A Multi-agent Model for Panic Behavior in Crowds

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Abstract. This paper presents a conceptual model for the panic in crowds' phenomenon. The proposed model is based on social science theories related to collective behavior. Such model could be applied in two dimensions: (i) to assist in proposing new structures or variations for collective panic situations, checking the viability of their existence and inner-working; (ii) to get a better understanding of social, anthropological and psychological foundations, etc. which drive and maintain the panic in crowds type of collective behavior. One of the challenges to be faced by this study is the integration of different theories in a coherent and robust way, since many of them have contradictory positions. Besides, thanks to the fact that these theories show a higher degree of abstraction, adjustments will be made in order to achieve the computability of the proposed conceptual model.

1 Introduction

The study of human groups' behavior, which is controlled by institutionalized rules and traditions, is the focus of Sociology. In turn, the research field called Collective Behavior deals with situations which human behavior is not based on current and socially accepted cultural norms. Specifically, the panic in crowds' phenomenon is a kind of collective behavior which involves a certain amount of people being exposed to a dangerous situation. In such situation there is always an imminent risk and a feeling of urgency for action.

Studies regarding panic in crowds are important because they assist in achieving a clearer and detailed understanding of the social theories, and could be used as a basis of algorithms which will uncover new ways of solving computational problems. Also, the studies' results could help in predicting the birth of collective panic and/or highlighting actions that might reduce material and mostly human losses. The understanding of this behavior makes it possible to design safer and more efficient public places such as theaters, movie theaters, residential buildings and stadiums.

However, even with the importance of studies about panic in crowds phenomenon there is a restrict amount of simulations that deals with this kind of collective behavior [1]. In order to help in filling this gap, a multi-agent conceptual model for collective panic is proposed. The first contribution of this model is the fact that it could be used for simulation building which offers a more precise comprehension of the phenomenon dynamics, taking some aspects into consideration such as social, psychological and anthropological elements. The second contribution refers to the application of Multi-agent Systems (MAS) theory for model building because MAS allow us to establish a relationship between a program and an individual, so it will be to simulate an artificial world formed by interactive computational entities. This multi-agent modeling process is able to transpose from a crowd in panic behavior to a similar conceptual model, with a proper theoretical-technical framework for modeling and understanding complex social processes such as coordination, formation of coalitions and groups, conventions and norms' evolution, micro-to-macro linking, and so on.

The remaining of this paper is structured as follows: in Section 2 there is a brief description of the theory which this paper is based on. Section 3 is the core of this paper, featuring a proposal for a conceptual model for panic in crowds. Related works and a single comparison can be found in Section 4. Finally, in Sect. 5, some conclusions are presented.

2 Collective Behavior

The main focus of the sociological studies is the culturally-based human groups, more specifically certain groups that behave according to well-established and institutionalized rules. On the other hand, the field of collective behavior deals with collectivities that contradict or reinterpret society norms and standards. Among the classical definitions for collective behavior we cite [2]: "*collective behavior is the set of social behaviors which the usual conventions stop driving the actions and the individuals transcend, exceed or collectively subvert the standards and the institutionalized structures*".

In the collective behavior field, there is a consensus in defining at least three classes of this kind of behavior: the public, the mass and the crowd. The crowd is a localized collective behavior which individuals are close enough to make a physical contact. Some authors classify the crowds in: (i) Active crowd, such as mutinies, lynching mobs and rebellions; (ii) Casual crowd, such as crowds that get together to watch a display window being decorated; (iii) Conventional crowd, for instance an audience for a soccer game or any other recreational activity; (iv) Expressive crowd, for instance the dancing crowds at carnaval and some religious groups; (v) Panic crowd, which is formed when people are exposed to a dangerous situation and that leads them to create the perception of need to stay away from danger in a social and shared way, such as earthquakes and fires. The next subsection will cover the structural and functional aspects of the panic crowd behavior.

2.1 Panic Crowd Behavior in an Interactionism Approach

The theoretical model presented herein is based on the emergent-norm interactionist approach presented in the Sec. 4. Its basic scheme is displayed at Figure

1. The steps were placed sequentially just for didactical purposes. However, a person could skip, repeat or take a different step order.

