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Abstract. Disasters or catastrophes engender social and spatial disorganization of the territories affected by these events and specific human behaviour. In this paper, we look both at the responses of societies in terms of specific human behaviour in times of disaster or catastrophe, which may be either a form of vulnerability or on the contrary of social resilience, and at the forms of emergence associated with such exceptional events. The first part proposes a typology of behaviours observed at times of catastrophe and identifies properties common to all such behaviours. Parts two and three ask whether behaviours observed at times of disaster or catastrophe (behaviours that stand apart from everyday behaviours and that can be observed both individually and collectively) can be characterized as emergent behaviours. Answering this involves weighing up inputs from the science of risk and the science of complexity. We present the different properties for characterizing emergent human behaviour, in order to recombine the disciplinary approach of scientific communities. This knowledge of the conditions underlying the emergence of behaviours points the way to how the phenomenon might be modelled.

Keywords. Human behaviour, emergent group, global behaviour, catastrophe, disaster, complex system, emergence, qualitative change.

1 Introduction

Disasters or catastrophes engender social and spatial disorganization of the territories affected by these events. Such disorganization is usually temporary and seldom irreversible. Fritz (1961) lists four main properties characterizing catastrophes or disasters: (a) events that are identified in space and time (date, frequency and duration) (b) that have impacts, (c) on social units, (d) which in return come up with responses or adjustments to those impacts. Fritz thus makes connections between the event, the impacts and the responses to those impacts. The social unit is variable in scale as it encompasses individuals, families, groups, institutions or the entire society. Lares (1992) enhances this concept of disaster by integrating the idea of individual and group behaviour, which are an atypical, immediate and contextualized response to the event: 'El desastre o la emergencia masiva se puede definir come un peligro que se fue mas alla y que incide en la conducta individual y de grupos, ya que los diversos sectores de la poblacion deben dejar de lado sus meta individuales et sociales que configuran su marco de referencia, y formular de manera inmediatamente nuevas metas que deben ser resueltas aqui y ahora '[1].

In this paper, we look both at the responses of societies in terms of specific human behaviour in times of disaster or catastrophe, which may be either a form of vulnerability or on the contrary of social resilience, and at the forms of emergence associated with such exceptional events.

This research postulates that a large majority of societies, no matter their level of economic development, are unprepared to face man-made or natural disasters and domino effects. Paradoxically, the Japan, which is among the most advanced countries in terms of risk culture, has just suffered a chain of events that led to one of the most severe catastrophe that has ever occurred. Despite this exceptional event, recent years have been characterized by the multiplication of major catastrophic phenomena. This tendency is not likely to reverse in the futur because of population growth and the densification of infrastructures and population in high risk areas. If the trend continues, thousands of human lives will be lost and the costs of disasters should exceed USD 300 billion a year (Groupe URD-Urgence, réhabilitation, développement-, 2010). Moreover, as stated by Lagadec 'shocks are becoming very rapidly sytemic, they are evolving quickly from the local level to the national and the international ones' as it has been demonstrated by the eruption of the Eyjafjallajökull volcano in 2010 (Iceland) which caused air traffic disruption in our globalized world, or by the dissemination of an avian influenza virus (H5N1virus) in 2004. Some organizations are now using the devastating natural catastrophe term to describe an event were

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[1]The massive disaster or emergency can be defined as a danger that went beyond and that affects the individual and group behaviour because the various sectors of the population must put aside their individual and social goals that form their framework and they must immediately formulate new goals so that must be resolved "here and now"

the number of fatalities exceeds 500 and/or overall loss exceeds USD 650 millions. (Munich Re, 2011). Moreover, great natural catastrophe term is now used if a regions ability to help itself is distinctly overtaxed, making supraregional or international assistance necessary. As a rule, this is the case when there are thousands of fatalities, hundreds of thousands are left homeless and/or the overall or insured losses are of exceptional proportions given the economic circumstances of the country concerned. (Munich Re, 2011 on the basis of the United Nations definition).

Our societies have to enhance the culture of risk, in order to save human lives but also because the costs of disasters are increasing. The insurance and reinsurance scheme can no longer cover those costs if the increase of "greats" natural or man-made catastrophes observed since early 2010 continues. For example, if a great earthquake, like the one which hit San Francisco in 1906 strikes again in the same region, the number of fatalities would be comparable to what it was in 1906 (due to the growth of population) despite improvements in building codes and construction practices, and the forecast property loss to buildings would be in the range of approximately USD 90 to USD 120 billion (Kircher et al. 2006). Moreover, state governments which until now have always undertaken measures to support financial damage above a certain threshold are actually facing colossal budget deficits (Le Monde, 2011). The challenge is particularly complex in densely populated societies and/or in areas, as in Europe, that have a rich and varied heritage and that have been relatively safeguarded from a great or a devastating catastrophe.

