinality, necessarily > 1.
[L2bi]	Motion of individuals and collective is coordinated.
[C2b]	Collective purpose.
[R1]	No differentiation of role.

A procession is defined by its movement and when the participants of a procession stop moving, one might say that the procession ceases to exist as such. However, this is

not recognised by the classification of collective phenomena which classifies the location of this spatial collective as type L2bi: the location of both the collective and its members are variable, with the two motions being co-ordinated. The classification system does not identify how the motion is co-ordinated, or indeed, how the motion patterns of different participants are related to each other.

A procession consists of a group of individuals moving in an orderly way from a designated starting point, along a particular route, to an end point, where the procession ceases to exist. Participants within a procession may change along the route with individuals leaving and/or new ones joining, which means that in terms of membership the collective can be classified as M2bi. It cannot be M2bii since a procession cannot survive a depletion to a single member. Collectives of type M2bi relate to the movement pattern of *varying moving cluster* within the Dodge classification.

Again the Dodge classification allows us to comment further on the type of movement exhibited by the procession and therefore extend how a procession is classified in terms of location. The movement is co-ordinated because the participants follow the same route, at the same speed, sequentially rather than simultaneously; this is identified by the movement patterns 'lagged co-incidence', 'constancy' and 'concurrence'.

Like the football team, a procession can be classed as type C2b since individuals are taking part in the procession for a collective purpose; they also exhibit 'full synchronization'. Although the procession is organised by a group, when it is taking place the participants have no individual roles and follow a route not a leader. Therefore this spatial collective typically exhibits no role differentiation [R1].

5.3. An Orchestra

Like a football team, orchestras are fiat collectives for most of their existence and only becomes spatial collectives when the individuals come together to rehearse or perform. When considered as a spatial collective, an orchestra can be classified as:

[M1] Constant membership.
[L1a] The location of both the collective and its members are fixed.
[C2b] Collective purpose.
[R2b] Partitioned model.

The main difference between these spatial collectives and the ones previously discussed is that they do not rely on movement to exist. If fact, the position of each individual for the most part remains fixed, suggesting that no movement patterns could be exhibited. However, should their lack of movement be considered as a movement pattern in itself? Lack of movement can sometimes be an important piece of information when reasoning about collective phenomena. Consider a traffic jam where no traffic is moving; the lack of movement could indicate that the road has been been blocked by something such as an accident.

In the Dodge classification 'meet' is defined as a movement pattern consisting of 'a set of MPOs [Moving Point Objects] that stay within a stationary disk of specific radius in a certain time interval ... a stationary cluster' [7]. This could be suitable for describing the movement of an orchestra when considered as a spatial collective (i.e., when they are rehearsing or performing), but it should be noted that the classification is too crude to distinguish between cases like the football team at a match where the

individuals exhibit a wide variety of movement within the fixed region to which they are confined, and the the orchestra at a performance where such movement is largely absent. The 'meet' movement pattern thus seems to characterise our [L1] collectives without further discriminating between types [L1a] and [L1b].

Since the members of the orchestra in performance are stationary, they exhibit full synchronization. Like many other examples of collectives that exhibit this movement pattern, orchestras during performances and rehearsals are classed as of type C2b. It seems likely that all collectives of type C2b at least sometimes exhibit this movement pattern, although it is not the exclusive preserve of collectives of this type, e.g., a stampeding herd likewise exhibits full synchronization, and while one may debate as to whether this behaviour should be attributed to an external cause [C1a] or individual purposes [C2a] (or indeed both), there seems little reason to ascribe a collective purpose in this case.

Orchestras and choirs are grouped into sections (e.g., string section, woodwind section, ..., or sopranos, altos, ...) and therefore follow a partitioned model (R2b). However, this only affects where individuals sit within the collective, it has no effect on the movement pattern that they exhibit. This is not necessarily typical of collectives of type (R2b): an example where the differentiation of roles is accompanied by a differentiation of movement patterns is provided by the traffic on a motorway where the northbound traffic exhibits different movement from the southbound, and lorries, coaches and cars all show distinct behaviours.