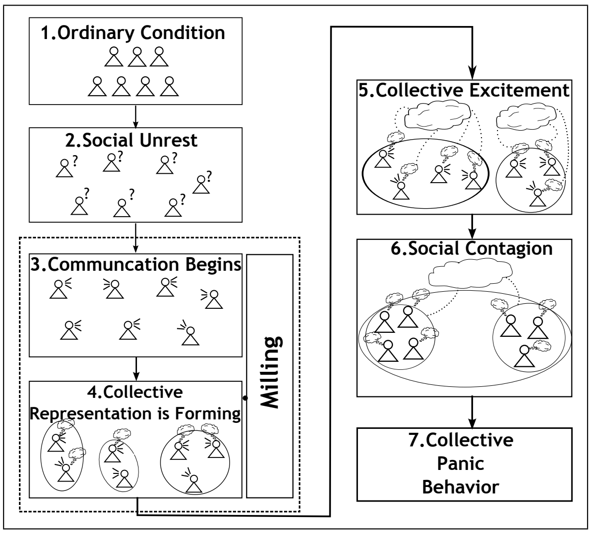


Fig. 1. Panic in Crowds Collective Behavior Overview.

Initially, the individuals are in an **ordinary condition** which norms and social structures are aligned with what is socially accepted. When is perceived a disorder on the established social structure the individuals feel uneasy and apprehensive, trying to understand the non-structured and ambiguous situation that just happened. A disturb is an event that presents itself as an imminent threat to the agent's life, like a fire alarm or a smoke cloud, and such event draws the person's attention and forces him to act, leading to a **social unrest**. After that, the individuals start looking for information that could help them in redefining the current context. In these conditions, people become more susceptible to rumors, since there is a feeling of uncertain and insecurity. The conventional behavior starts to break down. Since there is a need to understand the situation, people engage themselves in a **milling** process, looking the other individuals' reactions and comparing those reactions with your own set of expectations. In this process, a need for searching a sanctioned and socially-built meaning arises, into a relatively non-structured situation [2]. The milling is important because draws the individual attention to the situation and actions from the collectivity, taking himself out of focus e pointing his attention to the other agents actions.

With a higher focus on themselves, the individuals respond faster and more direct to each other, preparing the environment for the formation of a shared understanding of what is happening. Then, the collectivity pass to the **collective excitement** stage, when individual representations are combined and synthesized by the group, helping in the formation of a collective representation/image of the situation. This shared representation increases the individual's susceptibility, reducing his capability of creating different impressions from the collectivity. That way he could enter in a line of conduct socially forbidden that he could not conceive and execute, such as pushing and running over people. The **social contagion** is an intense form of collective excitement, promoting a fast dissemination of the collectively formed representation, empowering the social cohesion and making room for a collective action. Finally, when the individuals have built a collective representation of the situation it is possible to choose and execute actions. At this moment, the collective crisis created by a struggle for survival comes to an apex, and the **collective panic** is installed. Since the participants don't share traditional expectations about the way they should behave, the results are uncertain.

3 A Model for Panic Behavior

In order to build the proposed model for this paper, the following elements were taken into consideration: (i) the agent's architecture, which represents a person in a panic situation; (ii) three environments where the agents' main interactional aspects will happen; (iii) a socially-built system called Group Mind, which defines how each individual representation of the situation can be socially changed and synthesized by the collectivity, in order to make a shared context.

3.1 Environments Description

The agents of the model proposed by this paper have access to three environments (Fig. 2): Physical Environment, Communication Environment and Group Mind. The General Environment covers these three environments.

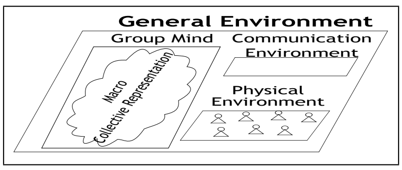
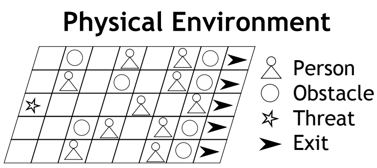


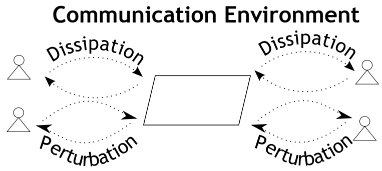
Fig. 2. General Environment and its Components.