Three levels can be used to reduce the vulnerability of territorial systems : planning policies, civil engineering and awareness raising, education and training for disasters situations. If, this last level is applied in societies that regulary are facing to particular types of hazards (earthquakes, hurricanes, floods), it remains marginally considered in societies where hazards frequency is low. More generally, research related to disasters focus on hazard and its mode of diffusion at detailed levels to improve planning policies and civil engineering. Recent developments in computer science and the evolution of computing power permit to make complex simulations. However, human behaviours modelling is less studied. Yet, this aspect also influences damages and thus their costs all the more when human behaviours are unadapted.

Modelling human behaviours suppose beforehand to identify observed behaviours during catastrophes, their frequency, conditions in which they appear and their effects. It is a necessary precondition to produce simulations as close as possible to reality.

But most often the analysis of human behaviour in disaster situations cover a specific event (many events were described and analyzed by the Disaster Research Center, the Center for the Study of Disasters, or by other authors as Mileti, 1993, Bourque and Russel 1994, who worked on the analysis of behaviours during the 1989 Loma Prieta earthquake ; Ripley, 2008 on the World Trade Center terrorist attacks on September 11, 2001; Morin and al., 2009 on the 2005 volcanic eruption of mount Karthala; Ruin, 2010, on the 2002 flood in the French department of Gard) or even more specifically on a specific behaviour, such as looting or panic (Dupuy, 1991; Quarantelli, 1994a ; Provitolo, 2003; Barsky et al. 2006; Hagenauer et al., 2011).

Analysis on the diversity of behaviours during domino effect are also limited. In addition, the results are generally based on surveys carried out before and/or after a disaster. But the analysis based on different surveys do not always allow a generalization of the results because samples are either too small or not representative of the population (Dauphiné, 2003) or even not reproducible. From the behaviours observed during a specific event, it is then possible to identify the recurring ones for a type of event (flood, earthquake, nuclear or industrial accidents) or for all the disasters. Among the attempts to draw up human behaviour typologies which aim to apply to all disasters, that proposed by Mawson (2005) should be noted.The latter is based on two axes : perceived degree of physical danger, location of attachment figures. But it does not take into account the diversity and change of human behavior according to the dynamics of the event. This typology is not really adapted to our ultimate aim which is to model and simulate human behaviour in spatial and temporal dimensions. That is why, to capture the diversity of behaviours, we adopt an approach based on empirical analysis of different types of disasters.

The originality of this research is to draw up a general typology of human behaviour, not according to the origin of the event (natural hazard, technological or social) but with respect to its temporality and the access to information. This research identifies also the common properties of human behaviours, wheter they are individual or collective behaviours.

Individual and collective behaviours are widely analysed from a disciplinary standpoint (sociological, psychological, economical standpoints) or in terms of complex systems. But collective behaviours are still underconsidered in analysis of human behaviours. However, any disaster creates collective behaviours in the sense that these behaviours are triggered by the same situation and affect the whole community, share common characteristics which are in sharp contrasts to the disparity of individual activities at the normal stage.

The complex systems and the notion of emergence (a notion which refers to two levels of analysis, the individual and the collective level and to the relationship between these levels), seems to be a promising way to identify and modeling the mechanisms underlying these behaviours (Benkirane, 2002; Provitolo and Daudé, 2008; Provitolo, 2009). The issue of emergent behaviours has been rarely considered. This is why, here we review the different points of view (those from risk sciences and those

from complex systems) that will allow to identify a behaviour as emergent. The notion of emergence is open to misinterpretation. For risk sciences the term is generally understood in literary terms, in the sense of the sudden appearance of something, or the arrival at the forefront of a leader or an organization . On the other hand, in the field of nonlinear dynamics and complex systems, emergence makes sense only when adressing levels of organization (Mayet, 2005).

This paper is arranged into three parts. The first part proposes a typology of behaviours observed at times of catastrophe and identifies properties common to all such behaviours. Parts two and three ask whether behaviours observed at times of disaster or catastrophe (behaviours that stand apart from everyday behaviours and that can be observed both individually and collectively) can be characterized as emergent behaviours. Answering this involves weighing up inputs from the science of risk and from complex systems. This knowledge of the conditions underlying the emergence of behaviours points the way to how the phenomenon might be modelled.

2 Diversity of human behaviour in situations of crisis, disaster or catastrophe

Several authors (Quarantelli 1995; Faulkner, 2001; Birkland, 2006) identified criteria for distinguishing disasters, crises and catastrophes : according to the scale or magnitude of the event (the magnitude should be measured in lives or property lost, or by the extent of the failure of the normative or cultural system (Perry, 2006)), according to the actions or inactions of an organization, according to the assistance from regional and national governments or from international or nongovernmental relief organizations, according to the damages, an event can be classified in terms of crises, disasters or catastrophes. But these authors do not specify which threshold or which combinations of variables are used to qualify the event as a crisis, disaster or catastrophe. Quarantelli (2005) identifies six elements to capture the major differences between catastrophes and disasters. In a catastrophe :
- There is massive physical impact (in contrast to the localized impact in disasters).
- Local officials are unable to undertake their usual work roles.
- Help will come mostly from more distant areas (such as international help).
- Most everyday community functions are sharply and simultaneously interrupted.
- International media focus their attention on the event.
- Very high-level officals and governmental agencies from the national level become directly involved in the management of the event.