5.4. A Queue

Using the classification of collectives a queue can be classified as:

[M2bii]	Variable membership which can survive a cardinality drop to 1.
[L1b]	The location of the collective is fixed but that of its members is variable.
[C2a]	Individual purposes.
[R1]	No differentiation of roles.

Although in a typical queue the members spend most of the time *not* moving, the steady progression of members from the tail-end of the queue to the head is a defining characteristic without which the queue ceases to be a queue. Thus a queue is defined by the movement pattern of its members: they join the queue at the back, move towards the front, and once at the front of the queue they conduct their business and leave. The queue can be reduced to a single member (perhaps even to none) and as long as new members join at one of the following time steps, the queue continues to exist. Since individuals in the queue cannot be differentiated by role, the queue is of type R1; however, this lack of role differentiation appears to play no part in defining their movement.. Arguably, one might distinguish the person at the head of the queue as exercising a distinct 'leadership' role, leading to type R2a, but if so it is very different from typical examples of this category, and indeed the classification R2a does not seem to sit well with the lack of collective purpose evinced by the classificaton C2a (individual purposes).

Since the queue itself is not moving, it cannot be described as a moving cluster in the Dodge classification, but instead as a varying meet. Although the location of the queue is fixed, the individuals within the queue move through the queue, making their location variable. This movement can be described using the movement pattern 'sequence' and the waiting with the movement pattern 'constancy'; the regular alternation of movement

with waiting is an example of 'repetition'. When viewed at a sufficiently fine temporal granularity, there is also an element of 'trend-setting' (and more specifically 'leadership'), in that the onward movement of the queue members is triggered by the individual at the head leaving the queue after concluding their business.

Participants of the queue exhibit the movement pattern 'full synchronization' but are classified as C2a, suggesting that this movement pattern may be exhibited by purposive collectives more generally, not just those of type C2b. This prompts one to wonder if there are any other movement patterns which can be used to discriminate between collectives of types C2a and C2b.

5.5. Leaves in the wind

Imagine the leaves that have fallen from a tree being blown around the garden; in our broad sense of the term, these leaves form a collective, which may be classified as:

[M2bi]	Variable membership with a cardinality that must be greater than 1.
[L2bii]	Motion of the collective and its members are not co-ordinated.
[C1a]	External Cause.
[R1]	No differentiation of role.

Since leaves may become lodged in trees or other areas of the garden, the membership can be classed as M2bi; a classification of M2bii cannot be used since one cannot reasonably consider a single leaf blowing around the garden as a collective. Since both the location of the collective and its members are variable, this collective must be considered as a form of moving cluster which allows the participants of the cluster to change (i.e., the movement pattern 'varying moving cluster').

Watching the leaves being blown around in the wind, one will see little indication of co-ordination as they would appear to move somewhat randomly thereby exhibiting the (inaptly named) movement pattern of 'dispersion' (defined by 'non-uniform or random motion' [7]) within the cluster, and it is likely that this movement pattern is generally indicative of collectives of type L2bii. Likewise, the leaves are not distinguished by role, and this R1 classification is likely to be strongly (though not exclusively) associated with the tendency to manifest the dispersion pattern.

Unlike the other collectives that have been discussed, the leaves from a tree that are blown around a garden can be classed as a causal collective — the collective's coherent behaviour is due to an external cause, namely the wind. However, what movement patterns indicate this? A degree of synchronization is exhibited since the leaves will only move when the external cause (i.e., the wind) occurs. However, one cannot distinguish causal (C1) from purposive (C2) collectives by the extent of the synchronization since one of our other causal examples, the water drops in a shower, exhibits a high degree of synchronization, and some purposive collectives such as the football team exhibit only partial or sporadic synchronisation.

6. Proposed Links

For each section in the classification of collective phenomena, how does their movement correspond to those that have been identified in the Dodge classification?

6.1. Membership Criteria

This section of the classification of collectives is one which has the weakest relationship with movement patterns. Since collectives, considered as entities existing over and above their individual members, are not being considered in the taxonomy of movement patterns, membership has not been fully addressed. The possibility of variable membership is noted with movement patterns such as 'varying meet' *vs* 'fixed meet' and 'varying moving cluster' *vs* 'fixed moving cluster'. However, the cardinality constraints that have been identified within the classification of collective phenomena have not so far been related to any specific types of movement patterns, if indeed any such relationship exists.