The Physical Environment (Fig. 3(a)) is the place where the agents will physically interact with each other and with other objects such as furniture, obstacles, walls, etc. There are specific points where the threat will appear, as well as exit points.

In the Communication Environment (see Fig. 3(b)) messages will be dissipated and the agents can be disturbed by them, according to parameters of cybernetics theories inspired by Norbert Wiener [3]. There is no direct information



(a) Physical Environment



(b) Communication Environment

Fig. 3. Physical and Communication Environment

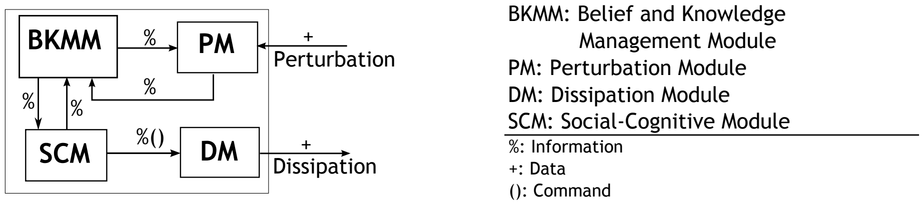
exchange among the agents. Instead, whenever an agent needs to communicate the messages are dissipated into the environment. In the same way, each agent is autonomous to check the Communication Environment in order to define whether the message is relevant for reaching its goals.

The Group Mind manages a collectivity-built framework made of expectations networks that are formed by the repetition of similar events. Expectations are incidents of expected behaviors by an agent in spite of a situation, and these expectations guide their actions [4]. Agents in society expect certain types of behavior from the others, and they deal with different types of behavior as expectation deviations. In this proposed model, each person makes its own expectations network, and it is stored in the Micro Collective Representation Module (Subsection 3.2, item B). Finally, the current situation is qualitatively-new information that cannot be identified by just looking at one of the forming units (the individual expectations networks). This emerging process of current context's shared representation is controlled by the Group Mind, which makes abstractions, generalizations, averages and schemes from the individual expectations. The resulting social structure (a net of shared expectations) is stored in the Macro Collective Representation.

In order to make the situation being processed and interpreted it is required that its base elements are socially built and act like significant symbols. In this model such symbols are: a goal, an object and a line of action. The goal restricts the actions allowed for the agent. For each goal there is a set of possible actions that the agent might engage. The object refers to the entity which the agents will be acting upon. Objects can be physical (a fire blaze), an abstract concept (sense of justice, homeland and family) or a junction of these two things. A line of action is a suggestion of how to act in an ambivalent and uncertain situation.

3.2 Architecture of the Person Agent

The Person agent represents an individual in a physical environment that will pass through a panic situation. Its architecture is formed by four modules, as seen at Fig. 4: Perturbation Module, Belief and Knowledge Management Module, Social-Cognitive Module and Dissipation Module. These modules are described below.

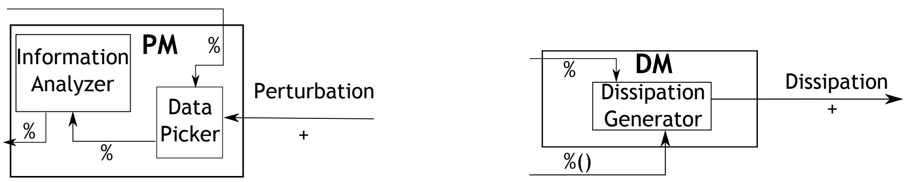


(a) Person Agent. (b) Agent Modules.

Fig. 4. Person Agent Architecture Overview.

A. Perturbation Module (PM) The Figure 5(a) shows PM's architecture, which is formed by Data Picker (DP) and the Information Analyzer (IA). The DP constantly scans the Communication Environment, looking for disturbing messages. In order to do so it analyzes - considering some information from the Rule Set (see item B) - whether the message is related to individual's action on reactive, functional or dynamic perspective.

When a message is accepted by the DP, it is sent to the Information Analyzer which, at first, checks the information formatting (syntax) in an Agent Communication Language. After that, a semantic analysis is performed, in order to check the way the information was externalized as a gesture or speech, and the mood (lovely, aggressive, neutral) [4]. After the syntactical and semantical analysis, the information is stored in the Belief Base or in the Knowledge Base (see item B) and that happens whether the information can be proved by physical evidences perceived by the agent (knowledge), or the information was caught from other agent without evidence (belief).