As for the crisis, it is often defined as an event that exerts heavy and destabilizing pressure on organizations, whether formal organizations or spontaneous. The crisis stakes the adaptive capacity of organizations. Although these authors have distinguished the catastrophe from the disaster and crisis, we use them interchangeably, because they "connote both the idea of a disastrous or catastrophic event, of a disruption, which may involve an infinite variety of situations " (Lepointe, 1991).

Human behaviour in crisis, disaster or catastrophe situations may be analysed over separate periods of time. In this paper, we look at the behaviour of the population before, during and immediately following disaster impact. We try to find out how people react at these times, what they do, and what decisions are made. We make no value judgements of the behaviours and do not look to say whether they are rational or irrational responses (as measured against standard economic yardsticks).

We propose a typology of behaviours observed in the course of various catastrophic events. The events selected (industrial catastrophes of Toulouse (2001) and Bhopal (1984), Three Mile Island nuclear accident (1979), earthquakes of Loma Prieta (1989), Northridge (1998) and Haiti (2010), the string of catastrophes in Japan (2011), mudslide of Vargas (1999), tsunami in Indonesia (2004), volcanic eruption of Karthala (2006), hurricane Katrina (2005), etc.) served as catalysts for observing (from survey data, texts, videos, etc.) how individuals and social units (whether existing before the event or emergent) organize their response and adopt one or more types of behaviour. The observations pertained to natural and technological events or sequences of events in different parts of the world so as to include the diversity of living standards and of cultures in the analysis of behaviour, even if the role of culture is not the specific purpose of this paper.

The typology of human behaviour (Fig. 1) based on observation was drawn up not in terms of the origin of the event but according to its time continuum and access to information. To do this, we have 1) identified (from various data sources) the diversity of behaviours that may occur during a catastrophic event, 2) classified these behaviours depending on the time continuum of the event (time from upstream to downstream of the event) and the information available to the public about the occurrence of a disaster (we take as axiomatic that access to information changes the behaviours), 3) identified the common properties to these behaviours, whether they are individual behaviours or collective behaviours that spread to the whole community (Noto et al., 1994).

Three time periods were distinguished: the phase before the disaster or catastrophe, the disaster/catastrophe phase, and the impact phase. For each of the three dimensions, behaviours of distancing or on the contrary of contact are observed. The pre-disaster phase, which as the name indicates precedes the event, consists of three sequences that are dependent on a system of surveillance and alert:

- When the threat is not announced, it is everyday behaviours that are observed. These are very varied and the travelling that may be associated with them, is spatially very varied.

- When the threatening event is announced but is not imminent, specific behaviours with respect to the event are put in place progressively: spontaneous or organized evacuation behaviour is observed (Three Mile Island, hurricane Katrina), behaviour to counter the potential impact of the danger (e.g. reinforcing defences against tornadoes or flooding), confinement and taking shelter (e.g. going straight back home) or on the contrary gathering close relatives (e.g. collecting children from school). In relation to spontaneous or organized evacuation behaviour, when the potential impact zone is pretty much delineated, a centre-periphery model is progressively put in place. A part of the population leaves the area and institutional emergency crews may move into the area to try to improve security for the population.

- Conversely, when the event is imminent and a personal threat (e.g. danger from a cyclone is confirmed), other behaviours appear: forced or chosen immobility, flight (in panic or reasoned), gathering or mustering of individuals or groups, assistance and emergency services interventions.

The disaster/catastrophe phase consists in a sequence that we call 'foreseen or unforeseen present danger': this is a period (of varying length depending on the type of event) of social and territorial disorganization where everyday behaviours give way to threat-specific behaviours. Most travel is to ensure the protection and survival of oneself or close relatives. Often travel is in groups, sometimes under the authority of a leader, sometimes by the interplay of individual actions. Behaviours of distancing from or coming into contact with the catastrophe are thus observed: flight or fight against the effects of the disaster (during the 1993 Mississippi floods, inhabitants stacked sandbags hoping to keep back the floodwaters), forced immobility (buried under a collapsed building) or chosen immobility (refusal to evacuate), sideration (inability to react), confinement or shelter (travel to get home or get to shelter, etc.), collecting of close relatives (generally within a short radius) or rescue, curiosity (floods at Draguignan in June 2010, France), grouping, assistance and rescue, ensuring public safety. Such behaviours are responses that are more or less adapted to the catastrophe and that change the population's vulnerability or on the contrary its resilience. Their respective importance varies with the type of catastrophe, its space and time dimensions, the alert arrangements, and the visualization of the event.