6.2. Location Criteria

This section of the classification of collective phenomena holds the strongest relationship with that of the classification of movement patterns. Since the classification of collective phenomena only notes the presence or absence of movement but says nothing about the type of movement, the classification of movement patterns can be used to refine this section by classifying the type of movement. However, which of the defined movement patterns can be exhibited by each of the locationally-defined classes of collective?

Movement patterns such as concurrence, moving cluster, divergence and convergence all indicate a degree of co-ordination between the movement of an individual and that of the collective it is a member of. In contrast, dispersion could be exhibited by a collective whose motion is not co-ordinated with that of its members. Further classification criteria could be added to take into account the co-ordination of movement between the members of a collective.

6.3. Coherence Criteria

All but one of the examples that have been looked at that are classified as a C2 — a purposive collective. It could be questioned whether causal collectives (C1) form a natural class of collectives and further research is needed to determine this. However, assuming the class of causal collectives is recognised, how can they be distinguished from purposive collectives? In the few examples that we have discussed, all purposive collectives exhibited the movement pattern 'full synchronization'. The example of leaves being blown around by the wind was the only causal collective discussed in detail, and it could be said that the leaves exhibit some degree of synchronization in their movement, at least locally (i.e., in a certain area the majority of leaves will respond in the same way to a particular gust of wind). As noted in section 5.5, however, other causal collectives exhibit more complete synchronisation, and we will therefore have to look elsewhere for movement criteria to distinguish causal from purposive collectives. More examples will need to be studied to identify the answer to this and also to determine if there are any movement patterns that distinguish collectives of type C1a and C1b and, C2a and C2b, as this is also unclear at present.

6.4. Differentiation of Roles

To some extent, the differentiation of roles is addressed within the Dodge classification by the identification of the leadership pattern. This clearly relates to collectives of type

R2a which follow the oligarchic model. However, the behaviour patterns of R2b (partitioned model) and R2c (individualistic model) do not appear to have been identified within the classification of movement patterns, and it remains an open question whether there are any movement patterns characteristic of these types.

7. Further Work

This paper is a first attempt to draw links between the classification systems for collective phenomena and movement patterns, by looking at a number of significantly different examples from both points of view. The Dodge classification does not investigate which types of movement patterns are exhibited by which type of collective phenomena; however, it is clear that there are links between their classification and our classification of collectives, and indeed many spatial collectives are dependent on the movement patterns they exhibit.

This investigation has clearly identified what must be done in order to develop a comprehensive classification of collective phenomena.

- A comprehensive classification of collective phenomena must include the different types of movement patterns that are exhibited by each type of collective. However, on its own, the Dodge classification is insufficient since it does not refer to the different types of collective phenomena which may exhibit the various movement patterns they identify.
- A more comprehensive and tightly organised classification system of movement patterns needs to be developed that specifically classifies the movement patterns that are exhibited by different classes of spatial collectives. The generic patterns identified in this more comprehensive classification may then be combined to produce complex behaviour patterns for each type of collective phenomenon.
- Further investigation is needed to ensure that all the links between the two classification systems can be found.
- Once movement patterns have been classified in detail, a comprehensive classification of collective phenomena can be developed that is supplemented by a full classification of movement patterns.
- This detailed classification system can then be formalised using first-order predicate logic or a similar tool.
- The formalised classification system can be used to allow collectives to be modelled within the relevant ontologies.

8. Conclusion

Through the use of examples, the relationship between a classification of collective phenomena [17] and a classification of movement patterns [7] has been investigated. From this investigation it is clear that spatial collectives are dependent on movement, and therefore, in order for a framework to be developed that adequately represents collective phenomena, a comprehensive classification of the movement patterns exhibited by such phenomena is needed. This paper has begun to identify the movement patterns defined by Dodge et al that are relevant to those exhibited by the different types of collective and has

also revealed some gaps in their classification. Thus a more comprehensive classification system is needed.

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