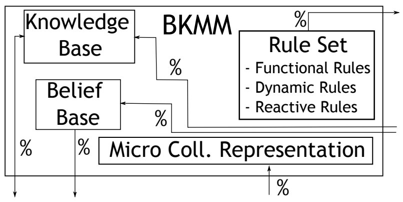


(a) Perturbation Module (b) Dissipation Module

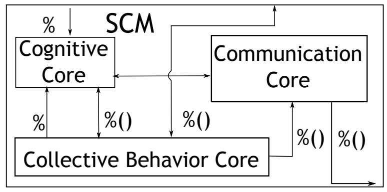
Fig. 5. Perturbation and Dissipation Modules

B. Belief and Knowledge Management Module The belief and knowledge management module works as a manager of the information bases required for the proper agent operation. This module is comprised of Knowledge Base, Rule Set, Belief Base and Micro Collective Representation. Figure 6(a) shows an overview of this module.

The Belief Base takes the information that has not been proved by the agent. For instance, if the agent decides to leave the environment and he does



(a) Belief and Knowledge Management Module.



(b) Social-Cognitive Module.

Fig. 6. Belief and Knowledge Management Module and Social-Cognitive Module

not know the exit position, he will inquire the nearby agents. The information provided by the other agents will be treated as a belief until the agent gets closer to an exit and testifies that the information is logical. On the other hand, the Knowledge Base deals with three kinds of information. At first there are variables that establish the agent's inherent features. They are called *Internal State Variables* and are presented in Table 1. The second group of variables, called *Physical-External Variables*, describes the information that is directly affected or is perceived from the physical environment. A list of these variables can be found in Table 2. Lastly there are *Social State Variables* which represent the agent's social condition and they are affected by the agents' interactions. Some of these variables are presented in Table 3.

Internal State Variables	
Name	**Description**
health	The agent's vital status. It depends on how much pressure the agent is taking.
speed	The displacement length in each time step (meters per second).
expEvent	The level of experience for the simulation's kind of panic event. It affects most of the agent's social decisions.
nervousness	The ratio between idealSpeed and speed. It can trigger agent's permissiveness increasing.
uncertainty	For each information available, how much certainty the information has.

Table 1. Internal State Variables

Physical-External Variables	
Name	**Description**
temperature	Localized temperature measured by the agent (Celsius).
pressure	How much pressure is forcing the agent (Newtons per meter). It directly affects health
dirThreat	The direction to the threat, for escaping procedures.
hazardLevel	It is based on temperature, pressure, free space availible and experience, how dangerous the situation is.

Table 2. Physical-External Variables

Social State Variables	
Name	**Description**
susceptibility	It defines how much the agent is susceptible to the other agents' opinions.
permissiveness	The level of acceptance of the socially inadequate actions in spite of the panic situation.
cbStatus	The agent's collective behavior status. Which collective behavior step the agent is currently engaged.

Table 3. Social State Variables

The rule set defines the agent operation in his life cycle. These rules are classified in: (i) Functionals, which establish the agent's identity and the pursue of his goals, such as Walking and checking its own health; (ii) Reactives, related to agent's survival and usually time-constrained, such as running away from the fire and throwing water at the fire; (iii) Dynamics, which rely on learning, such as learning how to put out the fire or how to safely escapes from the environment.

The Micro Collective Representation stores the representation/image of the current situation locally and individually created by each agent, but taking a mutual feedback process among the agency elements into consideration. The tendency is that during this collective process a symbol convergence will happen and that will make common imaginary and unified actions. Thus, these individual imaginaries will help in the formation of the Macro Collective Representation, located at the Group Mind (see item C).

C. Social-Cognitive Module This module is responsible for coordinating the agent Person other modules' actions, managing their autonomous and private process. It is made of the following cores (see Fig. 6(b)): Cognitive Core (CogC), Collective Behavior Core (CBC) and Communication Core (ComC). The CogC stands in continuous processing, managing information and guiding actions so the agent can pursue its goals. As long as the individual is in a situation that does not pose as a threat to its life (see Fig 1, item 1), the CogC leads the agent to a certain behavior that it accepts the rules and roles established in the society. However, if an event that poses a threat is triggered, the CogC passes his duties to the CBC. This replacement makes the agent act in a collective way, engaging in the collective behavior.