The phase that follows the event or the impact phase is marked by behaviours similar to those of the event with, in addition, 'antisocial' behaviour, to put a name on looting and theft, etc. Such behaviour is often confined to a minority but is widely reported by the media. Motivations differ greatly between individuals who have lost everything and are trying to survive the event (looking for clothing, water and food) and looters proper looking to get rich quick. On the scene of the catastrophe, organizations emerge to rescue and ensure the survival of individuals. The travel that progressively takes place is closely guided by the centre-periphery model. It intensifies to such an extent that the institutional emergency services very quickly look to set up buffer zones to limit any movement towards the centre other than for the emergency services. The buffer zone is frequently set up within the marginal zone that forms a transitional zone between the affected and unaffected areas. It is also a zone where various rumours may arise that the rescuers and authorities attempt to stifle by their presence and by reactivity to stop them spreading.

From this typology of human behaviours, it is possible to identify three properties common to all of the behaviours observed and identified in the pre-catastrophe, catastrophe and impact phases.

- Behaviours are essentially **non traditional**, they do not correspond to daily behaviours. They generally occur in a threatening environment where **standard methods of acting** cannot be followed or are inappropriate. What characterizes them therefore is that they are at odds with daily behaviour impelled by varied motivations. Such behaviours include sideration, confinement, flight, evacuation, panic, deviant behaviours, etc.

- **Behaviours in a catastrophe period are not specific to a level of analysis**. They may be read with respect to individuals, families, groups or organizations. Studying human behaviour therefore requires us to look at (1) individual, isolated behaviour at odds with traditional behaviour, (2) preestablished collective behaviour (role of collective actors, (3) individual behaviour spreading to the entire group (collective panic). These levels lead us to investigate the concept of emergence.

- **A short-lived behaviours**: behaviours that are limited in time with a return to daily behaviours. Specific behaviours arise with the catastrophe and disappear either with it or during the post-impact phase.

These properties are also presented by some scholars (Rodriguez et al., 2006) as properties allowing emergent behaviour to be characterized.

With respect to the typology of behaviours we propose, the question is whether these behaviours that are at odds with daily behaviours and that can be observed both among individuals and collectively can be characterized as emergent behaviour. To answer this we rely on the

Time continuum of event / Types of human behaviour	Pre disaster phase: Danger announced but not imminent	Pre disaster phase: Danger imminent and personal threat	Disaster phase: Foreseen or unforeseen present danger	Impact phase: Post-disaster phase
Evacuation	x	x	x	x
Fight against the effects of the disaster	x	x	x	
Forced or chosen immobility		x	x	x
Sideration			x	x
Flight (in panic or reasoned)		x	x	x
Confinement/Taking shelter	x	x	x	x
Search for close relatives	x	x	x	x
Looking for help			x	x
Curiosity			x	x
Back to the place of residence/of work			x	x
Grouping		x	x	x
Assistance/emergency services		x	x	x
"Antisocial" behaviour				x

Figure 1: Typology of human behaviour

typologies of emergent behaviours and groups proposed by thematics specialists, on the typology of emergence proposed by J. Fromm (2004) (viewpoint of complex systems) and on its applicability to the analysis of human behaviours. This knowledge of the conditions that underlie the emergence of behaviours allows us to posit the modalities for possible modelling.

3 Emergence of organizations and behaviours: the viewpoint of thematics specialists

Individual and collective behaviour is widely analysed from a disciplinary standpoint (sociological, psychological, economical standpoints) or in terms of complex systems. In sociology, the research initially gave priority to the study of individual reactions in stressful situations (Wolfenstein, 1957), even if from the 1960s some pioneering studies on individual and collective behaviour exist (Beach and Lucas, 1960). Research on collective behaviour has also been developed in the field of economic sociology or economics where the focus is on economic behaviour of individuals (Granovetter, 1978), in the field of psychology with the pioneering work of G. Le Bon (2003), for whom "the crowd is a flock that can not do without a leader". But more recent research has shown that the collective behaviour was not necessarily related to the appearence of a leader. For example, the collective panic would thus emerge from the diffusion of individual panic, without the attendance, the domination of a leader who would call to the panic (Provitolo, 2005, 2009).

It very quickly appeared that there is no consensus as to the definition of emergence. On this question of the emergence of human and organizational behaviour specific to times of danger or disaster, thematics specialists working in the analysis of behaviour often use the concept of 'emergent behaviour' and have proposed various typologies for identifying them. This research has been developed essentially by sociologists and especially by a field of sociology dealing with 'collective behaviour' (Rodriguez et al., 2006). This disciplinary field is more especially interested in the dynamics of social phenomena such as crowd behaviour, looting, panic, revolutions, etc.

Some work (*Disaster Research Center*; Kreps, 1984, 2006; Quarantelli, 1994b; Tierney et al., 2001; Rodriguez et al., 2006) has investigated the emergence of institutionalized groups (routine patterns of action in existing organizations, Weller and Quarantelli, 1973) or informal collective behaviour for managing an event (crisis, disaster, catastrophe).