In order to quantify the threat, the agent checks his experience for this kind of event (fire) and the hazardous level he assigned for that situation. At this moment, the functional and dynamic rules remain strong, and the reactive rules remain weak. Besides, the individual is lacking in information to follow a certain line of action. In order to go to next step (social unrest), the uncertainty level assigned for the situation must be higher than a certain threshold, which implies that the agent doesn't know what is happening, so he feels that he needs more information about the event.

Going into a social unrest (Fig. 1, item 2), the agent searches for information that helps him in analyzing what is happening. Its uncertainty level rises since it is unable to understand the event by himself, so it engages in the milling process (Fig. 1, item 2). At this point, the agent increases his communication with the others, trying to build his own Micro Collective Representation (Fig. 1, item 4). At the same time the personal value variable is affected, increasing the agent's acceptance for external thoughts. The agents become less aware of themselves as individuals and more aware of the others. The dynamic rules (e.g. learning how to perform an operational task) become weaker because the sense of urgency is stronger in a dangerous situation than in an ordinary condition.

Collective excitement (Fig. 1, item 5) begins when the permissiveness starts to interfere on the agent's choices. At this point the agents can choose socially unacceptable actions, such as running over people. Functional rules loose their strength (mostly because permissiveness is rising) and reactive rules get stronger. When the agents define a goal and an object for action, the macro collective representation starts to develop and to establish. This step is called social contagion (Fig. 1, item 6) because the communication and interaction among agents are in such condition that some individuals - not yet engaged in collective behavior - are attracted by the group, and they are induced to be part of this process. The reactive rules become the strongest rules for the agent. Since the permissiveness is high, the agents can choose actions treated as socially improper. Dynamic rules, such as learning how to escape are limited.

Finally, the collective panic behavior (Fig. 1, item 7) is installed when the agents choose a line of action to be followed by the collectivity. The agents are fully engaged in the collective behavior, and they will stay on that condition until they do not feel threatened. The ComC receives all requests for communication from the CogC and the CBC and puts those requests in a queue for being dispatched by the Dissipation Module.

D. Dissipation Module (DM) Whenever the agent needs to send a message to the other agents, this module is requested. The DM (Fig. 5(b)) receives the message from the Communication Core. Inside the DM the Dissipation Generator (DC) prepares the message to be dissipated on the environment by encoding, adding other relevant data, such as the message format (using an ACL) and how it should be expressed in the environment: if it is a gesture or a speech and how the message mood is (lovely, cold, etc.).

4 Comparative Analysis of Panic Behavior Models

After analyzing Collective Behavior literature, three theoretical approaches could be found to explain panic crowd phenomenon. The first one, called **Contagion Theory**, holds that the individual in a crowd loses his conscious personality and obeys all suggestions from the crowd, similar to a hypnotized person following a hypnotizer. Social sciences researchers such as Le Bon [5] followed this approach. The simulation model presented in [6],[7] were based on Contagion Theory for their modeling.

There is a second approach for collective behavior which deals with it in a more rational and objective-aware fashion and it is based on the Symbolic Interactionism theory, which considers that collective behavior is an outcome of the interactions among individuals, which are able to evaluate the information they receive and to decide on its usage at the present situation. In the **Emergent Norm Theory** [2] (employed by this paper) the agents assign positive or negative values to the information they receive and that leads to the development of an interactive cognition. This approach analyzes the agents' micro-properties that help in the social systems' formation. It also analyzes the behavior patterns at the group level. As examples of computational works based on this approach there is [8].

A variant of this second approach, commonly called **Structuralism**, inverts the formula and emphasizes the social structures studies and their impact of these structures on the individuals. It is a macro-to-micro approach since it considers the social changes are triggered from the social (macro) to the individuals (micro). Social Science researchers such as [9] embraced the structural theory approach. After analyzing the current literature, works that had computationally implemented the macro-to-micro approach for panic crowd situations were not found.