The Disaster Research Center (*DRC*) proposed back in 1963 a typology of organized behaviours at the time of the crisis period in disasters. This typology consists of a matrix with four quadrants, with one of the two axes defining the Tasks (regular or non regular) and the other the

Structure of the organization (old or new). From these two axes, the Disaster Research Center distinguishes four types of organized response, only one of which is considered emergent:

- **Type I:** Established responses (regular tasks and old structures): this group exists before an event and many of its actions are planned (hospitals, emergency medical services, etc.).
- **Type III:** Extending responses (nonregular tasks and old structures): this group exists before an event but many of its actions are not predetermined (the government agencies that aid in managing the removal of debris and help in rebuilding operations, as in Haiti, for example).

For types I and III, the organization exists before an event and many of its actions are either planned (T. I) or not predetermined (T.3).

- **Type II:** Expanding responses (regular tasks and new structures): many of the actions are planned but the basic structure of the organization shifts from a small group of professionals to a larger group of volunteers (Red Cross, National Guard, etc.).
- **Type IV:** Emergent responses (new tasks and new structures): its existence and activities are ad hoc and therefore unique to the event. These are small or large groups that take shape and carry out tasks or activities that institutionalized groups cannot accomplish. Thus the emergent organized response (people sometimes speak of 'emergent groups' too), is related to the idea of non traditional and new behaviour (example of mutual assistance groups that form just after a catastrophe to look for the injured and help evacuate them). While the informal emergent groups are generally organized in the period after the disaster and more rarely during the event, during which period individuals organize their actions more around their families and friends (Quarantelli, 1988), institutionalized groups, whether emergent or not, act both during and after the event.

Continuing this line of research, keeping as key variables the length of time the organization has existed and its functions, and looking into the question of forms of emergence, Quarantelli (1984, 1994b) distinguishes emergent behaviour from emergent groups. This typology, which applies to the time of crisis, identifies four types of emergent behaviour and considers emergence of the group as on of those types (Fig. 3). The originality of this typology is to reveal that in most of the organizations and groups that were not emergent, there were nonetheless considerable emergent phenomena (Tierney et al., 2001). During a disaster, each of these types of emergence may be present simultaneously.

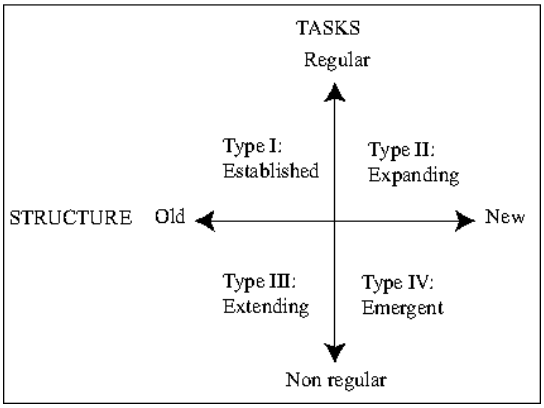

Figure 2: Typology of organized responses established by the Disaster Research Center

		STRUCTURES	
		Old	New
FUNCTIONS OR TASKS	Old	Quasi-Emergent Behavior	Structural Emergent Behavior
	New	Task Emergent Behavior	Group Emergence or Emergent Groups

Figure 3: Four types of emergent behaviour

Quasi-emergent behaviour correspond to established organizations (type I 'established groups' of the DRC typology) that continue to perform their roles and missions as often they do not undergo any major change in their structures or functions. However, there may sporadically be a change in actors so that the organization operates to the full (this is referred to as temporary or minor emergent behaviour).

Structural emergence corresponds to organizations which, to continue to perform their old functions, develop a new structure. Being unable to accomplish their missions, the organizations are then temporarily replaced by individual actors (e.g. amateur radio operators providing a liaison with the Weather Service Office during the New Orleans floods) (extending group by the DRC typology). A temporary link-up or social network is thus put in place.

Task emergence is what happens with organizations whose structure is unchanged in any way but that take on a new task. These, then, are organizations that take on the roles of a defaulting organization. This category replaces what the DRC calls an 'expanding organization'.

Lastly, emergent groups are characterized by both a new structure and function (identical definition to the DRC typology).

The typologies proposed by the DRC and Quarantelli apply to behaviours that emerge within institutional or informal organizations; but these typologies cannot readily encompass the variety of behaviours that can be ob-

served among individuals and which, because of the combinations of actions and interactions, engender emergent collective behaviour (e.g. collective flight, spontaneous gatherings).

Confronted with this observation, we wish to resituate the analysis of emergent behaviour (as meant by thematics specialists, that is, in the sense of non-traditional and unexpected behaviour associated with the performance of a task and the existence of a structure) in the more theoretical context of identification of the properties of emergence (in the sense of complex systems).