The Table 4 shows a comparison based on the following elements: reactive approach, cognitive approach, micro-level explicitation, macro-level explicitation, communication forms and panic behavior explicitation. The reactive and cognitive approaches are related to how individuals are modeled in the system. In a reactive standpoint the agents do not have well-defined symbolic constructions of their internal processes, neither of the environments where they are inserted. The behavior is of a stimulus-response type. On the other hand, a cognitive standpoint allows the agent to make an environment and collectivity members' explicit representation, bringing memory and reasoning about the past chosen actions and planning the future actions. The micro-level and macro-level explicitation parameters refer to the presence of components that represent the collectivity's micro and macro levels in an explicit way. The micro level deals with the agents and their interactions. The macro level displays the main forces that keep stability and force changes to society, making the social structures and the collective behaviors explicit [4]. The communication form parameter deals with the interactions among the collectivity agents. These interactions can happen (i) in an indirect manner, when the information is exchanged through the environment, (ii) in a direct manner, when there is direct information exchange among the agents, (iii) with the perturbation and dissipation processes, as proposed by Luhmann [10]. Finally, the panic behavior explicitation parameter deals with the usage of the collective behavior formation stages explained in Sec. 2. If such stages are modeled and the transition is described in detail for each agent, so they could behave more realistically, and the simulation could be closer to the real phenomenon. Or if a physical or mathematical model is adapted to fit collective behavior empirical data.

In [6] the main concept is moving groups of people from a place in a panic situation to a safer place. Emotions are used to guide the agents and they are used as clauses for the agent's state change. The crowd movement is ruled by

Table 4. Panic Behavior Modeling Comparison Matrix

	First Category		Second Category	
Features	[6]	[7]	[8]	Proposed Model
Reactive or Cognitive Approach	REA[1]	REA	COG	COG
Micro-level explicitation	Movement Formulas	Social Force Model	Individual Behavior Model and Global Rules	Collective modeled agents
Macro-level explicitation	Not available	Not available	Not available	Imaginary and Group Mind formation
Commun. forms	Indirect message exchange	No message exchange	Not available	Perturbation and dissipation
Panic Behavior Modeling explicitation	Not available	Not available	Not available	Framework based on Symbolic Interactionism

formulas [1]. The Micro-Level explicitation lies on crowds' formula-applied movement and pushing. There is no macro-level explicitation. On the communication side, the groups of people put pheromones on the environment to qualify it as safe or unsafe, promoting an indirect communication. There is no panic behavior explicitation, although the usage of emotions to aid the agent choices.

The authors in [7] present a crowd behavior model based on social forces and a mathematical model which uses physical forces and certain social behaviors as attractive or repulsive forces. There is no message exchange among the agents (since their interactions are based on differential equations and a simple force system application) either a macro-level explicitation. The micro-level explicitation described in this paper is entirely based on formulas and physical forces. After applying such formulas the agent can move or stay still.

The authors in [8] describe an individual behavior model for agents. Although there is no explicit way of interaction or communication, each agent is aware of himself and the other agents. Besides, there is an internal database inside each agent and a global database that stores state information of all agents. However there is not an explicit panic behavior framework. The agent applies rules based on three parameters (Crowd Density, Tension Level and Sensory Input) and his own database, then he attempts to escape and decides how he is going to escape. Finally, there is no macro-level explicitation.

The model proposed by this paper employs an indirect communication, by perturbation and dissipation of information. At the micro-level, agents make their choices based on information they could physically prove (knowledge) and information obtained from other agents and without physical evidence (belief). The macro-level explicitation is based on the imaginary and Group Mind formation. Finally, all steps of collective behavior formation are described and modeled for the agent.

[1] Movement ruled by formulas; behavior ruled by emotions.

5 Conclusion

This paper proposed a conceptual model for the panic in crowds' phenomenon. It also presented the steps related to the structure and operation of collective panic in a systemic and computable way, from its genesis up to its execution apex. This model integrates theories from social scientists such as [11, 2, 10], and that integration of distinct collective panic theories (in a coherent and computable way) is one of the challenges for this research because most of those theories presents a higher abstraction degree and, in some cases, even contradictory points.

Three theoretical approaches were detected and presented in Sec. 2, along with some computational works that adopt each one of these approaches. Specifically, the model presented by this paper is in the second group, following an emergent-norm interactionist approach. For future works, this conceptual model will be implemented using the Swarm framework [12]. A simulation will be performed and the resulting data will be analyzed along with theoretical and empirical datasets.

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