4 Human behaviours and organizational responses with respect to types of emergence

Emergence has many meanings within the complex systems. But all of the definitions proposed refer to the connections between the constituents of a system, to relations between the micro and macro levels, and to the appearance of structures, properties or forms at macroscopic level. For some scholars (Bunge, 1977; Searle, 1995), these entities or structures described at macro level cannot be reduced to the composition of individual properties at local level.

The purpose here is to analyse human behaviour and organizational responses in situations of crisis, disaster or catastrophe with respect to one of the emergence typologies used in the area of complex systems. This analysis allows us to identify emergent behaviour from the properties of emergence and to combine perspectives and disciplines by expressing the multiple points of view, those of thematics specialists and those of complex system model makers.

We use the typology of J. Fromm (2004) who, for all types of system, distinguishes four types of emergence (simple, weak, multiple and strong) and dissociates unilateral emergence (bottom-up but no top-down feedback) from bilateral emergence (with top-down feedback).

4.1 Simple Emergence without top-down feedback (Type I)

Type I describes unilateral emergence (Fig. 4), that is, with no feedback loop between macro- and microscopic levels. 'Unilateral emergence arises from the influence of attributes alone, from relations between the microscopic entities and the outside context' (B. Walliser, 2005).

The phenomenon emerges at macroscopic level because of combined actions or interactions between the constituents at microscopic level. Fromm distinguishes (Ia) simple intentional emergence from (Ib) simple unintentional emergence. In type Ib, individuals are unaware of the macroscopic phenomenon they are helping to create.

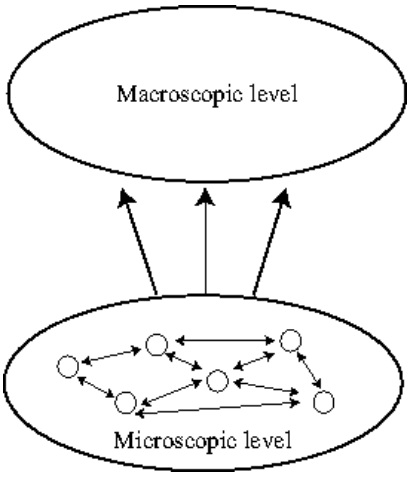

Figure 4: Simple emergence without top-down feedback (adapted from Fromm, 2004)

However, if for type Ia agents are aware of the emerging structure, a specific and fixed role is assigned to each part, and this role does not change in the course of time. Type Ia reveals an absence of flexibility and adaptability, because the roles are fixed and predictable. That means: 'A defect in a single component can bring the entire system to a halt'. The established organization/organized response (regular task and old structure, DRC type I) corresponds to this type of emergence where individual institutional actors take on specific and set roles and interactions among those actors emerge from organized intervention groups (hospital care services, emergency medical services, etc.). However, this type of emergence is rare in situations of crisis, disaster or catastrophe since the actors are generally able to adapt and modify their role so that the organization operates fully (this is known as actor substitution). This is the idea proposed by Quarantelli with the typology entitled Quasi-Emergent Behaviour. For type Ib, the system components have no specific role; emergence is said to be unintentional since it results solely from the interplay of combined actions or interactions among entities (microscopic level). If we refer to the typology of behaviour proposed in part one (Fig. 1), the fight against the effects of the disaster (chain of individuals interacting to fight flooding: e.g. the inhabitants of Des Moines (Iowa) stacked thousand of sandbags in the hope of damming the floodwaters of the Des Moines river in 1993), or mutual assistance behaviours put in place without a leader (as with mutual-help groups that may form spontaneously just after a catastrophe through a combination of individual actions to search for and help evacuate the injured: DRC type IV, emergent organized response) come under simple unintentional emergence. However, because of the principle of non-compositionality (in the sense that descriptions at macro level are not a simple composition of individual properties at micro level, Bunge, 1977), group behaviours such as flight are not emergent behaviour (each individual behaviour is a

flight and the group behaviour is simply the effect resulting from individual flight). There are therefore multiple viewpoints: that of thematics specialists for whom group behaviours are emergent when they break with everyday behaviour, that of model makers of complex systems for whom the concept of emergence can describe how a non-compositional behaviour at macro level rests on a structure of interactions at micro level.

Beyond a critical point, in addition to local interactions, the macroscopic level (e.g. mutual-assistance groups fighting the effects of a disaster) has a feedback effect on the micro level, which then requires such behaviour to be ranked in another category of emergence: weak emergence with top-down feedback.

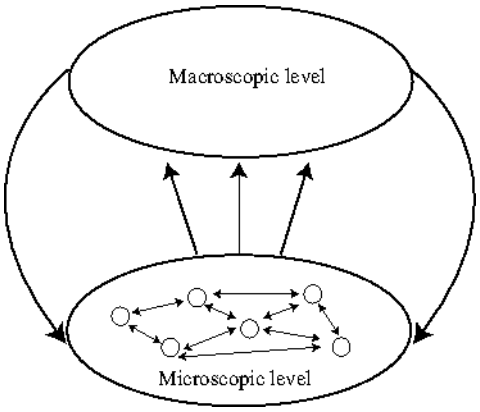

Figure 5: Weak emergence including top-down feedback (adapted from Fromm, 2004)

4.2 Weak Emergence including top-down feedback -Type II-

Weak emergence (type II) (Fig. 5) includes bottom-up (from micro to macro), top-down (from macro to micro) feedback and self-organizing processes. The roles of agents or actors are flexible. This is the framework of bilateral emergence since there is feedback action from the macroscopic phenomenon to the microscopic level. This bilateral emergence may be synchronic when the influences between levels are exerted instantaneously (e.g. actors co-ordinate their behaviours and an evacuation function emerges that vanishes as soon as the actors cease to be co-ordinated) or diachronic when a macroscopic structure arises from the dynamic behaviour of systems. For Fromm, top-down influences are exerted more slowly than bottom-up influences. All individual behaviours observed during catastrophic events (Fig. 1) may be included in this category provided that from these individual behaviours there emerges a new structure at macro level (a spontaneous mutual-assistance group – DRC type IV –, an assembly dynamic, etc.), and the new structure provides feedback for the microscopic entities without these entities having any representation of emergence. We call this 'indirect' or 'physical' feedback in the sense that the aggregate phenomenon exists only for an observer and may cause or modify the conditions that constrain individual behaviours (e.g. when a crowd grows, constraints on movement increase and so reduce the choices as to where to move; individual behaviour is then subjected to the movement of the crowd) in contradistinction to the concept of strong emergence which includes the idea of representation (type IV of Fromm's typology).

In the case of weak emergences, only the observer can 'observe, view' from above (like an airline pilot) what is going on: a common trajectory of population movement towards a precise location, etc. Accordingly the phenomenon can be read in two different ways: that of the individual agent acting locally within his environment, or that of the outside observer. Fromm distinguishes weak stable emergence from weak instable emergence. In both instances, bottom-up and top-down feedback loops come into play. For weak stable emergence, there is positive feedback from micro to macro level and negative feedback from macro to micro level. This double feedback loop regulates the system. However, for weak unstable emergence, there is a double positive feedback loop since the emergence of a new structure tends to reinforce the phenomenon. The emergence of collective panic from individual panic in a crowd made up of panicking and non-panicking individuals may fit in with 'unstable simple emergence' since instantaneous interactions among the microscopic entities (the panicking and non-panicking individuals) spread to the entire crowd (macro level) which, above a certain level of panicking population feeds back onto all of the individuals reinforcing the panic behaviour (process of propagation in space and time).

However, if the actor is aware of the emergent or emerging structure, behaviours no longer fit into the weak emergence but into the strong emergence typology.

4.3 Multiple Emergence with many feedbacks (Type III)

This type of emergence is based on the idea (1) that emergent structures are often a combination of stable and unstable weak emergence and (2) that feedback occurs over the short term (for positive feedback: e.g. when blindly imitating your neighbours behaviour) and the long term (for negative feedback: when adopting thoughtful behaviour, behaviour that is not the outcome of the pressure of conditions that compel individual behaviours in a simple way type II), and (3) that, in addition to these two properties, a form of emergence can be named 'adaptive emergence' for complex systems demonstrating adaptive capacities (Fig. 6). Of course, all complex systems are not adaptive, but all those involving living societies are.

In catastrophe situations, human behaviours are modified in the short term as a function of the cognitive factors and of the adaptive capacity of individuals (idea of appearance of new roles and disappearance of old ones: e.g. organizations that take on the roles of a defaulting

organization cf. typology Task emergent behaviour). This adaptive capacity changes over the long term with experience and learning (long-term memory).

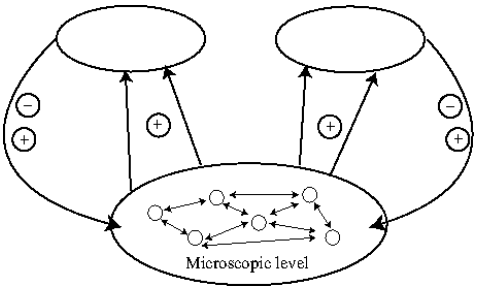

Figure 6: Multiple emergence with many feedbacks (adapted from Fromm, 2004)

4.4 Strong Emergence (Type IV)

Strong emergence (Fig. 7) is bilateral emergence that encompasses the idea of the intentionality and reflexivity of actors (Müller, 2004; Walliser, 2005). The system contains elements that are able to observe the collective effects of their interaction and the representations they derive from those observations influence their decisions and behaviour (Müller, 2004). These actors are more or less aware of the emergent phenomenon they tend to produce and of the mechanism that leads to it, which may modify the phenomenon itself (Walliser, 2005). Many institutionalized behaviours and some collective behaviours (hospital response in disasters) are the result of interaction among actors' individual actions. These actors consciously participate in voluntarily constructing organized groups with roles and missions that are relatively clearly defined beforehand or during the actor-substitution process. The actors are thus aware of the emergent phenomenon but, unlike with simple emergence, the roles and missions they must carry out are flexible (Red Cross, emergency fire services, etc.). Behaviours characterized as 'quasi emergent behaviour', 'task emergent behaviour' and 'structural emergent behaviour' may thus be classed in the strong emergence type when the overall project is explicitly known by individuals. However, spontaneous organizations (search and rescue groups) that appear during the post-shock phase may be part of this category of emergence if and only if the individuals are aware of the emergence process and of the organization that is being put in place. This information can only be extracted by interviews after the disaster or the catastrophe.

To conclude, in order to characterize emergence in all its forms, two levels must be distinguished: a local level of interacting individuals/entities and a global level. Emergence occurs if the behaviour or the global structure cannot be reduced to local behaviours or structures (Bunge,

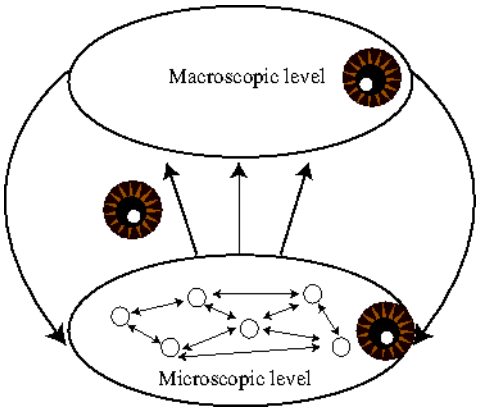

Figure 7: Strong emergence (adapted from Fromm, 2004)

1977; Searle, 1995). We characterize emergence as weak if the phenomenon as such does not have any feedback on the local level. In this sense the global phenomenon exists only for an outside observer. This global phenomenon may, nonetheless, have no influence on the micro level (type I of Fromm's classification), it may cause or modify the conditions that constrain individual behaviours in a simple way (type II of Fromm's classification), or it may be multiple (type III of Fromm's classification). Emergence is strong if the global phenomenon has feedback as such on the local level, which means local entities are 'aware' of the global phenomenon. All of these emergences are synchronic since the local level and global level co-exist at all times simply because they are posited by definition; such emergences are therefore necessarily instantaneous or more specifically a-temporal. We have also been able to see that any group of interacting entities engenders global behaviour (such as collective flight). It is therefore possible to model the dynamics (the behaviour) of the group in the form of a dynamic system whose trajectory in state space is to be observed. We are then interested in the qualitative change of this behaviour. Three situations may be observed:

(1) there can be a move from non-emergent to emergent behaviour (from collective flight to a structured evacuation behaviour, with roles as guides, etc.)

(2) there can be a move from one emergent behaviour to another (from evacuation behaviour to establishing a security perimeter)

(3) the emergent behaviour vanishes (collective flight resumes or everyone goes back about their business)

Cases (1) and (2) are examples of diachronic emergence. In case (1) emergence comes about, in case (2) there is a shift from one form of emergence to another (change of attractor). In case (3) where emergence disappears, it may come about that the global level is no longer identifiable as such. There is therefore a combination of two concepts of complex systems: (1) emergence, (2) the de-

scription of dynamic systems and especially of their characterization in terms of trajectories that make it possible to describe attractors and around them bifurcations and chaotic regimes. One is a-temporal and is a characterization of a system at two levels of observation; the other is temporal and describes trajectories.

5 Conclusion and directions for further research

In this paper, we have proposed a typology of behaviours observed during different catastrophic events, whether natural or technological in origin, and whether local or dispersed. We have constructed this typology not in accordance with the origin of the event but with respect to a time continuum: the pre-catastrophe phase, the catastrophe phase, and the impact phase. For these three dimensions, we have identified a variety of behaviours, some corresponding to distancing from the event, others on the contrary corresponding to coming into contact with it. We have also identified three properties common to all these behaviours: they are essentially non-traditional, they are not specific to a level of analysis (behaviours may take shape for individuals, families, groups or organizations), they are short-lived. These properties are also presented by certain scholars and by risk and catastrophe thematics specialists as properties for characterizing emergent behaviour. Now, in the field of complex systems, to characterize emergence in all its forms, two levels must be distinguished: a local level of interacting individuals/entities and a global level. In the absence of an identifiable global level, there is no emergence, which is therefore contrary to observations reported by pioneer field researchers: during the crisis period of disasters, there was a great deal of emergent behavior, both at the individual and group levels. The emergent quality took the form of nontraditional or new behaviour, different from routine or customary norm-guided actions.

We have therefore presented the different properties for characterizing emergent human behaviour, in order to recombine the disciplinary approach of scientific communities, both those conducting research in the domain of crises and disasters and those developing their research in the domain of complex systems. This first exercise has therefore enabled us to bring together approaches and disciplines and to express the multiple viewpoints. It could be useful subsequently for modelling whereby thematics specialists and model makers can account for emergent human behaviour in situations of crisis, disaster or catastrophe.

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